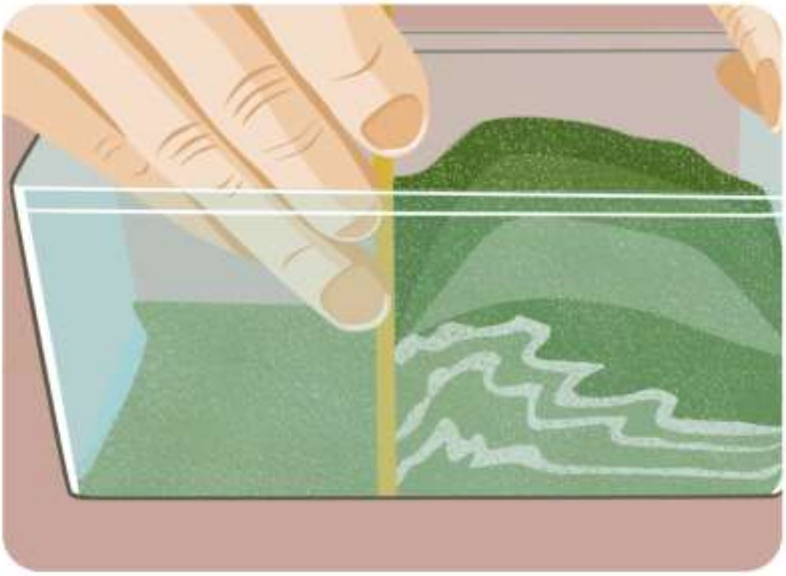
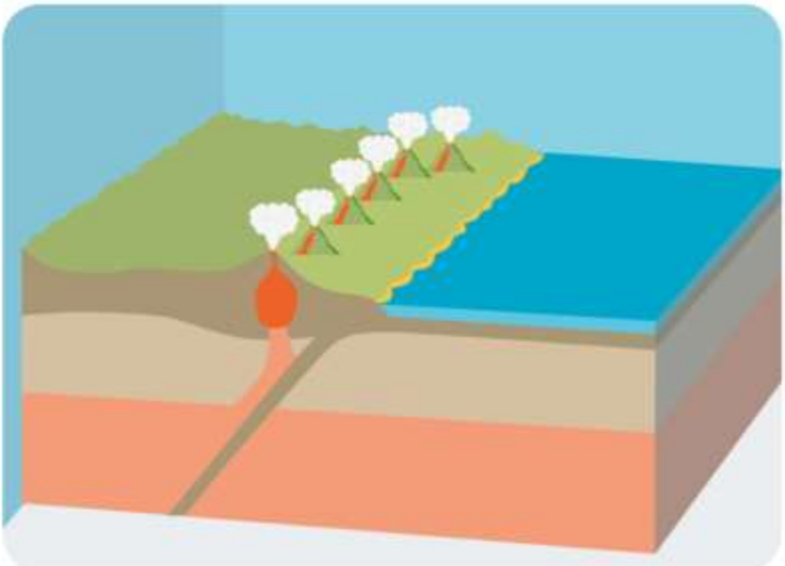
Teaching the Dynamic Earth

The plate tectonics story

ESEU KS3 geography workshop material

Earth science for KS3





EARTH SCIENCE EDUCATION UNIT

With the support of:

Oil & Gas UK

the voice of the offshore industry

Edited by: Chris King with contributions by Bernadette Callan

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ESEU Secondary Workshops

The plate tectonic story
Earth science for KS3 geography

Contents

Summary

'The plate tectonic story' workshop gets to grips with the wide-ranging evidence for the theory that underpins our detailed modern understanding of our dynamic planet – the theory of **Plate Tectonics**. The workshop begins with an introduction and progresses through a series of activities that are designed to help students develop their understanding. It uses several independent sources of evidence supporting the theory, including using rock and fossil evidence, seismic records, geothermal patterns, geomagnetism, and large-scale topographical features, both above and below sea-level. The workshop provides a reconstruction of plate movements over the past 450 million years which explains the record contained in the rocks of the UK - of an amazing journey across the face of our planet. It concludes by investigating some of the Earth hazards linked to plate tectonics, and how we can reduce loss of life.

Earth Science Education Unit workshops

These workshops have been devised for teachers and trainee teachers. They are intended to provide participants with a range of activities that can be used in the classroom, whilst helping them to develop the skills for using the activities in an engaging and motivating way that will enthuse and educate their pupils, whilst developing their critical thinking skills. The workshops should also develop the background Earth science knowledge and understanding of the teachers involved.

The workshop format may be transposed directly into a classroom, but often this is not appropriate. Similarly, individual activities, and the worksheets on which these are based, may be transferable directly into a classroom situation, but will often require modification for the classes and situations in which they are used, during which suitable risk assessments are undertaken.

Workshop outcomes

The workshop and its activities provide the following outcomes:

- an introduction to plate tectonics;
- distinction between the 'facts' of plate tectonics and the evidence used to support plate tectonic theory;
- a survey of some of the evidence supporting plate tectonic theory;
- an introduction to the evidence for the structure of the Earth and the links between the structure of the outer Earth and plate tectonics;
- explanation of some of the hazards caused by plate tectonic processes - earthquakes and eruptions;
- methods of teaching the abstract concepts of plate tectonics, using a wide range of teaching approaches, including practical and electronic simulations;
- approaches to activities designed to develop the thinking and investigational skills of students;
- an integrated overview of the concepts involved in teaching the processes of plate tectonics, as described in the KS3 geography curriculum.

The big picture and the 'facts' of plate tectonics

Topic: A short series of introductory diagrams provides an overview of plate tectonic theory to provide a framework for the rest of the workshop, so that the activities can be fitted into an overall picture of plate tectonics.

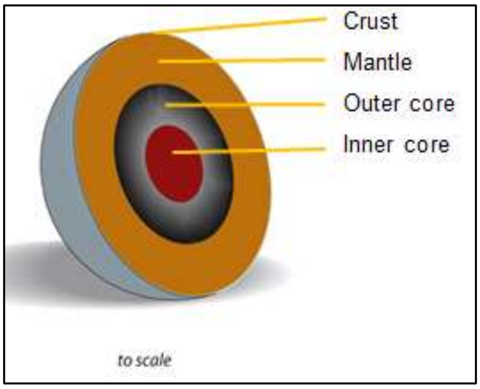
Activity:
Study the series of diagrams below to gain an overview of our current understanding of plate tectonic theory. Note that these diagrams can be seen as a series of 'facts' about plate tectonics but:

- plate tectonics is not a series of facts, as suggested by the series of diagrams, but is a theory supported by evidence;
- what the evidence for the theory is, can be studied through a sequence of workshop activities which have been designed to highlight the evidence for the theory and the explanation of the processes involved.

Plate tectonic theory is outlined in narrative form in 'The Story for Teachers' given in the attached sheets.

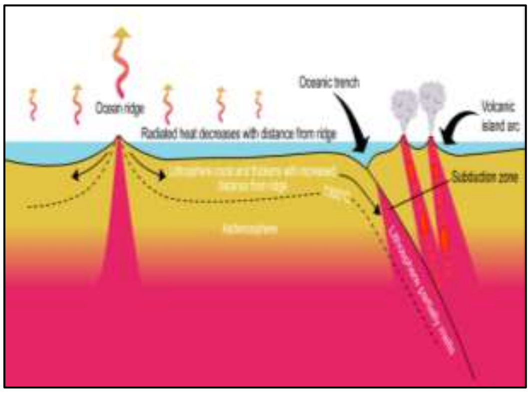
The 'big picture of plate tectonics

The Earth has a crust, mantle outer and inner core



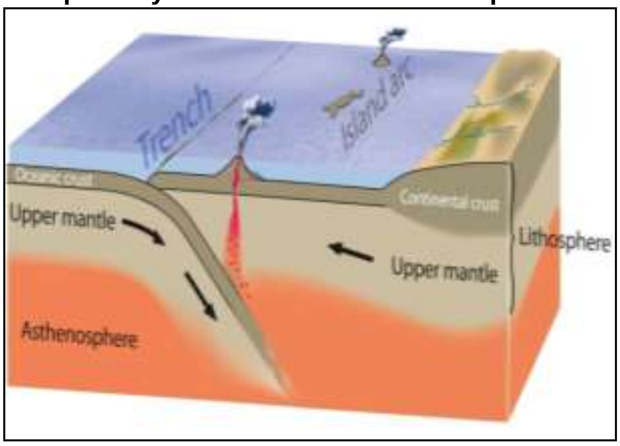
The Internal structure of the Earth - reproduced with kind permission of USGS, redrawn by ESEU

Over geological time, the mantle can flow

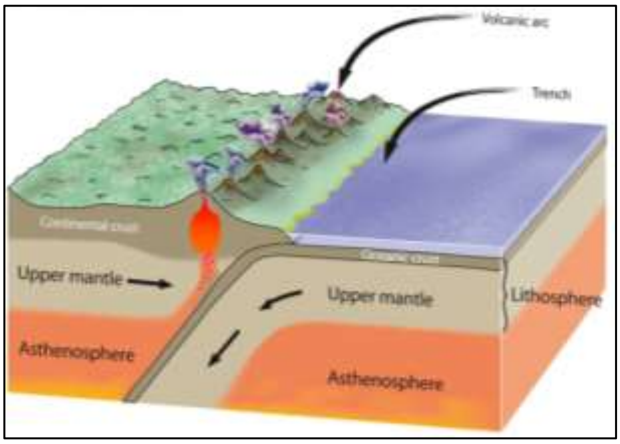


The upper part of the mantle and the crust
© Chris King and Dee Edwards, redrawn by ESEU

When one plate goes down at a subduction zone - it partially melts and volcanoes are produced



Sometimes the molten rock cools below the surface



Molten rocks cools down at or below the surface.
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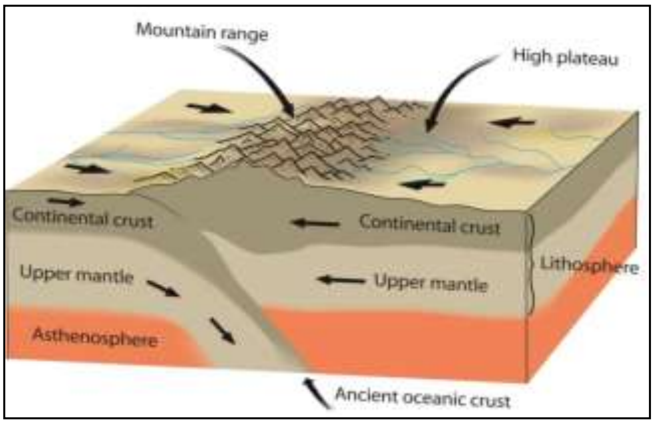
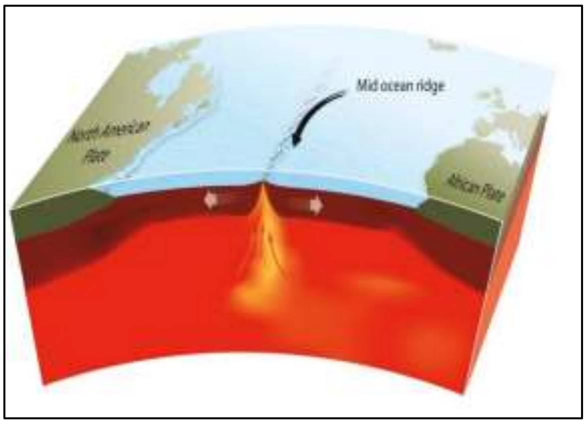
When two plates carrying continents collide – mountain chains are built



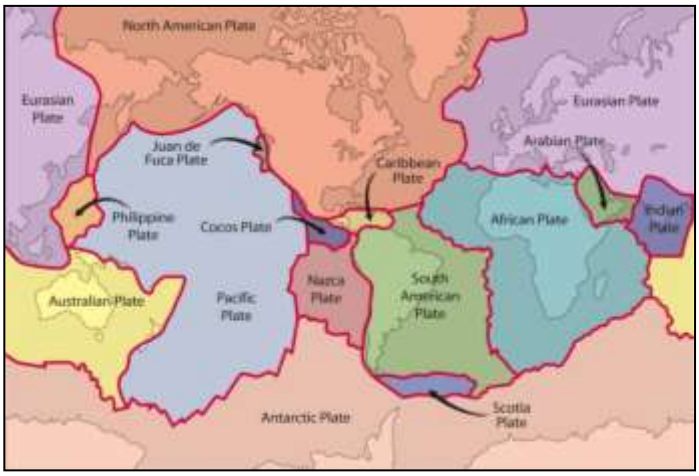
Continental plate collision zone. Reproduced with the kind permission of the U.S. Geological Survey, redrawn by ESEU

If plates are being destroyed, new plate material must be being made somewhere else …



An oceanic ridge
© Press & Siever, redrawn by ESEU

The result is – the map of plate margins today



Map of plates - reproduced with kind permission of USGS, redrawn by ESEU

Pupil learning outcomes: Pupils can:

- recall any previous work they have undertaken on plate tectonics
- explain the plate tectonic model in rudimentary terms
- describe the difference between 'facts' and the scientific evidence used to support theories

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding	**Sciences** **Topical science** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b **Social sciences** **People, place and environment** **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present **Geography** **KS3** • the hazardous world: global	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; iii) demonstrate knowledge and understanding of the processes and

Experimental skills and strategies • using scientific theories and explanations to develop hypotheses. **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks, weathering and soils; • understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems	and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps & geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	distribution, causes, and impacts of extreme tectonic and other hazardous events	landform associated with plate margins: – constructive plate margins: mid-ocean ridges; – destructive plate margins: subduction zone and ocean – trench; – collision zones: fold mountains; and – conservative plate margins: fault lines

Age range of pupils: 11 -16 years

Time needed to complete activity: 5 minutes

The story for teachers:
The plate tectonic story is described below using accessible language in around 700 words.

If you could sit in space and study the Earth you might see some strange patterns through the swirls of cloud. Many of the mountains are found in long chains; many of the islands form long curved chains; the coastline of South America fits the coast of Africa almost exactly. If you could probe beneath the oceans, more patterns would be revealed: there is a long ridge of mountains near the centres of most oceans and there are often deep sea trenches near island chains.

These patterns and more can be explained by plate tectonics. The evidence from earthquake waves shows that the outer part of the Earth is made of a thin rigid sheet of lithosphere that is broken into pieces called plates. Beneath the lithosphere is a thin layer called the asthenosphere where earthquake waves are slowed down because the rock is near its melting point. The heat causing this was produced from the decay of radioactive isotopes. The heat causes the mainly solid asthenosphere to flow, allowing the plates of lithosphere above to move.

Where plates move away from one another, this causes 'pull apart' tensional forces at the surface. The heating of the lithosphere makes it less dense so that it rises to form an oceanic ridge. As the ridge is pulled apart, the central section slides down along steep faults called normal faults making a central valley; the faulting causes earthquakes. Rock beneath the lithosphere partially melts, collects together and rises as magma. As the lithosphere at the surface is pulled apart, magma rises quietly into the fractures and solidifies to form new oceanic lithosphere. The solidifying magma takes on the magnetic field of the Earth and so the oceanic lithosphere contains a continuous record of the Earth's past magnetism as a series of zones of normal and reversed magnetism. The ridges are offset by large transform faults where the plates slide past one another producing earthquakes.

Where plates are moved towards one another, one of the plates is carried down or subducted into the asthenosphere producing an oceanic trench and a steadily deepening zone of earthquakes. The water carried down with the subducted plate reduces the melting point of the surrounding rocks so that they partially melt, the silica-rich material melting first. This silica-rich magma is viscous and so causes explosive volcanic eruptions when it reaches the surface. In ocean areas the volcanoes form a curved chain of volcanic islands.

Some plates carry continents and if a plate is subducted beneath a continent, a trench, volcanoes and earthquakes are formed, but the base of the continent is also partially melted producing magma very rich in silica and very viscous. This rarely reaches the surface but usually forms large igneous bodies within the continent that cool slowly, baking and metamorphosing the surrounding rock. The slow-cooling magma forms the coarse silica-rich rock called granite. If the silica-rich magma does reach the surface it forms highly explosive volcanoes. The two converging plates also crumple up the layered sediments and sedimentary rocks into mountain chains, causing compressional faulting, folding and metamorphism. If both plates carry continents, the collision is even more intense and highest mountain ranges on Earth can be produced as the continents are ‘welded’ together by the new mountain chain rocks.

Earthquake waves show the structure of the whole Earth. The evidence they provide shows the division of the outer part of the Earth into the rigid lithosphere and the plastic asthenosphere. The upper part of the lithosphere is the crust, which is iron-rich in oceanic areas and silica-rich in continental areas. The rocks under the crust, including the lower part of the lithosphere, the asthenosphere and beneath, form the mantle which continues down to 2900 km. below the surface. Beneath the mantle is the core made mainly of iron. The outer part of the core is liquid and it is outer-core currents that produce the Earth’s magnetic field. The inner core is solid.

Plate tectonic theory was first proposed in the 1960s as an explanation for Earth’s features and evolution, through the work of scientists of several different nationalities. It explains many of the Earth’s features but still leaves unanswered questions. These have provoked further scientific study ever since.

Following up the activity: Use the wide range of activities in the ESEU workshop to enable pupils to understand the theory of plate tectonics.

Source: Earth Science Education Unit.

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Preparation and set-up:
If the PowerPoint version of these diagrams is being used, time to set this up.

Resource list:
- Plate tectonic diagram sequence, either on PowerPoint or paper

Optional
- a computer
- projector
- ESEU PowerPoint presentation

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
The big picture and the ‘facts of plate tectonics	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
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Risk Priority (AxB):
12-25 = High risk – take immediate action
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ESEU activity guide sheet:

The big picture and the ‘facts’ of plate tectonics

A short series of introductory diagrams provides an overview of plate tectonic theory to provide a framework for the rest of the workshop, so that the activities can be fitted into an overall picture of plate tectonics.

Study the series of diagrams below to gain an overview of our current understanding of plate tectonic theory. Note that these diagrams can be seen as a series of ‘facts’ about plate tectonics but:

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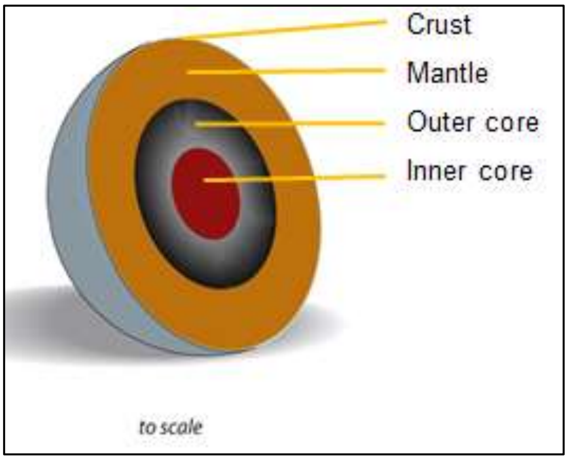

The Internal structure of the Earth - reproduced with kind permission of USGS, redrawn by ESEU

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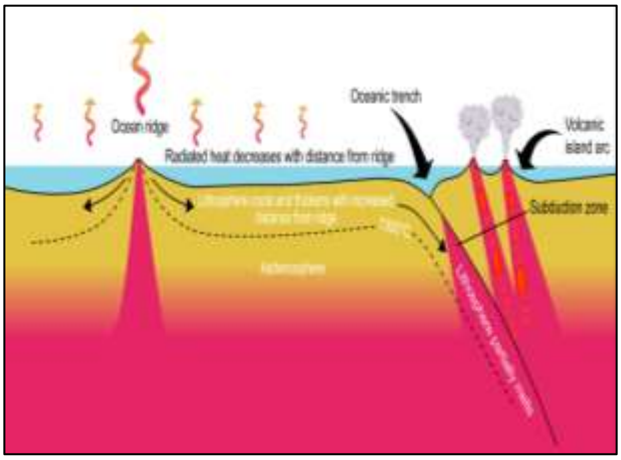
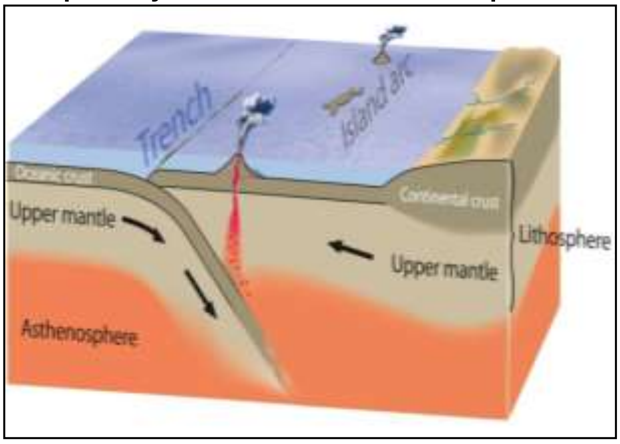
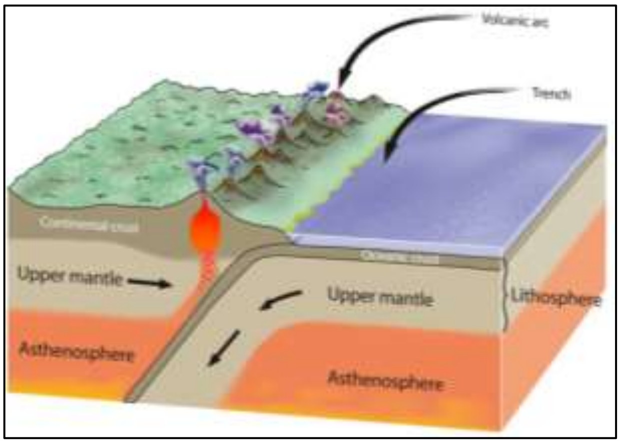


The upper part of the mantle and the crust © Chris King and Dee Edwards, redrawn by ESEU

When one plate goes down at a subduction zone - it partially melts and volcanoes are produced



Sometimes the molten rock cools below the surface



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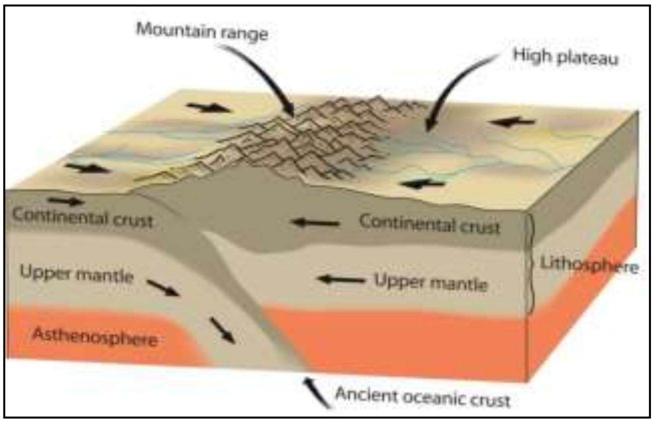

Continental plate collision zone. Reproduced with the kind permission of the U.S. Geological Survey, redrawn by ESEU

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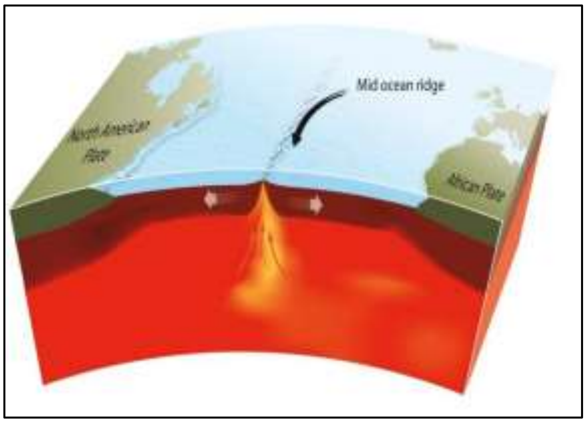
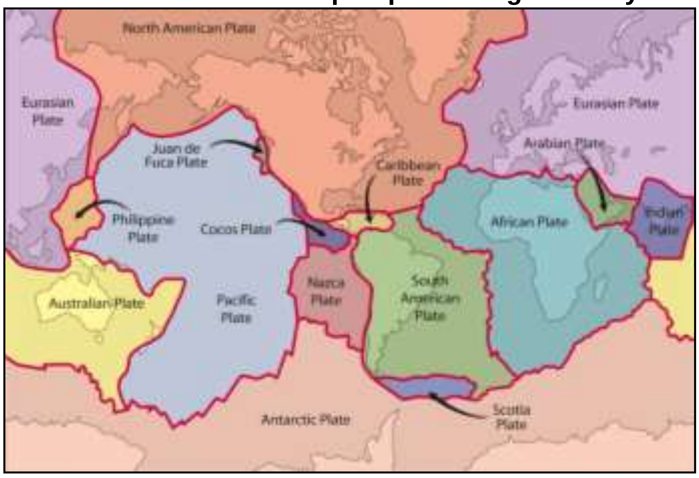


An oceanic ridge
© Press & Siever, redrawn by ESEU

The result is – the map of plate margins today



Map of plates - reproduced with kind permission of USGS, redrawn by ESEU

Geobattleships

Topic: A "pattern-seeking" activity, relating the distribution of earthquakes to that of volcanoes, by playing a well-known children's game adapted for the purpose.

Activity:
Pupils play "battleships" with maps showing volcanoes or major earthquakes, drawn on graph paper with squares marked by number and letter to help them to describe the distribution of volcanoes and earthquakes on the Earth's surface

Organise pupils into pairs. Issue a volcano sheet to one pupil and an earthquake sheet to the other. Tell them that there are at least 32 volcanoes or earthquake epicentres shown on the maps.
Pupils play "battleships", taking it in turns to "fire" at their opponent's maps. (Pupils call out a chosen grid square, e.g. "G5", and their opponents have to say whether or not they have scored a "hit". The outcome is marked on the caller's own blank map, and then it is the opponent's turn to call). Unlike the normal rules, a successful hit does NOT result in an extra go.

Geobattleships in action! © Peter Kennett, ESEU

Pupils can see the distribution of **either** the world's major earthquakes **or** volcanoes, on their own sheets, but have to guess where their opponent's features are located. It does not take many minutes for them to realise that the distribution of the one is closely matched by the other, **and there is no need to prolong the activity**. They should appreciate that the earthquake and volcano belts are not only coincidental but also form discrete lines and are neither evenly distributed nor haphazard.

Pupils will, however, find that there is one area where there are major earthquakes, but no volcanoes, i.e. the Himalayan belt. This is because the two colliding continental plates are nearly "locked" at considerable depth, and the resultant pressure/temperature regime is not conducive to the melting of rocks and formation of magma.

Similarly, there is one area of volcanoes with no earthquakes shown, the Hawaiian Islands, which has developed over a "hot spot" in the mantle, where magma is readily formed a few tens of kilometres down. This is of low viscosity and can easily flow to the surface often accompanied by minor tremors, but not usually by strong earthquakes.

Pupil learning outcomes: Pupils can:
- describe the similarity between the distributions of volcanoes and major earthquakes on Earth;
- describe the broad distribution of earthquakes and volcanoes on the Earth's surface.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the ormation of igneous,	**Sciences** **Topical science** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** i) describe the structure of the

sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Geography** **KS3** **Human and physical geography** • physical geography relating to: plate tectonics; • understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems	**Social sciences** **People, place and environment** **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	have changed since the Earth's origin and are changing at present **Geography** **KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges; – destructive plate margins: subduction zone and ocean trench; – collision zones: fold mountains; and – conservative plate margins: fault lines

Age range of pupils: 11 -16

Time needed to complete activity: 10 minutes, including discussion

The story for teachers:
See "Activity" above. Recognition of global earthquake/ volcano patterns involves skills of construction, with incomplete data in some areas posing a challenge. Linking the paper exercise to the real world involves bridging skills.

Lead in ideas:
The activity should be used **before** pupils are made aware of the detail of the surface distribution of earthquakes and volcanoes. This will then help them to understand the evidence for the location of the plate boundaries, rather than simply being told where they are.

Following up the activity:
Study the distribution of earthquakes and volcanoes from published maps and relate them to the boundaries of the named plates. Most school textbooks include these, but beware – some are not very accurate! Sources on the web include http://www.usgs.gov Use the ESEU activity "The earthquake distribution evidence".

Source: David Turner of the Earth Science Education Unit

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Preparation and set-up: Time to photocopy the required number of sheets.

Resource list:

One set per pair of pupils:

- sheet showing the distribution of volcanoes plus a blank map
- sheet showing the distribution of earthquakes plus a blank map

N.B. These are best printed onto different coloured cards.

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Geobattleships	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
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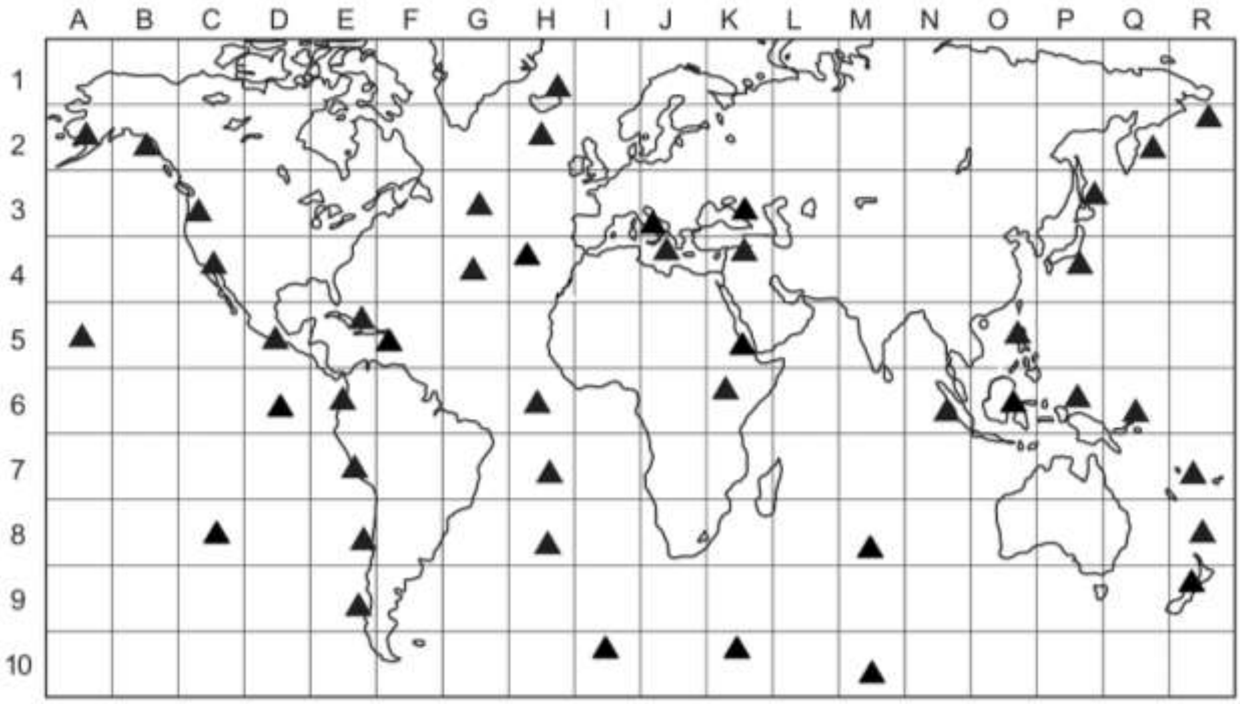
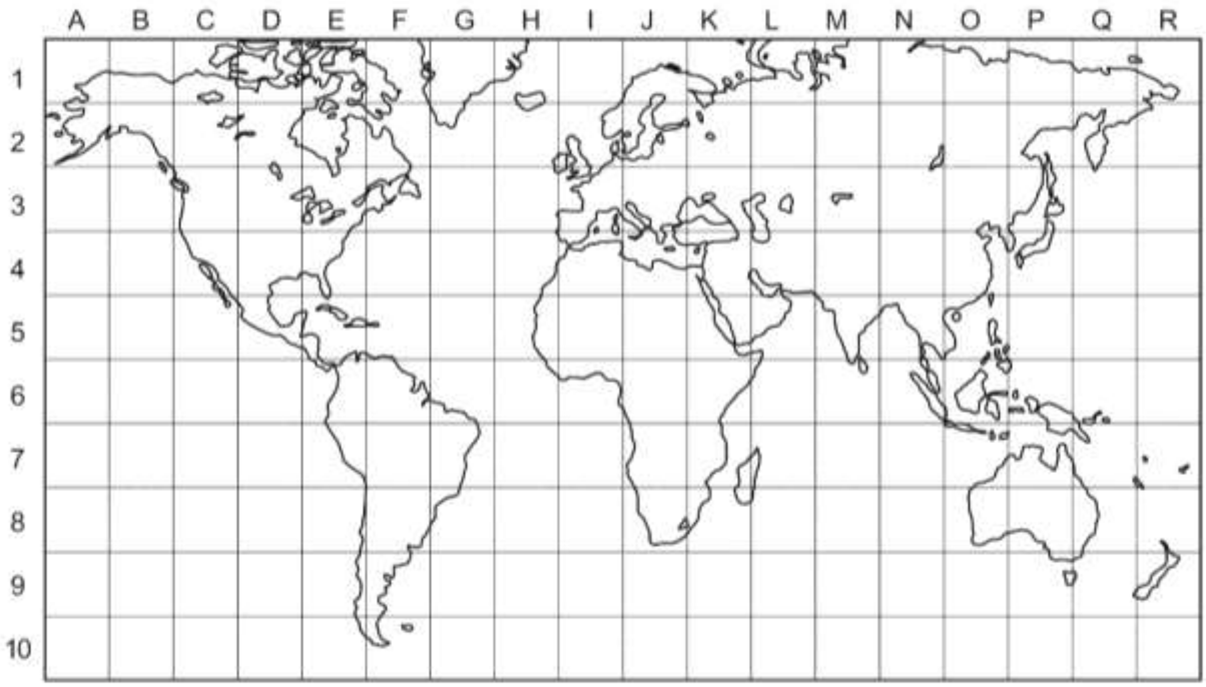
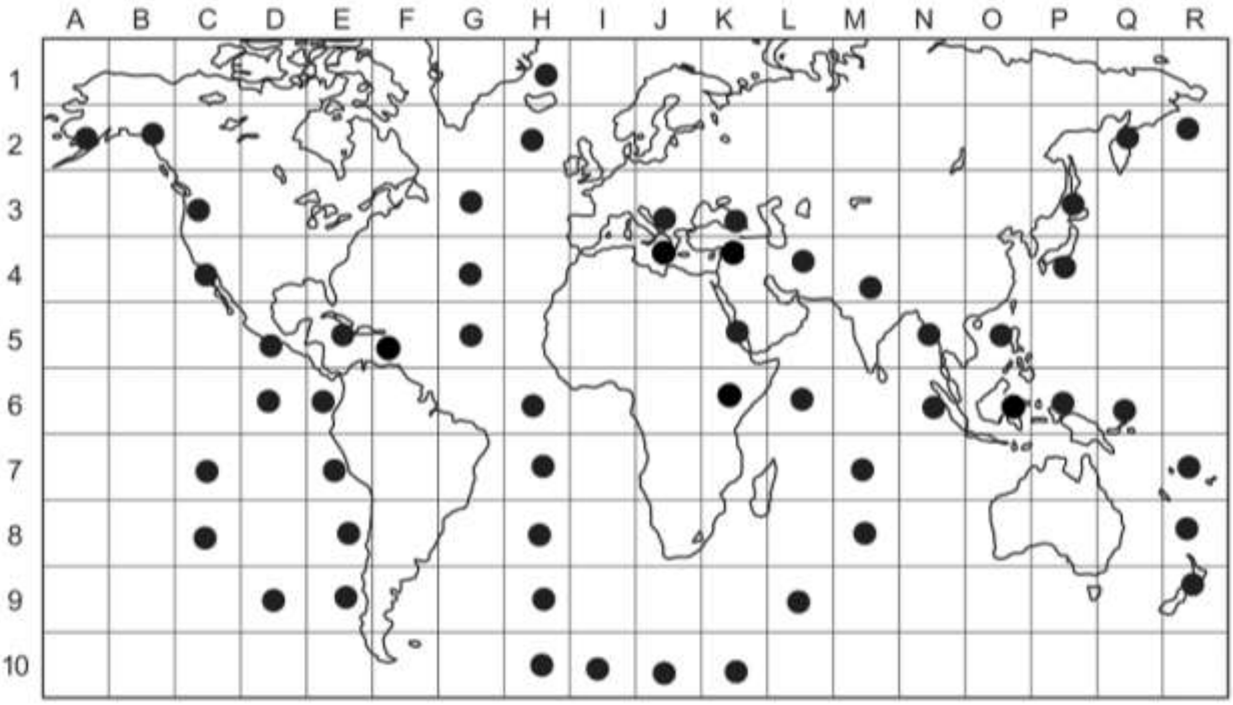


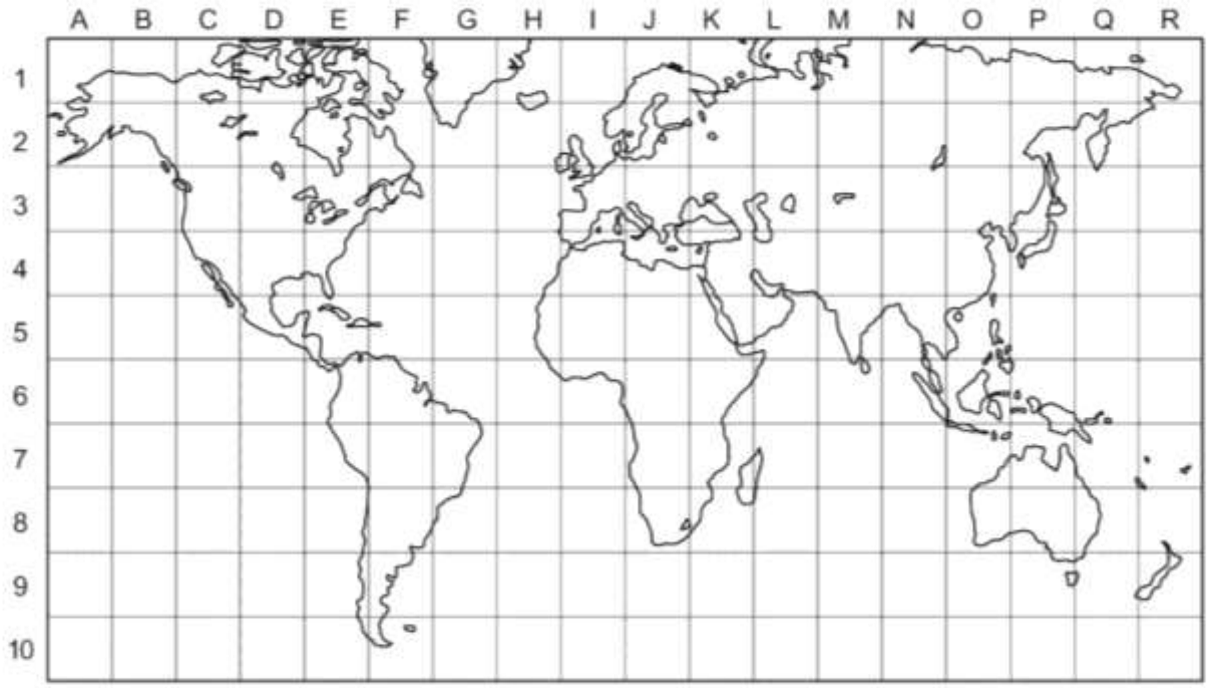
Main Volcanoes / Volcanic Activity map © Dave Turner

Map for plotting Earthquake locations © Dave Turner





Main Earthquake Activity map © Dave Turner



Map for plotting Volcanoes / Volcanic activity locations © Dave Turner

ESEU activity guide sheet:

Geobattleships

A “pattern-seeking” activity, relating the distribution of earthquakes to that of volcanoes, by playing a well-known children’s game adapted for the purpose.

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Geobattleships in action! © Peter Kennett, ESEU

Pupils can see the distribution of **either** the world's major earthquakes **or** volcanoes, on their own sheets, but have to guess where their opponent's features are located. It does not take many minutes for them to realise that the distribution of the one is closely matched by the other, **and there is no need to prolong the activity**. They should appreciate that the earthquake and volcano belts are not only coincidental but also form discrete lines and are neither evenly distributed nor haphazard.

Pupils will, however, find that there is one area where there are major earthquakes, but no volcanoes, i.e. the Himalayan belt. This is because the two colliding continental plates are nearly "locked" at considerable depth, and the resultant pressure/temperature regime is not conducive to the melting of rocks and formation of magma.

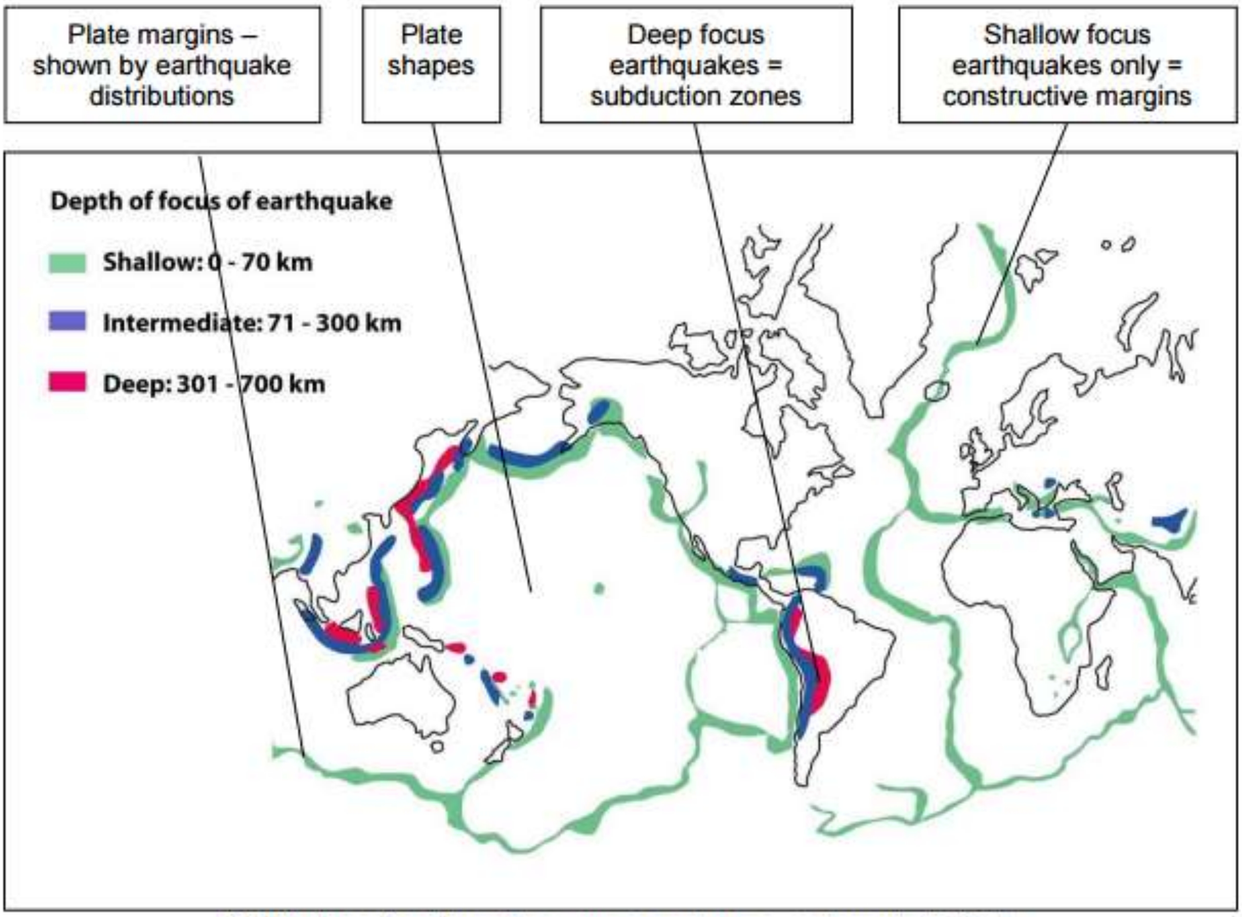
Similarly, there is one area of volcanoes with no earthquakes shown, the Hawaiian Islands, which has developed over a "hot spot" in the mantle, where magma is readily formed a few tens of kilometres down. This is of low viscosity and can easily flow to the surface often accompanied by minor tremors, but not usually by strong earthquakes.

The earthquake distribution evidence

Topic: Demonstrate how the distribution of earthquakes on Earth supports plate tectonic theory.

Activity:
The diagram shows the distribution of earthquakes on Earth. This can be used, in discussion with the students, to highlight the following.

- The plate margins, where earthquakes are active.
- The shapes of the plates, outlined by the earthquake plate margins.
- The zones where plates are being subducted, shown by shallow, intermediate and deep focus earthquakes – the direction of downward slope of the earthquakes is the direction of subduction.
- The zones of shallow focus earthquakes only, where constructive margins occur.



Distribution of earthquakes - source unknown, redrawn by ESEU

Pupil learning outcomes: Pupils can:

- describe the general distribution of earthquakes on Earth, of shallow, intermediate and deep focus;
- explain how this evidence can be used to support plate tectonic theory.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks	**Sciences** **Topical science** **Second** I can report and comment on current scientific news items to develop my knowledge and understanding of topical science. SCN 2-20b **Third** Through research and discussion, I have contributed to evaluations of media items with regard to scientific content and ethical implications. SCN 3-20b	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** i) describe the structure of the Earth (core, mantle and crust);

KS4 Science Working scientifically The development of scientific thinking: • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Geography KS3 Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks, weathering and soils; • understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems	**Fourth** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b **Social sciences** **People, place and environment** **Second** I can describe the major characteristic features of Scotland's landscape and explain how these were formed. SOC 2-07a I can describe the physical processes of a natural disaster and discuss its impact on people and the landscape. SOC 2-07b To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	changing at present **Geography KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	(ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges; – destructive plate margins: subduction zone and ocean – trench; – collision zones: fold mountains; and – conservative plate margins: fault lines

Age range of pupils: 12-16

Time needed to complete activity: 5 minutes

Lead in ideas:
Students can be asked to think about what they already know about earthquakes, and where they occur. They can use their existing knowledge to predict where earthquakes are most likely to occur in the future, and the impacts this will have on people in different countries.

Following up the activity:
Use "Earthquakes – the slinky simulation" and "Wave motion – student molecules" to demonstrate how seismic waves can provide information about the Earth's internal structure.

Source: The Earth Science Education Unit.

…………………

Preparation and set-up: None

Resource list:
- earthquake diagram, either as PowerPoint slide or on paper
- (optional) computer, projector

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
The earthquake distribution evidence	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

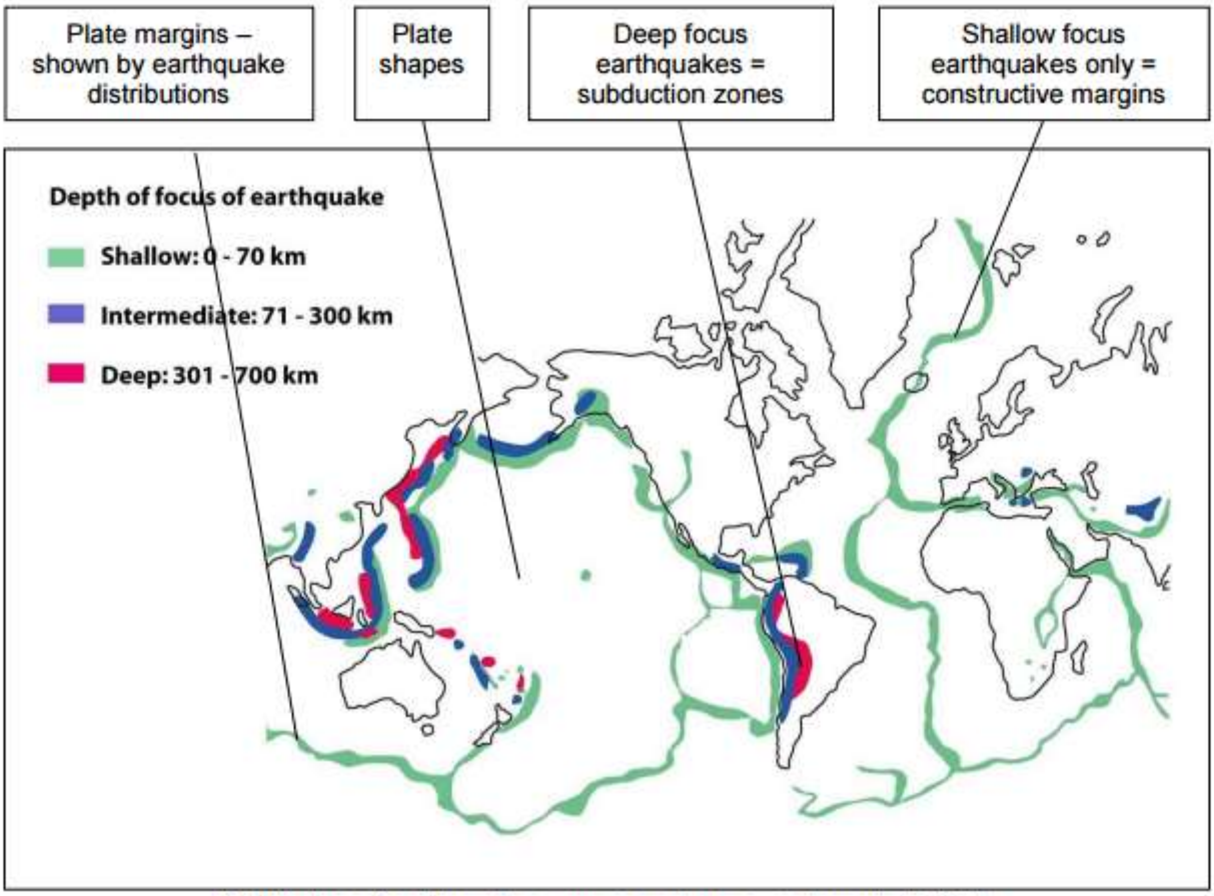
ESEU activity guide sheet:

The earthquake distribution evidence

Demonstrate how the distribution of earthquakes on Earth supports plate tectonic theory.

The diagram shows the distribution of earthquakes on Earth. This can be used, in discussion with the students, to highlight the following.

- The plate margins, where earthquakes are active.
- The shapes of the plates, outlined by the earthquake plate margins.
- The zones where plates are being subducted, shown by shallow, intermediate and deep focus earthquakes – the direction of downward slope of the earthquakes is the direction of subduction.
- The zones of shallow focus earthquakes only, where constructive margins occur.



Distribution of earthquakes - source unknown, redrawn by ESEU

Why are the Earth's tectonic plates called plates?

Topic:
Use a china plate to draw an analogy with the Earth's tectonic plates.

Activity:
Use a chipped china plate to draw an analogy with the plates of the Earth's lithosphere: both are have a large surface area and are thin, rigid, brittle, and curved, with all the damage at the edges.

Note that the concentration of most seismic activity is at the edges of tectonic plates in contrast to the aseismic interior of the tectonic plate.

Pupil learning outcomes: Pupils can:
- describe the main features of the Earth's plates;
- explain how a china plate provides an analogy for the Earth's plates.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS4 Science** **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Geography** **KS3** **Human and physical geography** • physical geography relating to: plate tectonics	**Social sciences** **People, place and environment** **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present **Geography** **KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins

Age range of pupils: 11-16

Time needed to complete activity: 5 minutes

Lead in ideas:
Establish the nature of the lithosphere, and its thickness (100 km or so), which is very thin in relation to its surface area.

Following up the activity:
Use “Geobattleships” and “The earthquake distribution evidence” to reinforce the seismic evidence for plate boundaries.

Source: Earth Science Education Unit.

…………………

Preparation and set-up: None

Resource list:
- a chipped china plate

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Why are the Earth’s tectonic plates called plates?	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

ESEU activity guide sheet:

Why are the Earth's tectonic plates called plates?

Use a chipped china plate to draw an analogy with the plates of the Earth's lithosphere: both are have a large surface area and are thin, rigid, brittle, and curved, with all the damage at the edges.

Note that the concentration of most seismic activity is at the edges of tectonic plates in contrast to the <u>aseismic</u> interior of the tectonic plate.

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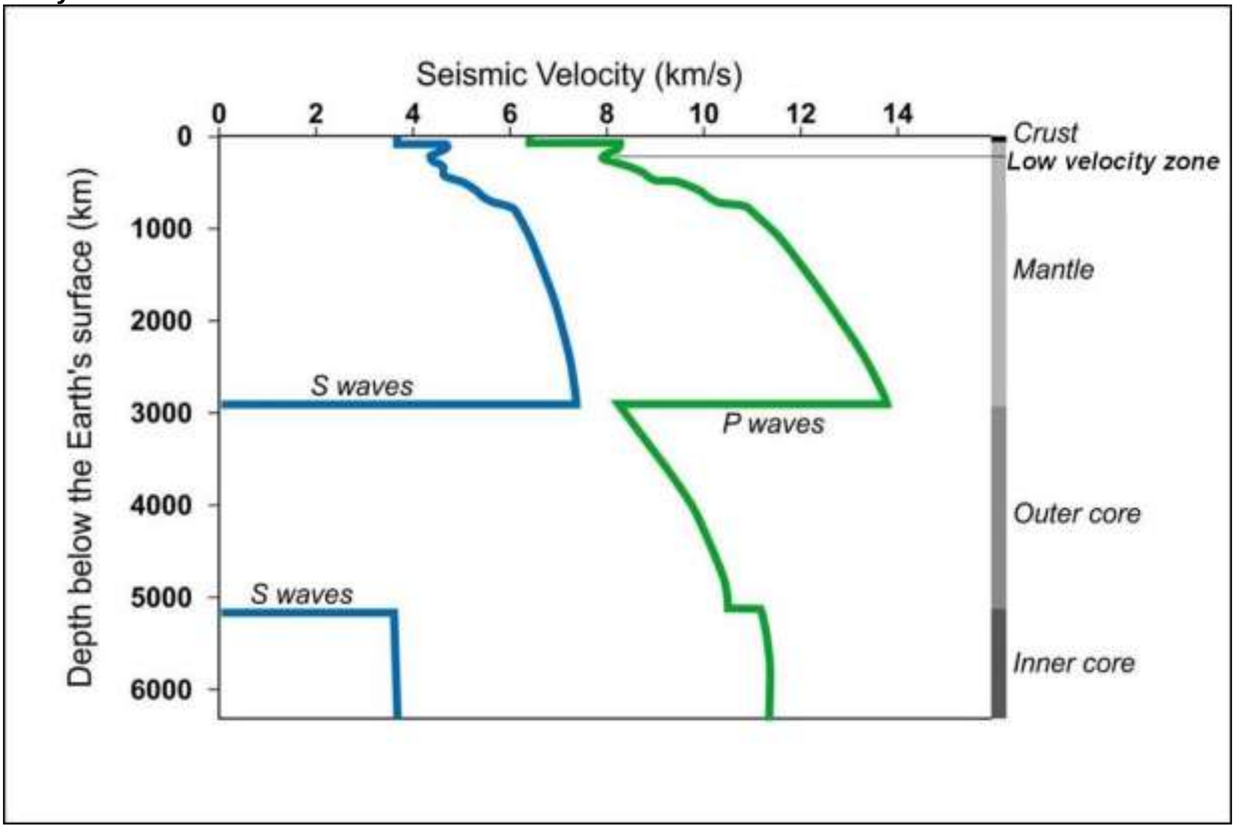
The seismic evidence for the structure of the Earth

Topic: Analysis of cross section diagrams relating to Earth's structure.

Activity:



The velocities of seismic waves in the Earth
Originally from The Earth Science Teachers' Association, 'Investigating the Science of the Earth 2: Geological changes – Earth's Structure and Plate Tectonics', redrawn by ESEU.

The graph is a plot of the velocities of P- and S-waves as they penetrate the Earth. Note that it is an unusual graph in that the depth increases downwards. Use this, through discussion, to show that:

- there are no S-waves in the outer core – so this must be a fluid (since fluids don't transmit S-waves); the pressures are so intense at these depths that it cannot be gas, so it must be liquid;
- the inner core must be solid, since it transmits S-waves;
- the rest of the Earth, including the mantle and the crust, must be solid, since they transmit S-waves (contrary to the 'liquid mantle' or 'magma beneath the crust' stories of some textbooks);
- there is a zone near the outer part of the mantle where P-wave and S-waves velocities reduce, this is the Low Velocity Zone (LVZ) or asthenosphere ('weak sphere') which is able to flow plastically over geological time.

The following diagram shows a summary of the 'structure of the Earth' seismic evidence – with the thickness of the upper part of the Earth greatly exaggerated to show:

- the solid lithosphere (crust plus extreme upper mantle – averaging 100 km thick);
- the plastic asthenosphere which can flow;
- the solid rest of the mantle (which due to intense temperatures and pressures, can also flow);
- the liquid outer core;
- the solid inner core.

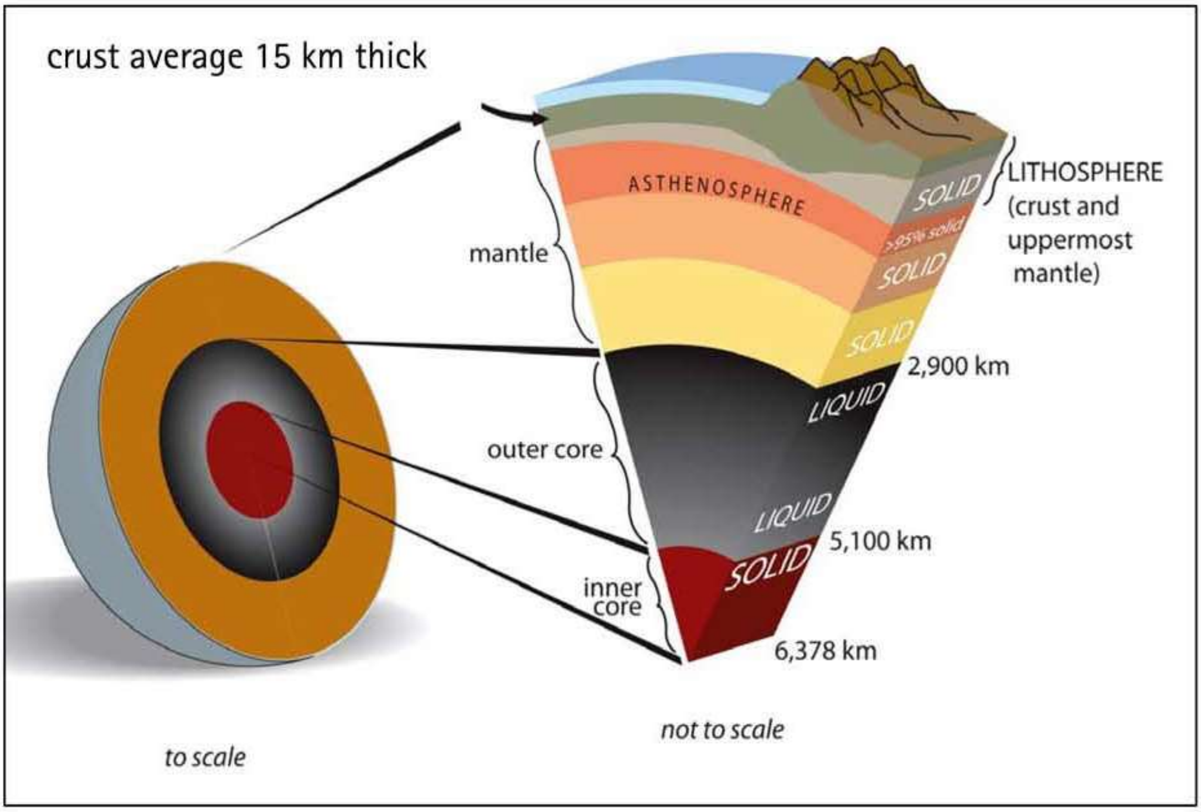
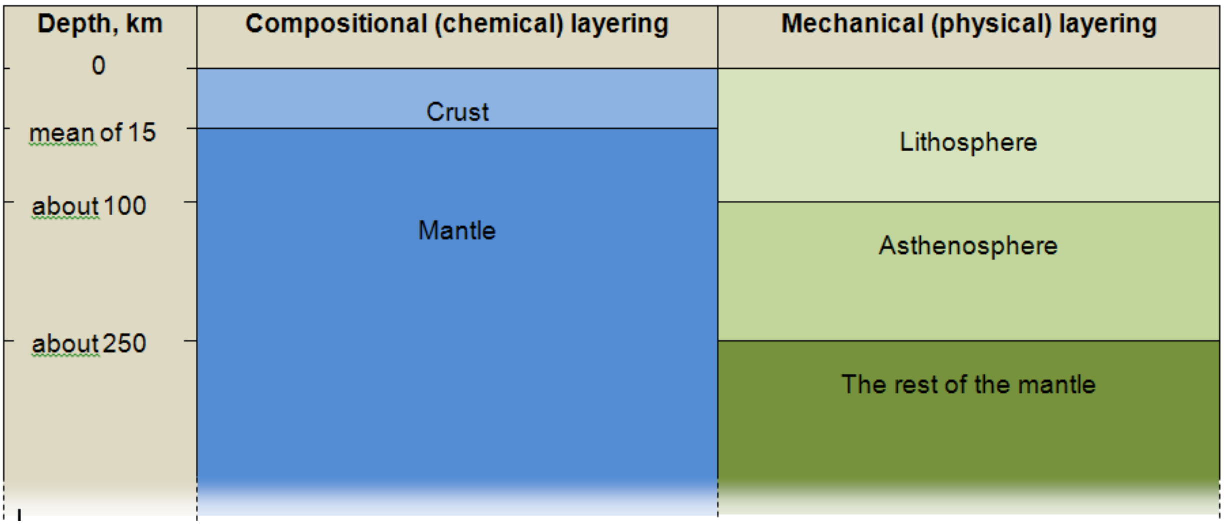


Diagram of the internal structure of the Earth, an example of a diagram
showing the crust very much thicker than in reality.
Reproduced with the kind permission of the U.S. Geological Survey, redrawn by ESEU.

A diagram of the composition and structure of the outer Earth (i.e. the top of the diagram above) is shown below.



(*ESEU*)

Notes:

1. The crust has a mean thickness of 35 km beneath continents and 6 km beneath oceans giving an overall mean of about 15 km
2. The Earth's tectonic plates are made of solid, rigid lithosphere (around 100 km thick) comprising the crust (averaging 15 km thick) and the outer part of the mantle. Plastic deformation of the asthenosphere allows the plates to move.
3. Nearly all cross section diagrams of the Earth show the crust very much too thick – since in reality it's thickness on a diagram is less than the thickness of a line in the diagram – a good analogy is a postage stamp stuck on a football.

Pupil learning outcomes: Pupils can:
- describe the structure of the Earth;
- explain how the seismic evidence can be used to interpret the internal structure of the Earth.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3 Chemistry – Earth and atmosphere** • the composition of the Earth • the structure of the Earth **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Physics** **Forces:** • **…**elastic and inelastic stretching **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks	**Sciences** **Second** **Earth's Materials** Having explored the substances that make up the Earth's surface, I can compare some of their characteristics and uses. SCN 2-17a **Third** **Processes of the planet** By contributing to experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature. SCN 3-05a	No direct references	**GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges; – destructive plate margins: subduction zone and ocean – trench; – collision zones: fold mountains; and – conservative plate margins: fault lines

Age range of pupils: 12-16

Time needed to complete activity: 5 minutes

Lead in ideas:
Demonstration of P- and S-wave transmission using ESEU activities with a slinky or pupil molecules

Source: Earth Science Education Unit.

Copyright: © Earth Science Education Unit
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Preparation and set-up: None

Resources list:
- the diagrams contained in the activity

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
The seismic evidence for the structure of the Earth	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
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5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

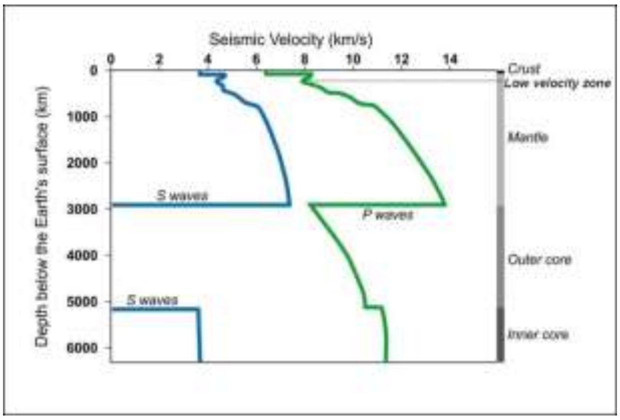
ESEU activity guide sheet:

The seismic evidence for the structure of the Earth

Analysis of cross section diagrams relating to Earth's structure.

The graph is a plot of the velocities of P- and S-waves as they penetrate the Earth. Note that it is an unusual graph in that the depth increases downwards. Use this, through discussion, to show that:

- there are no S-waves in the outer core – so this must be a fluid (since fluids don't transmit S-waves); the pressures are so intense at these depths that it cannot be gas, so it must be liquid;
- the inner core must be solid, since it transmits S-waves;



The velocities of seismic waves in the Earth. Originally from The Earth Science Teachers' Association, 'Investigating the Science of the Earth 2: Geological changes – Earth's Structure and Plate Tectonics', redrawn by ESEU.

- the rest of the Earth, including the mantle and the crust, must be solid, since they transmit S-waves (contrary to the 'liquid mantle' or 'magma beneath the crust' stories of some textbooks);
- there is a zone near the outer part of the mantle where P-wave and S-waves velocities reduce, this is the Low Velocity Zone (LVZ) or asthenosphere ('weak sphere') which is able to flow plastically over geological time.

The following diagram shows a summary of the 'structure of the Earth' seismic evidence – with the thickness of the upper part of the Earth greatly exaggerated to show:

- the solid lithosphere (crust plus extreme upper mantle – averaging 100 km thick);
- the plastic asthenosphere which can flow;
- the solid rest of the mantle (which due to intense temperatures and pressures, can also flow);
- the liquid outer core;
- the solid inner core.

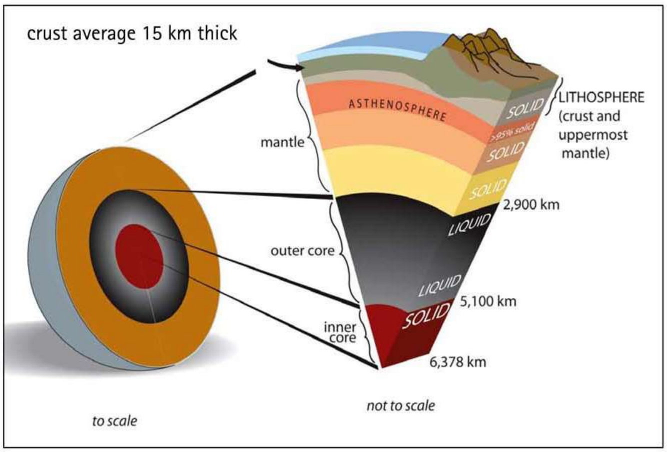
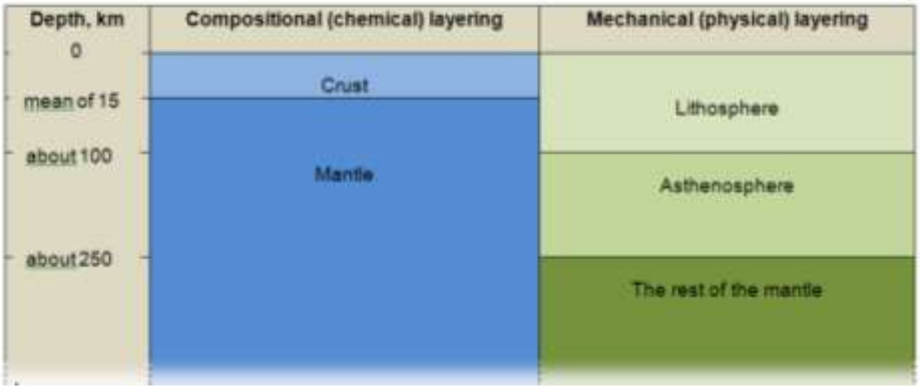


Diagram of the internal structure of the Earth, an example of a diagram showing the crust very much thicker than in reality. Reproduced with the kind permission of the U.S. Geological Survey, redrawn by ESEU.

A diagram of the composition and structure of the outer Earth (i.e. the top of the diagram opposite) is shown below.



(*ESEU*)

Notes:

1. The crust has a mean thickness of 35 km beneath continents and 6 km beneath oceans giving an overall mean of about 15 km

2. The Earth's tectonic plates are made of solid, rigid lithosphere (around 100 km thick) comprising the crust (averaging 15 km thick) and the outer part of the mantle. Plastic deformation of the asthenosphere allows the plates to move.

3. Nearly all cross section diagrams of the Earth show the crust very much too thick – since in reality it's thickness on a diagram is less than the thickness of a line in the diagram – a good analogy is a postage stamp stuck on a football.

The properties of the mantle – potty putty™

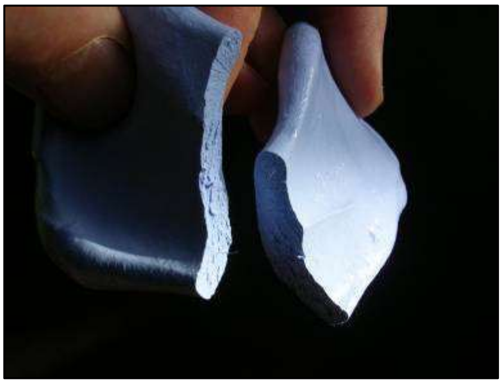
Topic:
A demonstration of the properties of Potty Putty™, as an analogy for the rocks in the mantle.

Activity:
Demonstrate the elastic, plastic and brittle properties of Potty Putty™, showing that the behaviour depends on the scale and duration of the applied stress. Potty Putty™ therefore provides a useful analogy for the rocks in the mantle, which under short duration stress, act elastically, transmitting S-waves, but under longer stress duration, act plastically – flowing.

- Break up a lump of Potty Putty™ into small pieces (e.g. 1cm diameter) and distribute to group members.
- Invite members to roll the putty into a ball and gently bounce it on the bench (elastic deformation).
- Ask them to pull it out and let it droop under its own weight (plastic deformation)
- Ask them to roll it up again and try to snap with a short sharp pull (brittle deformation).
- Optional - demonstrate shattering of the putty when hit by a hammer (use a safety screen and collect all the shattered pieces. Do not allow the pieces to fall on carpet or clothing as it will flow into the material and can never be removed! Alternatively, put the Potty Putty™ into a transparent plastic bag before hitting).
- Ask them to roll it into a ball and leave it on the bench/desk for the rest of the lesson, the ball will collapse into a round blob – ask if this is demonstrating elastic, plastic or brittle behaviour (A. *plastic*) and what is causing the stress (A. *gravitational forces*).
- Gather up all the Potty Putty™ and return it to its container. Warn students not to put it into their pockets as it will flow into the material and be there for ever!


Bounce it (elastic deformation)
© Peter Kennett


Bend it (plastic deformation)
© Peter Kennett


Snap it (brittle deformation)
© Peter Kennett


Shatter it (brittle deformation)
© Peter Kennett

Pupil learning outcomes: Pupils can:
- appreciate that, under different scales and durations of stress a solid material can behave:
  - in an elastic way (and could therefore transmit earthquake waves);
  - in a plastic/ductile way (and can therefore flow or creep) and;
  - in a brittle way (and can therefore fracture, which could create an earthquake);
- use the Potty Putty™ analogy to explain how the mantle can transmit S-waves, and yet flow.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3 Chemistry – Earth and atmosphere** • the composition of the Earth • the structure of the Earth **KS4 Science** **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding **Physics** **Forces:** • **…**elastic and inelastic stretching **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks,	**Sciences** **Third** **Processes of the planet** By contributing to experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature. SCN 3-05a	No direct references	**GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement;

Age range of pupils: 11-16

Time needed to complete activity: 5 minutes

The story for teachers:
Whilst pupils may not be familiar with solids that flow, in fact, they are very familiar with a solid substance that flows – ice. They will know that a ice cube can be shattered with a hammer but that a large lump of ice on a mountain slope will flow – as in a glacier. (If they suggest that this might be due to the sliding of the ice on the liquid base of the atmosphere, remind them that polar glaciers are frozen to the base, so must flow through internal flow).

Lead in ideas:
Any discussion of the mantle:
- being able to transmit earthquake body waves (by elastic deformation);
- allowing movement of plates above (by plastic deformation);
- being the source of earthquakes, down to about 700km (by brittle deformation).

Seismic wave properties – P-waves (primary waves) can be transmitted through both solids and liquids, but S-waves (secondary waves) through solids alone.

Following up the activity:
Discussion of the rate of movement of plates: convection of the mantle is slow, but possible even though mantle is NOT liquid.

Source: Earth Science Education Unit.

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Preparation and set-up: 2 minutes

Resources list:
- Potty Putty™ (or Silly Putty™) a silicone polymer available from toy shops, or your own version, made from PVA glue and borax using the recipe shown below, that can be found on http://www.esta-uk.net/jesei/index.htm

Recipe for making 'Potty putty'
Resources
- 20 cm^3 PVA glue (not a rubberized variety from DIY shops, a simple glue as often used in school art rooms)
- a few cubic centimetres of dilute sodium tetraborate solution (borax) (approximately 25 ml).
- a small beaker or other container in which to mix the potty putty

Method

Add drops of the borax solution to the PVA glue in a small container and mix vigorously. When the polymer begins to crosslink (becomes less liquid and comes away from the sides of the container) it may be rolled between the hands to ensure complete mixing of the borax solution. If it remains sticky, then it has to be kneaded more vigorously. If it still remains sticky add a little more borax solution.
When left on the desk the potty putty will sink and spread.
However it will also bounce like a ball if enough borax is used.
It can be stretched far more than Plasticine™ if pulled gently, but can also be fractured if pulled suddenly.

Hints

The trick is to mix the borax solution into the PVA well, rather than to add lots of it. Adding too much will result in a hard material that will not stretch.
If the mixture remains sticky, more borax solution is required.
You are recommended to try this in advance so that you can see when the mix starts to 'go'.
Often the potty putty improves if left for 20 minutes on a surface.
It will dry out eventually so to keep a good sample, keep it in a sealed plastic bag.
A few drops of food colouring can be added to make the final product more interesting. However adding too much will dilute your mixture and make it more difficult to make into potty putty. Also handling the coloured potty putty will result in food colouring staining the hands.

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
The properties of the mantle – potty putty™	No significant hazard	-	-	-	No
Making 'potty putty'	Getting PVA glue or borax in the eyes	1	1	1	Where eye protection

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

ESEU activity guide sheet:

The properties of the mantle – potty putty™

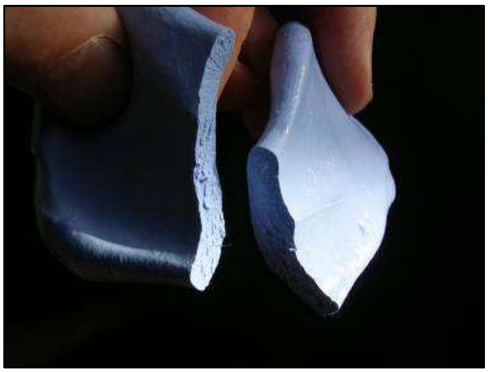
A demonstration of the properties of Potty Putty™, as an analogy for the rocks in the mantle.

Demonstrate the elastic, plastic and brittle properties of Potty Putty™, showing that the behaviour depends on the scale and duration of the applied stress. Potty Putty™ therefore provides a useful analogy for the rocks in the mantle, which under short duration stress, act elastically, transmitting S-waves, but under longer stress duration, act plastically – flowing.

- Break up a lump of Potty Putty™ into small pieces (e.g. 1cm diameter) and distribute to group members.
- Invite members to roll the putty into a ball and gently bounce it on the bench (elastic deformation).
- Ask them to pull it out and let it droop under its own weight (plastic deformation)
- Ask them to roll it up again and try to snap with a short sharp pull (brittle deformation).
- Optional - demonstrate shattering of the putty when hit by a hammer (use a safety screen and collect all the shattered pieces. Do not allow the pieces to fall on carpet or clothing as it will flow into the material and can never be removed! Alternatively, put the Potty Putty™ into a transparent plastic bag before hitting).

Bounce it (elastic deformation)
© Peter Kennett

Bend it (plastic deformation)
© Peter Kennett



Snap it (brittle deformation)
© Peter Kennett

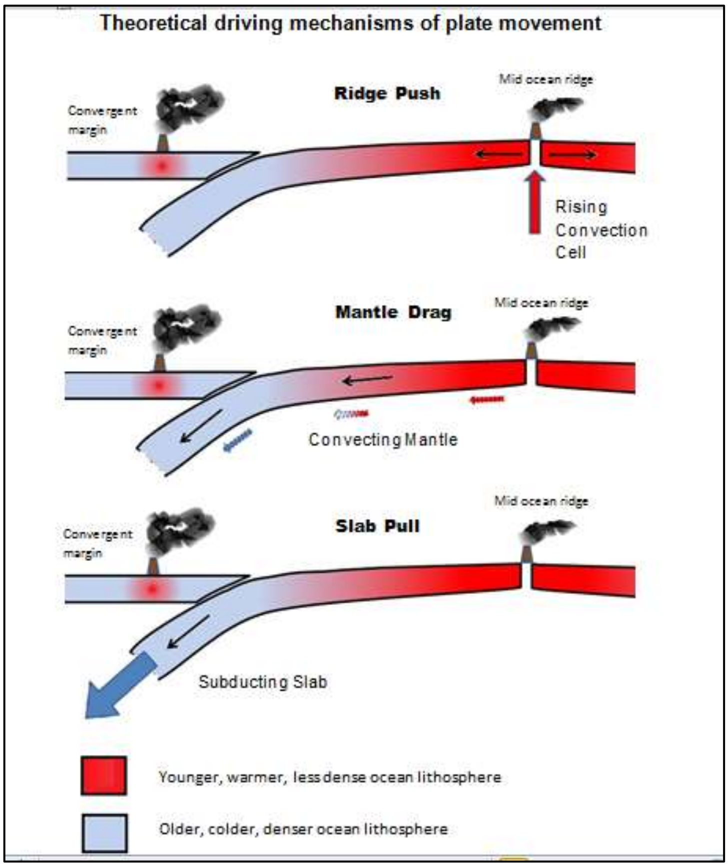
Shatter it (brittle deformation)
© Peter Kennett

- Ask them to roll it into a ball and leave it on the bench/desk for the rest of the lesson, the ball will collapse into a round blob – ask if this is demonstrating elastic, plastic or brittle behaviour (A. *plastic*) and what is causing the stress (A. *gravitational forces*).
- Gather up all the Potty Putty™ and return it to its container. Warn students not to put it into their pockets as it will flow into the material and be there for ever!

What drives the plates?

Topic: Using a pupil model to demonstrate that slab pull is the main plate driving force.

Activity:
The Earth's tectonic plates move, but what processes cause this movement?



(*Pete Loader*)

Three of the forces that have been proposed as the main drivers of plate movement are:

- **mantle convection currents** – mantle currents carrying plates of lithosphere along on top, like shopping on a supermarket conveyor belt;
- **ridge push** – newly-formed plates at oceanic ridges are warm, and so have higher altitude at the oceanic ridge than the colder, more dense plate material further away; gravity causes the higher plate at the ridge to push away the lithosphere that lies further from the ridge;
- **slab pull** – older, colder plates sink at subduction zones because as they cool, they become more dense than the underlying mantle – so the sinking plate pulls the rest of the plate along behind it.

Recent research has shown that the major driving force for most plate movement is **slab pull** because the plates with more of their edges being subducted are the faster-moving ones.

Meanwhile, if there are **mantle convection currents**, as traditionally pictured (and they have not been detected by geophysics), they seem to have a small or no effect on plate movement. **Ridge push** only seems to be effective where there are no slab pull forces.

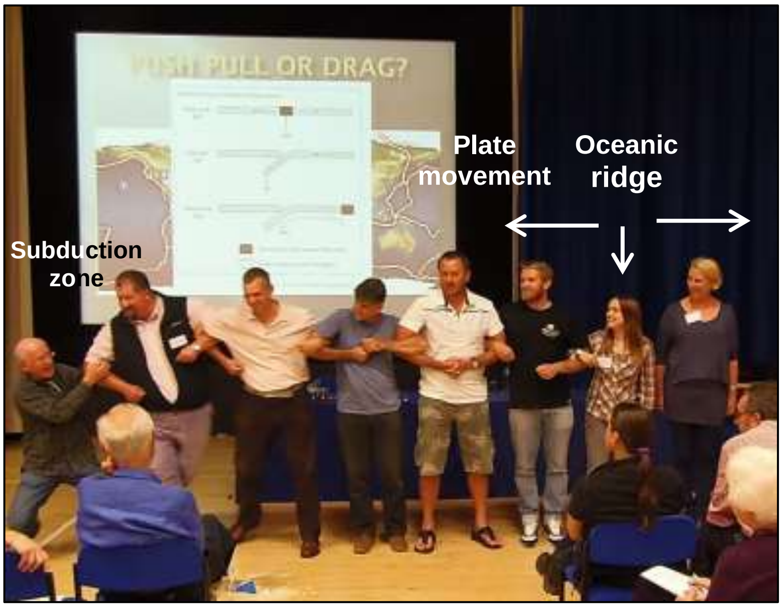
Demonstrate this by asking two pupils to stand together at the front of the room, representing two plates together at an oceanic ridge. Then ask around five pupils to stand beside one of these 'plate margins', and link arms to form a 'pupil tectonic plate' of lithosphere, as in the photo.

- Simulate a **mantle convection current** force by walking along behind the linked line of pupils, from the oceanic ridge plate margin, nudging the students in the back as you do so – showing that a mantle convection current has little effect on plate movement.

- Simulate **ridge push** by pushing between the two 'plate margins', as in the photo, showing that this has only a small impact on the 'pupil tectonic plate'.
-

(*David Bailey*)

- Simulate slab pull by going to the end of the line and pulling the last pupil, and so the whole 'pupil tectonic plate' (photo) – showing that this is the force which has the greatest effect.



(*David Bailey*)

Slab pull, which appears to be the main driving force of lithospheric plate movement, is convection in the solid state. Convection is caused when the solid lithospheric plate cools, becomes more dense than the underlying mantle, and so sinks – this causes the **slab pull** process to take place in the solid state as plates sink into the mantle at subduction zones. If **ridge push** also contributes to plate movement, this too is an example of convection in the solid state, where higher, less dense material pushes downwards and outwards.

Note that geophysical evidence shows that the mantle is a solid, not a liquid (S-waves travel through the mantle and they only travel through solids). Between around 100 and 250 km depth is the asthenosphere (or weak-sphere), where seismic waves slow down slightly, which is evidence of a tiny amount of liquid (~1%). The small amount of liquid softens the solid mantle and forms the weak layer over which the rigid lithospheric plates can slide. So plate movement is a convecting solid (rheid) phenomenon – the mantle is not molten.

Pupil learning outcomes: Pupils can:
- describe three forces that could cause plate movement;
- identify slab pull as the main driving force;
- explain that this is an example of convection in the solid state.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks, weathering and soils; • understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems	**Sciences** **Topical science** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b **Social sciences** **People, place and environment** **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present **Geography** **KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	**Science** **KS3** **Earth and Universe** The environment and human influences **GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges; – destructive plate margins: subduction zone and ocean – trench; – collision zones: fold mountains; and – conservative plate margins: fault lines

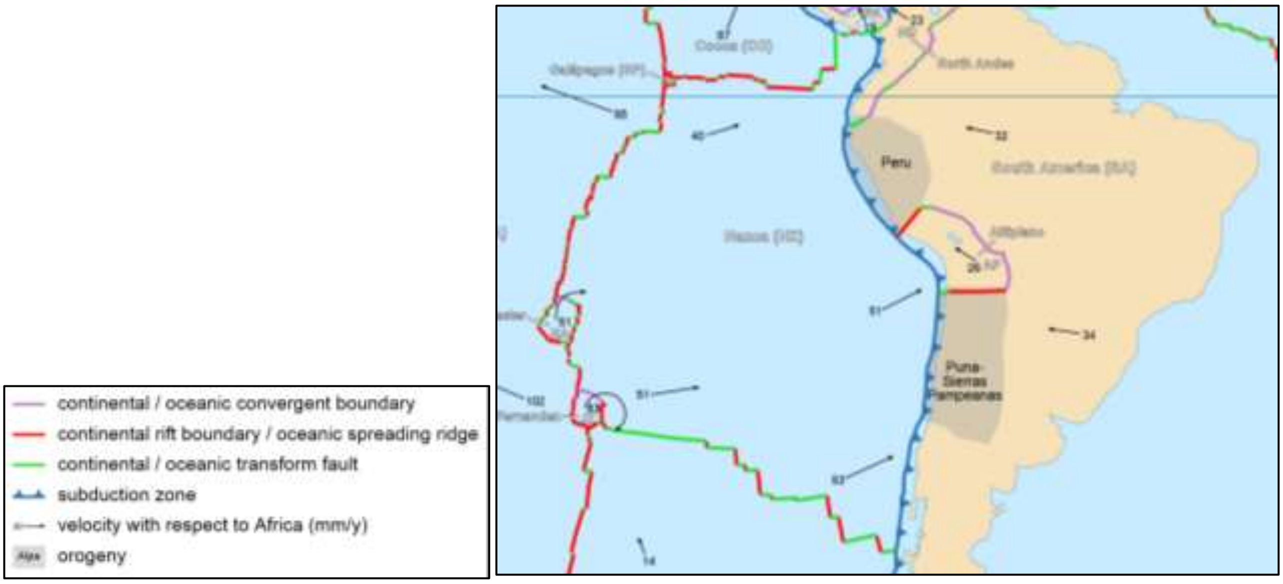
Age range of pupils: 11 – 18 years

Time needed to complete activity: 10 minutes

The story for teachers:
Recent evidence has shown that the traditional view of mantle convection being the main driving force in lithospheric plate movement is probably incorrect. If it were the main driving force, then plates with the largest surface area would move fastest because they would have the largest area on which the mantle convection forces would act – this is not the case. However, those plates that have the longest subducting margins, with geophysical evidence of the deepest subduction slabs, do seem to be moving fastest – which is why this is now considered to be the main driving force.

A fourth force that might be important is **subduction suction** where the old, cold oceanic plate subduction trench migrates towards the oceanic ridge pulling the over-riding plate behind it. Some geophysicists argue that this is an important driver of plate movement.

Following up the activity:
Ask the pupils to test the idea that the fastest moving plates have the greatest proportion of subducting margin (and therefore the greatest slab pull effect) as follows:
- ask them to identify three plates on a plate map: the Pacific plate, the Nazca plate and the South American plate;
- for each if these plates, ask them to approximately measure the total length of the plate margin (all parts of the margin, including the ridges/rifts, transform faults, and subduction zones);
- then they should measure the length of that plate margin which is subducting (in the direction of the triangular 'teeth' shown on most maps – e.g. at the Nazca/South American plate boundary, it is the Nazca plate which is subducting, <u>not</u> the South American plate), see map overleaf.



(Part of the map published by Eric Gaba (Wikimedia Commons user: Sting) under the Creative Commons Attribution-Share Alike 2.5 Generic license)

The whole map is available for free download from:
http://en.wikipedia.org/wiki/Plate_tectonics#mediaviewer/File:Tectonic_plates_boundaries_detailed-en.svg

- they should then compare the two figures to work out the percentage of margin which is subduction zone;
- then they should compare these results with the fact that the Pacific is the fastest-moving plate, the Nazca plate is moving at an intermediate rate, whilst the South American plate is slow-moving.

A. The Pacific plate has about a third down-going subduction margin (at the Aleutian, Kurile, Japan, Philippine and Fiji-Tongan trenches) and is an old, cold plate = fastest rates
The Nazca plate has about a quarter subduction margin (Chile-Peru trench) and is a young, warm plate = intermediate velocities
The South American plate has no down-going subduction margin = slow velocities (probably caused by ridge push from South Atlantic oceanic ridge)

Source: Activity devised by Pete Loader, with helpful contributions from Ian Stimpson.

…………………

Preparation and set-up time: none

Resource list:
- several willing participants

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
What drives the plates?	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

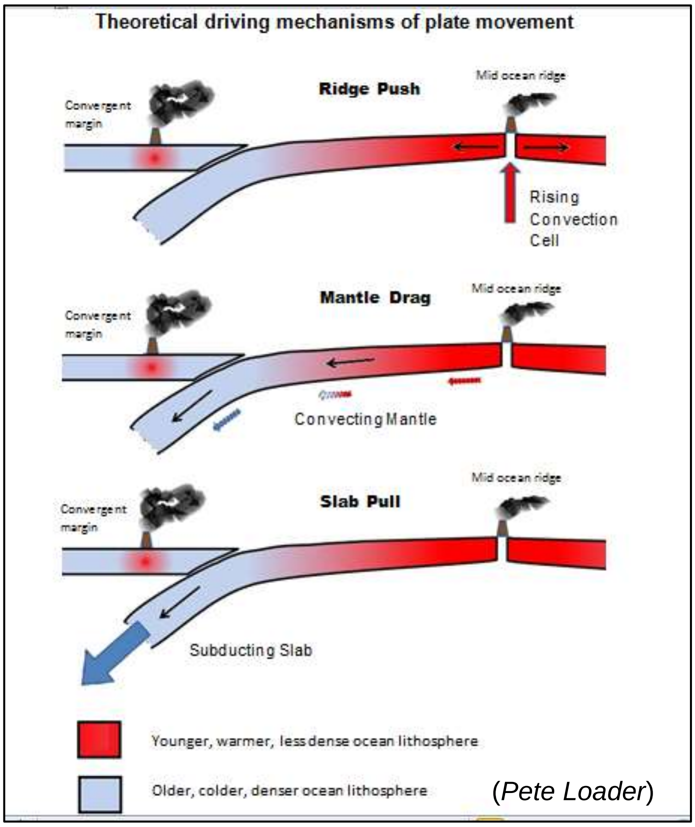
ESEU activity guide sheet:

What drives the plates?

Using a pupil model to demonstrate that slab pull is the main plate driving force.

The Earth's tectonic plates move, but what processes cause this movement?

Three of the forces that have been proposed as the main drivers of plate movement are:



(*Pete Loader*)

- **mantle convection currents** – mantle currents carrying plates of lithosphere along on top, like shopping on a supermarket conveyor belt;
- **ridge push** – newly-formed plates at oceanic ridges are warm, and so have higher altitude at the oceanic ridge than the colder, more dense plate material further away; gravity causes the higher plate at the ridge to push away the lithosphere that lies further from the ridge;
- **slab pull** – older, colder plates sink at subduction zones because as they cool, they become more dense than the underlying mantle – so the sinking plate pulls the rest of the plate along behind it.

Recent research has shown that the major driving force for most plate movement is **slab pull** because the plates with more of their edges being subducted are the faster-moving ones.

Meanwhile, if there are **mantle convection currents**, as traditionally pictured (and they have not been detected by geophysics), they seem to have a small or no effect on plate movement. **Ridge push** only seems to be effective where there are no slab pull forces.

Demonstrate this by asking two pupils to stand together at the front of the room, representing two plates together at an oceanic ridge. Then ask around five pupils to stand beside one of these 'plate margins', and link arms to form a 'pupil tectonic plate' of lithosphere, as in the photo.

- Simulate a **mantle convection current** force by walking along behind the linked line of pupils, from the oceanic ridge plate margin, nudging the students in the back as you do so – showing that a mantle convection current has little effect on plate movement.
- Simulate **ridge push** by pushing between the two 'plate margins', as in the photo, showing that this has only a small impact on the 'pupil tectonic plate'.

(*David Bailey*)

- Simulate slab pull by going to the end of the line and pulling the last pupil, and so the whole 'pupil tectonic plate' (photo) – showing that this is the force which has the greatest effect.

(*David Bailey*)

Slab pull, which appears to be the main driving force of lithospheric plate movement, is convection in the solid state. Convection is caused when the solid lithospheric plate cools, becomes more dense than the underlying mantle, and so sinks – this causes the **slab pull** process to take place in the solid state as plates sink into the mantle at subduction zones. If **ridge push** also contributes to plate movement, this too is an example of convection in the solid state, where higher, less dense material pushes downwards and outwards.

Note that geophysical evidence shows that the mantle is a solid, not a liquid (S-waves travel through the mantle and they only travel through solids). Between around 100 and 250 km depth is the asthenosphere (or weak-sphere), where seismic waves slow down slightly, which is evidence of a tiny amount of liquid (~1%). The small amount of liquid softens the solid mantle and forms the weak layer over which the rigid lithospheric plates can slide. So plate movement is a convecting solid (rheid) phenomenon – the mantle is not molten.

From magnetic globe to magnetic rock evidence

Topic: A Plasticine™ ball containing a magnet is used to demonstrate how the inclination of the Earth's magnetic field is related to latitude, and how this can then be used to discover the latitude of rocks at the time when they formed.

Activity:

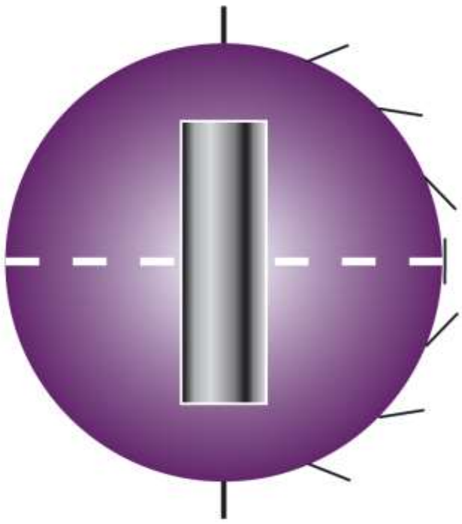
a) A model magnetic Earth

- Take the solid sphere of Plasticine™ containing a bar magnet.
- Use a Magnaprobe™ (or a plotting compass or a magnetised needle on a thread) to locate the North and South Poles (the places where the probe points vertically to the surface of the sphere) and mark these positions by pushing the matchsticks into the Plasticine™ vertically at these points.
- Use the Magnaprobe™ to locate the magnetic equator (where the probe is horizontal to the surface of the globe) and mark the position using another matchstick pushed into the Plasticine™ parallel with the surface.
- Use the Magnaprobe™ along a 'line of longitude' (a line joining the North and South poles) to find out the varying angle of magnetic dip. Mark the angle at about nine points by pushing in matchsticks parallel to the Magnaprobe™ magnet. The result should look like the diagram below.

This activity indicates the **inclination** of the Earth's magnetic field at different latitudes (the dip of the Earth's magnetic field, as measured using a freely floating needle or a dip needle), it is vertical at the poles, horizontal at the Equator and dips at different angles in between.

You can test student understanding of what they have seen by asking them by how many degrees a magnet would rotate through, in being carried from the North Pole to the South Pole. Many will answer that the angle is 180 degrees, not realising that it would rotate though 180^o from the North Pole to the Equator and a further 180^o to the South Pole, a total of 360^o.

Note that this activity demonstrates the magnetic field around a bar magnet hidden inside a sphere of Plasticine™; it only gives a rough idea of what the magnetic field of the Earth is like. The Earth's magnetic field is probably caused by currents in the outer core; the Earth certainly does <u>not</u> have an enormous bar magnet in the middle!



Model of the Earth's magnetic field (*ESEU*)

Model magnetic Earth (*ESEU*)

b) Preserving remanent magnetisation


'Petri-dish magnetic field preserved in iron filings in wax' (*Michèle Bourne, ESEU*)

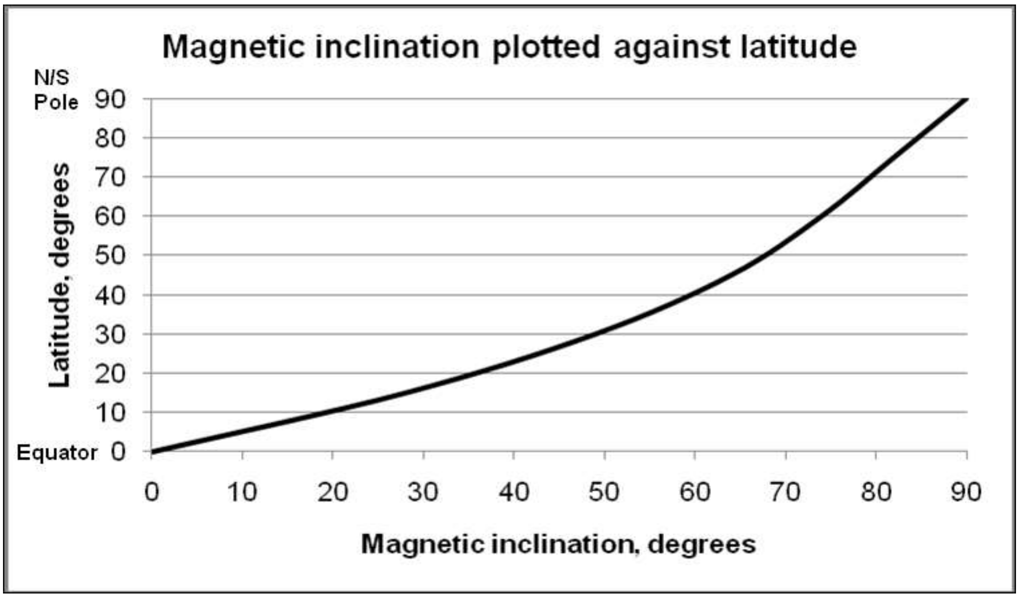
Demonstrate how magnetism can be preserved using the pre-prepared petri-dish of wax with iron filings, cooled in the presence of the magnet. The dish has clearly preserved the magnetic field of the magnet as it solidified. It doesn't matter how much the dish is later moved, the 'remanent magnetisation' of the magnet is still preserved.

Explain that when molten rocks containing magnetic elements (like iron minerals) cool, they take on and preserve any magnetic field in which they cool down. As all such rocks cool in the Earth's magnetic field, they preserve the inclination of the Earth's magnetic field at the time; this is the remanent **magnetisation** of the rocks.

This is most common when basalt lavas cool at the Earth's surface, since basalts are rich in iron.
Ask the students, if a basalt had a remanent magnetisation with a vertical inclination, where must it have been formed? *A. At one of the two poles.* Then ask, if it had a horizontal inclination, where must it have formed? *A. At the equator.*

Ask the students the meaning of this data from outcrops of rock <u>in the UK</u>:

- A rock of Precambrian age, about 1000 million years old (Ma) has vertical inclination (North up), corresponding to a former latitude at the South Pole.
- A rock of Carboniferous age (300 Ma) has horizontal polarity, corresponding to a former equatorial latitude.
- A red sandstone of Triassic age (220 Ma) has a gently inclined polarity (North down) corresponding to tropical northerly latitudes.
- *The data show the plate tectonic movement of the UK over geological time.*
- Finally ask, if a basalt lava formed and cooled in the UK today, latitude between 50 and 60^{o}N (this is geologically <u>highly</u> unlikely), what magnetic inclination might the preserved magnetism have?
- *The answer can either be measured from the graph below or shown using the Magnaprobe™ to be around 70^o.*



Pupil learning outcomes: Pupils can:
- describe how a Magnaprobe™ can be used to detect and mark a magnetic field;
- describe how a Plasticine™ ball with a magnetic field indicated shows magnetic field lines in three dimensions;
- explain how the ball provides an analogy with the magnetic field of the Earth;
- explain how the magnetic field of the time can be 'fossilised' in cooling magnetic rocks;
- explain how remanent magnetism in rocks can be used to show the latitude at which they formed;
- explain how this evidence can be used to support plate tectonic theory.

Curriculum references:

<table>
<tr><th>England</th><th>Scotland</th><th>Wales</th><th>Northern Ireland</th></tr>
<tr>
<td>KS3 Science
Working scientifically
Several aspects of Working Scientifically may be developed in this activity.
Chemistry
Earth and atmosphere
• the composition of the Earth
• the structure of the Earth
KS3 Physics
Forces
Magnetism
• magnetic poles, attraction and repulsion.
• magnetic fields by plotting with compass, representation by field line.
• Earth's magnetism, compass and navigation
KS4 Science
Working scientifically
Several aspects of Working Scientifically may be developed in this activity.
Physics
Magnetism
• exploring the magnetic fields of permanent and induced magnets, and the Earth's magnetic field, using a compass.</td>
<td>Sciences
Forces, electricity and waves
First
By exploring the forces exerted by magnets on other magnets and magnetic materials, I can contribute to the design of a game.
SCN 1-08a
Second
I have collaborated in investigations to compare magnetic, electrostatic and gravitational forces and have explored their practical applications.
SCN 2-08a
Second
Forces
I have collaborated in investigations to compare magnetic, electrostatic and gravitational forces and have explored their practical applications.
SCN 2-08a
Earth's Materials
Having explored the substances that make up the Earth's surface, I can compare some of their characteristics and uses.
SCN 2-17a
Third
Processes of the planet
By contributing to experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature.
SCN 3-05a
Geography
People, place & environment
Second
I can describe the major characteristic features of Scotland's landscape and explain how these were formed
SOC 2-07a.
Third
Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond.
SOC 3-07a
I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world.
SOC 3-14a</td>
<td>Science
KS2
• forces of different kinds, e.g. gravity magnetic and friction</td>
<td>GCSE Geography
i) describe the structure of the Earth (core, mantle and crust);</td>
</tr>
</table>

Age range of pupils: 11-16 years

Time needed to complete activity: 10 – 15 minutes

The story for teachers:
Recognition of the magnetic pattern shown by the matchsticks is a pattern-seeking activity. Finding the equator is a challenge, and relating the activity to the real world involves bridging skills.

Lead in ideas: Ideas for leading into the activity:
You could set up this activity by asking these questions:
- In which direction does the needle of a magnetic compass point? *A. The needle of a magnetic compass is constrained by its pivot and can only point north-south.*

- If you could hang a magnet from its centre of mass by a piece of cotton, in which direction would you expect it to point? Why? *A. A dip circle or a freely suspended magnet (so long as it is suspended at the centre of mass) will point north-south but will also dip down into the ground. In the UK, this is around 70°; this can be demonstrated using the Magnaprobe™ later.*
- Why wouldn't it point in the same direction as the needle of a magnetic compass? *A. Because the needle of a magnetic compass has one end weighted so that it remains horizontal in the Earth's 3D magnetic field; for this reason, magnetic compasses designed for use in the Northern Hemisphere do not work in the Southern Hemisphere because the wrong side of the magnetic needle is weighted for Southern Hemisphere work.*
- The needle of the magnetic compass is a magnet. Is the red end of the compass that points northward a south pole or a north pole? *A. The 'red end' is a south pole that is attracted to the Earth's north magnetic pole; it can also be called a north-seeking pole.*

Following up the activity:
Follow up this activity by asking this question:
- Most Ordnance Survey maps of the UK state that the 'magnetic variation' is changing slightly from year to year. Magnetic variation is the angle between the true North Pole and the Magnetic North Pole, which is in a different place. How does this information tell you that the Earth's magnetic field is NOT caused by a bar magnet buried deep within it? *A. Ordnance Survey maps show the magnetic variation from Grid North, but also state the rate at which it is changing. The change indicates that there is something dynamic inside the Earth and not a solid lump of iron like a bar magnet!*

Source: Taken from ESEU's 'Model Earth – Plasticine™ balls' activity and from 'What is the Earth's Magnetic Field Like?' in ESEU's workshop publication 'Through the Lab Window to the World: teaching KS3 physics through an Earth context'

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Preparation and set-up:
It takes a few minutes to make the Plasticine™ ball containing a magnet, plus a few minutes to prepare the petri-dish, as described below.

Resource list:
a) a model magnetic Earth
- a strong bar magnet, enclosed as centrally as possible in a large solid sphere of Plasticine™ (e.g. a 7cm magnet in a 12cm diameter sphere)
- a Magnaprobe™ (tiny magnet suspended in gimbals – currently around £10 each) a plotting compass or a magnetised needle hanging from a thread
- 15 spent matchsticks

b) preserving remanent magnetisation
- a pre-prepared plastic petri dish into which molten candlewax has been poured, iron filings have been sprinkled on the surface, the dish has been placed on top of a bar magnet, and the wax allowed to solidify, thus preserving the shape of the magnetic field in the pattern of the iron filings

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
From magnetic globe to magnetic rock evidence	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

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12-25 = High risk – take immediate action
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ESEU activity guide sheet:

From magnetic globe to magnetic rock evidence

A Plasticine™ ball containing a magnet is used to demonstrate how the inclination of the Earth's magnetic field is related to latitude, and how this can then be used to discover the latitude of rocks at the time when they formed.

a) A model magnetic Earth

- Take the solid sphere of Plasticine™ containing a bar magnet.

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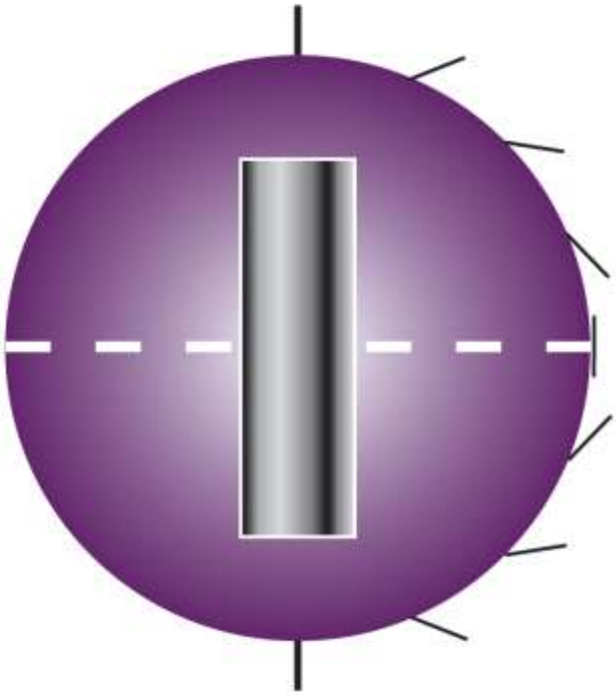

Model of the Earth's magnetic field (*ESEU*)

Marking the points and direction of magnetism using cocktail sticks (*ESEU*)

b) Preserving remanent magnetisation


'Petri-dish magnetic field preserved in iron filings in wax' (*Michèle Bourne, ESEU*)

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This is most common when basalt lavas cool at the Earth's surface, since basalts are rich in iron.
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- *The data show the plate tectonic movement of the UK over geological time.*

- Finally ask, if a basalt lava formed and cooled in the UK today, latitude between 50 and 60^{o}N (this is geologically highly unlikely), what magnetic inclination might the preserved magnetism have?

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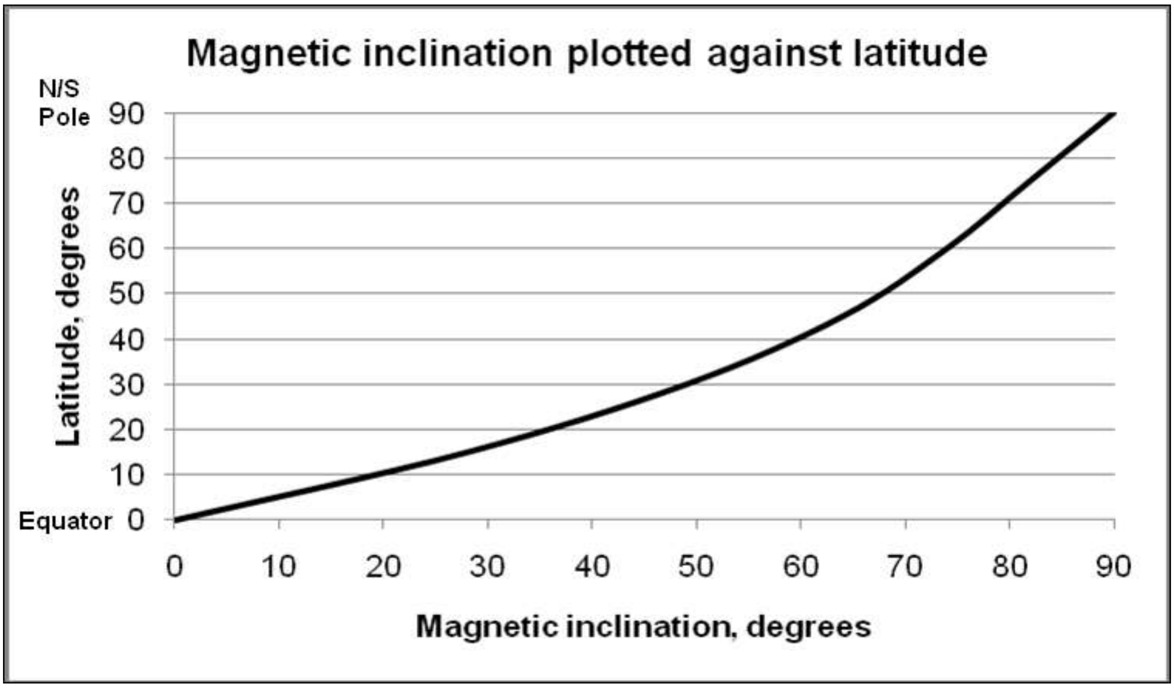


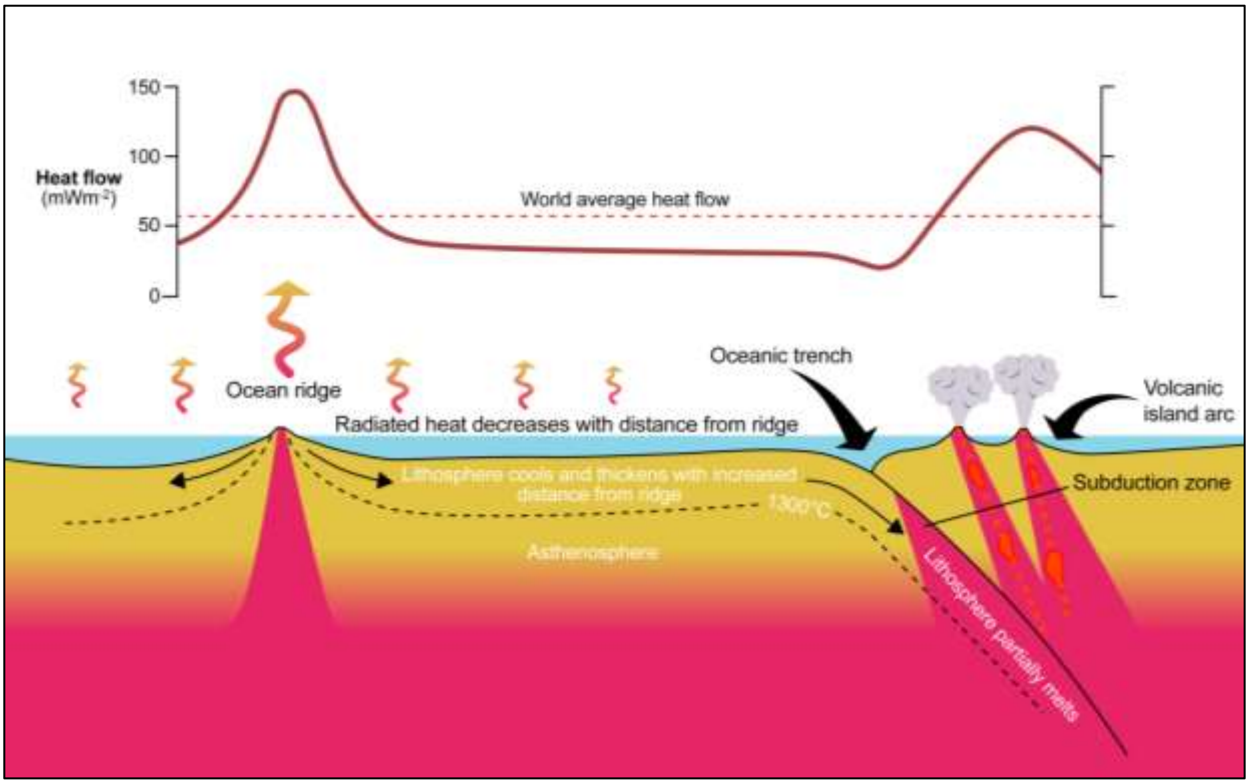
© ESEU

The heat flow evidence

Topic:
Discuss how the pattern of heat flow from the Earth's surface supports the theory of plate tectonics.

Activity:
The diagram shows a plot of the loss of heat from the Earth's surface, providing excellent evidence supporting the theory of plate tectonics. This can be used, in discussion with the students, to show:

- high heat flow over ocean ridge constructive plate margins, where the rising and eruption of magma releases large amounts of heat;
- the plate cooling as it is moved away from the ridge (the near-horizontal line in the graph slopes slightly downwards to the right) – by cooling in this way, the plate becomes more and more dense, until it eventually is more dense than the underlying materials and is subducted;
- the lowest heat flow at the oceanic trench, where subduction occurs;
- the high heat flow over the volcanic areas of the continent, where igneous activity brings heat to the surface.



The pattern of heat flow out of the ocean floor and the upper part of the mantle and the crust.
© Chris King and Dee Edwards, redrawn by ESEU

Pupil learning outcomes: Pupils can:

- describe how heat flow varies in different plate tectonic situations;
- explain how this evidence can be used to support plate tectonic theory.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3 Chemistry – Earth and atmosphere** • the composition of the Earth • the structure of the Earth	**Sciences** **Third** **Processes of the planet** By contributing to	No direct references	**GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of

KS4 Science **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks	experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature. SCN 3-05a		a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: - constructive plate margins: mid-ocean ridges; - destructive plate margins: subduction zone and ocean - trench; - collision zones: fold mountains; and - conservative plate margins: fault lines

Age range of pupils: 12-16

Time needed to complete activity: 5 minutes

Lead in ideas:
Use the activity 'Properties of the mantle – potty putty ™' to show that solid materials may actually flow, given enough time.

Following up the activity:
Study a world map of the ocean floors, to point out that areas of high heat flow coincide with the major oceanic ridges.

Source: Earth Science Education Unit.

Copyright: © Earth Science Education Unit
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Preparation and set-up: None

Resources list:
- diagram or PowerPoint presentation, computer and projector

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
The heat flow evidence	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

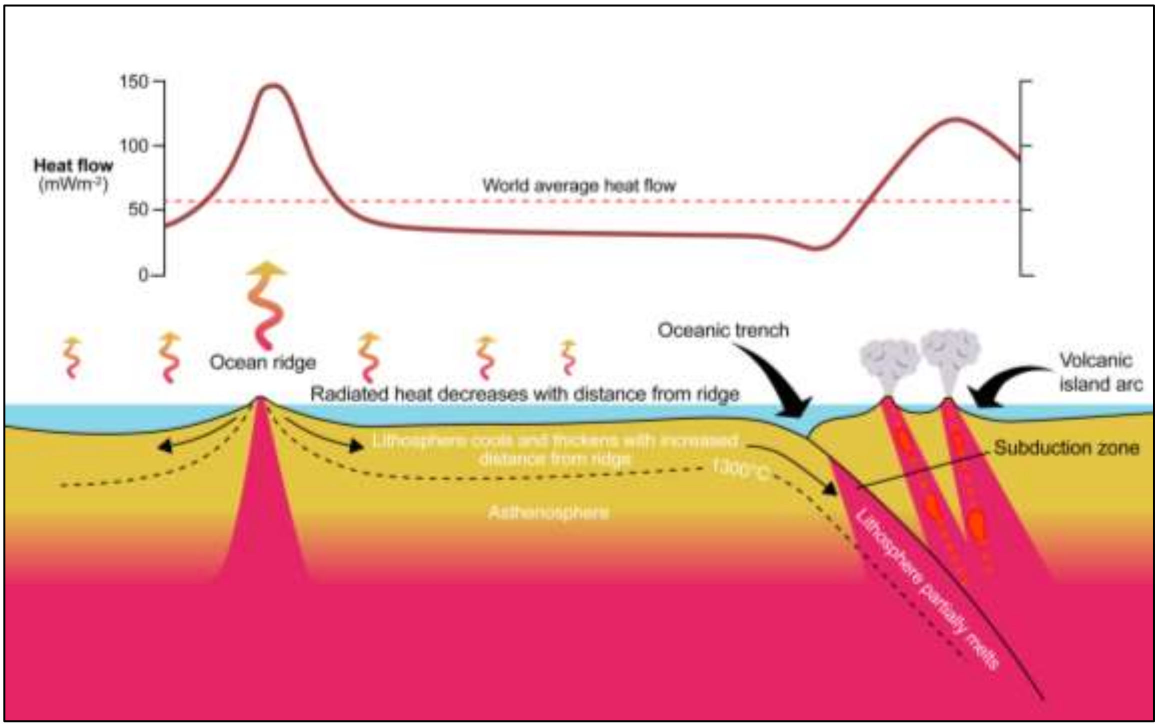
ESEU activity guide sheet:

The heat flow evidence

Discuss how the pattern of heat flow from the Earth's surface supports the theory of plate tectonics.

The diagram shows a plot of the loss of heat from the Earth's surface, providing excellent evidence supporting the theory of plate tectonics. This can be used, in discussion with the students, to show:

- high heat flow over ocean ridge constructive plate margins, where the rising and eruption of magma releases large amounts of heat;
- the plate cooling as it is moved away from the ridge (the near-horizontal line in the graph slopes slightly downwards to the right) – by cooling in this way, the plate becomes more and more dense, until it eventually is more dense than the underlying materials and is subducted;
- the lowest heat flow at the oceanic trench, where subduction occurs;
- the high heat flow over the volcanic areas of the continent, where igneous activity brings heat to the surface.



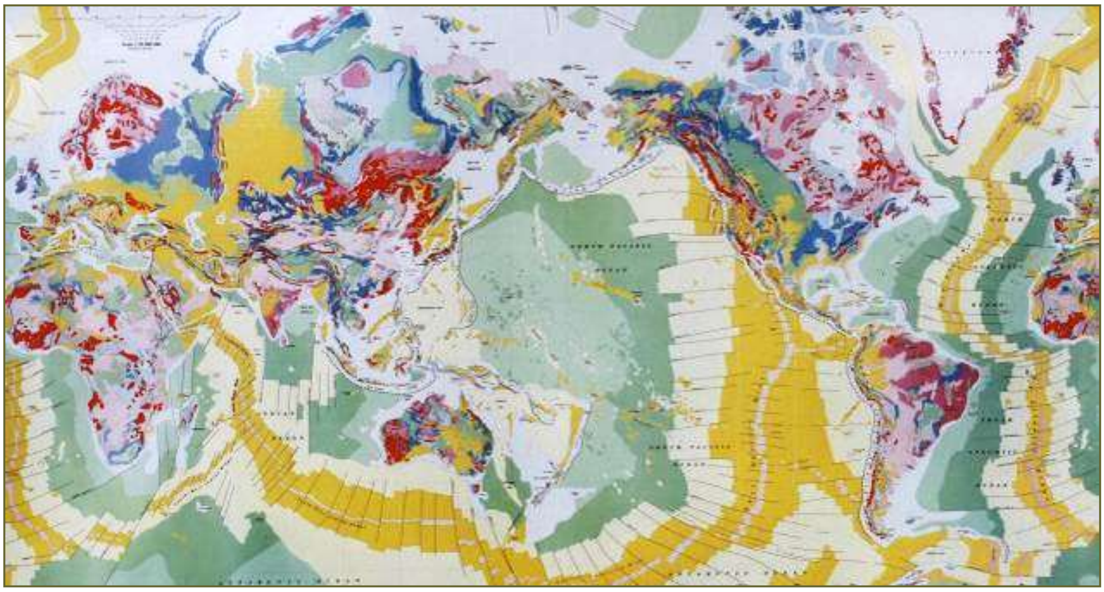
The pattern of heat flow out of the ocean floor and the upper part of the mantle and the crust.
© Chris King and Dee Edwards, redrawn by ESEU

Evidence from the age of the sea floor

Topic:
Discuss how the variation of age of different sections of the sea floor supports the theory of plate tectonics.

Activity:
The map shows the age of the oldest parts of the ocean floor, as shown by the deep sea drilling programme, which plots the age of the oldest rocks it finds in a borehole. Understanding of this map can be tested by asking:

- why some areas of the ocean have much broader red zones than others (*A. because spreading rates are faster at broader areas*);
- how you could work out rates of spreading from this map. (*A. Measure the distance from the centre of a dark yellow area (the spreading centre) to the edge of a pale green area (which is 154 Ma old); then use the equation: speed = distance/time to calculate the spreading rate*).



Photograph of 'The Geological Map of the World'. © Open University
Note that the youngest rocks are shown in dark yellow, whilst the oldest ocean floor rocks are pale green; the continents are largely formed of much older rocks.

Pupil learning outcomes: Pupils can:

- explain how the age of the sea floor provides evidence supporting plate tectonic theory.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and	**Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present	**GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges;

explanations to develop hypotheses. **Geography KS3 Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks,	**People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.		– destructive plate margins: subduction zone and ocean – trench; – collision zones: fold mountains; and – conservative plate margins: fault lines

Age range of pupils: 11-16

Time needed to complete activity: 5 minutes

Lead in ideas:
Use the activities 'The Heat Flow Evidence' and 'Properties of the mantle – potty putty' to establish that slow movement is possible at oceanic ridges and that it may be symmetrical about the ridge crest.

Following up the activity:
Compare the symmetrical pattern of ages on the ocean floor, all of them less than 200 million years ago, with the presence of much older rocks on the continents, in a non-linear pattern.

Source: Earth Science Education Unit.

…………………

Preparation and set-up: None

Resources list:
- diagram or PowerPoint presentation, computer and projector
- (optional) 'The Geological Map of the World'. © Open University

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Evidence from the age of the ocean floor	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
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Risk Priority (AxB):
12-25 = High risk – take immediate action
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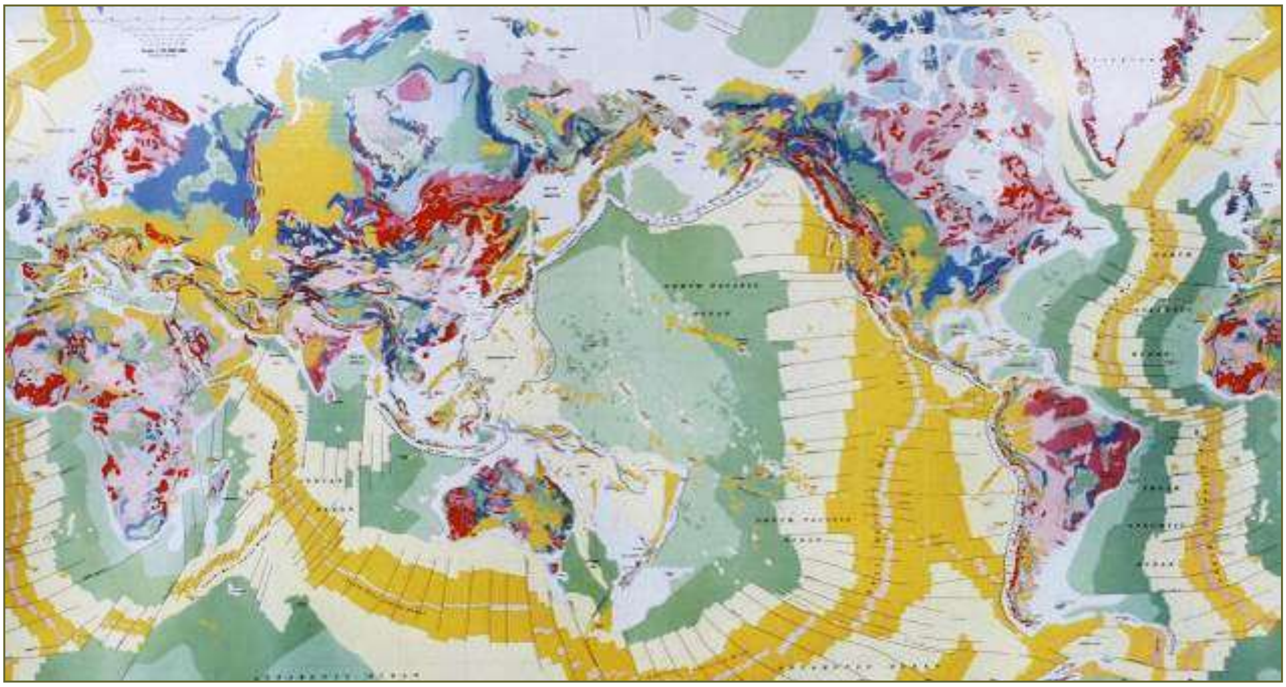
ESEU activity guide sheet:

Evidence from the age of the sea floor

Discuss how the variation of age of different sections of the sea floor supports the theory of plate tectonics.

The map shows the age of the oldest parts of the ocean floor, as shown by the deep sea drilling programme, which plots the age of the oldest rocks it finds in a borehole. Understanding of this map can be tested by asking:

- why some areas of the ocean have much broader red zones than others (*A. because spreading rates are faster at broader areas*);
- how you could work out rates of spreading from this map. (*A. Measure the distance from the centre of a dark yellow area (the spreading centre) to the edge of a pale green area (which is 154 Ma old); then use the equation: speed = distance/time to calculate the spreading rate*).



Photograph of 'The Geological Map of the World'. © Open University

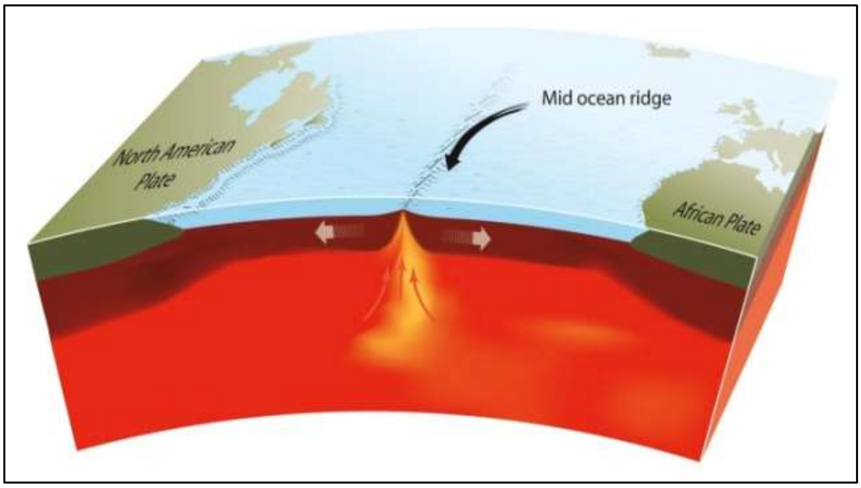
Note that the youngest rocks are shown in dark yellow, whilst the oldest ocean floor rocks are pale green; the continents are largely formed of much older rocks.

Constructive plate margins - adding new plate material

Topic: Discuss the processes at a constructive plate margin

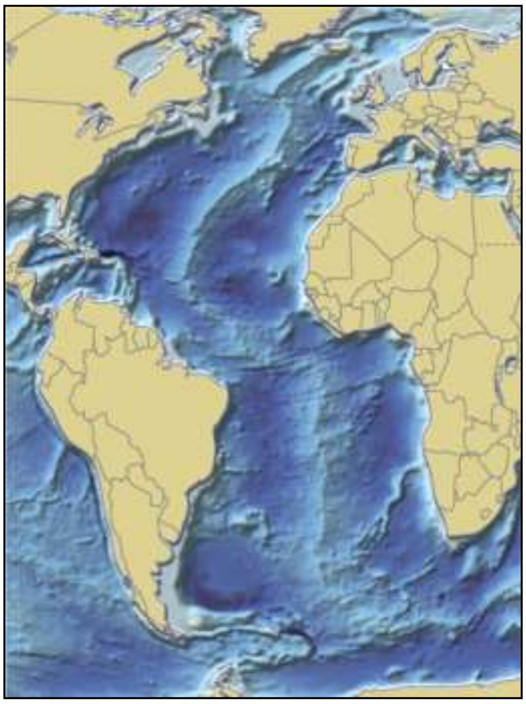
Activity:
The diagrams, maps and photographs shows the processes active at a constructive (divergent) plate margin. The first diagram shows:

- magma rising to form new plate material as plates are carried apart;
- thermal expansion of the whole area reducing the density and therefore gravitational pull, causing an oceanic ridge to form;
- a rift valley in the centre, as the plates are moved apart and the central block slides down;
- offsetting of the ridge by transform faults.



Mid ocean ridge © Press & Siever, redrawn by ESEU

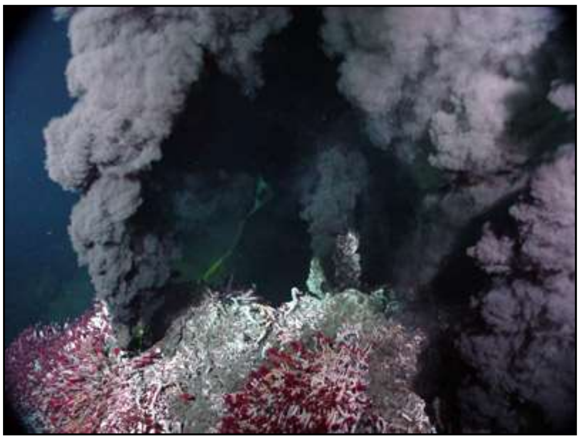
Many of these features can be seen on the topographic map of the Atlantic Ocean floor.



'Mid-Atlantic Ridge' Map © Hugo Ahlenius, UNEP/GRID-Arendal, http://maps.grida.no/go/graphic/world-ocean-bathymetric-map

The photographs show evidence of the high temperature activity at a constructive plate margin:

- Black smoker activity, hot water laden with black minerals bubbling out of vents.
- Runny (low viscosity) basaltic lavas flowing from a fissure eruption, as is common on Iceland, in the centre of the Mid-Atlantic Ridge.
- Ancient pillow basalts, caused by basaltic lava flows eruption into water.



Black Smoker by US National Oceanic & Atmospheric Administration – image in the public domain

Black Smoker © This Dynamic Earth: the Story of Plate Tectonics, USGS

Icelandic-type eruption - reproduced with kind permission of U.S. Department of Interior, USGS

Ancient Pillow lavas © Peter Kennett

Pupil learning outcomes: Pupils can:

- explain the processes active at constructive plate margins.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and	**Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present	**GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges;

explanations to develop hypotheses. **Geography KS3 Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks,	**People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.		

Age range of pupils: 11-16

Time needed to complete activity: 5 minutes

Lead in ideas:
Use the activities 'The Heat Flow Evidence' and 'Properties of the mantle – potty putty' to establish that slow movement is possible at oceanic ridges and that it may be symmetrical about the ridge crest.

Following up the activity:
Demonstrate the magnetic evidence for the addition of new plate material by the use of the activity 'The magnetic stripes evidence'.

Source: Earth Science Education Unit.

Copyright: © Earth Science Education Unit.
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Preparation and set-up: None

Resources list:
- diagrams and photos or PowerPoint presentation, computer and projector

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Constructive plate margins – adding new plate material	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
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Risk Priority (AxB):
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Less than 6 = Low risk – plan future actions where required

ESEU activity guide sheet:

Constructive plate margins - adding new plate material

Discuss the processes at a constructive plate margin

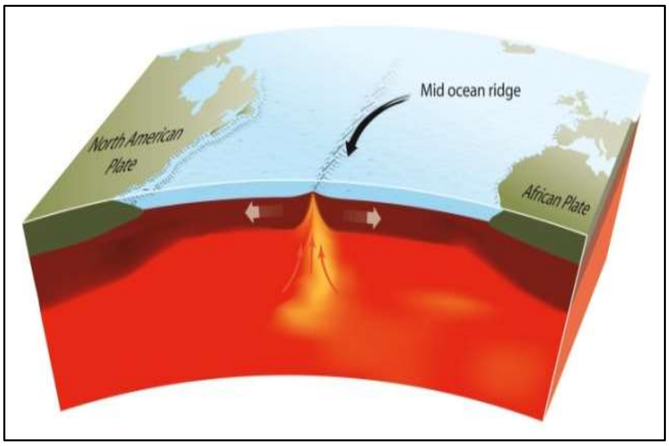
The diagrams, maps and photographs shows the processes active at a constructive (divergent) plate margin. The first diagram shows:

- magma rising to form new plate material as plates are carried apart;

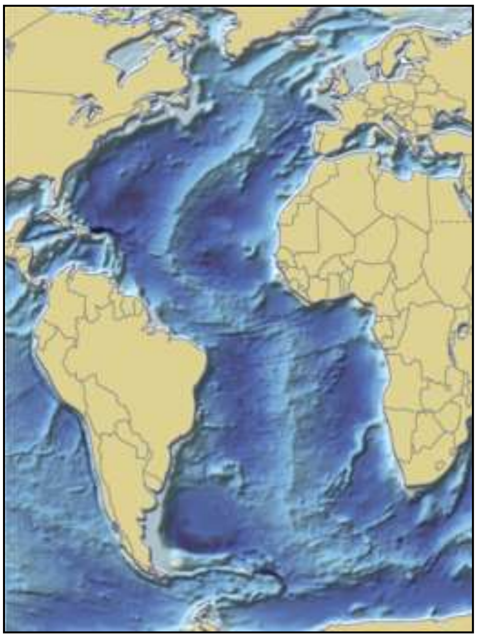
- thermal expansion of the whole area reducing the density and therefore gravitational pull, causing an oceanic ridge to form;

- a rift valley in the centre, as the plates are moved apart and the central block slides down; offsetting of the ridge by transform faults.

Many of these features can be seen on the topographic map of the Atlantic Ocean floor.



Mid ocean ridge © Press and Siever, redrawn by ESEU


'Mid-Atlantic Ridge' Map © Hugo Ahlenius, UNEP/GRID-Arendal, http://maps.grida.no/go/graphic/world-ocean-bathymetric-map

The photographs show evidence of the high temperature activity at a constructive plate margin:

- Black smoker activity, hot water laden with black minerals bubbling out of vents.
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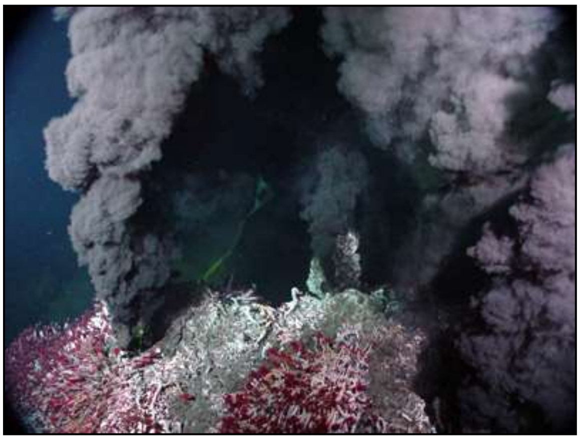
- Ancient pillow basalts, caused by basaltic lava flows eruption into water.



Black Smoker by US National Oceanic & Atmospheric Administration – image in the public domain

Black Smoker © This Dynamic Earth: the Story of Plate Tectonics, USGS

Icelandic-type eruption - reproduced with kind permission of U.S. Department of Interior, USGS

Ancient Pillow lavas © Peter Kennett

Faults in a Mars™ Bar

Topic: Pull apart a Mars™ Bar to demonstrate the features at a sea floor spreading centre.

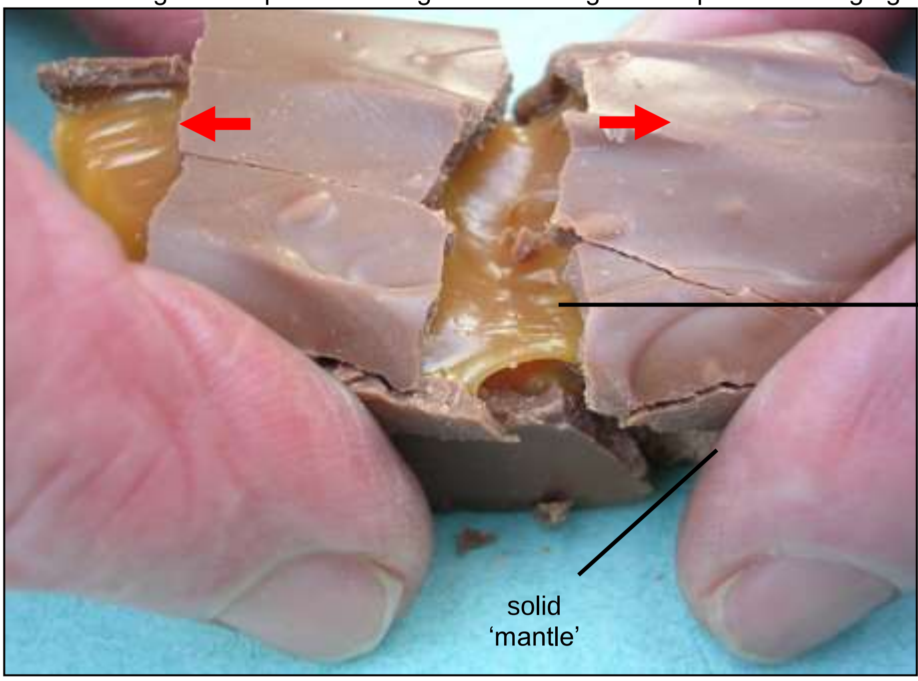
Activity:
Ensure that the Mars™ Bar is at room temperature and not too cold. Explain that the features at sea-floor spreading centres relate to the pulling apart of the lithosphere as two plates move away from each other.

Gently pull the Mars™ Bar until it begins to crack in the middle. The brittle outer layer of chocolate shows cracking (i.e. brittle failure), at right angles to the direction of pulling. This is equivalent to the brittle lithosphere cracking under tension and producing a rift valley down the middle of the oceanic ridge. Any cracks which are parallel to the direction of pulling are in the same direction as the transform faults which cut across oceanic ridges (although true transform faults are actually formed by a more complex process).

The gooey caramel beneath the chocolate can be seen to have flowed and thinned under tension. This is equivalent to the 'weak' layer, or asthenosphere beneath the lithosphere. The solid nougat beneath the caramel layer represents the solid mantle beneath the asthenosphere.

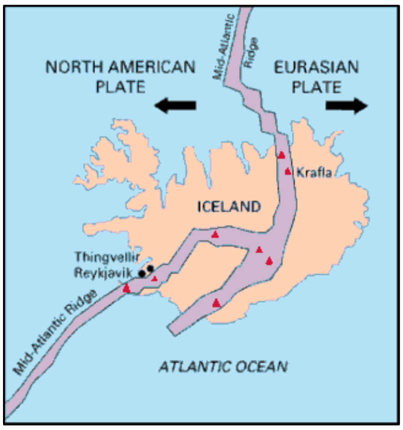
central 'rift valley

rigid 'lithosphere' moving left rigid 'lithosphere' moving right



ductile flowing
'asthenosphere'

A 'rift valley' in a Mars™ bar. © Peter Kennett



Iceland, Mid-Atlantic Ridge © USGS

Gap between the North American and Eurasian continental plates © Randomskk

Bridge between two continents © Chris73

Pupil learning outcomes: Pupils can:

- describe the response to tension caused by a Mars™ Bar as it is pulled apart;
- relate the features seen in this analogy to the processes active at oceanic constructive margins.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Physics** **Forces:** • **…**elastic and inelastic stretching **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks, • understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems	**Sciences** **Third** **Processes of the planet** By contributing to experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature. SCN 3-05a **Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present **Geography** **KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges

Age range of pupils: 12-16

Time needed to complete activity: 5 minutes

Lead in ideas:
Establish the layered nature of the Earth - crust, mantle, core, from seismic wave evidence. Explain that the crust and outermost mantle act together, to form the lithosphere and that it is the lithosphere which moves and not the crust alone.

This brief activity can follow treatment of the main evidence for sea-floor spreading, e.g. magnetic data; the topography of the oceanic ridges; high heat flow; volcanic activity; shallow earthquake foci, etc.

Use Potty Putty™ to show the nature of the mantle, permitting elastic, plastic and brittle deformation, depending on the circumstances.

Following up the activity:
Continue with other evidence for plate tectonics.

Source: Earth Science Education Unit.

Copyright: © Earth Science Education Unit.
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Preparation and set-up: None

Resources list:
- one Mars™ Bar (any size!)

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Faults in a Mars Bar™	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
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5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
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ESEU activity guide sheet:

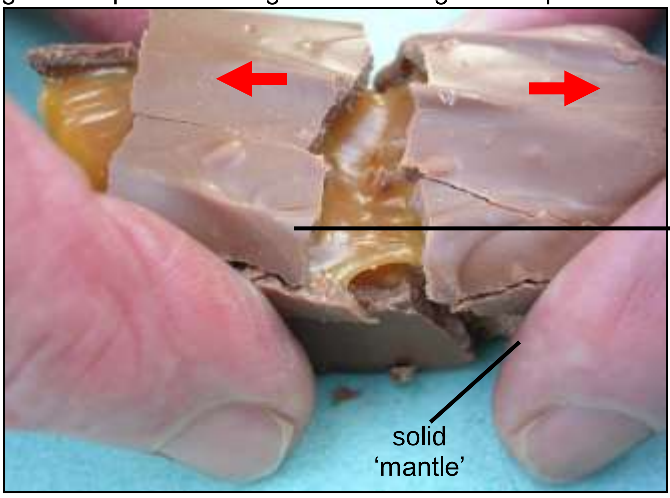
Faults in a Mars™ Bar

Pull apart a Mars™ Bar to demonstrate the features at a sea floor spreading centre.

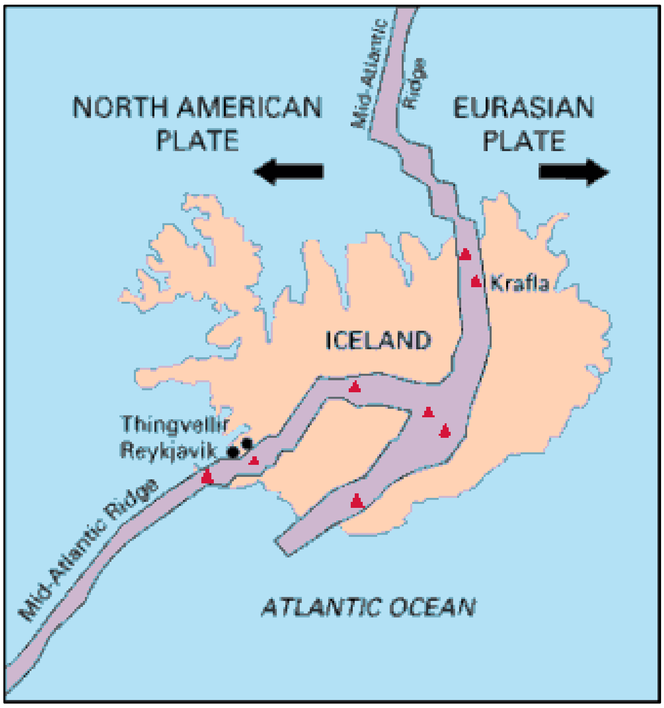
Ensure that the Mars™ Bar is at room temperature and not too cold. Explain that the features at sea-floor spreading centres relate to the pulling apart of the lithosphere as two plates move away from each other.

Gently pull the Mars™ Bar until it begins to crack in the middle. The brittle outer layer of chocolate shows cracking (i.e. brittle failure), at right angles to the direction of pulling. This is equivalent to the brittle lithosphere cracking under tension and producing a rift valley down the middle of the oceanic ridge. Any cracks which are parallel to the direction of pulling are in the same direction as the transform faults which cut across oceanic ridges (although true transform faults are actually formed by a more complex process).

The gooey caramel beneath the chocolate can be seen to have flowed and thinned under tension. This is equivalent to the 'weak' layer, or asthenosphere beneath the lithosphere. The solid nougat beneath the caramel layer represents the solid mantle beneath the asthenosphere.



A 'rift valley' in a Mars™ bar. © Peter Kennett



Iceland, Mid-Atlantic Ridge © USGS

Gap between the North American and Eurasian continental plates © Randomskk

Bridge between two continents © Chris73

The magnetic stripes evidence

Topic:
The magnetic field of the Earth is modelled using iron filings and a bar magnet. The magnetic stripes on the ocean floor are modelled by magnetising pins attached to cardboard, which is pulled up through a gap, to simulate sea floor spreading.

Activity:
Iron filings in wax are used to demonstrate how a rock may be able to "hold" a magnetisation. A paper model of a sea-floor spreading centre, with pins, is then pulled up between two benches/desks/piles of textbooks and the pins magnetised by stroking with a magnet on one direction in the dark stripes and the other direction in the pale stripes. Finally a magnetic compass is moved across the top of the stripes, and the 'flipping' compass needle shows how they are magnetised in different directions.

Carry out a risk assessment (see below).

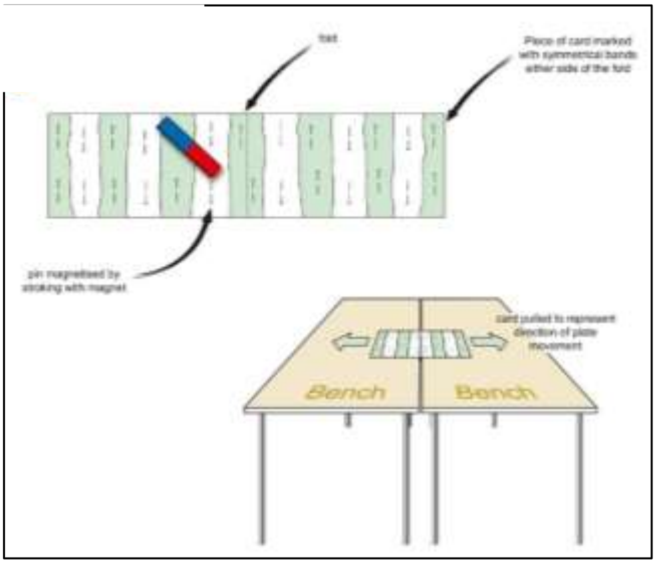
Pupils are familiar with the shaking of iron filings onto a card over a bar magnet. If the card is sprayed with spray-on glue, the iron filings remain in the position of the magnetic field, even when the magnet is removed. This is analogous to a rock holding a previous magnetisation, even after the Earth's field has changed (called remanent magnetism). Alternatively, the filings can be shaken into a petri dish of molten wax over the bar magnet and the wax allowed to set (see the 'Magnetic globe to magnetic rock evidence' activity).

Some igneous rocks are so strongly magnetised that a good magnetic compass will be deflected by several degrees, and North and South pole positions can also be located.

Prepare a strip of paper or thin card (e.g. 50 x 20cm) as shown in the diagram. This can be done by hand by drawing and colouring alternate stripes <u>symmetrically</u> about the midline or by preparing one A4 sheet of stripes on computer, printing two copies and sticking them together as a mirror image of one another. Stick dressmakers' pins in each section, pointing <u>alternately</u>, as shown in the diagram and cover them with sticky tape to prevent injury.

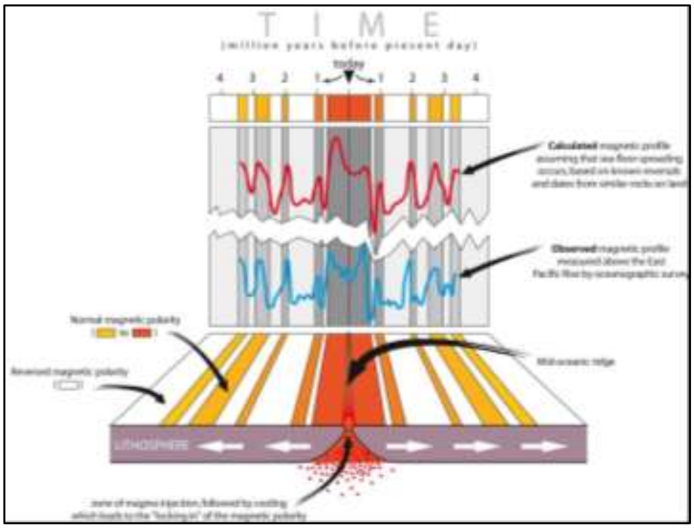
Fold the sheet and slot it down between two benches, so that most of it is hidden. Explain that this represents an oceanic ridge, like the Mid-Atlantic Ridge, with magma welling up, cooling and crystallising. Once the rock has dropped below a certain temperature (the Curie Temperature – discovered by Pierre Curie, husband of Marie), it is capable of acquiring an induced magnetisation from the ambient magnetic field of the Earth.

Draw up the sheet between the benches as shown in the diagram below. As the first set of pins appears, magnetise them by gently stroking them repeatedly with the North end of a strong bar magnet, stroking <u>towards</u> the point of the pin. As the next set of pins appears, stroke them with the North end of the magnet, again towards the point (i.e. in the opposite direction). Continue *ad nauseam*.



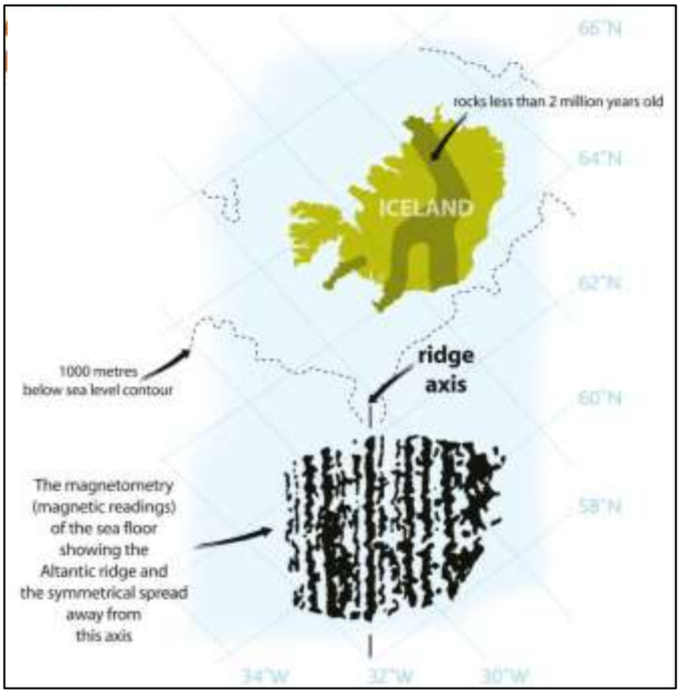
Classroom demonstration of concepts associated with sea floor spreading. © ESTA redrawn by ESEU

Put the magnet well out of the way, and then test the polarity of each set of pins with a good magnetic compass. This should reveal that the pins (the "basaltic rocks of the ocean floor") in the dark stripes are magnetised in the opposite direction to those in the pale stripes. This is analogous to the reversed polarity of magnetisation, acquired when the Earth's magnetic field periodically reverses (see diagram below). The compass is being used like a magnetometer being towed by a ship across the surface of the ocean, detecting magnetic changes in the rocks of the ocean floor below.



Magnetic evidence for ocean floor spreading
© This Dynamic Earth: the Story of Plate Tectonics, USGS, redrawn by ESEU

Compare the result with the 'real thing' of 'magnetic stripes' recorded in ocean floor rocks south west of Iceland. The stripes are irregular because the magnetisation is being recorded there by basalt lava flows. The rough mirror image pattern can be seen in the Icelandic area, either side of the ridge axis.



Magnetic anomalies over the Reykjanes Ridge. © Geoscience, redrawn by ESEU
Black – positive anomaly; white = negative anomaly

Pupil learning outcomes: Pupils can:

- describe how a magnetic field can be 'frozen' and retained as remanent magnetism in both models and rocks;
- use the paper and pins model to explain how new ocean floor is generated at constructive plate margins, and how the new rocks formed are magnetised by the Earth's magnetic field, with different magnetisation, depending on the direction of the Earth's field at the time;

- describe the resultant magnetisation of the sea floor as a series of 'stripes' parallel to the oceanic ridges;
- describe how a magnetic sensor (magnetometer or compass) can detect the changes in magnetic field, when moved across the stripes;
- describe how the model relates to ocean floor magnetisation, as seen in south west of Iceland.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **Physics** **Magnetism** • magnetic poles, attraction and repulsion. • magnetic fields by plotting with compass, representation by field lines. • Earth's magnetism, compass and navigation. **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Physics** **Magnetism** • exploring the magnetic fields of permanent and induced magnets, and the Earth's magnetic field, using a compass. **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks,	**Sciences** **Forces, electricity and waves** **First** By exploring the forces exerted by magnets on other magnets and magnetic materials, I can contribute to the design of a game. SCN 1-08a **Second** I have collaborated in investigations to compare magnetic, electrostatic and gravitational forces and have explored their practical applications. SCN 2-08a **Topical science** **Second** Through research and discussion I have an appreciation of the contribution individuals are making to scientific discovery and invention and the impact made on society. SCN 2-20a **Third** I have collaborated with others to find and present information on how scientists from Scotland and beyond have contributed to innovative research and development. SCN 3-20a **Fourth** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b **Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	**Science** **KS2** • forces of different kinds, *e.g. gravity magnetic* **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE** **Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges

Age range of pupils: 11 -16 years

Time needed to complete activity: 10 minutes

Lead in ideas:
This can follow any other aspects of the nature of the oceanic ridges. It can also form part of the story of the development of scientific thinking in the context of Vine and Matthews' original hypothesis of 1963. See: https://www.geolsoc.org.uk/Plate-Tectonics/Chap1-Pioneers-of-Plate-Tectonics/Vine-and-Matthews

Source: Taken from 'SoE2: Investigating the Science of the Earth. Activity 5, 'Clues to sea floor spreading from magnetic ocean floor – a simulation' by the Earth Science Teachers' Association.

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Preparation and set-up:
10 minutes to prepare a card over a bar magnet, with iron filings shaken over the top and 'fixed' with spray on glue or a petri dish with iron filings set in wax; 20 minutes to prepare a card with stripes drawn on and pins pushed in and made safe with sticky tape.

Resource list:
- bar magnet
- iron filings, *either*, in spray-on glue on paper set in magnetic field orientation *or* in wax in a petri dish
- (optional) sample of naturally magnetised, dark, igneous rock
- compass, e.g. orienteering or plotting compass
- dressmakers' pins
- strip of paper or thin cardboard, with stripes, as described
- access to a crack between two benches/desks, or piles of books etc. (see diagram)

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
The magnetic stripes evidence	The pins used might stick into the pupils' hands	1	1	1	Ensure the pins used are covered by sticky tape

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

ESEU activity guide sheet:

The magnetic stripes evidence

The magnetic field of the Earth is modelled using iron filings and a bar magnet. The magnetic stripes on the ocean floor are modelled by magnetising pins attached to cardboard, which is pulled up through a gap, to simulate sea floor spreading.

Iron filings in wax are used to demonstrate how a rock may be able to “hold” a magnetisation. A paper model of a sea-floor spreading centre, with pins, is then pulled up between two benches/desks/piles of textbooks and the pins magnetised by stroking with a magnet on one direction in the dark stripes and the other direction in the pale stripes. Finally a magnetic compass is moved across the top of the stripes, and the ‘flipping’ compass needle shows how they are magnetised in different directions.

Carry out a risk assessment.

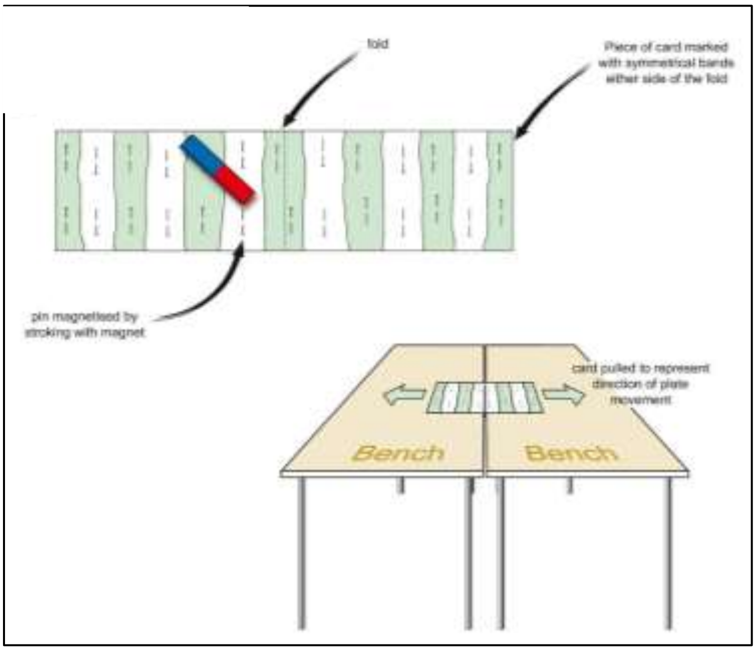
Pupils are familiar with the shaking of iron filings onto a card over a bar magnet. If the card is sprayed with spray-on glue, the iron filings remain in the position of the magnetic field, even when the magnet is removed. This is analogous to a rock holding a previous magnetisation, even after the Earth’s field has changed (called remanent magnetism). Alternatively, the filings can be shaken into a petri dish of molten wax over the bar magnet and the wax allowed to set (see the ‘Magnetic globe to magnetic rock evidence’ activity).

Some igneous rocks are so strongly magnetised that a good magnetic compass will be deflected by several degrees, and North and South pole positions can also be located.

Prepare a strip of paper or thin card (e.g. 50 x 20cm) as shown in the diagram. This can be done by hand by drawing and colouring alternate stripes <u>symmetrically</u> about the midline or by preparing one A4 sheet of stripes on computer, printing two copies and sticking them together as a mirror image of one another. Stick dressmakers’ pins in each section, pointing <u>alternately</u>, as shown in the diagram and cover them with sticky tape to prevent injury.

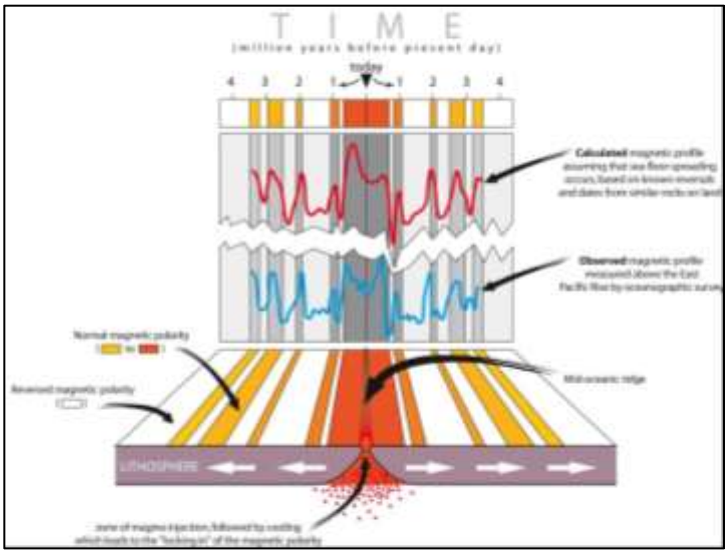
Fold the sheet and slot it down between two benches, so that most of it is hidden. Explain that this represents an oceanic ridge, like the Mid-Atlantic Ridge, with magma welling up, cooling and crystallising. Once the rock has dropped below a certain temperature (the Curie Temperature – discovered by Pierre Curie, husband of Marie), it is capable of acquiring an induced magnetisation from the ambient magnetic field of the Earth.

Draw up the sheet between the benches as shown in the diagram below. As the first set of pins appears, magnetise them by gently stroking them repeatedly with the North end of a strong bar magnet, stroking towards the point of the pin. As the next set of pins appears, stroke them with the North end of the magnet, again towards the point (i.e. in the opposite direction). Continue *ad nauseam*.



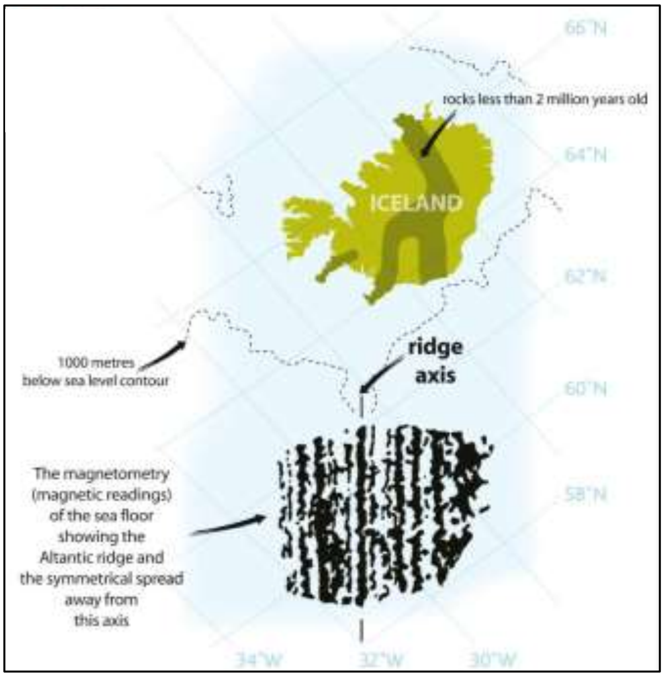
Classroom demonstration of concepts associated with sea floor spreading.
© ESTA redrawn by ESEU

Put the magnet well out of the way, and then test the polarity of each set of pins with a good magnetic compass. This should reveal that the pins (the “basaltic rocks of the ocean floor”) in the dark stripes are magnetised in the opposite direction to those in the pale stripes. This is analogous to the reversed polarity of magnetisation, acquired when the Earth’s magnetic field periodically reverses (see diagram following). The compass is being used like a magnetometer being towed by a ship across the surface of the ocean, detecting magnetic changes in the rocks of the ocean floor below.



Magnetic evidence for ocean floor spreading
© This Dynamic Earth: the Story of Plate Tectonics, USGS, redrawn by ESEU

Compare the result with the 'real thing' of 'magnetic stripes' recorded in ocean floor rocks south west of Iceland. The stripes are irregular because the magnetisation is being recorded there by basalt lava flows. The rough mirror image pattern can be seen in the Icelandic area, either side of the ridge axis.



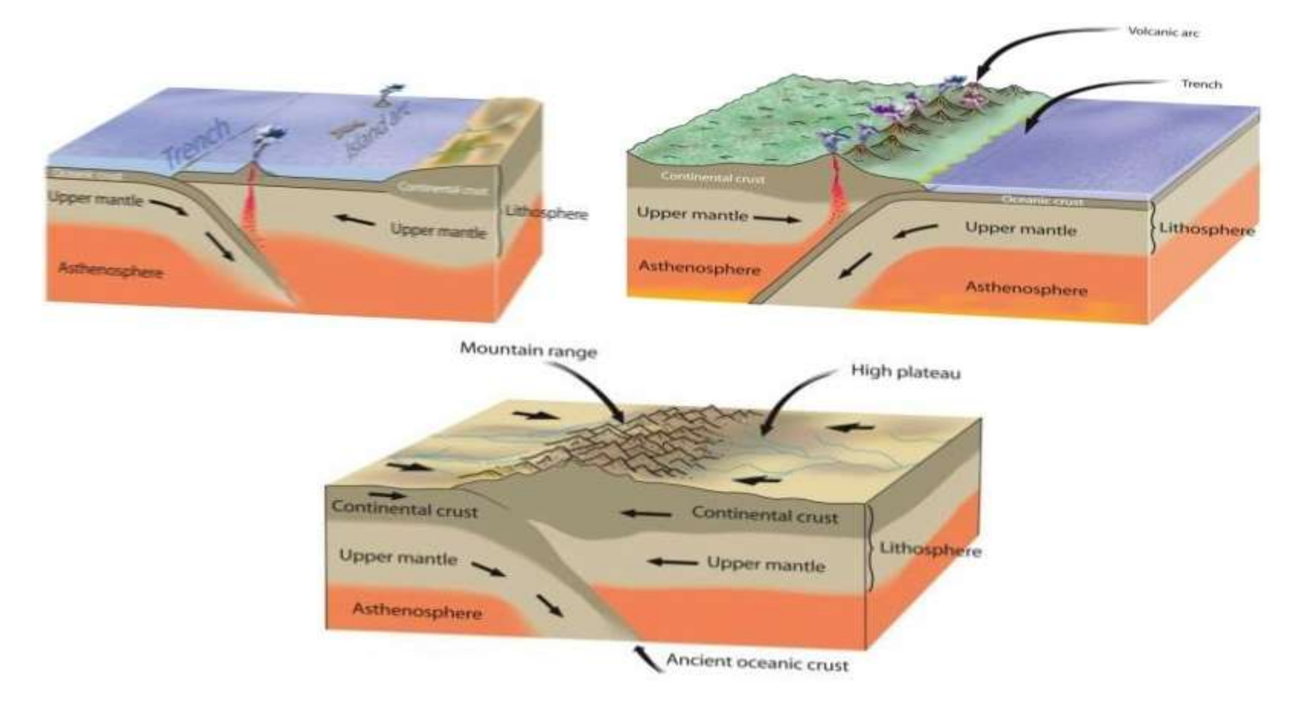
Magnetic anomalies over the Reykjanes Ridge. © Geoscience, redrawn by ESEU
Black – positive anomaly; white = negative anomaly

Destructive plate margins - recycling material

Topic: A discussion of the processes at a destructive plate margin.

Activity:
Diagrams summarising the three different types of destructive (convergent) plate margins:

- Ocean v ocean – where one oceanic plate (the coolest and therefore the densest) is subducted beneath another, resulting in partial melting and volcanic activity.
- Ocean v continent – where an oceanic plate is subducted beneath a continental plate (the continent on the continental plate is of low density, so cannot be subducted), resulting in partial melting causing volcanic activity and also deeper plutonic activity; also mountain ranges, with folding, faulting and metamorphism.
- Continent v continent – where two continental plates collide and, being of low density, neither can be subducted; the result is a mountain range caused by plate collision, with folding, faulting and metamorphism.



The three types of destructive plate margin, reproduced
with the kind permission of the US Geological Survey, redrawn by ESEU.

Pupil learning outcomes: Pupils can:

- describe the differences between the three different types of destructive plate margins.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding	**Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present	**GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and

Experimental skills and strategies • using scientific theories and explanations to develop hypotheses. **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks,	**Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.		landforms associated with plate margins: – destructive plate margins: subduction zone and ocean trench; – collision zones: fold mountains

Age range of pupils: 11-16

Time needed to complete activity: 5 minutes

Lead in ideas:
See the activity **'**Fold mountains in a chocolate box'. Get the pupils to carry out the activity themselves and then and ask whereabouts in the world they would expect to see such forces operating.

Following up the activity:
- Encourage pupils to make their own cardboard replica of a destructive plate margin – see 'Plates in motion: cardboard replica'.
- Examine pictures of fold structures in fold mountain belts such as the Himalayas or Alps. Relate the folds to the directions in which the compressive forces acted when the plates collided.

Source: Earth Science Education Unit.

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Preparation and set-up: None

Resources list:
- diagrams and photos or PowerPoint presentation, computer and projector

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Destructive plate margins – recycling material	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

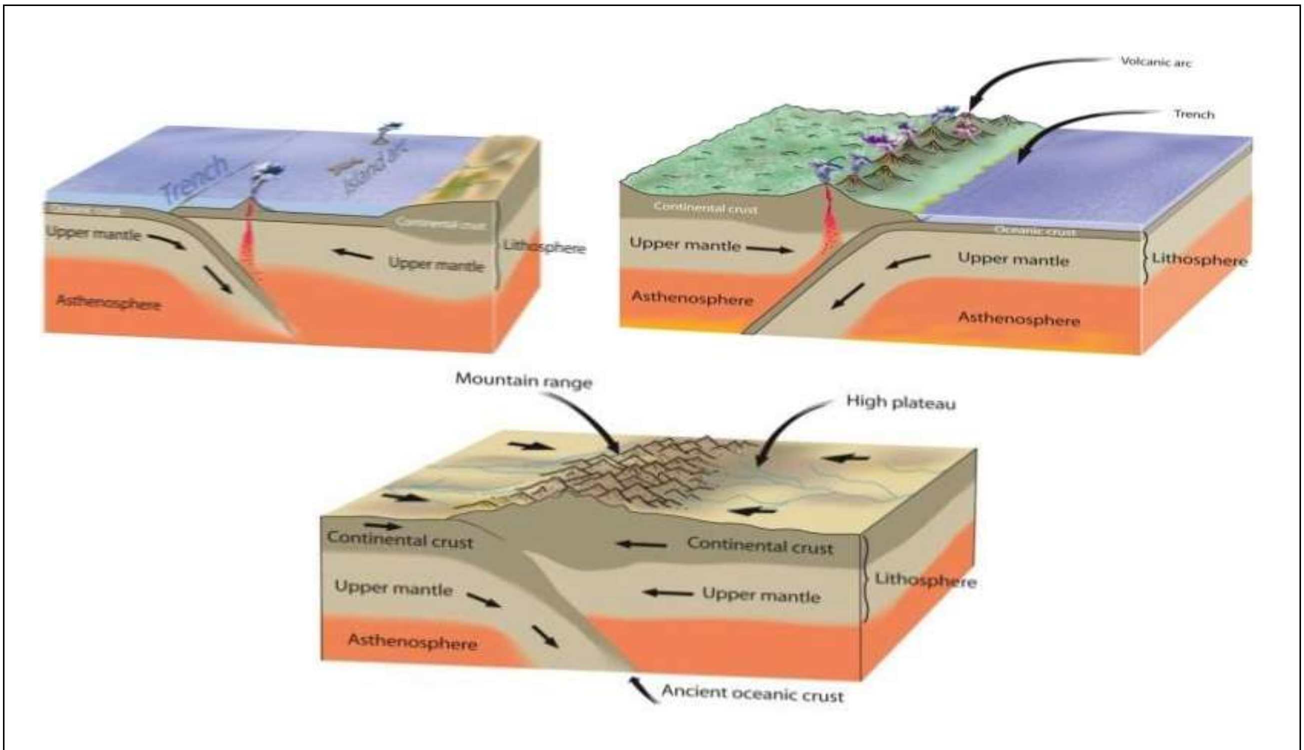
ESEU activity guide sheet:

Destructive plate margins - recycling material

A discussion of the processes at a destructive plate margin.

Diagrams summarising the three different types of destructive (convergent) plate margins:

- Ocean v ocean – where one oceanic plate (the coolest and therefore the densest) is subducted beneath another, resulting in partial melting and volcanic activity.
- Ocean v continent – where an oceanic plate is subducted beneath a continental plate (the continent on the continental plate is of low density, so cannot be subducted), resulting in partial melting causing volcanic activity and also deeper plutonic activity; also mountain ranges, with folding, faulting and metamorphism.
- Continent v continent – where two continental plates collide and, being of low density, neither can be subducted; the result is a mountain range caused by plate collision, with folding, faulting and metamorphism.



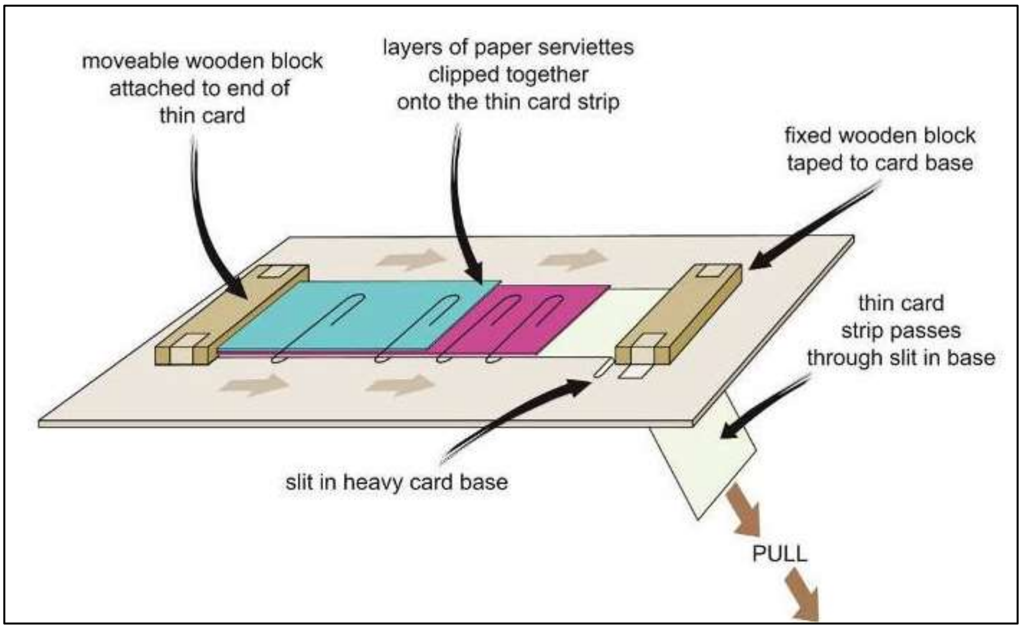
The three types of destructive plate margin, reproduced with the kind permission of the US Geological Survey, redrawn by ESEU.

Plates in motion – cardboard replica

Topic: Building a cardboard model to illustrate plate subduction.

Activity:
a) Subduction
In this activity, subduction of a plate is modelled using cardboard.

Pulling on the thin card tag below the model simulates the subduction shown in the diagram by causing the 'subduction' of the card (the dense 'oceanic lithosphere'), whilst the low density 'sediments' pile up between the wooden 'continents' to form a 'mountain range' and will not disappear down the 'subduction zone' (unless the slot has been made too wide!).



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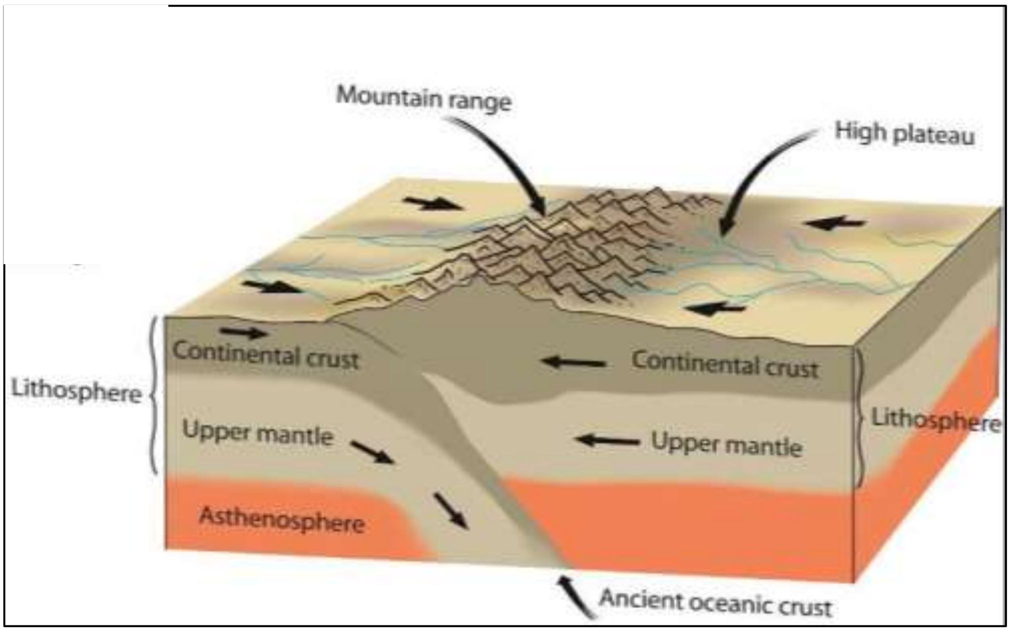

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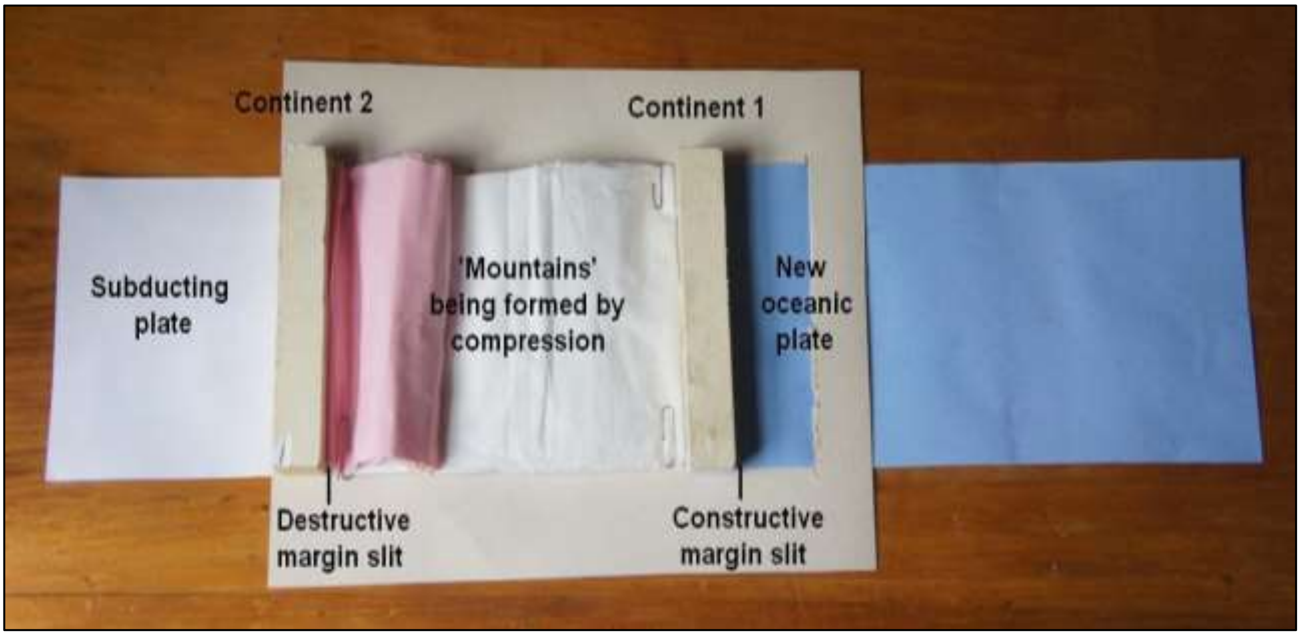
b) Subduction - and new plate formation:
You can add a literal extension to this model by attaching an 'oceanic plate' to the moving 'continent' that rises out of a slit on the far side of the model – as shown in the photos.

As one plate is subducted, causing 'mountains' to develop as the 'sediments' (paper serviettes) are compressed, new plate material is seen forming on the far side of the moving continent. You could colour this blue, to denote the new oceanic plate.



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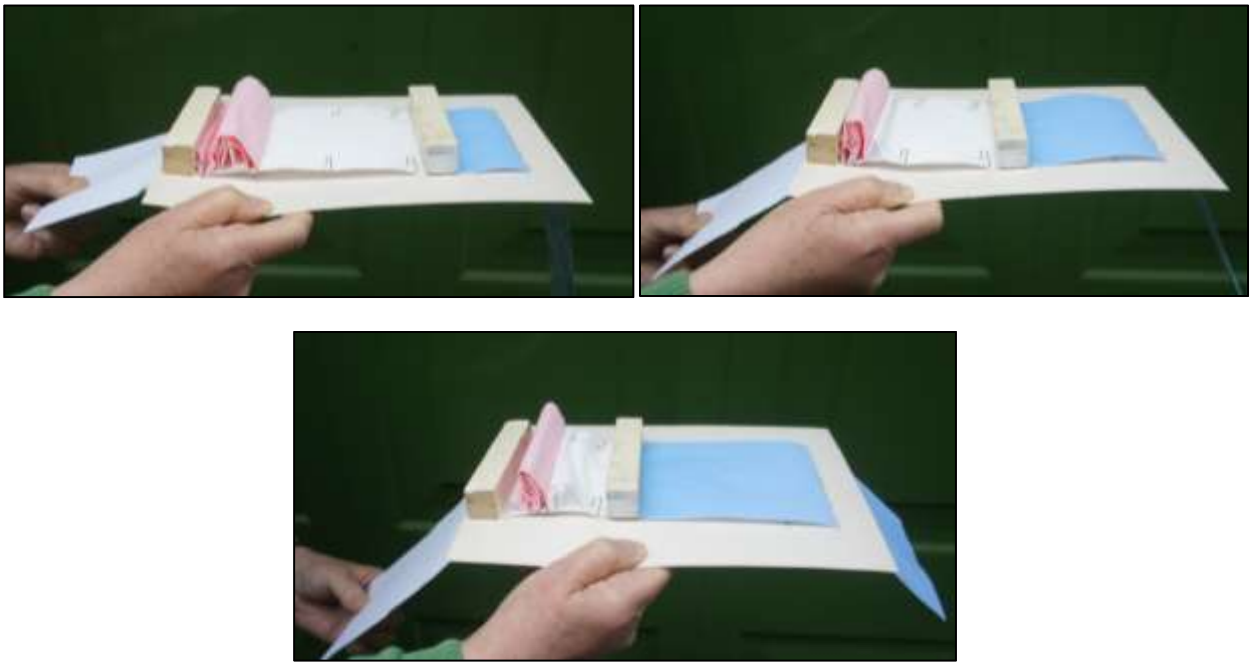

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Pupil learning outcomes: Pupils can:
- make a model of colliding continents;
- extend their model to include a constructive margin, and oceanic plate-formation;
- explain which parts of the model relate to which plate tectonic features.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks	**Sciences** **Earth's materials** **Second** Having explored the substances that make up the Earth's surface, I can compare some of their characteristics and uses. SCN 2-17a **Third** Through evaluation of a range of data, I can describe the formation, characteristics and uses of soils, minerals and basic types of rocks. SCN 3-17a **Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present **Geography** **KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE** **Geography** (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges; – destructive plate margins: subduction zone and ocean trench; – collision zones: fold mountains

Age range of pupils: 11-16

Time needed to complete activity: 3 minutes plus discussion

The story for teachers:
Low density ocean floor sediments cannot go very far down a subduction zone into the mantle. Instead, they become 'welded' on to the continental margins. Such accretion has been estimated to take place at about 1.3 km^3 per year.
Although much of the Earth's geological history is cyclic, such changes mean that the Earth's surface is evolving in a linear sense too, with more and more continental material being formed over time. It 'floats' on the surface like the scum on a bath, since it is too buoyant to be subducted deep below the surface.

Lead in ideas:
Outline of plate tectonic theory, leading to the nature of destructive plate margins.

Following up the activity:
Use the 'Fold mountains in a chocolate box' ESEU activity to show the results of compression on a sand/flour model, producing compressional faulting and chevron folding. This is similar to the deformation caused by colliding continental plates resulting in the formation of mountain chains.

Search for plate margins on a world geological map.

Source: Part a) The Earth Science Teachers' Association, 'Investigating the Science of the Earth 2: Geological changes – Earth's Structure and Plate Tectonics' published by Geo Supplies, Sheffield.
Part b) Royanne Wilding.

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Preparation and set-up:
30 minutes (make them up before the lesson, using the diagram for guidance). No set up time in the lesson itself. Pupils enjoy making up their own models for homework.

Resources list:
'Plates in motion' model (see diagram), made from:
- cardboard
- A4 paper
- paper serviettes
- two small wooden blocks
- tape to attach the blocks
- paper clips
- knife to cut slits in cardboard (unless pre-prepared)

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Plate motion – cardboard replica	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

ESEU activity guide sheet:

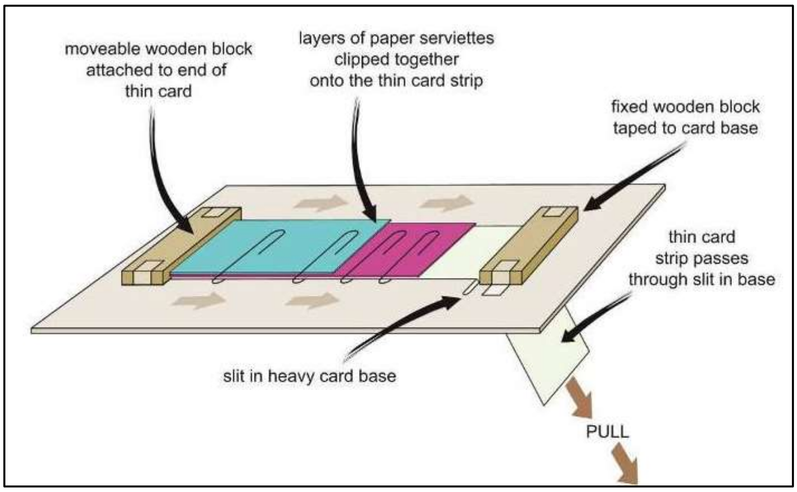
Plates in motion – cardboard replica

Building a cardboard model to illustrate plate subduction.

a) Subduction

In this activity, subduction of a plate is modelled using cardboard.

Pulling on the thin card tag below the model simulates the subduction shown in the diagram by causing the 'subduction' of the card (the dense 'oceanic lithosphere'), whilst the low density 'sediments' pile up between the wooden 'continents' to form a 'mountain range' and will not disappear down the 'subduction zone' (unless the slot has been made too wide!).



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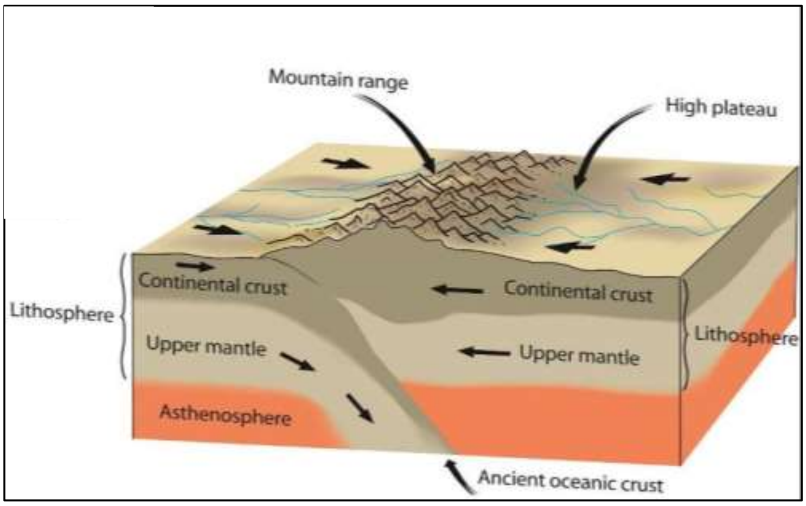

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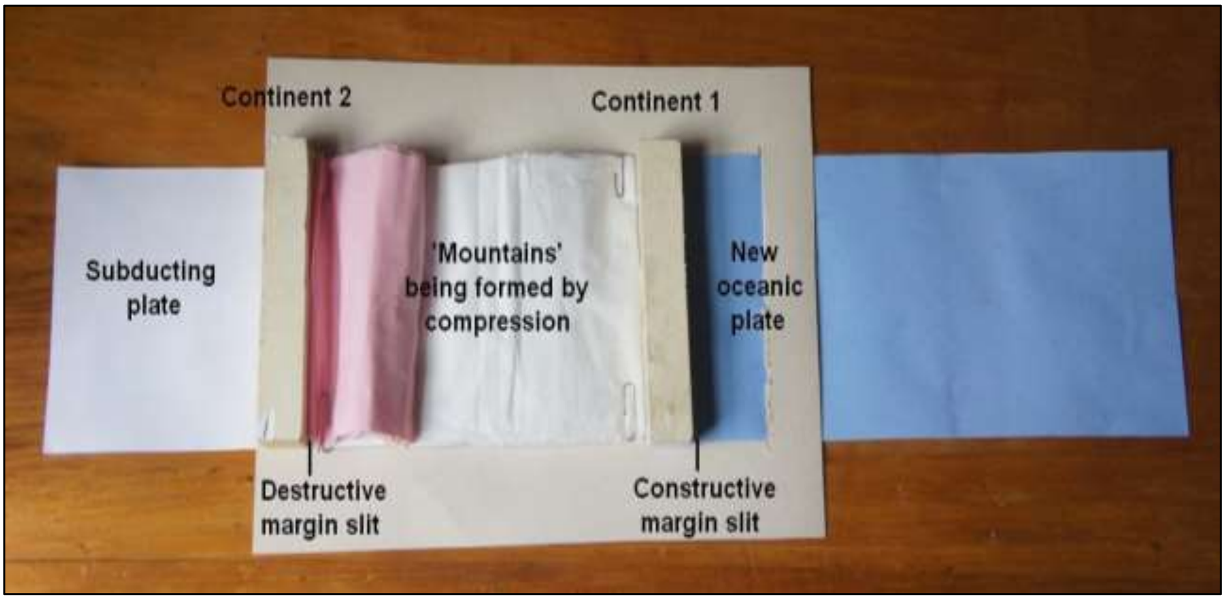
b) Subduction - and new plate formation:
You can add a literal extension to this model by attaching an ‘oceanic plate’ to the moving ‘continent’ that rises out of a slit on the far side of the model – as shown in the photos.

As one plate is subducted, causing ‘mountains’ to develop as the ‘sediments’ (paper serviettes) are compressed, new plate material is seen forming on the far side of the moving continent. You could colour this blue, to denote the new oceanic plate.



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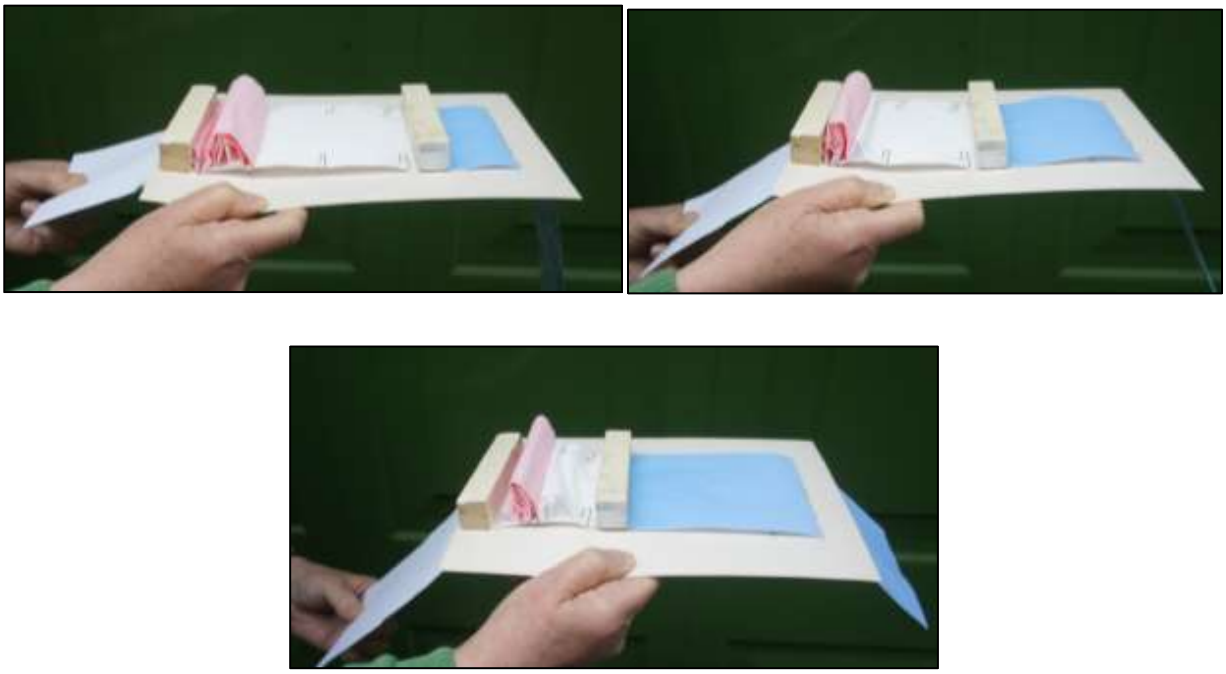
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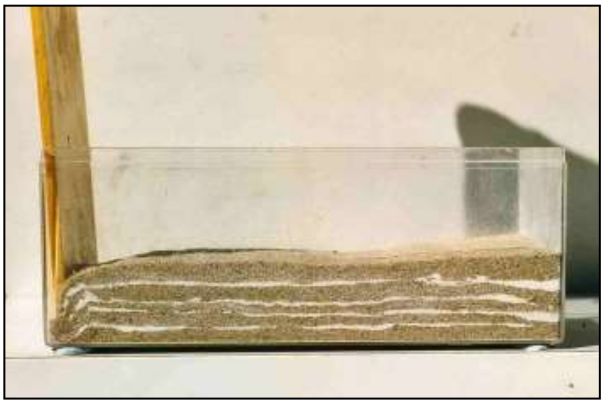
Fold mountains in a chocolate box

Topic: In this activity, layers of sand and flour in a transparent box are compressed from the side, to create folding and faulting.

Activity:

- Place the board vertically inside one end of the box.
- Build up several thin layers of flour and sand. **Do not** fill it more than half-full. Spread the flour along the **front** of the box only (to save flour).
- Very carefully, push the vertical board across the box, so that it begins to compresses the layers, stopping at intervals to inspect and sketch the result.
- Usually, one set of layers slides over the rest, producing a fault in which layers of sand and flour are pushed up and over other layers. These types of faults are often nearly horizontal. A set of chevron folds, that look like a breaking wave, also forms.



The “squeezebox” in action.
© Peter Kennett, ESEU

Pupil learning outcomes: Pupils can:

- make up their own sand and flour model and compress the layers by moving the vertical board;
- describe the chevron folding and reverse faulting seen in the model;
- use these observations to explain how rocks are folded and faulted by compressional forces during plate collisions in the Earth.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **Motion and forces** **Forces** • forces as pushes or pulls, arising from the interaction between two objects • using force arrows in diagrams, adding forces in one dimension, balanced and unbalanced forces • forces: associated with deforming objects; stretching and squashing **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop	**Sciences** **Earth's materials** **Second** Having explored the substances that make up the Earth's surface, I can compare some of their characteristics and uses. SCN 2-17a **Third** Through evaluation of a range of data, I can describe the formation, characteristics and uses of soils, minerals and basic types of rocks. SCN 3-17a **Social sciences** **People, place and environment** **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a	**Science** **KS2** **How things work** • the ways in which forces can affect movement and how forces can be compared **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated with

scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Geography KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks	In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	**Geography KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	plate margins: – destructive plate margins: subduction zone and ocean trench; – collision zones: fold mountains

Age range of pupils: 11 -16 years

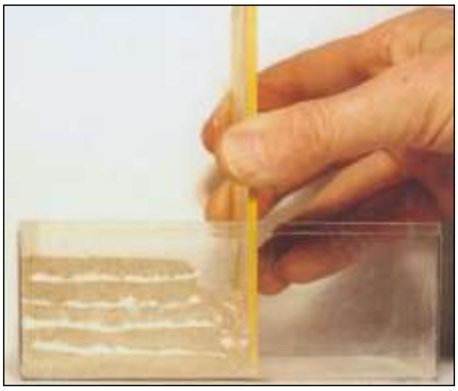
Time needed to complete activity: 10 minutes

The story for teachers: See notes in "Lead in ideas" and "Following up the activity" below.
Forces produce deformation of the rocks that they are acting upon. When there is movement, the force working on the board overcomes friction within the sand, causing it to fold, and also works against gravity, causing uplift.
Force x distance = work done. It requires less work to move the sand particles nearer the board than at a distance from the board. (Distance in the equation is the amount of movement of the board).
This is why an asymmetrical fold is produced by two equal and opposite forces.
Folding (plastic deformation) normally precedes faulting (brittle deformation).
The reverse faulting produced by compression is called thrusting, if it is at a low angle.
The sand layers are deformed on a particle by particle basis: this is akin to the deformation of rocks on a molecule by molecule basis.

Lead in ideas: Students can be reminded of their earlier work on Hooke's Law. They might also be asked to recapitulate some of their KS3 work on the formation of rocks.

Following up the activity:
The model illustrates plastic deformation first, followed by brittle deformation (as students might expect from their earlier physics work). Students can be asked where they would expect fold mountain ranges, given the map of destructive plate boundaries (of the ocean-continent, or continent–continent type).

The box can also be set up to show the steeper (normal) faulting caused by tension at the spreading margins of plates, as shown in the photograph below. In this case, the board is pulled gently away from the sand and flour layers, (keeping it vertical). With luck, a normal fault will develop about 1 cm away from the board (photo). Sometimes, the sand simply avalanches down next to the board to settle at its natural angle of rest, but that is another story.



The "squeezebox" set up for tensional forces.
© Peter Kennett, ESEU

Source: Earth Science Education Unit.

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Preparation and set-up:
Allow time to dispose of 8 boxes of Ferrero Rocher chocolates! Sand needs to be well dried out, and a piece of board must be cut for each box. All the materials can be used again, with the flour winnowed or sieved out of the sand after a few uses.

Resources list:
- transparent plastic box (e.g. Ferrero Rocher chocolate box or a component drawer)
- a piece of board to fit snugly into the box eg. of hardboard or rigid plastic
- spatula or dessertspoon
- tray
- 500g of dry fine sand
- 25g of flour

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Fold mountains in a chocolate box	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

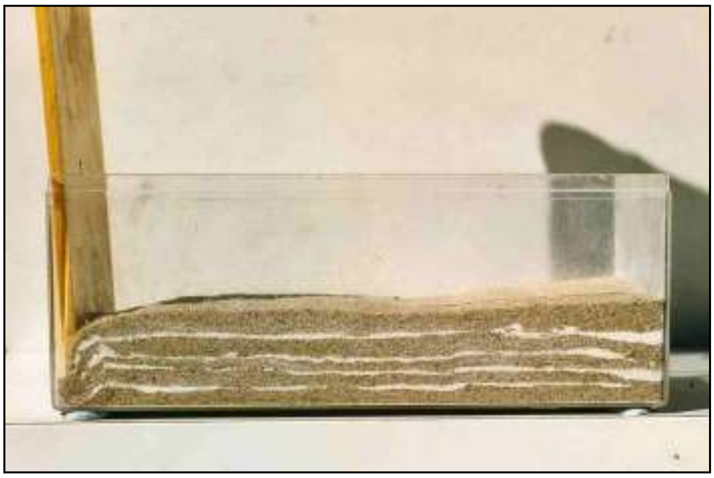
Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

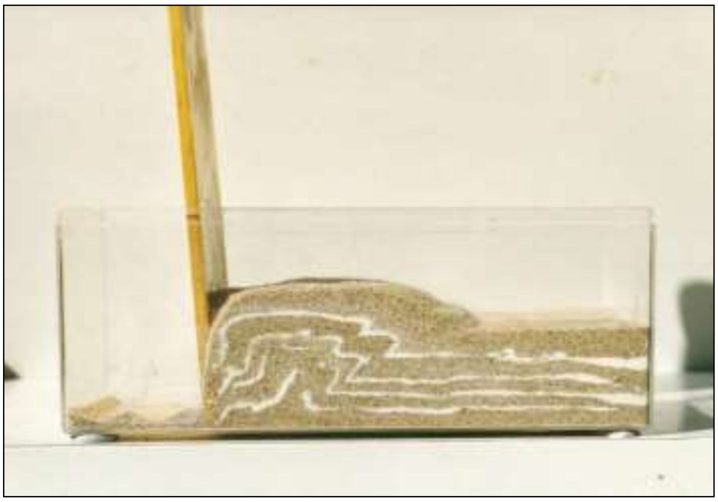
ESEU activity guide sheet:

Fold mountains in a chocolate box

In this activity, layers of sand and flour in a transparent box are compressed from the side, to create folding and faulting.

- Place the board vertically inside one end of the box.
- Build up several thin layers of flour and sand. **Do not** fill it more than half-full. Spread the flour along the **front** of the box only (to save flour).
- Very carefully, push the vertical board across the box, so that it begins to compresses the layers, stopping at intervals to inspect and sketch the result.
- Usually, one set of layers slides over the rest, producing a fault in which layers of sand and flour are pushed up and over other layers. These types of faults are often nearly horizontal. A set of chevron folds, which look like a breaking wave, also forms.





The “squeezebox” in action.
© Peter Kennett, ESEU

Continental jigsaws

Topic: Review a range of evidence from the continents that supports plate tectonic theory.

Activity:
Take one or more sets of jigsaws of the continents and attempt to reassemble the outlines, to make a former super-continent. Pupils could either be asked to do a different jigsaw from neighbouring groups, and then to compare notes, or else do one after the other.

The jigsaws provided are:
- the outlines of the Gondwanaland continents (an 'answer' to the matching of continental outlines of Africa and South America is also given, showing matching along the edges of the true continental structure at 1000m depth below sea level);
- the former distribution of ice across the Gondwanaland continents;
- the distribution of land-based fossils across the Gondwanaland continents;
- the distribution of ancient rocks across South America and Africa;
- the distribution of younger rocks across South America and Africa up to the beginning of the continental split.

Debating the reconstruction of the super continent of Gondwanaland. (*Peter Kennett*)

Pupil learning outcomes: Pupils can:
- reassemble the cut out continents correctly, using the evidence provided by their shapes and the other information provided;
- explain how this evidence can be used to show how the continents have moved;
- use this evidence to support plate tectonic theory.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding	**Sciences** **Topical science** **Second** Through research and discussion I have an appreciation of the contribution individuals are making to scientific discovery and invention and the impact made on society. SCN 2-20a **Third** I have collaborated with others to find and present information on how scientists from Scotland and beyond have contributed to innovative research and development. SCN 3-20a **Fourth** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b **Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present **Geography** **KS3** • the hazardous world: global	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** i) describe the structure of the Earth (core, mantle and crust); (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate knowledge and understanding of the processes and landforms associated

Experimental skills and strategies • using scientific theories and explanations to develop hypotheses. **Geography KS3 Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks, weathering and soils; • understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems	information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	distribution, causes, and impacts of extreme tectonic and other hazardous events	with plate margins: – constructive plate margins: mid-ocean ridges; – destructive plate margins: subduction zone and ocean – trench; – collision zones: fold mountains; and – conservative plate margins: fault lines;

Age range of pupils: 12-16

Time needed to complete activity: 5 minutes for each jigsaw.
15 minutes if each group does all jigsaws.

The story for teachers:
Alfred Wegener devised his 'continental drift' theory, which was published in English in 1922. In his book, called '*The origin of continents and oceans'* he put forward a great deal of evidence supporting his idea that the continents had moved laterally over geological time (contrasting with the prevailing theories at the time that continents and oceans were fixed). His book contains evidence from:

- continental coastline shapes
- continental geology
- fossil distribution evidence
- evidence from modern biological distributions
- geophysical evidence that the 'land bridges' used by some geologists to explain strange fossil distributions couldn't have existed
- palaeoclimatic evidence showing ancient global distributions of coal (tropical swamp deposits) and ice-formed deposits, very difficult to explain without the movement of continents.
- evidence from his own measurements of longitude in Greenland compared with earlier measurements, showing that Greenland was moving at 20m per year (these were later shown to be in error; Greenland is moving, but at centimetres, not metres, per year).

Wagener died at the age of 50 on the Greenland ice cap and so never lived to see how his 'Continental drift' theory has been modified and developed into the over-arching theory of plate tectonics.

This activity explores the continental coastline shapes, continental geology, fossil distribution and ice-deposit palaeoclimatic evidence available to Wegener.

A modern 'continental jigsaw' 'best fit' map of the margins of the Americas and Europe/Africa juxtaposed at the edge of the continental shelf (1000m contour line) shows just how closely the 'jigsaw' matches. Areas of overlap are mostly where features such as deltas have added to the continental margins since break-up.

© Andrew McLeish

Lead in ideas:
Students can be asked what kind of evidence they would look for, if they sought to test the hypothesis of plate tectonics.

Following up the activity:
Ask students how they think people used to explain the features on the jigsaw maps, before the 1960s, when most geologists believed that continental drift could not happen (*A. land bridges*).

Source: the Earth Science Education Unit.

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Preparation and set-up:
Each set of jigsaws needs to be photocopied onto card and cut into its constituent pieces in advance of the lesson. Ensure that you photocopy the various jigsaw maps onto thin card before you cut them up! Prepare enough for the class to work in small groups, and try to use a different coloured card for each of the sets of maps on any one theme, to help avoid the bits becoming muddled up when they are collected in. Once done, they can be kept in envelopes and reused many times. The preparation may take an hour or two, unless it can be shared around the family, or a group of detainees!

Resource list:

- 'Jigsaws' prepared by photocopying the master sheets following onto card and cutting around the outlines. One set of each 'jigsaw' is required for each small group of students.

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Continental jigsaws	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
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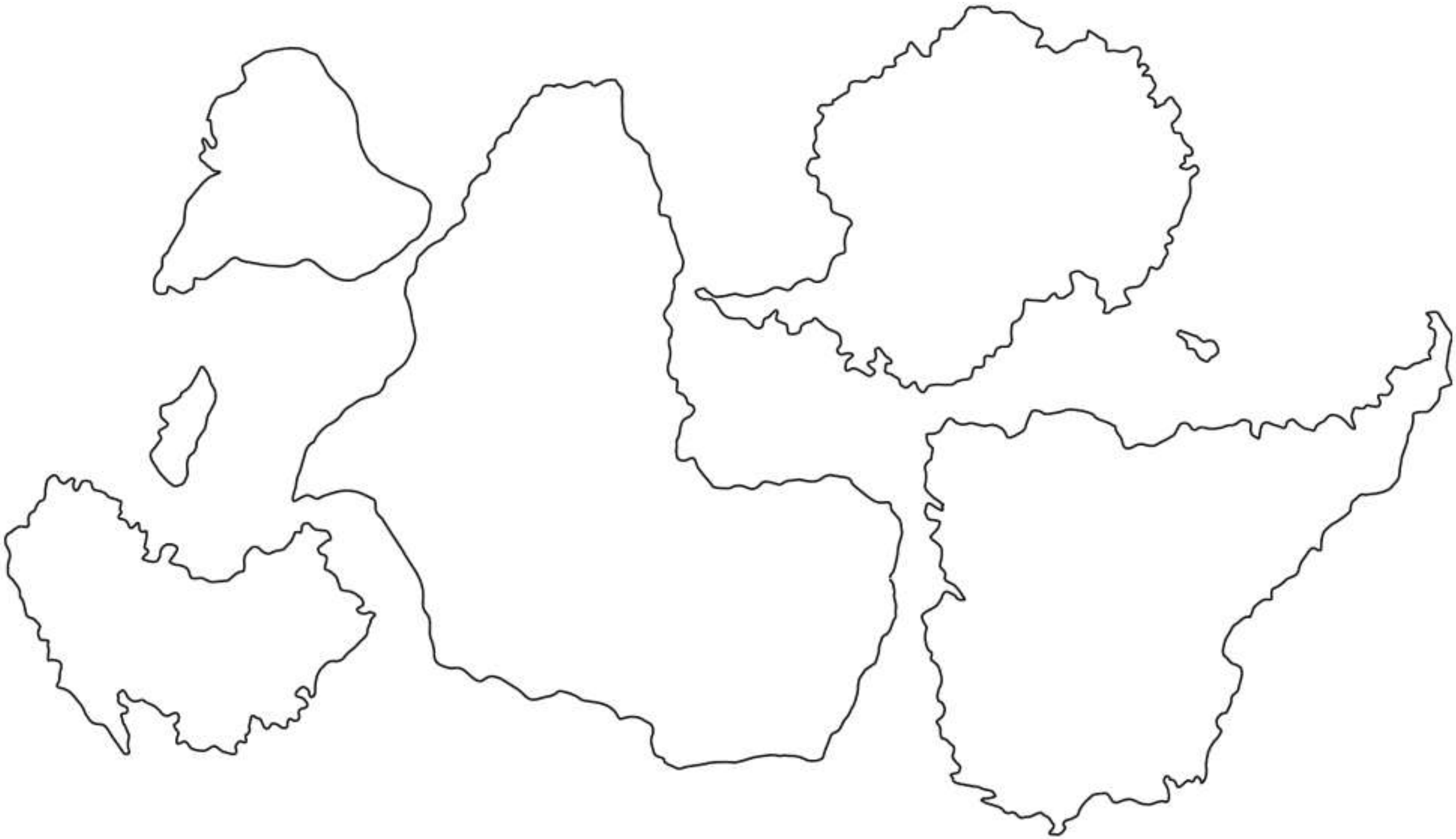
4 = Probable
5 = Inevitable

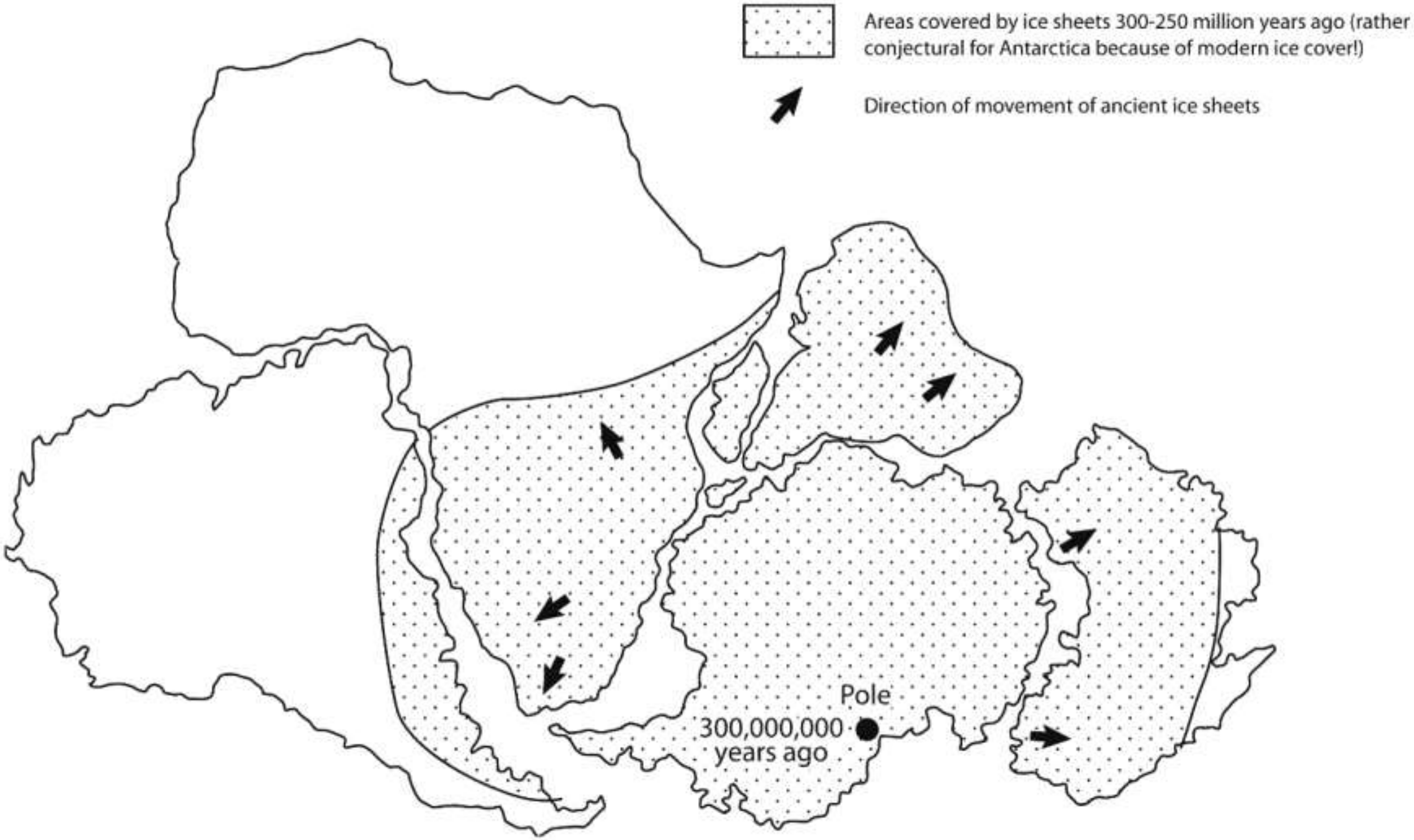
Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

MASTER SHEETS FOR STUDENT SET OF 'JIGSAW CARDS'
Best copied onto thin coloured card using a different colour for each 'jigsaw' i.e.5 colours



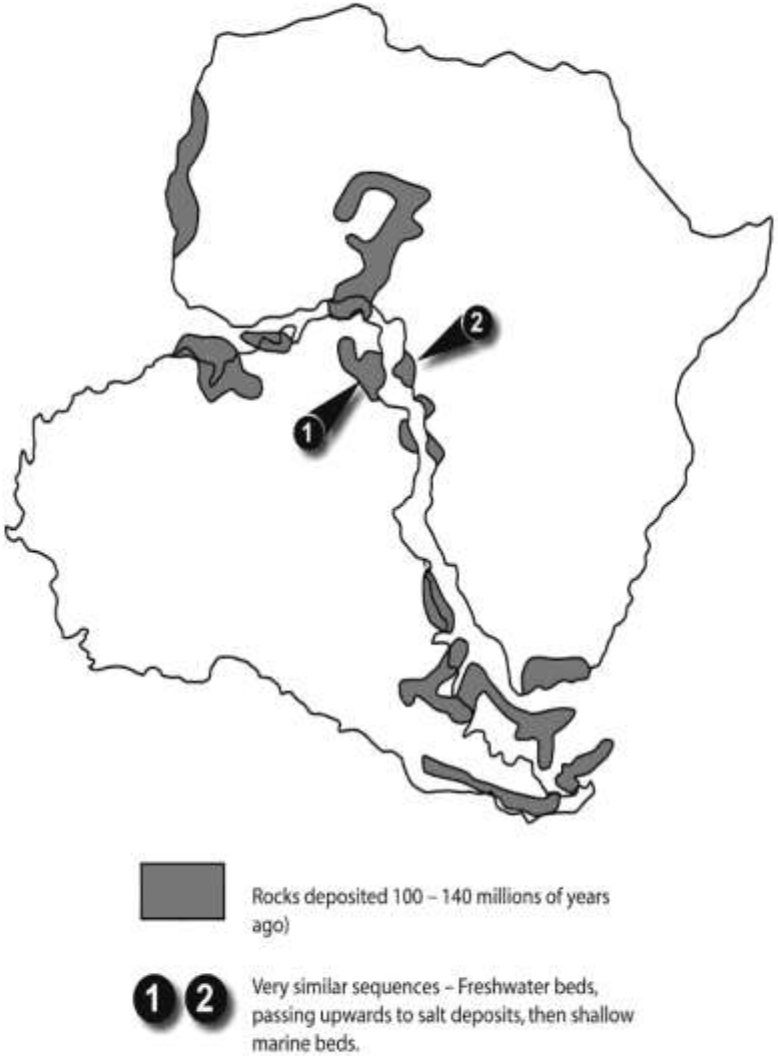
The outlines of the Gondwana continents

Former distribution of ice across the Gondwana continents



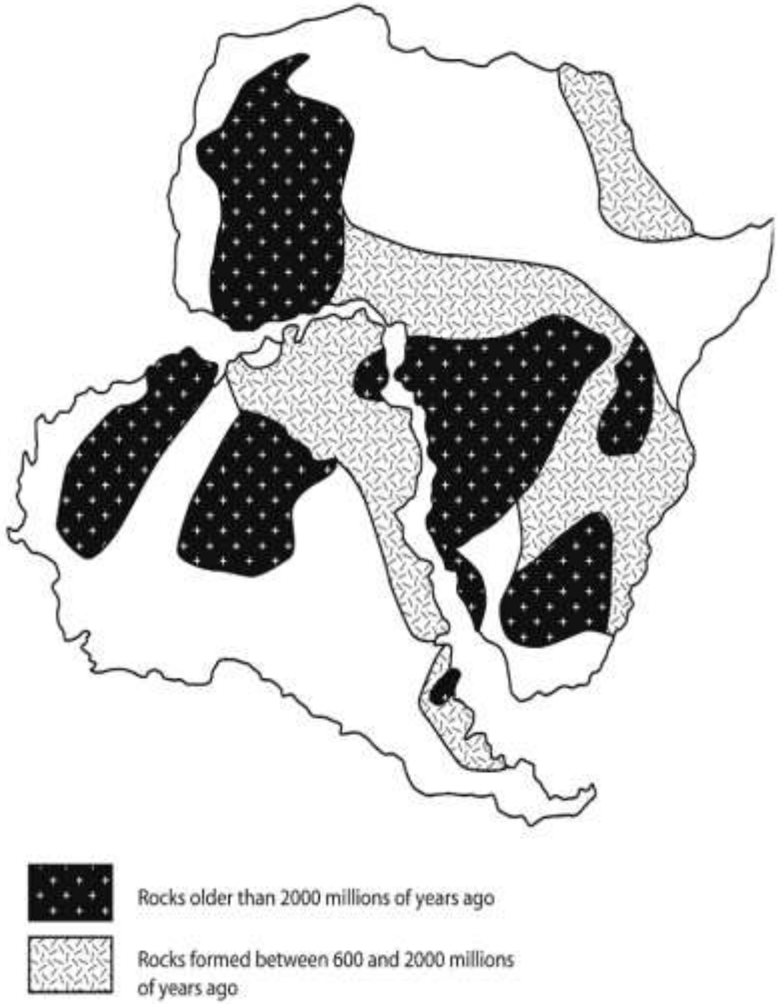
Former distribution of ice across the Gondwana continents

Distribution of ancient rocks across South America and Africa



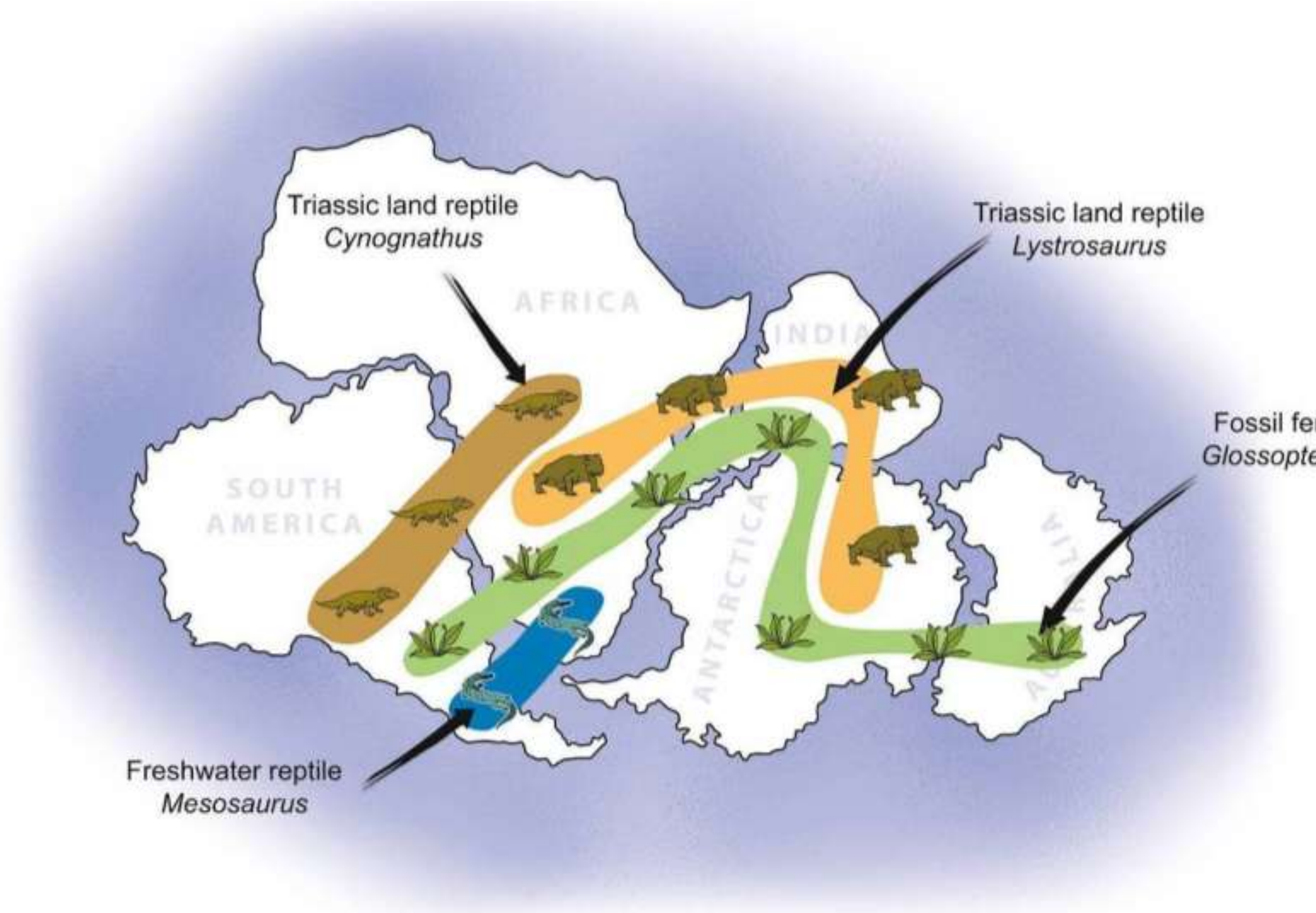
Author/origin unknown © redrawn by ESEU

Distribution of younger rocks across South America and Africa up to the beginning of the continental split



© Andrew McLeish

Distribution of land/freshwater animals and plants in the continents of Gondwana



ESEU activity guide sheet:

Continental jigsaws

Review a range of evidence from the continents that supports plate tectonic theory.

Take one or more sets of jigsaws of the continents and attempt to reassemble the outlines, to make a former super-continent. Pupils could either be asked to do a different jigsaw from neighbouring groups, and then to compare notes, or else do one after the other.

The jigsaws provided are:

- the outlines of the Gondwanaland continents (an 'answer' to the matching of continental outlines of Africa and South America is also given, showing matching along the edges of the true continental structure at 1000m depth below sea level);
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- the distribution of land-based fossils across the Gondwanaland continents;
- the distribution of ancient rocks across South America and Africa;
- the distribution of younger rocks across South America and Africa up to the beginning of the continental split.

Debating the reconstruction of the super continent of Gondwanaland. (*Peter Kennett*)

Plate animation – Britain's journey

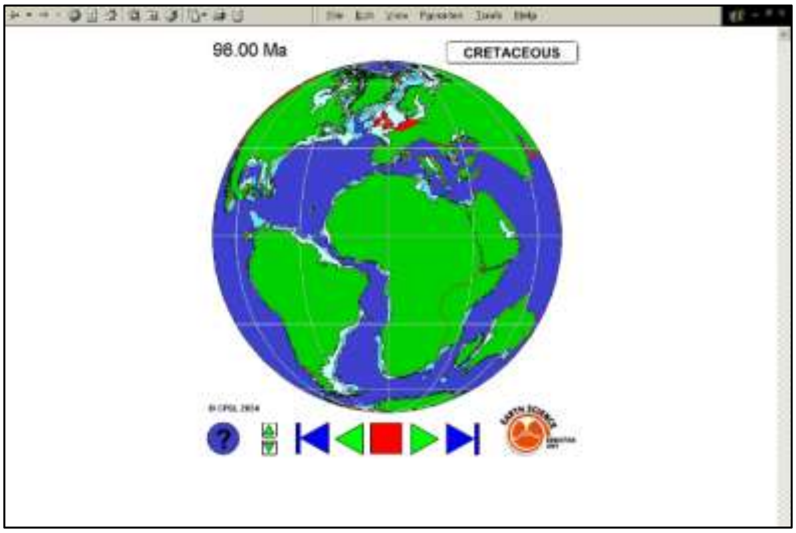
Topic: 'Britain's Journey' is a Flash animation showing how the continents have moved over the last 450 million years, with a focus on the UK.

Activity:
Open the 'Britain's Journey' flash animation and follow the instructions on the screen which opens.

From the main screen, you can play the animation in either direction, vary the speed, stop or skip to the start or end. To find out what a button on the control panel does, hover the mouse pointer over it while the animation is running.

The animation shows the movements of the Earth's continents over the last 450 million years. Continents are shown in green, oceans are shown in blue (light blue = depths of 0-200m, mid blue = 200-2000m, dark blue = deeper than 2000m). The UK is highlighted in red. Part of continental Europe is also highlighted because, together with Southern Britain, it formed a distinct geological region known as Eastern Avalonia.

The geological time is displayed in millions of years (Ma, or mega-annum) together with the name of the geological Period. Epoch names are more commonly used for the last 65 Ma - these are given in blue in order to distinguish them from Periods (in black).



© ESEU

Pupil learning outcomes: Pupils can:
- describe, in general terms, the way in which the continents have been moved across the Earth by plate tectonic processes over geological time;
- explain how supercontinents can form, and then break up.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4 Science** **Working scientifically** **The development of scientific thinking:** • understanding how scientific methods and theories develop over time • using a variety of models to develop scientific explanations and understanding	**Social sciences** **People, place and environment** **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present	**Science** **KS3** **Earth and Universe** • The environment and human influences **GCSE Geography** (ii) know that the Earth's crust is made up of a number of plates and understand

Experimental skills and strategies • using scientific theories and explanations to develop hypotheses. **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks	In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.		how convection currents cause plate movement;

Age range of pupils: 11 -16 years

Time needed to complete activity: 10 minutes

The story for teachers: The animation shows the "continental drift" aspects of plate tectonic theory, over the last 450 million years. Thus we see the growth of the supercontinents of Gondwana (southern continents plus India) and Laurasia (Europe and North America), combining briefly to form Pangaea (Greek for "all lands"). This is followed by the more familiar sequence of break up into the continents as we know them today. It is worth drawing attention to: the rapid union of 'Scotland' and 'Northern Ireland' with 'England' and 'Wales' at an early stage; the gradual widening of the North and South Atlantic Oceans; the rapid movement of 'India' until it collided with Asia, throwing up the Himalayas as it did so.

Lead in ideas: You could introduce this by the 'Continental jigsaw' activity.

Following up the activity: Consider the evidence for plate movement, e.g. 'Magnetic stripes'

Source: Earth Science Education Unit. This animation represents a collaboration between the Earth Science Education Unit and Cambridge Paleomap Services Ltd, who produced the map images used. ESEU gratefully acknowledges the expertise and assistance of Alan Smith and Lawrence Rush of CPSL. An orthographic projection with a 30° latitude and longitude grid is used.

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Preparation and set-up: Time to set up the computer

Resources list:
- CD ROM of animation
- computer and projector

You will require Flash Player 7 or later to use this animation. Flash Player is free and available as a Macromedia Flash Player Download.

Depending on the size and resolution of your screen, you may find it helpful to set your browser to full screen view (by pressing F11, or selecting 'Full Screen' from the View menu, in most browsers).

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Plate animation – Britain's journey	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
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Risk Priority (AxB):
12-25 = High risk – take immediate action
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ESEU activity guide sheet:

Plate animation – Britain's journey

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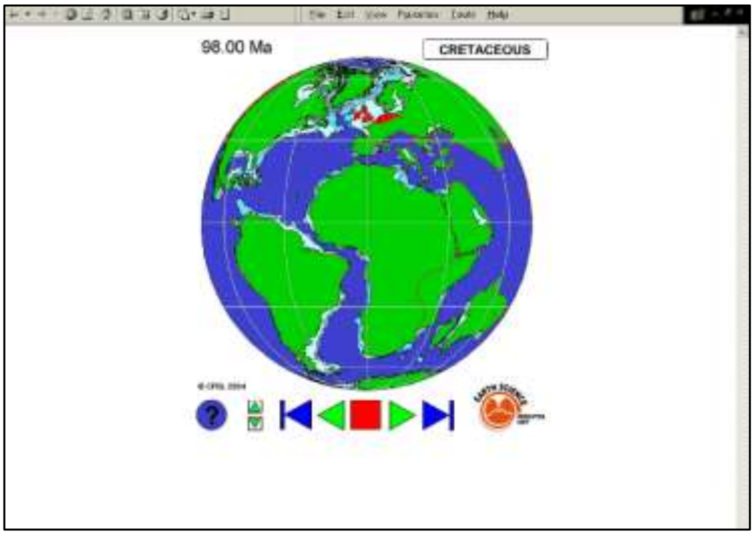


© ESEU

What is the speed of a plate?

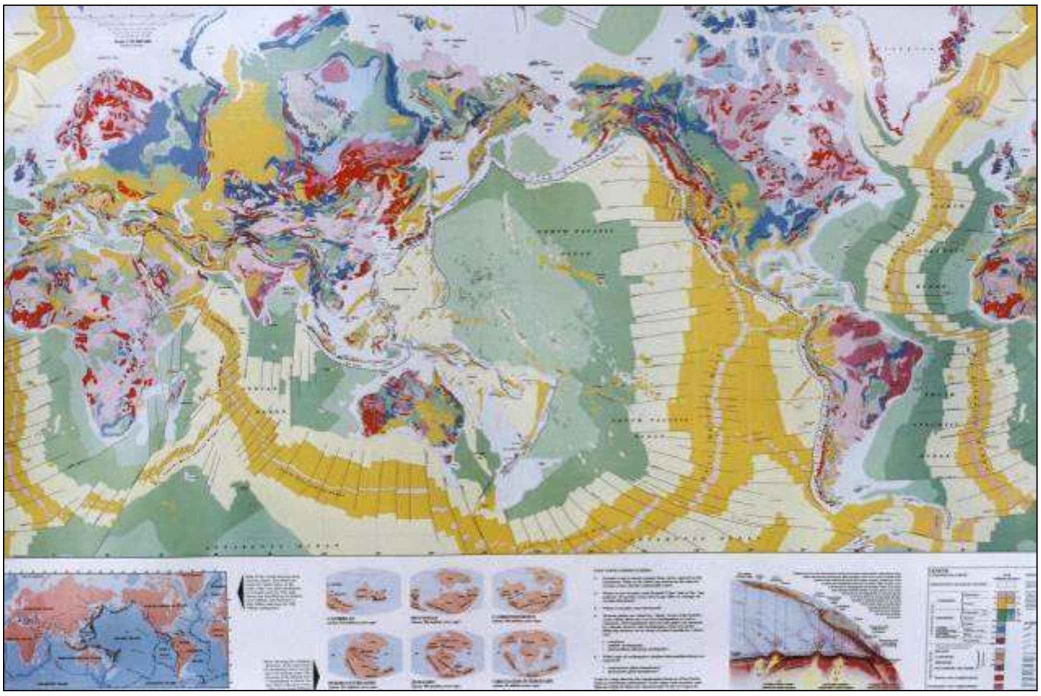
Topic: The rates at which movement is taking place at three major plate constructive boundaries are calculated from measurements taken from the Open University's Geological Map of the World.

Activity:
The World Map uses coloured bands on the ocean floors to represent rocks of ages shown in the key.
Three people can use the map together, working on:
1. The East Pacific Rise, on the Equator (as far as the Galapagos Islands)
2. The Atlantic Ocean, on the Equator
3. The Carlsberg Ridge (in the northern Indian Ocean), on the Equator.

In each case, students measure (in millimetres), the whole width of the pink and yellow coloured bands together, at right angles to the bands. On the Equator, 1 mm represents approximately 100 km

Students calculate the total width of the pink and yellow bands in kilometres. The pink and yellow bands together represent rocks up to 23 million years in age.

Students calculate the average rate at which the ocean ridges have grown at each of the three locations, in kilometres per million years. They can also recalculate the rate in millimetres per year.



The Geological Map of the World. © Open University

Pupil learning outcomes: Pupils can:
- measure a distance from a map;
- read the ages of the rocks of the sea bed from a map
- calculate the speed of spreading across an ocean ridge by Speed = Distance/Time.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS3** **Chemistry** **Earth and atmosphere** • the composition of the Earth • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks	**Social sciences** **People, place and environment** **Second** To extend my mental map and sense of place, I can interpret information from different types of maps and am beginning to locate key features within Scotland, UK, Europe or the wider world. SOC 2-14a **Third** Having investigated processes which form and shape landscapes,	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed	**GCSE** **Geography** (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement; (iii) demonstrate

KS4 Science **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses. **Geography** **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks	I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world SOC 3-14a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a **People, past events and societies** **Fourth** I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes. SOC 4-14a In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.	since the Earth's origin and are changing at present	knowledge and understanding of the processes and landforms associated with plate margins: – constructive plate margins: mid-ocean ridges

Age range of pupils: 11 – 16 years

Time needed to complete activity: 10 minutes

The story for teachers:
The answers vary a little depending on the exact location of the measurement, but we obtained the following (Ma = millions of years):
1 East Pacific Rise: 7200 km ÷ 23Ma = 313 km/Ma or 313 mm p.a.
2 Atlantic: 2200km ÷ 23Ma = 95.6 Km/Ma or 95.6 mm p.a.
3 Carlsberg Ridge, Indian Ocean: 1800km ÷ 23Ma = 78.2 km/Ma or 78.2 mm p.a.

The relatively fast rate of spreading at the East Pacific Rise does not necessarily mean that the Pacific Ocean is becoming wider: oceanic lithosphere is also being returned to the mantle at the destructive margins which ring most of the Pacific.

Lead in ideas: Any aspect of the sea-floor spreading hypothesis

Following up the activity:
The story of plate tectonic in general. Use the activities "Evidence from the age of the sea floor" and "The magnetic stripes evidence"

Source:
Taken from 'Physics in an Earth Context: Teaching KS4 Physics – Sensing the Earth. Activity 6, 'Which is the Fastest Spreading Ocean?' by the Earth Science Education Unit.

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Preparation and set-up: None

Resources list:
- Geological map of the World (1000mm x 660mm) published by The Open University
- ruler measuring in millimetres
- calculator

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Rate of plate movement	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
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ESEU activity guide sheet:

What is the speed of a plate?

The rates at which movement is taking place at three major plate constructive boundaries are calculated from measurements taken from the Open University's Geological Map of the World.

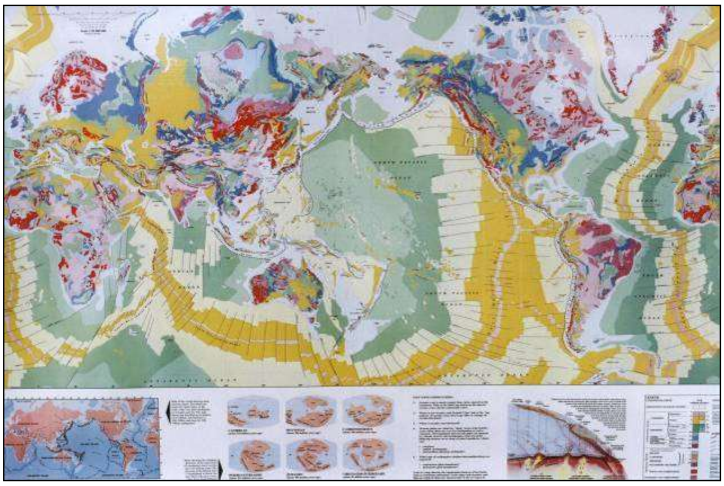
The World Map uses coloured bands on the ocean floors to represent rocks of ages shown in the key.
Three people can use the map together, working on:

1. The East Pacific Rise, on the Equator (as far as the Galapagos Islands)
2. The Atlantic Ocean, on the Equator
3. The Carlsberg Ridge (in the northern Indian Ocean), on the Equator.

In each case, students measure (in millimetres), the whole width of the pink and yellow coloured bands together, at right angles to the bands. On the Equator, 1 mm represents approximately 100 km

Students calculate the total width of the pink and yellow bands in kilometres. The pink and yellow bands together represent rocks up to 23 million years in age.

Students calculate the average rate at which the ocean ridges have grown at each of the three locations, in kilometres per million years. They can also recalculate the rate in millimetres per year.



The Geological Map of the World. © Open University

Plate riding - how is the plate you live on moving now?

Topic: The presenter (or, if too embarrassed, a pupil!) faces east and pretends to be riding a surf board, or skate board. This is akin to the whole European Plate, on which the British Isles are situated, moving bodily in that direction.

Activity:
You (or a student), stand on the floor facing east as if balancing on a surf board. Ask the students:

- 'What am I doing?' (*A. plate-riding*);
- 'How fast am I going?' (*A. as fast as our fingernails grow*);
- 'In which direction am I travelling?' (*A. towards the East*);
- 'What is happening behind me?' (*A. new plate material is being formed, as in Iceland*);
- 'What is happening in front of me?' (*A. I'm heading towards the Japanese subduction zone, with its earthquakes, volcanoes and mountains*);
- 'How can I tell I'm moving?' (*A. GPS measurements over several years, magnetic stripe evidence; evidence from the age of ocean floor sediments*.)

'Surfer' by United States Marine Corps, image in public domain.

'Earth' © Noldoaran

Pupil learning outcomes: Pupils can:
- relate plate tectonics to the environment in which they live.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science **KS4** **Working scientifically** **The development of scientific thinking:** • using a variety of models to develop scientific explanations and understanding **Experimental skills and strategies** • using scientific theories and explanations to develop hypotheses.	**Social sciences** **People, place and environment** **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a **Fourth** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a	**Science** **KS4** **Environment, Earth and universe** • The surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present	**GCSE** **Geography** (ii) know that the Earth's crust is made up of a number of plates and understand how convection currents cause plate movement

Geography **KS3** **Human and physical geography** • physical geography relating to: geological timescales and plate tectonics; rocks,	In these outcomes children and young people will discover the impact forces such as ice, rivers, wind, coasts and tectonics have on the landscape and develop an understanding of the interaction between these forces. Consideration of, for example, aspects of geological time, geology and atmosphere may help to clarify this relationship.		

Age range of pupils: 11 -16 years

Time needed to complete activity: 5 minutes

Lead in ideas: Presentation of plate tectonic theory

Following up the activity: Considering how answers might differ for people riding different plates.

Source: The Joint Earth Science Education Initiative (http://www.esta-uk.net/jesei/index2.htm).

Copyright: © Earth Science Education Unit
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Preparation and set-up: None

Resources list: None

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
Plate riding – how is the plate you live on moving now?	No significant hazard	-	-	-	No

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

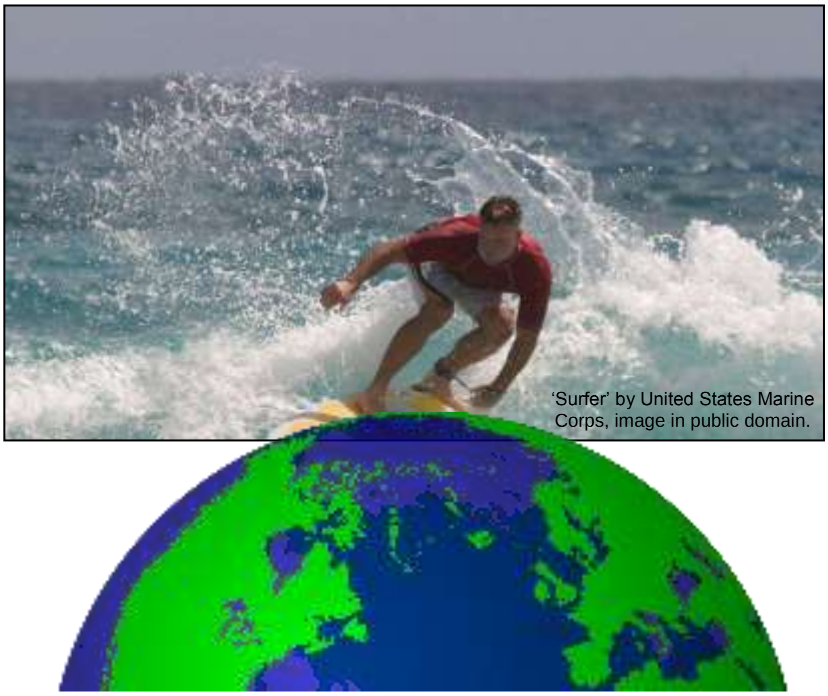
ESEU activity guide sheet:

Plate riding - how is the plate you live on moving now?

The presenter (or, if too embarrassed, a pupil!) faces east and pretends to be riding a surf board, or skate board. This is akin to the whole European Plate, on which the British Isles are situated, moving bodily in that direction.

You (or a student), stand on the floor facing east as if balancing on a surf board. Ask the students:

- 'What am I doing?' (*A. plate-riding*);
- 'How fast am I going?' (*A. as fast as our fingernails grow*);
- 'In which direction am I travelling?' (*A. towards the East*);
- 'What is happening behind me?' (*A. new plate material is being formed, as in Iceland*);
- 'What is happening in front of me?' (*A. I'm heading towards the Japanese subduction zone, with its earthquakes, volcanoes and mountains*);
- 'How can I tell I'm moving?' (*A. GPS measurements over several years, magnetic stripe evidence; evidence from the age of ocean floor sediments*.)



'Surfer' by United States Marine Corps, image in public domain.

'Earth' © Noldoaran

‘Brickquake’ – can earthquakes be predicted?

Topic: This activity provides a simple demonstration of the build-up of stress as house bricks are pulled over each other, using an elastic rope, in the same way as stress builds up and is released suddenly in earthquakes.

Activity:
Carry out a risk assessment (see below).

The bricks are set up with two in line, with two more on top of the rear brick. String is tied round the middle brick in the ‘tower’. Explain that this represents two vast rock masses which will come under stress until they start to slide over or past each other. This is what happens in an earthquake.

The front brick should either be held by hand so that it does not move, or restrained by a clamp, as in the photograph.

Gradually increase the tension on the elastic rope attached to the string, until the bricks begin to move. Ask the students to predict at what point this will happen if the activity is repeated and then carry out several runs. The point at which the bricks move is seldom exactly the same as any previous run, either in terms of time taken to apply the tension, or the extension of the elastic rope. This is akin to earthquakes, where it is rarely possible accurately to forecast when a tremor will occur by studying strain gauge data or by judging the interval between seismic events.

Making a ‘brickquake’ (*Peter Kennett*)

Watch out for bricks falling onto the floor.

Pupil learning outcomes: Pupils can:
- describe how tension increases until the brick suddenly moves;
- explain how this related to similar processes causing earthquakes.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science: Upper KS2 **Years 5 and 6** **Working scientifically** • planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary • using test results to make predictions to set up further comparative and fair tests • reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of and degree of trust in results, in oral and written forms such as displays and other presentations • identifying scientific evidence that has been used to support or refute ideas or arguments. Pupils should use their science experiences to: explore ideas and raise different kinds of questions;	**Sciences** **Second** **Vibration and waves** Through research on how animals communicate, I can explain how sound vibrations are carried by waves through air, water and other media. SCN 2-11a **Earth’s Materials** Having explored the substances that make up the Earth’s surface, I can compare some of their characteristics and uses. SCN 2-17a **Topical science** I can report and comment on current	**Science** **KS2** • forces of different kinds, *e.g. gravity magnetic and friction, including air resistance* • the ways in which forces can affect movement and how forces can be compared	**The world around us** **Strand 3: place** **Change over time in places** • how natural and human events / disasters can cause changes to the landscape and environment (G)

select and plan the most appropriate type of scientific enquiry to use to answer scientific questions; They should make their own decisions about what observations to make. They should use relevant scientific language and illustrations to discuss, communicate and justify their scientific ideas. **Science: KS3** **Working scientifically** • ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience • use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, paying attention to health and safety **Motion and forces** • forces as pushes or pulls, arising from the interaction between two objects **KS4** **Working scientifically** • using a variety of models to develop scientific explanations and understanding • appreciating the power and limitations of science and considering ethical issues which may arise • explaining everyday and technological applications of science; evaluating associated personal, social, economic and environmental implications; and making decisions based on the evaluation of evidence and arguments • evaluating risks both in practical science and the wider societal context, including perception of risk. **Geography** **KS2** • physical geography, including: climate zones, biomes and vegetation belts, rivers, mountains, volcanoes and earthquakes, and the water cycle **KS3** • physical geography relating to: plate tectonics • understand how human and physical processes interact to influence, and change landscapes, environments	scientific news items to develop my knowledge and understanding of topical science. SCN 2-20b **Third** **Processes of the planet** By contributing to experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature. SCN 3-05a **Topical science** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b **Social studies:** **People, place and environment** **Second** I can describe the major characteristic features of Scotland's landscape and explain how these were formed SOC 2-07a I can describe the physical processes of a natural disaster and discuss its impact on people and the landscape. SOC 2-07b **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a **Fourth** **People, past events and societies** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a	**Geography KS2** • investigations of 'geography in the news', topical events and issues in the local area and the wider world **KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	**Science KS3** **Forces and energy** • Forces and energy transfer **Earth and Universe** • The environment and human influences **Geography KS3** develop an understanding of: • physical processes of landscape development;

Age range of pupils: 9 -16 years

Time needed to complete activity: 10 minutes

The story for teachers:
As the Earth's plates move, friction 'sticks' them together at the edges and they bend slightly under pressure. Eventually the pressure is so great that a break occurs and the rock springs back elastically, causing an earthquake.

Lead in ideas:
Ask the pupils if they have ever felt an earthquake (they may have done so, since earthquakes large enough to be felt do occur in some parts of the UK) or if they have seen the effects of earthquakes in the media.

Following up the activity:
Follow up the qualitative 'brickquake' activity above by this quantitative version.

The brick 'earthquake' shows that energy is dissipated with a jog motion. By repeating the experiment, the distribution of jog distance and maximum force applied immediately prior to failure can be found.

If the distance moved by the brick each time it slips is recorded, a histogram can be plotted to show frequency for each size of slippage. An approximation of the relative energy released can be calculated using the equation: Force x Distance = Energy Transferred. This can be compared with a histogram showing the frequency of different magnitude earthquakes.

Brickquake, pulled by hand *(ESEU)*

Brickquake, pulled by a winding mechanism (ESEU)

The bricks are set up with two in line and the third one on top of the rear brick, just overlapping the gap. Its edge is marked on the lower brick, so that the distance moved can be measured. String is tied round this brick. The other end of the string is tied to a bungee which is connected in turn to a Newton meter and winding mechanism as in the diagram (if you have no winding mechanism, the Newton meter can just be pulled by hand, in as controlled a manner as possible).

The two lower bricks must be held firmly by blocks, clamps, or your hand.

A tray of water is put next to the lower bricks. A laser pointer is pointed at a shallow angle to the water surface so that the beam is reflected on to a screen or the ceiling and will make ripples in the water easier to see. A slinky spring can be fastened with tape under the table hanging down until it reaches the floor (optional).

The string is wound onto the winder, or pulled by hand. The measurement on the Newton meter is noted at the moment the brick moves. The distance moved by the brick is measured in metres.

When the brick moves, any motion of the water surface, magnified by the laser beam, and slinky spring are noted.

Optional: A fourth brick can be added to the top of the apparatus and the experiment repeated to find out how the results differ.

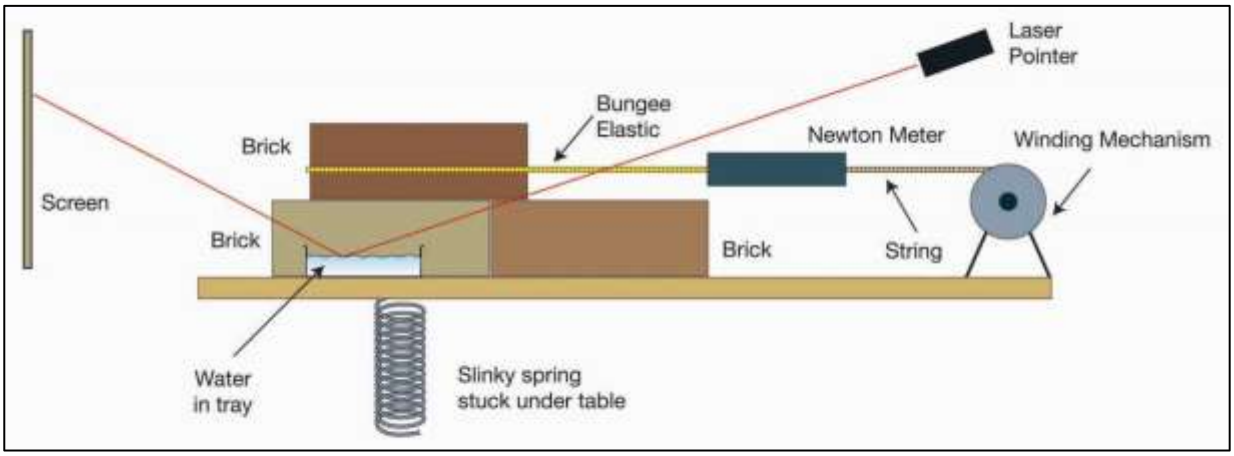


Diagram of apparatus for Brickquake (*ESEU)*

Notes:
For safety reasons, position the audience to one side so that they are out of the way of the laser beam. Be wary of bricks falling on the floor, or someone's toes.

This activity is best done on a free standing table rather than a fixed bench so that it shakes more effectively.

Results expected:
Surface waves will be seen in water in the tray at the side. Body waves (P- and S-waves) will be seen in the slinky spring.

The brick will move smoothly once started or in discrete jogs. The chart below gives some actual results from the above activity and illustrates that although it may be possible to forecast an 'earthquake' it is not possible to predict the energy released.

Distance moved Meters (m)	Force Newtons (N)	Relative Energy transferred Joules (J)
0.02	15	0.30
0.075	45	3.375
0.035	35	1.225
0.04	25	1.00

Earthquakes generate three sorts of waves, two sorts of body waves (that pass through bodies – S- and P-waves) and also surface waves. The S-waves are transverse waves (shear, shake or secondary waves (secondary because they arrive after P-waves)). The P-waves are the longitudinal body waves (primary, push-pull, pressure). Surface waves are caused when P- and S-waves interact with the surface, and cause the most damage in earthquakes.

The magnification of the effect of the seismic waves by the laser pen reflecting off the water surface is a mechanism similar to that used in early seismometers to magnify shock wave traces.

Source: Earth Science Education Unit.

Copyright: © Earth Science Education Unit.
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Preparation and set up:
Set-up time about 5 minutes.

Resource list:
For activity (qualitative):
- 4 clean house bricks, (one with string tied round it lengthwise)
- Newton meter
- elastic rope (e.g. elastic luggage bungee about 40 cm long)

For follow up (quantitative) activity – all optional:
- string, about 3 m long
- a range of Newton meters (e.g. up to 50N)
- laser pointer (or torch if laser pointer not available)
- a shallow tray containing water
- winding mechanism (e.g. pulley block) clamped to the table with a G-clamp
- a slinky spring
- sticky tape

Risk assessment:

Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
'Brickquake' – can earthquakes be predicted?	There is a hazard that the brick might fall onto the demonstrator / students' foot	2	3	6	Ensure that the bricks are placed near the centre of benches, so they are not pulled onto the floor by the sudden movement as the bungee is pulled, causing a hazard.

Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

ESEU activity guide sheet:

'Brickquake' – can earthquakes be predicted?

This activity provides a simple demonstration of the build-up of stress as house bricks are pulled over each other, using an elastic rope, in the same way as stress builds up and is released suddenly in earthquakes.

Carry out a risk assessment.

The bricks are set up with two in line, with two more on top of the rear brick. String is tied round the middle brick in the 'tower'. Explain that this represents two vast rock masses which will come under stress until they start to slide over or past each other. This is what happens in an earthquake.

The front brick should either be held by hand so that it does not move, or restrained by a clamp, as in the photograph.

Gradually increase the tension on the elastic rope attached to the string, until the bricks begin to move. Ask the students to predict at what point this will happen if the activity is repeated and then carry out several runs. The point at which the bricks move is seldom exactly the same as any previous run, either in terms of time taken to apply the tension, or the extension of the elastic rope. This is akin to earthquakes, where it is rarely possible accurately to forecast when a tremor will occur by studying strain gauge data or by judging the interval between seismic events.

Watch out for bricks falling onto the floor.

Making a 'brickquake' (*Peter Kennett*)

Finale: How predictable are volcanic eruptions? - party popper simulation

Topic: Party poppers are suspended in clamp stands and are then progressively loaded with 100g masses until they burst, as an analogy with the build up to a volcanic eruption. The results vary widely, which can be equated to the unpredictability of volcanic eruptions.

Activity:
This activity gives a method to quantify the stress needed to cause party poppers to 'erupt'.

Carry out a risk assessment (see below).

Set up the party poppers in several clamp stands, as shown in the photograph, with books or pads of paper beneath the masses to catch them when they fall. Then invite pupils to gradually increase the stress on each party popper by adding 100g (1N) masses until the inevitable happens. This is akin to the steady build-up of stress under the solid plug of a volcano until the plug fails, causing the volcano to erupt. The results normally show 'eruption' from different amounts of stress, and a range of 'eruption stresses' from 200g to 3500g has been observed. This activity has been designed deliberately to show unpredictability, to simulate the difficulty of predicting exactly when a volcano will erupt.

Set up for the party popper activity'.
© Peter Kennett, ESEU

Volcano alert 'Chance card'.
© Dave Turner

Take a 'Chance' on the volcano erupting:
This extension to the activity gives a method to quantify the stress needed to cause party poppers to 'erupt'.

Set up the party poppers in clamp stands, as described above, with books or pads of paper beneath the masses to catch them when they fall.

Provide students with a pack of 'Chance' cards, cut from the following sheets. They can either share a pack, or have a pack each. Explain that each card gives one type of evidence which might indicate whether the volcano was more or less likely to erupt. Each card will tell the students to add one or more masses, or sometimes even to remove a mass.
Explain that each volcano has a major town nearby (teachers may wish to invent a name for each town). Students should also be provided with an 'Emergency' card stating "Evacuate" and "Return to homes". They can choose whether to play these cards at any point in the game.

Now, ask the students to take turns to take a 'Chance' card from the pack and to carry out what it says on the card. Masses should be added gently, in order to obtain a valid comparison between each 'volcano'.
Usually, the total mass required to 'erupt' each party popper varies widely between them – an analogy for the difficulty that scientists have in trying to predict volcanic eruptions precisely.

Pupil learning outcomes: Pupils can:
- reflect on the unpredictability of some natural processes in the light of the activity.

Curriculum references:

England	Scotland	Wales	Northern Ireland
Science: Upper KS2 **Years 5 and 6** **Working scientifically** • planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary Pupils should use their science experiences to: explore ideas and raise different kinds of questions; select and plan the most appropriate type of scientific enquiry to use to answer scientific questions; They should make their own decisions about what observations to make. They should use relevant scientific language and illustrations to discuss, communicate and justify their scientific ideas. **Science: KS3** **Working scientifically** • ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience • use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, paying attention to health and safety **Chemistry** **Earth and atmosphere** • the rock cycle and the formation of igneous, sedimentary and metamorphic rocks **KS4** **Working scientifically** • evaluating risks both in practical science and the wider societal context, including perception of risk. **Geography** **KS2** • physical geography, including: climate zones, biomes and vegetation belts, rivers, mountains, volcanoes and earthquakes, and the water cycle **KS3** • physical geography relating to: plate tectonics • understand how human and physical processes interact to influence, and change landscapes, environments	**Sciences:** **Materials** **Second** Having explored the substances that make up Earth's surface, I can compare some of their characteristics and uses. SCN 2-17a **Third** **Earth materials** Through evaluation of a range of data, I can describe the formation, characteristics and uses of soils, minerals and basic types of rocks. SCN 3-17a **Third** **Processes of the planet** By contributing to experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature. SCN 3-05a **Topical science** Having selected scientific themes of topical interest, I can critically analyse the issues, and use relevant information to develop an informed argument. SCN 4-20b **Social studies:** **People, place and environment** **Second** I can describe the major characteristic features of Scotland's landscape and explain how these were formed. SOC 2-07a I can describe the physical processes of a natural disaster and discuss its impact on people and the landscape. SOC 2-07b **Third** Having investigated processes which form and shape landscapes, I can explain their impact on selected landscapes in Scotland, Europe and beyond. SOC 3-07a **Fourth** **People, past events and societies** I can explain how the interaction of physical systems shaped and continue to shape the Earth's surface by assessing their impact on contrasting landscape types. SOC 4-07a	**Geography** **KS2** • investigations of 'geography in the news', topical events and issues in the local area and the wider world **KS3** • the hazardous world: global distribution, causes, and impacts of extreme tectonic and other hazardous events	**The world around us** **Strand 3: place** **Change over time in places** • how natural and human events / disasters can cause changes to the landscape and environment (G) **Science KS3** **Earth and Universe** • The environment and human influences **Geography KS3** develop an understanding of: • physical processes of landscape development;

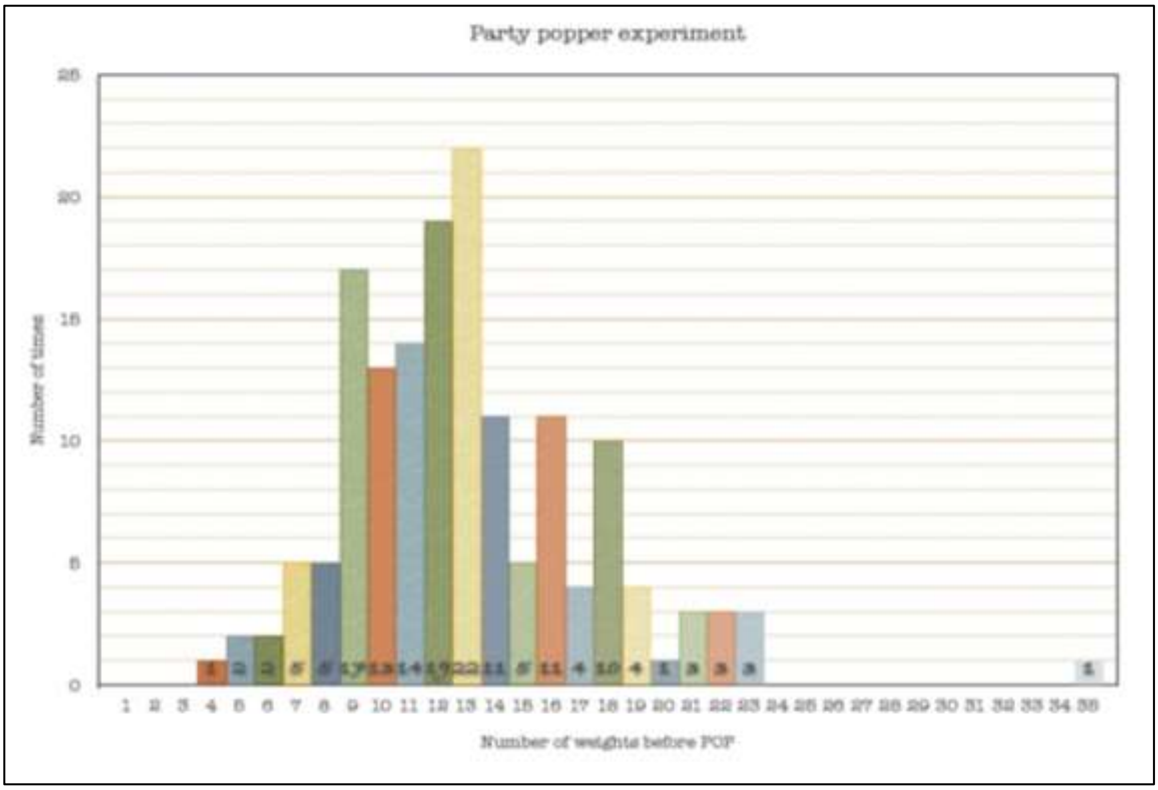
Age range of pupils: 11 -16 years

Time needed to complete activity: 10 minutes

The story for teachers:
See "Lead in ideas" and "Following up the activity" on page 112. Constructive thought is involved in anticipation that the greater the applied mass becomes, the more likely the party popper is to 'blow' (erupt). The unpredictability of this activity is a challenge. Linking from the party popper activity to the unpredictability of volcanic eruptions involves bridging skills

Lead in ideas:
Discuss the difference between forecasting and prediction. A forecast gives a statistical view of the likelihood of an event in a certain amount of time in a certain vicinity, such as a thunderstorm or a volcanic eruption. A prediction is much more precise, and specifies a time and place. It is often possible to forecast volcanic eruptions (ie. that an eruption of a certain volcano is statistically likely to take place within a certain time), but it is currently impossible to predict the timing of such an eruption. This is why 57 people were killed in the 1980 eruption of Mt. St. Helens; geologists had forecast an eruption, but were unable to predict exactly when it would take place.

The graph shows the results of many exploding party poppers (156 experiments). The weights referred to on the x axis are 100gms so 3500gms is the greatest weight so far.



© David Bailey, British Geological Survey

Following up the activity:
Discuss the different methods used to monitor volcanoes, including:

- satellite monitoring that can identify temperature changes, emission of sulfur dioxide or ash clouds, or small changes in shape of the surface of the volcano;
- ground monitoring techniques including:
- seismic monitoring (many eruptions have increased small earthquake activity before eruption, whilst some seismic traces are characteristic of lava movement at depth),
- monitoring of the shape of the volcano (by tiltmeters, that detect changes in the slopes of surfaces and by measuring the changes in altitude and distance across key parts of the volcano, to spot the development of volcanic bulges before eruptions);
- monitoring the emission of volcanic gases for any changes in gas composition that may occur before eruption;
- testing for small scale changes in gravity and magnetism.

Source:
Earth Science Education Unit. ‘Take a ‘Chance’ on the volcano erupting’ by Dave Turner and Earthlearningidea.com

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Preparation and set-up: 3 minutes to set up

Resources list:
For four set ups, required are:
- 4 x party poppers
- 4 x clamp stands, bosses and arms
- 8 x mass hangers, each with 10 100g (1N masses)
- 4 x books or pads of paper for the masses to fall onto when the party poppers 'erupt'
- 24 x 'Chance cards'

Risk assessment:

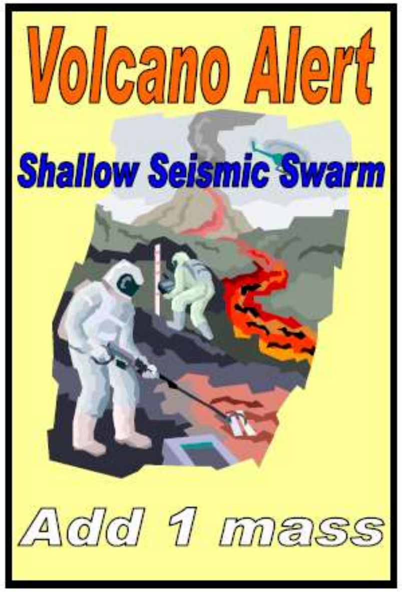
Potentially Hazardous Activity	Who/What may be Harmed?	Hazard Rating (A)	Likelihood (B)	Risk (AxB)	Further Action Required?
How predictable are volcanic eruptions? – party popper simulation	The cardboard disk/contents from the party popper could fly into someone's eye. The masses could fall onto the floor.	2	3	6	Ensure that the party popper is not aimed at anybody; ensure that masses don't fall onto the floor

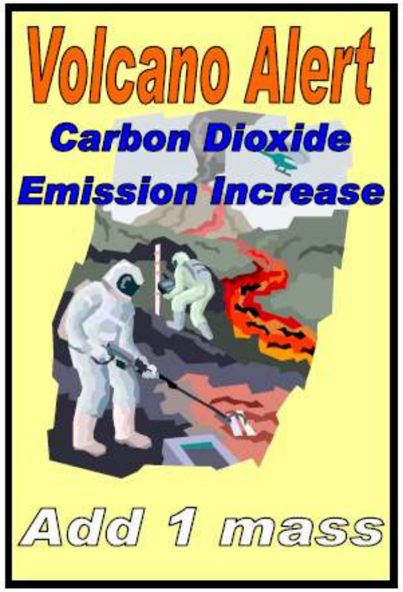
Hazard Rating (A):
1 = Insignificant effect
2 = Minor Injury
3 = Major Injury
4 = Severe Injury
5 = Death

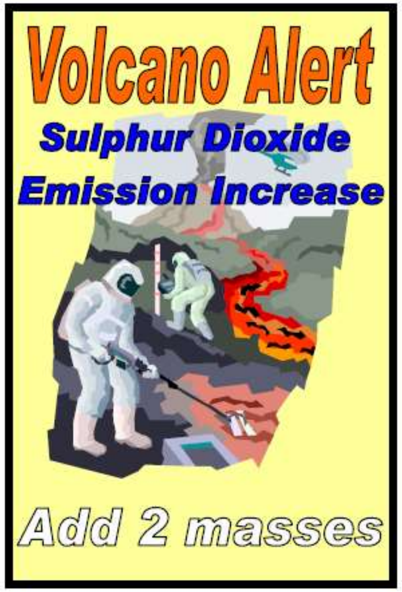
Likelihood of occurrence (B):
1 = Little or no likelihood
2 = Unlikely
3 = Occasional
4 = Probable
5 = Inevitable

Risk Priority (AxB):
12-25 = High risk – take immediate action
6-11 = Medium risk – take action as soon as possible
Less than 6 = Low risk – plan future actions where required

Volcano alert 'Chance cards' © Dave Turner







Volcano Alert

Minor Magnetic Field Changes

Add 1 mass

Volcano Alert

Tilt Meter Increases

Add 1 mass

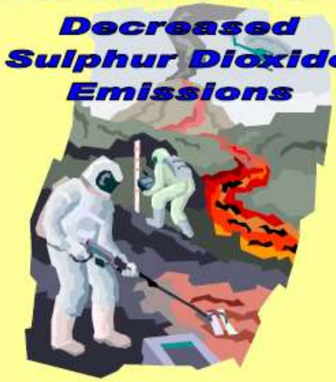
Volcano Alert

Long Period Earthquakes

Add 1 mass

Volcano Alert

Decreased Sulphur Dioxide Emissions



Remove 1 mass

Volcano Alert

Zero Activity

You Choose

Volcano Alert

Decreased Seismic Activity

Remove 1 mass

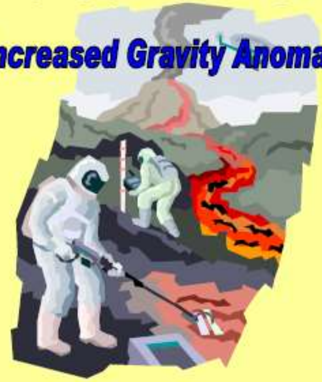
Volcano Alert

Hot Spring Temperature Increase

Add 1 mass

Volcano Alert

Increased Gravity Anomaly



Add 1 mass


Volcano Alert
EVACUATE


Volcano Alert
RETURN TO HOMES


Volcano Alert
Decreased
Slope Angle
Remove 1 mass


Volcano Alert
Minor Rock Falls
Near Summit
Add 1 mass


Volcano Alert
Major Steam Venting
Add 1 mass


Volcano Alert
Minor Seismic Events
Add 1 mass


Volcano Alert
No Data
You Choose


Volcano Alert
Increased
Fumarole Activity
Add 1 mass

ESEU activity guide sheet:

How predictable are volcanic eruptions? - party popper simulation

Party poppers are suspended in clamp stands and are then progressively loaded with 100g masses until they burst, as an analogy with the build-up to a volcanic eruption. The results vary widely, which can be equated to the unpredictability of volcanic eruptions.

This activity gives a method to quantify the stress needed to cause party poppers to ‘erupt’.

Carry out a risk assessment (see below).

Set up the party poppers in several clamp stands, as shown in the photograph, with books or pads of paper beneath the masses to catch them when they fall. Then invite pupils to gradually increase the stress on each party popper by adding 100g (1N) masses until the inevitable happens. This is akin to the steady build-up of stress under the solid plug of a volcano until the plug fails, causing the volcano to erupt. The results normally show ‘eruption’ from different amounts of stress, and a range of ‘eruption stresses’ from 200g to 3500g has been observed. This activity has been designed deliberately to show unpredictability, to simulate the difficulty of predicting exactly when a volcano will erupt.

Set up for the party popper activity. © Peter Kennett, ESEU

Take a 'Chance' on the volcano erupting:

This extension to the activity gives a method to quantify the stress needed to cause party poppers to 'erupt'.

Set up the party poppers in clamp stands, as described above, with books or pads of paper beneath the masses to catch them when they fall.

Provide students with a pack of 'Chance' cards, cut from the following sheets. They can either share a pack, or have a pack each. Explain that each card gives one type of evidence which might indicate whether the volcano was more or less likely to erupt. Each card will tell the students to add one or more masses, or sometimes even to remove a mass.

Explain that each volcano has a major town nearby (teachers may wish to invent a name for each town). Students should also be provided with an 'Emergency' card stating "Evacuate" and "Return to homes". They can choose whether to play these cards at any point in the game.

Now, ask the students to take turns to take a 'Chance' card from the pack and to carry out what it says on the card. Masses should be added gently, in order to obtain a valid comparison between each 'volcano'.

Usually, the total mass required to 'erupt' each party popper varies widely between them – an analogy for the difficulty that scientists have in trying to predict volcanic eruptions precisely.

Volcano alert 'Chance card'
© Dave Turner

Resource list

Resource list: The big picture and the facts of plate tectonics	**Supplied By** Facilitator	Institution
One set:		
• plate tectonic diagram sequence, either on PowerPoint or paper	✓	
Optional		
• a computer		✓
• projector		✓
• ESEU PowerPoint presentation	✓	

Resource list: Geobattleships	**Supplied By** Facilitator	Institution
One set per pair of pupils:		
• sheet showing the distribution of volcanoes plus a blank map	✓	
• sheet showing the distribution of earthquakes plus a blank map	✓	
N.B. These are best printed onto different coloured cards.		

Resource list: The earthquake distribution evidence	**Supplied By** Facilitator	Institution
One set:		
• earthquake diagram, either as PowerPoint slide or on paper	✓	
• (optional) computer, projector		✓

Resource list: Why are the Earth's tectonic plates called plates?	**Supplied By** Facilitator	Institution
One set:		
• a chipped china plate	✓	

Resource list: The seismic evidence for the structure of the Earth	**Supplied By** Facilitator	Institution
One set:		
• the diagrams contained in the activity	✓	

Resource list: The properties of the mantle – potty putty™	**Supplied By** Facilitator	Institution
One set:		
• Potty putty™ (or Silly Putty™) a silicone polymer available from toy shops, or your own version, made from PVA glue and borax using the recipe shown below, that can be found on http://www.esta-uk.net/jesei/index.htm	✓	
To make your own potty putty you will need:		
• 20 cm^3 PVA glue (not a rubberized variety from DIY shops, a simple glue as often used in school art rooms)	N/A	
• a few cubic centimetres of dilute sodium tetraborate solution (borax) (approximately 25 ml)	N/A	
• a small beaker or other container in which to mix the potty putty	N/A	

Resource list: What drives the plates?	**Supplied By** Facilitator	Institution
One set:		
• several willing participants		✓

Resource list: From magnetic globe to magnetic rock evidence	**Supplied By** Facilitator	**Supplied By** Institution
One set:		
a) a model magnetic Earth		
• a strong bar magnet, enclosed as centrally as possible in a large solid sphere of Plasticine™ (e.g. a 7cm magnet in a 12cm diameter sphere)	✓	
• a Magnaprobe™ (tiny magnet suspended in gimbals – currently around £10 each) a plotting compass or a magnetised needle hanging from a thread	✓	
• 15 spent matchsticks	✓	
b) preserving remanent magnetisation		
• a pre-prepared plastic petri dish into which molten candlewax has been poured, iron filings have been sprinkled on the surface, the dish has been placed on top of a bar magnet, and the wax allowed to solidify, thus preserving the shape of the magnetic field in the pattern of the iron filings	✓	

Resource list: The heat flow evidence	**Supplied By** Facilitator	**Supplied By** Institution
One set:		
• diagram or PowerPoint presentation	✓	
• computer and projector		✓

Resource list: Evidence from the age of the sea floor	**Supplied By** Facilitator	**Supplied By** Institution
One set:		
• diagram or PowerPoint presentation	✓	
• computer and projector		✓
• (optional) 'The Geological Map of the World'. © Open University	N/A	

Resource list: Constructive plate margins – adding new plate material	**Supplied By** Facilitator	**Supplied By** Institution
One set:		
• diagrams and photos or PowerPoint presentation	✓	
• computer and projector		✓

Resource list: Faults in a Mars™ bar	**Supplied By** Facilitator	**Supplied By** Institution
One set:		
• one Mars™ Bar (any size!)	✓	

Resource list: The magnetic stripes evidence	**Supplied By** Facilitator	**Supplied By** Institution
One set:		
• iron filings, *either*, in spray-on glue on paper set in magnetic field orientation *or* in wax in a petri dish	✓	
• bar magnet	✓	
• (optional) sample of naturally magnetised, dark, igneous rock	N/A	
• compass, e.g. orienteering or plotting compass	✓	
• dressmakers' pins	✓	
• strip of paper or thin cardboard, with stripes, as described	✓	
• access to a crack between two benches/desks, or piles of books etc. (see diagram)		✓

	Supplied By	
Resource list: Destructive plate margins – recycling material	**Facilitator**	**Institution**
One set:		
• diagrams and photos or PowerPoint presentation	✓	
• computer and projector		✓

	Supplied By	
Resource list: Plates in motion – cardboard replica	**Facilitator**	**Institution**
One set:		
'Plates in motion' model (see diagram), made from:		
• cardboard	✓	
• A4 paper	✓	
• paper serviettes	✓	
• two small wooden blocks	✓	
• tape to attach the blocks	✓	
• paper clips	✓	
• knife to cut slits in cardboard (unless pre-prepared)	N/A	

	Supplied By	
Resource list: Fold mountains in a chocolate box	**Facilitator**	**Institution**
One set:		
• transparent plastic box (e.g. Ferrero Rocher chocolate box or a component drawer)	✓	
• a piece of board to fit snugly into the box eg. of hardboard or rigid plastic	✓	
• spatula or dessertspoon	✓	
• tray	✓	
• 500g of dry fine sand	✓	
• 25g of flour	✓	

	Supplied By	
Resource list: Continental jigsaws	**Facilitator**	**Institution**
One set:		
• 'Jigsaws' prepared by photocopying the master sheets onto card and cutting around the outlines. One set of each 'jigsaw' is required for each small group of students.	✓	

	Supplied By	
Resource list: Plate animation – Britain's journey	**Facilitator**	**Institution**
One set:		
• CD ROM of animation	✓	
• computer and projector		✓

	Supplied By	
Resource list: What is the speed of a plate?	**Facilitator**	**Institution**
One set:		
• Geological map of the World (1000mm x 660mm) published by The Open University	✓	
• ruler measuring in millimetres		
• calculator		

Resource list: Plate riding – how is the plate you live on moving now?	**Supplied By**	
	Facilitator	**Institution**
One set:		
None	N/A	

Resource list: 'Brickquake' – can earthquakes be predicted?	**Supplied By**	
	Facilitator	**Institution**
One set:		
For activity (qualitative):		
• 4 clean house bricks, (one with string tied round it lengthwise)	✓	
• Newton meter	✓	
• elastic rope (e.g. elastic luggage bungee about 40 cm long)	✓	
For follow up (quantitative) activity – all optional:		
• string, about 3 m long	N/A	
• a range of Newton meters (e.g. up to 50N)	N/A	
• laser pointer (or torch if laser pointer not available)	N/A	
• a shallow tray containing water	N/A	
• winding mechanism (e.g. pulley block) clamped to the table with a G-clamp	N/A	
• a slinky spring	N/A	
• sticky tape	N/A	

Resource list: Finale: How predictable are volcanic eruptions – party popper simulation	**Supplied By**	
	Facilitator	**Institution**
For four set ups, required are:		
• 4 x party poppers	✓	
• 4 x clamp stands, bosses and arms		✓
• 8 x mass hangers, each with 10 100g (1N masses)		✓
• 4 x books or pads of paper for the masses to fall onto when the party poppers 'erupt'		✓
• 24 x 'Chance cards'	✓	