Plate tectonics

10

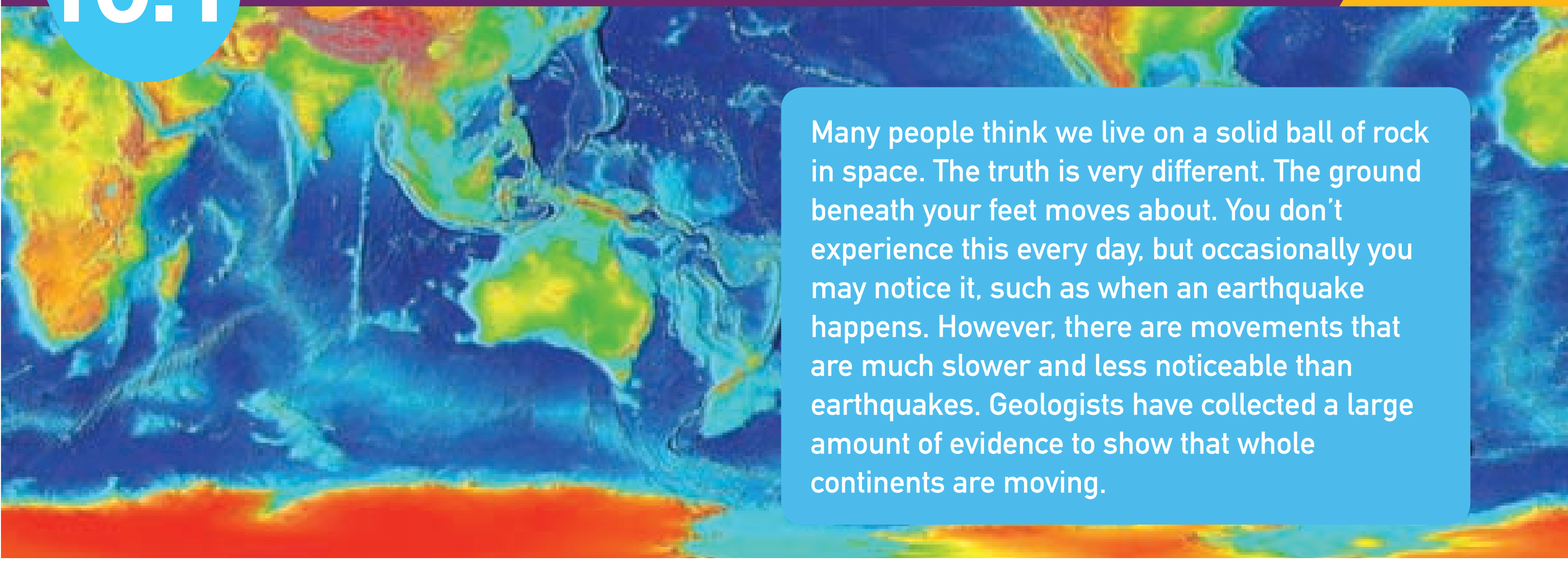
HAVE YOU EVER WONDERED …

- why earthquakes happen?
- why volcanoes exist?
- what causes tsunamis?
- why volcanoes are found in some places and not others?
- what makes mountains form?

After completing this chapter students should be able to:

- identify the major plates on a world map
- explain seafloor spreading
- describe how earthquakes and volcanoes are related to movement at plate boundaries
- explain the role of heat energy and convection in plate movement
- discuss and evaluate evidence that supports the theory of plate tectonics
- use plate tectonics to explain why Australia is geologically old and stable
- outline how the theory of plate tectonics developed
- describe modern technologies used in mapping plate movements
- describe how living near plate boundaries affects people's lives.

10.1 Moving continents



Many people think we live on a solid ball of rock in space. The truth is very different. The ground beneath your feet moves about. You don't experience this every day, but occasionally you may notice it, such as when an earthquake happens. However, there are movements that are much slower and less noticeable than earthquakes. Geologists have collected a large amount of evidence to show that whole continents are moving.

Continental drift

A revolutionary new theory about the Earth was proposed between 1912 and 1915. Alfred Wegener, a German meteorologist and geophysicist, claimed that the continents were once connected to each other. He called the large landmass Pangaea, and concluded that the continents must somehow have separated and be drifting across the oceans. The theory was called **continental drift.** At the time, most people thought the idea could not possibly be correct.

Wegener based his conclusions on two main observations. The first observation was that the continents seemed to fit together like a jigsaw (Figure 10.1.1).

Figure 10.1.1 Africa and South America seem to fit together.

Wegener's second observation was that fossils of the same species were found on continents that were a long way apart. He could see no way the organisms could cross the oceans to reach all these places. Instead, he thought that the continents themselves had shifted. As they did so, they took the fossils with them. Wegener rearranged the continents to join them up so that the distribution of the fossils matched up across the continents. This can be seen in Figure 10.1.2.

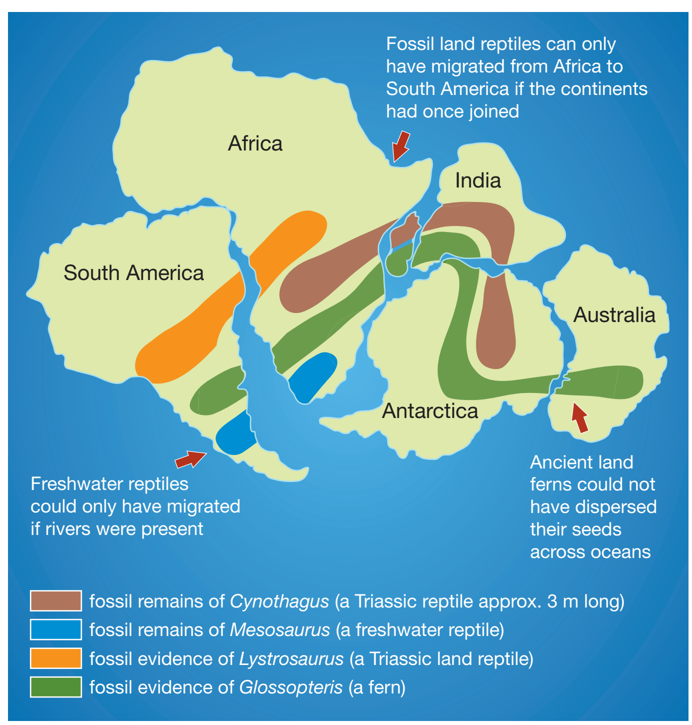


Figure 10.1.2 Fossil distribution makes sense if the continents were connected as shown here.

Few scientists believed Wegener was correct. The main reason was that there was no mechanism known by which huge continents could move. There was also no way of measuring whether the continents moved or not. Wegener died in 1930, before the discovery of new evidence that would prove him correct.

Seafloor spreading

In 1872, scientists were surveying for an undersea cable. They did this by dropping down very long cables and measuring their length. They discovered a large mountain ridge in the middle of the Atlantic Ocean. The ridge was found to extend a long way in the South Atlantic, but the extent of the ridge was not investigated. In 1925, sonar studies by German scientists confirmed that this ridge existed and ran the length of the Atlantic Ocean.

After World War II, further studies showed that the underwater ridge continued into other oceans and right around the Earth. In 1953, the ridges were found to have a huge series of cracks (called rifts) in their centres. The system was then named the Great Global Rift system. You can see some of it in Figure 10.1.3.

In 1962, Harry Hess, an American geologist, tried to explain what was happening at the ocean ridges. He was interested because during World War II he had discovered many flat-topped mountains under the Pacific Ocean. When the Great Global Rift was discovered, he thought back to his discoveries of the undersea mountains.

Hess proposed that new rocky crust was being formed at the ocean ridges and spreading outwards. This process was later called **seafloor spreading**. Hess proposed that the crust was sinking down into the Earth in other places, called **ocean trenches**. The process of the crust sinking down is called **subduction**. You can see these processes of forming new crust and destroying it in Figure 10.1.4.

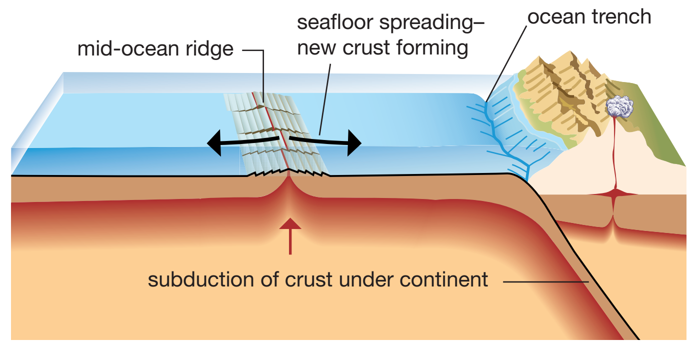


Figure 10.1.4 Seafloor spreading and subduction are processes involved in the creation and destruction of the crust.

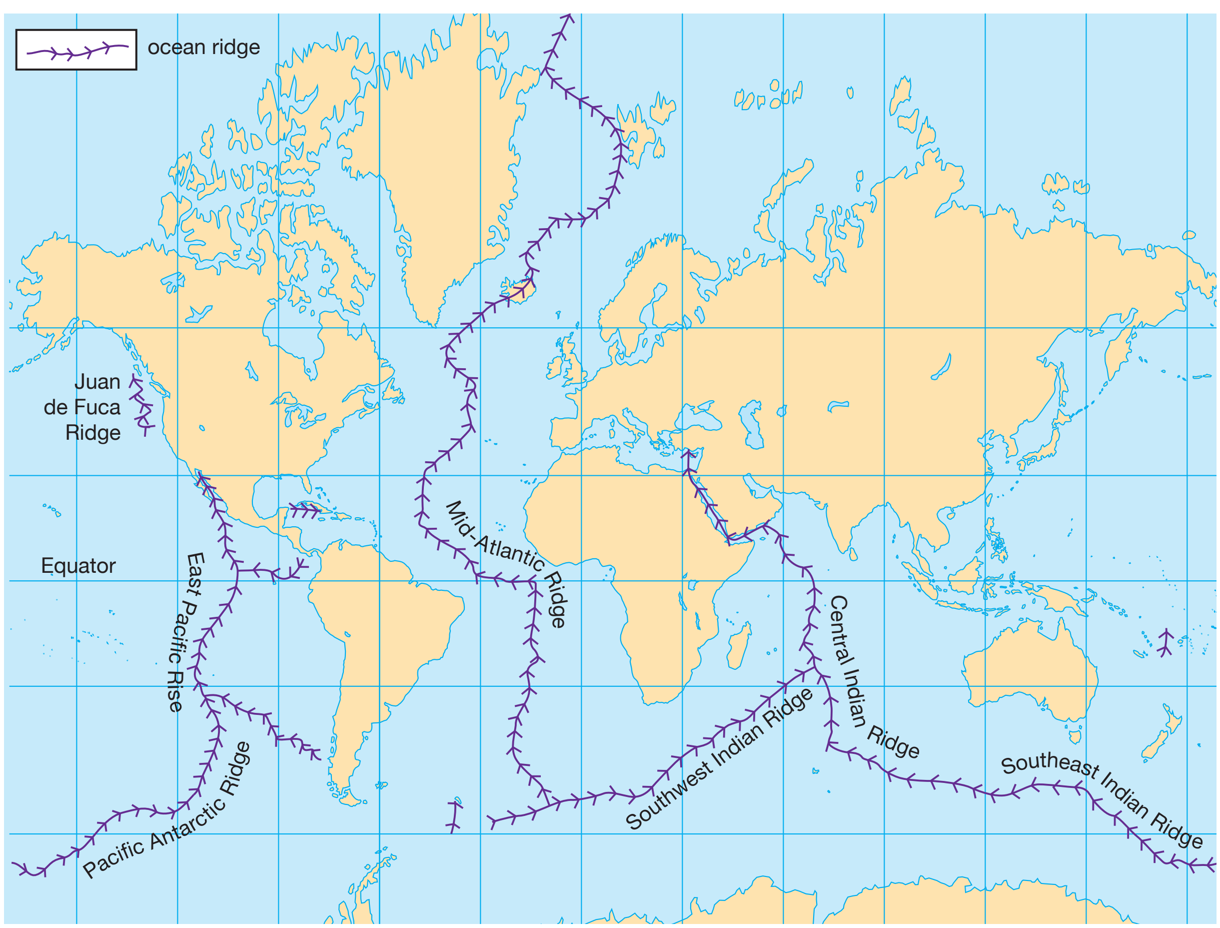


Figure 10.1.3 The Great Global Rift system of ocean ridges.

Magnetic striping

In the 1950s, scientists discovered that many rocks contained the iron oxide mineral called magnetite. A piece of magnetite that is suspended from a string will spin around and act as a compass. Magnetite has a north-seeking pole and a south-seeking pole, just like a compass needle.

INQUIRY science 4 fun

Making a compass

Can you make a compass?

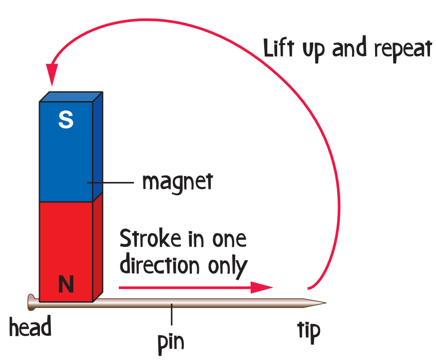
No

Collect this …

- small steel nail or pin
- bar magnet
- 20 cm of cotton
- compass
- sticky tape

Do this …

1. Place the pin on the desk and stroke it ten times from head to tip with the north-seeking pole of the bar magnet. Lift the magnet up and place it at back at the head of the pin after each stroke.
2. Tie or sticky tape the piece of cotton firmly in the middle of the pin so it hangs horizontally, and let it hang down and spin freely. Make sure you are further than 2 metres away from any metal object and the magnet.
3. Note which direction the pin tip points in. Spin it around a few times to see if it always points in the same direction. Compare the direction with a compass if you have one.
4. Repeat step 1 but use the opposite end of the magnet. Note any differences this time.



Record this …

Describe what happened.

Explain why you think this happened.

When molten rock solidifies, all the magnetite particles of any size line up in the magnetic field, pointing in the same direction. Therefore, the direction of the Earth's magnetic field at the time is preserved in the rock. Geologists can detect which part of the rock is the north-seeking pole. In this way any piece of rock acts like a tiny magnet.

During World War II, the US navy had discovered that there were bands of alternating strong and weak magnetism on the sea floor. They found that these bands were parallel to the mid-ocean ridges. You can see this in Figure 10.1.5. More studies by geologists confirmed this result and showed that it was due to changes in the magnetic field of the Earth over its history.

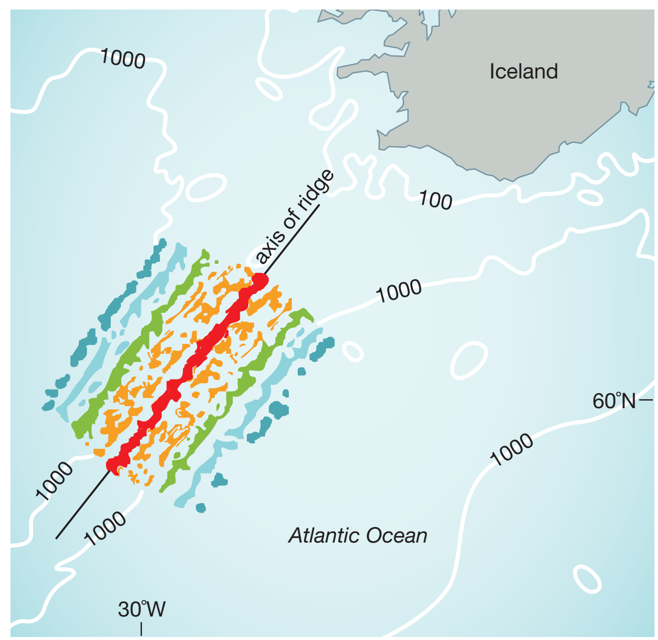


Figure 10.1.5 The magnetism in the rocks on each side of the mid-ocean ridges is symmetrical.

Geologists found that as they went away from the ridge, the direction of north preserved in the rocks kept changing. At the start, the rocks had north pointing in the correct direction. Suddenly the direction of north changed to the opposite direction. North became south, then changed back again. This was very puzzling, because there was no way that the rocks could have spun around. The conclusion was that the Earth's magnetic field had changed every few million years.

These patterns of strips of rocks with alternating magnetism are called **magnetic striping**. The patterns on either side of the ridge were symmetrical—rocks at a particular distance from the ridge on one side always had the same magnetic direction as rocks the same distance away on the other side. At a particular distance they would both point to the current position of north, or they would both point to the current south.

At about the time that this magnetic striping was being researched, geologists began to use the term **plate tectonics** to explain Hess's theory. The cracked pieces of crust were called *plates*, *crustal plates* or *tectonic plates*.

Support for Hess's theory

More research into magnetic striping led geologists to support Hess's theory about seafloor spreading. They concluded that there were great cracks in the crust and that magma rose up and added to each side of a crack to form new crust on the seafloor. New seafloor was being added equally on each side of the ridge.

This is why the pattern of magnetism was symmetrical—because the rocks at equal distances from the ridge on each side were formed at the same time in the past. So the direction of the Earth's magnetic field was the same in these sets of rocks on each side of the ridge. As the Earth's magnetic field changed over many millions of years, so did the magnetic direction preserved in the rocks (see Figure 10.1.6).

1 p322

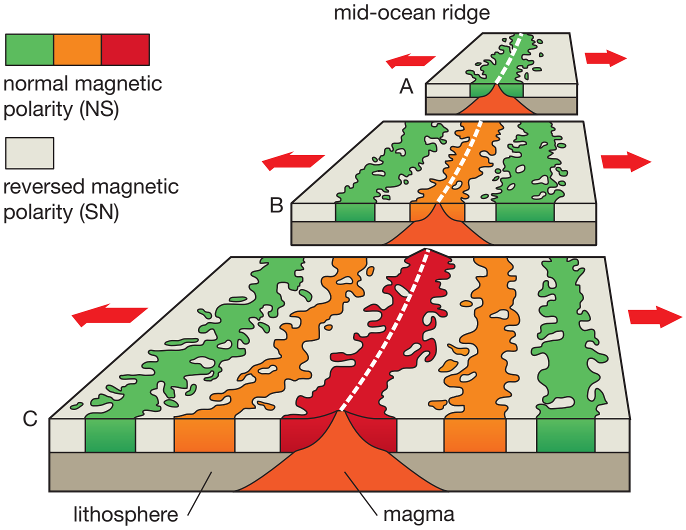


Figure 10.1.6 Magnetic striping is due to new seafloor forming on each side of a crack in the crust. The time sequence here goes from A to C.

Age of the sea floor

More evidence supporting the seafloor spreading hypothesis came from the dating of rocks on the seafloor. The further the rocks of the seafloor were from the ridges, the older they were. This is exactly what you would expect if new rocks form near the ridge and move outwards away from it.

So the seafloor was moving, travelling away from the mid-ocean ridges. The other important fact was that the oldest seafloor rocks found were only about 200 million years old. Some of the rocks in the continents were thousands of millions of years old. So the seafloor was very young compared with the continents.

Sediment thickness

When the sedimentary rock layers on the ocean floor were studied, it was found that the layers became thicker as you move away from the ridges. This was interpreted by geologists as showing that sediments had been falling for a longer time on the seafloor rocks furthest away from the ridges.

SciFile

Glomar challenger

Studying the thickness of sediments on the bottom of the ocean is not easy. The solution was to use a special drilling ship called the *Glomar Challenger*. This used extremely long 'drill strings'. The motor was in the ship and the drill bit cut the rock over 5 km below.

How plates move

The picture that scientists now have of the Earth supports Wegener's original view of continental drift. Scientists have concluded that the Earth consists of several layers with different physical properties. Figure 10.1.7 shows the current view of the structure of the Earth. The upper mantle layer, called the asthenosphere, is the really important layer in plate tectonics.

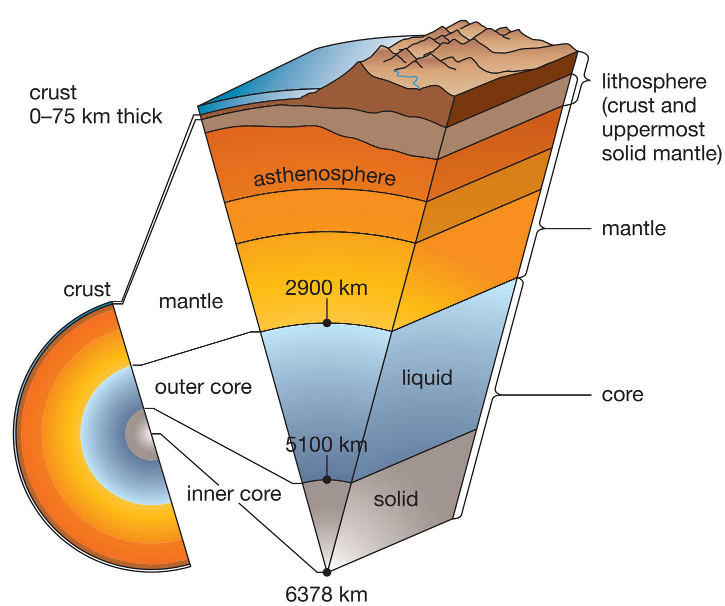


Figure 10.1.7 The Earth consists of layers. The asthenosphere is like a very thick, slow-moving liquid that allows tectonic plates to move on it.

The crust consists of many huge, cracked plates that are larger than continents. These plates 'float' on a layer of 'plastic' semi-solid rock in the upper mantle called the **asthenosphere**. Rock in the asthenosphere can flow very slowly and is very hot.

Exactly how the plates move on the asthenosphere is still being debated. There are two main theories. One is that plates are dragged along as the hot magma in the asthenosphere rises up and then flows horizontally along under the plates, creating convection currents. As the liquid rock flows, the friction between it and the tectonic plates above may be enough to move them. The other theory is that gravity pulls the new crust away from the ridge as it cools and becomes denser. Figure 10.1.8 shows the convection currents.

Then the process of seafloor spreading occurred. As new crust formed at the ridges, the continents moved along with the ocean floor as it spread away from the ridges. This is shown in Figure 10.1.9. One such rift, the Red Sea, is shown in Figure 10.1.10.

2 p323

10.2

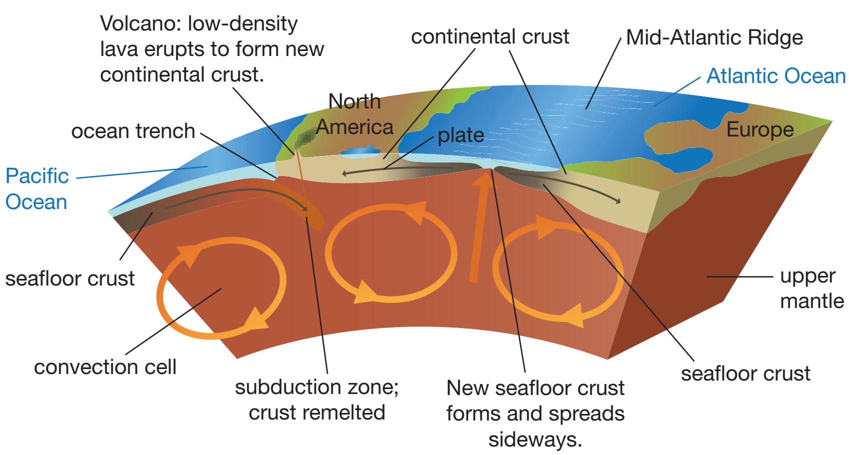


Figure 10.1.8 Convection currents may move plates by friction, but other theories also exist to explain the movement of the plates.

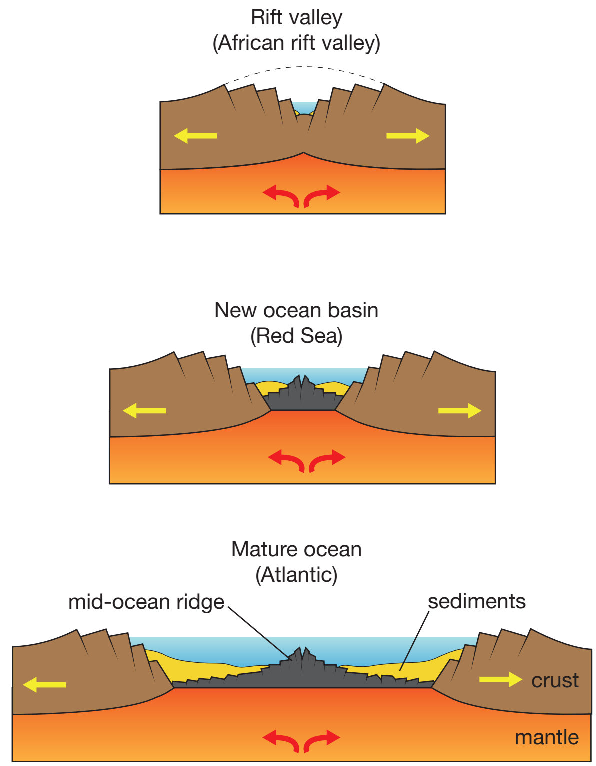


Figure 10.1.9 Continents can split apart by rifting and new ocean basins form. Seafloor spreading provided a mechanism to explain Wegener's ideas of continents that drifted apart.

Rifting and continental drift

Wegener's theory of continental drift had no known mechanism by which the continents could move. Wegener had proposed that gravity and the spinning of the Earth could be involved. He thought the continents just scraped across the ocean floors.

Hess's theory of seafloor spreading offered a much more likely mechanism for movement of the continents. He believed that the continents broke up by a process called **rifting**. The crust cracked and subsided, allowing in the oceans.

Figure 10.1.10 This satellite image shows the Red Sea, a giant water-filled rift valley at the edge of two tectonic plates.

10.1 Unit review

Remembering

1 **Name** the scientist who proposed:
   b continental drift
   a seafloor spreading.

2 **State** the observation that led to the hypothesis of seafloor spreading.

3 **List** the characteristics of the asthenosphere.

Understanding

4 **Define** the following terms.
   a subduction
   b seafloor spreading

5 **Outline** the two main observations that led Wegener to propose the theory of continental drift.

6 **Explain** how Wegener deduced what Pangaea looked like.

7 **Explain** Hess's theory of seafloor spreading.

8 **Describe** three types of evidence that supports the hypothesis of seafloor spreading.

Applying

9 **Use** the theory of plate tectonics to **explain** why Africa and America are older than the seafloor of the Atlantic Ocean.

10 **Use** Figure 10.1.6 on page 319 to **explain** the process of magnetic striping.

11 **Use** Figure 10.1.8 on page 320 to **explain** how heat and convection may be involved in the movement of crustal plates.

Analysing

12 **Compare** the theories of continental drift and plate tectonics.

13 **Distinguish** between magnetic striping and magnetic field reversal.

14 **Compare** Figures 10.1.9 and 10.1.10, and use them to **explain** how the Red Sea formed.

Evaluating

15 The photo at the top of page 316 shows satellite images of the Earth's topography using special sensors that detect various wavelengths of light. Geographic features are colour-coded by their height. You can see the coding in Figure 10.1.11.

Consider the topography image shown on page 316 and Figure 10.1.3 on page 317. Using these two images and Figure 10.1.11, **evaluate** whether there is any relationship between the topography and the position of the rifts.

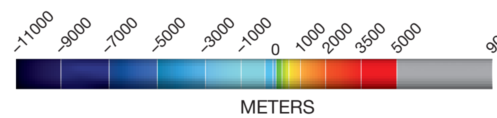


Figure 10.1.11

16 There is an ocean trench separating Indonesia and Australia. There is an ocean ridge halfway between Australia and Antarctica. **Justify** why geologists would believe Australia is moving north.

Creating

17 **Construct** a table that summarises the evidence supporting the theory of plate tectonics. Have three columns in your table, with the following headings: Feature, Description, Sketch. A simple sketch of each feature alongside its description will help you remember it. Remember to include Wegener's observations.

Inquiring

1 Harry Hess was a geology professor before World War II. Research his US Navy career and why he became interested in continental drift.

2 Research the following scientists and their contribution to the plate tectonics theory: Arthur Holmes, Robert Dietz and Frank Taylor.

3 Research Alfred Wegener's theory of continental drift and how his theory compared with Antonio Pellegrini's.

Figure 10.1.12 Alfred Wegener

10.1 Practical activities

1 Magnetic striping

Purpose

To simulate the magnetic striping patterns found in the rocks from seafloor spreading.

Materials

- 2 plain A4 sheets of paper
- compass
- bar magnet
- red and yellow pencils
- 2 clothes pegs
- sticky tape

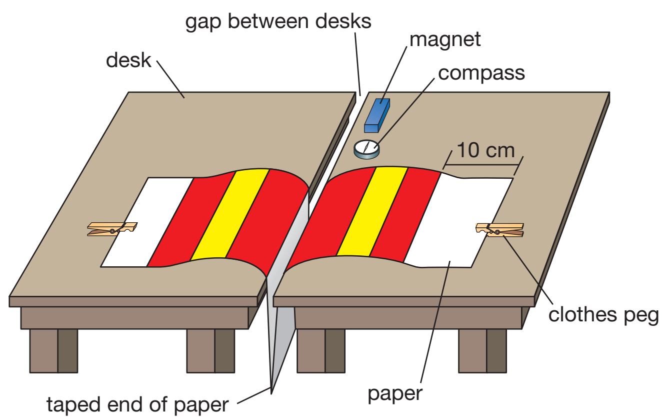


Figure 10.1.13

Procedure

1. Tape the two A4 paper sheets together at one end so you have one long piece of paper. Rule a line across the open end of each sheet 10 cm from the end. Close the paper so the two A4 sheets are face to face with the ruled lines on the inside face of each paper.
2. Push two desks together, leaving a gap of a few millimetres.
3. Push the taped end of the paper down into the gap between the desks until you reach the ruled line. Leave 10 cm of the paper projecting above the desktop.
4. Place a compass on the desktop, next to the top edge of the paper. Place a magnet on the desk about 5 cm away from the compass. Have the north end of the magnet pointing away from the compass.
5. Gently fold the ends of the paper down, one end on each desk, and put a peg on each to weigh each end down (see Figure 10.1.13).
6. You are now ready to start your simulation. Under the desk, gently push up on the taped end of the papers until about 2 cm of paper has come out above the desk. Hold the paper still and use the red pencil to colour the 2 cm strip between the opening in the desk and the line on the paper. You should have a 2 cm red strip on each side of the opening in the desk. Your setup should look like Figure 10.1.13.
7. Spin the magnet around so that the north end is pointing at the compass.
8. Repeat step 6, but use the yellow pencil to colour in the 2 cm strip. You now should have a red strip and a yellow strip on each side of the opening in the desk.
9. Repeat steps 6–8 until you have three red lines and three yellow lines on each side of the opening in the desk. For step 7, spin the compass around so the north pole is to the top of the desk.
10. On each of your sheets, number the layers 1–6 in the order that they formed. Write on the oldest layer of rock the word ‘oldest’, and on the youngest layer, the word ‘youngest’.

Discussion

1. In this simulation, **identify** what the:
   a. gap between the desks represents
   b. two sheets of paper represent
   c. magnet represents
   d. purpose of the compass is
   e. red colour on the paper represents
   f. yellow colour on the paper represents.
2. **State** the number and position of the layer that was the youngest on each sheet, and the layer that was the oldest on each sheet.
3. **Explain** how this simulation is useful in understanding magnetic striping along the ocean ridges.

2 Convection

Purpose

To simulate the convection currents in the asthenosphere.

Materials

- two 250 mL beakers
- potassium permanganate crystals
- tweezers
- hotplate or Bunsen burner, tripod, gauze mat and bench mat
- small coloured ice cube (water with food colouring)

SAFETY

Potassium permanganate stains—only handle it with tweezers.

Wear safety glasses.

Procedure

1. Place 200 mL of water in a 250 mL beaker on the hotplate or gauze mat on the tripod.
2. Using tweezers, gently drop about five potassium permanganate crystals into the centre of the beaker. Do not move the beaker.

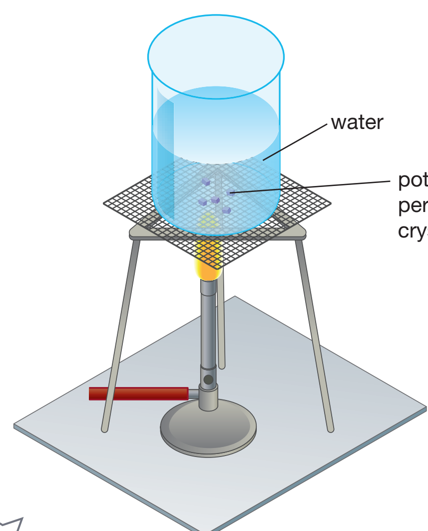


Figure 10.1.14

3. Gently heat the beaker. (If using a Bunsen burner, use with a cool flame directly below the crystals.) Carefully observe what happens to the streams of purple colour that come off the crystals. (It should happen within a minute or two.)
4. Fill the other beaker with 200 mL of tap water.
5. Use tweezers (because food colouring stains) to place a coloured ice cube into the beaker of cool water.

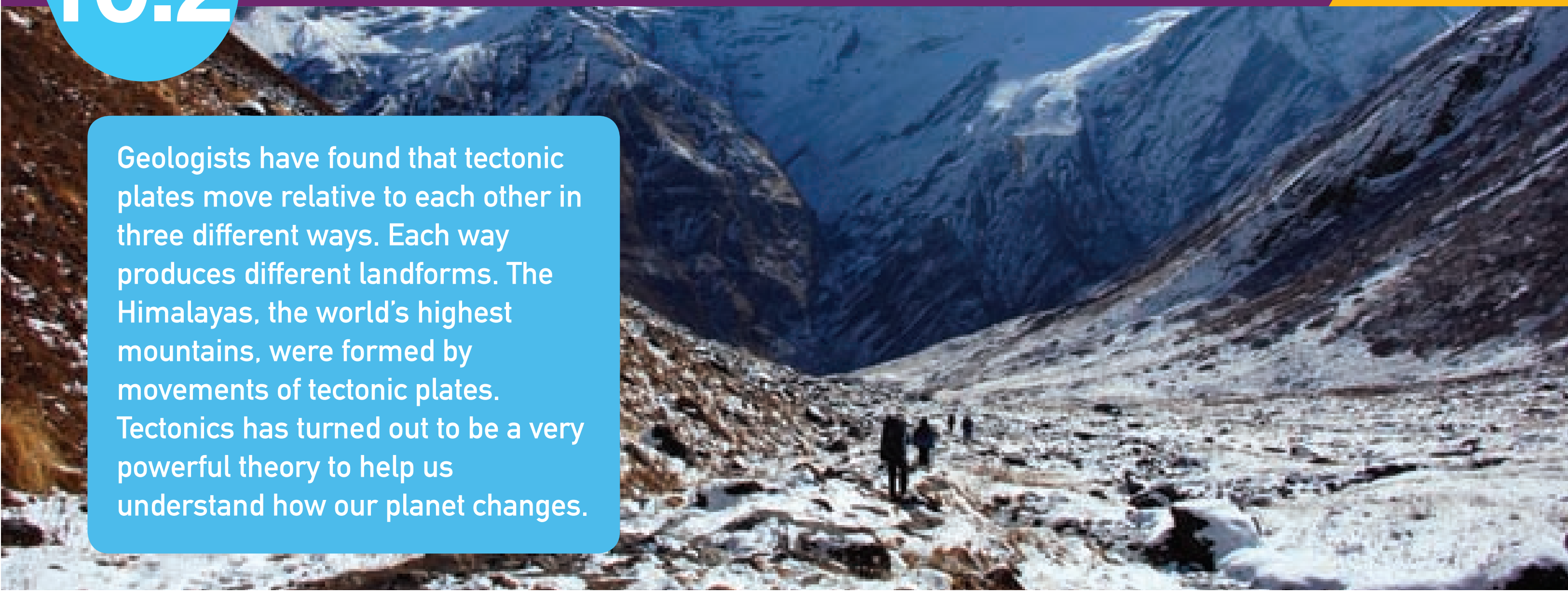
Results

Record your observations for steps 3 and 5 as labelled sketches.

Discussion

1. **Describe** how the stream of purple colour behaved when you heated the water.
2. **Explain** why the coloured ice cube behaved as it did.
3. **Use** the behaviour of the coloured ice cube to **propose** why the purple-coloured water sinks after reaching the surface of the beaker.
4. **Propose** a way of testing your answer to question 3 by using a bag of ice, purple crystals, a beaker and water.
5. **Explain** how this experiment helps understand what happens with magma in the asthenosphere.

10.2 Plate movements



Geologists have found that tectonic plates move relative to each other in three different ways. Each way produces different landforms. The Himalayas, the world's highest mountains, were formed by movements of tectonic plates. Tectonics has turned out to be a very powerful theory to help us understand how our planet changes.

Types of crust

There are two types of crust—continental and oceanic. The **oceanic crust** is found on the ocean floor. The **continental crust** is the crust forming the continents. Oceanic crust is denser than continental crust. This is because oceanic crust has less silicon and more of the heavier elements such as iron and magnesium. Continental crust has a lot of aluminium and silicon. The densities of these types of crust are important when the plates are moving near each other.

The ocean crust is a darker colour than the continental crust and is much thinner. Oceanic crust generally lies below sea level, while the continental crust projects above sea level.

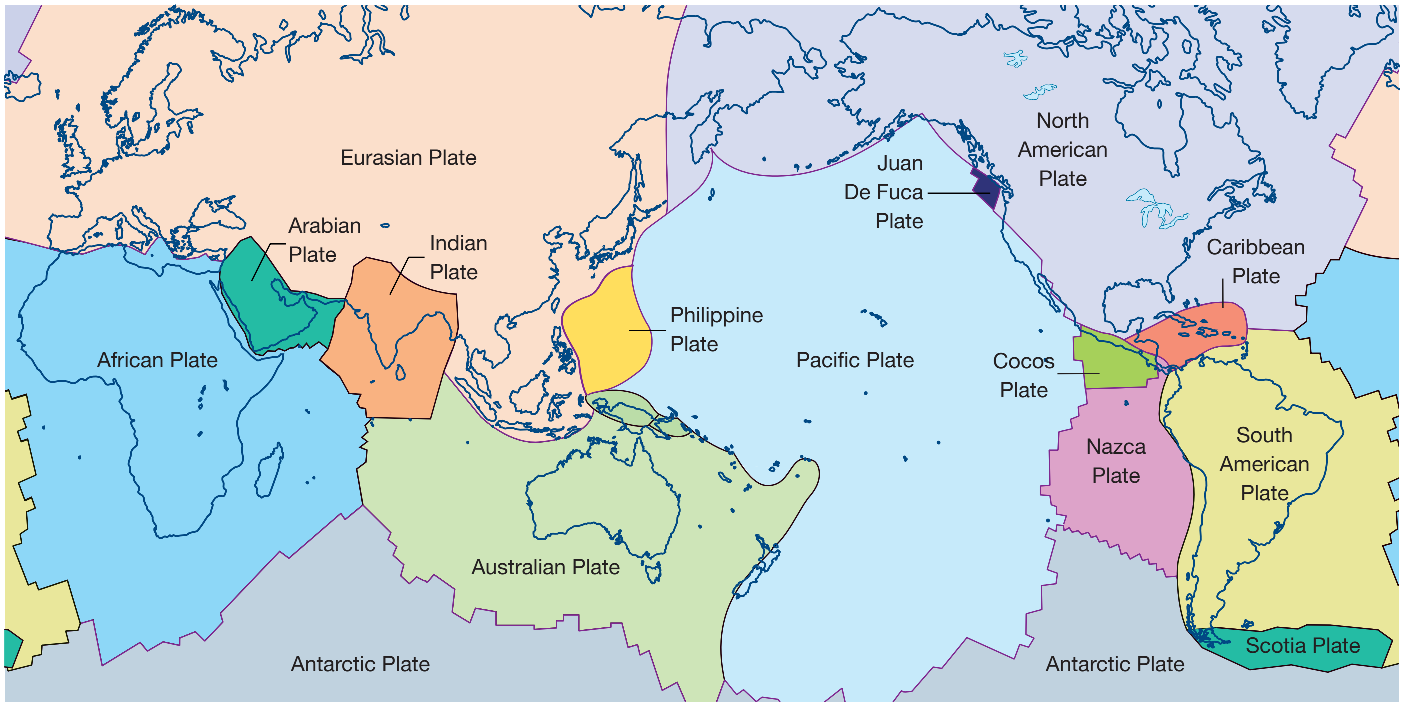


Figure 10.2.1 There are many tectonic plates of differing sizes. This diagram shows where fifteen of the major plates are located, though many of these are split into other smaller plates.

Where are the plates?

There are many tectonic plates of varying sizes. There are seven extremely large ones that are bigger than most continents. There are another ten or so medium-sized ones, and about 60 smaller plates. The larger plates are splitting into smaller ones in many places. The main plates can be seen in Figure 10.2.1.

Types of plate movement

As Figure 10.2.2 shows, the tectonic plates move in three different ways at the boundaries between them.

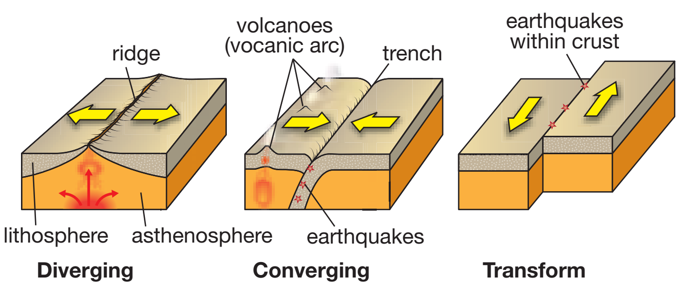


Figure 10.2.2 The three different types of boundaries between plates. Movement is different at each boundary.

These boundaries are:

- diverging boundaries—where the plates are moving apart from each other
- converging boundaries—where the plates are colliding with each other
- transform boundaries—where the plates are sliding past each other.

You can see in Figure 10.2.3 what type of boundaries exist between the major tectonic plates.

Diverging boundaries

Diverging boundaries are where the plates are moving apart from each other in opposite directions. To *diverge* means to separate. The mid-ocean ridges form a diverging boundary.

When the plates separate, there is a rift (deep crack) between them. Magma from the asthenosphere rises up into the rift and solidifies as it cools. This forms new crust, and so diverging boundaries are also known as constructive boundaries. Wherever there is an ocean ridge, there must be plates that are diverging.

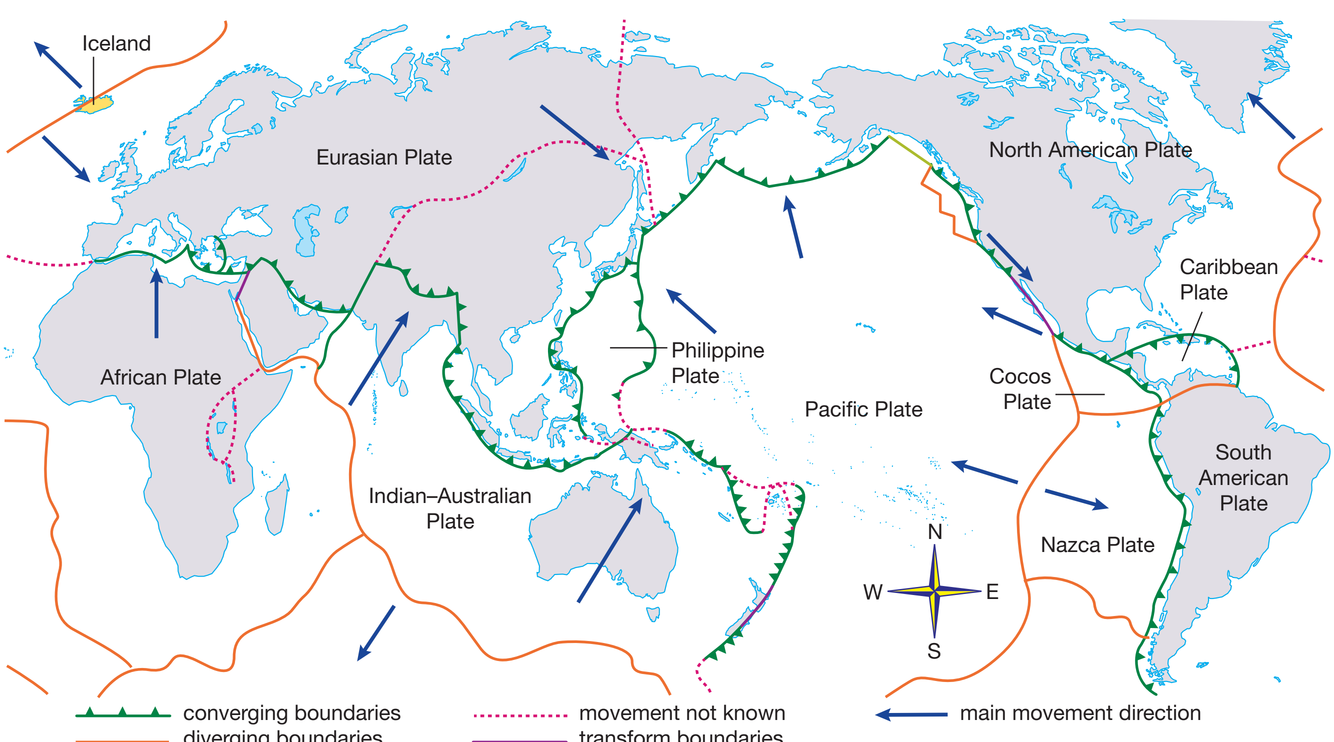


Figure 10.2.3 The sites of the three different types of boundaries between the major plates

Diverging boundaries also occur on land. You can see the unique position of Iceland in Figure 10.2.4. The Mid-Atlantic Ridge runs right through the island of Iceland. Consequently, the island is widening as new crust is formed. Iceland has constant volcanic eruptions as the magma spews up into the rift. Measurements of the rate of widening are about 2–5 cm per year. That may not seem like much, but this spread has formed the Atlantic Ocean.

Figure 10.2.4 Iceland is right on the Mid-Atlantic Ridge and so the island is steadily growing wider.

SKILL BUILDER

Calculating the age of oceans

Geologists can estimate the age of geological features such as the ocean basins, rift valleys or continental islands. To do this, they use the rate of movement of tectonic plates.

For example, they can calculate the age of the Atlantic Ocean. Iceland is widening at about 2–5 cm per year. The Atlantic Ocean is about 4000 km wide between the parts of Africa and South America that appear to have been joined. So how long did it take to form the Atlantic Ocean?

First convert the distance across the ocean into centimetres.

$$4000\text{ km} = 400\,000\,000\text{ cm}$$

Now divide the rate of widening of the plates into this distance.

$$\frac{400\,000\,000}{2} = 200\,000\,000\text{ years} = 200\text{ million years}$$

So if the rate of movement of the plates has been averaging 2 cm per year, the Atlantic Ocean is 200 million years old. However, if the rate of widening is 5 cm per year, then the Atlantic Ocean is about 80 million years old.

WORKED EXAMPLE

Calculating the age of oceans

Problem

Iceland is about 250 km wide. **Calculate** how long the island may have existed.

Solution

$$250\text{ km} = 25\,000\,000\text{ cm}$$

$$\frac{25\,000\,000}{2} = 12.5\text{ million years}$$

Another place where diverging boundaries seem to be forming is in East Africa. A massive rift valley, called the Great Rift Valley, runs along the whole eastern part of the continent, as shown in Figure 10.2.5. At present there is no obvious crack or rift in the crust with magma welling up into it, but the land is subsiding. Geologists have proposed that in the future this could be where the next ocean will form on Earth.

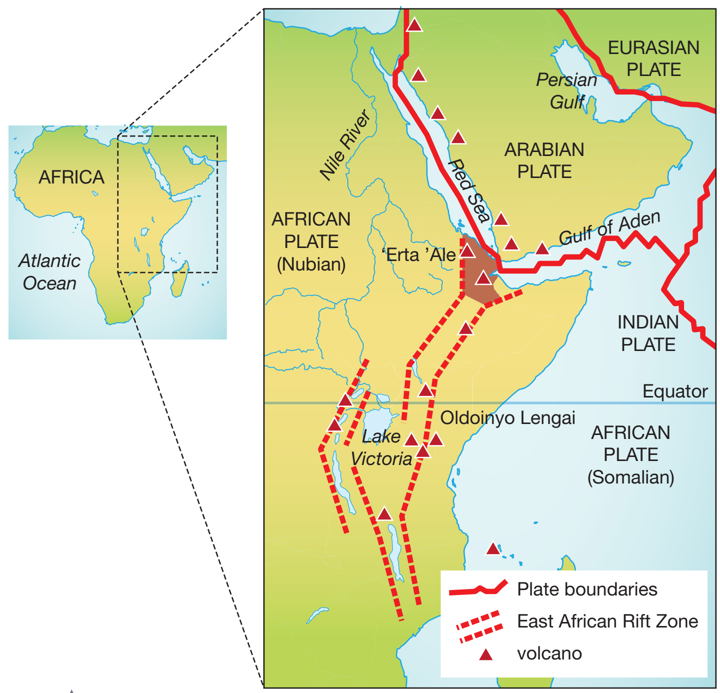


Figure 10.2.5 The Great Rift Valley of Africa could be the site of the next ocean to form on Earth. The dashed lines show where the edges of the rifts (cracks) are. The red triangles show active, dormant and extinct volcanoes.

Converging boundaries

Converging boundaries occur when two plates are colliding into each other. To *converge* means to come together. These collisions form many land features such as mountains. The features that are formed will depend on what types of crust collide. Rock is destroyed at converging boundaries, and so these boundaries are also known as destructive boundaries.

If oceanic crust is colliding with continental crust, then the denser oceanic plate sinks under the lighter continental plate. This is known as **subduction**, and can be seen in Figure 10.2.6. The continental plate becomes distorted, forming fold mountains and also volcanoes. Where the oceanic plate subducts under the continental plate, a deep ocean trench is formed. A good example is where the Nazca Plate collides with South America. The Andes Mountains have been formed along the west coast of South America, and the 8000-metre deep Peru–Chile Trench has formed.

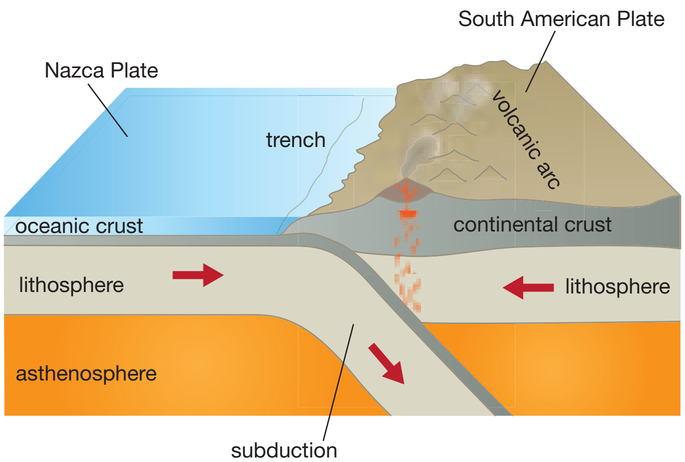


Figure 10.2.6 Subduction of an oceanic plate under a continental plate

The plate that subducts is diving down deep into the mantle, which is extremely hot. The friction of the plates colliding is also generating heat. This heat is enough to melt the crust and form magma. So crust is being destroyed as it subducts.

When two continental plates collide, both are pushed upwards because neither is denser than the other. This forms very high mountain systems. The best-known example of this is where the Indian Plate is colliding with the Eurasian Plate. This has formed the highest mountain range on Earth, the Himalayas (Figure 10.2.7). The highest mountain, Mt Everest at 8848 metres above sea level, was formed by this process.

Into the depths

SciFile

In 1960, the Mariana Trench was investigated by Donald Walsh and August Picard in a submarine called the *Trieste*. The enormous pressure cracked a window at 9000 metres on the descent and the nervous explorers spent only 20 minutes at the bottom. They saw some fish in the depths—the first time scientists knew that vertebrate organisms could live at extreme depths. They noted that the seafloor was covered in fine sediment of dead diatoms.

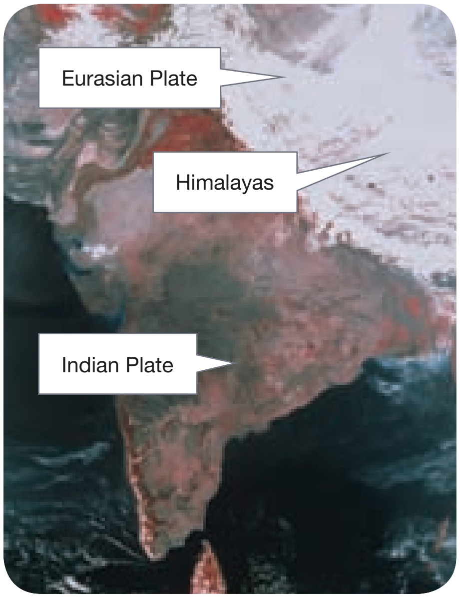


Figure 10.2.7 The Himalayas were formed by the collision of two continental plates: the Indian Plate and the Eurasian Plate.

More evidence for tectonics

When two oceanic plates collide, one always subducts under the other. The faster-moving plate subducts. This forms a deep trench (see Figure 10.2.8). The descending plate melts and is destroyed. A chain of volcanic islands (called an **island arc**) appear as the magma formed by the subducting plate rises up to the surface. This observation of volcanic islands in the ocean was one of the mysteries that had puzzled Harry Hess before he realised that subduction must be occurring where the trenches existed. So the presence of ocean trenches and volcanic islands nearby is more evidence of plate tectonics.

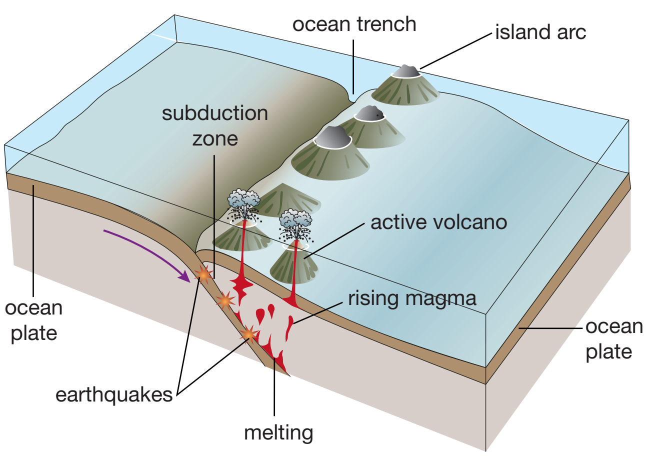


Figure 10.2.8 Oceanic plates colliding forms ocean trenches and volcanic islands. The presence of these trenches and islands supports the theory of plate tectonics.

The Mariana Trench is the deepest ocean trench as yet discovered. It occurs between two oceanic plates that are colliding. This trench occurs where the Pacific Plate meets a small plate called the Mariana Plate (part of the Philippines Plate). The trench is 10 911 metres deep. A string of volcanic islands form an island arc along the boundary.

Transform boundaries

A **transform boundary** is where two plates are sliding parallel to each other but in opposite directions. The plates often move very slowly and then suddenly slip quickly past each other. When this happens, there is an earthquake. On land, a transform boundary usually has fold mountains along its length. There are also many cracks in the rock, called fault lines. Fold mountains and fault lines also occur under the ocean where transform boundaries exist. Fault lines usually do not form one continuous crack in the crust along the plate boundary. Instead there are many cracks parallel to each other.

One transform boundary is the San Andreas Fault in California, United States. This is where the Pacific Plate and the North American Plate move past each other. The cities of Los Angeles and San Francisco are built near the fault line. This fault has moved in the past and has caused massive earthquakes, such as in 1906, in which San Francisco was flattened.

Another transform fault runs right through New Zealand. Meeting at this fault are the Australian Plate, which is moving north-east, and the Pacific Plate, which is moving south-west. Movement of this transform boundary created the magnificent mountains of the South Island of New Zealand. You can see the transform boundary in Figure 10.2.9.

1 p332
2 p332

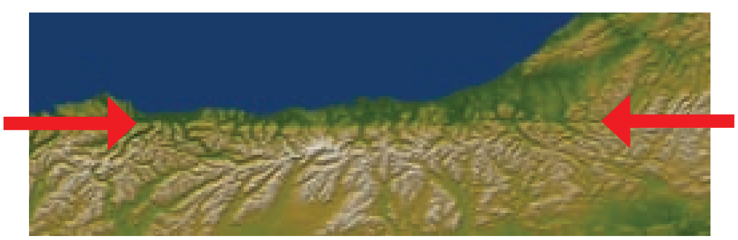


Figure 10.2.9 This aerial view shows that the Alpine Fault of New Zealand is a transform fault. The fault line runs between the red arrows.

Figure 10.2.10 The stunningly beautiful Milford Sound in the South Island of New Zealand sits right next to the transform fault that runs along the west coast.

Pangaea break-up

Pangaea was the original land mass of the Earth. This gradually broke into two major landmasses: Laurasia in the north and Gondwana in the south. Australia was part of Gondwana. In the Cretaceous Period, about 65 million years ago (just as the dinosaurs were becoming extinct), Australia was separating from Gondwana. Reconstructions of how the land masses appeared in the past are shown in Figure 10.2.11.

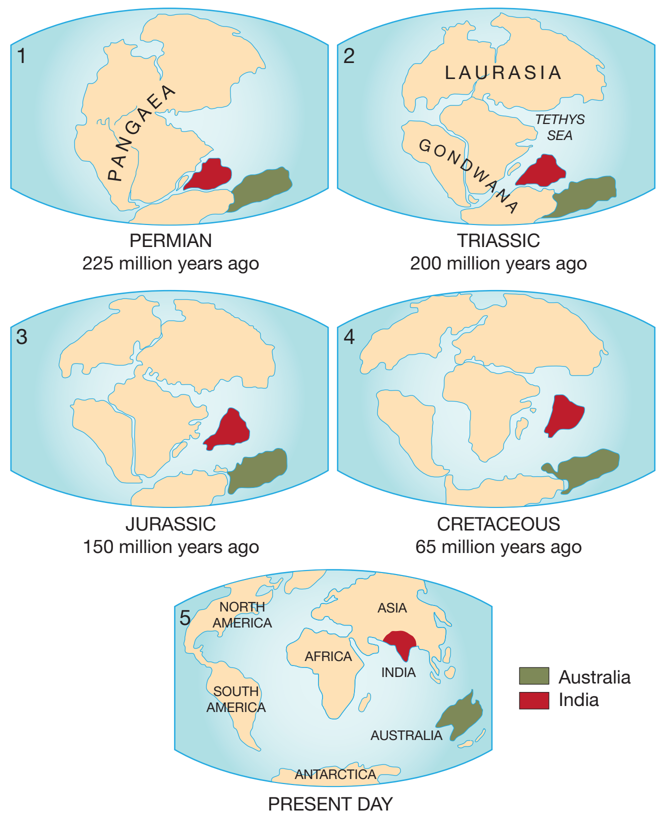


Figure 10.2.11 Reconstruction of the break-up of Pangaea, Laurasia and Gondwana. Note the movements of Australia and India.

Australia breaks from Antarctica

Australia's landforms and climates changed as it moved northwards on the Indian–Australian tectonic plate. About 125 million years ago, Australia was still connected to Antarctica. Almost the whole centre of Australia was covered by a sea that separated the country into four landmasses. The sea level dropped around 85 million years ago, exposing more land.

Australia slowly moved northwards, but still remained connected to Antarctica at the South Tasman Rise, a small area of land near Tasmania. About 40 million years ago, the South Tasman Rise separated, and Australia became an island continent.

INQUIRY science 4 fun

Plates and currents

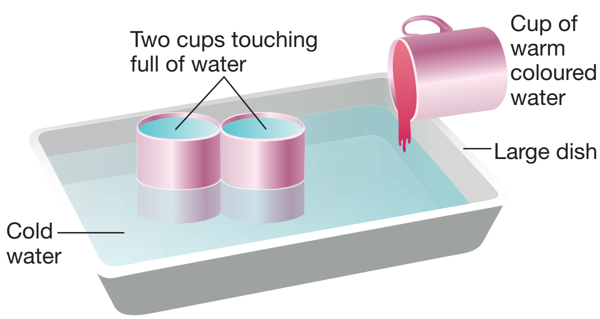
How do tectonic plates affect ocean currents?

Collect this …

- large dish
- three cups
- food colouring

Do this …

1. Set up the equipment as shown in the diagram.
2. Fill the third cup with warm tap water and add three or four drops of food colouring.
3. Very slowly (over about 30 seconds) pour the warm coloured water into one end of the large dish and watch where the colour goes.
4. Replace the water in the dish and separate the two cups in the dish so there is a gap between them about as wide as a cup.
5. Repeat step 3 and observe any difference.



Record this …

Describe what happened.

Explain how this is relevant to plate tectonics.

Currents and tectonic plates

Ocean currents are affected by the movement of tectonic plates. When Australia separated from Antarctica, this allowed a new current (called the Antarctic Circumpolar Current) to form. This current was a very cold ocean current that changed the climate of southern Australia and had global influences. Antarctica steadily became colder, and southern Australia became drier as water became locked up in Antarctic ice sheets.

The warm current that flowed southwards down Australia's eastern coast was blocked by the Circumpolar Current, and southern Australia became colder and drier. However, the northern parts of Australia were becoming warmer as Australia moved into the tropics.

Flora and fauna

Australia was isolated from all other land masses from 40 million years ago. This isolation led to the evolution of unique species of plants and animals in Australia.

Marsupials dominate Australia, with nearly 200 species. Only about 70 species of marsupial are found in the rest of the world, mostly in South America. The monotremes—the echidna and platypus—are unique to Australia.

As Australia drifted north, much of the climate gradually became drier. A large dry plain (the Nullarbor Plain) was formed. This continued the isolation of Western Australia and led to the evolution of a very high proportion of unique native plants in that state, like the ones shown in Figure 10.2.12. About 80% of its flora (plant life) is found nowhere else.

10.3

Figure 10.2.12 The flora of Western Australia is one of the most diverse in the world, a result of its isolation due to plate tectonics and climate change.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Measuring the speed of tectonic plates

Figure 10.2.13 A GPS receiver, solar cells and a satellite link

Scientists now have excellent technology to directly measure how fast tectonic plates are moving. The modern geologist has several different techniques.

The most widely used technique involves satellites and the global positioning system (GPS). A **GPS ground station** is a receiver and computer that is placed on top of a stand (like the one shown in Figure 10.2.13). The legs of the stand are fixed into the rock.

There are many GPS ground stations located on tectonic plates around the Earth. A group of 24 satellites circling the Earth sends radio signals to the GPS ground stations. If a ground station detects at least three satellites, it can work out its position on the ground. The ground station computer works out where it is. By comparing all the data from different ground stations, scientists can see how much the ground stations have moved compared with the others. The computer can determine movement sideways and also up and down (if four satellites can be detected).

The best GPS stations are accurate to a few millimetres. Measurements from these stations show that rates of plate movement vary greatly between the different plates and even between parts of the same plate. The fastest-moving plate is near Easter Island in the Pacific Ocean. This part of the Pacific Plate is moving at about 15 centimetres per year. The slowest-moving plate is the Antarctic Ridge, which is moving at only 2.5 centimetres per year.

Another instrument that helps measure the speed of tectonic plates along particular faults is a strainmeter. This is a series of markers buried into the ground in a straight line across a fault (as shown in Figure 10.2.14). If any of the markers move out of line, the distance can be measured. This results from this type of instrument show that GPS measurements are very accurate.

Figure 10.2.14 A strainmeter, looking through the viewing window along the line of markers (the light grey coloured 'T' shapes) that runs across a fault line.

10.4

10.2 Unit review

Remembering

1 **Name** the three types of plate boundary.

2 **Name** the two types of crust that form the tectonic plates.

3 **Name** one place where the following type of plate boundary occurs.
   a diverging boundary
   b converging boundary
   c transform boundary

4 **Recall** the direction in which the plates move at the:
   a diverging boundary
   b converging boundary
   c transform boundary

Understanding

5 **Describe** the process of subduction.

6 **Describe** plate boundaries where the following may occur.
   a subduction
   b ocean trenches
   c fold mountains
   d rifting under the sea
   e island chains
   f an ocean trench next to a continental mountain range

7 **Explain** how the evolution of unique Australian flora and fauna can be explained by changed environmental conditions following the break-up of Gondwana.

Applying

8 The Australian Plate forms a converging boundary with the Indonesian island of Java at the Java Trench. The distance between the Australian land mass and Java is about 500 km. The Australian Plate is moving at about 7 cm per year. **Calculate** how long it could be before Australia crashes into Indonesia.

Analysing

9 **Compare** the types of movement of the tectonic plates.

10 **Compare** subduction when two ocean plates converge with subduction when an oceanic and continental plate converge.

11 **Analyse** Figure 10.2.11 on page 328 and **explain** the origin of the Himalayas.

Evaluating

12 **Propose** what evidence could help you decide whether two plates had converged in the past to form a continent.

13 At diverging boundaries, seafloor spreading is occurring as new crust is continually created. **Propose** why the Earth's crust is not getting any bigger.

14 **Propose** why fossils of sea creatures have been found near the top of Mt Everest (8848 m above sea level).

15 The oldest known fossils in the ocean floor are about 180 million years old, yet fossils from continents have been found that are 3400 million years old. **Propose** reasons why.

16 **Propose** why Australia became drier as it moved north on the Indian–Australian tectonic plate.

Creating

17 In the table you constructed for Question 17 in Unit 10.1, add some more evidence from Unit 10.2 that supports the theory of plate tectonics.

Inquiring

1 Research the following physical features to identify the plates that are moving in each case, and explain how each landform was created.
   a Andes
   b Dead Sea
   c Kermadec Islands
   d Japan Trench

2 Research the Great Rift Valley of Africa and explain why geologists predict that it could be the next major ocean on Earth.

3 Research the possible impact of moving continents on ocean currents and the global climate through geological time.

4 Research the history of plate tectonic movements of Australia and explain why Australia is a particularly stable and very old continent.

5 Research the evolution of Australia's unique flora and fauna. Using examples, explain how this is due to changed environmental conditions following the break-up of Gondwana.

10.2 Practical activities

1 Paper plate tectonics

Purpose

To build and use paper models of plate tectonics.

Materials

- paper template. To obtain this, type into a web browser: 'Sea-floor spreading and subduction model by John C Lahr'
- cardboard
- sticky tape
- scissors
- coloured pencils

Procedure

1. Colour in the paper templates provided.
2. Construct the model using the instructions provided. Note: You don't need a shoebox as it says in the instructions. It can be made from flat sheets of cardboard and stuck together afterwards. The measurements are in inches. 1 inch = 2.54 cm.
3. With a partner, operate the model. This represents seafloor spreading where there are also fault lines perpendicular to the rift. The seafloor is separating away from the central rift, but it is doing it in three separate strips. Your partner must gently keep holding the three paper strips below the top. You hold the two side pieces and slowly pull them apart, watching the magnetic strips as they appear.
4. Imagine what would be happening in real strips of ocean crust as their inside edges slide past each other like the paper strips.

Discussion

1. **Describe** what the model shows about seafloor spreading.
2. **Describe** where the three transform faults are on the seafloor spreading and subduction model.
3. a. **Identify** the following features of the seafloor spreading and subduction model.
      i. subduction
      ii. convection currents
      iii. volcanic islands
      iv. sea floor spreading
      v. magnetic striping

   b. **Explain** your answer in each case.

2 Types of crust

Purpose

To measure the density of granite and basalt, and relate this to the behaviour of oceanic and continental tectonic plates at converging boundaries.

Materials

- displacement can
- granite and basalt (to fit in the displacement can)
- scales or triple beam balance
- 100 mL measuring cylinder
- beaker
- cotton

Procedure

1. Measure the mass of the basalt and the granite. Record them in a table.
2. Place the granite in a displacement can and measure the volume of water displaced.
3. Place the basalt in a displacement can and measure the volume of water displaced.

Results

Calculate the density of the basalt and the granite using:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Remember: 1 cm^3 = 1 mL water (at about 20°C)

Discussion

1. **Compare** the density of basalt and granite.
2. If the oceanic crust is high in basalt and the continental crust is high in rocks like granite, **explain** why oceanic crust subducts under continental crust at a collision boundary between these two types of plate.

10.3 Volcanoes and earthquakes

Volcanoes are among the most awesome sights on the planet. The largest explosion in history was from a volcano. Earthquakes can also be deadly. Earthquakes and volcanoes provide evidence of the interior processes of the Earth. They provide information that supports the theory of plate tectonics.

Volcanic eruptions

A **volcano** is a place where extremely hot material from inside the Earth erupts at the Earth's surface. This material includes:

- gas such as steam and hydrogen sulfide
- ash (fine particles of rock)
- **lava** (molten rock)
- lumps of solid volcanic rock like scoria.

Volcanoes form where there are weak spots in the Earth's crust and where extremely hot molten rock called **magma** has accumulated below the weak spots. This magma is occasionally pushed upwards under great pressure into the volcano. The effects of a volcanic eruption can be seen in Figure 10.3.1.

The magma reaches the surface, and is now known as lava. It erupts white hot at a temperature of over 1200°C. The lava changes colour as it cools, from white through yellow, orange and red, until it finally becomes a black colour as it hardens and solidifies into rock.

The type of magma that is formed will affect what the volcanic eruption is like. The eruption can be explosive when the magma:

- is viscous (flowing very slowly)
- contains a lot of water and gas.

Figure 10.3.1 Casts made of dead bodies found after an eruption near Pompeii, Italy, in 79 CE. The bodies were covered in ash that became rock. When the bodies decayed, they left a cavity in the rock. Plaster was poured in to make the cast.

This forms an explosive mix because the gas and steam bubbles grow larger as the magma rises to the surface. The bubbles grow larger because the pressure around them is dropping. This is similar to the way bubbles expand as they rise in a bottle of fizzy drink. In the magma, the expanding gas bubbles put pressure on the liquid around them. If the magma is starting to thicken and turn solid as the bubbles expand, then it can suddenly break apart explosively.

The explosions can throw out 'volcanic bombs' of rock called scoria. Scoria typically has many spaces in it where the gas bubbles have accumulated. The explosions also create a massive ash cloud. The ash cloud of a volcano (like the one in Figure 10.3.2) can rapidly rise upwards at over 200 km/h and can reach heights of 50–80 km.This is high enough to be dangerous to aircraft.

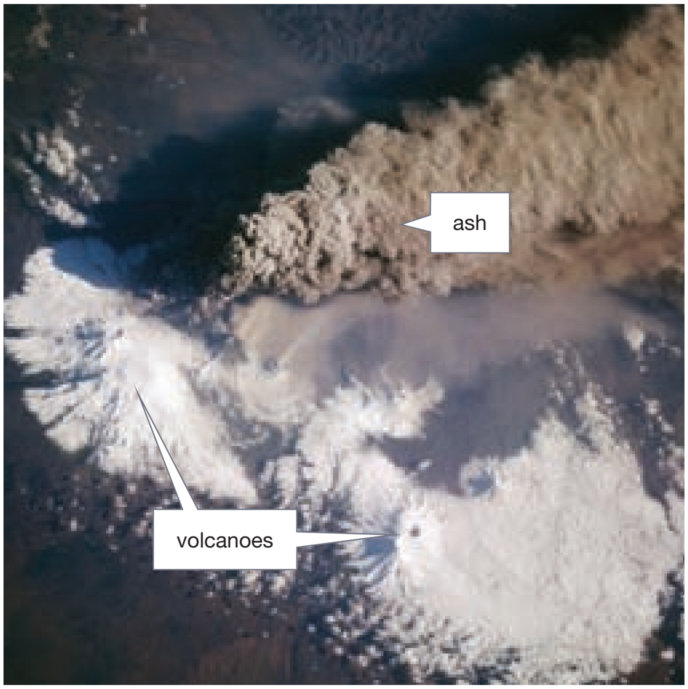


Figure 10.3.2 A volcanic ash cloud can reach up to 80 km in half an hour. The ash cloud of this volcano on the Kamchatka Peninsula, Russia, is spreading high into the atmosphere. This photo was taken from space.

Occasionally there can be a **pyroclastic flow**, where a cloud of ash, rock and gas at about 500°C rushes down the volcano like an avalanche at over 100 km/h. This will kill every living thing in its path.

SciFile

Big volcano

Mauna Loa on the island of Hawaii is the largest volcano on Earth. It is 4000 metres (4 kilometres) above sea level. But the sea floor is 5000 metres deep around the island. So the volcano is really over 9000 metres high, higher than Mt Everest.

Where do volcanoes form?

Volcanoes at the edges

As Figure 10.3.3 shows, most volcanoes form near the edges of tectonic plates. This is because the movement of the plates creates weaknesses in the crust and also generates a lot of heat, which can melt rock.

Diverging plate boundaries create weaknesses in the crust because the separating plates thin the crust. This lowers the pressure on the underlying hot rocks of the asthenosphere and they melt. The magma created then finds its way up through the weaknesses in the crust.

Figure 10.3.3 Most volcanoes form near the edges of the tectonic plates. This observation provides further support for the theory of plate tectonics.

Converging plates, especially where subduction occurs, create weaknesses in the crust and generate a lot of heat. If the colliding boundaries occur under the ocean, chains of volcanic islands (island arcs) can be formed at the edges of the tectonic plates (Figure 10.3.4). An example is the Lesser Sunda Islands, Indonesia (Figure 10.3.5).

1 p341

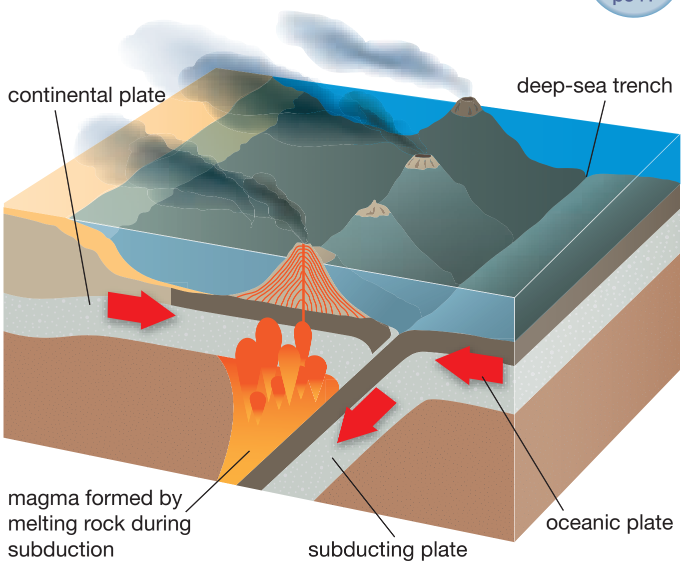


Figure 10.3.4 Subduction results in weakness in the crust and generates of a lot of heat. A string of volcanic islands (an island arc) is evidence for colliding tectonic plates.

Figure 10.3.5 Satellite image of the Lesser Sunda Islands, Indonesia, a chain of volcanic islands.

SciFile

Krakatoa

Krakatoa (also called Krakatau) was a volcanic island in Indonesia. In 1883, it exploded, blowing two-thirds of the island to pieces. It is the largest explosion ever witnessed by humans. A total of 21 km^3 of land was blown into the air. Try to imagine that! The sound was clearly heard over 5000 km away and over 36 000 people died. The photo shows the remains of Krakatoa. The bottom island and the middle island were originally joined.

Explosive eruptions

Subduction generates heat, melting rock and forming magma. The magma rises up in huge packets through lines of weakness in the crust. It accumulates in spaces called magma chambers and is occasionally released to the surface as the pressure builds up.

There can be explosive eruptions where oceanic plates subduct under continental plates. Continental plates tend to have more silica in them than oceanic plates, and this often makes the magma formed from them quite sticky and viscous (thick). Rocks with a lot of water in them also create a lot of steam when they are heated during subduction.

Hot spot volcanoes

While most volcanoes form near plate boundaries, some form well away from the edges of the plates. These volcanoes sit over 'hot spots' in the Earth's crust. **Hot spots** are isolated places where a lot of hot magma is being created. They can occur under oceanic or continental plates. Geologists are not sure why these hot spots exist.

In the ocean these volcanoes occur in chains of islands. In each chain there is always one island with an active volcano, while all the other islands have dormant (inactive) volcanoes. Geologists realised that the formation of these volcanoes could be explained by the theory of plate tectonics. Each island forms as it sits over the hot spot. As the plate moves, the island goes with it and so it no longer sits over the hot spot. A new part of the plate is now above the hot spot and this gradually forms a new volcano. The Hawaiian islands (shown in Figure 10.3.6 on page 336) are a good example of an island chain over a hot spot.

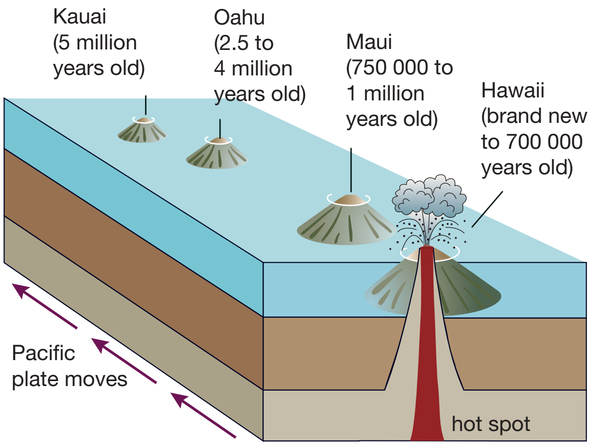


Figure 10.3.6 The Hawaiian islands have been formed by movement of the Pacific Plate over a single hot spot in the Earth's mantle.

What causes an earthquake?

An **earthquake** is the rapid movement of the ground, usually back and forth and up and down in a wave motion. It is caused by the rapid release of energy as the tectonic plates move. Friction between the plates must be overcome before they can move. When the force is great enough, the plates suddenly move as friction can no longer hold them. This sudden movement sends out waves of energy through the rock and the water. The ground and water then shake as the waves of energy pass through them.

Detecting earthquakes

Earthquakes are measured using an instrument called a **seismometer**. Old-style seismometers consisted of a pen on a moving drum. They used the principle of inertia. The heavy mass attached to the pen has a lot of inertia, meaning it tends to stay still. The rest of the seismometer moves with the vibrations of the Earth.

There are many designs for seismometers, and modern ones are electronic. You can see two designs in Figures 10.3.7 and 10.3.8. The trace of a seismometer is called a seismograph.

SciFile

Big quakes

The largest earthquake ever recorded was one of magnitude 9.5 in Chile in 1960.

The world's deadliest recorded earthquake occurred in 1556 in central China. It killed an estimated 830 000 people. In 1976, another deadly earthquake struck in Tangshan, China, where more than 250 000 people were killed.

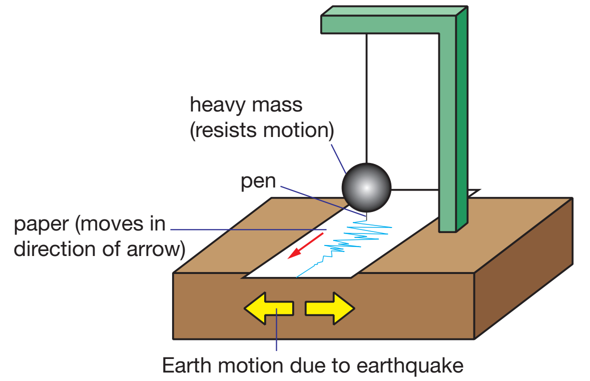


Figure 10.3.7 This design of a seismometer uses a swinging pendulum. The pen does not move much. The supporting arm and the recording paper vibrate back and forth with the ground.

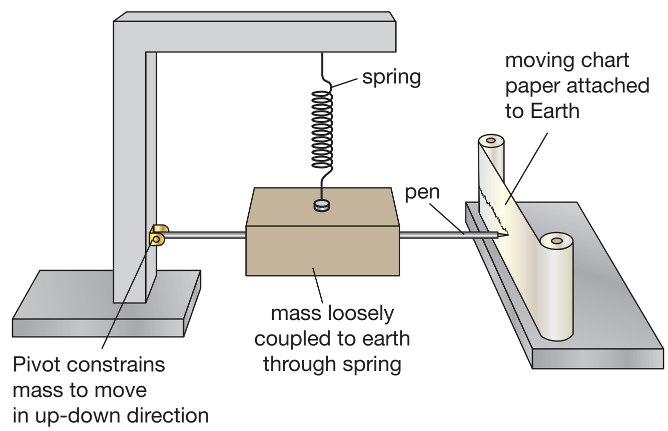


Figure 10.3.8 A vertical-mounted seismometer. The pen stays fairly still, while the recording paper and the support move up and down with the Earth.

Seismic waves

The movement of the ground in an earthquake occurs in a shaking back-and-forth motion called a wave. These waves in the Earth caused by earthquakes are called **seismic waves**. Three main types of seismic waves can be detected (Figure 10.3.9).

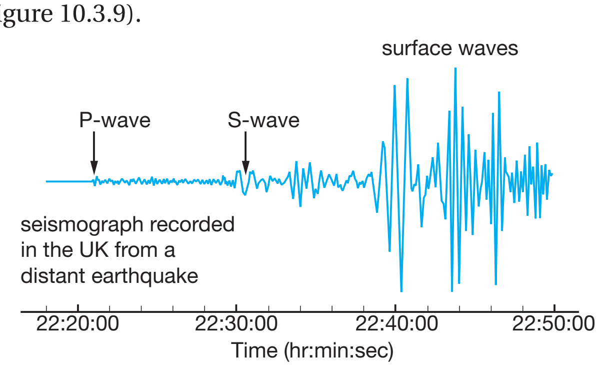


Figure 10.3.9 This seismograph shows the pen trace when S-waves, P-waves and surface waves reach the seismometer.

- **Primary waves (P-waves)** are longitudinal waves that travel fast through the Earth.
- **Secondary waves (S-waves)** are transverse waves that travel slightly slower than P-waves through the Earth.
- **Surface waves** are the slowest waves and cause the most destruction.

S-waves and P-waves travel deep under the ground and then bend upwards to reach the surface of the crust. P-waves shake the ground up and down. S-waves shake the ground sideways, back and forth.

Surface waves travel along the crust near the surface. They travel more slowly than P-waves and S-waves, but they can be much larger. They are particularly destructive if the earthquake is near the Earth's surface.

2 p341

Where earthquakes occur

Nearly all earthquakes start at the edges of the tectonic plates. This is very obvious when you look at Figure 10.3.10. It shows that the locations of earthquakes align with the boundaries of the tectonic plates.

The strongest earthquakes occur near collision (converging) boundaries. This distribution of earthquakes provides further evidence for the theory of plate tectonics.

Epicentres and foci

Earthquakes happen at particular places under the ground where the Earth slips, usually along a fault. The place where the quake starts is called the **focus**. This may be many hundreds of kilometres deep in the Earth. The point on the Earth's surface directly above the focus is called the **epicentre**. Buildings near the epicentre are usually the most heavily damaged.

The severity of an earthquake is calculated in several different ways. One early method, still used in some cases today, is measured on the Richter scale. This scale goes between 1 and 9. Each successive number is ten times greater than the previous number. So an earthquake measuring 5.0 is ten times more destructive than one measuring 4.0. There are two other scales commonly used as well.

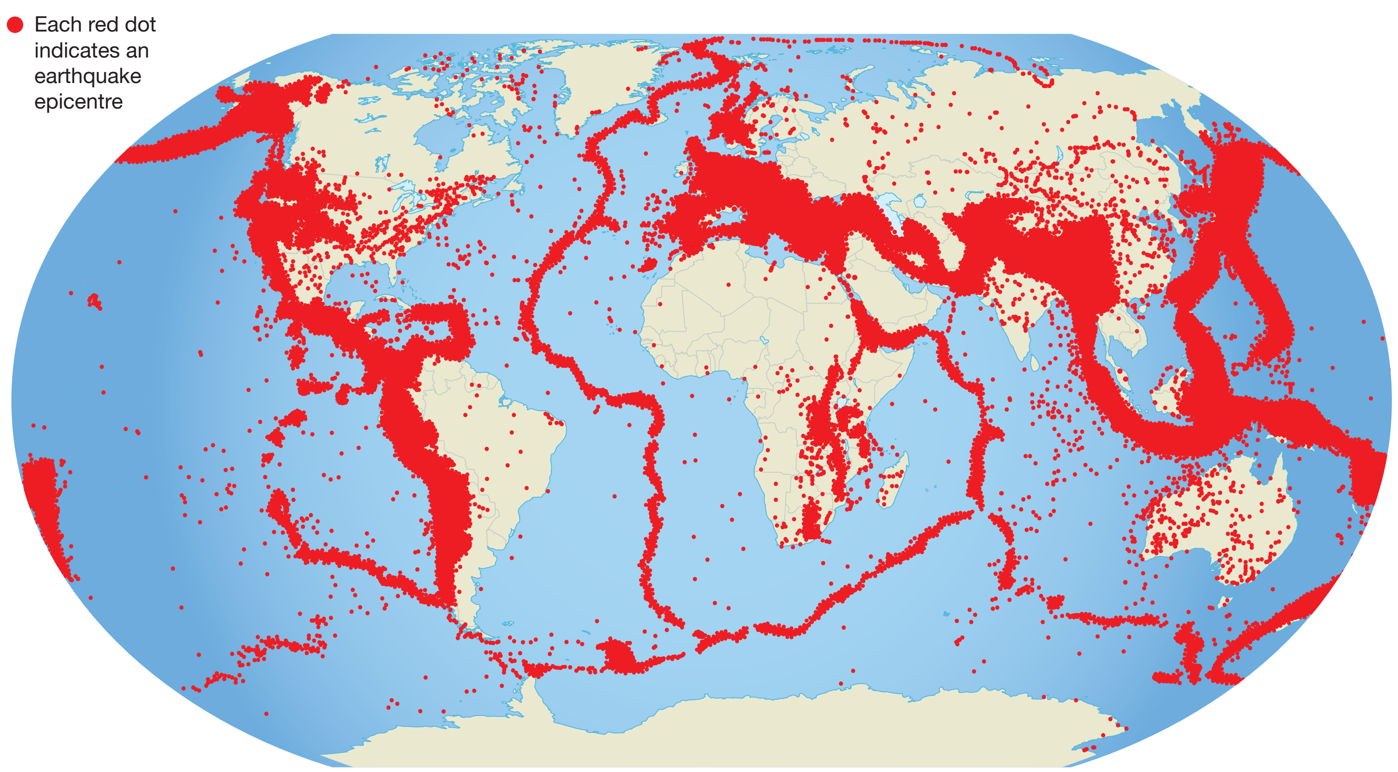


Figure 10.3.10 Earthquakes nearly all occur near the boundaries of the tectonic plates. However, some types of boundaries have more earthquakes.

Effects of earthquakes

Earthquakes cause damage to buildings on land, and can cause landslides. However, they also cause destruction in the ocean. An earthquake under the ocean can cause a huge wave called a **tsunami**. These waves can be 100 metres high and cause massive destruction if they collide with the land near where people are living (Figures 10.3.11 and 10.3.12).

10.5

Figure 10.3.11 A tsunami hit the north-east coast of Japan on 11 March 2011, after a massive magnitude 9.0 earthquake occurred 129 km east of the town of Sendai.

Figure 10.3.12 A tsunami is a massive wave caused by an undersea earthquake. It can be devastating when it reaches land.

Building design

It is important to design buildings to withstand earthquakes in places where earthquakes are common, such as Los Angeles (United States), Tokyo (Japan) and Christchurch (New Zealand). Engineers have found that the most effective solution is vibration control. This employs:

- dampers—structures that move in opposition to the waves and oppose their effect (Figure 10.3.13)
- base isolation—pads, springs and bearings that allow the building to suppress the waves by moving rather than vibrating with the Earth (Figure 10.3.14).

3 p342

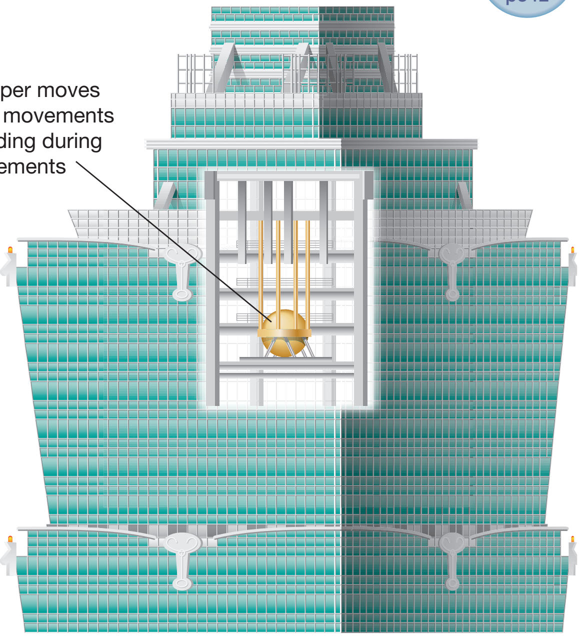


Figure 10.3.13 A damper is a structure in a building that moves and opposes the wave motion pushing on the building.

Figure 10.3.14 Base isolation involves placing structures such as these rubber bearings under a building.

Figure 10.3.15 Earthquakes cause much destruction but they also tell scientists about the structure of the Earth.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Structure of the Earth

Scientists cannot look directly inside the Earth. To understand its structure, they have to rely on indirect observation and data, then construct theories and models based on these. These theories and models are constantly changing as new evidence emerges.

Seismic waves

Seismologists use seismometers to study the Earth, and have learnt about the Earth's structure by studying earthquakes. In particular, studying how the S-waves and P-waves behave has enabled seismologists to construct the layered model of the Earth shown in Figure 10.1.7 on page 319.

Following the study of many earthquakes, seismologists used the arrival times of seismic waves at different points on the Earth's surface to draw images of the interior of the Earth. Figure 10.3.16 shows the model they constructed using this information.

Seismologists had observed that there was a 'shadow zone' where no S-waves were recorded at the surface after an earthquake. Seismologists knew from experiments that S-waves would not travel through liquids, but would travel through solids. So they proposed that there is a liquid layer around the core of the Earth. This would stop the S-waves passing through.

Seismologists also tried to explain why there was an area where few P-waves are detected. After much research studying many earthquakes, they proposed that this was due to the P-waves bending (refracting) as they passed through the liquid outer core. The waves bent down into the liquid core and this directed them away from the weak P-wave area at the surface. Further discussion and debate among seismologists led to the proposal that some P-waves bent because they had reflected off a solid inner core.

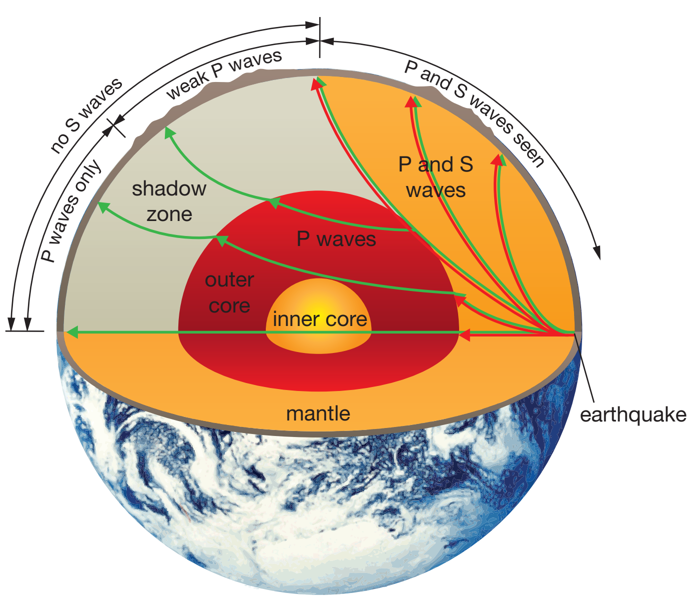


Figure 10.3.16 The behaviour of S-waves and P-waves during earthquake activity helped scientists create the layered model of the Earth's structure.

10.3 Unit review

Remembering

1 **List** the colour changes in magma as it cools.

2 **List** the materials found in volcanic eruptions.

3 **Name** a tectonic process that generates heat at the boundaries of the plates.

4 **Name** the instrument used to measure earthquakes.

5 **Recall** an outcome of an earthquake under the ocean.

Understanding

6 **Explain** why erupting magma can become explosive.

7 a **Describe** a pyroclastic flow.
  b **Explain** why it is so dangerous.

8 **Explain** how volcanoes can be dangerous to aircraft.

9 **Explain** why volcanoes are often found near the edges of converging tectonic plates.

10 **Explain** how island chains form from hot spots below the ocean crust.

11 **Define** the following terms.
  a earthquake
  b seismic wave

12 **Explain** the cause of earthquakes.

Applying

13 The Australian Plate forms a converging boundary with the Indonesian island of Java at the Sunda Trench (also called the Java Trench). Java is one of the most volcanically active places on Earth. **Use** your knowledge of plate tectonics to **explain** the presence of these volcanoes.

14 **Use** the theory of plate tectonics to **explain** why earthquakes and volcanoes are mainly found near plate boundaries.

15 **Identify** two features of building design that prevent damage by earthquakes.

16 The distance from the Hawaiian island Kauai to the active volcano Mauna Loa is about 450 km. **Use** Figure 10.3.6 on page 336 to estimate how fast the Pacific Plate is moving (in cm/year).

Analysing

17 **Compare** the formation of an island arc with the formation of an island chain from a hot spot.

18 **Compare** the magma produced by an oceanic plate subducting under a continental plate with that produced by an oceanic plate subducting under another oceanic plate.

19 **Compare** S-waves and P-waves.

20 **Distinguish** between the focus and the epicentre of an earthquake.

Evaluating

21 **Propose** what evidence could help you decide whether a chain of islands was formed by a hot spot.

22 **Propose** why Japan has many active volcanoes.

23 **Use** Figure 10.3.10 on page 337 to **justify** the statement that Australia is a very geologically stable country.

Creating

24 In the table you constructed for Question 17 in Unit 10.1, add some more evidence from Unit 10.3 that supports the theory of plate tectonics.

Inquiring

1 Research the Reunion Hotspot and explain its possible link to the extinction of the dinosaurs.

2 Research and describe the past and possible future effects of explosive volcanoes on local and global climates.

3 Research evidence that Australia has had volcanoes in the past. List at least three different sites where there must have been volcanoes, and explain how these features were formed.

4 Research five earthquakes that have happened in the past few weeks. State where they occurred, their magnitude, any damage that occurred and some reasons why you think the earthquake happened where it did. You could start with an internet search of the US Geological Survey (USGS).

5 Research how buildings are designed to withstand earthquakes, showing examples of the use of dampers and base isolation.

10.3 Practical activities

1 Model volcanoes

Purpose

To build a model volcano and observe its eruptions.

Materials

- cardboard
- aluminium foil
- newspaper
- plastic tape (e.g. duct tape)
- white laboratory tray or old newspapers
- baking soda
- vinegar
- glass stirring rod
- scissors
- 100 mL beaker
- food dye
- cornflour
- Alka-Seltzer® tablets
- reaction vessel (e.g. small jar)

Procedure

1 Fold the cardboard into a cone shape with a base diameter of about 30 cm, but leave a hole at the top large enough to hold the reaction vessel. Tape the cardboard to form the cone shape.

2 Insert the reaction vessel and tape it in securely. Seal around the edges of the cardboard with plastic tape or aluminium foil.

3 Cover the cardboard with aluminium foil to waterproof it. Tape the foil to seal it.

4 Place the volcano in a laboratory tray or on about 20 sheets of old newspaper.

5 Decide how much baking soda and vinegar to use for your first mix. Measure these out. Place the baking soda in the reaction vessel. Add a couple of drops of food dye.

Lastly, add your measured amount of vinegar.

6 If the result was disappointing, explore different amounts of vinegar and baking soda to see if you can improve the effect. Video the experiment on your mobile phone if given permission.

7 An alternative mixture to try is a thin paste of cornflour and water (consistency of cream) and Alka-Seltzer® tablets.

Results

Record your observations.

Discussion

1 **Construct** a word equation for the baking soda and vinegar reaction.

2 **Compare** your model with a real volcano.

2 Seismometers

Purpose

To build and test a model seismometer.

Materials

- retort stands and clamps
- metal rod
- string
- metal weights or brick
- pen and paper
- other materials as requested

Procedure

1 In a team, decide what your seismometer design will be like. You will have to pull the paper by hand as the pen moves over it. Construct a diagram and provide a list of necessary materials to your teacher.

2 If your teacher gives you permission, collect your equipment and build your seismometer. Test the seismometer by gently bumping the desk without moving the desk.

3 Improve on your design to make it more sensitive.

4 Observe other designs in the class and note how effective their seismographs were.

Discussion

1 **Compare** your seismographs with those of other groups, and evaluate the effectiveness of your design.

2 **Explain** how you may be able to improve on your design.

3 Earthquakes and buildings

Purpose

In this experiment you will generate your own 'earthquake' and study its effects on a small model building. You will have to design a way of testing how three variables may affect the performance of a building in earthquake areas. The three variables are:

- distribution of weight in a building
- width of the building or different sections of the building
- base isolation of the building.

Materials

- hardcover book
- pencils
- wooden blocks, styrofoam blocks, cardboard boxes
- plasticine
- ice-cream container
- ball bearings, marbles, sand, 'hundreds and thousands'
- other materials you request

Procedure

1. In your team, decide how you will make your 'earthquake generator', which is a way of rocking your model buildings back and forth in a wave motion. A hardcover book on pencils (like the set-up shown in Figure 10.3.17) is the simplest solution, but you will need to consider this as an experimental variable and how to control its effect.
2. Your buildings must be made in three or four sections. Use different sections (floors) about 10 cm high and base about 5 cm by 5 cm each section. You can change this if there is enough material available. You will need to make the sections from different materials such as wood or styrofoam to test variable 1.

   To test variable 2, some sections will need to be different widths.
3. To test variable 3, base isolation, you can use the ice-cream container and different materials such as ball bearings, sand, marbles and 'hundreds and thousands'. If you want to try anything else, ask your teacher.
4. Build your first model building to test one of the three variables. Place the model building on your earthquake generator and test its performance. Remember that how you operate your earthquake generator is a variable. Record your observations.
5. When you have everything working well, test the other two variables.

Discussion

1. **Explain** how you kept the earthquake generator as a controlled variable in your three different tests.
2. **Evaluate** the importance of the three variables on building design in earthquake areas.
3. **Evaluate** the experimental procedure you used and, if necessary, **recommend** any improvements.

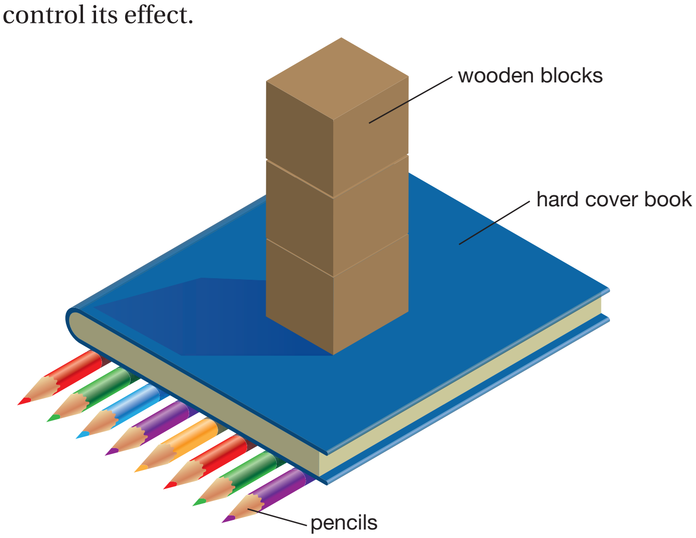


Figure 10.3.17

Chapter review 10

Remembering

1 **Name** the first person to propose that the continents moved.

2 **List** ten major tectonic plates.

3 **List** the evidence that supports the hypothesis of seafloor spreading.

Understanding

4 **Define** the following terms.
  - a lithosphere
  - b asthenosphere

5 **Explain** the process of seafloor spreading and subduction, and how these relate to convection.

6 **Describe** the three types of tectonic plate movements and the effects these have on the crust.

7 **Account** for the relationship between the places where earthquakes and volcanoes occur and where convergent and divergent tectonic plate boundaries exist.

8 **Account** for the great age and geological stability of Australia compared with many other continents.

9 **Discuss** some evidence that explosive volcanoes have affected the climate of the Earth in the past.

Applying

10 **Use** the theory of plate tectonics and the break-up of Gondwana to **explain** the evolution of Australia's unique flora and fauna.

11 **Use** the theory of plate tectonics to **discuss** its past impact on ocean currents and the climate of the Earth.

Analysing

12 **Compare** the characteristics of oceanic crust and continental crust.

13 **Compare** the effects of subduction when oceanic plates meet, with the effects when oceanic and continental plates meet.

Evaluating

14 **Justify** the view that mountains form because of plate tectonics.

15 **Justify** the view that oceans form from rifting.

16 **Critically assess** Alfred Wegener's 'continental drift' theory.

Creating

17 **Construct** a poster to display in your science room, adding illustrations and notes on the evidence that supports the theory of plate tectonics.

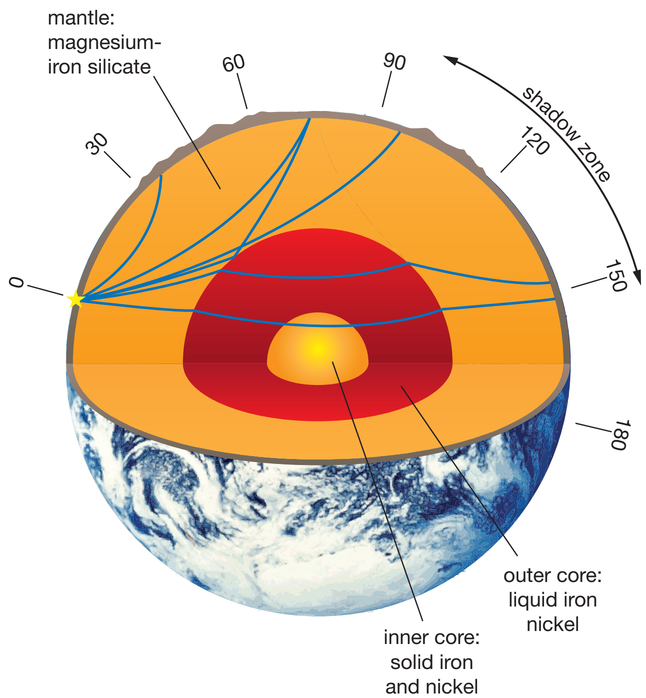
18 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

seafloor spreading
magnetic striping
converging boundary
diverging boundary
transform boundary
ocean trench
mountains
island arcs and chains
volcanoes
earthquakes

10.7

Thinking scientifically

Q1 Consider the following diagram.



This diagram is presenting evidence of:

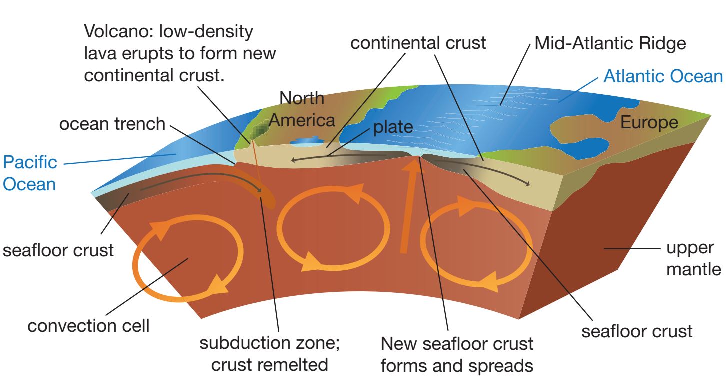
A volcanic activity in the crust due to tectonic plate movement

B the existence of earthquakes caused by subduction

C the interior structure of the Earth based on measurements of earthquakes

D how drilling has determined the chemical composition of the layers of the Earth.

Questions 2 and 3 refer to the following diagram.



Q2 The diagram is being used to show that:

A the Earth is composed of layers

B continents are formed by seafloor spreading

C plate tectonics can change the Earth's climates

D tectonic plates move due to convection currents.

Q3 From the diagram, you could deduce that subduction and seafloor spreading together:

A cause the convection currents

B show that the crust is recycled and therefore does not grow larger

C explain the formation of North America and Europe

D explain why volcanoes form from magma originating in the crust.

Q4 Consider the following data on the composition of the crust.

Mineral group	% of crust	Approximate density of mineral (weight compared with water)
Feldspars	49	2.5–2.7
Quartz	21	2.6
Pyroxene, olivine and others	15	3–4.3
Micas	8	2.7–3
Magnetite	3	5.2
Other minerals	4	varies greatly

Basalt has a density of about 2.9 g/cm^3 whereas granite is about 2.6 g/cm^3. Which of the following is a likely deduction from this information?

A Continental crust is heavier than ocean crust.

B Basalt probably has more feldspars and quartz than granite has.

C Basalt is largely made of magnetite.

D There is probably more magnetite, pyroxene and olivine in basalt than in granite.