A-LEVEL GEOGRAPHY RESOURCE FILE

Hazards

Central Saint Michael's Sixth Form

A UNIVERSITY-STYLE SIXTH FORM

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 exploring the origin and nature of these hazards and the various ways in which people respond to them, you will be able to engage with many dimensions 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.

You should be aware that in this chapter we have presented you with the details of a number of hazard events, which will widen your knowledge and understanding of the hazards themselves. You are expected to have studied, in terms of impacts and human responses, one recent volcanic event, one recent seismic event and one recent wildfire event. With recent tropical storms, you are expected to have studied two events 'in contrasting areas of the world'.

In this chapter you will study:

- the concept of hazard in a geographical context
- volcanic hazards
- seismic hazards
- storm hazards
- wildfires

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. The problem 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, although this applies to the populations of less well developed countries. In developed areas, most of the people who occupy hazardous areas are often well aware of the risks, which they choose to minimise or even ignore
- 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 put in place 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, the built environment and the natural environment. 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.

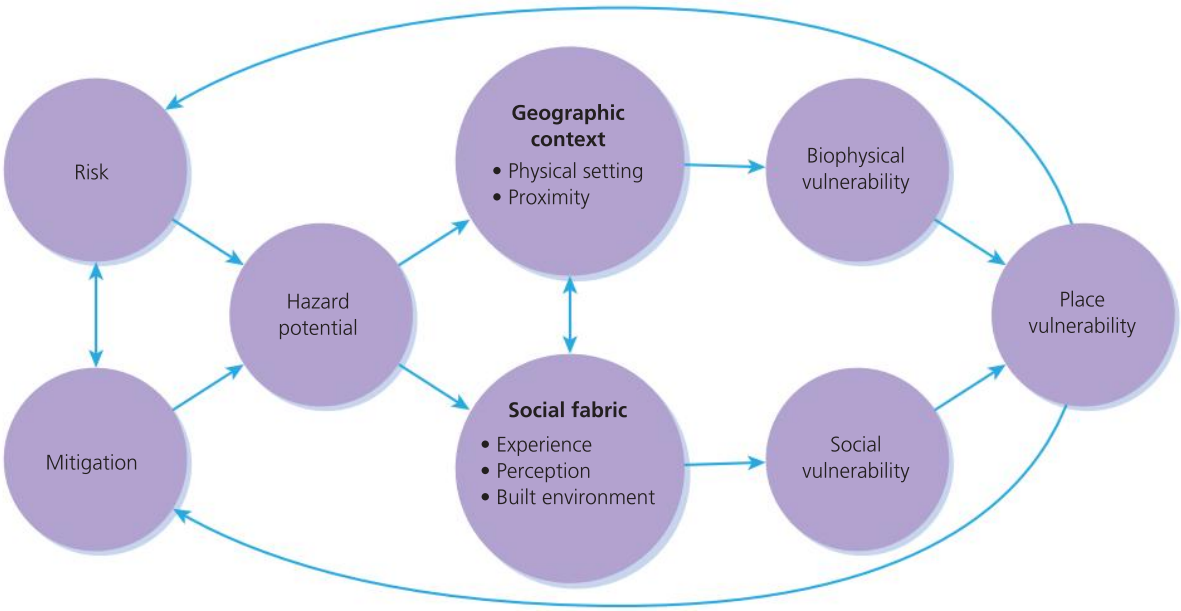

Figure 5.1 Model of vulnerability

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

Key question

Does your chance of surviving a natural hazard event depend upon your level of wealth?

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 that you are prepared, 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.

Frequency – The distribution of a hazard through time.

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.

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

Prediction – The ability to give warnings so that action can be taken to reduce the impact of hazard events. Improved monitoring, information and communications technology have meant that predicting hazards and issuing warnings have become more important in recent years.

Key terms

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.

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.

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.

People respond to natural hazards and the threats that they can pose by seeking ways to reduce the risk. Responses can come from individuals, the local community with people working together, and from 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 which 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, and 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.

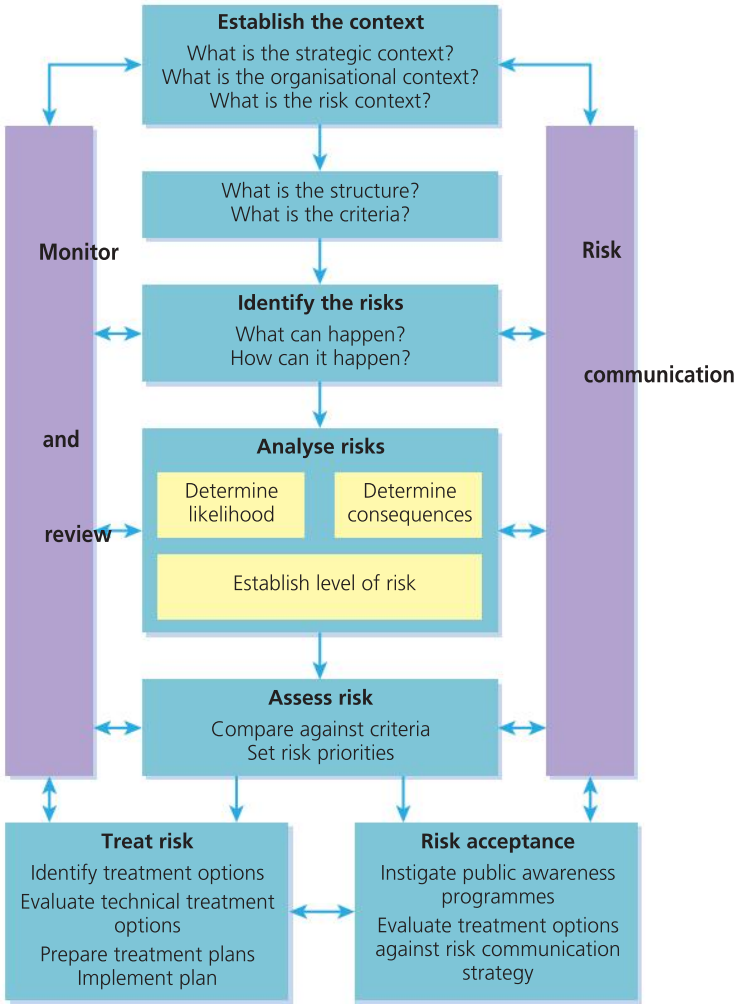

Figure 5.2 The process of risk management

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 Japanese felt that they were well prepared for earthquakes and yet in 1995 the city of Kobe suffered the Great Hanshin earthquake, which destroyed over 100,000 buildings (with three times that number damaged) and a death toll of over 6,000 with 35,000 injuries. (For more details see the later local case study, page 224.)

All this can be put together as the 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.

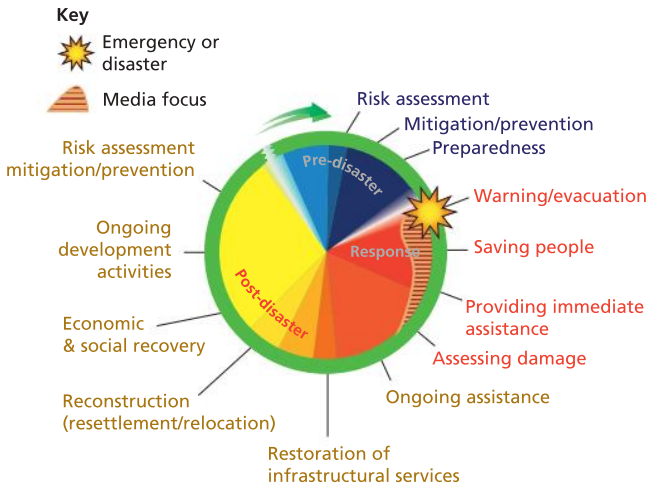

Figure 5.3 The disaster/risk management cycle

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, in 1991 Park 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.

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.

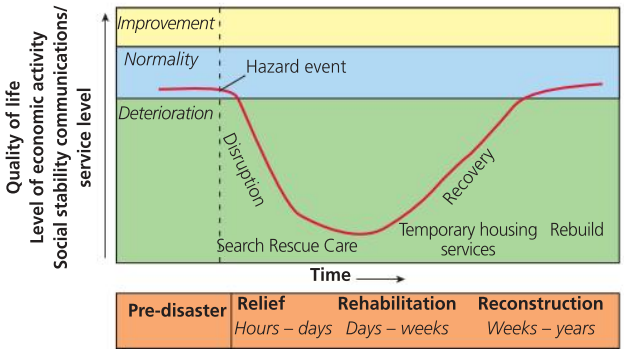

Figure 5.4 The Park impact/response model

Next comes **rehabilitation**, where people try to return the state of things 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 reconstructed 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.

Park also showed how different events can have different impacts. This is shown in Figure 5.5 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.

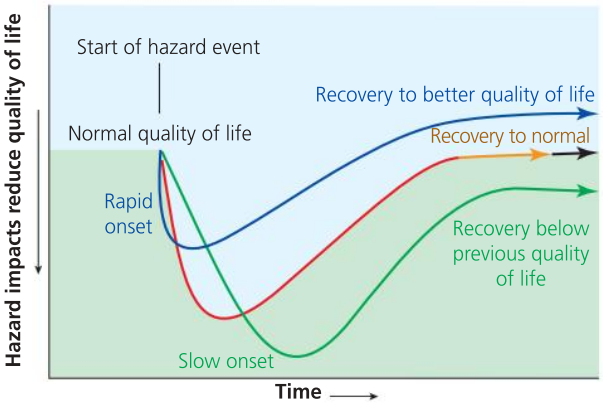

Figure 5.5 Variations within the Park model

Key question

Select one of the case studies of a hazard event to be found later in this chapter and describe how the Park model can show the impact through time of that event.

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 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, in the long term, increasingly fewer events as magnitude rises.

Skills focus

What sources would you investigate to determine the frequency with which hazard events have occurred in any area? How reliable is the evidence obtained from those sources?

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.

5.2 The theory of plate tectonics

Before the development of plate tectonic theory, Earth scientists divided the interior of the Earth into three layers: the crust, the mantle and the core.

The **core** is made up of dense rocks containing iron and nickel alloys and is divided into a solid inner core and a molten outer one, with a temperature of over 5000 °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 radioactive decay of isotopes, particularly Uranium-238, Thorium-232 and Potassium-40.

The **mantle** is made up of molten and semi-molten rocks containing lighter elements such as silicon and oxygen.

The **crust** is even lighter because of the elements that are present, the most abundant being silicon, oxygen, aluminium, potassium and sodium. The crust varies in thickness – beneath the oceans it is only 6–10 km thick but below the continents this increases to 30–40 km and under the highest mountain ranges this can be as high as 70 km.

The theory of plate tectonics has retained this division, but new research has suggested that the crust and upper mantle should be divided into the lithosphere and asthenosphere.

The **lithosphere** consists of the crust and the rigid upper section of the mantle and is approximately 80–90 km thick. This is the section of the Earth that is divided into seven very large plates and a number of smaller ones (Figure 5.6). Plates are divided into two categories, oceanic and continental, depending on the type of material from which they are made (see Table 5.1).

The **asthenosphere** lies beneath this layer and is semi-molten on which the plates float and move.

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 (SIAL)	Mainly basalt; silicon, magnesium, oxygen (SIMA)

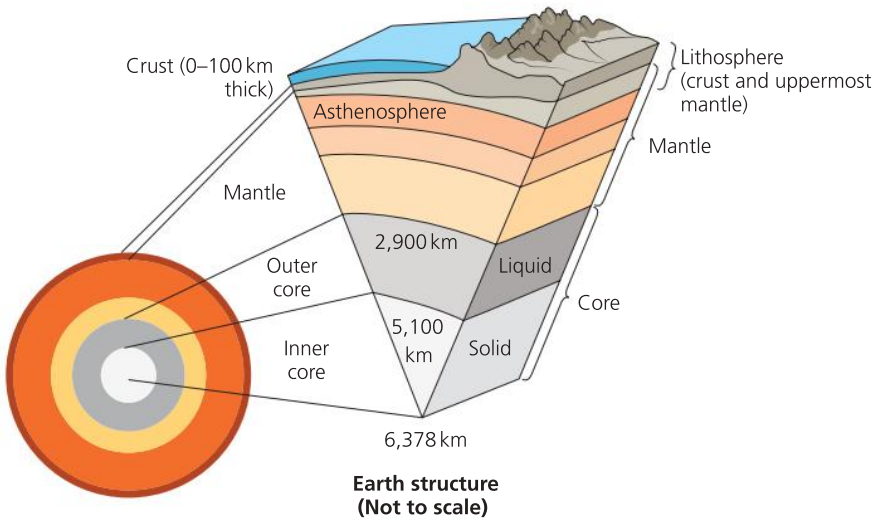

Figure 5.6 The structure of the earth

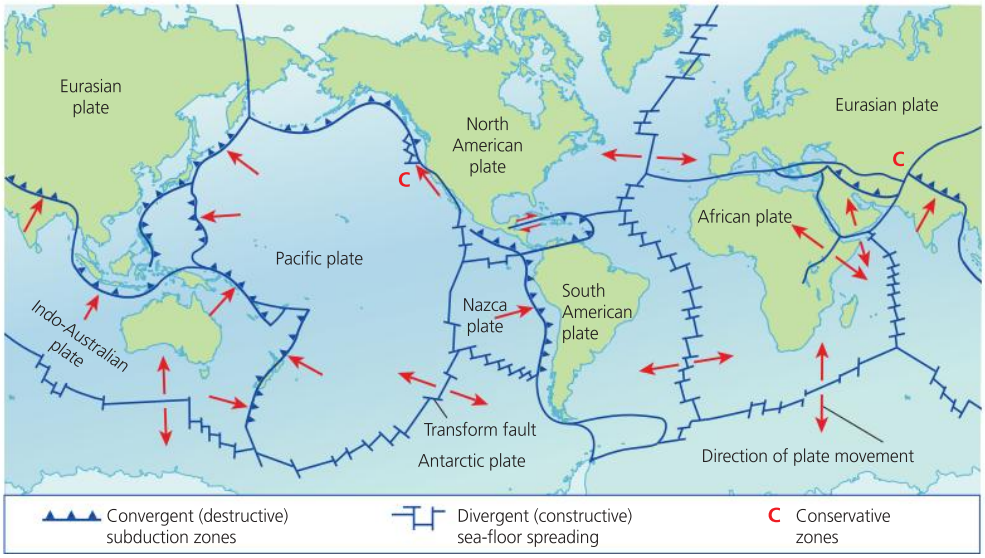

Figure 5.7 Tectonic plates and their margins

The theory

Plate tectonic theory revolutionised the study of Earth science. As soon as maps of the Atlantic Ocean were produced, people began to notice that the continents either side seemed to fit together remarkably well – the bulge of South America fitting into the indent below West Africa (Figure 5.7). Francis Bacon had noticed this fit as early as the seventeenth century but it did not attract any serious attention as no one thought that the continents could move.

In 1912, a German, Alfred Wegener, published his theory that a single continent existed about 300 million years ago. He named this super-continent Pangaea and maintained that it had later split into the two continents of Laurasia in the north and Gondwanaland in the south. Today's continents were formed from further splitting of these two masses. Wegener published this theory of continental drift and claimed that it was supported by several pieces of evidence that these areas were once joined.

Geological evidence for the theory includes:

- the above-mentioned fit of South America and west Africa
- evidence of a late-Carboniferous glaciation (290 million years ago), deposits from which are found in South America, Antarctica and India. The formation of these deposits cannot be explained by their present position; they must have been formed together and then moved. There are also striations on rocks in Brazil and West Africa which point to a similar situation
- rock sequences in northern Scotland closely agree with those found in eastern Canada, indicating that they were laid down under the same conditions in one location.

Biological evidence for the theory includes:

- fossil brachiopods found in Indian limestone are comparable with similar fossils in Australia
- fossil remains of the reptile *Mesosaurus* are found in both South America and southern Africa. It is unlikely that the same reptile could have developed in both areas or that it could have migrated across the Atlantic
- the fossilised remains of a plant which existed when coal was being formed have been located only in India and Antarctica.

Development of the theory

Wegener's theories were unable to explain how continental movement could have taken place and his ideas gained little ground. From the 1940s onwards, however, evidence began to accumulate to show that Wegener could have been correct.

The mid-Atlantic ridge was discovered and studied along with a similar feature in the Pacific Ocean. Examination of the ocean crust either side of the mid-Atlantic ridge suggested that **sea-floor spreading** was occurring. The evidence for this is the alternating polarity of the rocks that form the oceanic crust. Iron particles in lava erupted on the ocean floor are aligned with the Earth's magnetic field. As the lavas solidify, these particles provide a permanent record of the Earth's polarity at the time of the eruption (palaeomagnetism). However, the Earth's polarity reverses at regular intervals (approximately every 400,000 years). The result is a series of magnetic 'stripes' with rocks aligned alternately towards the north and south poles (Figure 5.8). This striped pattern, which is mirrored exactly on either side of a mid-oceanic ridge, suggests that the oceanic crust is slowly spreading away from this boundary. Moreover, the oceanic crust gets older with distance from the mid-oceanic ridge.

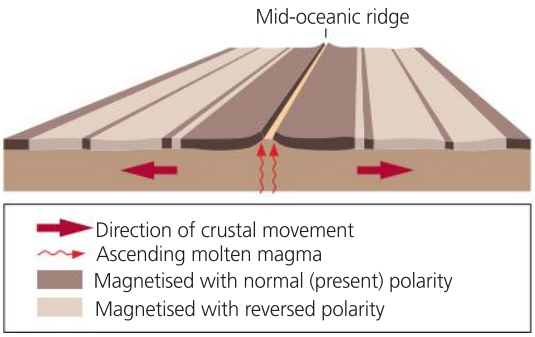

Figure 5.8 Magnetic 'stripes' on the Atlantic Ocean floor

Sea-floor spreading implies that the earth must be getting bigger. As this is not the case, then plates must be being destroyed somewhere to accommodate the increase in their size at mid-oceanic ridges. Evidence of this was found with the discovery of huge oceanic trenches where large areas of ocean floor were being pulled downward in a process known as **subduction.**

Hot spots around the core of the earth generate thermal convection currents within the asthenosphere, which cause magma to rise towards the crust and then spread

before cooling and sinking (Figure 5.9). This circulation of magma is the vehicle upon which the crustal plates move. The crust can be thought of as 'floating' on the denser material of the asthenosphere. This is a continuous process, with new crust being formed along the line of constructive boundaries between plates (plates moving away from each other – divergent) and older crust being destroyed at destructive boundaries (plates moving towards each other – convergent). Where two crustal plates slide past each other and the movement of the plates is parallel to the plate margin, there is no creation or destruction of crust. At these conservative margins, there is no subduction and therefore no volcanic activity. (See information on the San Andreas fault zone (California) in the seismic hazards section.)

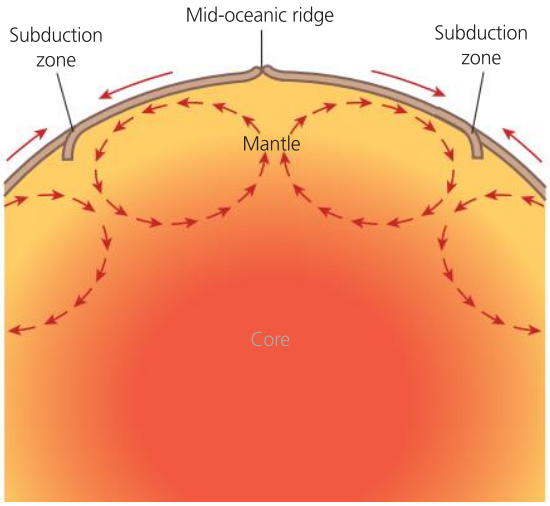

Figure 5.9 Convection currents and plate movements

Landforms associated with plate movements

The movement of the plates are therefore responsible for the production of the following landforms.

- **Ocean ridges:** The longest continuous uplifted features on the surface of the planet, they are formed when plates move apart in oceanic areas. The space between the plates is filled with basaltic lava upwelling from below to form a ridge. Volcanic activity also occurs along these ridges, forming submarine volcanoes which sometimes rise above sea level, such as Surtsey to the south of Iceland.
- **Rift valleys:** Such valleys form when plates move apart on continental areas. In East Africa, for example, the brittle crust fractures as sections of it move apart. Areas of crust drop down between parallel faults to form the valley. An area between two parallel rift valleys forms an upstanding block, known as a **horst.** The line of the African rift is thought to be an emergent plate boundary, the beginning of the formation of a new ocean as eastern Africa splits away from the remainder of the continent.
- **Deep sea trenches:** Where oceanic and continental plates meet, the denser oceanic plate is forced underneath the lighter continental one (subduction). The downwarping of the oceanic plate forms a very deep part of the ocean known as a trench. Off the western coast of South America, the Nazca plate is subducted under the South American plate forming the Peru-Chile trench. A similar process happens when two oceanic plates move towards each other. On the western side of the Pacific Ocean, the Pacific plate is subducted beneath the smaller Philippine plate forming the very deep Marianas trench.
- **Island arcs:** During subduction, the descending plate encounters hotter surroundings, and this coupled with the heat generated from friction, begins to melt the plate. As this material is less dense than the surrounding asthenosphere, it begins to rise towards the surface as plutons of magma. Eventually these reach the surface and form complex, composite and explosive volcanoes. If the eruptions take place offshore, a line of volcanic islands forms. These are known as island arcs. The Marianas Islands and Guam form a very good example, running parallel to the Marianas trench.
- **Young fold mountains:** The plates forming continental crust have a much lower density than the underlying layers, so there is not much subduction when such plates meet. As such plates move towards each other, their edges and the sediments between them are forced up into fold mountains. As there is little subduction, there is no volcanic activity. Material is also forced downwards to form deep mountain roots. At present, the Indo-Australian plate is moving northwards into the Eurasian plate. The previous intervening ocean, known as the Sea of Tethys, has had its sediments forced upward in large overfolds to form the Himalayas, a process which is continuing today. Sediments that have accumulated on the continental shelf, along the edge of a plate, can also be uplifted as the plate edges buckle during the subduction of a denser oceanic plate. The Andes, running down the area where the Nazca plate is being subducted beneath the lighter South American plate, are a good example. Molten magma rising from depth also gives rise to a number of explosive volcanoes in the Andes.
- **Volcanoes**.

Alternative ideas on plate movements

For a long time, the generally accepted view of plate motion was that it was brought about by convection currents. It is now believed that forces behind plate motion are not as simple as would be explained entirely by convection currents.

Forces that act on plates can also be generated at their boundaries. These forces push from the ridge, drag the plates down at the trenches, or act along the sides of plates at conservative boundaries.

At constructive boundaries, the upwelling of hot material at ocean ridges generates a buoyancy effect that produces the ocean ridge which stands some 2–3 km above the ocean floor. Here, oceanic plates experience a force that acts away from the ridge, known as **ridge push**, which is the result of gravity acting down the slope of the ridge. 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 do not like the term 'ridge push' and would prefer to name the process **gravitational sliding**.

The situation at destructive plate boundaries is more complex. A major component is the downward gravitational force acting on the cold and dense descending plate as it sinks into the mantle. This gravity-generated force pulls the whole oceanic plate down as a result of the negative buoyancy of the plate. This force is known as **slab pull**. Due to the pushing of the subducting plate against the overriding plate, there is frictional resistance that gives rise to both shallow and deep earthquakes in subduction zones.

Each plate, however, 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 agent is the sole driving mechanism of plate motion; plates are therefore controlled by a combination of forces.

5.3 Volcanic hazards

Key terms

Lahars – These are formed by volcanic ash mixing with water and flowing downhill. Essentially they are volcanic mudflows. In the Philippines, if a typhoon occurs after a volcanic eruption, then lahars can result.

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).

Lithosphere – The layer of the Earth which consists of the crust and the upper section of the mantle. It is this layer which is split into a number of tectonic plates.

Pyroclastic flows – Also known as **nuées ardentes**, formed from a mixture of hot gas (over 800°C) and tephra. After ejection from the volcano they can flow down the sides of a mountain at speeds of over 700 km per hour. Some volcanologists apply the term nuées ardentes when the cloud is formed only from hot gas.

Tephra – The solid matter ejected by a volcano into the air. It ranges from volcanic bombs (large) to ash (fine).

Nature and distribution

Most volcanic activity is associated with plate tectonic processes and is mainly located along plate margins.

Volcanic activity is therefore found at the following sites:

- Along **oceanic ridges** where plates are moving apart and magma is forcing its way to the surface, cooling and forming new crust. As the plates move further apart, this new crust is carried away from the ridge (**sea-floor spreading**). The best example is the mid-Atlantic ridge where Iceland represents a large area formed by volcanic activity (Figure 5.10). Volcanoes formed here have fairly gentle sides because of the low viscosity of the basaltic lava. Eruptions are frequent but relatively gentle (effusive). (See material on Eyjafjallajökull, Iceland.)

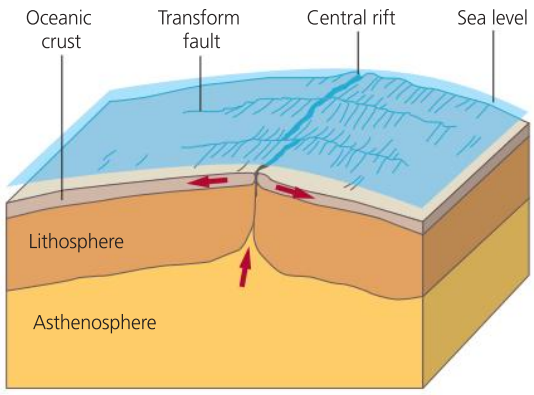

Figure 5.10 Cross section of the mid-Atlantic ridge

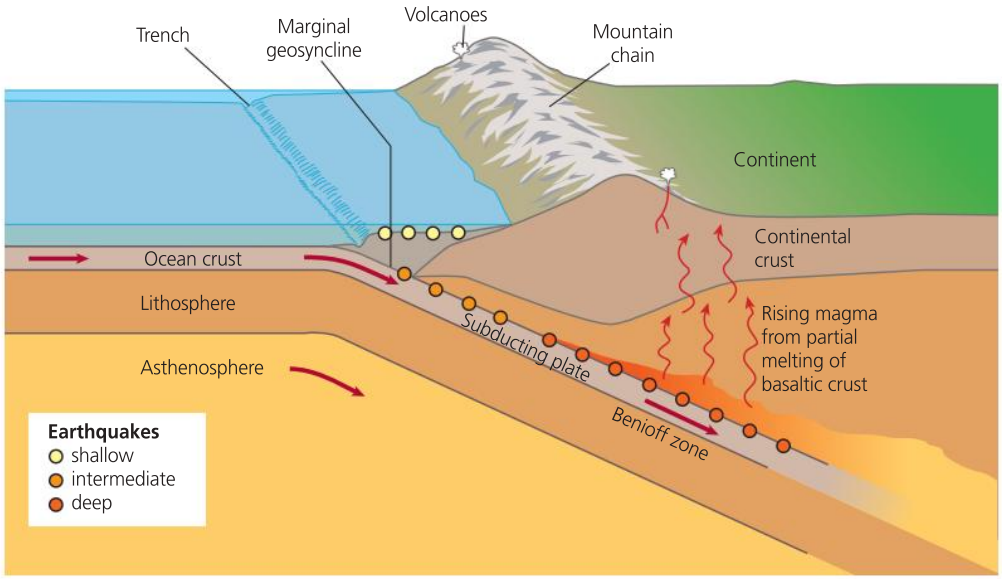

Figure 5.11 Cross section of oceanic/continental plate convergence at a destructive margin

- 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 rise as plutons of magma. Eventually, these reach the surface and form volcanoes (Figure 5.11). 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, for example, the West Indies. Island arcs can also occur when oceanic plates meet and one is forced under the other, with the consequent subduction processes taking place. On the western side of the Pacific Ocean, the Pacific plate is being dragged 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.

- Associated with **rift valleys**: At constructive margins in continental areas such as east Africa, the brittle crust fractures as sections of it move apart. Areas of crust drop down between parallel faults to form rift valleys (Figure 5.12). The crust here is much thinner than in neighbouring areas, suggesting that tension in the crust is causing the plate to thin as it starts to split. Through this thinning crust, magma forces its way to the surface to form volcanoes and there are a number of active volcanoes situated along the rift in east Africa. (See the material on Mt Nyiragongo.)

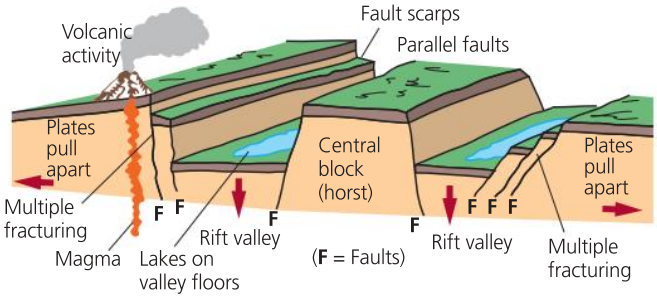

Figure 5.12 Cross section of a rift valley

- Over **hot spots**: In certain places, a concentration of radioactive elements below the crust causes a hot spot to develop. From this, a plume of magma rises to eat into the plate above. When this lava breaks through to the surface, active volcanoes form above the spot. The basaltic lava flows slowly and forms huge but (relative to the area covered) flattish volcanoes, sometimes referred to as 'shield' volcanoes. Figure 5.13 shows the example of the Hawaiian Islands in the Pacific Ocean. The hot spot is stationary, so as the Pacific plate moves over it, a line of volcanoes is created. The one above the hot spot is active and the remainder form a chain of islands with extinct volcanoes. The oldest volcanoes have put so much pressure on the crust that subsidence has occurred. This, together with marine erosion, has reduced these old volcanoes to seamounts below the

level of the ocean. Figure 5.13 shows the line of the Hawaiian islands and their ages. From this evidence it is clear that the Pacific plate is moving northwest (see also Figure 5.14).

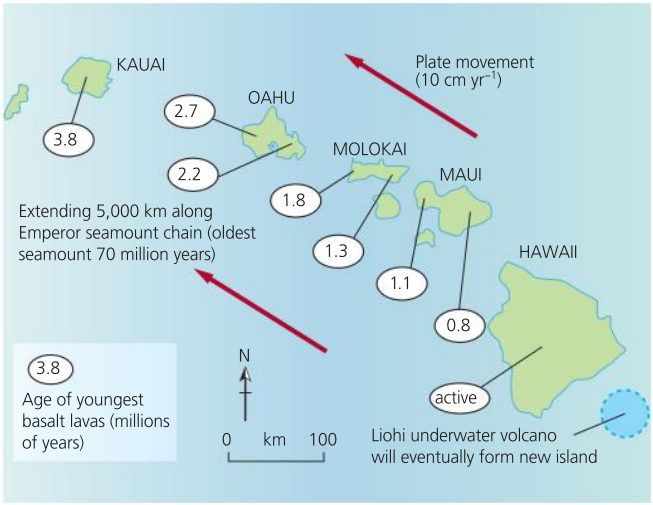

Figure 5.13 The Hawaiian hot spot

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.

The magnitude and frequency of events

Volcanic eruptions show an enormous variation. On the one hand they can involve the tranquil effusion of a sluggish lava; on the other they can take the form of huge explosions that eject gas and dust and can blot out the sun for many years, bringing on global climatic change. The main method of measurement of **magnitude** has been the **volcanic explosivity index (VEI)**, a logarithmic scale running from 0 to 8. Quiet lava-producing eruptions score 0–1 on the index whereas the eruption of Mt St Helens (USA) (1980) scored 5 and Pinatubo (Philippines) (1990) was rated at 6 on the scale. Colossal eruptions on the scale of 7–8 occur very infrequently. Volcanologists estimate that the last eruption at 7 on the scale was Tambora (Indonesia) in 1815 and to find the last eruption which was graded 8, we have to go back around 73,000 years to Toba (Indonesia). Critics of the VEI point out that it does not take into account gas emissions or the atmospheric/climatic impact of eruptions.

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

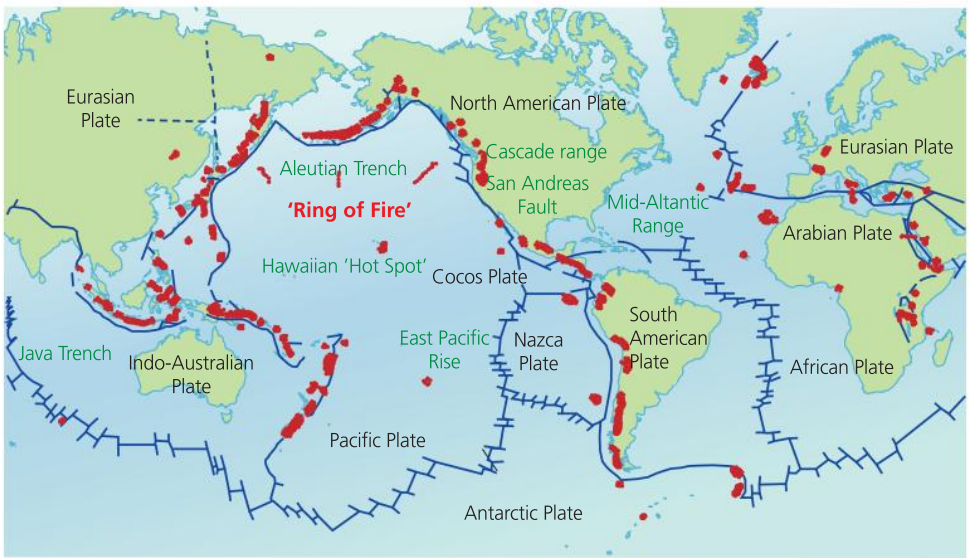

Figure 5.14 Global distribution of active volcanoes

- 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.**
- **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 mud flows):** Melted snow and ice as a result of the eruption combined with volcanic ash forms mud flows that can move down the course of river valleys at high speeds. In 1985, a lahar destroyed the Colombian town of Armero after an eruption of the volcano Nevado del Ruiz. 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.**
- 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 203–204)
- **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.

Volcanic events become hazardous when they impact upon people and the built environment, killing and injuring people, burying and collapsing buildings, destroying infrastructure and bringing agricultural and other economic activities to a halt.

Management of the volcanic hazard

- **Prediction:** Locating volcanoes is straightforward, but it is very difficult to predict when activity will take place. The already mentioned Colombian volcano, Nevado del Ruiz, came to life in late 1984 with small-scale activity but volcanologists, although they knew the danger a major eruption would pose to the surrounding area, were unable to predict when that major event would take place. As the volcano continued with small-scale activity for several months, people stayed and worked in the area. When the final violent event took place, almost all the population had remained and devastating lahars swept down several valleys, killing over 20,000 people.

  A study of the previous eruption history of any volcano is important, along with an understanding of the type of activity produced. There are several ways in which volcanologists are seeking to give a fairly accurate timing for an eruption. These include the monitoring of land swelling, changes in groundwater levels and the chemical composition of groundwater and gas emissions. It is also possible to monitor seismic activity looking for the shock waves that result from magma moving towards the surface, expanding cracks and breaking through other areas of rock.
- **Protection:** In this case, protection usually means preparing for the event. Monitoring a volcano, as shown above, will possibly identify a time when the area under threat should be evacuated. The governments of several countries with volcanoes, such as New Zealand, have made risk assessments and from them produced a series of alert levels in order to warn the public of the threat.

Geological studies of the nature and extent of deposits from former eruptions and associated lahars and floods may also provide evidence for hazard assessment. Following this, it is possible to identify areas at greatest risk and land use planning can be applied to avoid building in high risk areas. Figure 5.15 shows the risk assessment made for the area around Mt Rainier (part of the Cascade Range in the USA), one of the most studied volcanoes in North America, which is not surprising as 3.5 million people live and work in proximity to it.

Once the lava has started to flow and is fairly viscous, 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 has been successful in slowing down the flow and, in some cases, diverting it. In 1973, the

inhabitants of Haeimaey (Iceland) were able to divert a lava flow by pouring seawater on the front so it would quickly solidify. In parts of the Hawaiian Islands, barriers have been built across valleys to protect settlements from lava flows and lahars.

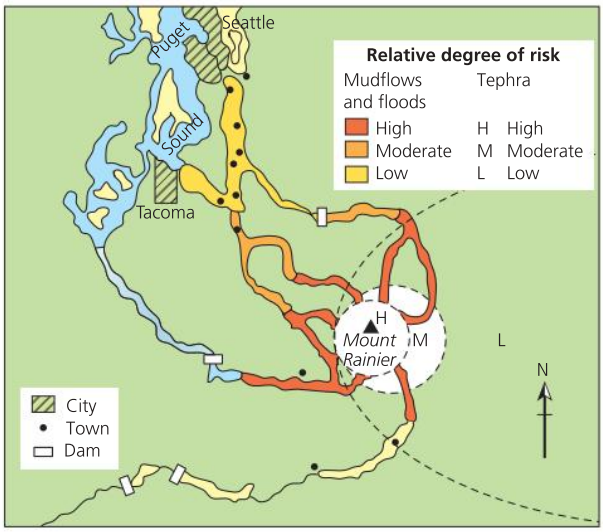

Figure 5.15 Risk assessment of Mt Rainier, Cascade Range, USA

Many devastated areas in poorer countries require aid for considerable periods of time as volcanic events can be prolonged and very damaging to the local economy. Such aid is needed for monitoring, evacuation, emergency shelters and food, long-term resettlement of the population and the restoration of the area's economic base and infrastructure.

Responses can also be seen as both short and long term. Immediate responses are those which take place just before or after the volcanic event such as warnings, evacuation and attempts to stop lava flows. In the long term, responses include the monitoring of a volcano, research into finding new methods of prediction and even building barriers in anticipation of the direction of lava flows and lahars.

Volcanic events

The eruption of Mt Nyiragongo, Congo, January 2002

Mount Nyiragongo lies in the Virunga Mountains in the Democratic Republic of the Congo (Figure 5.16) and it is associated with the African Rift Valley.

The main crater of the volcano is 250 m deep, two kilometres wide and often contains a lava lake. Since records of the area began in the nineteenth

Figure 5.16 The location of Mt Nyiragongo

century, the volcano has erupted over 30 times, and together with its neighbouring volcano, Mount Nyamuragira, it is responsible for around 40 per cent of Africa's recorded volcanic eruptions. Lava erupted by Nyiragongo is very fluid and has been known to move downhill at speeds of over 90 kilometres per hour.

- **Risk and vulnerability:** The Goma area is part of a fertile agricultural region. The combination of altitude (1,500 m), extended growing season and the fertile volcanic soils has encouraged large numbers of people to settle there, despite the presence of the volcano. Since 1882, there have been 34 eruptions, although each period of activity does not always involve lava flows. Because the lava is slow flowing, the volcano does not pose a huge threat to people, but the flows can overwhelm agricultural areas and large swathes of the built environment. In recent times, though, people have also become very vulnerable to the emissions of poisonous carbon dioxide gas seeping from the ground around the volcano.

Although there had been some seismic activity in the area, the eruption in January 2002 was unexpected, although warnings of the lava flows enabled most people to flee from their effects. This was a large eruption, with a 13 km fissure opening on the southern flank of the volcano spewing lava, up to two metres deep, which flowed in the direction of Goma and Lake Kivu. The eruption, however, was not violent, being recorded as only one on the VEI scale.

The major effects of the eruption were:

- lava flows that destroyed at least one third of Goma, a town with over 200,000 inhabitants (Figure 5.17)
- the commercial centre of the town was destroyed along with water and power supply facilities and many of the medical facilities including three health centres and one hospital
- the lava covered the northern third of the runway at Goma airport
- the death toll reached 147 (largely through inhaling poisonous gases, drinking contaminated water and the collapse of buildings)
- it was estimated that over 350,000 people fled the area, many over the border to Rwanda, particularly the town of Gisenyi. This caused an enormous problem in providing food and shelter in this small country
- sulphurous lava entered Lake Kivu and poisoned the water which was a major source of drinking water in the area
- there was a fear that the rise in temperature of Lake Kivu, due to the lava, could allow toxic gases (carbon dioxide and methane) to be released from the lake bed
- several earthquakes accompanied the eruption, one measuring over 5 on the Richter scale. These tremors were strong enough to cause structural damage to some buildings in the area
- thousands of people required medical attention, first from the effects of smoke and fumes from the lava, which caused eye irritation and respiratory problems, and secondly from such complaints as dysentery linked to the drinking of contaminated water
- there was a vast amount of looting from abandoned homes and commercial properties. (Many people were killed when a petrol store, which they were attempting to loot, exploded. It is believed that the looters were hoping to sell the petrol in order to buy food.)

The initial response to the eruption was that the authorities were able to issue a 'Red Alert' for Goma and the surrounding area, which enabled a full evacuation to take place. This prompt response was one of the factors which kept the death rate relatively low.

Two days after the eruption, the UN was able to ferry in humanitarian aid. Emergency rations initially consisted of such provisions as high energy biscuits, followed by more substantial food aid (maize, beans and cooking oil) as communications began to improve. The UN also set up camps to house the displaced people. The organisation has estimated the cost of providing food, blankets, household utensils, temporary shelter, clean water, sanitation and health care to the refugees at $15 million. A much higher cost, though, will be incurred in rebuilding Goma's infrastructure, homes and livelihoods. One of the main problems was that the lava flows destroyed many businesses, resulting in a massive increase in unemployment in the area.

Minor volcanic activity has continued on Mt Nyiragongo right up to the present day. Recently several children and animals died as a result of inhaling poisonous carbon dioxide gas which had seeped from the ground in relatively large amounts. This is not uncommon in the area; the local people even giving the phenomenon a name: 'Mazuku'.

Key question

Study Figure 5.1 (page 185), the model of vulnerability. Using the information contained in this study of a volcanic event, replace the generalities of the model with the real details of the Nyiragongo eruption. What does the completed figure tell you about the extent of the risk to people and the environment (and their vulnerability) in living in the area around Mt Nyiragongo?

Figure 5.17 The impact of the eruption of Mt Nyiragongo, Goma, Congo in 2002

The eruption of Eyjafjallajökull (Iceland), April 2010

Iceland's position on the mid-Atlantic ridge means that it has a number of active volcanoes, the major ones being shown on Figure 5.18. In the past, they have proved devastating. Hekla, it has been estimated, has erupted around 20 times since AD 874, pouring out a total of 8 km^3 of lava from a line of fissures that stretches over 5 km across the mountain. Many of these volcanoes are covered by ice caps feeding glaciers, which means that when they erupt much ice is melted resulting in flooding and huge ash clouds also develop. As the magma hits the ice it suddenly cools, forming a glass-like material which instantly disintegrates. Explosions of gas within the main vent pulverise the fragments into very tiny particles. As the gas and steam blown from the vent carry this ash into the atmosphere it can rise to great heights where it is caught in high-altitude winds (jet stream). As this ash is carried away from the volcano it disperses and becomes invisible but it can be sucked into the engines of aircraft so endangering their operation.

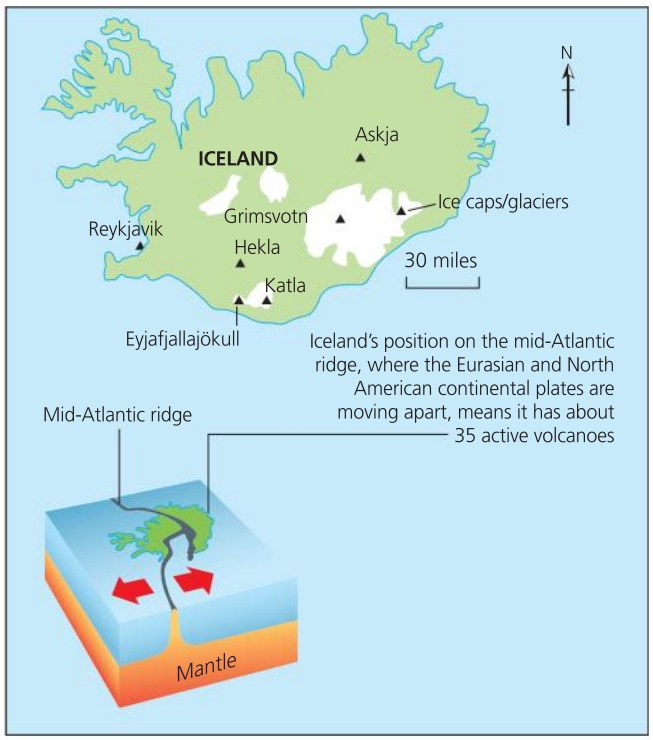

Figure 5.18 Iceland's major volcanoes and its position on the mid-Atlantic ridge

In early 2010, seismic activity was detected in the area of Eyjafjallajökull. This gave geophysicists evidence that magma was pouring from underneath the crust into the volcano's magma chamber. Minor eruptions followed and then the volcano went quiet for a short period. On 14th April, however, an explosive eruption occurred (4 on the VEI scale) in the top crater, which had the following effects:

- huge amounts of ice were melted causing floods to rush down the nearby rivers, requiring nearly 1,000 people to be evacuated
- as the eruption continued, large quantities of ash poured from the volcano into the higher levels of the atmosphere (Figure 5.19, page 200). Once picked up by the jet stream, this ash cloud was blown towards Europe. Many European countries were forced to shut down their air space; the largest such shut down since World War II. It has been estimated that this cost the airlines £130 million per day for the six days that the airspace was closed. This affected several million people and had knock-on travel effects across the globe.

By the end of 2010, Eyjafjallajökull was considered to be dormant, but volcanologists switched their attention to its neighbour, Katla, as its last eruption in 1918

produced five times the amount of ash as the eruption of Eyjafjallajökull. There have been signs that magma is rising beneath Katla and a major eruption may not be very far away.

- **Risk and vulnerability:** There is very little risk to people's lives from this volcano as so few of them live in this part of Iceland, although some had to be evacuated after the most recent eruption. The real threat comes via the ash cloud produced by such volcanoes. This means that people are vulnerable at some distance away from the volcano, not in terms of their lives, but in their ability to travel, as flights would be severely restricted due to the ash cloud.

Fieldwork opportunities

There is the possibility of doing some work (along with other physical geography aspects, such as glaciation) in Iceland. You will have a chance to observe first-hand the volcano you have just read about and other active volcanoes, lava flows, ash deserts, geysers and the rift which is opening up between the North American and Eurasian plates.

Figure 5.19 Ash cloud from the eruption of Eyjafjallajökull

Other volcanic events worth studying

Etna (Sicily, Italy) 1991–99

Montserrat (West Indies) 1995–97

Merapi (Indonesia) 2010

Mt Ontake (Japan) 2014

5.4 Seismic hazards

Key terms

Earthquake – As the crust of the Earth is constantly moving, there tends to be a slow build up of stress within the rocks. When this pressure is released, parts of the surface experience, for a short period, an intense shaking motion. This is an earthquake.

Retrofitting – In earthquake-prone areas buildings and other structures can be fitted with devices such as shock absorbers and cross-bracing to make them more earthquake proof.

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

Nature and distribution

As the crust of the Earth is mobile, there tends to be a slow build up of stress within the rocks. When this pressure is suddenly released, parts of the surface experience an intense shaking motion that lasts for just a few seconds. This is an **earthquake**. The point at which this pressure release occurs within the crust is known as the **focus**, and the point immediately above that on the earth's surface is called the **epicentre** (Figure 5.20). The depth of the focus is significant in the effects on the surface and three broad categories of earthquake are recognised:

- **shallow focus (0–70 km deep):** these tend to cause the greatest damage and account for 75 per cent of all the earthquake energy released
- **intermediate focus (70–300 km deep)**
- **deep focus (300–700 km deep)**

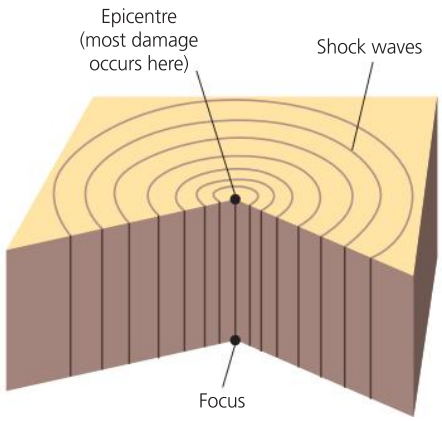

Figure 5.20 The focus and epicentre of an earthquake

The vast majority of earthquakes occur along plate boundaries (Figure 5.21), the most powerful being associated with destructive margins. At conservative margins, the boundary is marked by a fault, movement along which produces the earthquake. Perhaps the most famous of these is the San Andreas Fault in California, which represents the boundary between the North American and Pacific plates. In reality, the San Andreas system consists of a broad complex zone in which there are a number of fractures of the crust (Figure 5.22).

Some earthquakes occur away from plate boundaries and are associated with the reactivation of old fault lines. In September 2002, an earthquake (4.8 Richter) occurred in the UK Midlands. The epicentre was at Dudley, west of Birmingham, and was believed to have been caused by movements on an old fault line called the Malvern lineament.

It has been suggested that human activity could be the cause of some minor earthquakes, through building large reservoirs which puts pressure on the underlying rocks, or subsidence of deep mine

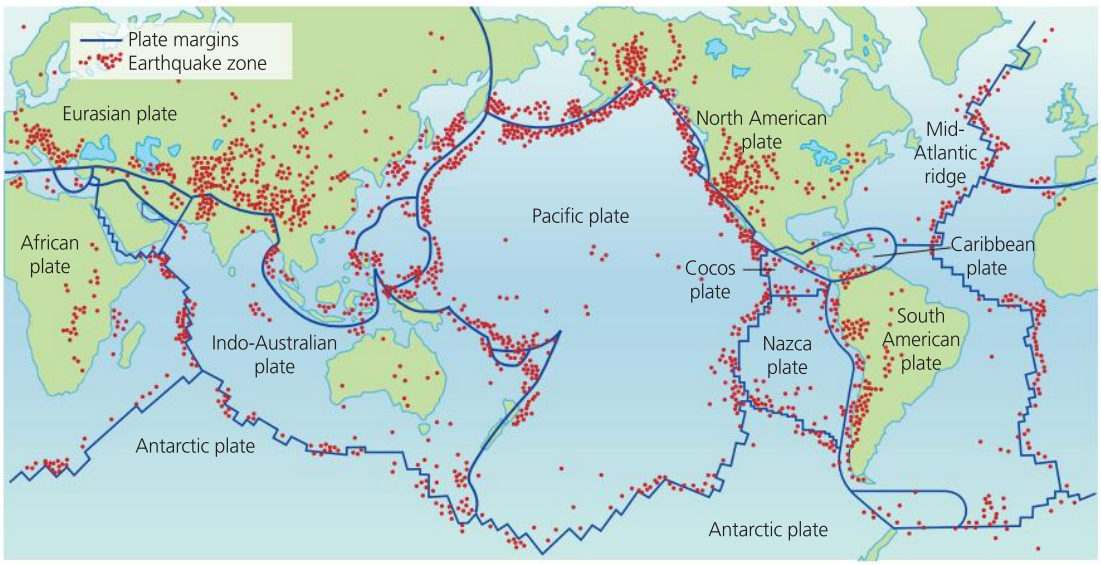

Figure 5.21 Global distribution of earthquakes

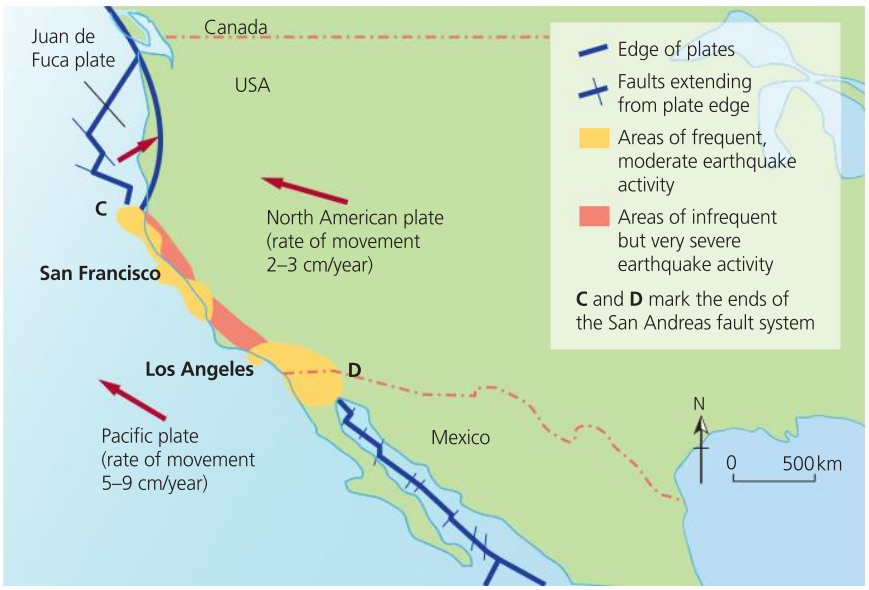

Figure 5.22 The San Andreas fault system: a conservative plate margin

workings. In recent times, people have become increasingly worried about the process of fracking (hydraulic fracturing of rock in order to release gas). In Oklahoma (USA), for example, some areas of the state have experienced a tremendous increase in minor earthquakes since fracking began in 2009.

Magnitude and frequency

The **magnitude** of earthquakes is measured in a variety of ways. The **Richter scale** (Table 5.2) is a logarithmic scale – an event measured at 7 on the scale has an amplitude ten times greater than one measured 6 on the scale. The energy release is proportional to the magnitude, so that for each unit increase on the scale, the energy released increases by approximately 30 times. Some geologists have been unhappy with the fundamentals of the Richter scale for some time and now it is more usual to use the **moment magnitude scale (MMS)** which identifies energy release. Its scale is the same as that of Richter, that is, 1–10. The largest earthquake ever recorded was estimated to be the Valdivia (Chile) event in 1960 (9.5 MMS).

Table 5.2 The Richter scale

Number (Logarithmic)	Effects
1–3	Normally only detected by seismographs, not felt
4	Faint tremor causing little damage
5	Widely felt, some structural damage near epicentre
6	Distinct shaking, less well-constructed buildings collapse.
7	Major earthquake causing serious damage (e.g. Kobe 1995, Turkey 1999)
8	Great earthquake causing massive destruction and loss of life (e.g. Mexico City 1985, San Francisco 1906)
9–10	Very rare great earthquake causing major damage over a large region and ground seen to shake

Another scale which has come into use is the **Mercalli scale** (Table 5.3) which measures the intensity of an event and its impact. It is a 12-point scale where Level 1 is approximate to 2 on the Richter scale. It goes up to Level XII (approximately 8.5 on Richter).

Table 5.3 The Mercalli scale

I. Not felt	Not felt except by a very few under especially favourable conditions
II. Weak	Felt only by a few persons at rest, especially on upper floors of buildings
III. Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognise it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated
IV. Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably
V. Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop
VI. Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight
VII. Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken
VIII. Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings, with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned
IX. Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations
X. Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent
XII. Extreme	Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly
XIII. Extreme	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air

Source: USGS

Seismic records enable earthquake frequency to be observed, but these records only date back to 1848 when an instrument capable of recording seismic waves was first developed. Before that we have to consult historical records as to the date and the effects of the identified event.

The effects of seismic events

The initial, or **primary** effect (impact), of an earthquake will be **ground shaking**, the severity of which will depend upon the magnitude of the earthquake, its depth, the distance from the epicentre and the local geological conditions. In the Mexico City earthquake of 1985, for example, the seismic waves that devastated the city were amplified several times by the ancient lake sediments upon which the city is built.

Another primary effect is **ground rupture**, which is the visible breaking and displacement of the earth's surface, probably along the line of the fault. Ground rupture poses a major risk for large engineered structures such as dams, bridges and nuclear power stations.

Secondary effects are as follows:

- **soil liquefaction:** when violently shaken, soils with a high water content lose their mechanical strength and start to behave like a fluid
- **landslides/avalanches:** slope failure as a result of ground shaking
- **tsunamis**: giant sea waves generated by shallow-focus underwater earthquakes involving movements of the sea bed, or landslides into the sea (see below)
- **fires:** resulting from broken gas pipes and collapsed electricity transmission systems
- **effects on people and the built environment:** collapsing buildings; destruction of road systems and other forms of communication; destruction of service provision such as water, electricity and gas; flooding; disease; food shortages; disruption to the local economy, either subsistence or commercial. Some of the effects on the human environment are short term; others occur over a longer period and will depend to a large extent on the ability of the area to recover.

Tsunamis

Tsunamis are giant sea waves (tsunami means 'harbour wave' in Japanese) generated by shallow-focus underwater earthquakes (the most common cause), volcanic eruptions, underwater debris slides and large landslides into the sea. Tsunamis have a very long wavelength (sometimes over 100 km) and a low wave height (under one metre) in the open ocean, and they travel quickly at speeds of over 700 km per hour (some tsunamis take less than a day to cross the Pacific Ocean) but, when reaching shallow water bordering land, increase rapidly in height.

Quite often, the first warning given to coastal populations is the wave trough in front of the tsunami which results in a reduction in sea level, known as a drawdown. Behind this comes the tsunami itself, which can reach heights in excess of 25 m. The event usually consists of a number of waves, the largest not necessarily being the first. When a tsunami reaches land, its effects will depend upon:

- the height of the waves and the distance they have travelled
- the length of the event (at source)
- the extent to which warnings could be given
- coastal physical geography, both offshore and on the coastal area
- coastal land use and population density.

Figure 5.23 The area affected by the Indian Ocean tsunami

The wave will wash boats and wooden coastal structures inland, and the backwash may carry them out to sea. People are drowned or injured by the tsunami as both the water itself and the debris that it contains are hazards. Buildings, roads, bridges, harbour structures, trees and even soil are washed away, most tsunamis having an effect at least 500–600 m inland, depending upon the coastal geography. Tsunamis generated by the explosion of the volcano Krakatoa in 1883 have been estimated to have drowned over 35,000 people and produced waves that travelled around the world, the highest being over 40 m.

Around 90 per cent of all tsunamis are generated within the Pacific Basin, associated with the tectonic activity taking place around its edges. Most are generated at convergent plate boundaries where subduction is taking place, particularly on the western side of the Pacific and the bordering eastern side of the Indian Ocean (25 per cent of all events). Some recent events which have taken place in that area are described below:

- December 2004, **east Indian Ocean off Sumatra, 'the Boxing Day' tsunami:** Generated by a powerful magnitude 9.0 earthquake some 25 km below the Indian Ocean floor off northwest Sumatra (one of the biggest earthquakes ever recorded). The tsunamis which spread across the Indian Ocean killed an estimated 300,000 people in bordering countries and devastated hundreds of communities (Figure 5.23, page 203). Extensive damage was caused to coastal communications, particularly bridges and railway lines and damage to local economies left people unable to feed themselves. A positive result was that a warning system was set up among the countries that border the Indian Ocean. Despite the enormous human cost, the insurance industry estimated that the disaster could cost less than $5 billion.
- July 2006, **south Java coast**: Generated by a 7.7 magnitude earthquake 112 miles offshore, a tsunami devastated the area around Pangandaram resulting in over 600 deaths.
- April 2007, **Solomon Islands**: Generated by a 8.0 magnitude earthquake, the tsunami swept across the islands killing at least 15 people.
- March 2011, off the Pacific coast of the **Tohoku region of Japan** (Figure 5.24) Earthquake occurred 70 km offshore and of a magnitude of 9.0: the most powerful earthquake ever recorded in Japan (it was estimated that it moved the main island of Japan, Honshu, 2.4 m east). Tsunamis generated reached over 40 m in height and in some places penetrated over 10 km inland. These tsunamis devastated part of Japan's Pacific coast, causing nearly 16,000 deaths with over 6,000 people injured and 2,500 missing. It was estimated that over 300,000 people were also displaced from their homes. The built environment suffered with 127,000 buildings destroyed, 277,000 'half collapsed' and 750,000 partially damaged. In addition, the Fukushima nuclear power plant was seriously affected resulting in the evacuation of people living within 20 km of the facility. The assessed cost of the damage by insurers was over $30 billion while it has also been estimated that the economic cost to Japan was $235 billion. Tsunami waves ran right across the Pacific to North and South America; in Chile the tsunami created waves 2 m high.

The geological record indicates that huge tsunamis have affected areas such as the Mediterranean Basin (for example, the Santorini eruption around 1450 BC) and the North Sea area (for example, the Storegga slide, around 7250 BP) resulting from huge submarine debris slides off Norway which produced tsunamis of over 6 m in height in Scotland and other areas bordering the North Sea. It is believed that these tsunamis continued across the Atlantic to hit the coastlines of Spitsbergen, Iceland and Greenland.

Figure 5.24 Devastation caused by the Tohoku tsunami, Japan 2011

Skills focus

Find photographs on the internet of two urban areas in very different parts of the world that have suffered from devastating earthquakes (not the cities covered in this chapter). Use your observational skills to describe the damage shown in each photograph, in particular focusing on the differences that may be seen. If you identify any major differences, try to explain how they have come about.

Managing the seismic hazard

- **Prediction:** The prediction of earthquakes is very difficult. Regions at risk can be identified through plate tectonics, but attempts to predict a few hours before the event are questionable. Such attempts are based upon monitoring groundwater levels, release of radon gas and unusual animal behaviour. Fault lines such as the San Andreas can be monitored and the local magnetic fields measured. Areas can also be mapped on the basis of geological information and studies made into ground stability in order to predict the impact of an earthquake and to produce a hazard zone map that can be acted upon by local and even national planners.

  Close studies of fault lines can sometimes indicate the point along the fault where the next earthquake could be due. A study of the pattern of the events along the San Andreas fault between 1969 and 1988 indicated the existence of a **'seismic gap'** in the area of Loma Prieta (that is, the area had not had any real seismic activity for the past twenty years). This area suffered an earthquake in October 1989 that measured 6.9 MMS and was the worst to hit the San Francisco region since 1906. In total, 63 people died as a result of the event with over 3,700 seriously injured. Because of the seismic survey, this event was not entirely unexpected, but like all earthquakes, it was not possible to predict it precisely. Such a system, however, would not work for events such as the one at Northridge, as this took place on an unknown fault line.
- **Prevention:** Trying to prevent an earthquake is thought by almost all to be impossible. This, however, has not stopped studies into the feasibility of schemes to keep plates sliding past each other, rather than 'sticking' and then releasing, which is the main cause of earthquakes. Suggestions so far as to lubricating this movement have focused on water and oil. Some people have even gone as far as to suggest nuclear explosions at depth!
- **Protection:** Since earthquakes strike suddenly, violently and without warning, it is essential that everyone from civil authorities to individuals are prepared. In the USA, the Federal Emergency Management Agency's (FEMA) programme has the following objectives:
  - to promote understanding of earthquakes and their effects
  - to work to better identify earthquake risk
  - to improve earthquake-resistant design and construction techniques
  - to encourage the use of earthquake-safe policies and planning practices.

Protection therefore means preparing for the event by modifying the human and built environments in order to decrease vulnerability. It also includes attempts to modify the loss by insurance and aid. Some of the ways are described below:

- **Hazard-resistant structures:** Buildings can be designed to be aseismic, in that they can be earthquake resistant. There are three main ways in which this can be achieved:
  - By putting a large concrete weight on top of the building which will move, with the aid of a computer programme, in the opposite direction to the force of the earthquake in order to counteract stress.
  - Putting large rubber shock absorbers in the foundations which will allow some movement of the building.
  - By adding cross-bracing to the structure to hold it together better when it shakes.

  Older buildings and structures, such as elevated motorways, can be **retrofitted** with such devices to make them more earthquake proof. A comparison between the 1989 Loma Prieta earthquake (6.9 MMS) and the 1988 event in Armenia (6.8 MMS) shows the effects of different types of buildings. The greater earthquake-proof buildings of California resulted in 63 deaths, whereas in Armenia, over 25,000 people died, many inside buildings that collapsed as a result of soft foundations and no earthquake-proofing features. In the town of Leninakan, for example, over 90 per cent of more modern 9–12 storey pre-cast concrete frame buildings were destroyed.

- **Education:** For many areas, this is the main way that loss of life can be minimised. Instructions are issued by the authorities in how to prepare for such events by securing homes, appliances and heavy furniture, and assembling 'earthquake kits'. Children have earthquake drills at school as do people in offices and factories. Government offices and many companies in Japan observe Disaster Prevention Day (1 September) which marks the anniversary of the Tokyo (Kwanto Plain) earthquake in 1923. Following the Loma Prieta event (1989), the American Red Cross issued a list of supplies that people should keep at hand in case of an earthquake. These include water (at least a three-day supply for all persons in the house, and pets!); a whole range of foodstuffs (particularly canned and high energy foods); clothing and bedding; first aid kit; and tools and supplies (to include radio, torch batteries, can opener, matches, toilet paper, small fire extinguisher, pliers and aluminium foil).
- **Fire prevention:** 'Smart meters' have been developed that can cut off the gas if an earthquake of sufficient magnitude occurs. In Tokyo, the gas company has a network that transmits seismic information to a computer which then informs employees where to switch off major pipelines, so reducing the number of fires.
- **Emergency services:** These need careful organisation and planning. Heavy lifting gear needs to be available and many people should be given first aid training, as it could be some time after the event that trained medical personnel arrive. Much of the preparation in California involves the establishment of computer programs that will identify which areas the emergency services should be sent to first.
- **Land-use planning:** The most hazardous areas in the event of an earthquake can be identified and then regulated in terms of land use. Certain types of buildings should be put in areas of low risk, such as schools and hospitals. It is also important to have sufficient open space, as this forms a safe area away from fires and aftershock damage to buildings.
- **Insurance**: In richer areas, people are urged to take out insurance to cover their losses, the only problem being that for individuals, this is very expensive. In the Kobe earthquake in Japan in 1995, for example, only seven per cent of the people were covered by earthquake insurance.
- **Aid**: Most aid to poorer countries has generally been to help in the few days after the event, providing medical services, tents, water purification equipment, search and rescue equipment, etc. Aid over the longer term is much more problematical; it is something which is needed for the reconstruction of the built environment and redevelopment of the economy.
- **Tsunami protection:** Tsunamis cannot be entirely predicted, even if the magnitude and location of an earthquake is known. Certain automated systems can be installed to give warnings, the best of which uses bottom pressure sensors, attached to buoys, which constantly measure the pressure of the overlying water column. Regions with a high tsunami risk use warning systems (such as a klaxon) to warn the population before the wave reaches land. The Pacific Warning System is based on Hawaii. It monitors earthquake activity and issues warnings to countries around the Pacific edge if tsunamis are likely. Some countries have built prevention walls up to 12 m in height. These have not proved very effective, as large tsunamis are likely to overwhelm them.

Seismic events

Haiti (West Indies), January 2010

In January 2010 an earthquake of magnitude 7.0 MMS and depth of 13 km, struck the Caribbean country of Haiti, the poorest country in the western hemisphere. The epicentre was located 25 km west of the capital, Port-au-Prince (Figure 5.25). Following the initial event, the area recorded at least 50 aftershocks measuring 4.5 or greater.

- **Risk and vulnerability:** The risk from physical hazards is high in Haiti. It lies at the junction of the North American and Caribbean plates and between two fault zones: the Septentrional Zone to the north and the Enriquillo-Plantain system that runs directly beneath Port-au-Prince. The 2010 earthquake was the seventh major event recorded since observations began in the 1550s. Earthquakes also occur in the neighbouring country of the Dominican Republic; a tsunami generated by an earthquake there in 1946 killed 1,800 people in Haiti and injured many others. People are also at risk from tropical cyclones, with frequent flooding and widespread damage. Several storms in 2008 killed over 800 people.

People in Haiti are also very vulnerable when hazard events occur. There has been a long history of national debt, extreme poverty and poor housing conditions that tend to exacerbate the death toll as the effects often last long after the earthquake (often several years).

Figure 5.25 The location of the 2010 Haiti earthquake

Major effects of the event:

- The estimated death toll varied from 100,000 to 316,000. The Haitian government was accused of inflating the higher figure in order to gain more aid from the international community. More reliable estimates from outside agencies put the figure around 160,000, with at least 300,000 people injured.
- An estimated 2.3 million people were made homeless.
- The earthquake had a devastating effect on the built environment (Figure 5.26, page 208). It was estimated that 250,000 residences and 30,000 commercial properties were either destroyed or needed to be demolished. One of the major reasons for this was that construction standards were low in Haiti and the country had no building codes. Many government and public buildings were damaged or destroyed including the Palace of Justice, the National Assembly, the Supreme Court, Port-au-Prince Cathedral, the main art museum and the National Palace. The main prison was also destroyed, leading to the escape of around 4,000 inmates.
- Vital infrastructure necessary to respond to the event was severely damaged or destroyed. This included major roads (blocked by falling debris or cracked), the control tower at the airport and the harbour.
- All the hospitals in Port-au-Prince were destroyed and many medical facilities in other parts of the country were seriously damaged.
- There was also considerable damage to the communications infrastructure such as the public telephone service and also to cell phone masts.
- The education system collapsed with 1,300 schools destroyed and the university buildings seriously damaged.
- There was a breakdown in law and order in parts of the country with sporadic violence and looting reported.
- The collapse of water supplies, a lack of basic sanitation and thousands of unburied bodies led to a spread of disease. It has been estimated that over 8,000 people died in a cholera outbreak.

A major relief programme was directed towards the disaster, but rescuers, relief/aid agencies and national governments faced extreme difficulties in dealing with the aftermath of the earthquake. The country, for example, had little heavy lifting equipment, so it was difficult to look for survivors in fallen buildings. One immediate response from the US government was to deploy 3,500 soldiers to the country. In the UK, a large search and rescue team with dogs was sent to look for survivors. One difficult task was the removal of dead bodies, the number of which was so enormous that they had to be buried in large communal graves.

All of this meant that recovery for Haiti was an extremely slow process and even three to four years after the event, the effects are still obvious within the country. By 2014, over 170,000 people were still in 'displacement camps' (from a 1.5 million peak), 23 per cent of children were not at primary school, 70 per cent lacked access to electricity and 600,000 were said to be still 'food insecure'. On the positive side, 50 per cent of the debris has been removed, new building codes have been established, part of the country's debt has been written off and most agencies are resolved to make sure that the recovery is sustainable. Overall, it has been estimated that the final cost of the event could be around $8 billion.

Key question

Study Figure 5.1 (page 185), the model of vulnerability. Using the information contained in this study of an earthquake, replace the generalities of the model with the real details of the Haiti event. What does the completed figure tell you about the extent of the risk to people and the environment (and their vulnerability) in living in Port-au-Prince?

Figure 5.26 Devastation caused by the Haiti earthquake, January 2010

Christchurch (South Island, New Zealand), February 2011

In September 2010, the region of Canterbury suffered an earthquake of magnitude 7.1 MMS, the epicentre of which was 40 km west of Christchurch (Figure 5.27). The earthquake of 2011 was of a lower magnitude, 6.3 MMS, but had much greater and devastating effects. Many seismologists regard this event as an aftershock from that of 2010. The epicentre was only 10 km southeast from the centre of Christchurch, which in part accounts for the impact of the event on structures already weakened by the 2010 earthquake. Following on from February 2011, a number of strong aftershocks were recorded (over 5.5 MMS) in the next few months, which further damaged buildings, particularly in the city centre and the eastern suburbs. One estimate put the depth of the earthquake at only 5 km, which would also account for the amount of damage that it caused.

- **Risk and vulnerability:** New Zealand is an earthquake-prone country as it lies on the 'Pacific Ring of Fire', which is geologically active. The country experiences over 20,000 earthquakes every year, only 200 of which can actually be felt. Christchurch does not lie in New Zealand's major earthquake zone, although there were earthquakes in the region in 1869, 1888 and 1901, the effects of which were mainly damage to property (including the spire of Christchurch Cathedral). As the epicentres were outside of Christchurch, the risk to people was minimal as most of the area, apart from the city, was sparsely populated.

The inhabitants of Christchurch did not see themselves as particularly vulnerable. Apart from the central business district, many of the buildings in the city are of single-storey construction and the housing density is low. Also, with its geological position in mind, there are very stringent building regulations in place.

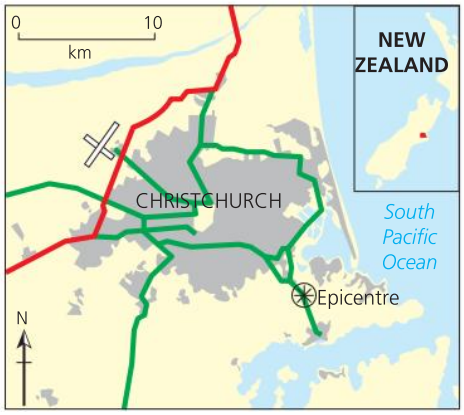

Figure 5.27 Location of the Christchurch earthquake

Effects of the earthquake:

- The death toll was 185, of whom 115 were in the Canterbury Television building which collapsed and then caught fire.
- Nearly 7,000 people were treated for injuries.
- The city centre of Christchurch was devastated. In the centre, at least 1,000 buildings collapsed or were demolished afterwards as they were dangerous. All of this meant that the city centre was cordoned off for some considerable time after the earthquake, with shops and other services having to relocate to outside of the central district.
- The spire of Christchurch Cathedral was brought down.
- Around 10,000 houses in the suburbs had to be demolished. It was also estimated that over 100,000 dwellings had been damaged.
- Harbour facilities at Lyttleton were extensively damaged.
- There was widespread soil liquefaction across the suburbs. Areas affected could not be built upon after the earthquake. Water was released during liquefaction leading to flooding in some suburban areas.

- At the Tasman glacier, some 200 km from the epicentre, ice was dislodged and fell into Lake Tasman causing a tsunami in the lake over 3 m high.
- By 2013, the New Zealand government estimated that the rebuild cost would be NZ$ 40 billion.

While damage occurred to many older buildings, particularly those with unreinforced masonry and built before stringent building codes were introduced, many high rises built within the past thirty years performed well. Some economists have estimated that it might take the New Zealand economy at least 50 years to recover from this event (Figure 5.28).

Key question

The earthquakes in Haiti and at Christchurch were of a similar magnitude but the death toll in each area was completely different. Why was this?

Figure 5.28 Devastation caused by the Christchurch earthquake, New Zealand, 2011

Other seismic events worth studying

Northridge (Los Angeles, USA) 1994

Gujarat (India) 2001

Indian Ocean (off Sumatra) 2004

L'Aquila (Italy) 2009

Tohoku (Japan) 2011

Bohol (Philippines) 2013

Kathmandu (Nepal) 2015

5.5 Tropical cyclone (typhoons, hurricanes) hazards

Key terms

Mitigation – Mitigation strategy is designed to reduce or eliminate risks to people and property from natural hazards. Money spent prior to a hazardous event to reduce the impact of it can result in substantial savings in life and property following the event.

Storm surge – A rapid rise in sea level in which water is piled up against a coastline to a level far in excess of the normal conditions at high tide. Usually produced during the passage of a tropical storm when wind-driven waves pile up water against a coastline combined with the ocean heaving upwards as a result of much lower air pressure.

Nature, distribution and magnitude

Tropical revolving storms (hurricanes, cyclones, typhoons) are intense low-pressure weather systems that develop in the tropics. These violent storms usually measure some 200–700 km in diameter. They begin with an area of low pressure, resulting from surface heating, into which warm air is drawn in a spiralling manner. Such small-scale disturbances can enlarge into tropical depressions with rotating wind systems and these may continue to grow into a much more intense and rapidly rotating system – the tropical revolving storm. It is not entirely clear why tropical storms are triggered into becoming so intense, but we do know that several conditions need to be present:

- An oceanic location with sea temperatures above 27°C – this provides a continuous source of heat in order to maintain rising air currents.
- An ocean depth of at least 70 m – this moisture provides latent heat; rising air causes the moisture to be released by condensation and the continuation of this drives the system.
- A location at least 5° north or south of the Equator in order that the Coriolis force can bring about the maximum rotation of the air (the Coriolis force is weak at the Equator and will stop a circular air flow from developing).
- Low level convergence of air in the lower atmospheric circulation system – winds have to come together near the centre of the low-pressure zone.
- Rapid outflow of air in the upper atmospheric circulation – this pushes away the warm air which has risen close to the centre of the storm.

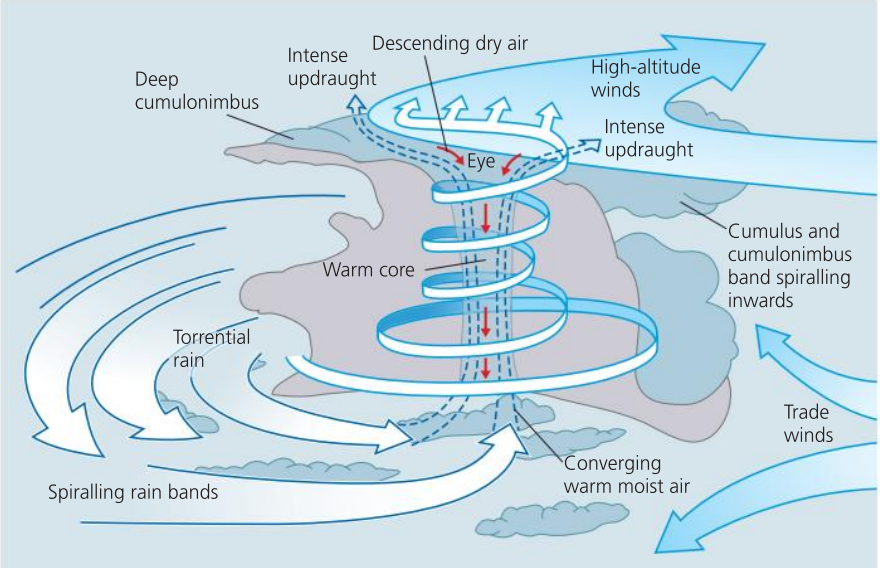

Figure 5.29 The structure of a tropical revolving storm

The tropical revolving exists while there is a supply of latent heat and moisture to provide energy and low frictional drag on the ocean surface. Once the system reaches maturity, a central eye develops. This is an area 10–15 km in diameter in which there are calm conditions, clear skies, higher temperatures and descending air. Wind speeds of more than 300 km/hour have been observed around the eye. Figure 5.29 shows the structure of a typical mature tropical revolving storm. Once the system reaches land or colder waters polewards, it will decline as the source of heat and moisture is removed.

- **Distribution:** Such storms occur between 5° and 20° degrees north and south of the Equator. Once generated, they tend to move westwards and are at their most destructive:
  - in the Caribbean Sea/Gulf of Mexico area where they are known as **hurricanes** (11 per cent of all tropical revolving storms)
  - on the western side of Central America (eastern Pacific) (17 per cent)
  - in the Arabian Sea/Bay of Bengal area where they are known as **cyclones** (8 per cent)
  - off southeast Asia where they are known as **typhoons** (this is the major area for such storms with one-third of all storms every year occurring here)
  - off Madagascar (southeast Africa) (11 per cent)
  - off north-western and north-eastern Australia (20 per cent). Off north-western Australia they are given the local name, **willy-willies**.
- **Magnitude:** Tropical revolving storms are measured on the **Saffir-Simpson scale**, a five-point scale based upon central pressure, wind speed, storm surge and damage potential. A scale 5 event, for example, has:
  - central pressure at 920 mb or below
  - wind speeds at 250 km/hr (69 m/sec) or greater
  - storm surge at 5.5 m or greater
  - damage potential that refers to 'complete roof failure of many buildings with major damage to lower floors of all structures lower than three metres above sea level. Evacuation of all residential buildings on low ground within 16–24 km of coast is likely.

The average lifespan of a tropical storm is 7–14 days. Every year, around 80–100 such storms develop around the world, with approximately 80 per cent of these going on to become tropical revolving storms.

The impacts of tropical revolving storms

The vulnerability of people to storm events depends upon a range of factors, both physical and human:

- the intensity of the storm (scale 1–5)
- speed of movement, that is, the length of time over the area

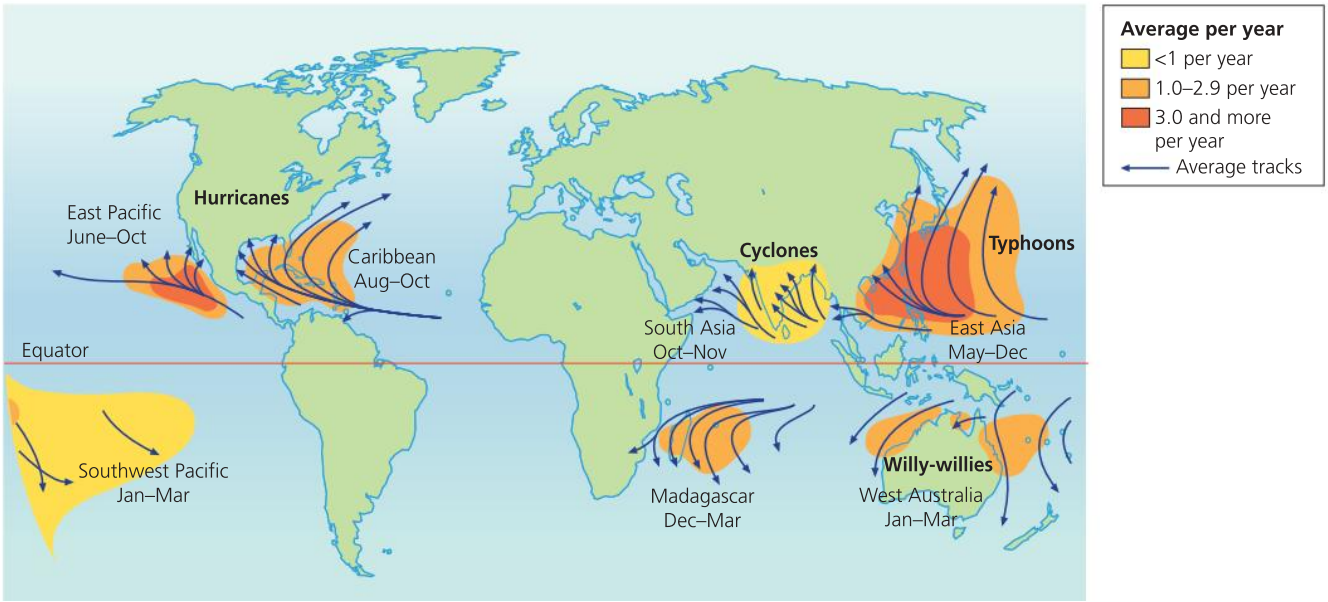

Figure 5.30 Global distribution and seasons of tropical revolving storms

- distance from the sea
- physical geography of the coastal area – width of coastal plain or size of delta, and location of any mountain ranges relative to the coast
- the preparations made by a community
- warnings and community response.

The major impacts that a tropical revolving storm can have on an area are described below:

- **Winds:** They can often exceed 150 km/hr (over 250 km/hour in a scale 5 event). Such high winds can cause structural damage to buildings (even collapse) and roads, bridges, etc. They can bring down electricity transmission lines and devastate agricultural areas. The huge amounts of debris that are flung about are a serious threat to peoples' lives.
- **Heavy rainfall:** It is not unknown for rainfall to exceed 200 to 300 mm, bringing about severe flooding, landslides and mudslides. If there is high relief near the coastal area, rainfall could increase to over 500 mm/day.
- **Storm surges:** High sea levels result when the wind-driven waves pile up and the ocean heaves upwards as a result of the lower atmospheric pressure. These storm surges can have a devastating effect on low-lying coastal areas such as river deltas where the flooding can extend a long way inland. Storm surges cause the majority of deaths in such events and agricultural areas can suffer for a long time as soil is contaminated by sea water (see details of Hurricane Katrina (2005) on page 213).

Managing the tropical revolving storm hazard

- **Prediction:** The prediction of tropical cyclones depends upon the state of monitoring and warning systems. Weather bureaux, such as the National Hurricane Centre in Florida (USA), are able to access data from geostationary satellites and from both land- and sea-based recording centres. The USA also maintains a round-the-clock surveillance of tropical storms that have the potential to become hurricanes by the use of weather aircraft. Such information is compared with computer models so that a path can be predicted and people warned to **evacuate** an area. It is essential that such warnings are correct, as there is a high economic cost associated with evacuation, and as with all false alarms, people might become complacent and refuse future advice. It has been estimated in the USA that to evacuate coastal areas, the cost is roughly one million dollars per kilometre of coastline due to losses in business and tourism and the provision of protection. As cyclones tend to follow an erratic path, it is not always possible to give more than 12–18 hours warning, which means that in most poorer areas where communications are poor, this is insufficient for a proper evacuation. Some areas, however, have established warning systems that do give the people a chance to take

some precautions. Examples include areas of Central America (such as Belize) and along the shores of the Bay of Bengal (India and Bangladesh). In 1997, a tropical cyclone warning in the Cox's Bazaar area of Bangladesh allowed for the evacuation of over 300,000 people. As a result, the death toll in the disaster was kept below 100.

- **Prevention:** Like other natural hazards, tropical cyclones cannot really be prevented, but there has been research into the effect of cloud seeding in order to cause more precipitation. The theory is that if the cyclone could be forced to release more water over the sea, then this would result in a weakening of the system as it approached land. There was some concern expressed over the effects of this on the global energy system, and as a result, research has not continued.
- **Protection:** As with all natural hazards, this refers to being prepared. Predicting the landfall of a tropical cyclone will enable evacuation to take place, together with the emergency services being put on full alert. If evacuation does take place, then protection units, such as the National Guard in the USA, have to be called in to prevent homes and commercial properties from being looted. People are also made aware of how to strengthen their homes and commercial properties in order to withstand the high winds. **Cyclone/hurricane drills** can be practised along the lines of those that are carried out in earthquake-prone areas. In Florida, for example, there is 'Project Safeside', a hurricane awareness programme that is composed of precautionary drills for use in schools and the Emergency Operations centre of the state. Where storm surges are a problem, **land-use planning** can identify the areas at greatest risk and certain types of development can be limited in such areas. **Sea walls, breakwaters** and **flood barriers** can be built and houses put on stilts. The sea wall that was built to protect Galveston (Texas) from further flooding, after the storm surge of 1900 that killed over 6,000 people, was so expensive that it is unlikely to be repeated elsewhere. In the USA, local authorities are required to address this problem by limiting expenditure on developments in high-risk areas and directing population away from them, as well as having sound plans to reduce evacuation times and for post-disaster redevelopment. In poorer areas, however, the need for land usually outweighs such considerations. Some structures can be **retrofitted** (adjusting the building to make it resistant to winds) to ensure greater safety during an event. In Dominica (West Indies), in 1994, some homes were retrofitted as part of a joint exercise carried out by the Organization of American States and the government of Dominica. The value of the project was shown in the following year when all the retrofitted buildings withstood the impact of Hurricane Marilyn.
- **Preparedness:** This is one way in which many communities are able to use their abilities in order to mitigate the effects of tropical storms. On the eastern seaboard of the USA, part of the state of North Carolina consists of barrier islands known as the Outer Banks, which are susceptible to the dangers brought by hurricanes. Local communities have got together to put into a practice the Outer Banks Mitigation Plan. Its major aims are the saving of lives and money, property and natural resource protection, reducing future vulnerability, speedy recovery from the effects of hurricanes and post-disaster funding. Also in the plan is a great emphasis on making as much information as possible available to the people of the Outer Banks area.

As with other natural phenomena, people in richer areas are urged to take out insurance, whereas in poorer countries it is important that following a cyclone event aid is available, both in the short and long term, as damage to the economic base of the affected area is likely to last for a number of years.

People's ability to resist natural hazards, such as cyclones, very much depends upon a range of political and economic factors. Poorer areas suffer more because land-use planning, warning systems, defences, infrastructure and emergency services are inadequate and this usually results in a higher death toll. Richer countries will have some planning systems in place, sophisticated warning arrangements, better defences and infrastructure and emergency services that are much more comprehensive and better prepared. Countries such as the USA therefore suffer much lower death tolls from individual hurricanes but they have to bear a much greater monetary loss because of the damage to the built environment. It is true to say, however, that the loss of a house in a richer country will probably be covered by insurance, but the simpler dwelling

of the inhabitant of a poor country may very well be a greater loss, taking into account the time invested in it and the years of irreplaceable and uninsured savings that it represents. The cyclone that hit Bangladesh in 1991 was responsible for an estimated 131,000 deaths and a monetary cost of $1.7 billion, whereas a hurricane of similar strength that hit Florida in 1992 (Hurricane Andrew) killed only 60 people but caused damage estimated at $20 billion.

Tropical storm events

Hurricane Katrina (southern USA), August 2005

In 2005, Hurricane Katrina was the eleventh named tropical storm, fourth hurricane and first Category 5 hurricane in what was to become one of the most active hurricane seasons ever recorded in the Atlantic area. The storm first developed on 23 August over the Bahamas and was upgraded and named Katrina the next day.

On 28 August, Katrina was upgraded to Category 4 and it became clear that it was heading for the coasts of Mississippi and Louisiana (Figure 5.31). It continued to intensify that day, rapidly becoming a Category 5 hurricane with sustained windspeeds of 280 km/hr and gusts of up to 345 km/hr and a central pressure of 902 mb, making it the fifth most intense Atlantic basin hurricane on record.

Advance warnings were in force by 26 August and the possibility of 'unprecedented cataclysm' was already being considered. President Bush declared a state of emergency on 27 August in Louisiana, Alabama and Mississippi, two days before the hurricane was expected to make landfall. Risk assessments conducted in preparation for such an event had been published; for example the *National Geographic* magazine had run an article less than 12 months before the storm occurred. When it happened, however, the authorities found it difficult to respond to the sheer scale of the disaster. At a news conference on 28 August, shortly after Katrina had been upgraded to a Category 5 storm, the mayor of New Orleans ordered that the city be evacuated.

- **Risk and vulnerability:** As New Orleans lies on the Gulf Coast of the USA, it is in an area which can expect severe tropical storms at certain times of the year. Since 1924 there have been 33 Atlantic hurricanes that have reached Category 5 and Katrina was the only one to hit New Orleans. The city is also at risk because the original flood control measures had resulted in the shrinkage of soils, which meant that over 50 per cent of the land was now below sea level.

  This made much of the population vulnerable to a severe storm, of which Katrina at Category 5 was certainly a good example. Much of the levee system that had been built to protect the city had not been constructed to modern standards

Figure 5.31 The path of Hurricane Katrina

and the replacement work was only 60–90 per cent complete. The situation was severe enough for the magazine *Scientific American* to state that 'New Orleans is a disaster waiting to happen.' As a consequence, levee failure was inevitable given the severity of the storm surge. In the aftermath it was alleged that the population had been made more vulnerable through a lack of leadership, an evacuation plan being drawn up by the state authorities only 19 hours before Katrina's landfall.

Most of the population managed to leave in private cars and on school buses, but some 150,000 people remained, mostly by choice. As a last resort, refugees who had been 'left behind' were encouraged to seek protection in the massive Louisiana Superdome. Basic supplies of food and water were delivered to support 150,000 for three days. When Katrina hit Louisiana on the morning of 29 August, it was accompanied by a massive storm surge, up to 10 m high in places. Although it had weakened to a Category 3 storm as it reached the border of Louisiana and Mississippi, the storm was so intense that its powerful winds and storm surge smashed the entire Mississippi Gulf Coast as it passed through.

Main effects of hurricane Katrina:

- More than 1 million people became **refugees**, displaced from their homes. One month after the storm, refugees from Katrina were registered in all 50 states. Although 75 per cent of evacuees had stayed within 400 km of their homes, tens of thousands had located more than 1,000 km away.
- In New Orleans, a city mostly below sea level, the complex system of flood defences was breached and 80 per cent of the city was deluged by **flood water** (Figure 5.32).
- Of the 180,000 **houses** in the city of New Orleans, 110,000 were flooded and 55,000 were too badly damaged to repair.
- **Power and water supplies were disrupted.** Almost 233,000 km^2 were declared a disaster zone, an area almost as large as the United Kingdom. An estimated 5 million people were left without power and it took almost two months for everybody to be reconnected.
- The number of **fatalities**, 1,242 people, was far below initial estimates. Of these, 1,035 were in Louisiana and 228 in Mississippi. Few people died in the aftermath of the storm because the USA had the infrastructure to ensure that people had access to clean water, medical care and food supplies.
- Many **oil installations (rigs and refineries)** in the Gulf area were damaged. An immediate effect of this was that the price of oil shot up, affecting people worldwide. For the first time, the price of petrol in the United Kingdom reached £1 per litre.
- The famous French Quarter of New Orleans was severely damaged, thus **reducing tourism revenues.**
- **Looters** ransacked the abandoned homes and shops in New Orleans. This resulted in the deployment of the National Guard, which was given orders to treat looters ruthlessly.
- The **financial cost** of the storm broke all records in the USA, with damage estimated to be in the region of $200 billion.
- Many **businesses** were affected by storm damage. Most were adequately insured, which led to some major **insurance companies** issuing profit warnings to their shareholders in light of the large number of claims which they had to meet.

Government aid was rapidly assigned to help recovery. The US Senate authorised a bill assigning $10.5 billion in aid in the first week of September. On 7 September another $51.8 billion was allocated from Federal funds. Other countries also responded to the disaster, even Afghanistan! The public donated $1.8 billion to the American Red Cross alone; more than the amounts raised for 9/11 and the 2004 Indian Ocean tsunami appeal.

The rescue and aid programme, though, was not without its critics. Reports claimed that those most affected by Katrina were black American urban dwellers, the poorest and most disadvantaged members of society. It has been alleged that the authorities would have responded differently if those affected were white. President Bush also came in for criticism for being slow to visit the affected area.

Key question

Study Figure 5.2 (page 187), which shows the processes involved in risk management. Use the information given in the study of Hurricane Katrina to assess if the authorities, both national and local, were efficient in dealing with this event, both before and after the storm had affected New Orleans.

Figure 5.32 Destruction caused by Hurricane Katrina, New Orleans, 2005

Typhoon Haiyan (Philippines), November 2013

Typhoon Haiyan (also known as Yolanda) was one of the strongest tropical cyclones ever recorded and the deadliest Philippine typhoon in modern history. It originated from an area of low pressure in the Federated States of Micronesia (western Pacific Ocean) on 2 November. Tracking westward it gradually developed into a tropical storm by 4 November (Figure 5.33). It then began a period of rapid intensification that brought it to typhoon intensity by 5 November. By 6 September, the system was assessed as a Category 5 or super-typhoon with wind speeds already reaching over 250 km/hr, with gusts reaching over 300 km/hr.

On 7 November Haiyan reached the Philippines where it caused great destruction in the area around Tacloban, which was struck by the northern eyewall, the most powerful part of the storm. By this time, central pressure had dropped to 895 mb and the highest wind speeds reached 315 km/hr (calculated as sustained for one minute). This meant that Haiyan was the most powerful storm ever to strike land. After crossing the Philippines, Haiyan continued westward towards southeast Asia, eventually reaching the north of Vietnam on 10 November as a severe tropical storm. It eventually dissipated as a tropical depression over southern China on 11 November.

- **Risk and vulnerability:** Tacloban lies in the centre of the Philippines where tropical storms cross from the Pacific Ocean towards southeast Asia, which makes the region the most affected in the world by this type of hazard.

  In recent years many Filipinos have moved in large numbers from countryside areas to cities such as Tacloban looking for opportunities to work and make money. This has led to high densities of population and often overcrowded residential areas, which makes the people more vulnerable when events such as Haiyan occur. Many of the people have built poorly constructed houses on the flat land nearest the sea and such locations make people there vulnerable to storm surges and flooding. Others have built houses on steep hillsides, which again makes them vulnerable to the high rainfall of tropical

Figure 5.33 The track of Typhoon Haiyan (wider area and central Philippines)

cyclones which, on slopes where vegetation has been removed, will cause landslides that can devastate whole communities. Poor people are especially vulnerable to the aftermath of such events. Unable to provide for themselves, they look to regional and national government agencies who often do not have the resources to cope in such emergencies. This makes people, such as those in Tacloban, dependent on foreign government help and on NGOs, such as charitable organisations.

Apart from the severe winds, Haiyan also caused:

- very heavy rainfall. In one area of the Philippines, nearly 300 mm was recorded, much of which fell in under 12 hours
- huge storm surges, measuring up to six metres, which were responsible for most of the damage and loss of life.

Major effects of the storm:

- There were over 6,000 **fatalities**, with over 1,000 people declared missing. Bodies were being discovered well into 2014. Some estimates have put the death toll as high as 10,000.
- There was widespread **damage to buildings and infrastructure** (Figure 5.34). The American army officer in charge of relief flew over Tacloban and observed 'I do not believe there is a single structure that is not destroyed or severely damaged in some way.' Some journalists described the devastation as 'off the scale' and 'apocalyptic'.
- It was estimated that nearly 2 million people were made **homeless** and more than 6 million people **displaced**, with at least 20,000 fleeing to the capital, Manila.
- The low-lying areas on the eastern side of Tacloban were particularly vulnerable with some areas completely **washed away.**
- Large areas were **cut off,** with communication and power systems destroyed.
- With **flooding and landslides**, major roads were blocked (also with fallen trees) which made relief work almost impossible except from the air.
- Tacloban city's **airport** was damaged by the storm surge (the terminal building destroyed by a 5.2 m storm surge) but facilities had to be repaired quickly as it became the centre of the international relief operation.
- Widespread **looting** was reported.
- **Local government** in many areas collapsed as so many local officials were killed during the storm.
- The **total damage** has been estimated at $2.9 billion.

After the event it was feared that there would be substantial outbreaks of diseases such as cholera, leading to an even higher death toll. Prompt action by the WHO and other relief agencies ensured that outbreaks, such as that of dysentery, were kept isolated and to a minimum.

Immediately after the storm, the United Nations stated that 'access remains a key challenge as some areas are still cut off from relief operations. Unknown numbers of survivors do not have basic necessities such as food, water and medicines and remain inaccessible for relief operations, as roads, airports and bridges were destroyed or covered in wreckage.' Many countries contributed to the relief effort through cash donations or practical help. The UK government deployed two navy ships to the Tacloban area supplying over 200,000 tonnes of aid, while the Americans sent numerous ships and aircraft and over 13,000 service personnel.

Key question

Both New Orleans (Katrina) and Tacloban (Haiyan) were hit by very powerful tropical storms but the estimated cost of the damage to each area was completely different. Why was this?

Figure 5.34 Devastation caused by Typhoon Haiyan in Tacloban, Philippines, November 2013

Other tropical storms worth studying

The Bangladesh cyclone (BOB 01)(Bay of Bengal) 1991

Hurricane Andrew (USA) 1992

Hurricane Mitch (Central America) 1998

Cyclone Nargis (Myanmar) 2008

Hurricane Sandy (USA) 2012

5.6 Fires in nature

The nature of wildfires

Wildfire is a natural process in many ecosystems and can be a necessary and even beneficial process in some of them. It is also true to say that fire can be a very destructive process in the natural world, one which has both natural and human causes.

Fires can be major events, occurring on a large scale and causing widespread destruction and killing much wildlife. Surface fires sweep rapidly over the ground, consuming plant litter, grasses and herbs, and scorching trees, and it is possible for ground temperatures to rise to over 1000 °C. At higher levels there are crown fires that spread through the canopy of trees.

The nature of the fire will depend upon the types of plants involved, strength of the winds, topography of the area in question and the behaviour of the fire itself. Once vegetation has dried out, the nature of the fire will depend largely upon the wind, as the largest fires occur in dry windy weather with low humidity. Wind drives the fire forwards and burning embers that ignite more vegetation are more easily spread in windy weather. The key factors therefore in any fire are the climate and the nature of the plants involved.

Key terms

Retardants – Chemicals sprayed on to fires in order to slow them down. They are composed of nitrates, ammonia, phosphates, sulphates and thickening agents.

Pyrophytic vegetation – Pyrophytes are plants adapted to tolerate fire. Methods of survival include thick bark, tissue with a high moisture content and underground storage structures.

Causes of wildfires and their spread

For a natural fire to occur and to spread, two things are needed:

- **An ignition source:** in the case of natural fires, lightning is by far and away the main cause. Climate will affect the frequency of electrical storms, particularly one in which there is hardly any rainfall. Increasingly, fires are the result of human intervention, particularly those which occur in and around settlements. Such fires are started by falling power lines, carelessly discarded cigarettes, children playing with matches, camp fires and agricultural fires (controlled burning) which get out of hand. In some cases, there is evidence that devastating fires of this kind have been deliberately started by arsonists. In the USA and Australia, greater access to wild areas by tourists has increased the danger of fires through some of the ways listed above.
- **Fuel:** the fuel has to be of sufficient quantity and dry enough to burn. Climate affects the frequency and duration of droughts during which the vegetation and litter has an opportunity to accumulate and dry out. Climate also affects the type of vegetation that will grow in an area and the rate at which litter can be produced.

Distribution

Wildfires are essentially a rural hazard and can occur in most environments, although with the continued expansion of human habitation, wildfires now occur within the boundaries of even substantial settlements in California, Australia and the countries of southern Europe. Areas that are most susceptible are those with a combination of dry vegetation and lightning strikes. Clearly, areas with a dry season are most likely to be affected as are those regions of the world with a semi-arid climate and susceptible to drought. Such regions of the world include:

- parts of Australia
- USA and Canada – including California and Florida (Figure 5.35, page 218)
- southern Europe – including southern France, Italy, Greece, Turkey and Mediterranean islands such as Sicily, Cyprus, Corsica and Sardinia.

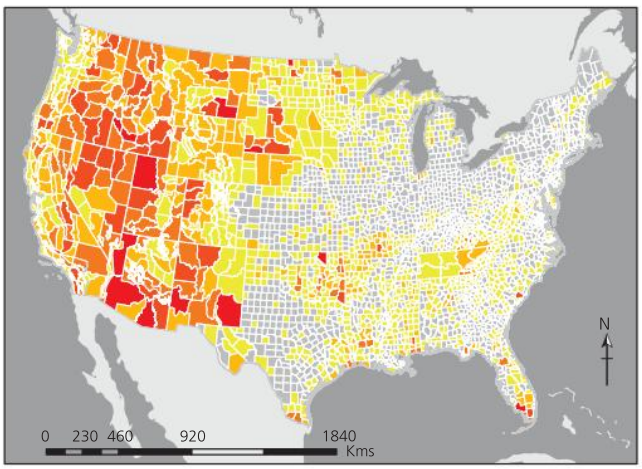

Figure 5.35 Wildfires in the USA (1980-2014)

Fires and natural ecosystems are often closely linked, particularly Mediterranean climate regions and the savannah grasslands. Fire can clear vegetation and aid new seed germination, stimulate the growth of certain plants and rid an area of insects and some parasites. Some species are **pyrophytic** in that they can withstand fire through some mechanism such as resistant bark, for example the baobab tree. In Australia, plants such as banksia need fire for their woody fruit to open and thus regenerate.

Fire has not been a real hazard of tropical rainforest areas due to the humid climate, but recent burning for forest clearance has often got out of hand, resulting in widespread fires that burned out of control for long periods. Both the Amazon Basin (Brazil) and south-east Asia (Indonesia) have suffered from such fires in recent years.

A good example of an area where wildfires are a continuing problem is the Los Angeles Basin in California. Wildfires that occur here often get a great deal of media coverage (in some cases globally) as it is likely that a wildfire event could threaten the homes of famous film and TV personalities. Wildfires are common in the Los Angeles area and pose a serious threat for the following reasons:

- much of the area is covered by drought-resistant chaparral, which is a scrub vegetation, as the area is too dry for much tree growth. This vegetation, after the summer drought, can be tinder dry.
- a dry wind called Santa Ana, that descends from the local mountains, increases the dryness of the vegetation to the point where a spark, lightning or a carelessly discarded cigarette can cause a major fire. This wind also allows for the easy spread of fire, which makes it very difficult to control.
- much of the area, outside the centre of Los Angeles, consists of low-density building where the natural vegetation has been allowed to remain between properties, which exposes a large number of them to the fire risk.

Key question

Some natural environments are more likely than others to experience fire as a hazard. Identify such environments and describe their global situation.

The effects of wildfires

The direct effects of a wildfire event are:

- **Loss of crops, timber and livestock:** Forest fires can have a huge impact in timber producing areas, with the loss of trees that will take many years to replace. In the USA, it has been estimated that over $10 million per day is spent fighting such fires.
- **Loss of life:** Although many fires are events from which people can get out of the way, some fires move so fast that people can be trapped, although this is not usual. In the Victoria (Australia) bushfires of 2009, 173 people lost their lives (see page 220).
- **Loss of property:** At one time, only a few rural communities were at risk from fires, but with urban expansion, the fringes are now susceptible, for example Sydney (Australia) and Los Angeles (see above). The cost of damage and of fighting the fires can run into hundreds of millions of dollars. After such events, large numbers of people can be left homeless.
- **Release of toxic gases and particulates:** The Southeast Asia 'haze' is fire-related large-scale air pollution that occurs regularly and is still present in parts of the region. It is largely caused by illegal agricultural fires due to slash-and-burn practices in Indonesia. The resulting pollution

covers a number of countries in the region including Singapore, Malaysia, Thailand and Vietnam. This introduces a political dimension, as the governments of these countries have demanded that the Indonesian government take action against companies responsible for illegal forest fires. The size of the haze produced by the Indonesian fires of 1997-98 can be seen in Figure 5.36. These fires were described by one commentator as 'probably amongst the two or three, if not the largest forest fires, in the last two centuries of recorded history'.

- **Loss of wildlife:** In Indonesia, the fires of 1997 destroyed the Wein River orangutan sanctuary on Kalimantan.
- **Damage to soil structure and nutrient content:** With the intense heat generated at ground level, wildfires can destroy many soil nutrients and lead to an alteration in the soil's structure.

Secondary effects can be:

- **Evacuation:** Many people will flee from the area of the fire. Such people will not be allowed back into the affected area, often for a long period, if not forever. Emergency shelters/accommodation will have to be found along with food, etc.
- **Increased flood risk:** In certain environments, where rain comes in heavy bursts, the loss of so much vegetation, and the consequent decrease in interception, can lead to increased flooding.

Figure 5.36 The extent of the haze produced by the Indonesian fires of 1997–98

Dealing with the fire hazard

There are several ways of dealing with this hazard, such as planning to mitigate the effect of an event, coping with the wildfires as they happen and addressing the effects.

Preparedness, mitigation and prevention

There are several ways in which the hazard can be managed before the event occurs:

- **Managing the vegetation:** This is done by controlled burning to get rid of much of the litter and by creating firebreaks in the vegetation in advance rather than during the event.
- **Managing the built environment:** This is done by increasing the gap between houses and vegetation and by incorporating more fire-resistant methods in construction (using more stone and brick rather than wood; fitting spark arresters to chimneys).
- **Modelling:** This involves studying the ways in which fires behave with computer simulations in order to comprehend and predict fire behaviour. Figure 5.37 (page 220) shows a fire propagation model.
- **Education:** In areas susceptible to wildfires, it is important to make people aware with regard to home safety and how to avoid starting fires.
- **Warning systems:** These can be put in place by establishing lookout towers and even air patrols. In tourist areas, notice boards at strategic locations could carry warnings of the fire hazard.
- **Community action:** In Victoria (Australia) in February 1983, there were a series of disastrous fires that claimed 47 lives, destroyed over 2000 homes and cost around AU $200 million. As a result, a community education programme was established known as 'Community Fireguard', whose purpose was to assist people in developing their own fire survival strategies. To relay the message, the authorities avoided the 'top down' method they had been using, instead focusing on identifying the most vulnerable areas in fire-prone communities and then generating local interest to make residents aware of how they could be responsible for their own safety. From this, the residents developed their own fire survival techniques such as local warning systems, ensuring that buffer zones were maintained, conducting brush and street cleanups, running equipment training sessions and preparing emergency plans.

- **Being well insured:** in wealthier countries, residents are urged to take out insurance against fire damage, although this can be very expensive in fire-prone areas.

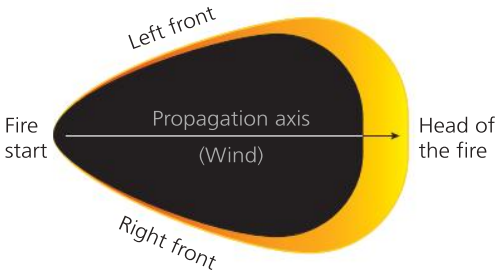

Figure 5.37 Fire propagation model

Dealing with the event as it happens

This involves fighting the fires as they happen, which can be a very dangerous operation and it is not unknown for firefighters to suffer fatalities when they are involved in this action. Spraying with water and chemicals both from the ground and in the air is costly. Firefighters also work on the ground beating out the flames and bulldozing large breaks in the vegetation, preventing the fires jumping in certain directions. **Retardants**, to slow the pace of the wildfire, are often sprayed on fires in areas which are fairly inaccessible or when human safety and structures are endangered.

Addressing the effects

Once the fire has been extinguished, it is important that, in the short term, communities and governments first try to repair the damage caused by the fire. After this, long-term action will mean that attention will be directed towards making sure that areas are well prepared for the next fire. Action will be as follows:

- **replanting trees (1)**: particularly in commercial forestry areas in order to improve the economy of areas devastated by fire.
- **replanting trees (2):** after vegetation has been removed by fire, there is a great danger of flash flooding and mudslides on, what are now, unprotected slopes. Planting trees should stabilise slopes and should also lead to an improvement in water quality.
- **preparedness:** this means making sure that people are better prepared for the next fire by having emergency supplies ready, along with survival kits, etc., and by setting up community groups such as that in Victoria (Australia).

Wildfire event

Victoria (Australia), February 2009

In early February 2009, a series of bushfires swept across the Australian state of Victoria (Figure 5.38). These were named the 'Black Saturday bushfires' and were Australia's all-time worst bushfire disaster, resulting in the highest loss of life from fires in the country's history.

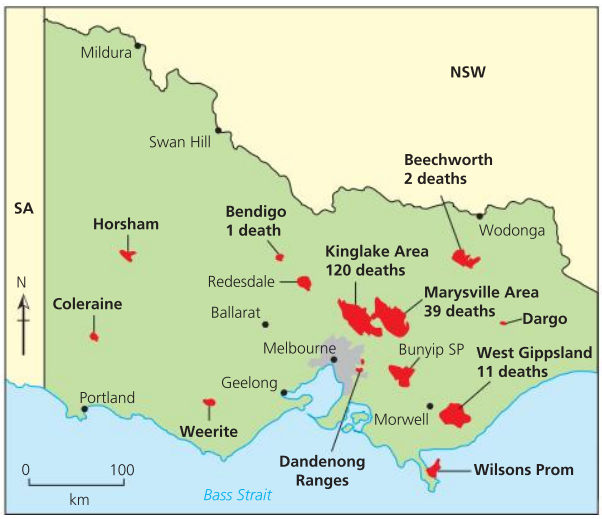

Figure 5.38 Wildfires in Victoria, Australia, February 2009

Risk and vulnerability

Victoria is covered by eucalyptus forests which have an oil-rich foliage which easily burns. The summer climate often features periods where the temperature is over 40 °C with low humidity and the state also suffers from periodic droughts. All this can produce tinder-dry vegetation, and it will only take a spark to set off a major fire. The area also can be susceptible to high winds (over 100 km/h) blowing out of Australia's interior, which will not only produce drier conditions but can fan flames and drive them over considerable distances. Lightning strikes are also a feature of the summer weather. Power cables also cross the state, bringing this essential service to isolated rural communities, but these can be brought down by adverse weather conditions, producing the spark that sets off a fire. In rural areas, there has been depopulation in recent years which has led to a decline in rural services which makes it more difficult to fight the fires when they occur.

Background to the fires

In late January 2009, an exceptional heatwave affected the south-eastern parts of Australia. Temperatures were regularly above 40 °C, some of the hottest days in Victoria's history. The configuration of the pressure systems also meant that hot tropical air was directed towards the area. On the morning of 7 February, hot, north-westerly winds of over 100 km/h hit the state, also causing very low humidity (under 10 per cent).

Fires started in a number of areas (Figure 5.38) from various sources. Fire investigators in Victoria have identified a number of these including lightning strikes, sparks from falling power cables, sparks from power tools and machinery and, in some cases, the fires being deliberately started (arson).

The fires had the following effects:

- **Fatalities:** 173 deaths were attributable to these fires including one firefighter
- **Property loss:** it was estimated that around 3,500 properties were destroyed including over 2,000 houses and 1,500 farm buildings
- **Displaced people:** it was estimated that over 7,000 people were displaced from their homes
- **Forest loss:** an area of around 450,000 ha was burnt (over 1 million acres)
- **Agricultural losses:** this included the loss of livestock (around 12,000 head, including sheep, cattle and horses); stored fodder, grain, hay and silage; loss of standing crops, pasture, fruit trees, vines and olives; plantation timber; loss of thousands of kilometres of boundary fences
- **Parks damaged:** large areas of national parks and other protected areas were destroyed, along with some of the wildlife they contained. The RSPCA estimated that over 1 million animals perished during the fires
- **Electricity supply:** disrupted to over 60,000 residents
- **Looting:** a number of cases of people looting empty properties were reported
- **Cost:** it has been estimated that the fires cost A$4.4 billion of which the largest component was insurance. The total cost of insurance claims has been estimated at A$1.2 billion.

In October 2009, it was announced that a new fire hazard system would replace the one existing before the fires. Under this new system, every day during the fire season the Bureau of Meteorology (BOM) would forecast an outlook for the *Fire Danger Index (FDI)* by considering the predicted weather including temperature, relative humidity, wind speed and dryness of vegetation. On the highest risk days, residents would be advised to leave the potentially affected areas.

In response to the event, new building regulations for bushfire-prone areas were fast tracked by the government. As part of an ongoing debate, the government was also urged by experts to ban housing in the highest fire risk areas, which they claimed were 'some of the most dangerous in the world'. The government also came under criticism for allowing rebuilding in Marysville, which had been 90 per cent destroyed during the event.

Key question

Study Figure 5.1 (page 185), the model of vulnerability. Using the information contained in this description of a fire, replace the generalities of the model with the real details of the event in Victoria. What does the completed figure tell you about the extent of the risk to people and their environment (and their vulnerability) in living in parts of Victoria?

Case study of a multi-hazard environment beyond the UK: The Philippines

The Philippines is a country off the mainland of southeast Asia consisting of an archipelago of over 7,000 islands (Figure 5.39). It is also home to over 100 million people. By virtue of its geographical position it is highly prone to natural disasters. Its position on the western rim of the 'Pacific Ring of Fire' brings both **earthquakes** and **volcanic activity**, with secondary impacts such as **lahars**. It is also situated in an area where tropical disturbances (**typhoons**) cross from the Pacific towards southeast Asia making the Philippines the most exposed country in the world to this particular hazard. Tropical storms bring a great deal of **flooding** and the threat of **landslides**, which again add to the hazardous nature of life in these islands. All of this hinders the attempts by government to reduce the incidence of poverty and to reduce the number of people and assets vulnerable to these hazards. The cost to the Philippine economy has been estimated at 0.5 per cent of national GDP and indirect and secondary impacts further increase this cost. In addition to the significant economic cost, there are substantial social and environmental impacts. In 2013, for example, the country was subject to one severe earthquake (Bohol), touched or crossed by seven typhoons, including Haiyan (see above) and eight tropical storms. At the same time, the major volcanoes were still rumbling away with intermittent small-scale emissions of lava, steam and gas.

Key question

Is it possible in a multi-hazard environment that some of the hazards may be linked?

Major threats to the population of the Philippines are described below:

Earthquakes: These are a fairly common occurrence in the Philippines. In the twenty-first century, between 2000 and 2013, there were 17 earthquakes with a magnitude of at least 5.6, which have caused numerous deaths and damaged a large number of buildings. The most devastating in recent years have been:

- **1976 off Mindanao (Moro Gulf):** this earthquake (magnitude 7.9) caused tsunamis which inundated the western shore of Mindanao killing up to 8,000 people

Figure 5.39 Map of the Philippines

- **1990 Luzon:** (magnitude 7.8) killed over 1,600 people and caused widespread ground rupturing and soil liquefaction
- **2013 Bohol:** a magnitude 7.2 earthquake which killed over 200, injured 800, and caused damage to tens of thousands of buildings.

Volcanic activity: The Philippines has a number of active volcanoes on its islands (opinions vary, but 23 would seem to be a reasonable figure). Among these are three volcanoes which have a history of violent eruptions:

- **Mayon:** This is the most active, having erupted nearly 50 times in the last 400 years, with the most destructive event coming in 1814. The last eruption was in 2014 (Figure 5.40). Mayon is noted for its lahars, with volcanic ash mixing with heavy rainfall from tropical storms to produce rivers of mud.
- **Pinatubo:** Erupted violently in 1991, being the second largest eruption on the planet in the twentieth century. Pinatubo can be deadly as large numbers of people live in the vicinity of the volcano (500,000 people within 40 km). Early warnings and evacuations probably saved at least 5,000 people in 1991 (Figure 5.41).

  The explosion was so violent that it hurled gases, ash and steam into the upper atmosphere where they continued to affect global temperatures for at least two years (average global temperature down 0.5°C).

This was followed by Typhoon Yunya, with very heavy rainfall combining with volcanic ash to produce deadly lahars. Final death toll was around 850.

- **Taal:** One of the most active volcanoes in the country, having 33 eruptions noted on the historical record. All of these eruptions have come from a volcano that sits in the middle of a crater lake formed when a huge explosion in prehistoric times formed the caldera of Taal. In the historical record it is thought that Taal has been responsible for 5,000–6,000 deaths as it lies close to populated areas.

Tropical disturbances: Numerous storms cross the country every year bringing with them the risk of severe flooding, landslides and lahars if combined with a volcanic eruption. Such disturbances account for the highest numbers of deaths from natural hazards in the Philippines, most fatalities being the result of storm surges. For an account of the passage of a typhoon, see the previous section on Typhoon Haiyan (November 2013).

In a multi-hazard environment such as the Philippines, people are often at a greater risk than elsewhere. Not only are they vulnerable to the main hazards of earthquakes, volcanic activity and typhoons, but these hazards can be linked to others, in some cases being the direct cause of those hazards. These hazards – tsunamis, landslides/mudslides, flooding, fires and lahars – are sometimes seen simply as secondary effects of the main hazard, but they are often recognised in their own right as a hazard. Earthquakes can lead on to tsunamis, fires and landslides and in a human context, the hazard of crime (looting). Heavy rainfall associated with typhoons can cause serious flooding and landslides. The combination of volcanic activity (ash) and the same heavy rainfall can initiate lahars which can devastate whole communities.

Figure 5.40 Lava cascading down the slopes of the Mayon Volcano in Manila, 2009

Figure 5.41 The Pinatubo Volcano eruption in the Philippines, 1991

In the past two decades, the Philippines has experienced over 300 natural disasters and Filipino officials insist that the typhoon hazard is becoming more severe, in part because of climatic change. Over the past decades, Filipinos have flocked to risky low-lying areas, havens for cheap, crammed housing where there is a clear link between poverty and vulnerability to natural disasters. Rapid urbanisation has exacerbated the problem, with its tightly packed, flimsily constructed housing and the environmental degradation such as deforestation that has only added to the problem (steep, unprotected slopes leading to rapid run-off, flooding and the potential for landslides).

The Philippines institutional arrangements and disaster management systems have tended to rely on a response or reactive approach, when they should be, in contrast, taking a more effective proactive approach in which disasters can be mitigated, even avoided, by appropriate land-use planning, construction and other preventative measures which avoid the creation of disaster-prone conditions. There has been widespread emphasis on post-disaster relief and short-term preparedness (forecasting/evacuation), rather than on mitigation and post-disaster support for economic recovery. The current system tends to be more of a centralised top-down administrative system than one which is community based and gives rise to local initiatives. What is required is initiatives which emphasise the bottom-up approach that will help the most vulnerable communities cope with the hazards when they occur.

Some programmes have been started along these lines. The Philippines National Red Cross (PNRC), in conjunction with foreign Red Cross organisations, has started programmes at community level. The aim of these is to reduce the impacts of natural disasters by encouraging people to collaborate in protecting their

lives and the resources upon which they depend. Such plans address the following areas:

- co-operation and partnership with governmental bodies in order to gain financial support for mitigation measures and to ensure that the programmes have long-term sustainability
- training local volunteers in disaster management
- identifying risk through land-use mapping and determining which mitigation measures might be possible
- initiating mitigation measures which could be physical (sea walls, dykes), health related (clean water supplies) or planning tools (land-use plans, evacuation plans)
- dissemination of information to the whole community.

Many commentators have pointed to the great resilience of the Filipino people in the face of the problems in living in a multi-hazard environment. Others have simply described the attitude of the people as fatalistic; they accept that these events are part of living in such an area (even 'God's will') and that losses are inevitable from time to time.

The central government, however, is trying to do something about the situation. The United Nations claims that the Philippines already has some of the best risk-reduction laws in the world, but unfortunately most of these are still on paper. With a country of over 7,000 islands, too much of the responsibility for reducing disaster risk falls to local government where money is not always wisely spent. Recent government legislation, however, calls for 70 per cent of disaster spending to be used on long-term plans with only 30 per cent going on emergency aid. The main problem of living in a multi-hazard environment remains, though, as one government official put it, 'resources are stretched; even before we could recover from one disaster, here is the next one.'

Key question

What attitudes have the people of the Philippines taken towards living in such a multi-hazard environment?

Case study at a local scale of a place in a hazardous setting: Kobe, Japan

On 17 January 1995, an earthquake of magnitude 6.8 devastated the Japanese city of Kobe (Figure 5.42). The Great Hanshin Earthquake, as it is known, had an epicentre only 20 km from the central parts of the city and was the costliest urban disaster up to that point in time, economic damage being put at $100 billion (or 2.5 per cent of Japan's GDP). Over 6,000 people were killed in the earthquake, with over 35,000 injured and nearly a quarter of a million people made homeless. Those people whose dwellings had been seriously damaged or destroyed faced financial ruin too, as only three per cent of the city's buildings were insured. Kobe was also struck by a typhoon six months after the event.

Risk and vulnerability: The Japanese felt that they were well prepared for earthquakes given their research into the hazard and the wealth of the country which had enabled them to spend money on several forms of risk management. Some commentators, however, believe that there was an illusion of preparedness among the people and the city authorities and that they were caught unaware by the severity of the event. There were still too many older, traditional houses in the city. Many of these had heavy tiles on the roof (to withstand typhoons) but these tiles killed and injured many people when the supports collapsed. Many houses also had not been retrofitted, along with much of the transport infrastructure.

Figure 5.42 The location of Kobe

It was also suggested that as Kobe had not experienced a serious earthquake for 400 years, the people and the authorities had not maintained sufficient emergency supplies.

Many commentators have accused the Japanese government of poorly managing the aftermath of the event. They point out that they made people more vulnerable to the event by being slow to react to the

scale of it, by not encouraging enough community volunteers and by refusing offers of help from foreign governments.

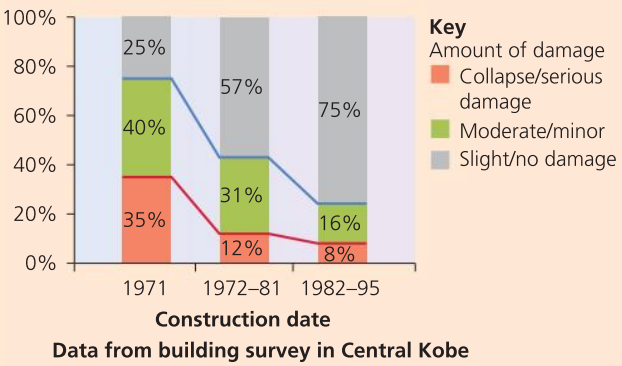

Figure 5.43 Building damage in central Kobe as a result of the Great Hanshin Earthquake

Skills focus

Figure 5.43 is an example of a compound bar graph. Some of these graphs are often difficult to read but we have made it easier by joining the segments bar to bar and even giving the percentage figures for each year shown. Joining the segments, without giving the percentage (or other) figures, will enable you to see if any particular component is increasing or decreasing. Students often produce bar graphs that are too complicated, with too many bars or segments. This loses the greatest assets of the method – simplicity and clarity of presentation.

The scale of the disaster and its complexity posed tremendous economic and logistical problems for the people of Kobe. There were also enormous emotional problems to overcome with the trauma of a shattered community in which people were struggling to readjust. Many in the city, though, saw this as an opportunity to put in place sustainable development plans that took disaster threats into account. The total bill for this reconstruction has been estimated at $120 billion, but Kobe seems to have coped well and many experts have commented on how impressive its efforts have been (Figure 5.44 and Figure 5.45).

Within a short time after the disaster, the city had achieved the following:

- Electric power, gas, water, telecommunications, and major road and rail links were restored within months of the event.
- Within several months, 48,000 housing units had been supplied to take care of the homeless who made up 20 per cent of the city's population after the event.
- 70 per cent of the port operations were restored within one year.
- Almost all of the debris resulting from the event was removed within a short time, with 60 per cent of it successfully re-used in landfill sites.
- 15 months after the event, manufacturing output of the Kobe region was up to 96 per cent of what it had been before the earthquake.

Figure 5.44 Damage caused by the Great Hanshin Earthquake, Kobe, Japan, January 1995

Figure 5.45 Reconstruction after the Great Hanshin Earthquake, Kobe, Japan

The Japanese government issued a document after the earthquake, setting out its policy towards such disaster-stricken areas. This was entitled '**Disaster Management in Japan**' and it summarised its aims in the following statement:

The objective of providing the recovery and reconstruction of a disaster-stricken area is to aid victims to return to normal life, restore facilities with the intention of preventing disasters in the future, and implementing fundamental development plans that focus on safety in the community. In view of the decline in social activities

in a community following a disaster, it is important that recovery and reconstruction measures are conducted as swiftly and smoothly as possible.

Apart from the reconstruction, it has been regarded as very important that the city as a whole should learn lessons from the events of January 1995. Learning from the Kobe event has enabled the government to put into place measures which have meant a more rapid and effective response to later earthquakes in the country. Since the event, there have been a vast number of conferences and research studies that have analysed the experience from various professional points of view. From these, the city council considers the following to be the most important lessons to be learned from the earthquake and its aftermath:

- **Improved seismic resistance of existing buildings:** Large numbers of houses collapsed and many of those remaining do not meet modern seismic standards. The city council has indicated that all older buildings will be retrofitted.
- **Improve the fire fighting capacity:** As a vast number of buildings were damaged in the fires that followed the earthquake, the city council is determined to explore all possible sources for extinguishing future fires, including rivers and the sea.
- **Protecting lifelines:** Backup systems must be put in place wherever possible, despite the cost. With telecommunications, for example, they have constructed a duplicate fibre optic system.
- **Community participation:** The city council now understands that in order to reduce future risks, the community needs to be better informed through **awareness and education programmes**. Areas of concern revealed by the disaster included the stockpiling of resources in readiness for an event, the ability of ordinary people to fight fires and the availability of basic tools for search and rescue.
- **NGOs:** The city council is also encouraging a range of NGOs, as they seemed flexible during the event in a way that official bodies were not.
- **Disaster-resistant measures:** A variety of measures has been proposed which would protect people from the effects of earthquakes, fires, landslides and typhoons. These include firebreaks to be established along rivers and roadways, a mountain greenbelt in order to reduce landslides, a new canal system to ensure a reliable water supply and backup systems for hospitals.

The mayor of Kobe sent out this message from his city to other communities that face the same hazard problem:

Wherever you live, city or village, you have to keep in mind that you must protect yourself. You have to prepare to protect yourself, but you cannot fight alone. You must have a system to fight disasters, where you must co-operate with relations and your colleagues. Each community has to have its own plan to respond in case of emergency. Your community may not be enough, though, so then you can work with other communities, the government and with other countries. But first, you must protect yourself, for yourself, wherever you are in the world.

Key question

To what extent are the measures now put in place in Kobe sustainable?

Further reading

Bankoff, G. (2015) *Culture of Disaster: Society and Natural Hazard in the Phillipines* (Routledge)

Bishop, V. (2001) *Hazards and Responses* (Collins)

Bryant E. (2004) *Natural Hazards* (Cambridge University Press)

Chaffey J., Frampton S., McNaught A., and Hardwick J. (2000) *Natural Hazards; Causes, Consequences and Management* (Hodder & Stoughton)

Nagle G. (1999) *Focus on Geographical Hazards* (Nelson Thornes)

Ross S. (1998) *Natural Hazards* (Nelson Thornes)

Rothery D. (2010) *Volcanoes, Earthquakes and Tsunamis* (Teach Yourself Series)

Skinner M. (2003) *Hazards* (part of the *Access to Geography* series) (Hodder & Stoughton)

Warn S. & Holmes D. (2008) *AS/A2 Geography Contemporary Case Studies: Natural Hazards and Disasters* (Philip Allan)

Eyjafjallajökull (Iceland) and Mount Ontake (Japan) – Resources on both are available from the Geographical Association (GA)

Review questions

1 Explain why volcanic and earthquake events should not be called 'acts of God'.

2 Why are poor people more vulnerable to a natural hazard event?

3 Why are urban areas, particularly large ones, considered to be very vulnerable to natural hazard events?

4 Why do certain areas experience both volcanic and seismic events?

5 In the context of natural hazards, what do you understand by 'fatalism'?

6 Using examples, explain why, in different countries, human responses to tropical storms are not the same.

7 What are the factors that contribute to the development of tropical storm systems?

8 How have people sought to manage the volcanic hazard through prediction?

9 What determines the impact of a tsunami?

10 'Resources are stretched, even before we could recover from one disaster, here is the next one.' Does this really sum up the attitude of people living in a multi-hazard environment?

Question practice

A-level questions

1. In the context of natural hazards, what is meant by the term 'primary impact'? (3 marks)

2. What are secondary impacts arising out of seismic events?
   a) Secondary impacts are those which take a long time to occur after the event and usually their impact is small.
   b) Secondary impacts arise in the aftermath of a seismic event and are a consequence of primary impacts.
   c) Secondary impacts come about as a result of aftershocks, such as landslides.
   d) After the initial ground-shaking in a seismic event, the secondary impact is the rupturing of the ground surface. (1 mark)

3. In this chapter, which covers natural hazards, consult Figure 5.15 Risk assessment of Mt Rainier, Cascade Range, USA (page 197). Using this figure, assess the scale of any possible future eruption and its potential impact. (9 marks)

4. How far is it possible to mitigate against the hazards associated with earthquakes? (20 marks)

AS questions

1. Describe the characteristics of **two** of the hazards associated with tropical storms. (4 marks)

2. Which part of the structure of the Earth is known as the lithosphere?
   a) Part of the upper mantle of the Earth on which the plates move
   b) The crust of the Earth which is divided into plates
   c) The layer of the Earth which consists of the crust and the upper section of the mantle
   d) The combined mass of water found on, under, and over the surface of the Earth (1 mark)

3. In this chapter, which covers natural hazards, consult Figure 5.15 Risk assessment of Mt Rainier, Cascade Range, USA (page 197). Describe the distribution of the risks shown by this assessment. (6 marks)

4. Where do most earthquakes occur and why are those locations earthquake-prone? (6 marks)

5. Compare the damage caused by two tropical storms that you have studied. (6 marks)

6. With reference to **one** seismic event that you have studied, evaluate the management of and the responses made to that event. (20 marks)