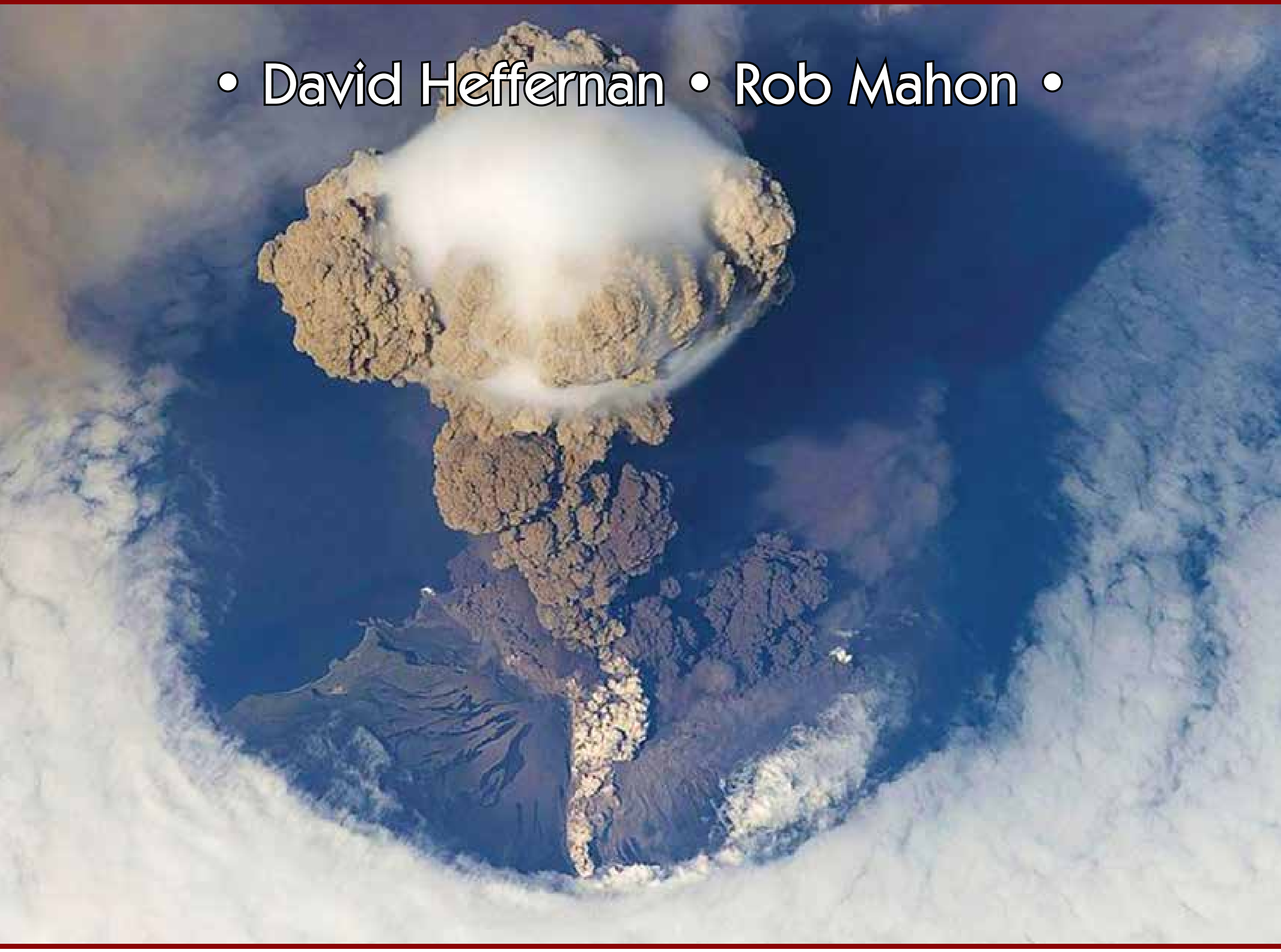
Surfing

NATIONAL EARTH AND ENVIRONMENTAL SCIENCE

Unit 4 The Changing Earth: The Cause and Impact of Earth Hazards



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Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

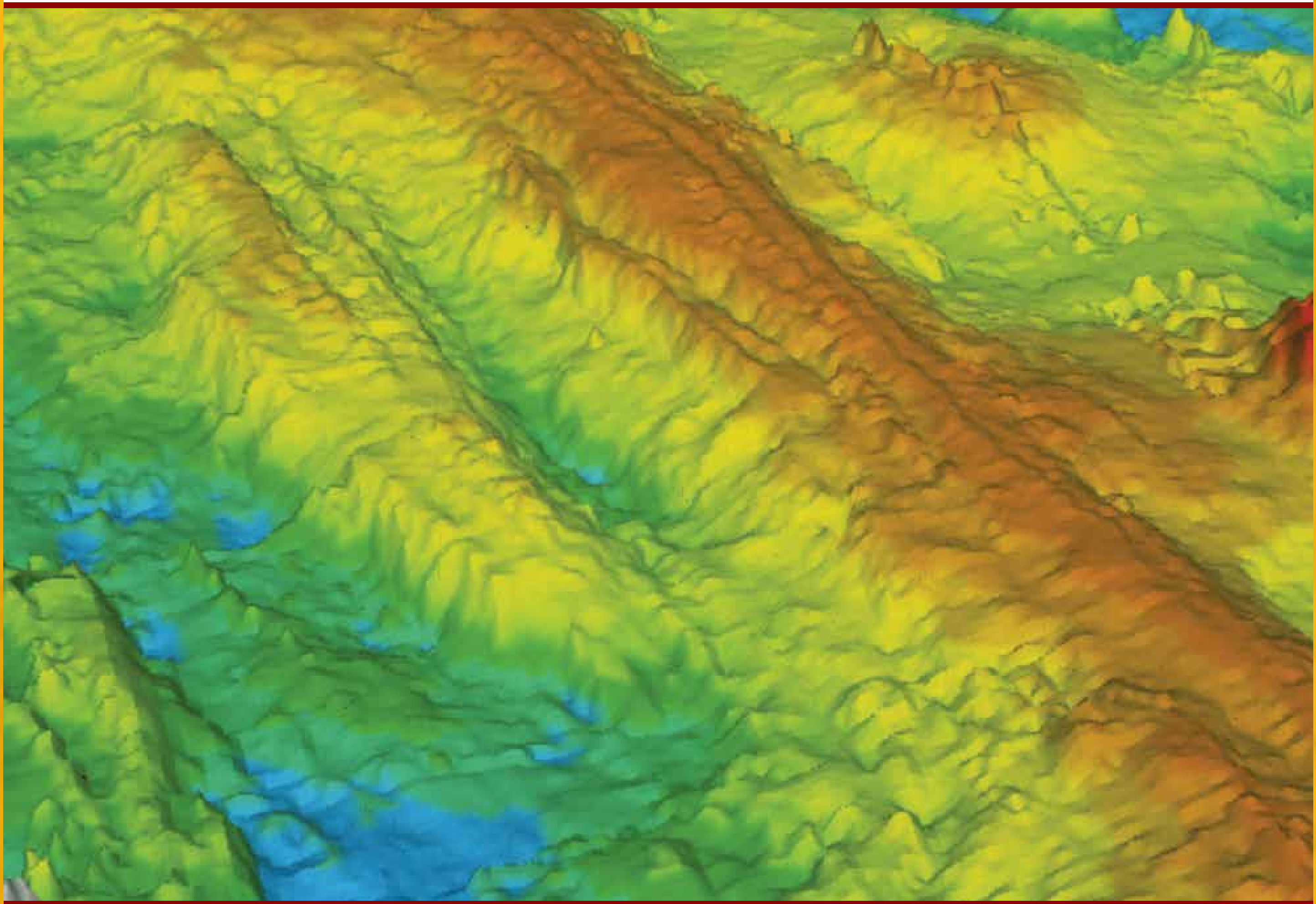
state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Modelling the Earth's Crust



1 Evidence for Plate Tectonics

Alfred Wegener proposed his theory of continental drift in the early 1900s. The theory of continental drift was not immediately accepted because the evidence available at the time could not directly disprove the old theories. This enabled geologists to attach different meanings to their evidence or to write some off as mere coincidences or curiosities.

However, the theory was resurrected when new technology allowed exploration of the ocean floor and found numerous features that directly contradicted established theories and which could only be explained by continental drift. A summary of evidence that convinced the world that continental drift has and still does occur is given below.

The evidence includes:

- Continental shapes.
- Cross-continental geological formations.
- Glacial deposits.
- Palaeoclimates (ancient climates).
- Apparent wandering poles.
- Magnetic reversals.
- Age of ocean rocks and sediments.
- The mid-oceanic ridge.
- Direct measurement.

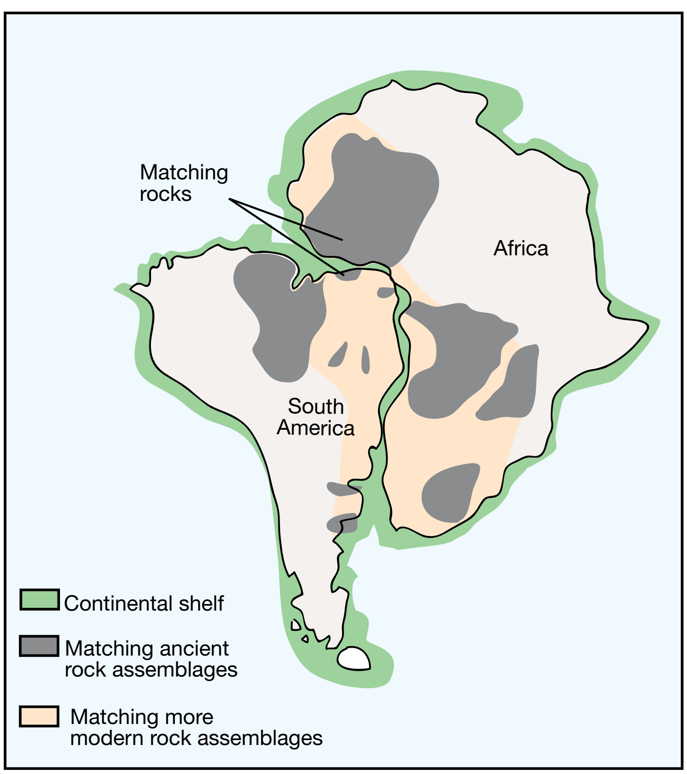


Figure 1.1 Some geological features that align between South America and Africa.

Continental shapes

As stated already, scholars have commented for centuries on how perfectly South America fits with Africa (Figure 1.1). This jigsaw-type fit is not always apparent when looking at the shapes of the other continents. For what we see as land is not the entire continent, only the part currently above sea level. The mapping of the sea floor thus enables us to view the continental shelf – the edges of a continent where water depth plummets. When using the entire continental shape rather than just the dry land component, the jigsaw fit occurs with many other continents. This strongly suggests they were once connected and have since drifted apart.

Cross-continental geological formations

Offering strong support for the idea that continents have moved is the fact that the positions of some geological features on widely separated continents align perfectly when the continents are placed together. Various features – such as folded mountain ranges, sedimentary deposits and the localities of specific fossils – act like the parts of a picture printed onto blank jigsaw pieces (Figure 1.2).

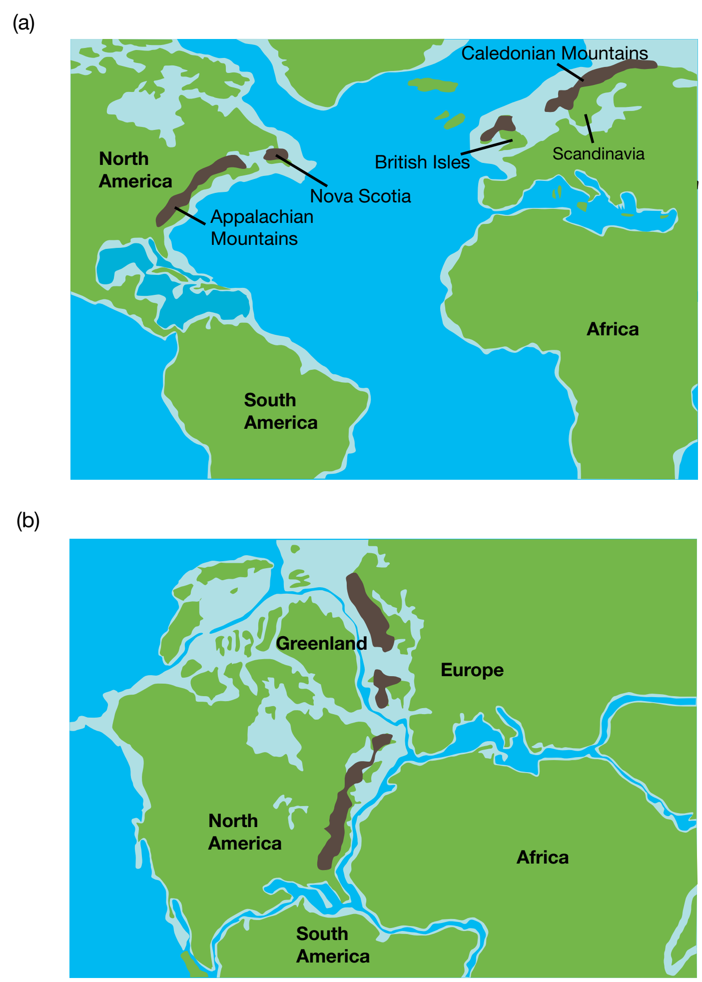


Figure 1.2 The Appalachian Mountains and mountains in Nova Scotia, Scotland and Scandinavia are matching.

Examples of this alignment include the wide distribution of fossils. For example, fossils of the seed fern *Glossopteris* is found in parts of South America, Africa, Antarctica, Australia and India. A plateau in Brazil, South America, matches up with another in the Ivory Coast, Africa (Figure 1.1). The Appalachian Mountains of eastern United States match mountain ranges of similar age in Nova Scotia, Scotland and Scandinavia (Figure 1.2). When the continents are placed together like jigsaw pieces, each of these locations line up, like print across a torn sheet of newspaper. In light of this compelling evidence Wegener claimed, 'There is nothing left but to conclude that the pieces were in fact joined in this way.'

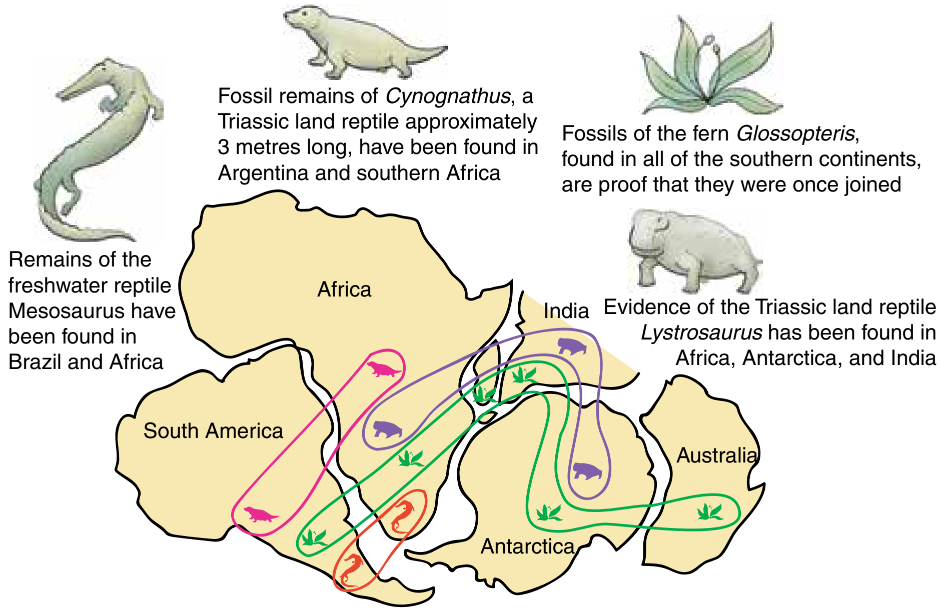


Figure 1.3 What pattern of fossil distribution results when continents are matched?

Glacial deposits

We know that during the ice ages, glaciers spread outward over large regions from the poles. Glaciers leave deep scratches on otherwise smooth rock and deposit unsorted sediments called tillites that can be easily identified and dated. The Palaeozoic glaciation, which took place about 300 million years ago, left its mark on rocks that are now on several continents and far away from the poles, even on the equator (Figure 1.4). The locations of the features formed by this glaciation make no sense unless the continents involved are realigned jigsaw-style and moved over the South Pole. When this is done, the locations and latitudes of these glacial formations fall into place.

Palaeoclimates (ancient climates)

Numerous types of rocks or minerals can only be created under specific climatic conditions. For example, coal is formed from organic material deposited in warm, swampy areas. The fact that Antarctica has coal deposits tells us that it once had a much warmer climate. This can mean one of two things:

- It was once located in warmer latitudes and has since drifted to its current location over the South Pole; or
- The poles were warm and free of ice when these coal deposits formed.

The idea of the poles being free of ice has been ruled out by matching the age of the coal with that of glacial formations elsewhere. If it was cold enough at that time for glaciers to have occurred anywhere else, the poles would have also been frozen, making coal formation impossible.

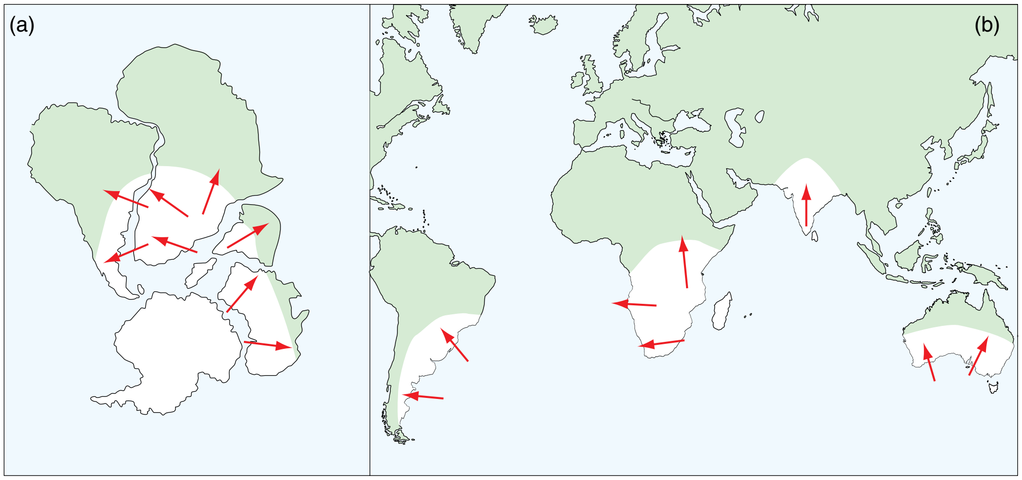


Figure 1.4 Glacial deposits. (a) Position of the continents during the Palaeozoic. (b) The present distribution of widely separated continents align perfectly when the glacial deposits from the Palaeozoic glaciation continents are placed together.

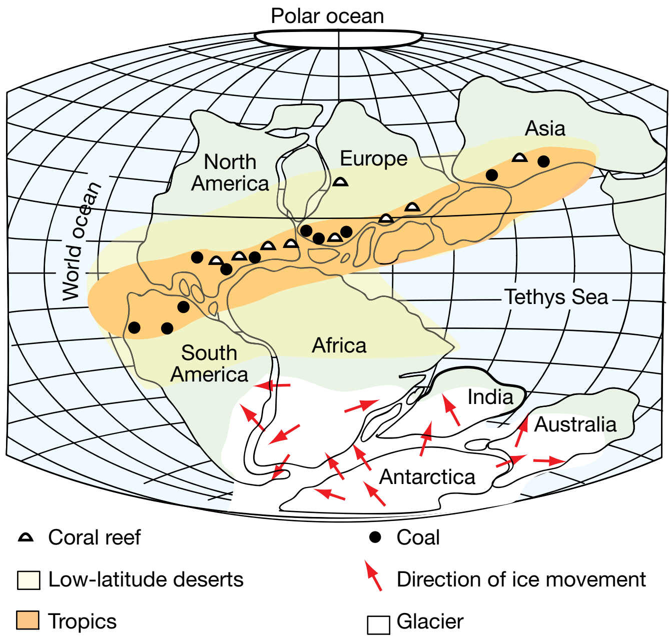


Figure 1.5 Palaeozoic glaciation is shown, as well as the matching palaeoclimates in other parts of the world at the same time.

Other indicators of climate change include deposits of sandstones formed from desert dunes and of mineral salts formed by evaporation, such as halite and gypsum. These further confirm drastic climate changes that can be explained by continental drift.

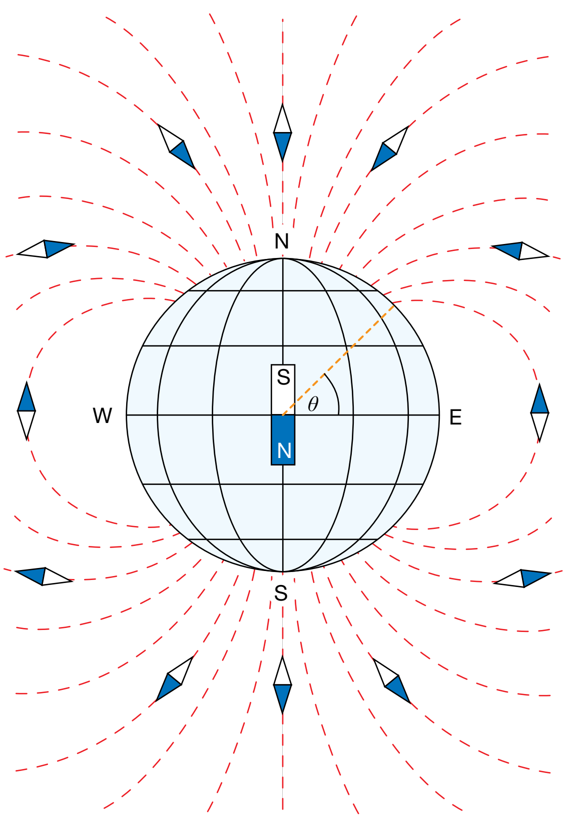


Figure 1.6 The Earth acts like a huge magnet. Thus the alignment of magnetism in minerals tells us both the direction of the North Pole and the distance from the pole when the minerals solidified.

A hand compass held vertically to the ground tells us the angle of the Earth's magnetic field (Figure 1.6). At the equator the compass needle will be parallel to the ground. At the magnetic South Pole the south end of the compass needle will point straight to the ground, whereas at the magnetic North Pole the north end of the compass points straight down. Midway between the equator and the poles, the compass needle will point down at a 45-degree angle with the end of the compass that corresponds with that hemisphere (Figure 1.6). For example, south points down in the Southern Hemisphere. Magnetic minerals in lava preserve the inclination of the Earth's magnetic field at the time the lava solidified. So if lava erupted at Sydney today, the south end of the magnetic minerals within it would point down at 34 degrees.

Apparent wandering poles

When lava erupts onto the surface, the iron minerals within it, such as magnetite, align themselves with the Earth's magnetic field in the same way as a compass. Once it cools and solidifies, the minerals are locked into position. By analysing the alignment of magnetic minerals within lava, geologists are able to determine the directions of the North and South Poles when the lava erupted. In addition to magnetic bearings, the distance at which the lava formed from either pole can also be estimated by the angle of tilt of these magnetic minerals.

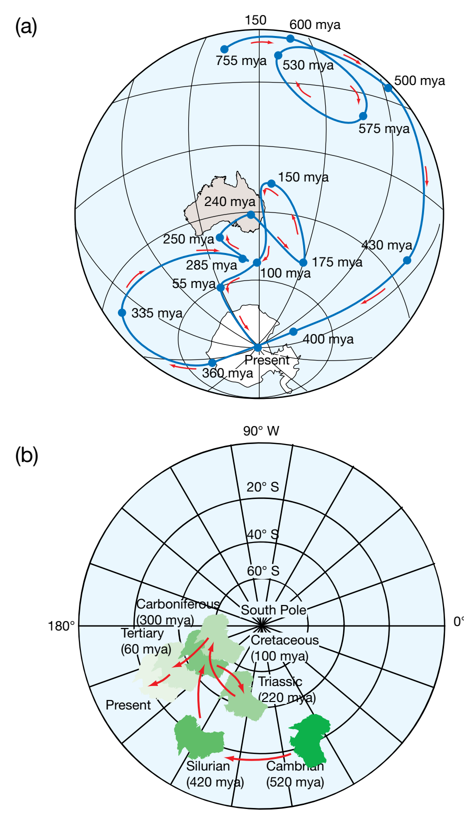


Figure 1.7 Wandering poles. (a) The apparent changing locations of the poles is explained by the movement of Antarctica over the surface of the Earth. (b) Movement of Australia viewed from the South Pole.

When studying the magnetic alignment of different volcanic rocks in the same region, they give different readings for the location of the poles, and their distance from the poles. The poles appear to be wandering around over time. We know this is not the case because volcanic rocks of the same age but on different continents give contradictory locations of the poles. The only explanation for this apparent polar wandering is that it is the continents rather than the poles that are moving (Figure 1.7). Volcanic rocks formed on different continents while they were still joined show a common location of the poles. Only the lava that cooled after the continents separated indicates different positions of the poles.

Magnetic reversals

For reasons not yet understood, the polarity of Earth's magnetic field reverses every few million years. In other words, the magnetic North Pole becomes the magnetic South Pole and vice versa. Such magnetic reversals may be caused by changes in the circulation patterns of molten iron in the Earth's outer core. This flipping is geologically quite rapid (taking between 1000 and 10 000 years), and the locations of the poles at the 'top' and 'bottom' of the globe stay much the same. If this were to happen today, the north end of our compasses would point toward Antarctica.

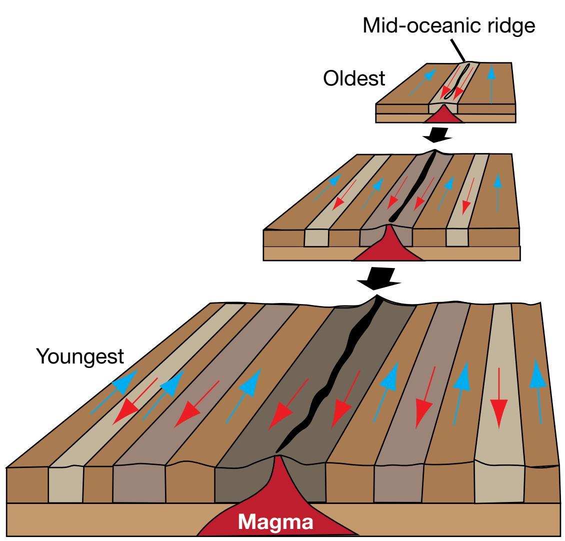


Figure 1.8 Magnetic minerals within lava align with the Earth's magnetic field when they are erupted, and they are 'frozen' in this alignment once the lava hardens. The alternating pattern of normal and reversed polarity of these minerals seen at divergent boundaries is the result of reversals in the Earth's magnetic field while new rock is formed and separated over time (sea floor spreading).

A series of magnetic reversals was first identified in lava fields on land (Figure 1.8). On land, new eruptions of lava pile up vertically over older ones as you would expect. The importance of magnetic reversals to continental drift can be seen when examining the polarity of rocks across mid-oceanic ridges – long submarine mountain ranges with deep valleys down the middle. The fact that the pattern of magnetic reversals on one side of oceanic ridges is a mirror image of that on the other can only be explained if the crust is being pulled apart at these ridges (Figure 1.9). As the crust breaks open in the central valley of an oceanic ridge, lava erupts, forming a long and narrow plug. Further spreading at the ridge causes the old plug to tear down the middle and fresh lava creates a new plug. If the Earth's magnetic field reversed between these eruptions, the different lava flows can be identified and the newer plug will bisect the older one. This pattern of magnetic reversals can only be explained by sea floor spreading and was one of the major reasons why geologists revisited the work of Wegener.

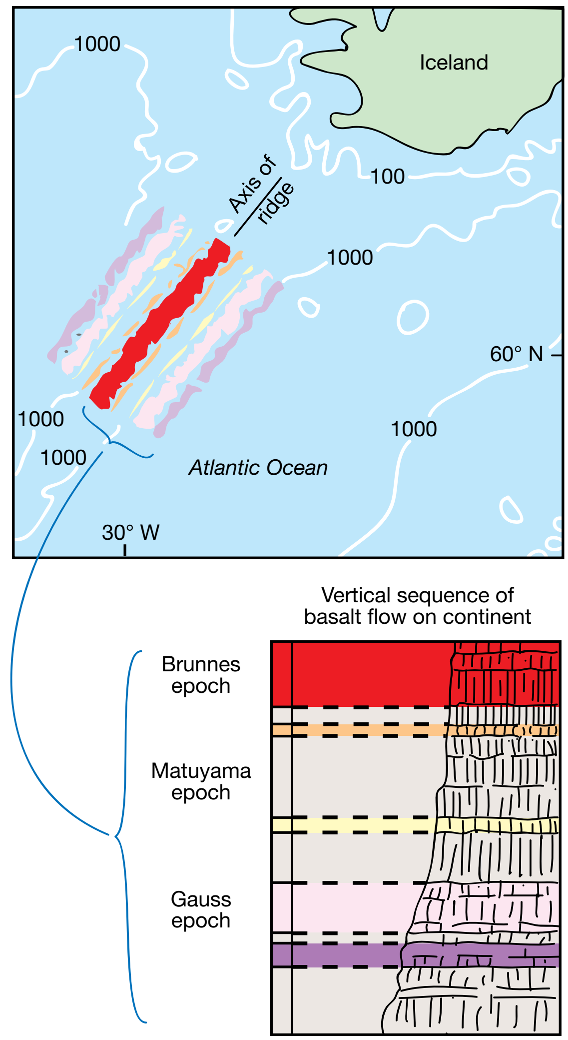


Figure 1.9 Magnetic reversals. (a) Symmetrical patterns of magnetism on either side of the mid-oceanic ridges. (b) Matching patterns on the continents. The epoch names are given to identify specific periods of magnetic reversal or normality

It was this evidence of mirror-image magnetic reversals across oceanic ridges that led to the popular resurrection of Wegener's continental drift theory in the 1960s. The only conclusion that can be drawn from such observations of worldwide oceanic ridges is that the crust is pulled apart and that new crust is formed at these ridges (Figure 1.10).

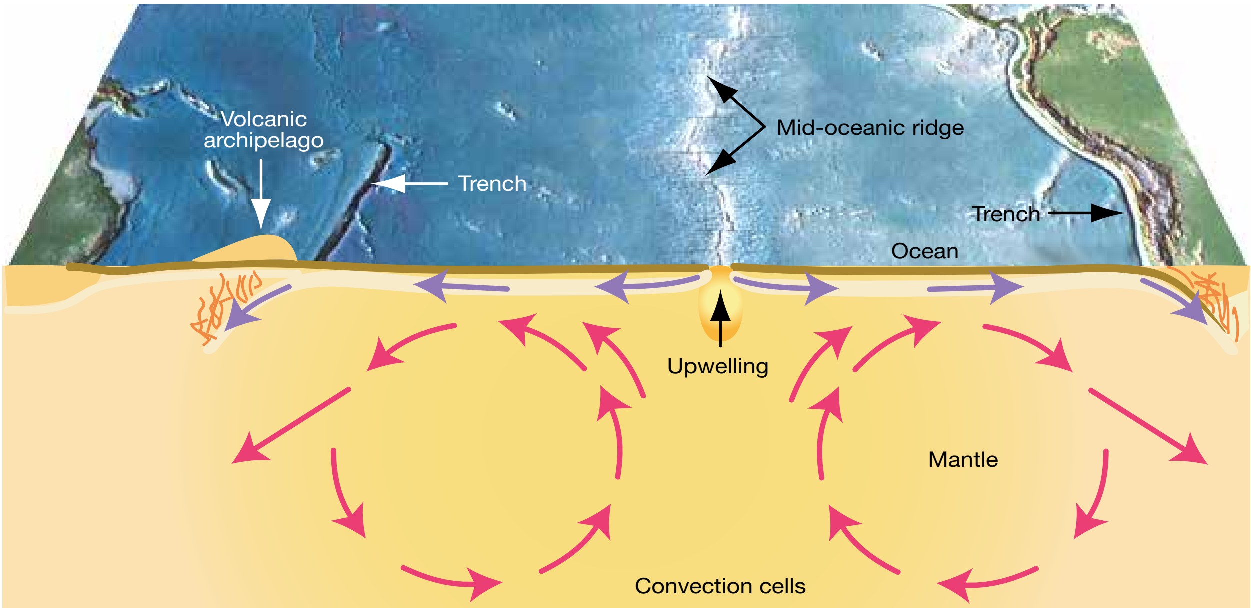


Figure 1.10 New crust is created along the mid-oceanic ridges and is lost when oceanic crust plunges beneath continental crust.

If new crust was being created here, did this mean the Earth was steadily increasing in diameter? After checking other sources of evidence that indicated the Earth's size had remained more or less constant since its early formation, geologists realised old crust was being destroyed at the opposite end of the plates from the mid-oceanic ridges. This destruction of crust typically occurs beneath continental landmasses and happens at the same rate as the formation of new crust, thus preserving the size of our planet.

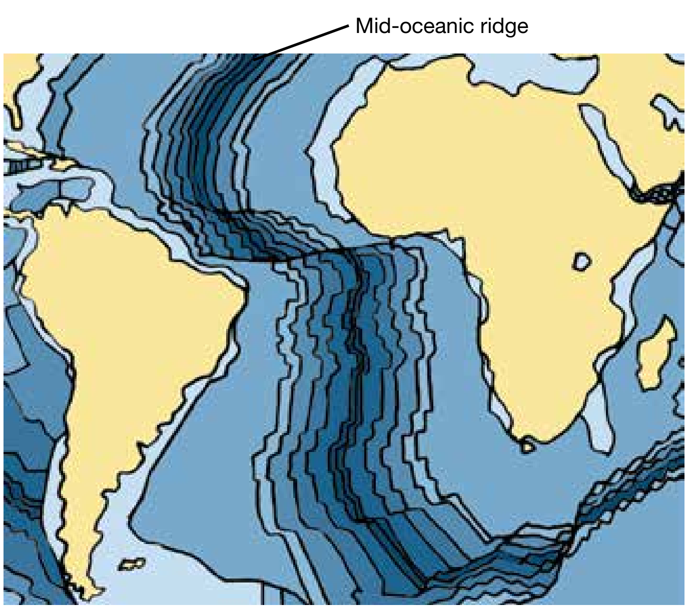


Figure 1.11 The ages of the rocks across the floor of the Atlantic Ocean show how the continents of Africa and South America have separated. The darker shaded rocks closest to the oceanic ridge are the youngest, while the lighter shaded rocks close to the continental edges are oldest.

Age of ocean rocks and sediments

If new crust is continuously formed at mid-oceanic ridges and is then pulled apart sideways, rocks should get progressively older the further they are from the ridge. Radioisotope dating has shown this to be the case at all mid-oceanic ridges. In fact, the oldest parts of the ocean basins formed at these ridges are only 200 million years old or younger – very young compared with continental crust. The global pattern of sea floor spreading becomes obvious when ages of sea floor rocks are mapped. The newest oceanic crust is at the oceanic ridges while the oldest is furthest from them (Figure 1.11).

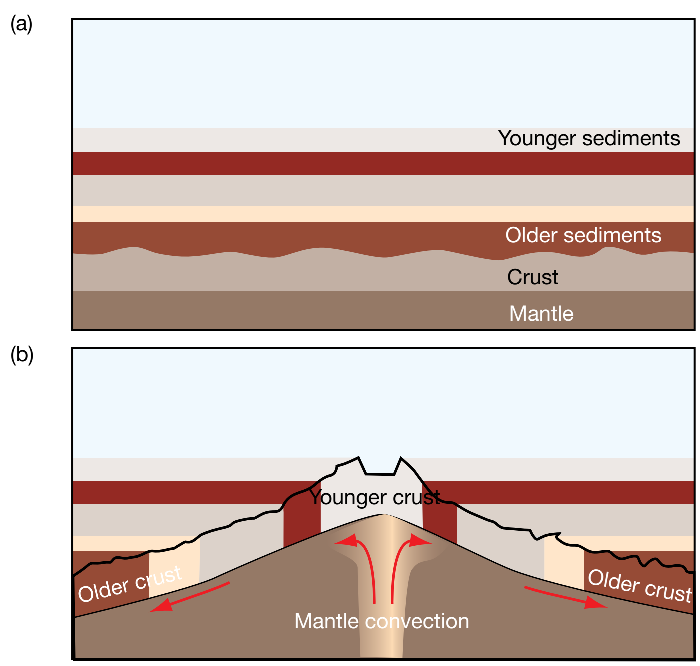


Figure 1.12 The sediments on the ocean floor become thicker away from mid-oceanic ridges because the rocks beneath are older and have been collecting sediments for longer.

Complementing this direct dating is the pattern of sedimentation on the sea floor near these ridges (Figure 1.12). Organic debris and other sediments rain down onto the deep ocean floor at a fairly steady rate. The fact that little or no sediment covers rocks at the ridge, while sediment layers get thicker as you move away from it, is a clear confirmation that ocean rocks increase with age away from the ridges. Radioisotope dating of the sediments themselves also confirms this trend.

We can now also explain why the temperature of the ocean floor decreases the further we get from a mid-oceanic ridge. Rocks that reach the surface from within the mantle are very hot and slowly cool to form new oceanic crust. As they move away from the heat source of the mid-oceanic ridge they continue to cool and their temperature declines.

The mid-oceanic ridge

The mid-oceanic ridge is the most dramatic single tectonic feature on the planet (Figure 1.13). It is an almost continuous mountain chain, rising as high as 3 kilometres from the ocean floor and winding for over 65 000 kilometres around the globe, much like the seam on a baseball or tennis ball. If the mid-oceanic ridge was not covered by water, it would be visible from the Moon.

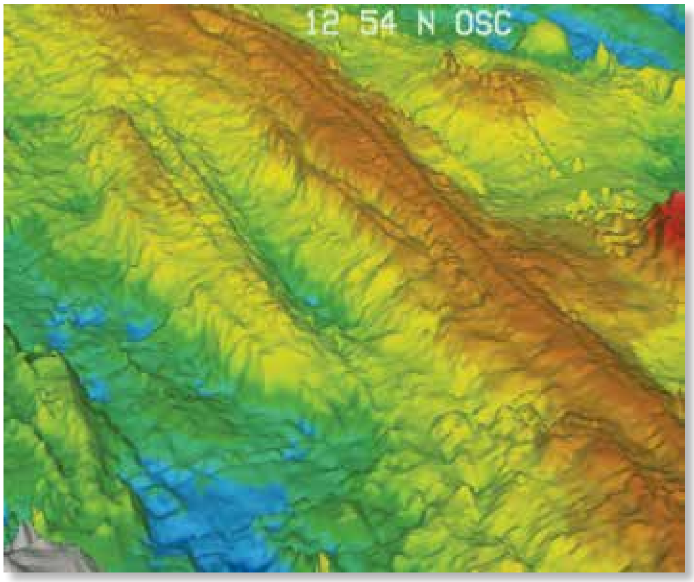


Figure 1.13 Mid-oceanic ridge is an underwater mountain chain (NOAA).

The mid-oceanic ridge is very different from continental mountain chains. It is composed entirely of undeformed (i.e. not folded by compression) basalt that has cooled from lava. It contains many fractures travelling across it which can themselves be thousands of kilometres in length. The mid-oceanic ridge also contains a deep central valley, where two plates pull apart and new crust forms. Its discovery was the 'smoking gun' evidence to show where sea floor spreading (as part of continental drift) was taking place.

Direct measurement

With the advent of such technologies as computers, laser measurement and satellite remote sensing, the slow movement of tectonic plates can be measured directly (Figure 1.14). By calculating the distance between two points on either side of a plate boundary, the rate and direction of relative movement can be determined. Figure 1.15 shows the direction and speed of movement in centimetres per year of Earth's main tectonic plates. The fact that they move in different directions means they sometimes collide, sometimes separate and sometimes rub past other plates.

(a)

(b)

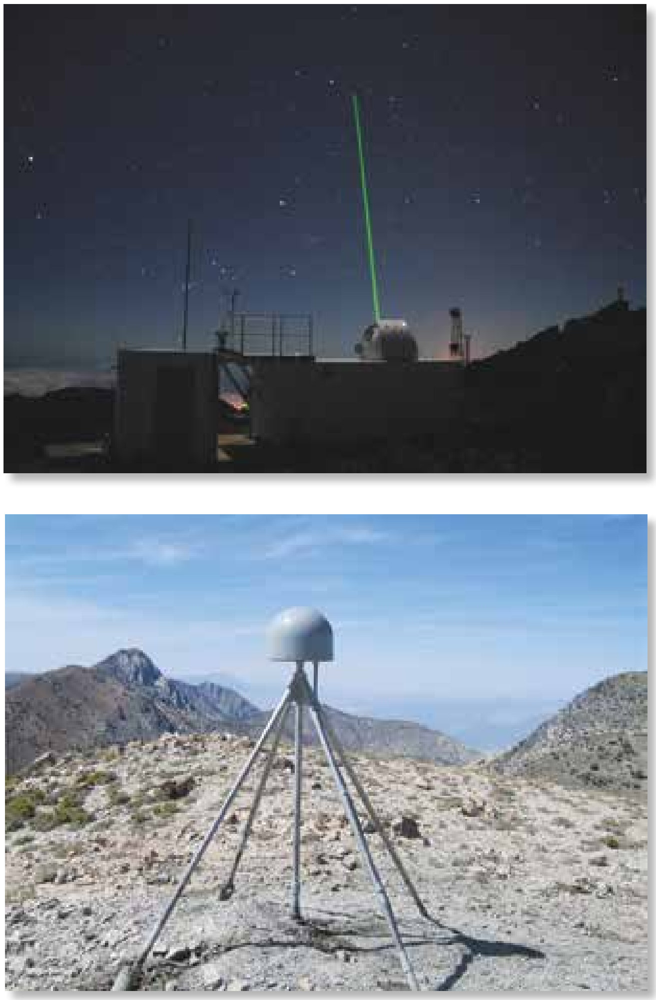


Figure 1.14 The movement of the Earth's plates can be determined with the help of: (a) Satellite laser ranging (SLR) and (b) The global positioning system (GPS).

Note that while individual plates have one general direction of movement, the rate at which different parts of that plate move can vary considerably. These variations cause the tearing or folding of the plates where the pressures are greatest or the rocks are weakest. Such forces generate fault lines which can generate earthquakes in the interiors of the plates (i.e. away from the edges). For example, the Newcastle earthquake, which killed 13 people and caused over 4 billion dollars in damage in 1989, was caused by rock movement along such a fault line (Figure 1.16).

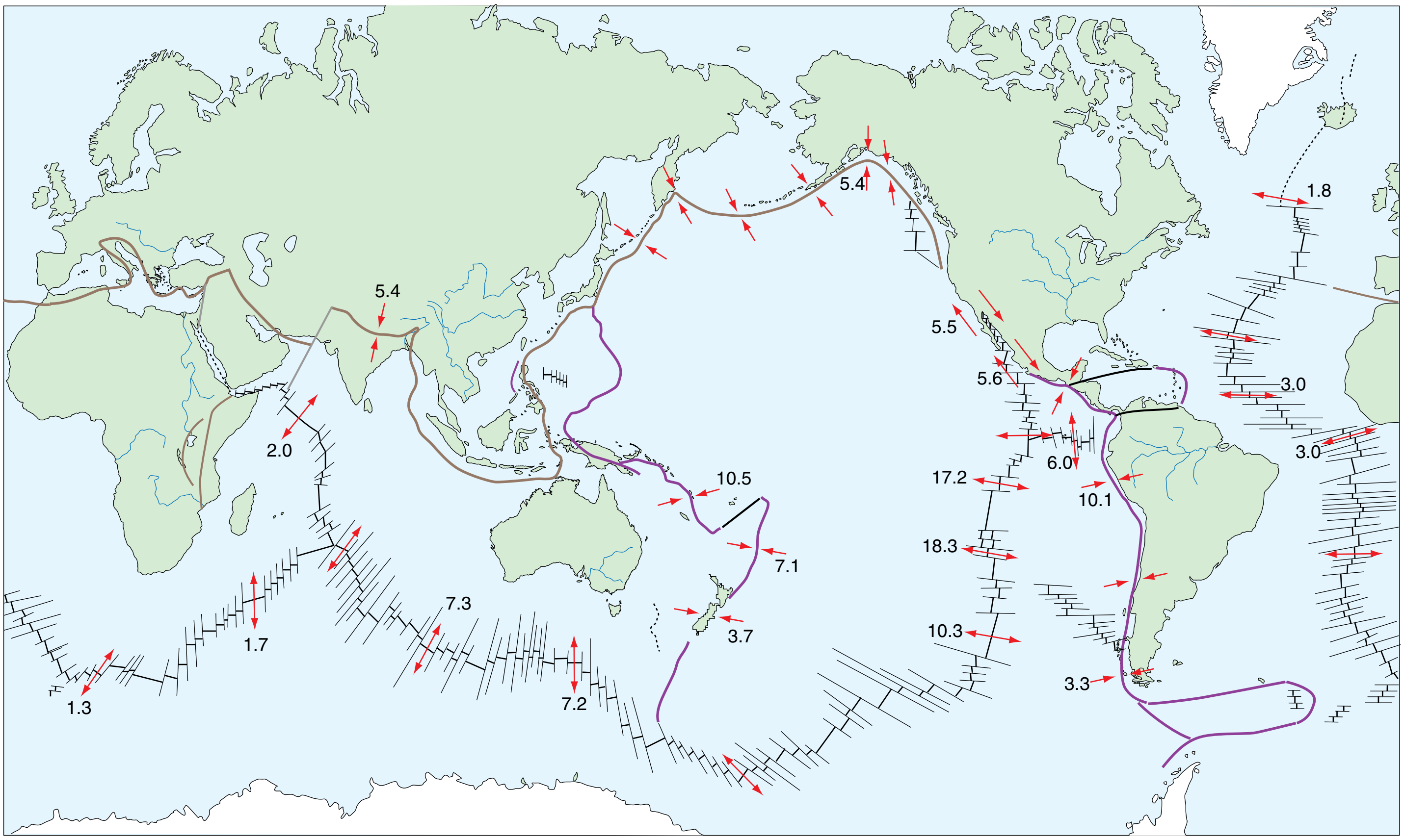


Figure 1.15 There are seven major crustal plates and many smaller ones. The directions of movement are shown as arrows. The values shown are in centimetres per year.

The cooling Earth hypothesis and others like it could not account for observed features such as young ocean basins and magnetic reversals. The sheer weight of evidence for continental drift led the scientific community to accept Wegener's ideas in the wider form of the plate tectonic theory. The man who was considered a crank by most of his colleagues during his life was embraced as a visionary some 30 years after his death.

Figure 1.16 The Newcastle earthquake was due to movement along a fault line.

QUESTIONS

1. Explain why matching continents works better when the continental shelves are used.
2. Describe two examples of now separated continents that provide evidence that they were once joined together.
3. Explain why ancient glacial deposits are now found at the equator.
4. Explain how coal deposits are now found near the South Pole.
5. Describe how we know that the Australian continent has moved.
6. Explain the symmetrical magnetic banding of the ocean floor on either side of the mid-oceanic ridge.
7. Describe how rocks on the ocean floor become older the further one travels from a mid-oceanic ridge.
8. Describe how the ocean floor becomes cooler the further one travels from a mid-oceanic ridge.
9. Describe what happens along the mid-oceanic ridge.
10. Many people use GPS units in cars or during bushwalking. Could very accurate GPS units be used to measure the movement of the continents?

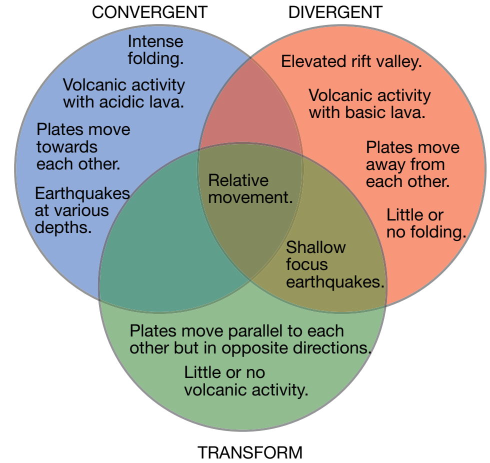
Answers

1 Evidence for Plate Tectonics

1. The complete continent is only evident when we include the continental margins. While only part of the continent is visible at this time in history, much more of the continent was visible in past ages.
2. Several answers: The two sides of the Atlantic Ocean match; the Appalachian Mountain range in North America matches mountain ranges in Britain and Scandinavia; parts of Antarctica fit into the Great Australian Bight.
3. Continents that were once located near the poles have moved into equatorial regions.
4. Coal deposits were formed in warm regions and have since moved into polar regions.
5. Several answers: Lines of volcanoes on the east coast showing the path taken; distribution of striations produced by glaciers; distribution of fossils such as *Glossopteris* matching other continents; matching shape with parts of Antarctica.
6. As magma rises into the mid-oceanic ridge, it slowly solidifies thus preserving the direction of the Earth's magnetic field at that time. As this rock moves away from the mid-oceanic ridge, the Earth's magnetic field may change direction, thus producing a band of rocks with magnetism in the reverse direction.
7. Oceanic crust is produced at a mid-oceanic ridge. It then gradually moves away from the ridge towards a subduction zone, often on the other side of the ocean. This can take a couple of hundred million years, so the rocks get older further from the oceanic ridge as new oceanic crust continues to be produced.
8. At a mid-oceanic ridge, hot magma cools and solidifies. This rock is still quite hot and cools gradually as it moves away from the divergent boundary.
9. As magma rises into the mid-oceanic ridge, it slowly solidifies and begins to move away from the divergent boundary. It continues to move across the ocean basin, often taking a couple of hundred million years to reach the other side. There the rock is subducted, melting as it re-enters the mantle.
10. Very accurate GPS units are currently being used to measure the movement of landmasses such as New Zealand.

2 Plate Interactions

1. At divergent boundaries, lava pushes up from the mantle to cool on the surface and form new crust. At convergent boundaries, oceanic crust is pushed down into the mantle where intense heat causes melting producing sometimes explosive volcanic activity.
2. At a divergent boundary, the lava comes from the mantle. Earthquakes are shallow as magma movement is relatively close to the surface and is free-flowing.
3. Oceanic crust is denser than continental crust.
4. Deep ocean trenches identify subduction zones where oceanic crust plunges down into the mantle.
5. A convergent boundary where oceanic crust meets continental crust.
6. Mid-oceanic ridge.
7. A convergent boundary where continental crust meets continental crust.
8. Intense heat is produced due to friction that causes sediments and rocks to melt. The magma rises through the continental crust above where it may melt more rock and collect in magma chambers. Some of this magma may migrate to the surface at volcanoes. Remaining magma may form large masses of granite.
9. Magma high in silica is very viscous, while magma low in silica flows freely from a volcano. The viscous magma can allow high pressures to build until they are released explosively.
10. We would need to travel to a divergent zone such as Iceland (or to a volcano over a hotspot within a crustal plate).
11. A deep ocean trench indicates the presence of a subduction zone where tectonic plates are in relative movement towards each other. There will also be earthquakes and volcanic activity. The rock will vary – those from a continental/oceanic plate will be more acidic than those from a oceanic/oceanic plate boundary where they will be more basic.
12. Comparing boundaries.



13. Comparing boundaries.

Divergent	Transform
Move away from each other	Move parallel to each other but in opposite directions
Volcanic activity	Little or no volcanic activity
Shallow focus earthquakes	Shallow focus earthquakes
Elevated rift valley	No rift valley

3 Tectonic Plates – How They Move

1. A mantle plume is a mass of hot magma that rises from the mantle.
2. A part of the mantle is hotter than the surroundings and being less dense it rises. It moves along under the crust gradually cooling and when it becomes more dense than the surroundings it begins to sink again.
3. The are several places, including the Afar triangle of Somalia and surrounding oceans, where the crust is moving in three or more different directions. It has not been possible to construct a set of convection currents that can explain this movement.
4. In slab pull, the weight of crust is in the mantle and drags more oceanic crust along with it. In ridge push, the newly formed crust is higher than the nearby ocean floor and its weight pushes the new crust down the slope.
5. The 'plastic' mantle is very viscous, but not rigid as with a solid. Thus it can move but only very slowly.
6. A hotspot is a rising mantle plume beneath a section of continental crust within a tectonic plate. It may lift the crust and break through to produce a volcano.
7. There is a volcano above a hotspot. As the plate moves away it carries the volcano with it and no longer having a plume beneath it becomes extinct. A new volcano forms above the plume and the process repeats itself.
8. Pangaea was a huge continent. There was no way for heat to escape from under the middle of this huge continent. As a result, the magma expanded and lifted the continent upwards. This broke the continent so that it formed two continents. The process was repeated again later.
9. Starting with Pangaea, Australia was part of this supercontinent. When it split in two, it remained part of Gondwana. Later this large continent split to form a number of landmasses including Africa, India, Australia and the Antarctic.