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Chapter 5

Current geological events commonly reported in the media

5.1 Earth hazards

Geological events and activities are frequently reported in newspapers, on the radio and TV, and on the internet, but quite often it is clear that the reporter didn't have a good understanding of the geoscience being reported. The most common reports refer to geological hazards, climate change, fossil finds and local issues such as quarrying and landfill and the background to all these aspects is given below.

Earth processes can destroy single buildings and whole regions and it is the fast-acting large-scale processes that are most destructive. Earthquakes themselves can be highly dangerous and even more so when they trigger landslides or tsunamis. Small, 'safe' earthquakes occur in most parts of the world most of the time, caused by flexing of the moving plates, but large earthquakes are most common at the active margins of plate boundaries.

Figure 5.1: A school in San Salvador destroyed by an earthquake.

Most earthquakes occur when plate movement causes pressures to build up in the crust. When the pressures become too high, the rocks fracture along a fault, rather like the way a piece of wood snaps when you bend it too much. The

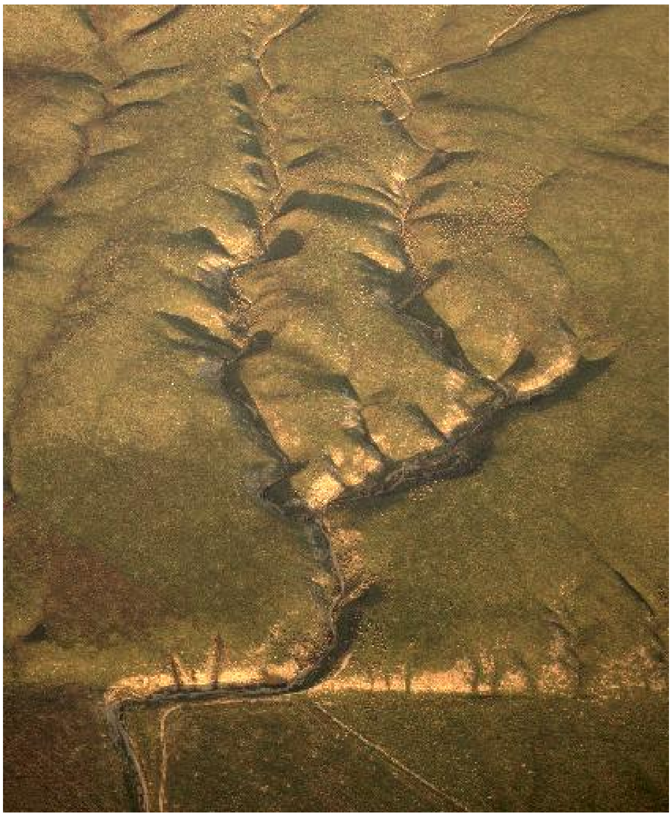

Figure 5.2: Strike-slip movement (rocks in the lower part of the photo to the left) along the San Andreas transform fault in California, USA.

two sides spring back causing shock waves to pass through the rocks. The place under the surface where this happens is called the **focus**; and shock waves radiate out from the focus in all directions. The shock waves first reach the surface directly above the focus, at the **epicentre**. Here they move outward causing the ground surface to move up and down in waves, rather like ripples radiate out across a pond when you throw a stone into the middle. When these surface waves are large, earthquakes can be very destructive, with the greatest destruction usually occurring at the epicentre, reducing outwards. You can use bricks and elastic to model how earthquakes work using the 'Earthquake prediction - when will the earthquake strike?' activity from http://www.earthlearningidea.com.

Major earthquakes occur at transform faults (conservative plate margins), like the San Andreas Fault in the USA, where parts of the Earth's crust slide past one another in strike-slip faulting (Figure 1.2). If this slip is slow and steady, earthquakes are uncommon. However, if friction causes one plate to stick against another, pressures build until the fault suddenly fractures in a large earthquake. These are near-surface or **shallow focus earthquakes**.

Shallow focus earthquakes are also common at divergent constructive plate margins, such as beneath Iceland and the East African Rift Valley. Here the tension caused by plates

Figure 5.3: Earthquake damage in Japan - Chuetsu earthquake, 2004.

moving apart results in blocks of crust slipping downwards at normal faults. These shallow focus earthquakes are usually small and not very destructive.

The largest earthquakes occur at transform faults and destructive plate margins. At destructive margins, huge compressive forces move the plates towards one another causing the crustal rocks to fracture along reverse and thrust faults. Since plates are subducting in these areas, earthquakes can occur in the subduction zone at any depth down to 700 km (below this depth, subducting plates begin to melt so can no longer fracture). This is why shallow, **intermediate depth** and **deep focus earthquakes** affect convergent plate margins, and some of these are the largest earthquakes ever recorded.

When loose surface material is shaken by earthquakes, it can 'liquefy' and lose all its strength allowing buildings to collapse and shallow slopes to slip as shown in the photo (Figure 1.3). You can see this **liquefaction** process in action yourself using the 'Quake shake - will my home collapse' activity at `http://www.earthlearningidea.com`. Earthquakes can also trigger other damaging Earth processes, including landslides and tsunamis.

Tsunamis are series of waves triggered in large bodies of water, such as lakes or oceans, by geological events. When there are sudden movements of rock under the water (or large landslides into the water), the displacement produces waves on the surface. In open water, these waves are low and have little effect, but as they approach land, the base of the waves slows down, causing the height of the wave to rise. Tsunamis can be so devastating because they involve huge volumes of water and cross oceans at more than 800 kilometres per hour. As they reach the coastline the power of the tsunami can drive large volumes of water onto the land with surges measured up to 14 metres high. Since

Figure 5.4: The South East Asian tsunami, 26th December, 2004.

these rush in faster than you can run, many people can be killed, as in the South East Asian Tsunami in December, 2004, which killed more than 300,000 people on coasts all around the Indian Ocean. Tsunamis used to be called tidal waves, but the Japanese word 'tsunami' is a better term, since they are not linked to tides at all. See the 'Tsunami: What controls the speed of a tsunami wave?' and the 'A tsunami through the window' activities at http://www.earthlearningidea.com.

Movement of the crust can cause slow gentle effects or catastrophically fast effects, and the same spectrum is seen in volcanic eruptions, which can range from gentle extrusion of lava to devastating blasts of volcanic debris. The main factor controlling the violence of eruptions is the viscosity of the lava: runny lavas can flow gently out of the ground forming sheets of lava and shallow-slope volcanoes, whilst thick slow-flowing lavas are much more explosive and form steeper-sided volcanoes. Magma viscosity is affected by its composition: basaltic, iron-rich magmas have low viscosity whilst intermediate and silica-rich magmas are highly viscous. Viscosity is also affected by the temperature of the lava and whether there is much solid material (as crystals) present. In general, hot, iron-rich magmas with little crystal content flow quickly, whilst cooler, silica-rich magmas containing crystals flow slowly. The significance of this is that basaltic volcanoes, as found at constructive plate margins, and 'hot spots' on Earth like Hawaii, produce relatively safe eruptions. So, providing you are careful you can go and watch or photograph these eruptions safely (see Figure 1.5 for an example); the lava sprays into the air as 'fire fountains', rains down as liquid and then flows downhill. The volcanic eruptions of intermediate and silicic magma at subduction zones are quite different and cause a range of highly dangerous volcanic processes, producing solid volcanic blocks and huge

Figure 5.5: A basaltic eruption in the Hawaii Volcanoes National Park.

volumes of ash. To simulate changing the viscosity of lava, try the 'See how they run: investigate why some lavas flow further and more quickly than others' activity on the http://www.earthlearningidea.com website.

The viscous magma can sometimes flow out of steep-sided volcanoes like toothpaste, but more often, it solidifies in the vent so that pressure mounts, eventually triggering a violent eruption. This may be a horizontal blast, like the one that flattened a 600 square kilometre forest of trees like matchsticks at Mount St. Helens in 1980, or a vertical blast, as blasted ash 34 km into the air in the eruption of Mount Pinatubo in the Philippines in 1991.

Volcanic ash itself can pose a hazard. In a thick volcanic ash fall, there is total darkness; ash in the air makes it difficult for people to breathe, particularly those who already have breathing problems. The ash blown high into the atmosphere in major volcanic eruptions (Figure 1.6) can rain down over thousands of square kilometres of land, blanketing towns and agricultural land; near volcanoes it can rain down so thickly that roofs collapse

Figure 5.6: An ash eruption rising into the upper atmosphere - Redoubt Volcano, Alaska, 1990.

and elsewhere it can cover and kill crops. Ash and volcanic gas from the Mount Pinatubo eruption reached the upper atmosphere and had global effects, producing beautiful sunsets and causing the Earth to cool by 0.4°C that year.

If volcanic ash, having fallen on the sides of the volcano, becomes mixed with large amounts of water, from a crater lake, melting ice or snow, or from the thunderstorms that are frequently triggered by volcanic eruptions, the results can be a devastating mudflow of volcanic debris called a lahar (see Figures 1.7 and 1.8). Lahars are like liquid concrete, flowing down valleys at tens of kilometres per hour carrying ash and boulders and, if large enough, spreading out on the plains below, before becoming solid. Lahars can be huge: one formed a wall of mud 140 metres high and another covered an area of more than 300 square kilometres.

Lahars are so dangerous because, if not monitored carefully, they can arrive unexpectedly and with devastating power, tens of kilometres from the volcanic vent. This happened with the lahars from the Nevado del Ruiz volcano that buried the town of Armero in Columbia in 1985, killing more than 20,000 people. Although geologists and other experts had warned the authorities of the danger beforehand, city officials downplayed the warnings and, the night before the eruption, the mayor had told the inhabitants that there was nothing to fear.

Figure 5.7: A lahar from the crater of Mount St. Helens.

Figure 5.8: A bus damaged by a lahar flow from Mount St. Helens.

Figure 5.9: Pyroclastic flows (nueées ardentes) flowing down the slopes of Mayon in the Philippines during the 1984 eruption.

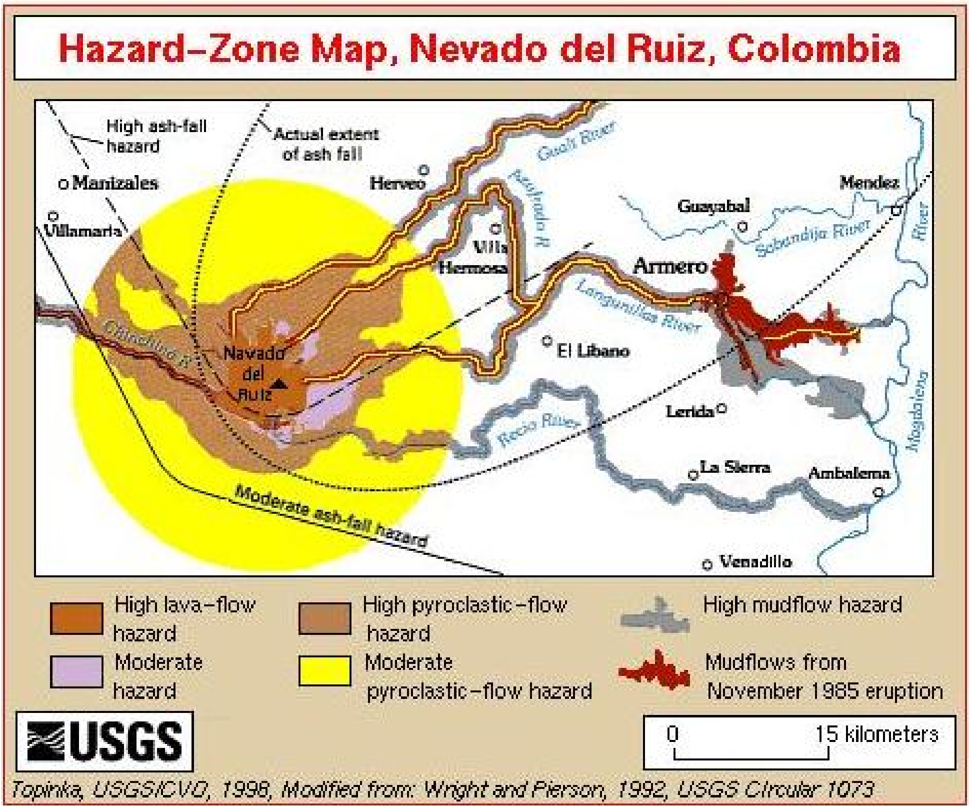

Figure 5.10: A hazard zone map of the Nevado del Ruiz volcano showing volcanic hazards, including the high mudflow (lahar) hazard areas (which included Armero) and pyroclastic flow (nuée ardente) risk areas; the map was produced after the Armero disaster.

Destructive volcanoes with intermediate and silica-rich magmas not only erupt columns of ash into the air, but the column may collapse and flow sideways as red hot (up to 1000°C) clouds of ash and gas called **nuées ardentes** (glowing clouds) or **pyroclastic flows**. Since these clouds of ash in air are denser than the surrounding air, they flow downhill as density currents at speeds of hundreds of kilometres per hour, incinerating anything in their paths (Figure 1.9). They tend to become funnelled down valleys and spread out on the plains beneath, rather like lahars, but much hotter and faster, and can even flow across water. The hazard map of Nevado del Ruiz (Figure 1.10) shows potentially hazardous pyroclastic flow paths as well as lahar flow paths.

The landslide at Mount St Helens which triggered the 1980 eruption occurred after months of activity had built a huge bulge on the side of the mountain. An earthquake triggered the largest landslide in recorded history at the steep edge of the bulge. This released the lateral blast that was followed by the full eruption. Although this landslide was an unusual event, most other major landslides were triggered by earthquakes too, although some were also triggered by storms.

Landslides are the result of the collapse of unstable slopes under gravity. The stability of slopes depends upon how steep they are, the weaknesses in the material (from faults,

Figure 5.11: Landslide triggered by the El Salvador earthquake in 2001.

joints, bedding and other slippage surfaces) and the pressure of the water in the pore spaces (the **pore water pressure**). Slopes are more prone to fail if they have been steepened by human activity or by erosion of material from the foot of the slope, if weaknesses have been attacked by weathering, or if they become waterlogged during storms. In these circumstances, a small amount of extra stress can cause slopes to fail and collapse. Near vertical slopes can collapse by toppling, but most fail by simply sliding downwards, usually breaking up into debris, large and small. Such debris can be carried a long way, particularly if there is enough water for it to become a slurry. **Mudflows** and **debris flows** usually begin as landslides; debris flows carry boulders whilst mudflows are mostly formed of finer material, but both can be devastating, as shown in Figure 1.11. See the 'Landslide through the window' 'thought experiment' and the 'Sandcastles and slopes: what makes sandcastles and slopes collapse?' activity at `http://www.earthlearningidea.com`.

Catastrophic Earth processes only become hazards when they affect people, as they clearly did in the 2001 El Salvador earthquake (Figures 1.1 and 1.11), so if an Earth process has a devastating effect on a wilderness area, it is not classed as a hazard because there is no risk to humans. The amount of risk caused by geological hazards, or **geohazards**, often depends upon the types of human activities involved, whilst people often increase their risk by their behaviour. Humans construct settlements and large scale building projects in geologically hazardous areas for a wide variety of reasons, including good access, good agriculture, or lack of other available land. Risk is increased by population density; the more people in a vulnerable area the greater the loss of life that can result.

Geohazard risk is reduced by taking a series of actions: first the risk should be assessed and evaluated; then if there has to be construction in risky areas, buildings and other civil engineering projects should be built as safely as possible; then mechanisms should be put in place to monitor and forecast future potential hazards; finally plans should be made to protect the human population during and after a geohazardous event.

The first stage of preparing for geohazards is to assess the hazard and possibly to prepare a geohazard map, like that in Figure 1.10. It is fairly easy to assess tsunami risk - any low-lying area in a tsunami-prone region is in danger; it is relatively easy to map volcanic risks, since the presence of volcanic materials from the recent past is good evidence that they may be deposited again, and there may even be historical evidence of past events. Mapping landslide danger is more difficult, since any steep slope may be prone to landslides, but techniques involving careful examination of rocks and evaluation of earthquake potential can be effective in producing landslide geohazard maps. It is, however, very difficult to produce good local earthquake geohazard maps, since so many variables are involved, including the intensity of the earthquake and the strength of the subsurface rocks.

Figure 5.12: Buildings that did not resist the Mexico City earthquake of 1985.

If building has to take place in geohazardous areas, then the constructions should be hazard-resistant. Many countries in areas prone to geohazards have building codes, so that in earthquake-prone areas, buildings are constructed to be able to flex and not fracture during earthquakes, they are given sturdy foundations and use strong building materials. Older buildings can be 'retrofitted' to make them more earthquake-resistant - the objective is not for buildings to remain completely undamaged by a major earthquake, but to to make them resistant enough for their inhabitants to survive. Unfortunately in many developing countries, building codes are not enforced for a range of reasons, including expense and lack of suitable infrastructure, so much construction in developing regions may be affected by geohazards in the future (as in Figure 1.12). In tsunami-prone areas, buildings of concrete are more likely to survive than buildings made of local materials. The safest way of constructing buildings safe from landslides is not to build them on or beneath slopes. Volcanic eruptions of most violent volcanoes are infrequent, and volcanic

Figure 5.13: Seismic monitoring of volcanic activity.

areas often have fertile soils and may be attractive to tourists, so that much building has taken place on potentially hazardous volcanic slopes. The most effective way of reducing risks in these areas is to monitor and prepare.

Volcanoes can be monitored by a wide variety of methods. Nowadays, some volcanoes are routinely monitored remotely by satellites that can identify temperature changes, emission of sulfur dioxide or ash clouds, or small changes in shape of the surface of the volcano. Meanwhile ground monitoring techniques that have been developed over many years include seismic monitoring (many eruptions have increased small earthquake activity before eruption and some seismic traces are characteristic of lava movement at depth); monitoring of the shape of the volcano (by tiltmeters, that detect changes in the slopes of surfaces); and by measuring the changes in altitude and distance across key parts of the volcano, to spot the development of volcanic bulges before eruptions. Try making your own tiltmeter from, 'When will it blow?: predicting eruptions' at http://www.earthlearningidea.com. On many volcanoes the emission of volcanic gases is monitored

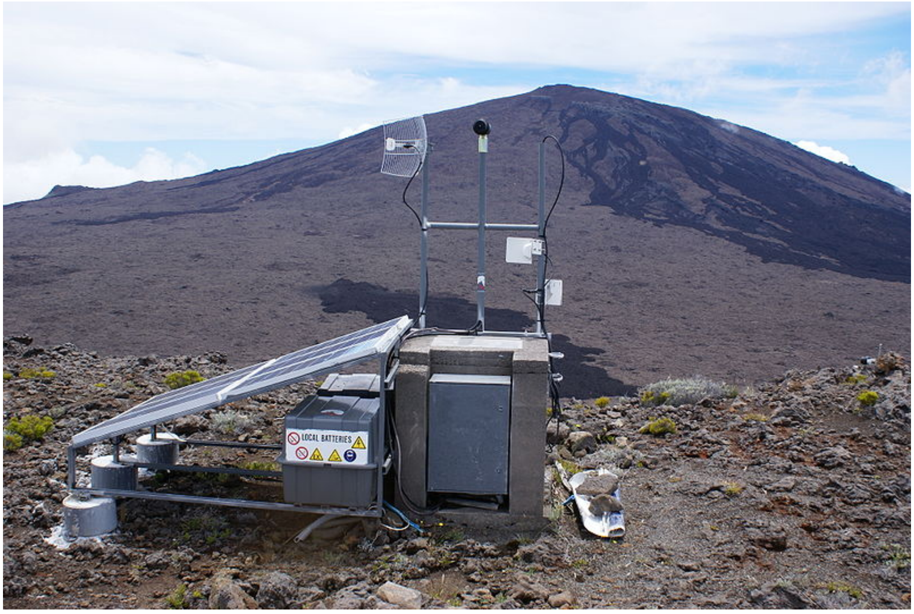

Figure 5.14: A GPS (global satellite positioning) remote volcano monitoring station, monitoring deformation of the slopes of a volcano.

for any changes in gas composition that may occur before eruption, whilst small scale changes in gravity and magnetism may also be used to predict eruptions. Unfortunately, all the equipment needed for thorough volcano monitoring is very expensive, so that, whilst many volcanoes in the USA are closely monitored, many in the developing world are not. Eruption risk to populations is much higher in volcanic regions that have less effective monitoring systems.

Scientists have been investigating earthquake prediction for many years and have shown that, while it is impossible to predict earthquakes (the exact time and place where they will occur) it may be possible to forecast earthquakes, suggesting the probability that an earthquake will occur at a given place at a given time. These forecasts have been based on a number of methods including:

- **seismic gaps**: when faults are under plate tectonic pressure, some parts of faults slip gently, whilst others are ‘locked’. The locked parts are seismic gaps, where earthquakes have been recorded on either side, but not in the middle; the next big earthquake is most likely in this seismic gap area. Figure 1.15 shows how the ground surface moved in the Izmit earthquake in Turkey in 1999. Other major earthquakes have happened along the fault to the east, so the next large earthquake is likely to be in the seismic gap to the west; this happens to be beneath the city of Istanbul.
- **foreshocks**: many major earthquakes have smaller foreshocks beforehand, however, many small foreshock-like earthquakes can occur along a fault without a major earthquake following them.

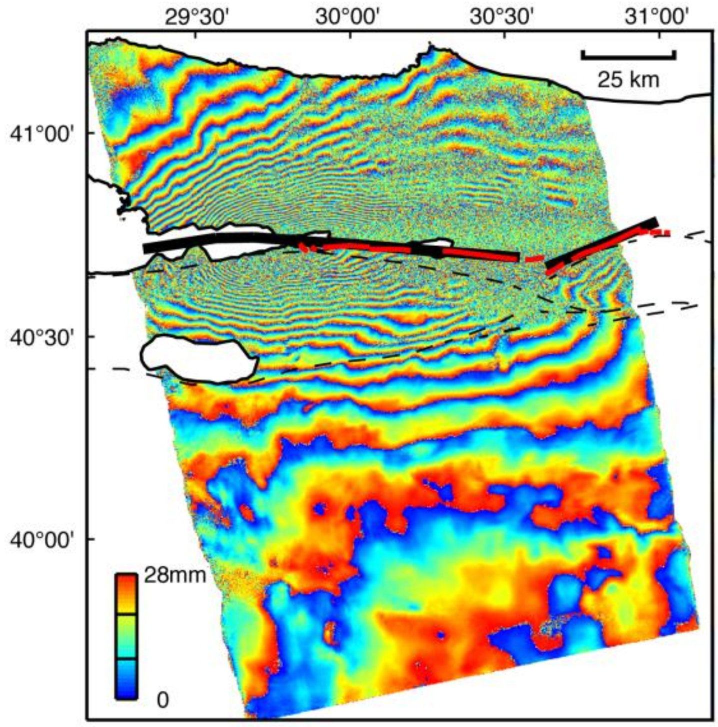

Figure 5.15: An interferogram of the Izmit earthquake, Turkey, 1999, produced by comparing satellite data from before and after the earthquake. Most movement of the ground surface occurred where the colour bands are closest together and this shows the position of the fault very clearly.

- ground deformation: deformation of the ground near a fault, measured using stress gauges, tiltmeters or by surveying, may provide signs of a future earthquake.
- groundwater variations: as pressure increases in the rocks around a fault, cracks may open or close causing the level of the water table in wells or boreholes to change, suggesting a future earthquake.
- radon gas: the cracking of rocks before an earthquake may release radon gas into the groundwater, which can be detected.
- geomagnetic and geoelectric changes: changes in both local magnetism and local electrical resistance have been recorded just before an earthquake struck.
- earthquake lights: there have been reports of 'earthquake lights' before earthquakes, flashes of red and blue light in the sky that may be caused by quartz crystals fracturing under stress.
- animal behaviour: there have been accounts of some animals like dogs and cats behaving strangely before earthquakes, but it has not been possible so far to use this in effective earthquake forecasting.

None of these methods has yet proved to be scientifically successful in reliably forecasting earthquakes. Meanwhile, scientists have to be very careful not to forecast an earthquake that doesn't happen, since an inaccurate forecast can be very costly and the population is less likely to take notice of future forecasts. The work of seeking reliable earthquake-forecasting techniques is likely to continue for many years to come.

Landslides can be fast or slow-moving. There is no time to monitor fast-moving events, but landslides that creep slowly and threaten buildings or other constructions such as roads, can be monitored by instruments to detect movement, ground vibration, groundwater changes, or rainfall. However, this is expensive, and is only usually possible in well-developed countries.

A range of techniques is available to reduce the effects of creeping landslides, including improving drainage, planting vegetation to bind the material with roots and remove water, and anchoring the toe of slips with heavy masses of material or stone-filled **gabion** baskets. Rockfall hazards in steeper areas can also be reduced by using **rock bolts** to tie down looser sections, by covering steep surfaces with mesh **geotextiles** or concrete blankets (**shotcrete**) and by building fences and ditches to catch debris. Again, these remediation techniques are usually only possible in well-developed countries.

The final stage of tackling geohazard risk, after assessing geohazard impact, controlling building construction, and using prediction/monitoring methods, is to develop plans to protect the population during and after an event. Such plans will differ, depending on the type of event and its likely scale. However, most plans have in common: the training of the emergency services, the education of the population on what to do and when, the use of early warning systems where possible, the development of evacuation plans, procedures to maintain essential services, and strategies to call in extra help and resources if necessary. See the 'Surviving an earthquake' activity at http://www.earthlearningidea.com.

5.2 Human impacts on climate change

Media reports often link all sorts of natural disasters to climate change but, although climate change will have long term effects on the Earth, it is not directly responsible for short term changes like those in the weather or sudden geohazard events.

Nevertheless, as shown in Section 3.3 of this book, climate change could have dramatic effects in the future. Global warming could cause marked temperature rises and increases in drought in some parts of the Earth, linked surprisingly to cooling in others. Global climate belts would tend to move towards the poles and the world's weather patterns would probably become more stormy. If the warming caused major melting of the continental ice sheets (on Greenland and Antarctica), global sea levels would rise significantly. Meanwhile the water in the warming oceans would also expand, causing many low-lying areas, including many of the world's major cities, to be prone to large-scale flooding during storms.

For these reasons, many scientists and an increasing number of politicians and other influential people across the world are arguing that the human population should do all

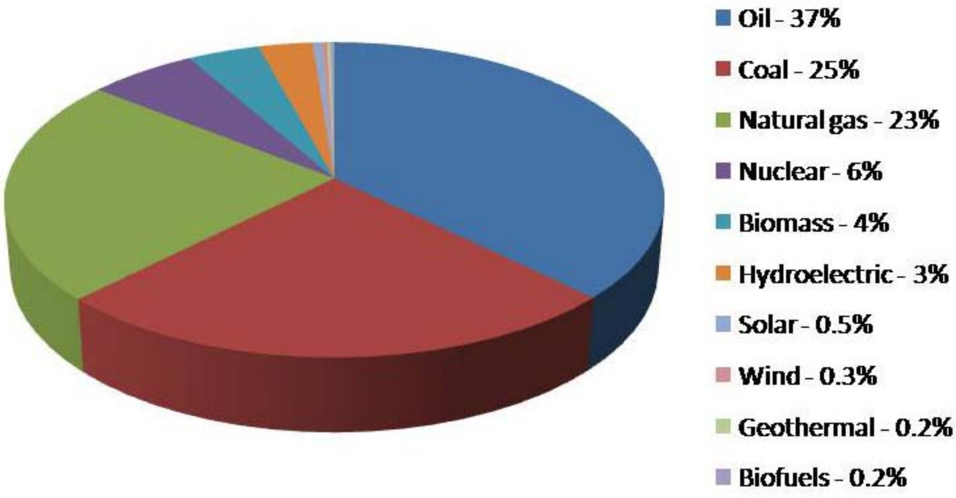

Figure 5.16: The sources of fuel used in current world energy consumption.

it can to reduce the effects of climate change. One of the main causes seems to be the increasing amount of carbon dioxide (and other 'greenhouse gases') in the atmosphere and their 'greenhouse effect'. Even though enormous amounts of carbon are cycled through the carbon cycle and the Earth's atmosphere each year, through such processes as photosynthesis in plants and respiration in all organisms, the amount of carbon dioxide in the atmosphere in the recent geological past had stayed fairly stable until the beginning of the Industrial Revolution. As more and more fossil fuel has been burnt since this time, the carbon dioxide content of the atmosphere has increased, so that now about 100 times more carbon dioxide is released into the atmosphere each year by burning fossil fuels than is released by natural volcanic emissions.

The fossil fuels, coal, oil and natural gas, together are called hydrocarbons. When the carbon in them burns, it combines with oxygen from the atmosphere to form carbon dioxide. As the atomic mass of oxygen (16) is greater than that of carbon (12), and each carbon atom combines with two oxygen atoms to make CO_2, the mass of the carbon dioxide produced by burning is greater than the mass of the original carbon. Even natural gas, the most efficient of the fossil fuels, emits more than its weight of carbon dioxide on burning.

Currently more than 80% of the power used on Earth comes from the burning of fossil fuels (Figure 1.16), so there will be no easy way to reduce carbon emissions. Nevertheless three different methods are being used to reduce the amount of carbon dioxide being released to the atmosphere:

- generate more power from non-hydrocarbon fuel sources, to reduce the burning of hydrocarbons;
- reduce the amount of power needed, by using fuel more efficiently;

Figure 5.17: A windfarm in Ireland.

Figure 5.18: Solar panels being used in Mallorca.

- burn hydrocarbons, but then trap the carbon dioxide formed and store it in old exhausted oil and gas fields.

Figure 1.16 shows how difficult it is going to be to generate a lot more energy from non-hydrocarbon sources. We can't easily increase **biofuel** production, as this would mean growing and burning more trees; biofuels are usually grown on land used to grow crops for human consumption, so production from these is not likely to increase greatly. Increasing power production from hydroelectricity would mean building more dams and reservoirs, which is not possible in dryer or low-lying countries. For these reasons, most effort is being focused on nuclear, solar and wind power generation. Nuclear power is being strongly developed in some countries and being considered by others, despite the problems of nuclear waste disposal and potential large scale nuclear disaster. Wind, solar and geothermal power supplies are also being developed, but these are starting from such low percentages that they won't make a great impact on global power supplies for some time.

Many countries are developing onshore and offshore **windfarms** of clusters of **wind turbines**. Meanwhile buildings in some regions are being fitted with solar panels to contribute to the energy needed by the building, whilst other building projects are using the 'geothermal energy' supplied by '**heat engines**'. These draw in heat from the surrounding ground (ground-source heat engines) or air (air-source heat engines) which is then used for heating the building. In warm summers, heat can be returned to the ground by reversing the heat engines to provide air conditioning. Most of the 'geothermal energy' used by ground-source heat engines, and all the air-source heat engine energy, is actually solar energy from the sun, and so is not 'geothermal' at all. Proper 'geothermal energy' is only available in 'hot spot' areas of the Earth, like Iceland or New Zealand, or where it has been trapped in deep underground water supplies over many thousands of years, as in parts of France.

One of the factors likely to be contributing to the increase of carbon dioxide in the atmosphere is the cutting down of forests, particularly in equatorial regions. Trees absorb and store carbon dioxide through photosynthesis, but can no longer do this if they have been felled. This is why there are global concerns over deforestation, particularly of the

Amazon rain forests. This is also why new trees are being planted in many parts of the world, sometimes as part of '**carbon trading**' where an organisation might plant new trees to offset its energy consumption from fossil fuels.

There are also major global attempts to reduce fuel consumption: by making engines, large and small, more efficient; by developing more efficient industrial processes; by reducing heat losses from older buildings; and by constructing new buildings that are more energy-efficient. In these ways, organisations and individuals are trying to 'reduce their **carbon footprint**'.

The new technology of removing carbon dioxide generated by burning fossil fuels and pumping it into abandoned oil and gas fields is still experimental. This is called '**carbon sequestration**' or '**carbon capture**' and is part of the '**clean coal technology**' being discussed as a method of using coal to produce energy without polluting the environment and adding greenhouse gases to the atmosphere. If this does become successful it is likely to be many years before it is available for large scale use.

For all the reasons described above, many countries are currently considering the 'nuclear option' as a way of supplying substantial amounts of power, and so reducing the consumption of fossil fuels, while other methods of power generation are being developed. See the 'Power through the window' 'thought experiment' activity at http://www.earthlearningidea.com to think about how energy production might affect your local environment.

5.3 Great fossil finds

The media often report important fossil finds, but these are only really 'great fossil finds' if they provide new evidence for life on Earth in the past. Such finds normally fall into four categories:

- exceptional preservation - the unusual circumstances where groups of fossils are so well preserved that their soft parts and living relationships can be studied;
- 'missing link' fossils - which show how some groups of organisms are linked to others;
- complex fossil skeletons - which, when re-assembled, show the mode of life of individual animals;
- hominid finds - the rare finds that help us to investigate human evolution.

One of the most famous examples of exceptional preservation is the Burgess Shale found high in the Rocky Mountains in Canada. Here, during Cambrian times (about 500 million years ago), organisms that lived in a shallow sea were swept off the edge of an undersea cliff, probably during storms, and were preserved in mud at the foot of the cliff. Not only was the preservation exceptional, in that the finest details of the soft parts of the animals are often preserved, but also a wide variety of animals has been found, many completely unlike animals found on Earth today (see Figure 1.20). Evolutionary scientists have hotly

Figure 5.19: A beautifully preserved *Archaeopteryx* fossil, with a model in the foreground.

Figure 5.20: One of the strange animals found exceptionally preserved in the 505 million year old Cambrian Burgess Shale in Canada.

debated whether these strange animals are related to modern animal groups or not and what this means for the evolutionary story - and the debate continues. This debate would not have been possible if the unusual fossilisation circumstances had not preserved the specimens so completely.

Examples of rock sequences with exceptional preservation like this are called **lagerstätten** and only about 50 examples of lagerstätten are known from the whole geological record. However, these have given scientists unique 'windows' into the variety and detail of life at key times in the Earth's past.

Another example of lagerstätten is the Jurassic Solenhofen Limestone in Germany (about 150 million years old) in which fossils of *Archaeopteryx* have been found (see Figure 1.19). As in other lagerstätten, the *Archaeopteryx* fossils are beautifully preserved and it is clear that they not only had small teeth, like reptiles, but feathers like birds as well.

Before the finding of *Archaeopteryx* scientists had debated long and hard how birds had evolved. The *Archaeopteryx* specimens, with many features similar to dinosaurs (types of reptiles), but also with wings and feathers, showed how birds evolved from reptiles and so provide a 'missing link' in evolutionary history.

Another 'missing link' find has recently been reported. The headline in a UK newspaper read '***Fossil Ida: Extraordinary find is 'missing link' in human evolution'*** (the *Guardian* newspaper, 19 May 2009). The article continued, 'Scientists have discovered an exquisitely preserved ancient primate fossil that they believe forms a crucial "missing link" between our own evolutionary branch of life and the rest of the animal kingdom.' The newspaper story described the fossil which, very unusually, was 95% complete, with the hair, and even the last meal of the small animal preserved. It was a young female about 6 to 9 months old that may just have left its mother, and was found in sediments deposited in a volcanic lake 47 million years ago. It forms a 'missing link' between early small **primate** animals and the group that later evolved into monkeys, apes and eventually, humans.

Some media reports and many cinema films/movies suggest that the skeletons of large animals are often found intact in sedimentary rock layers. This only happens in really exceptional circumstances, as with 'Ida' above. Much more common is the finding of separate bones, like the one being excavated in Figure 1.21. The bones are usually separated because, after the animal died many things could happen before the bones were buried. Scavenging animals may have pulled the bones apart and chewed up the smaller bones, the animal may have rotted so that the skeleton fell apart, or it may have been swept away and broken up in a river or the sea. When groups of bones are found together, geoscientists usually try to reconstruct the animal to show what it was like when it was living. When this was first done, many mistakes were made. In the famous case of *Iguanadon*, early reconstructions showed a 'spike' on the nose, but it was later found to be one of the two thumb spikes.

When skeletons are reconstructed today, evidence is used from several skeletons, from the size and shape of the bones including the scars left by muscles, from how similar modern animals live, and from features like footprints that show how the animal moved. So, modern skeleton reconstructions are much more accurate, and realistic working models and animations can be made, like those in the 'Walking with dinosaurs' TV programmes and exhibition. Most of the details of these models and animations are as accurate as they can be, although we are never likely to know the exact colours of the skins, the sounds the animals made, or the detailed ways in which they lived (as in Figure 1.22).

The search for early human fossils is even more difficult, since they were much less common than many dinosaur groups and they usually lived on land well away from environments where they might be fossilised. So scientists and media reports are often very excited by very small human-related finds.

When a skeleton was found in rocks more than 3 million years old in Ethiopia, with parts of nearly all the major bones preserved, there was huge excitement. This was a fossil of an early type of **hominid** called *Australopithecus* on the evolutionary line that eventually produced *Homo sapiens*, humankind. This fossil was soon christened 'Lucy' and you can read the exciting story of the find on the internet. 'Lucy' was so important because she had the size and shape of a chimpanzee, but also had many characteristics of modern humans.

Figure 5.21: A dinosaur excavation.

Figure 5.22: A dinosaur reconstruction showing how they might have lived.

There was more excitement a few years later when footprints of *Australopithecus* were found in a bed of 3.6 million year old volcanic ash in Tanzania, Africa. Since igneous rocks like volcanic ash contain radioactive elements, we can date them quite precisely using radiometric techniques. The footprints are of three individual hominids, who had walked across the layer of ash in the same direction. They show that the Australopithecines walked upright (unlike chimpanzees) and computer simulations show that they were walking along at about 3.5 kilometres per hour, strolling speed.

Even though detailed evidence of hominid evolution like this is very rarely found, nowadays geoscientists have been able to build up a good picture of how humans have evolved. We can also use evidence from the DNA of modern primate groups to support the evolutionary story and to build an even more complete picture of how *Homo sapiens* evolved to be like we are today.

The more we study the rocks of the Earth's surface, the more fossil evidence we find of life in the past and how it contributed to the evolving environments on Earth. As more fossils are found and reported in the media in the future, more detail will be added to the jigsaw picture of life on Earth.

5.4 Planning, quarrying and landfill

The most commonly reported geoscience-related issues in local newspapers and news reports are usually about quarrying and **landfill**, and the planning related to them.

Figure 5.23: The bones of the more than three million year old *Australopithecus* skeleton 'Lucy' found in Ethiopia, Africa.

Figure 5.24: A reconstruction of the 'Lucy' *Australopithecus* skeleton.

Quarrying produces the raw materials needed for construction. Without quarry products, no building could take place. Indeed, nearly all the material used for the buildings around you came from the ground.

The materials produced by quarrying fall into five main categories:

- **aggregate** - crushed rock (e.g. limestone, sandstone, basalt) or sand and gravel from gravel pits, used to add to concrete, for foundations and for railways; some fine aggregates are also used to make building blocks that look like building stones;
- limestone - used to make cement, for the chemical and fertiliser industries and in **smelting** iron ore;
- brick clay - from brick pits, used to make bricks and roofing tiles;

Figure 5.25: A working aggregate-producing quarry on Sifnos, Greece.

- building stone - nowadays used mainly for ornamental **facing stones** for high prestige buildings (in thin slabs attached to the walls of the buildings) or as flooring, and for memorials, statues, and fireplaces, but also for repairs to old stone-built buildings, walls and pathways;
- specialist products - such as china clay, pottery clay, silica sand for glass-making; gypsum to make plaster, and slates for roofing older buildings.

This list shows that 'quarrying' normally includes sand and gravel pits, but does not include large opencast mines used for coal, copper or iron ore extraction. Neither does it cover deep mines for coal and ore minerals. Since quarry products are bulky and heavy, they are normally extracted as close to the site where they are being used as possible, to minimise transport costs. Thus many small abandoned quarries and pits are found near older built up areas. Nowadays, because it is difficult to get planning permission to excavate new quarries, the trend is for larger quarries to be developed near transport links, from where the materials can be transported to where they are needed. Sometimes superquarries have been developed on the coast, from where the products can easily be transported worldwide. The exception to this is the ornamental stone industry where today, it is often cheaper to import stone from large exporters abroad, than to quarry it locally.

When new quarries or gravel pits are being planned, or older sites are being extended, the planning application should cover the following issues:

- the size and shape of the development and the likely duration of the quarrying;

- noise and vibration - the sounds of explosive blasting and of heavy machinery should be minimised - earth banks (**bunds**) may be built and trees planted to reduce noise;
- dust and air quality - dust pollution should be minimised by, for example, spraying dirt roads with water during dry periods and washing vehicles regularly;
- water supplies and groundwater - boreholes are often drilled and monitored to check on groundwater flow directions and ensure that groundwater supplying water to surrounding areas does not become polluted - meanwhile water used on site needs to be stored, cleaned and recycled;
- landscape - quarries should be sited to minimise impact on local views - banks and trees may be positioned to hide the signs of quarrying;
- natural and cultural heritage - the local wildlife and areas of historical interest should be conserved;
- traffic impact - the local road system may need upgrading to deal with quarry traffic;
- waste - proper waste management systems should be in place;
- environmental management systems - the local environment during and after quarrying will need to be managed, including the development of a post-quarrying environmental plan.

If the planning application is opposed by local groups of people or national bodies, the planning proposal may be taken to a public inquiry. You can work out how the pros and cons of quarry proposal would be debated yourself, by role-playing the 'Limestone inquiry: 21st century' on the JESEI website at: http://www.esta-uk.net/jesei/index2.htm and thinking about how a quarry might affect your area through the 'Quarry through the window' activity at http://www.earthlearningidea.com.

When quarries, brick pits or gravel pits are closed, the post-quarrying environmental plan is likely either to convert the area to a public amenity or to use it for waste disposal. Quarries less suitable for waste disposal or important for amenity purposes, can be landscaped to form nature reserves or country parks; the Eden Project in Cornwall (Figure 1.26) has transformed an abandoned china clay pit into one 'of the UK's top gardens and conservation tourist attractions' according to its website. Many country parks and nature reserves in quarries conserve rock faces for educational and scientific use and these may be protected by local planning laws.

Most waste material across the world, is disposed of in landfill sites. These are often old quarries but, in countries where there is a shortage of sites, other depressions in the landscape are used as well.

The old method of dealing with waste, when little was being produced by human populations, was the "**dilute and disperse**" method, in which the poisonous fluids produced by decaying waste were allowed to disperse in the rocks, diluted by rainfall. As more and more waste was produced, environmental pollution increased, so the policy was changed to

Figure 5.26: The Eden 'biome' Project in Cornwall, UK, in an old china clay pit.

"**concentrate and contain**", where the waste was carefully controlled and fluids were not allowed to leak into the surrounding rocks. Today's policy is "**integrated waste management**" with its motto, "reduce, reuse, recycle", where as much waste as possible is reused, some is processed and recycled, and the remainder is crushed into the smallest volume possible and disposed of in carefully controlled landfill sites.

Three broad types of waste are generally recognised:

- 'inert' waste - such as rubble from demolished buildings that is largely unreactive;
- domestic, commercial and industrial waste - the rubbish/trash disposed of by households, business and industry;
- hazardous waste - dangerous waste products such as toxic chemicals, carcinogenic (cancer-forming) waste, inflammable liquids and radioactive waste.

When rainfall gets into waste, it becomes contaminated with decaying waste materials to form nasty liquids called **leachate**. Waste decay also produces landfill gases such as methane. Thus one of the most important controls on where different sorts of waste can be disposed, is the permeability of the rocks in which they are to be placed. If the rock is permeable, leachate and landfill gases can leak into the rock through the pore spaces. The leachate may then pollute groundwater and later reach the environment through springs and marshes or the local water supply. Meanwhile, the methane can build up in hollows like caves and cellars, and has been known to cause explosions.

Since 'inert' waste is largely unreactive, it can be disposed of in permeable rocks like limestone or sandstone quarries. However, decaying domestic, commercial and industrial waste produces both leachate and methane and has to be disposed of in impermeable sites. In such sites, a network of pipes is laid along the bottom to collect the leachate so that it can be extracted, processed and disposed of safely, whist a series of vertical pipes vent the methane to the surface or collect the methane and use it to generate electricity (since methane is a potent 'greenhouse gas' it is better to collect and use it than to vent it to the atmosphere). When the sites are full, they have to be carefully capped with impermeable material to stop rainwater getting in and causing the leachate to overflow.

Figure 5.27: A landfill site in Hawaii, USA. The base of the old quarry and the sloping sides have been covered with a black plastic landfill liner (membrane) to ensure that fluids don't leak into the surrounding rock; this is then covered by gravel for protection.

Since clay is impermeable, abandoned brick pits are important waste disposal sites. If quarries in permeable rocks have to be used, then an impermeable plastic **landfill membrane** is laid across the floor and walls of the site, to contain the fluids produced (Figure 1.27). Boreholes are drilled nearby so that the groundwater can be monitored for pollution. These are expensive methods and so permeable sites are only used when impermeable options are not available.

Even more care has to be taken with the disposal of hazardous waste. Some is carefully incinerated whilst other types are chemically treated or mixed with cement and buried in highly impermeable sites. There is still much debate over the disposal of radioactive waste. Low level radioactive wastes are currently being used as landfill in very carefully chosen and controlled sites. Currently, high level radioactive wastes are being turned into a form of glass and stored under water, while scientists in most waste-producing countries search for solutions to their long term disposal.

Since the disposal of waste can produce unpleasant by-products as well as affecting the local environment, it is not surprising that there are often local news reports on waste disposal plans. However, the enormous volumes of waste that humans produce, particularly in more developed countries, have to be disposed of safely somewhere, and so environmental debates on waste disposal are likely to continue for ever.