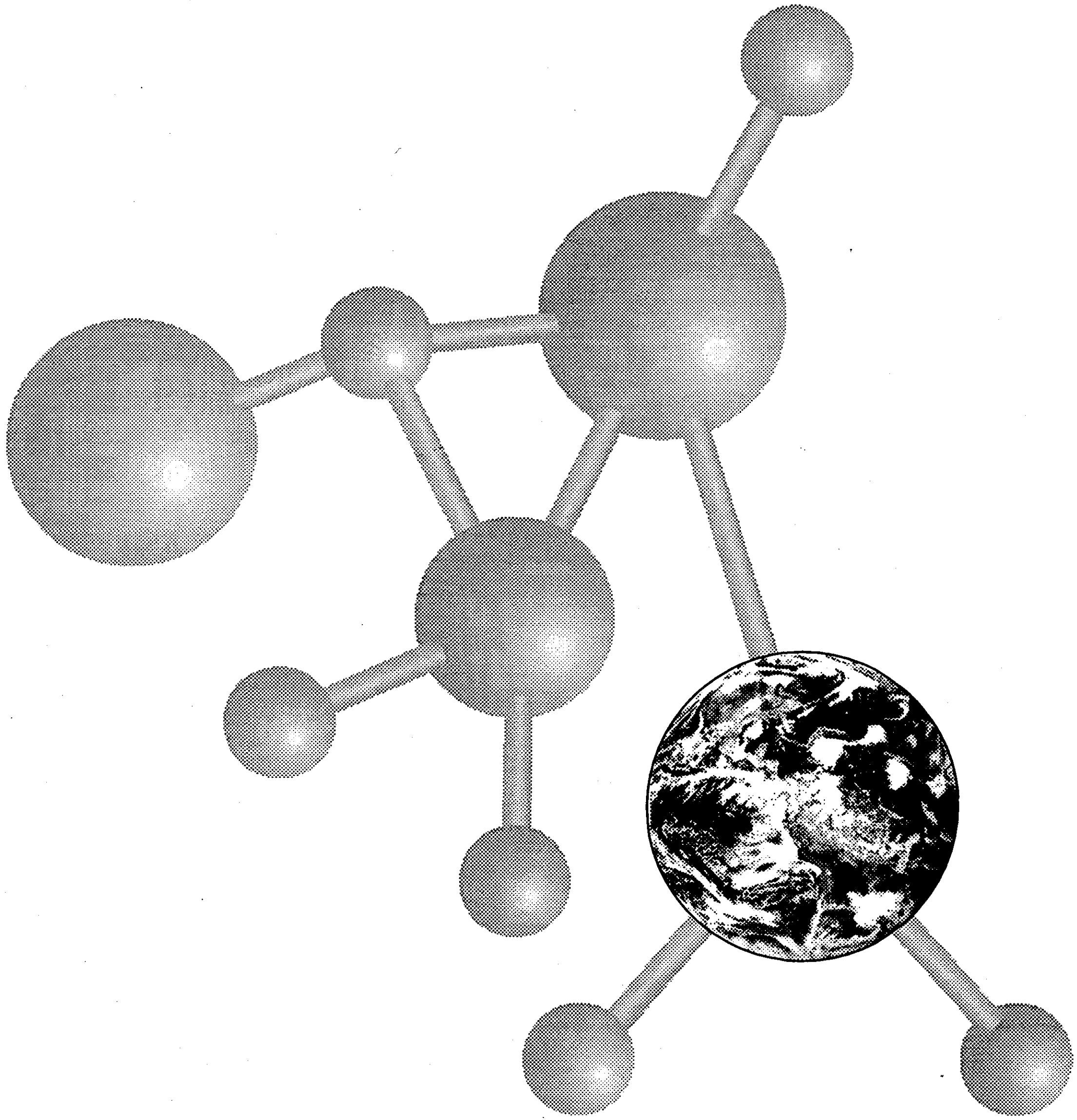
EARTH SCIENCE TEACHERS' ASSOCIATION

INVESTIGATING *the* SCIENCE *of the* EARTH



SoE2

Geological Changes - Earth's Structure and Plate Tectonics

CONTENTS

Investigating the Science of the Earth

Practical and investigative activities for Key Stage 4 and beyond

BOOK SoE2

Geological Changes - Earth's Structure and Plate Tectonics

Books in this series will include:

SoE1: Changes to the Atmosphere
SoE2: Geological Changes - Earth's Structure and Plate Tectonics
SoE3: Geological Changes - Rock Formation and Deformation

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1

INTRODUCTION

Studying 'Earth's Structure and Plate Tectonics'

The present distribution of the continents and oceans on the surface of our planet is the result of the movement of slabs of lithosphere otherwise known as plates. This movement has been going on for hundreds of millions of years and is responsible for many of the features and rocks that form the Earth. Plate movement is caused by processes in the Earth's interior. In this book you will find a series of activities that can be used to provide students with a basic understanding of the Earth's structure and plate tectonic processes.

Activity E1 simulates the methods by which Earth scientists can deduce the density variations within the Earth, whilst Activity E6 considers variations in the forces encountered with increasing depth.

The characteristics of earthquakes and the seismic waves they produce are considered in Activities E2, E3 and E4.

One of the fundamental pieces of evidence for plate tectonics and sea floor spreading is the pattern of magnetic reversals in rocks from the ocean floors. Activity E5 demonstrates how this magnetic evidence comes to be produced, by simulating the manner in which some plates move in relation to each other. Relative plate movement is further considered in Activity E7.

Activity E8 studies the modern global distribution of volcanoes and earthquakes as further evidence of plate movements, whilst Activities E9 and E10 examine aspects of the geology of the British Isles which show that plate activity took place in the geological past.

2

TEACHING NATIONAL CURRICULUM

'Earth's Structure and Plate Tectonics'

Table 1 Teaching 'Earth's Structure and Plate Tectonics' at KS3 and KS4.

National Curriculum Phrases	Geography/ Science	Key Stage	Suitable 'Science of the Earth' activities
'In studying earthquakes or volcanoes and their effects on people, pupils should be taught: a) the global distribution of earthquakes and volcanoes and their relationship with the boundaries of the 'crustal plates'	geography	3 and some GCSE	E8: Plate tectonics - the earthquake and volcano evidence E9: Drifting continents
EITHER b) the nature, causes and effects of earthquakes; OR d) the nature, causes and effects of volcanic eruptions	geography	3 and some GCSE syllabuses	Sections of E1, E2, E3, E4 & E6
Pupils should be taught:- 'how plate tectonics processes are involved in the formation, deformation and recycling of rocks'	science	4	E7: Plates in motion
'that longitudinal and transverse waves are transmitted through the Earth, producing wave records that provide evidence for the Earth's layered structure'	science	4	E1: Model Earth - a simulation of density contrasts in the Earth's structure E2: Earthquakes - the slinky simulation E3: Earthquakes - waves in the Earth E4: Earthquake shadow zones E6: Rockforce - investigating pressures on the rocks beneath your feet
'Pupils should be given opportunities to: develop their understanding of how scientific ideas are accepted and rejected on the basis of empirical evidence, and how scientific controversies can arise from different ways of interpreting such evidence'	science	4	E5: Clues to sea floor spreading from the magnetic ocean floor - a simulation E10: Britain's changing location - evidence from the rocks

In England and Wales the 'Earth's structure and plate tectonics' topic is studied at Key Stage 3 (11 - 14 year olds) in the Geography National Curriculum and then picked up again at Key Stage 4 (14 - 16 year olds) in many GCSE Geography examination syllabuses.

In the National Science Curriculum, plate tectonic processes and their links with rock formation, deformation and recycling are studied at Key Stage 4. This requires a scientific approach and understanding of a range of geological processes.

The activities in this book link best with this teaching approach as shown in Table 1 on page ii.

3

UNDERSTANDING

'Earth's Structure and Plate Tectonics' in the National Curriculum

The following guidance and exemplification is based upon 'The Earth Science Component of the Science National Curriculum at Key Stage 4' produced by the Earth Science Teachers' Association, 1995.

Science National Curriculum teaching points are in **bold** type. Material that pupils should be taught is in normal type. Guidance and exemplification for teachers is in *italic* type.

3. Waves: Seismic waves
3m. that longitudinal and transverse waves are transmitted through the Earth, producing wave records that provide evidence for the Earth's layered structure.

1. Understand that earthquakes produce longitudinal primary (P) waves and transverse secondary (S) waves.
Most earthquakes occur at plate boundaries where stress has accumulated over time. When stress is released in faulting, the rocks rebound elastically to produce P, S and surface, (L) waves. Since these travel with different velocities, they can be detected in turn by seismometers that are far enough away from the earthquake's epicentre.

2. Understand that the boundary between the crust and the mantle (the Moho) is identified by a sudden increase in P- and S-wave velocity.
The thickness of the oceanic crust (average 7 km) and continental crust (average 35 km) is calculated by detecting this increase in velocity. Where there are major mountain ranges, continental crust may be up to 90 km thick. The crust is, however, very thin compared to the Earth's radius, (6370 km); equivalent to a postage stamp stuck on a football.

3. Understand that at the mantle/core boundary the P-wave velocity decreases and S-waves are not transmitted, indicating that the material of the outer core is liquid.
The mantle/core boundary is at 2900 km depth. Note also that changes in P-wave velocity suggest a solid inner core at 5155 km depth.

4. Know that P-and S-wave data provide the evidence for the lithosphere (solid outer Earth), which forms the plates of the Earth's surface, and the asthenosphere (a ductile layer in the mantle), which allows their movement.
The solid lithosphere (around 60 km to 100 km in thickness) comprises the crust and a thin layer of upper mantle. The ductile asthenosphere, is able to flow very slowly over geological time. Its presence is detected by a decrease in P- and S-wave velocity. Slow convection currents in the mantle carry the lithospheric plates at rates of up to 5cm per year (the rate of fingernail growth). Plate movement, either directly or indirectly, is responsible for the major surface features of the Earth.

2z. how plate tectonic processes are involved in the formation, deformation and recycling of rocks.

1. Be able to use a simplified plate tectonic model of the outer layers of the Earth as the context for the statements that follow.
The evidence for the layered internal structure of the Earth from seismic waves is a prerequisite. The simple model is based on (lithospheric) plates made of crust and upper mantle 'floating' on the mantle and moving slowly.

2. Understand the hypothesis that one of the main processes causing plate movement is convection currents within the upper mantle of the Earth.
Evidence for the model is indirect, but convection currents are the most likely mechanism for driving plate movement.

3. Understand that, at constructive plate boundaries, magma which has been derived from the mantle rises to form new oceanic crust.
At constructive plate boundaries magma is injected and cools to form igneous rock that is new plate material. The texture and type of rock formed varies with depth and rate of cooling. Magma that has cooled slowly at depth, forms coarse-grained gabbro; when magma reaches the sea bed it cools rapidly to form lavas of fine-grained basalt. Gabbros and basalts are chemically identical igneous rocks that are rich in iron and magnesium and relatively poor in silica.

4. Understand that at destructive plate boundaries, plates partially melt to form silica-rich magmas.
At destructive plate boundaries, where two plates carry oceanic crust, one is subducted (pulled down beneath the other) and partially melts. Sediments on the subducted oceanic plate are buried and may partially melt to form new igneous rocks.

Where an oceanic plate collides with a continental plate, the oceanic plate is subducted, because it is denser. As the oceanic plate is heated at depth it partially melts and the magma formed is mixed with material from the melting of the base of the continental crust. The resulting material is more silica-rich than the magmas formed at constructive plate boundaries. When this magma cools slowly at depth it may form coarse-grained granite. Magmas that reach the surface form lavas of fine-grained andesite or rhyolite.

The huge forces of continent-continent collision cause deep burial of igneous and sedimentary rocks, heating and compressing them to form metamorphic rocks.

4

THE ACTIVITIES

'Earth's Structure and Plate Tectonics'

Each activity is self contained, although some naturally follow on from the others. They are aimed at Key Stage 4 (fourteen to sixteen year-olds) but some can be adapted for use with younger pupils, whilst others can be used at A/AS level.

The activities are described for teachers who may then adapt them for student use at levels appropriate to their abilities. Background details are given for each activity before the activity is described in detail. Each activity is followed by a series of appropriate questions for students to consolidate their learning. Following the answers given in the 'Explanation' section, ideas for further development of the activity and the underlying ideas are provided. The ten activities follow.

ACTIVITY E1

Model Earth - a simulation of density contrasts in the Earth's structure

Contents	Student laboratory modelling exercise to demonstrate the contrasting densities of layers in the Earth using plasticine and a steel ball bearing.
Aims	To illustrate that the Earth's core has a greater density than the rocks found on the Earth's surface.
Time	15 minutes (as part of a circus).
Assumed knowledge	Qualitative understanding of density.
Requirements	Each working group will require: 1 steel ball bearing of approximately 15mm diameter covered in a thin layer of plasticine (ball A). Ensure ball A is spherical. 1 ball of plasticine (ball B) with similar dimensions and shape to ball A. Balls A and B should be prepared in advance of the lesson. Digital balance; 2 blocks and a ruler or callipers; Eureka can; calculator.

BACKGROUND

The exercise develops an understanding of the contrasting densities between surface rocks and the Earth's core and allows students to investigate a model of the Earth's internal structure.

While the average density of crustal rocks of the Earth is about 2.8 g/cm^3, astronomical calculations put the average density of the Earth at 5.5 g/cm^3. This difference is due to the presence of a dense mantle and denser core. Calculations from earthquake data show that the core has a radius of 3470 km (see Figure E1.1) and it is thought to be composed predominantly of iron, sulphur and nickel. The density of the liquid outer core is between 9.9 and 12.3 g/cm^3, with the solid inner core reaching a maximum of 13.5 g/cm^3. The state of matter in these two parts of the core is the result of increasing pressure balanced against increasing temperature with depth.

THE ACTIVITY

In class:

1. Determine the density of ball A and ball B using the formula:

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

Use a digital balance to determine mass.

To determine the volume use either the Eureka can or calculate using the formula:

$$\text{Volume} = \frac{4\pi r^3}{3}$$

where r is the radius of the sphere.

The overall density of ball A depends on the densities and volumes of the outer layer and core.

Draw a cross section of ball A. Clearly show the density of the outer layer, core and the overall density.

4. Compare your completed cross section with Figure E1.1.

What are the similarities?

What are the differences?

How could the model be improved?

EXPLANATION

Students should find that ball A has a density of around 3.4 g/cm^3 whilst ball B has a density of around 1.7 g/cm^3. These figures compare with the mean density of the Earth of 5.5 g/cm^3 and the mean density of the core of 13.5 g/cm^3.

The students may suggest that the model would be better if it were made of denser materials and that an additional layer of another material was added to represent the crust.

The model could also be improved by attempting to make ball A to scale for the dimensions of core and mantle using the data from Figure E1.1.

DEVELOPMENT

Further investigations could be conducted into density differences in the crust by using rock samples from contrasting parts of the crust, eg granite with a density of 2.7 g/cm^3 to represent continental crust and basalt (density 3.0 g/cm^3) to represent oceanic crust.

The diameter of a sphere may be found by using callipers or by placing it between two blocks and measuring their distance apart. The radius is half the diameter.

2. Investigate the two balls to see why they have different densities. Calculate the density of the ball bearing separately using the procedure given above.
3. The density of ball B is the same as the density of the outer layer of ball A. The density of the 'core' of ball A is the density of the ball bearing.

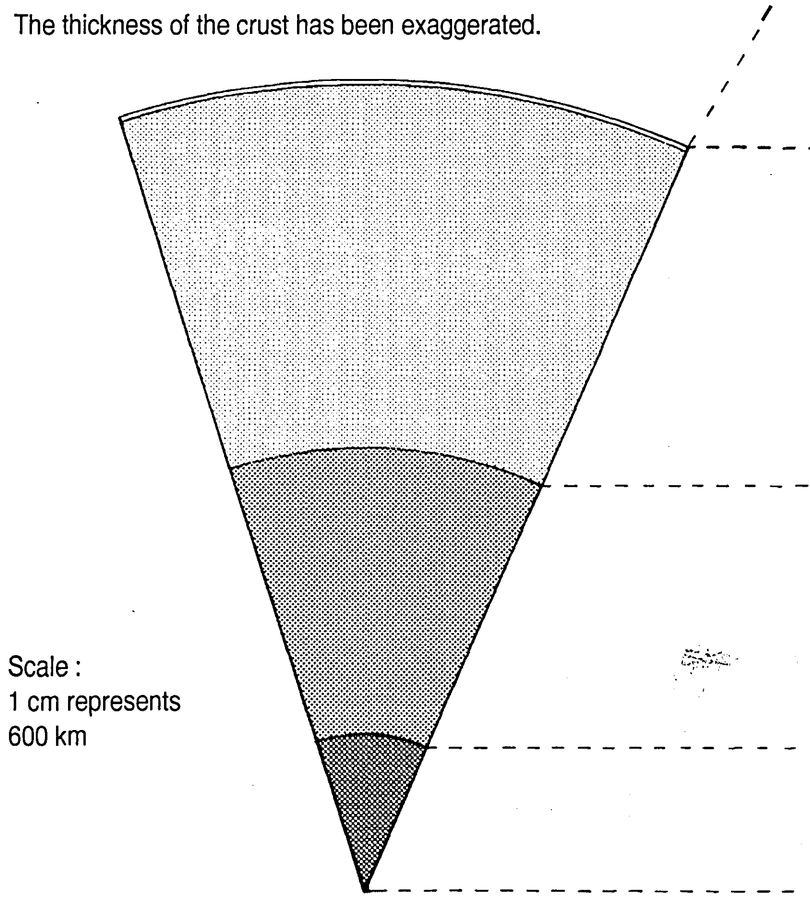
FURTHER READING

This activity is based on an idea in "Oxford Science Programme - The Earth and Beyond" Editors: Paul Denley and Stephen Pople, 1992, pub. OUP.

SOURCE/AUTHORS

John Reynolds, Stoke-on-Trent, and Maggie Williams, Birkenhead Sixth Form College.

Figure E1.1 Summary of the layered structure of the Earth



Name of layer	Depth (km)	Percentage of Earth's total mass	Density (g/cm^3)
CRUST	varies: 6 km under the oceans / 35km under the continents	0.7	2.7 - 3.0
MANTLE		68.0	3.3 – 5.4
	2900		
OUTER CORE			9.9 – 12.3
	5155	31.3	
INNER CORE			13.5 (approx)
	6370		

ACTIVITY E2 Earthquakes - the slinky simulation

Contents	Student laboratory modelling exercises to demonstrate the differences between the primary P-waves and secondary S-waves generated by earthquakes.
Aims	To show that earthquakes release energy in different types of waves which have different properties.
Time	20 minutes (as part of a circus).
Assumed knowledge	That sound travels as longitudinal and transverse waves.
Requirements	Slinky spring with luminous spots along one coil near the centre. The spots can be stuck on with tape or Blutack; alternatively they can be painted on.

BACKGROUND

Earthquakes produce three types of waves: primary or P-waves and secondary or S-waves that are transmitted through the Earth, as well as surface waves. P-waves are longitudinal, travelling as compressions and rarefactions in the same way as sound waves, whereas S-waves are transverse, like electromagnetic waves or waves on water.

The different types of wave may be modelled with a stretched slinky spring which responds to stresses elastically, in a similar way to the Earth. The slinky simulates the solid rocks and the molecules they contain.

Earthquake waves, also known as seismic waves, are detected by seismometers. The three types of wave travel at different velocities, so reaching distant seismic stations at different times to produce traces like the one shown in Figure E2.1. The factors that affect the velocity of P- and S-waves are complex.

THE ACTIVITY

Simulating P-waves (Figure E2.2)

- Stretch out a slinky spring on the bench.
- Hold one end and ask a student to hold the other, then give it a single push to send a pulse along the spring.
- Note the direction of travel of the pulse.
- Watch the position of the coloured spots and note their direction of movement.

Simulating S-waves (Figure E2.3)

- Stretch the spring out along a bench and ask a student to hold the other end again.
- Flick one end up and down to send a transverse pulse along the spring.
- Note the direction of movement of the pulse. Watch the positions of the coloured spots and note their direction of movement.

Figure E2.1 Part of a seismogram for an earthquake some 8500 km from the recording station.

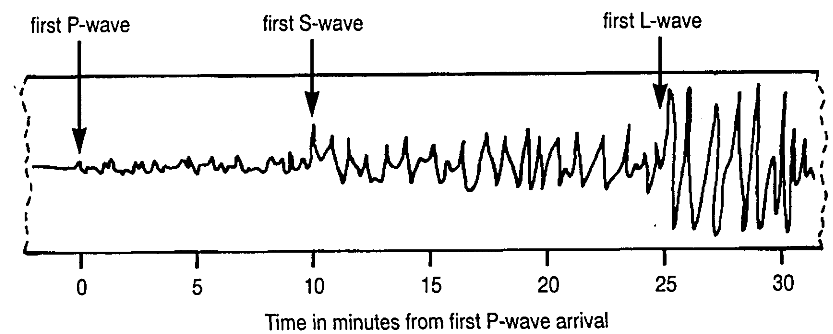
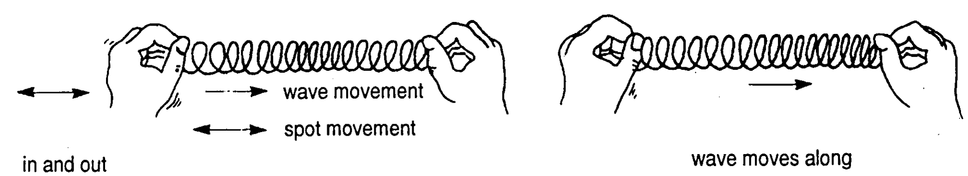


Figure E2.2 Simulating P-waves using a slinky spring.



FOLLOW UP

1. What is the direction of travel of the pulses in both cases?
2. What is the direction of movement of the coloured spots relative to the direction of travel of the pulse for:

   a) the simulated P-wave?

   b) the simulated S-wave?

EXPLANATION

1. The direction of travel of the pulses was from the point of displacement along the spring. A rebound also occurs.
2. The direction of motion of the coloured spots (the direction of displacement of the slinky) was:

   a) for the simulated P-wave - along the spring, the same as the direction of travel of the pulse;

   b) for the simulated S-wave - at right angles to the spring, perpendicular to the direction of travel of the pulse.

DEVELOPMENT

Large random movements may be used to simulate P- and S-waves together, as happens in real earthquakes.

Students could be asked to estimate whether the P- or S-waves travel faster along the slinky. This is very difficult to judge but the 'eye of faith' could decide that P-waves travel faster, as indicated in Figure E2.1.

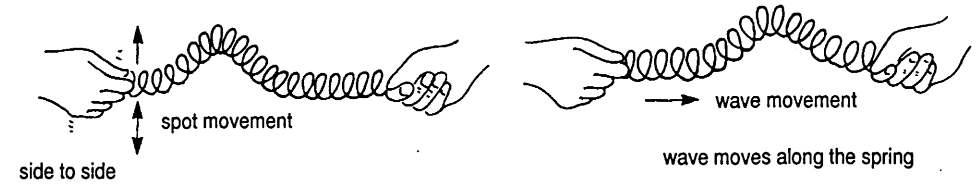
FURTHER READING

Science of the Earth Unit 2 'Earthquakes - Danger beneath our feet', Peter Brannlund 1990, pub. ESTA - in particular Student Sheet 2.

SOURCE/AUTHORS

John Reynolds, Stoke-on-Trent, and Maggie Williams, Birkenhead Sixth Form College, based on 'Science of the Earth, Unit 2'.

Figure E2.3 Simulating S-waves using a slinky spring.



ACTIVITY E3

Earthquakes - waves in the Earth

Contents Student worksheet and data analysis exercise based on graphs of earthquake velocities against depth.

Aims To show how velocities of earthquake waves vary with depth within the Earth.
To show how graphs of wave velocity can be used as evidence to interpret the internal structure of the Earth.

Time 30 mins.

Assumed knowledge National Science Curriculum, KS4, Sc4, 3; wave transmission, including the behaviour of earthquake waves.
Matter is made of particles.

Requirements Class set of the 'Waves in the Earth' worksheet.

BACKGROUND

This exercise focuses on the indirect evidence for the Earth's internal structure from earthquake waves.

Earthquakes produce P- and S-waves which pass through the Earth. The table below summarises the properties of P-waves and S-waves:

EARTHQUAKE WAVE	OTHER NAMES	MODE OF PROPAGATION	PROPERTIES
Surface waves	Love (L) and Rayleigh	Movement of the surface of the Earth	Reduce in intensity more quickly than other waves; these 'ground moving' waves cause earthquake devastation
Primary waves (body waves)	P-; push; pressure; compression; longitudinal	Compression and rarefaction of particles within the Earth	Faster of the two types of body waves; travel through solids and liquids but travel more slowly through liquids
Secondary waves (body waves)	S-; shear; transverse	Movement of the particles by shear, or motion at right angles to the wave travel direction	Slower of the two types of body wave; not transmitted by liquids (or other fluids)

5. Information on the characteristics of the various layers is given below; the summaries should include some of this information.

Crust
A thin outer layer with a mean density of about 2.8 g/cm^3. It is solid and consists of continental crust (mainly of granitic and sedimentary rocks) and oceanic crust (mainly of basaltic rocks). Oceanic crust has an average thickness of 6 km whereas continental crust has an average thickness of around 35 km. It can not easily be seen on the graph due its small scale.

Lithosphere
The solid crust and upper mantle material that may be up to 200 km thick in places.

Asthenosphere
The layer beneath the lithosphere, not synonymous with the low velocity zone. A zone of ductile behaviour that can accommodate movement.

Low velocity zone
A zone within the asthenosphere in the upper mantle, that is defined on seismic criteria. It varies in depth between 50 and 250 km and represents part of the mantle that may be about 5% liquid. It transmits S-waves but both S- and P-wave velocities are reduced.

Mantle
A layer about 2885 km thick with density increasing with depth from 3.3 - 5.4 g/cm^3. It is solid and is thought to consist of peridotite (an iron/magnesium-rich silicate rock).

Outer Core
A layer 2255 km thick which is very dense, increasing with depth from 9.9 - 12.3 g/cm^3. It is liquid and probably consists of an iron and sulphur mixture.

Inner Core
This has a 1215 km radius and is very dense, with a maximum density of 13.5 g/cm^3. It is solid, and is thought to consist of an iron and nickel mixture.

P-waves pass through both mantle and core, but are slowed and refracted at the mantle/core boundary at a depth of 2900km.

S-waves passing from the mantle to the core are absorbed because shear waves cannot be transmitted through liquids. This is evidence that the outer core does not behave like a solid substance.

S-waves are not transmitted through the liquid outer core. This produces a 'shadow zone' on certain parts of the Earth's surface where S-waves are not recorded and this is used as the main piece of evidence to deduce the size of the core. The core has a radius of 3470 km.

THE ACTIVITY

Students work through the 'Waves in the Earth' worksheet (final pages of this book).

Answers to the worksheet questions

1. S-wave velocity shows a sudden increase at 15 km depth, then it stays the same to about 70 km depth before dropping to a low at about 250 km; then it increases to the core/mantle boundary at 2900 km where the velocity decreases to zero. S-waves are transmitted through the inner core from 5155 km downwards.
2. S-wave velocity reduces to zero at 2900 km; this is evidence that the outer core is liquid, has no rigidity and thus cannot transmit S-waves.

3a. P-wave velocities differ, they are greater than S-wave velocities and reduce sharply at 2900 km, but not to zero.

3b. The P- and S-wave velocity plots have similar shapes.

3c. Below 2900 km, the P-wave velocity increases until 5155 km depth, where it shows a sudden increase. This higher velocity continues to the centre of the Earth.

4. From the evidence provided:

   The crust is marked between the surface and 15 km. S-wave velocity increases suddenly at the base of the crust.

   The low velocity zone should be marked between about 70 and 250 km. This is recognised by the decrease in S-wave velocity.

   The rest of the mantle should be shown from 250 to 2900 km. This is recognised by increasing P- and S-wave velocity.

   The outer core should be marked from 2900 to 5155 km. This is recognised by the absence of S-waves.

   The inner core occurs below 5155 km. This is recognised by the reappearance of the S-waves and the increased velocity of the P-waves.

DEVELOPMENT

The next stage could be to study plate tectonics using the information about the lithosphere and asthenosphere as evidence for a mechanism resulting in plate movement.

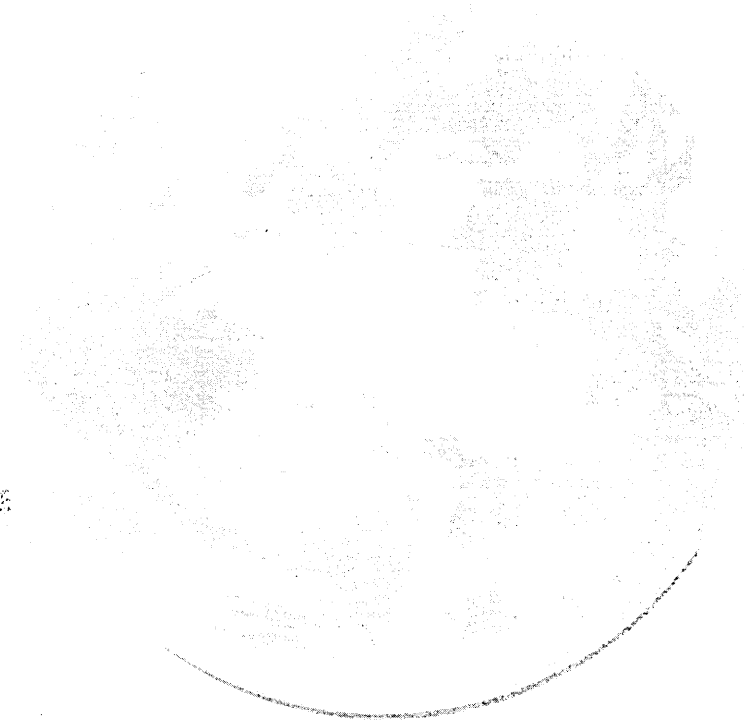
FURTHER READING

'Science Foundation Course S102 Unit 5-6', page 81 Table 7, 1987, pub. The Open University Press.

Science of the Earth Unit 2 'Earthquakes - Danger beneath our feet' Activity 5 by Peter Brannlund, 1990, pub. ESTA.

AUTHORS

Maggie Williams, Birkenhead Sixth Form College and John Reynolds, Stoke-on-Trent, based on 'Science of the Earth Unit 2', Activity 5 .



ACTIVITY E4 Earthquake shadow zones

Contents	Teacher demonstration, using a ripple tank to model an earthquake shadow zone, followed by an exercise to estimate the size of the core.	**Assumed knowledge**	Know that sound is produced by a vibrating object and travels as a wave.
Aims	To show that wave transmission can be affected by obstacles in the path of the waves, modelling the behaviour of S- (transverse or shear) waves as they pass through the Earth.	**Requirements**	Ripple tank or an open square pyrex oven dish, about 28 cm x 34 cm in size, to stand on an overhead projector. Overhead projector and screen; 30 cm wooden ruler or piece of wood to lie across oven dish; 50 or 100 ml beaker of sand. Class set of photocopied worksheets, 'Where is the core?'
Time	Demonstration: approximately 10 minutes. Exercise: approximately 20 minutes.		

BACKGROUND

Earthquakes produce three types of waves including primary (P-) waves and secondary (S-) waves which pass through the Earth. Our ideas about the Earth's internal structure are based on indirect evidence, notably that S- waves are not transmitted by the core, and P-waves are refracted at the boundary. The pattern of the S-wave shadow zone cast by the core enables scientists to determine the size of the core.

S-waves passing from the mantle to the core are absorbed because shear waves cannot be transmitted through liquids. This is evidence that the outer core does not behave like a solid substance.

P-waves pass through both mantle and core, but are slowed and refracted at the mantle/core boundary, at a depth of 2900 km. P-wave velocity then increases at a depth of 5155 km indicating a solid inner core. Figure E4.1. illustrates the paths that P- and S-waves follow through the Earth.

The following activity considers information from S-wave absorption only.

ACTIVITY 1: RIPPLE TANK DEMONSTRATION

1. Fill the ripple tank or oven dish with water to less than half full; place on the overhead projector. Project the image onto a screen or wall.
2. Put the ruler in the water at one end of the dish as illustrated in Figure E4.2. Generate waves to illustrate wave movement by pressing down/tapping on the ruler. Observe the waves on the screen.
3. Place the beaker of sand upright in the centre of the dish as illustrated in Figure E4.3.
4. As before, generate waves to illustrate the effects of the beaker on wave movement.

FURTHER READING

'Science Foundation Course S102 Units 5-6', page 73, 1987, pub. The Open University Press.
'Geological Science', A.McLeish 1986, pub. Nelson; pages 112 and 123.
'The Cambridge Encyclopaedia of Earth Sciences', Chapter 3, pub. Cambridge.

SOURCE/AUTHORS

Maggie Williams, Birkenhead Sixth Form College, and John Reynolds, Stoke-on-Trent, with additional suggestions by Eric Murphy, King Edward VII School, Sheffield.

Figure E4.2 The ripple tank on an overhead projector.

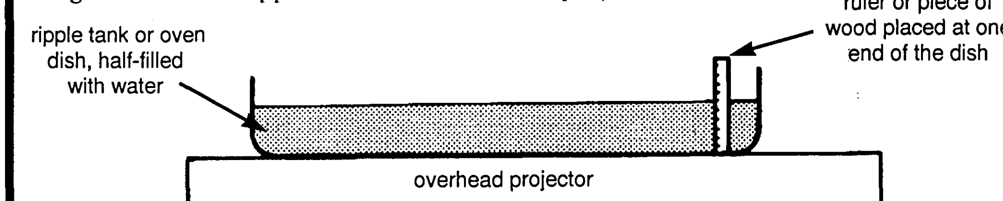
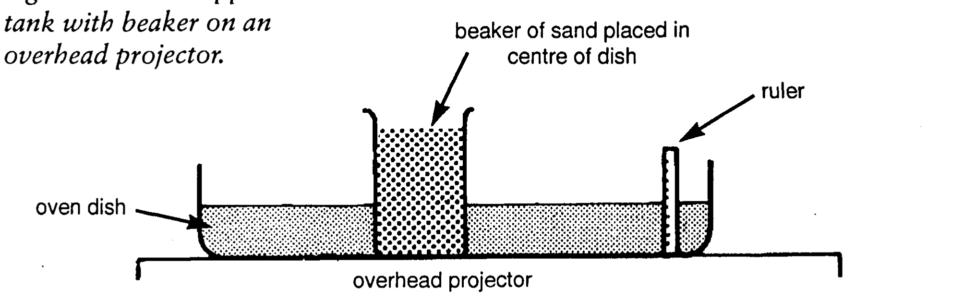


Figure E4.3 The ripple tank with beaker on an overhead projector.



Observe in particular the 'shadow' zone of relatively still water beyond the obstruction. The effect is best seen by observing the OHP projection through nearly closed eyes.

ACTIVITY 2: 'WHERE IS THE CORE?' WORKSHEET

Students should work through the worksheet.

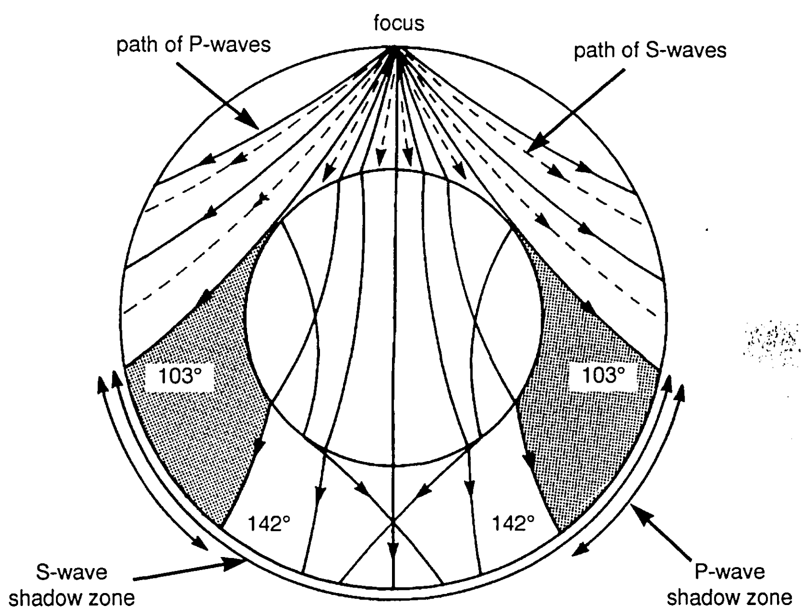
EXPLANATION

Answers to the questions posed on the 'Where is the core?' worksheet.

S-waves follow curved paths being refracted by the increasing density within the Earth. They do not pass through the core. If the curves of the lines are plotted accurately, the core radius is identified as approximately 3500 km.

It is possible to measure the angle from the centre of the Earth between the focus and edge of the shadow zone using a protractor. This angle should be approximately 103 degrees. For an earthquake occurring at the north pole (which is a very unlikely event!) the shadow zone would coincide with the line of latitude 13 degrees south.

Figure E4.1 Paths of P- and S-waves within the Earth.

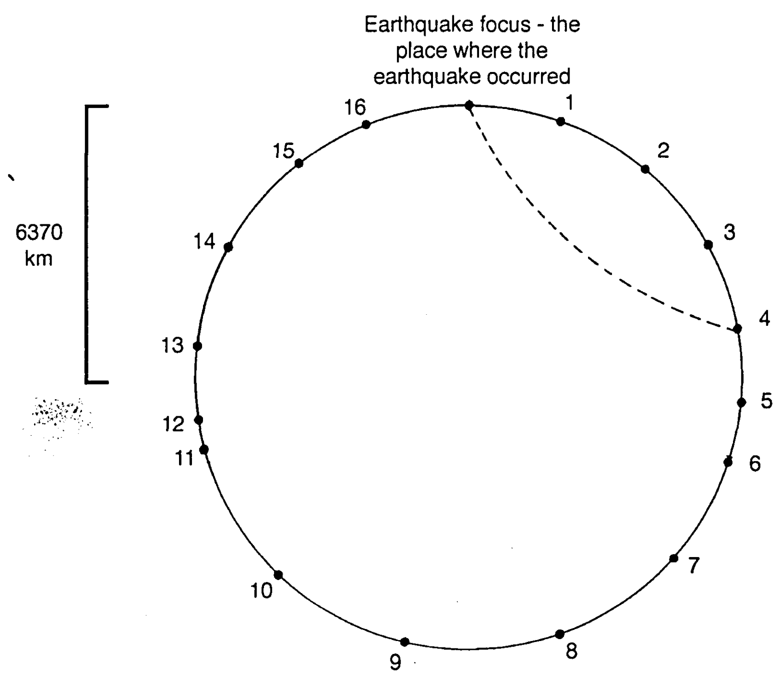


'Where is the Core?' Worksheet

A major earthquake has occurred at the position shown at the top of the diagram.

S-waves from the earthquake were detected at seismic stations 1, 2, 3, 4, 5, 12, 13, 14, 15, and 16 but S-waves were not recorded at seismic stations 6, 7, 8, 9, 10, 11.

1. Due to variation in density of the Earth with depth, the waves are refracted and travel in gently curved lines. The curve for station 4 has been drawn to show you the approximate shape of this curve. Draw the curved paths of the other earthquake waves from the focus to the stations where they were recorded.
2. Label the S-wave shadow zone, the part of the Earth's surface where S-waves were not recorded.
3. Sketch and label the likely size of the core and record its radius on the diagram.
5. Detailed studies show that the actual radius of the core is 3470 km. Why might your estimate of the core radius be different?



ACTIVITY E5 Clues to sea floor spreading from the magnetic ocean floor - a simulation

Contents	Laboratory simulation of the magnetic evidence for sea floor spreading at ocean ridges.
Aims	To understand and interpret evidence from ancient magnetism of rocks.
Time	Teacher demonstration - approximately 20 minutes. Student follow- up - approximately 30 minutes.
Assumed knowledge	The Earth's magnetic field, through familiarity with the magnetic compass.

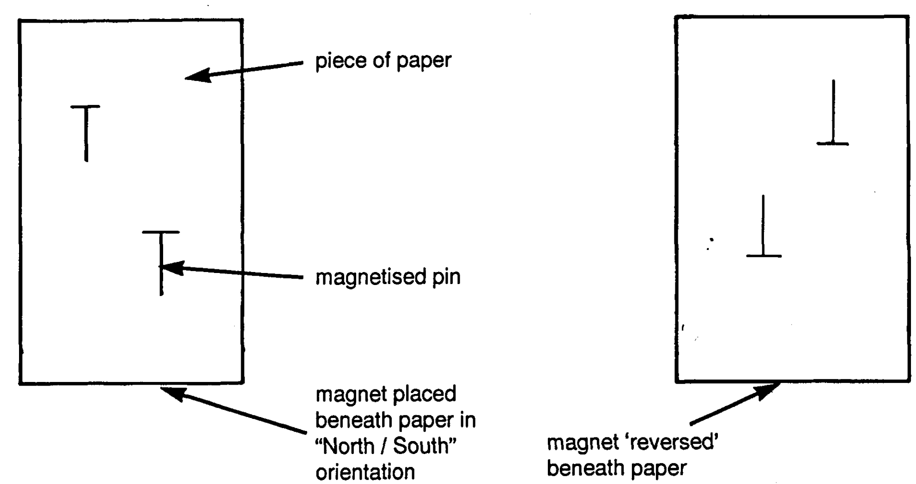
Requirements Large (eg 15cm long) bar magnet; *15 magnetised dressmaker's pins; Sellotape, compass (orienteering type or plotting compass); A4 plain paper.
*The magnetised pins may be prepared by stroking them with a bar magnet. Align the points in the same direction and stick the pins to a bench with Sellotape. Stroke the magnets in the same direction about 20 times towards the sharp end with the same end of a strong magnet.

BACKGROUND

Below mid-ocean ridges, mantle rocks partially melt and the molten rock accumulates to form a basaltic magma. The magma rises into the crust, cools and crystallises to form new crustal rocks. As these rocks cool, they become magnetised by the magnetic field of the Earth. Over past millennia the Earth's magnetic field has reversed many times, meaning that the magnetic poles have swapped over. During these reversals the south magnetic pole becomes sited where the old north magnetic pole used to be, and visa versa. The reason for this is not completely understood but is believed to be connected with circulation in the iron-rich liquid outer core.

Thus the cooling rocks at mid-ocean ridges record past magnetic reversals. Such ancient magnetism can be measured today, revealing symmetrical, linear patterns of reversals on either side of the oceanic ridges. The instrument used to measure variations in the Earth's magnetic field is called a magnetometer.

Figures E5.1a and E5.1b How magnetised pins align themselves with a bar magnet placed beneath a piece of paper.



THE ACTIVITIES

1. Magnetising the ocean floor

a) It is possible to demonstrate that magnetised pins will align themselves parallel to an ambient magnetic field by dropping two magnetised pins randomly onto a sheet of paper resting on the bench, below which is a bar magnet. Use the orienteering compass to illustrate north and south. (See Figure E5.1).

b) Stick the pins down with Sellotape.

c) For another sheet of paper, reverse the bar magnet and repeat a) and b) (see Figure E5.1b).

d) Demonstrate that the pins have retained their 'normal' and 'reversed' magnetism by removing the magnet and testing their polarity with the compass.

MAGNETIC PATTERN EXERCISE

This is based on the Magnetic Pattern Exercise worksheet provided in the final pages of this book. The table on the worksheet contains information collected by geologists in an area south west of Iceland. They used a magnetometer aboard an aircraft to measure the strength of the Earth's magnetic field at different places on the Earth's surface. A magnetometer above reversely magnetised rock shows the field to be weaker than when it is over normally magnetised rock.

On the map of the Iceland area, mark an X or an O at the location of each station listed in the table. Note that X indicates reversed magnetisation and O indicates normal

2. What does the magnetised 'ocean floor' show?

a) Take a sheet of A4 paper prepared in advance as shown in Figure E5.2.

b) Fold the prepared paper and set it up between 2 adjacent benches (or piles of textbooks) as shown in Figure E5.3, with a bar magnet held beneath and a compass on top.

c) Ask a student to pull both ends of the paper gently. As a 'reversed' section of the 'crust' appears from the gap, reverse the bar magnet beneath, to indicate the reversal of the Earth's magnetic field. Repeat this as each new section of the crust appears.

d) When all the paper has been pulled out, discard the bar magnet. Use the compass to demonstrate the alternately normal and reversed polarity in the retained magnetisation of the needles.

FOLLOW UP

The vital part of this exercise is to realise the symmetrical, linear nature of the magnetic patterns, parallel to the mid line of the paper. This represents the real symmetrical magnetic patterns found in the basalts of the sea floor which have been caused by the periodic reversals of the Earth's magnetic field as they were forming. Thus, each oceanic ridge has a pattern of symmetrical magnetic zones on either side. This is used as good evidence for the sea floor spreading hypothesis which became part of the theory of plate tectonics.

DEVELOPMENT

The symmetrical magnetic anomalies about the Mid-Atlantic Ridge can be illustrated through the Magnetic Pattern Exercise opposite. This was one of the parts of the ocean where the sea floor spreading hypothesis was first tested.

FURTHER READING

For students: 'Co-ordinated Science - The Earth', P. Whitehead, 1992, pub. Oxford University Press, pages 107 and 101.

For teachers: 'Aspects of Geology', P. Kennett and C. Ross, 1989, pub. Longman, pages 131 - 135.

SOURCE/AUTHOR

Peter Kennett, High Storrs School, Sheffield; Chris King, Altrincham Grammar School for Boys; and Peter York, King Edward VII School, Sheffield. The Magnetic Pattern Exercise is based on a Crustal Evolution Education Project activity. CEEP activities are published by the Southeast Missouri State University, USA.

magnetisation. Where the age of the rocks is given, write this next to the symbol. Station 2 has already been plotted on the map.

After you have marked all of the normal and reversed symbols and the ages that are given for some locations, draw a straight line to connect all the stations where the rocks are of present age.

Draw one straight line through each group of rocks that is 10 million years old.

Mark on the location of the mid-ocean ridge, which is the area where the crust is being pulled apart.

Suggest how this pattern might have developed.

Figure E5.2 A simulated ocean floor made with a shaded piece of paper and magnetised pins.

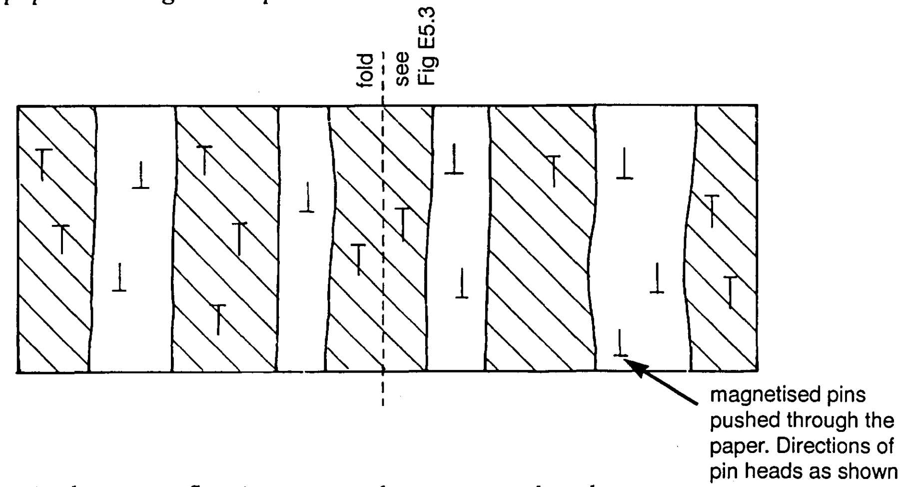
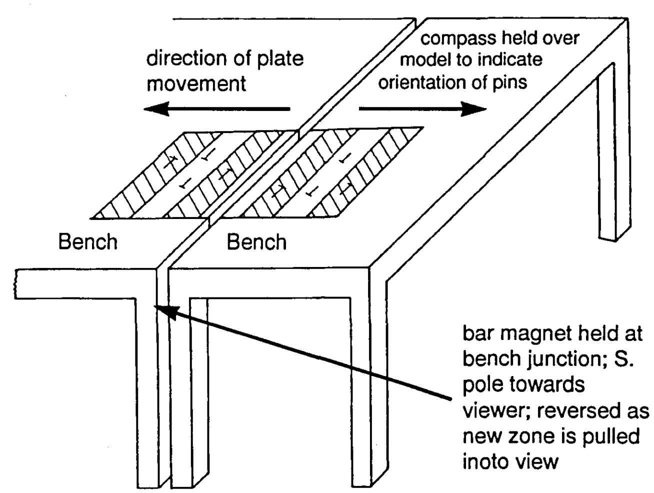


Figure E5.3 The 'ocean floor' appearing between two benches.



ACTIVITY E6 Rockforce - investigating pressures on the rocks beneath your feet

Contents Laboratory investigation into the increase in pressure with depth in the Earth.

Aims To show that pressure increases with depth and can be related to rock density.

Time 30 minutes.

Assumed knowledge An understanding of the relationship between an applied force, the area over which it acts and the resulting pressure.
Understanding of density.

Requirements : Each group requires: top pan balance; 250 ml measuring cylinder; water; 2-3 kg dry sand; ruler/ callipers.

BACKGROUND

A cross section of the Earth shows a number of concentric zones. These zones are recognised by the physical properties of the rocks found within them. The properties are linked to the chemical composition of the rocks and the pressure and temperature found at depth.

Both pressure and temperature increase with depth and the increase in pressure is a result of the mass of overlying rock. This investigation shows how pressure is related to depth. In the investigation, measurements are taken of the force on an area of rock material as it is buried deeper and deeper. Sand is used instead of rock for ease of handling.

THE ACTIVITY

1. Place the empty measuring cylinder on the top pan balance and find its mass. Enter the details in Part A of the Rockforce Worksheet.
2. Use a ruler or callipers to measure the internal diameter of the measuring cylinder as illustrated in Figure E6.1. Enter the details in Part B of the Worksheet and calculate the radius, r.
3. Calculate the area of the base of the cylinder as shown in the Worksheet. Record the answer in Part C.
4. Fill the measuring cylinder with sand to a depth of 2cm.
5. Find the mass of the measuring cylinder containing the sand. Record its mass in Part D column 2 of the table on the Worksheet.
6. Calculate the mass of the sand by subtracting the mass of the cylinder (recorded in Part A of the Worksheet) from the mass of the cylinder and sand. Record the mass of the sand in Part D column 3 of the table.
7. Convert the mass of the sand in g to its mass in kg by dividing by 1000. Record this in Part D column 4 of the table.

Rate of increase of pressure with depth (deduced from the graph) is :

$$\frac{0.275\ \text{N/cm}^2}{8\ \text{cm}} \quad \text{or } 0.034\ \text{N/cm}^2\text{/cm}$$

Pressure at 1 km (1000 m or 100,000 cm) is 3.4×10^3 N/cm^2

Pressure at 10 km is 3.4×10^4 N/cm^2

Pressure at 100 km is 3.4×10^5 N/cm^2

Pressure at 1000 km is 3.4×10^6 N/cm^2

DEVELOPMENT

The investigation could be repeated using 2 cm depths of water instead of sand to find out if the line drawn on the graph as a prediction for water was correct.

A further extension, having drawn the graph for water would be to calculate the water pressure at the bottom of the Marianas trench which is 11,055 m deep - the deepest area of water in the world.

Further investigations can be carried out using other materials such as cut blocks of rock or a sand/cement mixture cast as discs of the same size.

This exercise could be linked to Activity E1 - Model Earth.

FURTHER READING

This activity is based on Science of the Earth Unit 14 ‘A Hot Tight Squeeze in Inner Space, Investigation A’ by D. B. Thompson, 1991, pub. ESTA.

SOURCE/AUTHOR

The activity was devised by John Reynolds, Stoke-on-Trent, and Maggie Williams, Birkenhead Sixth Form College, based on Investigation A in ‘Science of the Earth’, Unit 14.

8. Calculate the force in newtons (N) using the formula:
   force = mass of the sand (Part D, column 4) x 10.
   (N.B. The gravitational force acting on one kilogram on the surface of the Earth is 9.8 N. This has been rounded to 10 N in this exercise.)
   Record the results in the table Part D column 5.
9. Calculate the pressure using the formula:

$$\text{pressure} = \frac{\text{force}}{\text{area}} = \frac{\text{(result recorded in Part D, column 5)}}{\text{(result recorded in Part C)}}$$

   Record the results in Part D column 6.
10. Add a further 2cm depth of sand to the measuring cylinder.
11. Repeat instructions 5 to 9 with 4cm, 6cm and 8cm depths of sand in the measuring cylinder.
12. Plot and label a graph of depth of sand (Part D, column 1) against pressure (Part D, column 6) as shown in E6.2.
13. Return the sand to the container.

FOLLOW UP

1. What conclusions can be drawn from the graph?
2. Imagine the investigation was repeated using a) water and b) iron filings (iron filings are used to represent minerals in the Earth that are denser than the minerals in sand). Where would you sketch the lines on the graph showing depth against pressure?
3. Using the sand line plot, calculate the pressure from sand of thickness 1 km, 10 km, 100 km and then 1000 km.
4. Calculate the rate of increase of pressure with depth from the sand graph.

EXPLANATION

1. Pressure increases in direct proportion to depth.
2. The water line would be drawn below the line for sand. The iron filings line would be drawn above the line for sand.
3. The answers depend upon results recorded by the students. A typical set of results is shown in the completed worksheet and plotted on Figure E6.2. These give the following figures:

Figure E6.1 The measuring cylinder on a top pan balance

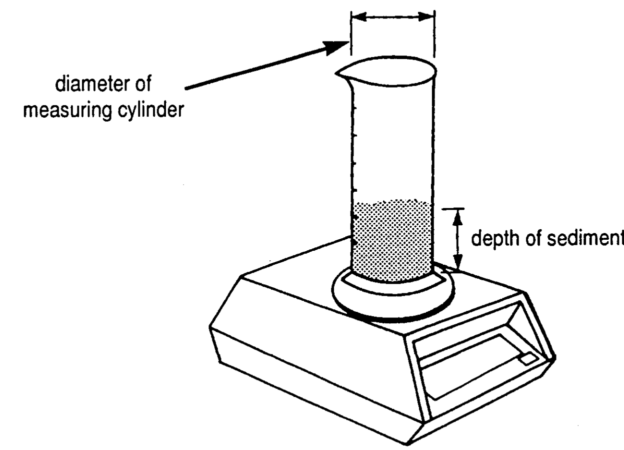
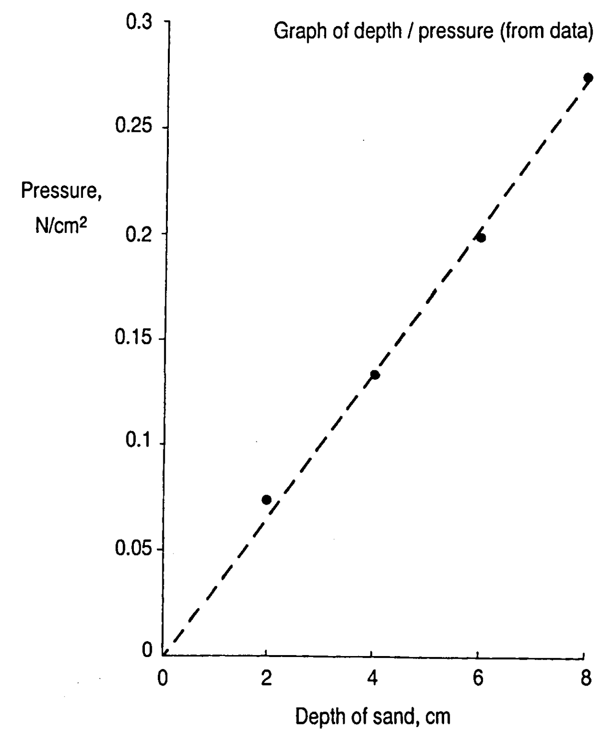


Figure E6.2 The specimen results from the completed worksheet used to plot a specimen graph.



ACTIVITY E7

Plates in motion

Contents	Modelling plate boundaries.
Aims	To illustrate some of the features of plate boundaries.
Time	30 minutes
Assumed knowledge	Awareness of plate tectonic processes.

Requirements

For the main activity, for each group:

6 paper clips; 2 wooden blocks approximately 10 cm by 6 cm by 2 cm; 1 white paper serviette; 1 coloured paper serviette; Sellotape; piece of cardboard, approximately 30 cm by 20 cm; strip of thin card.

For the development activity:

The requirements are the same but the cardboard should have a slit cut in the centre.

Open University/Esso 'Geological Map of the World' wallchart.

BACKGROUND

In some areas of the world, tectonic plates are converging. Where an oceanic and a continental plate collide, the oceanic one sinks beneath the continental one, into a **subduction zone**. The descending plate material is melted or assimilated into the surrounding rock. The plate boundaries where this occurs are called **destructive plate boundaries**. On the Earth's surface the locations of destructive boundaries can be recognised by the presence of deep ocean trenches such as the Marianas trench or the Peru-Chile trench.

In other areas of the world plates are moving apart. This usually occurs in oceanic areas such as in the centre of the Atlantic Ocean. Along the margin where the plates are moving apart, referred to as an **oceanic ridge** or **rise**, magma is intruded creating new oceanic plate material. Such a zone is called a **constructive plate boundary**. The new oceanic plate is gradually covered by layers of sediment as it is moved away from the ridge. The 'Geological Map of the World' wallchart, published by the Open University, illustrates this process well, both in the map and in the diagram at the foot of the chart.

The activity involves making a model to show what happens when two continents are brought together by plate movement, an example being the collision of India and Asia in the geological past.

THE ACTIVITY

Make the model as shown in Figure E7.1.

Your model represents an area of the Earth's surface where two plates are moving towards each other with one plate being subducted as the other plate rides over the top.

Figure E7.2 illustrates the Earth's lithosphere where two plates are moving together.

FURTHER READING

This activity is based on Science of the Earth, Unit 16 'The Earth's patchwork quilt - an introduction to plate tectonics', by Philip Lee, 1990, pub. ESTA.

SOURCE/AUTHOR

This activity was devised by Peter York, King Edward VII School, Sheffield, based on an activity in 'Science of the Earth', Unit 16.

Figure E7.1 The model destructive plate boundary.

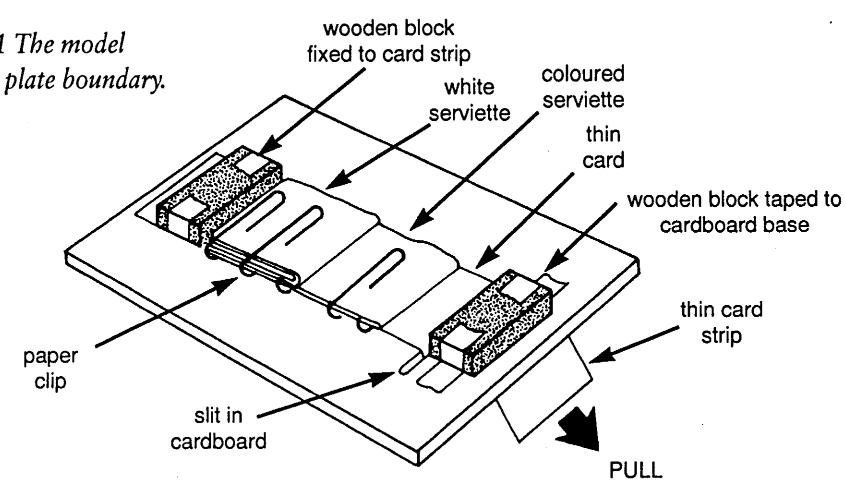


Figure E7.2 A destructive plate boundary in cross-section.

Compare your model with the diagram. Which parts of your model represent continents? Which part of your model represents sediment on the sea bed? Which part of the model represents the area where the plate is being subducted?

Now pull gently on the thin card strip where it sticks out from the base of the model until the two 'continents' do not come any closer together .

FOLLOW UP

Describe what happens to the 'sediments' on the 'sea bed' of your model.

Draw a diagram to show what your model looks like in cross section.

Which parts of Figure E7.2 are represented in your diagram?

EXPLANATION

The wooden blocks represent the continents while the serviettes represent sediments on the sea bed. The slit in the cardboard where the paper strip can be pulled through represents the area where the plate is being subducted.

As the two plates are pulled together the serviettes should fold and will also slide up over each other simulating the type of structures associated with colliding plates.

DEVELOPMENT

Make a model of a constructive plate boundary based on the diagram in Figure E7.3. Use a cardboard base plate with a central slit, two wooden blocks, strips of paper and coloured serviettes.

The students should use the two wooden blocks as continents as in the previous activity. The slit represents the mid oceanic ridge. The wooden blocks represent continental crust. Each block is attached to a strip of card. These are placed on either side of the slit as shown in Figure E7.4. The strips of card represent the ocean floor created as the blocks are moved apart. Coloured serviettes or tissue paper, representing sediments deposited on the sea bed, are laid at intervals on the sea bed. Each serviette will cover a larger area than the previous one. The final result is represented in Figure E7.4.

A study of the Open University 'Geological Map of the World' wallchart highlights destructive plate boundaries and oceanic ridges. The insert diagram in the centre at the bottom of the wallchart shows other features associated with these zones.

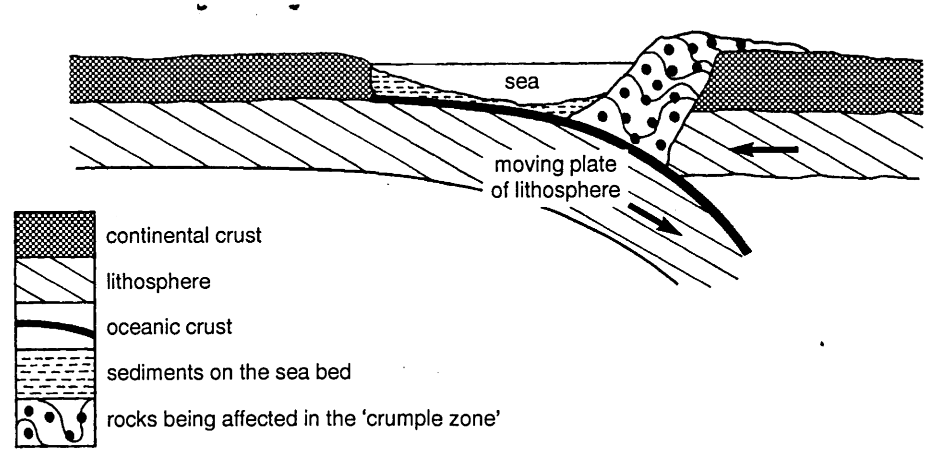
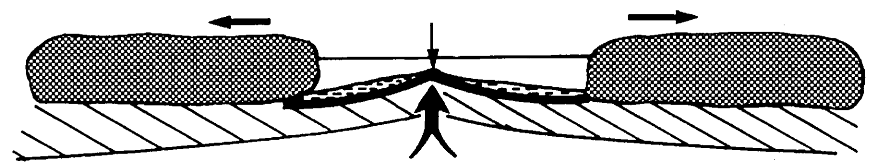
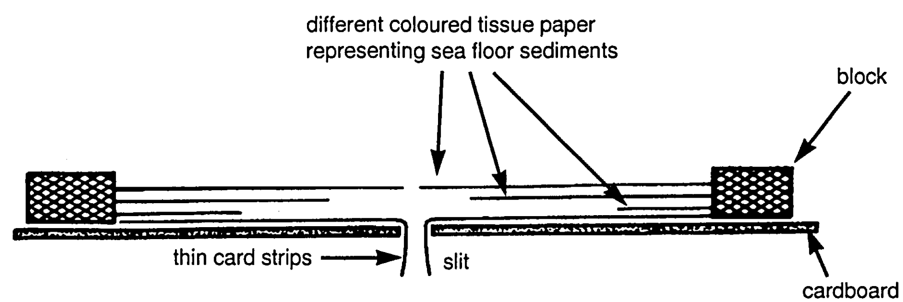


Figure E7.3 A constructive plate boundary in cross-section.



Key as Figure E7.2 above

Figure E7.4 The model constructive plate boundary.



ACTIVITY E8

Plate tectonics - the earthquake and volcano evidence

Contents A study of the evidence for plate tectonic theory from the distributions and types of earthquakes and volcanoes on Earth.

Aims To deepen understanding of plate tectonic theory.
To illustrate the differences between scientific fact and theory and to show how one is used as evidence for the other.

Time 70 minutes for the activity and discussion.

Assumed knowledge A general understanding of plate tectonic theory.

Requirements Copies of Figures E8.1 and E8.2.
Open University/Esso 'Geological Map of the World' wallchart.

BACKGROUND

A good deal of the evidence for plate tectonic theory requires high level understanding. However evidence from the distributions and types of earthquakes and volcanoes is relatively easy to understand and is the basis of this activity. The activity gives the opportunity for students to distinguish between observation and theory and to appreciate how evidence is used to support theories.

THE ACTIVITY

Figure E8.1 on the final pages of this book is a map of the Earth showing volcanoes, shallow, intermediate, deep focus earthquakes and plate boundaries.

Figure E8.2 also printed at the back, shows part of the Earth's surface and a cross section through the Earth which shows how the features shown in Figure E8.1 may be interpreted in terms of plate tectonic theory.

Link the evidence to the diagram which shows how the theory works by answering these questions:

1. Which of the following features shown on Figure E8.1 are:

a) known to be there (observable, scientific facts)

b) believed to be there according to plate tectonic theory?

continental crust; oceanic crust; different types of plate boundary; volcanoes; shallow focus earthquakes, intermediate focus earthquakes and deep focus earthquakes.

2. On Figure E8.1, where the Indo-Australian plate meets the Pacific plate north of New Zealand there is an 'active zone' of earthquakes and volcanoes. This is like the 'subduction zones' shown on Figure E8.2. What evidence from Figure E8.1 indicates that the subduction zone of the Pacific plate slopes down towards the west? This same evidence indicates that it is the Pacific plate that is being subducted here and not the Indo-Australian plate.

FOLLOW UP

How can the global distribution of the following be used as evidence to support the theory of plate tectonics?

a) earthquakes;

b) volcanoes.

DEVELOPMENT

The students could draw a cross section diagram, similar to the front edge of Figure E8.2 from North Africa to the Caribbean to show the major plate tectonic processes in the North Atlantic Ocean. Students could also be asked what evidence in Figure E8.1 may suggest that two regions of continental crust carried by moving plates had collided in the past as in the case of northern India and Asia in the Himalayan region.

FURTHER READING

'Geological Map of the World', 1994. Pub. The Department of Earth Sciences, The Open University.
Science of the Earth Unit 16 'The Earth's patchwork crust- an introduction to plate tectonics', by Philip Lee, 1990, pub. ESTA.

'Coordinated Science: The Earth', P. Whitehead, 1992. Pub. Oxford University Press. pages 100-105.

SOURCE/AUTHOR

This activity was devised by Peter York, King Edward VII School, Sheffield, and Chris King, Altrincham Grammar School for Boys. The activities are based on diagrams taken with permission from the Open University/ Esso 'Geological Map of the World' referred to above.

3. What evidence from Figure E8.1 shows that the Nazca plate is being subducted beneath the South American plate?
4. What evidence from Figure E8.1 shows that the boundary between the Pacific plate and the Nazca plate is **not** a subduction zone?
5. A comparison between Figures E8.1 and E8.2 shows that the boundary between the Pacific and the Nazca plates is an oceanic ridge and a constructive plate margin.

a) What type of earthquakes, shallow, intermediate or deep focus, are most commonly found at the margin between the Pacific and Nazca plate?

b) The general absence of the other two types of earthquake may be used to determine that the properties of the rock must be different from those at subduction zones. Suggest what those differences are and describe what this pattern of earthquakes tells us generally about the changing properties of the rocks with depth in the area of the Pacific/Nazca boundary.

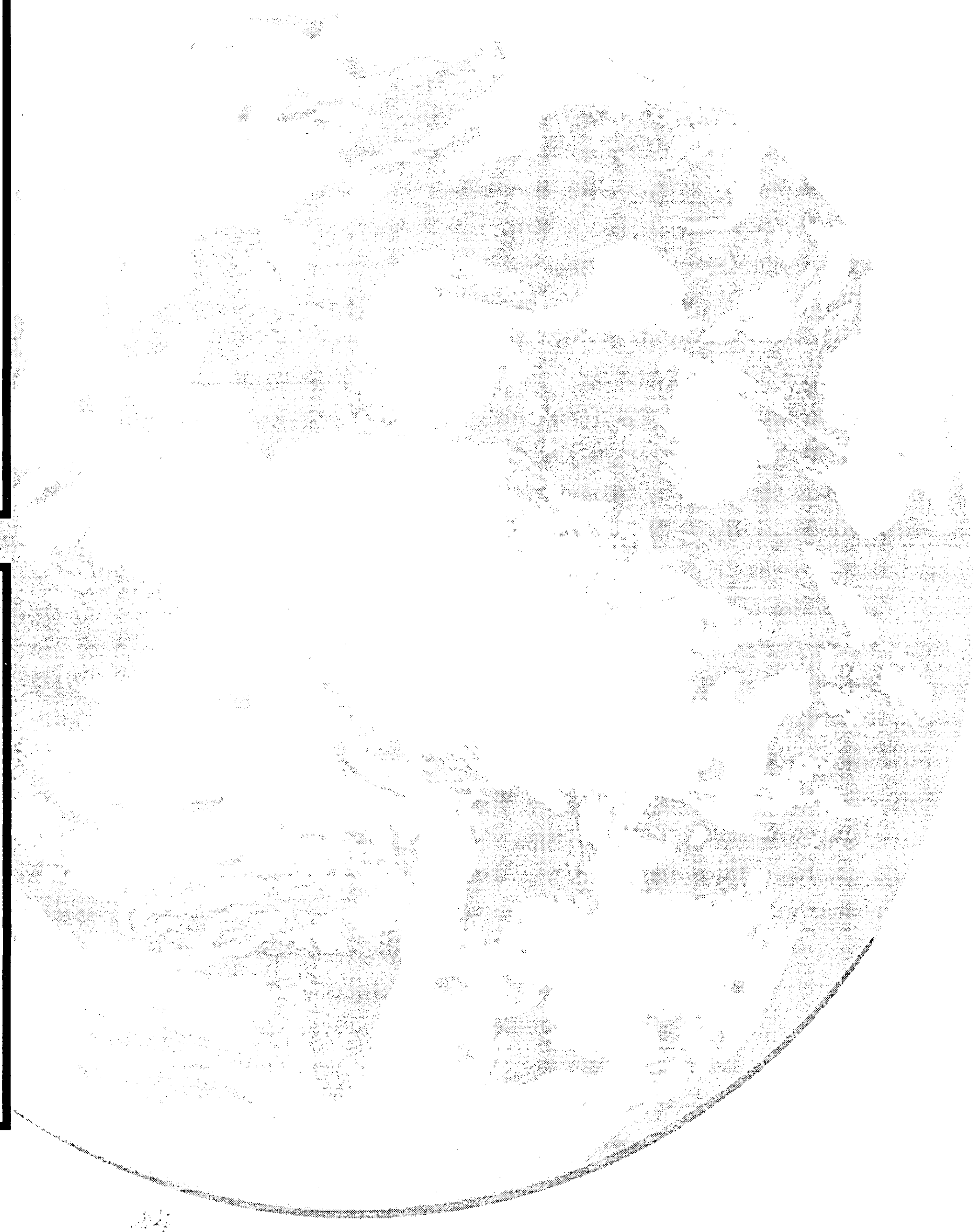
6. Figure E8.1 shows that we find some volcanoes away from the edges of plates and these volcanoes are sometimes aligned. How does the plate tectonic theory diagram, Figure E8.2, explain this alignment?

EXPLANATION

The scientific facts shown on Figure E8.1 are the positions of the volcanoes and earthquakes and the distributions of the oceanic and continental crust; it is the plate boundaries which are the interpretations from plate tectonic theory.

Earthquake evidence indicates the subduction directions of plates. North of New Zealand the westward subduction of the Pacific plate is shown by earthquake foci becoming deeper towards the west, whereas the eastward subduction of the Nazca plate is shown by the deepening of foci towards the east. The presence of shallow focus earthquakes only at the Pacific/Nazca plate boundary shows that this is not a subduction zone and that the brittle rocks of the lithosphere there cannot be more than 100 km thick. Note that faulting, causing earthquakes, can only occur in the brittle lithosphere, not in the more ductile asthenosphere beneath.

The lines of volcanoes that occur away from plate margins are explained by plate movement over a rising 'plume' of hot material from the asthenosphere. As the plate moves, the magma 'punches through' the lithosphere at intervals producing the volcanic alignment.



ACTIVITY E9

Drifting continents

Contents	Students study maps to recognise the movement of the land masses through geological time. They plot on a graph the details of Britain's changing position.	**Time**	60 minutes minimum.
Aims	To illustrate evidence for Britain's northward movement over geological time and its passage through different climatic zones.	**Assumed knowledge**	Knowledge of latitude and longitude.
		Requirements	The Open University/Esso 'Geological Map of the World.'

BACKGROUND

Figure E9.1, originally published at the foot of the Open University/Esso 'Geological Map of the World' wallchart, illustrates how the positions of the continents on the Earth's surface have changed throughout geological history. The British Isles, as part of a large portion of the Earth's crust, called a plate, have been part of this movement. As the British Isles have moved northwards they have passed through different climatic zones including equatorial, tropical, temperate climates, etc.

Each climatic zone has had environments in which sediments accumulated. Some of these sediments were deposited in land environments, for example rivers and deserts, whilst other sediments were deposited in the sea. Particular rock types are often associated with certain climatic zones and environments. For example, in equatorial swamps dead vegetation may accumulate in addition to sands and muds. This vegetation may eventually be preserved as coal which is thus an 'indicator' of an equatorial climate. The occurrence of some of these 'indicator' rocks in the stratigraphical record of the British Isles illustrates how the climate of the area we now call the British Isles has changed as a result of its northward movement.

THE ACTIVITY

Part 1: Understanding the map sequence.

Students should study the map sequence shown in Figure 9.1 in the final pages of this book. They could:

a) appreciate that the six maps represent different geological periods in time order: Cambrian, Devonian, Carboniferous, Permian/Triassic, Jurassic, Cretaceous/Tertiary.

b) recognise the Equator separating the northern and southern hemispheres.

c) study the movement of particular continents through geological time and their changing positions relative to the Equator, poles, northern or southern hemisphere.

d) recognise the changing positions of continents relative to each other.

geological time (millions of years ago)	location on Earth (latitude)
500	28° South
380	
340	
300	
250	
220	
170	
100	
50	
0	

The information can also be used to plot a graph and Figure E9.3 (final pages of book) illustrates the type of graph that could be produced, including geological time, periods and latitude.

Part 3. Travel across climatic belts.

As the British Isles have been moved northwards, they have crossed different climatic belts. Conditions in these climatic belts might be summarised as:

Polar	found between latitudes 70 and 90 degrees north and south of the Equator
Temperate	found between latitudes 45 and 70 degrees north and south of the Equator
Mediterranean	found between latitudes 30 and 45 degrees north and south of the Equator

e) recognise the changing location of the British Isles. Note, for example, on the Cambrian map that the British Isles were 'split' between North America and Europe.

f) note the names given to some of the continental areas that existed in the geological past. For example, Pangaea, Gondwanaland and Laurasia. Also note the names of some of the seas, Tethys for example.

The students could summarise these observations in table form, such as:

geological period	age (millions of years before present day)	position of Europe	position of North America	other notes
Cretaceous / Tertiary				
Jurassic				
Permian/ Triassic				All the modern continents were joined together as one continent called Pangaea, with a sea called Tethys between Africa and Europe / Asia
Carboniferous				
Devonian				
Cambrian	520	south of the Equator	on the Equator	

Part 2: The changing location of the British Isles.

Figure E9.2 summarises the position of the British Isles at various times throughout geological history. For example, 500 million years ago during the Ordovician period 'the British Isles' were located in the southern hemisphere at approximately 28 degrees south. Similar interpretations could be made from Figure E9.2 to produce a summary table, as follows:

Arid / Semi arid	found between latitudes 15 and 30 degrees north and south of the Equator
Equatorial	found between latitudes 0 and 15 degrees north and south of the Equator

This information could be transferred on to the graph previously completed in Part 2 of this activity to recognise the zones the British Isles have passed through in their geological history and at what times (see Figure E9.3). Also see Activity E10.

DEVELOPMENT

Using an atlas, selected climatic zones could be located and information collated on the range of temperatures, rainfall and vegetation types found in those areas today, as a guide to the type of environment that existed in the geological past.

FURTHER READING

'Geological Map of the World', 1994, Pub. The Department of Earth Sciences, The Open University.

'The British Isles through Geological Time', J.P.B, Lovell, 1977, Pub. Allen and Unwin.

SOURCE/AUTHOR

This activity was devised by Peter York, King Edward VII School, Sheffield, and Chris King, Altrincham Grammar School for Boys. It was based, with permission, on diagrams from the 'The British Isles through Geological Time' and the 'Geological Map of the World' detailed above. The maps in Figure E9.1 are redrawn from 'The Way the Earth Works', P. J. Wylie, 1976, pub. Wylie, originally in Deitz and Holden, Jour. Geophys. Res. 75.

ACTIVITY E10 *Britain's changing location – evidence from the rocks*

Contents Students study data to identify that different climates and environments have existed in the past in the British Isles. The changing climates and environments are used as evidence for Britain's northerly movement through geological time.

Aims To illustrate how the character of the sedimentary rocks formed in different geological periods can be associated with particular environments and climatic zones.
To show that this evidence can be used to illustrate Britain's movement through geological time.

Time 20 minutes.

Assumed knowledge Completion of Activity E9.

Requirements Figures E10.1 and E10.2; atlas.

BACKGROUND

As the British Isles have moved northwards they have passed through different climatic zones including equatorial, tropical, temperate, etc. Each climatic zone has environments in which sediments accumulate. Some of these sediments are deposited in land environments, for example rivers and deserts, whilst others are deposited in the sea.

Particular rock types are often associated with certain climatic zones and environments. For example, in equatorial swamps dead vegetation may accumulate in addition to sands and muds. The vegetation, eventually preserved as coal, is thus an 'indicator' of an equatorial climate. The occurrence of some of these 'indicator' rocks in the British stratigraphical record illustrates how the climate of the area we now call the British Isles has changed as a result of its northward movement on the back of the Earth's tectonic plates. Figure E10.1 summarises the types of environments that are associated with different climatic zones and typical examples of the varieties of sedimentary rocks formed in those environments.

THE ACTIVITY

Ask the students to:

a) study the table in Figure E10.1 (final pages of this book) to recognise the different climatic zones.

b) use an atlas to see the location of these zones today.

c) identify the climatic zone that the British Isles is in today and consider the type of sediments being deposited now in the rivers, lakes and seas of Britain.

Figure E10.2 is a simplified diagram of the geological sequence found in and around Bristol. It displays the geological periods and the types of rocks deposited at those times. The table is drawn to scale.

Ask the students to construct a table on an A4 piece of paper that can be added to the right

Answers:

Devonian red sandstones for building.

Carboniferous limestone for building; the chemical industry; making lime for use on acid soils; making cement; providing crushed rock aggregate for road-building, foundations, etc.

Carboniferous coal for fuel; for use in the chemical industry.

Triassic red sandstones for building.

Jurassic clays for brick-making and pottery.

Jurassic oolitic limestones for building.

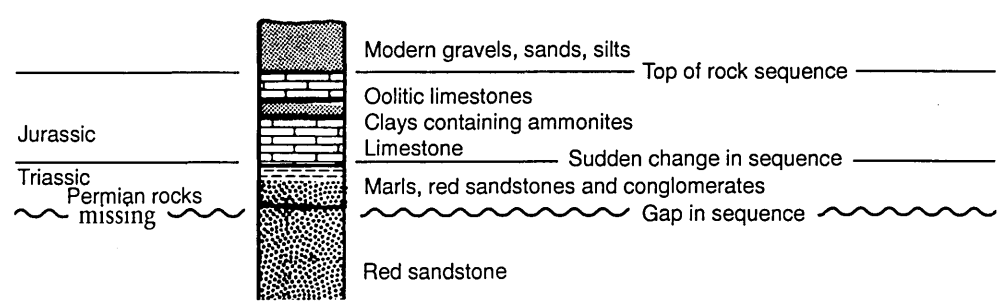
Modern sand and gravel for building materials.

Many of the rocks contain water and act as important aquifers (water source rocks) from which water is pumped to supply the Bristol region.

SOURCE/AUTHOR

This activity was devised by Peter York, King Edward VII School, Sheffield, and Chris King, Altrincham Grammar School for Boys.

Figure E10.2 The geological sequence of the Bristol area. Scale 1mm to 20m.



hand side of Figure E10.2. The table should have the following column headings, from left to right (which are similar to the column headings of Figure E10.1).

Typical sediments laid down that eventually became rocks	Type of environment	Approximate latitude	Climate

The rows of the table should be made by extending the 'Base of sequence' and 'Top of sequence' straight lines onto the A4 sheet, then by extending the 'Sudden change in rock sequence' straight lines and the 'Gap in sequence' wavy lines.

Students can then complete the table by comparing E10.1 and E10.2. The students should start at the bottom of the table and so trace the effects over time from the past towards the present. As such, the lowest section might read as follows:

Typical sediments laid down that eventually became rocks	Type of environment	Approximate latitude	Climate
shales	shallow tidal seas	45° - 90°	polar or temperate

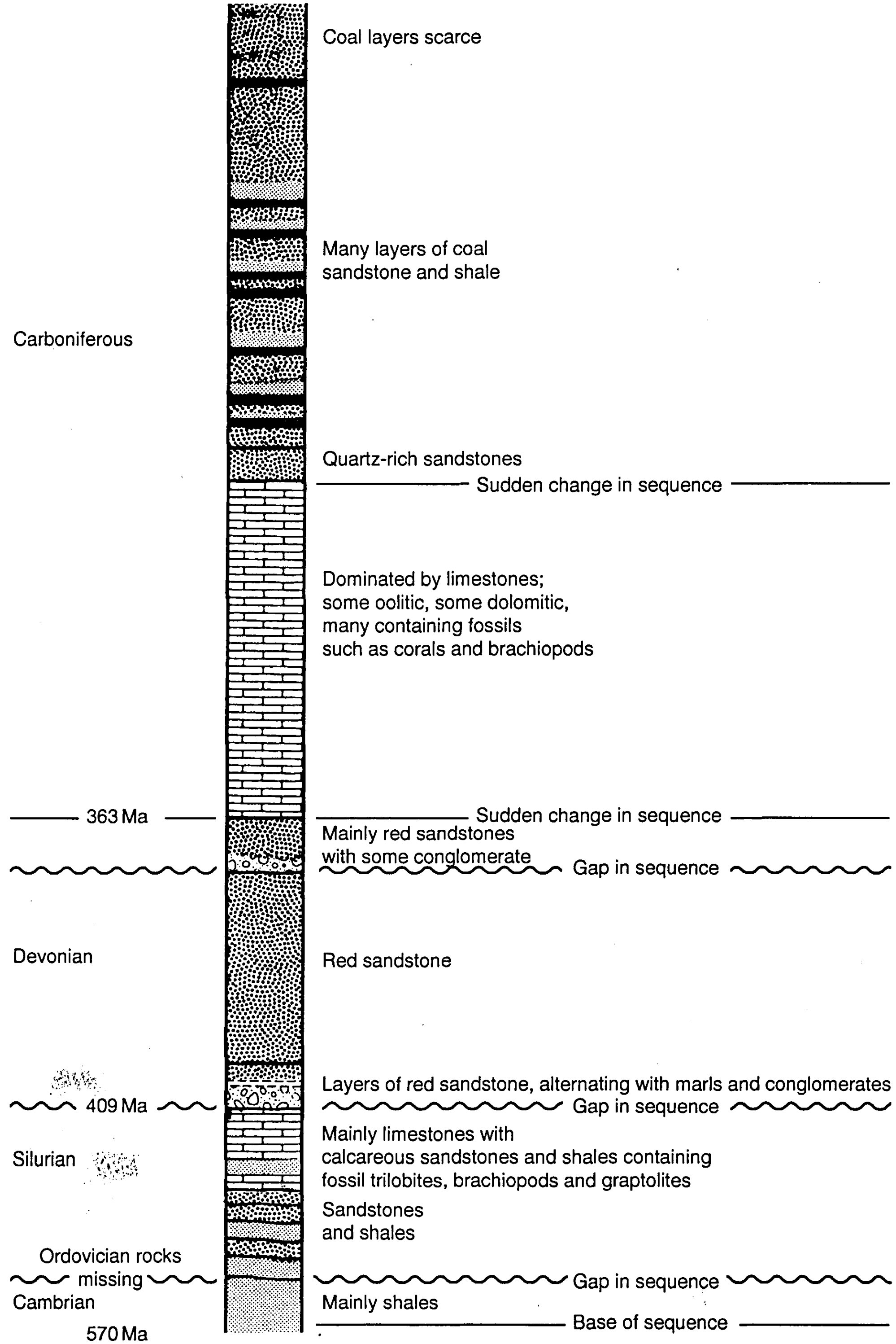
On completion of the table the students may summarise:

1. the evidence that the environment of the Bristol area has changed over geological time, between shallow seas and land.
2. the evidence that the climate of the Bristol area has changed over geological time.
3. how this evidence can be used to support the idea that the area we now call Bristol has moved northward as part of the British Isles over geological time.

DEVELOPMENT

A. Comparisons can be made with the work undertaken in Activity E9 to see how the movement of the Bristol area that students have plotted matches with that recognised in Figure E9.1.

B. The Bristol area is well known for the different sorts of rocks that have been used for a variety of purposes. Which of the rocks listed in Figure E10.2 might be of economic value and for what purposes might they be used?



Additional Diagrams

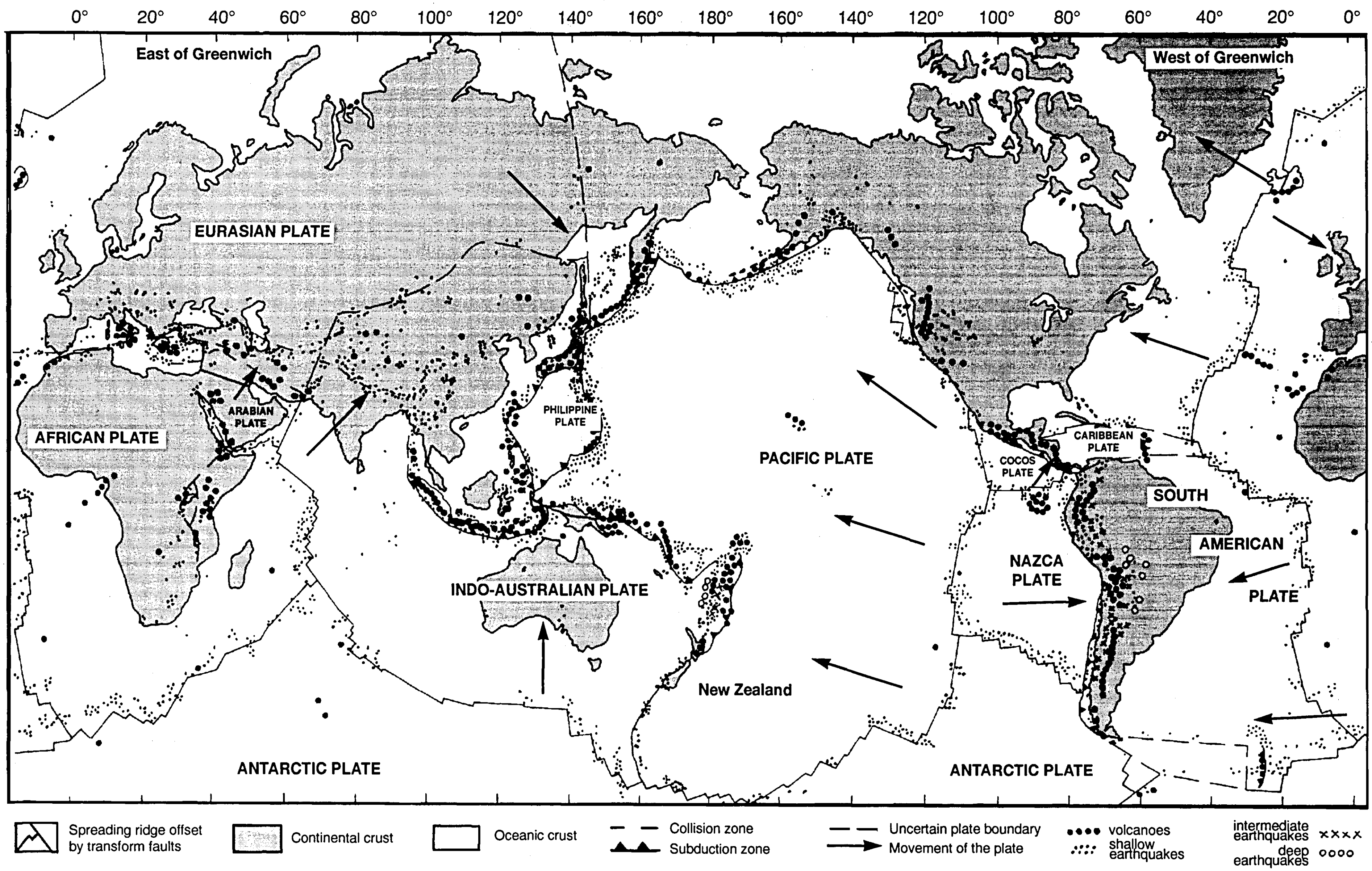
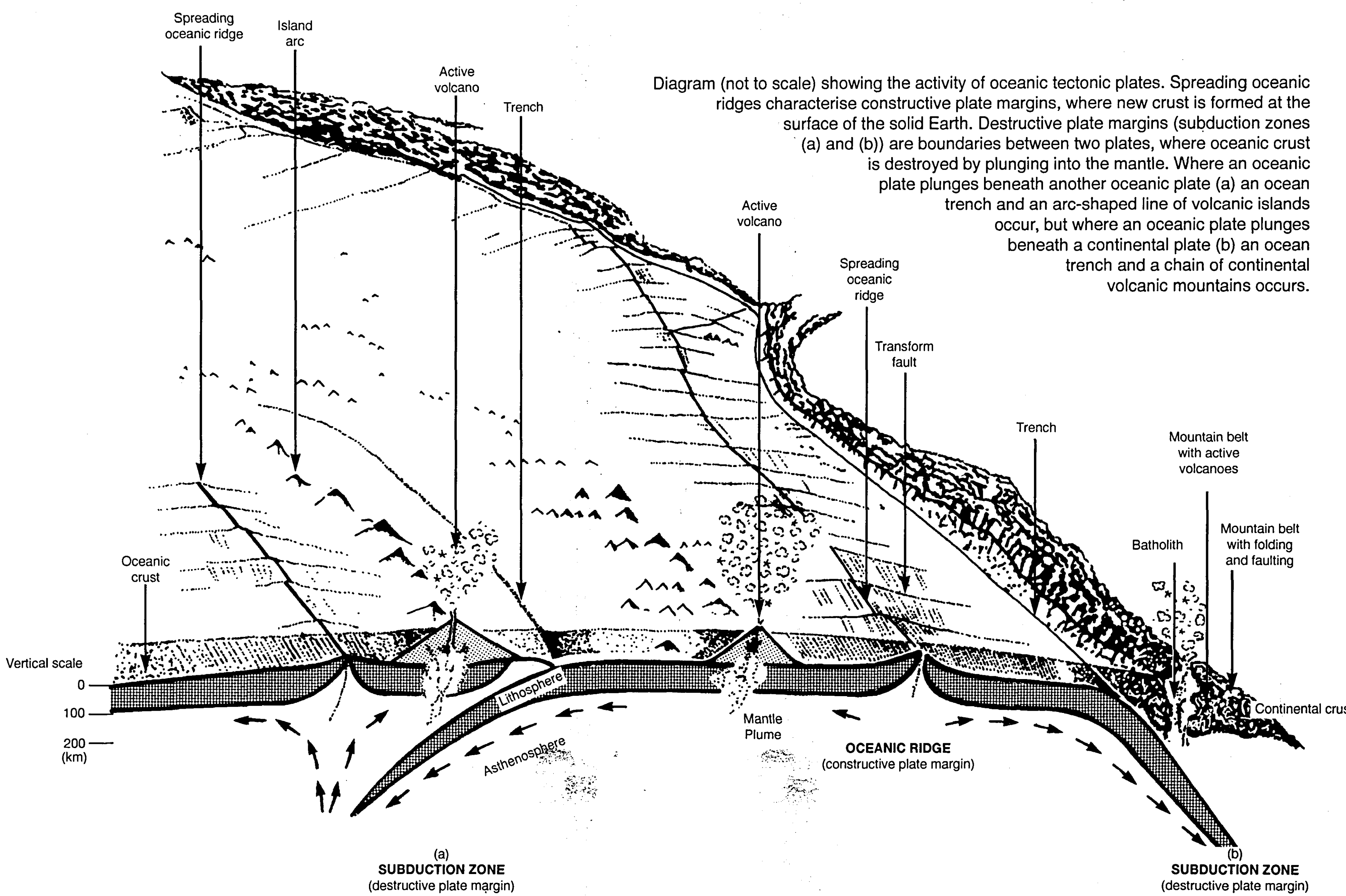


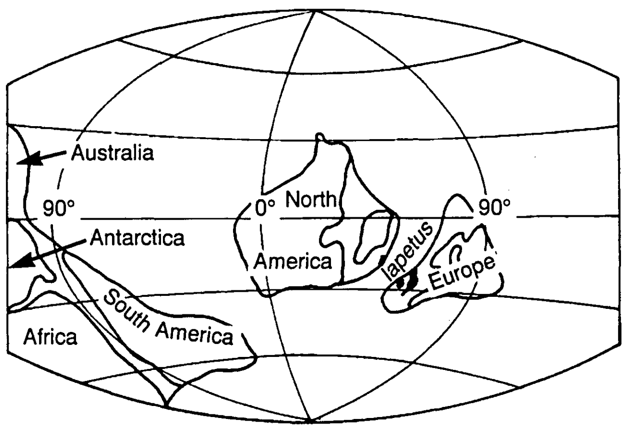
Figure E8.1 The distributions of volcanoes, earthquakes and plate boundaries; taken from the Open University/Esso 'Geological map of the world'.

Figure E8.2 A diagram illustrating how Earth's features may be interpreted through plate tectonic theory.

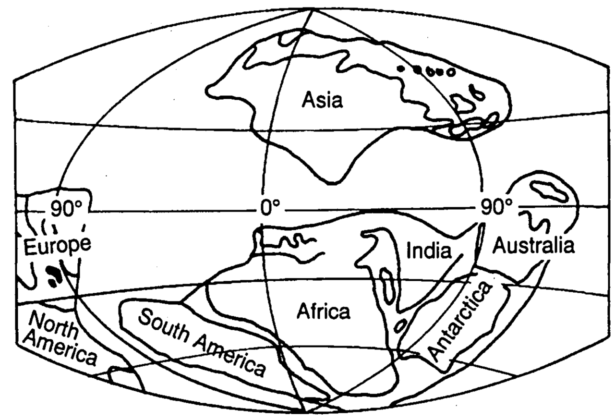


Additional Diagrams

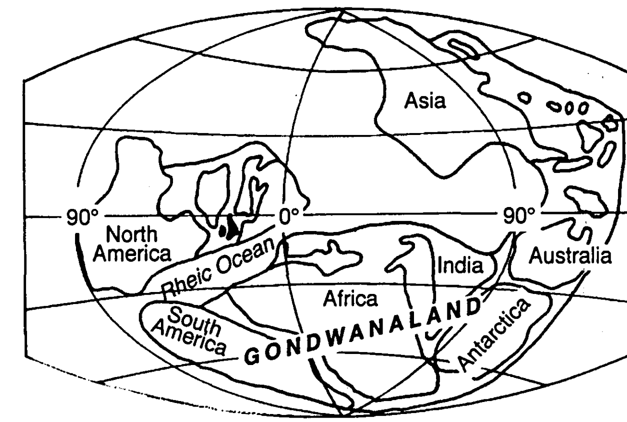
Figure E9.1 The movement of continents over geological time.



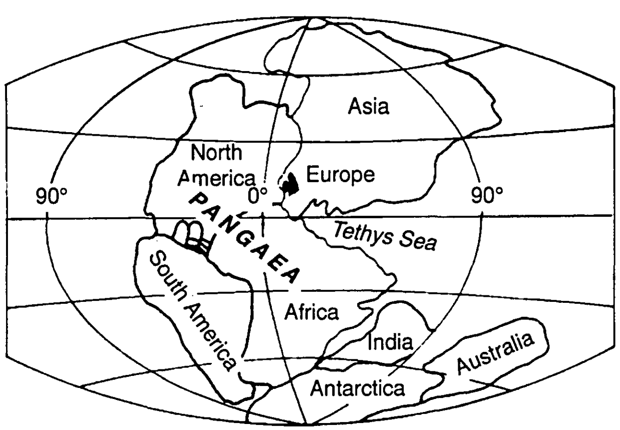
CAMBRIAN
(about 520 million years ago)



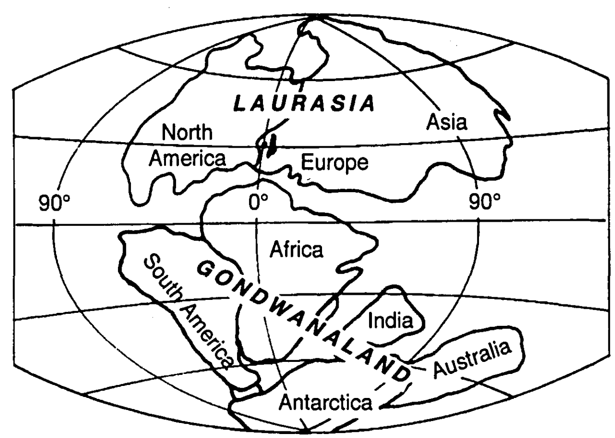
DEVONIAN
(about 380 million years ago)



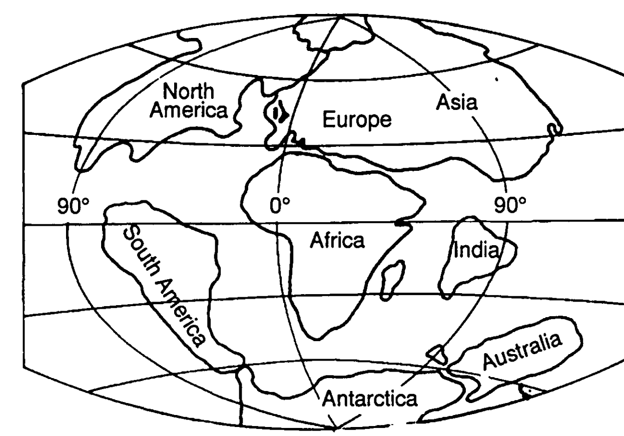
CARBONIFEROUS
(about 340 million years ago)



PERMIAN / TRIASSIC
(about 225 million years ago)



JURASSIC
(about 180 million years ago)



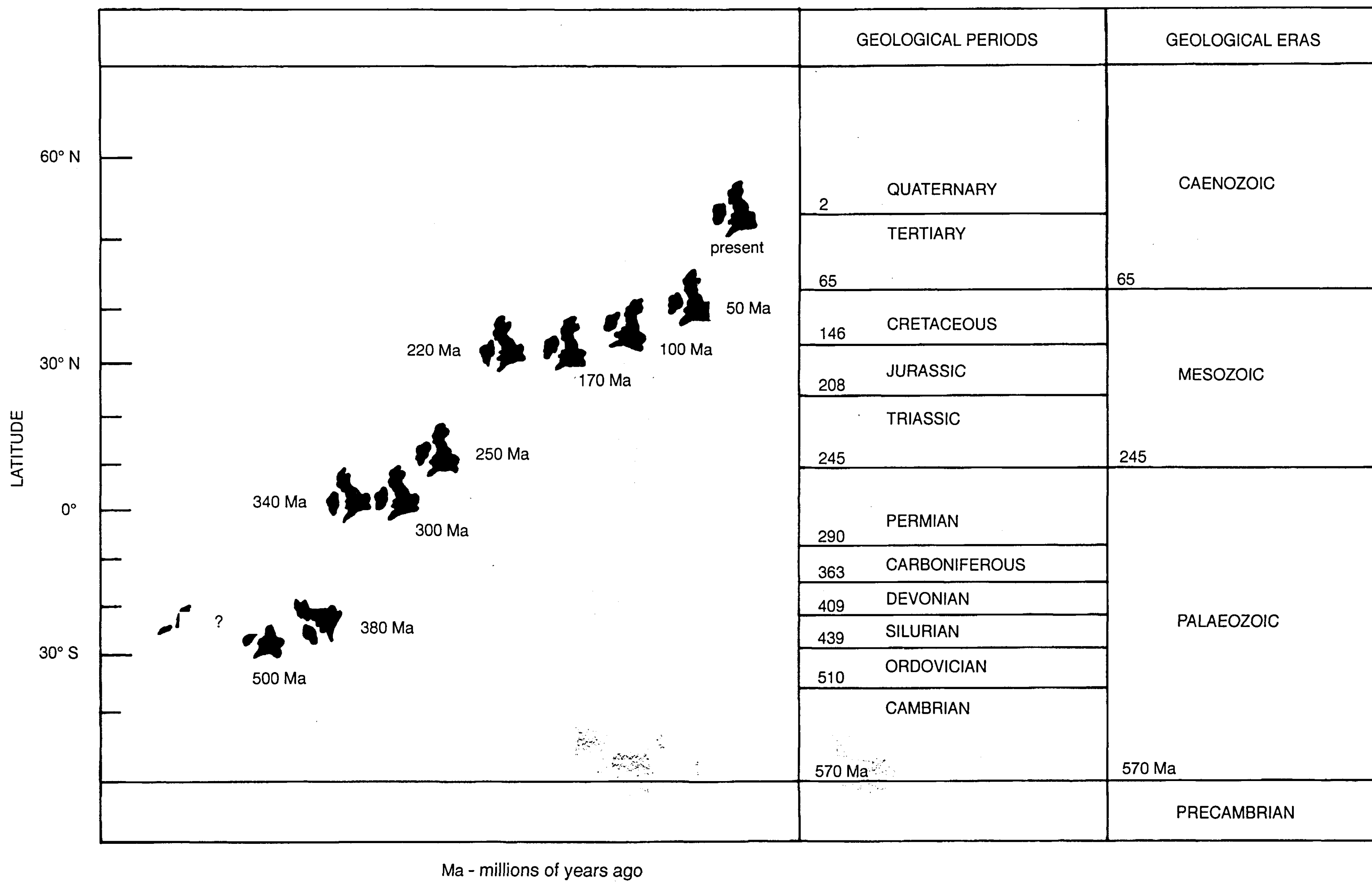
CRETACEOUS / TERTIARY
(about 65 million years ago)

FOLLOW UP

1. What is the direction of travel of the pulses in both cases?

Figure E2.3 Simulating S-waves using a slinky spring.

Figure E9.2 The changing position of the British Isles throughout geological history.



Additional Diagrams

Figure E9.3 The movement of the British Isles over geological time.

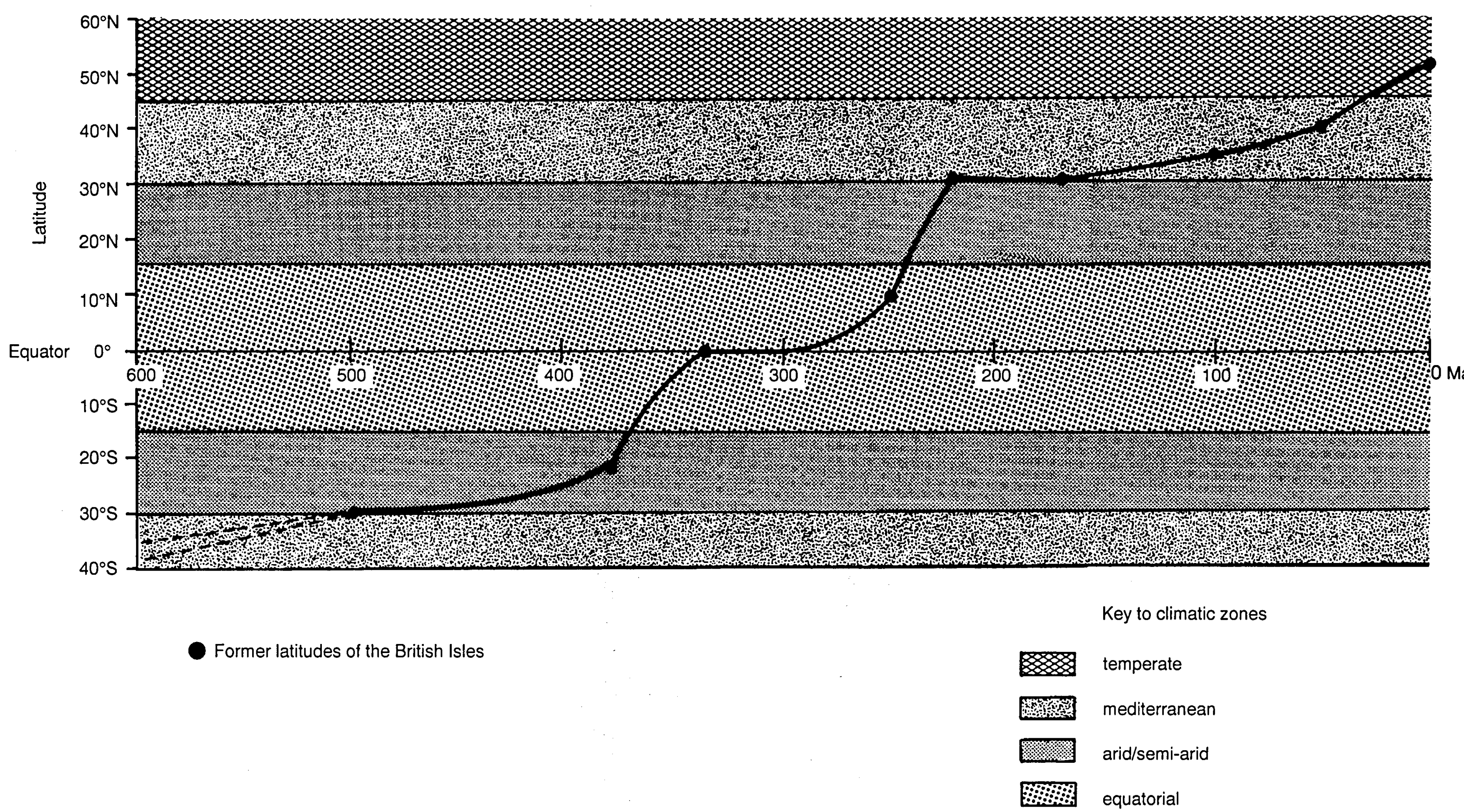
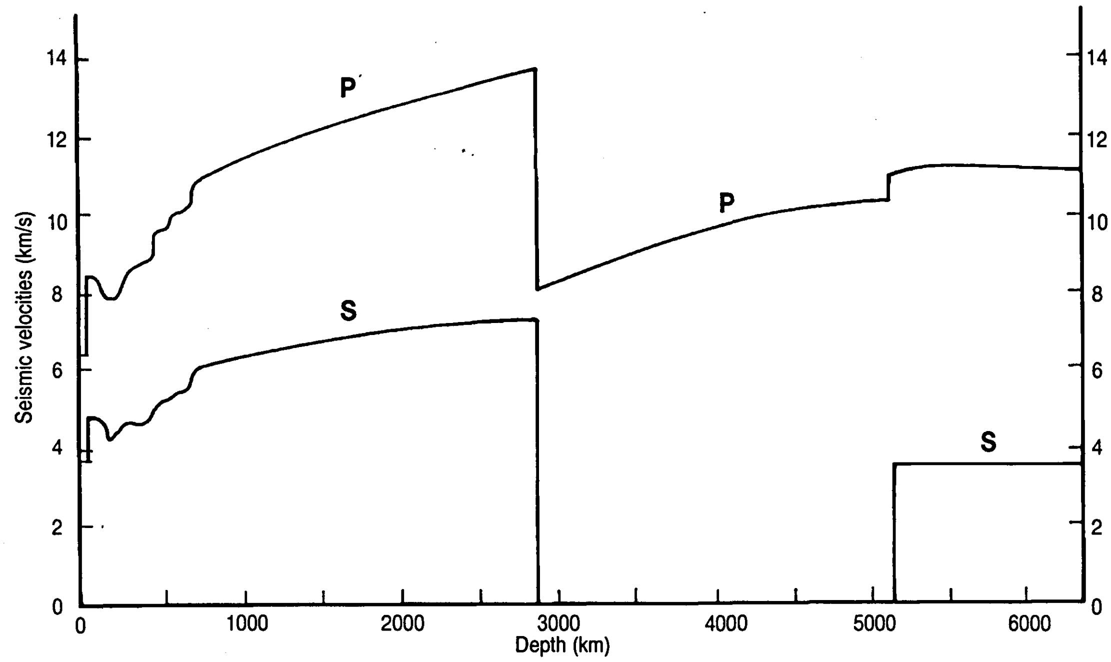


Figure E10.1 Geological characteristics of different climatic zones.

Climate	Latitude	Environment exemplified	Typical sediment laid down	Rocks that could form	Other notes
Polar	70°N - 90°N and 70°S - 90°S	on land: ice-covered or affected by cold .... in the sea: shallow tidal seas	boulder clay; lake silts; .... sands and muds	tillite; varved silts; .... sandstones; mudstones; shales	
Temperate	45°N - 70°N and 45°S - 70°N	on land: rivers .... in the sea: shallow tidal seas	gravels; sands and silts; .... sands and muds	conglomerates; sandstones; siltstones; .... sandstones; mudstones; shales	.... ancient shallow sea rocks may contain fossils such as trilobites, graptolites, brachiopods or ammonites
Mediterranean	30°N - 45°N and 30°S - 45°S	on land: rivers .... in the sea: coral reefs and lagoons in shallow seas	river deposits and soils .... reefs, shelly and oolitic sands	conglomerates; sandstones; siltstones; palaeosols; .... oolitic limestones; shelly limestones	.... ancient rocks may contain fossils such as corals, trilobites, brachiopods
Arid/semi arid	15°N - 30°N and 15°S - 30°S	on land: deserts .... in the sea: coral reefs, lagoons, hot coastal basins	red dune sands; river gravels; lake muds .... reefs, shelly and oolitic sands; salt deposits	red sandstones; conglomerates; evaporites e.g. rocksalt .... oolitic limestones; shelly limestones; evaporites e.g. rocksalt	
Equatorial	15°N - 15°S	on land: equatorial swamps; .... in the sea: coral reefs, and lagoons in shallow areas	sands, muds and thick vegetation; .... reefs and shelly sands	sandstones shales, with coal .... limestones with a wide variety of fossils	coal may contain plant fossils

Waves in the Earth Worksheet

WAVES IN THE EARTH



Seismic velocities plotted against depth below the Earth's surface.

1a. Draw vertical dashed lines across the graph to show where S-wave velocity changes suddenly.

b. Label each of the zones between the lines to show how S-wave velocity changes, for example write, 'wave velocity decreasing'.

2. Why does the S-wave velocity drop to zero at a depth of 2900 km?

3a. In what way is the P-wave velocity plot different from the S-wave velocity plot between the Earth's surface and 2900 km depth?

b. In what way is the P-wave velocity plot similar to the S-wave plot between the Earth's surface and 2900 km depth?

c. Draw vertical dotted lines for the area below 2900 km to show where P-wave velocity changes.

d. Label each of the zones between the dotted lines to show how P-wave velocity changes, for example write 'wave velocity decreasing suddenly' or 'wave velocity increasing gradually'.

4. Use the information provided on the graph to mark and label;

1. the crust; 2. the low velocity zone; 3. the mantle; 4. the outer core; 5. the inner core.

5. Summarise in the spaces provided on the diagram below the properties of the different layers. The low velocity zone is not shown and the properties of the crust have been completed for you.

P- and S-waves pass through the crust, so it is solid. On this diagram, it is shown thicker than it really is, so that it can be seen

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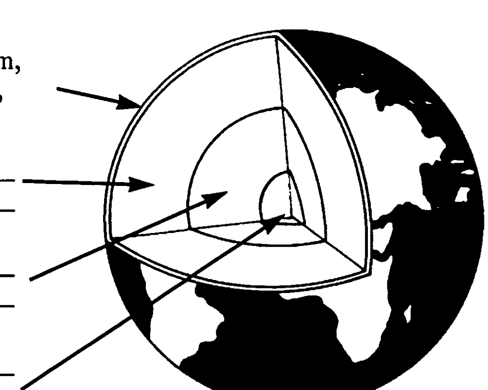
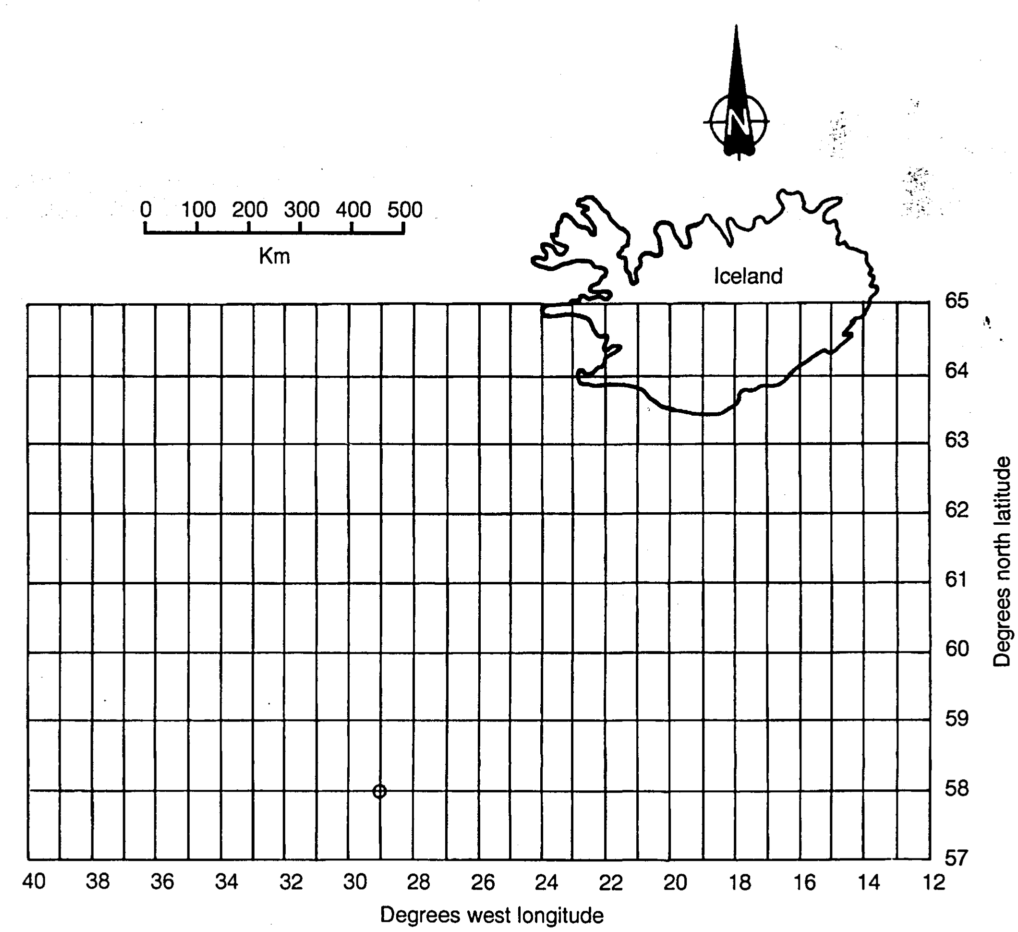


Magnetic Pattern Exercise

MAGNETIC PATTERN EXERCISE

Station	North Latitude	West Longitude	Magnetic Field Orientation	Symbol	Age (Ma = million years)
1	58.0°	28.0°	Reversed	X	
2	58.0°	29.0°	Normal	O	10 Ma
3	58.5°	29.5°	Reversed	X	
4	58.5°	31.0°	Normal	O	Present
5	59.0°	31.5°	Reversed	X	
6	60.0°	32.0°	Normal	O	10 Ma
7	61.0°	33.0°	Reversed	X	
8	60.5°	31.0°	Normal	O	10 Ma
9	60.0°	30.0°	Reversed	X	
10	60.0°	29.0°	Normal	O	Present
11	59.5°	28.5°	Reversed	X	
12	59.0°	27.5°	Normal	O	10 Ma
13	58.5°	26.0°	Reversed	X	
14	59.0°	25.0°	Reversed	X	
15	60.0°	24.0°	Reversed	X	
16	61.0°	24.5°	Normal	O	10 Ma
17	61.0°	25.5°	Reversed	X	
18	61.5°	26.0°	Reversed	X	
19	61.5°	26.5°	Normal	O	Present
20	62.0°	27.5°	Reversed	X	
21	62.0°	28.5°	Reversed	X	
22	62.0°	29.0°	Normal	O	10 Ma
23	62.5°	30.5°	Reversed	X	



Note: The data has been greatly simplified for this exercise. In real surveys magnetic data is collected continuously and plotted on graphs which show peaks and troughs of magnetic intensity. Peaks correspond to normal magnetisation and troughs to reversed magnetisation.

Rockforce Worksheet

ROCKFORCE

Part A: Mass of empty measuring cylinder .... g

Part B: Internal diameter of the measuring cylinder .... cm

Internal radius of the measuring cylinder: $\frac{\text{diameter}}{2}$

radius r .... cm

Part C: surface area of the base of the cylinder:

area = $\frac{22 \times r^2}{7}$ = ... cm^2

Part D:

1	2	3	4	5	6
depth of sand (in cm)	mass of cylinder and sand (in g)	mass of sand alone (in g)	mass of sand alone (in kg) (mass, g/1000)	force (in N) (mass x 10)	pressure (in N/cm^2) (force / area)
2					
4					
6					
8					

ROCKFORCE: SHOWING SPECIMEN RESULTS

Part A: Mass of empty measuring cylinder **240** g

Part B: Internal diameter of the measuring cylinder **3.6** cm

Internal radius of the measuring cylinder: $\frac{\text{diameter}}{2}$

radius r **1.8** cm

Part C: surface area of the base of the cylinder:

area = $\frac{22 \times r^2}{7}$ = **10.18** cm^2

Part D:

1	2	3	4	5	6
depth of sand (in cm)	mass of cylinder and sand (in g)	mass of sand alone (in g)	mass of sand alone (in kg) (mass, g/1000)	force (in N) (mass x 10)	pressure (in N/cm^2) (force / area)
2	**316**	**76**	**0.076**	**0.76**	**0.075**
4	**376**	**136**	**0.136**	**1.36**	**0.133**
6	**442**	**202**	**0.202**	**2.02**	**0.198**
8	**520**	**280**	**0.208**	**2.80**	**0.275**

5. Acknowledgements and analysis

Editors

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Further acknowledgements relating to individual activities are given with the appropriate activities.

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Analysis of Skills

Skills	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Designing and planning an investigation										
Practical investigation		√		√	√		√			
Experimental investigation	√					√				
Data collection and recording	√					√				
Data plotting exercise			√	√	√	√			√	
Data manipulation exercise	√		√	√				√	√	√
Decision making exercise				√						
Solving problems by applying results				√	√					√
Compiling a report							√			
Calculation	√					√				
Three-dimensional thinking				√	√			√		
Thinking in the time dimension					√				√	√

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