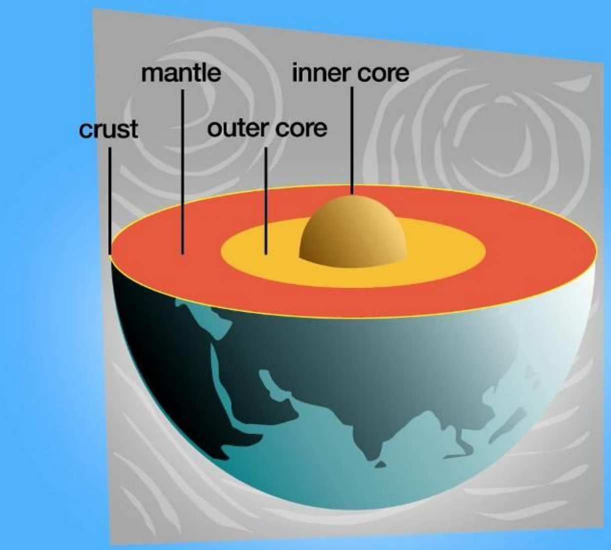
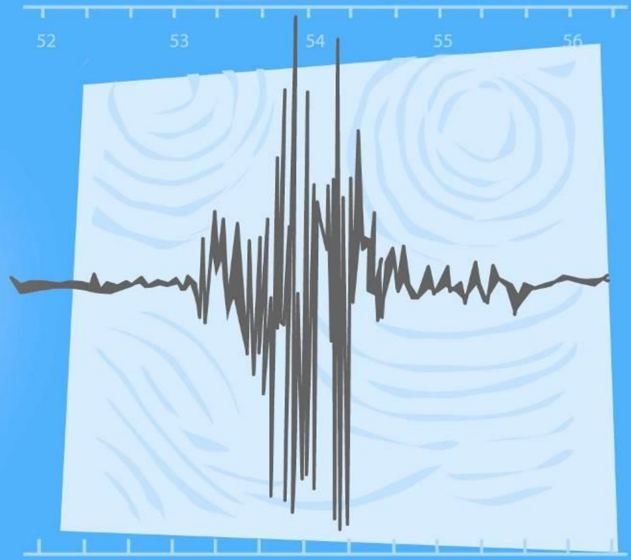
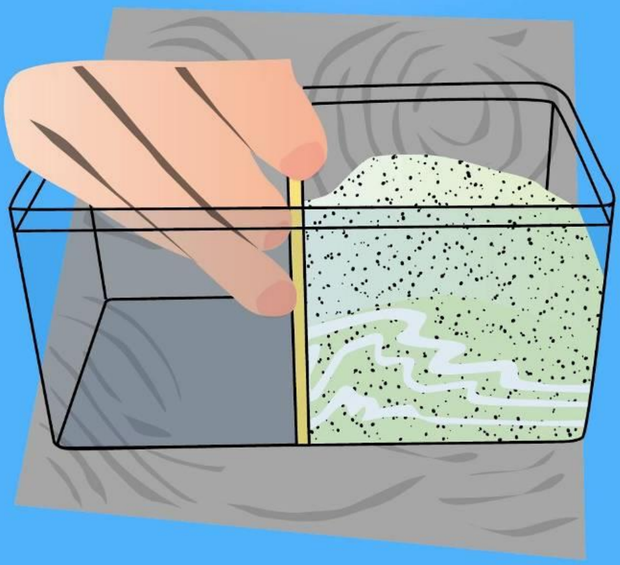
**Dynamic Earth Science**




# The Earth and plate tectonics

EARTH SCIENCE EDUCATION UNIT

With the support of:

**Workshop prepared by:**
*Paul Baggaley, Susan Beale, Dee Edwards, Peter Kennett, Phillip Murphy, Dave Turner, Royanne Wilding*

***Edited by:***
*Chris King, Susie Lydon, Cally Oldershaw, Peter Kennett and Hazel Benson*



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**The Earth Science Education Unit email: eseu@keele.ac.uk**

# ESEU KS4 Workshops:
# The Earth and Plate Tectonics

## Contents



**Summary**

'The Earth and Plate Tectonics' 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.

# 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 plate tectonic concepts commonly taught to secondary pupils.

# The Story for Teachers: Plate Tectonics

## Plate Tectonics

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 by small pockets of molten rock. The rock was melted by the heat produced from the decay of radioactive isotopes. The heat causes the mainly solid asthenosphere to flow plastically in convection currents and these currents carry the plates of lithosphere along with them.

Where plates are moved away from each other by convection currents that rise and flow outward 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. The partly molten iron-rich rock beneath the lithosphere 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 metamorphosing. 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.

# The big picture and the 'facts' of plate tectonics

**Activity:**
A short series of introductory PowerPoint slides 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.

It also presents plate tectonics as a series of 'facts', and concludes:

- But plate tectonics is not a series of facts, as suggested in the story above, but is a theory supported by evidence
- But what is this evidence and how does it support the theory?

This gives a springboard for the sequence of activities that follows, providing the evidence for plate tectonics and explanation of the processes involved.

Plate tectonic theory is outlined in narrative form in 'The Story for Teachers' on the previous page.

**Student learning outcomes:**
Students will be able to:

- 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

**Student practical or teacher demonstration:**
Teacher demonstration

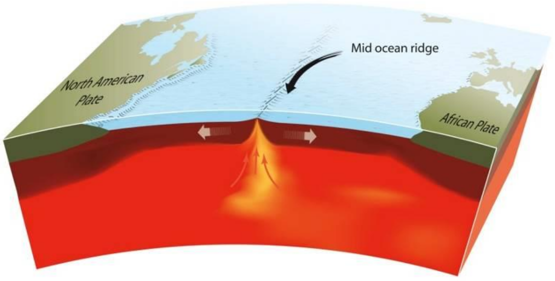
**Time needed to complete the activity:**
5 minutes

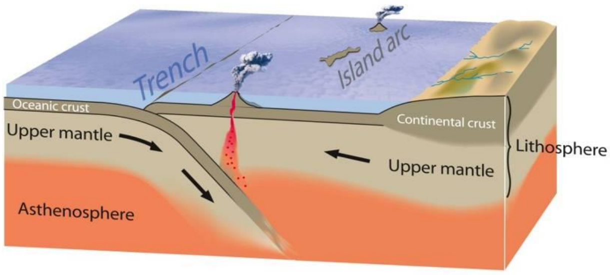
**Preparation and set-up time:**
Time to set up the computer and access the PowerPoint.

**Resources:**

- A computer
- Projector
- 'The Earth and plate tectonics' PowerPoint presentation

**Source of activity:**
Earth Science Education Unit, Keele University.



# Continental Jigsaws

**Activity:**
This activity uses a range of evidence from the continents to support plate tectonic theory.

Groups of students are issued with one or more sets of jigsaws of the continents and asked to reassemble the outlines, to make a former super-continent. They may 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 below 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.

**Student learning outcomes:**
Students will be able to:
- 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.

**Student practical or teacher demonstration:**
Student practical (paper)

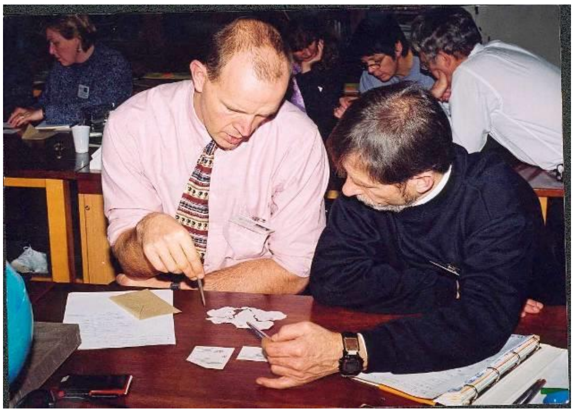
**Time needed to complete the activity:**
5 minutes for each jigsaw. 15 minutes if each group does all jigsaws.

**Preparation and set-up time:**
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 <u>before</u> 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!

**Resources:**
- 'Jigsaws' prepared by photocopying the master sheets (pages 9 to 12) onto card and cutting around the outlines. One set of each 'jigsaw' is required for each small group of students.

**Ideas for leading into the activity:**
Students can be asked what kind of evidence they would look for, if they sought to test the hypothesis of continental drift.

**Ideas for 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 (Answer = land bridges). Note that the continental drift hypothesis is now seen as a part of the over-arching plate tectonic theory.



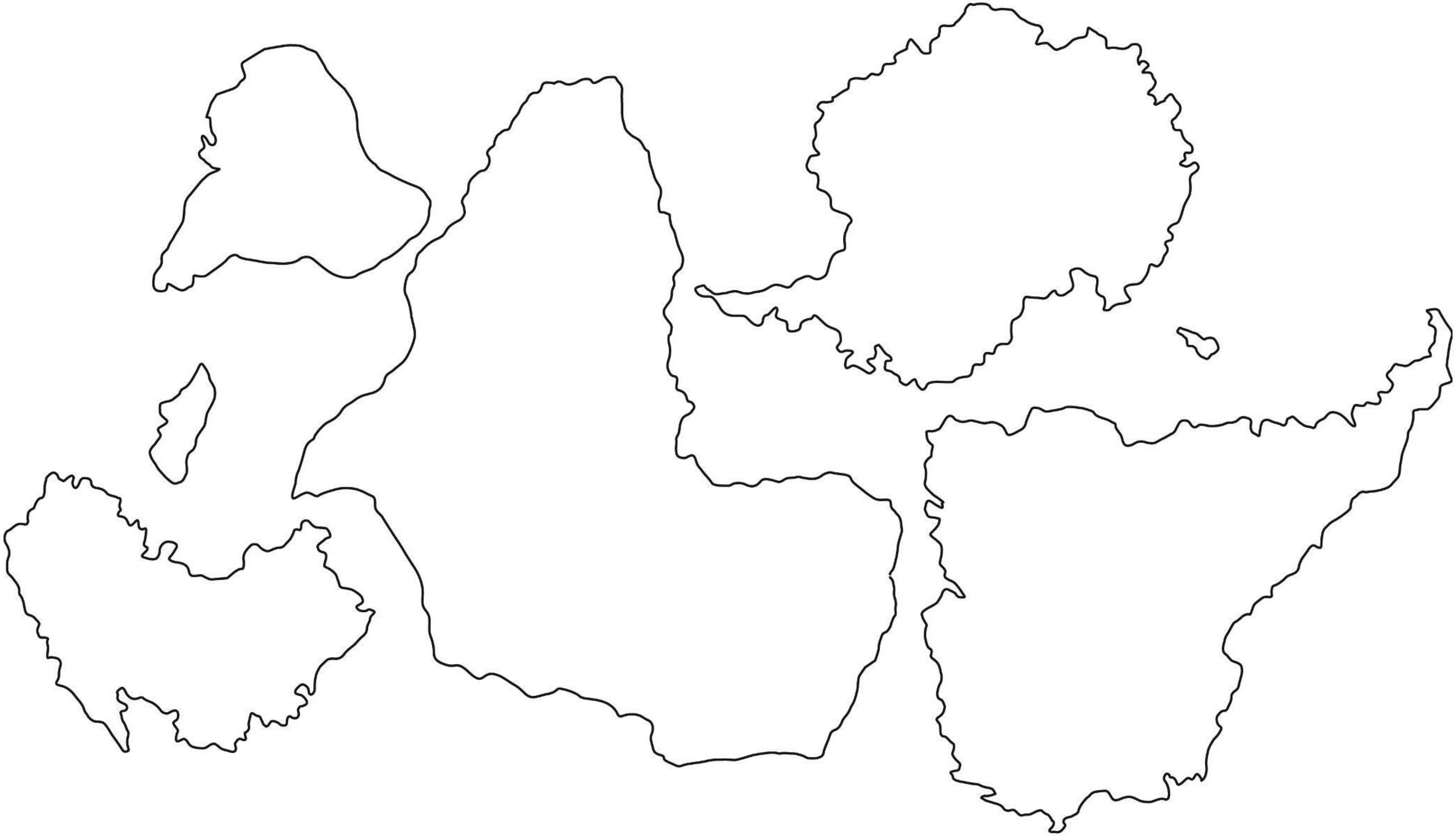
Debating the reconstruction of the super-continent 'Gondwanaland' © Peter Kennett

**Source of activity:**
Earth Science Education Unit, Keele University.

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

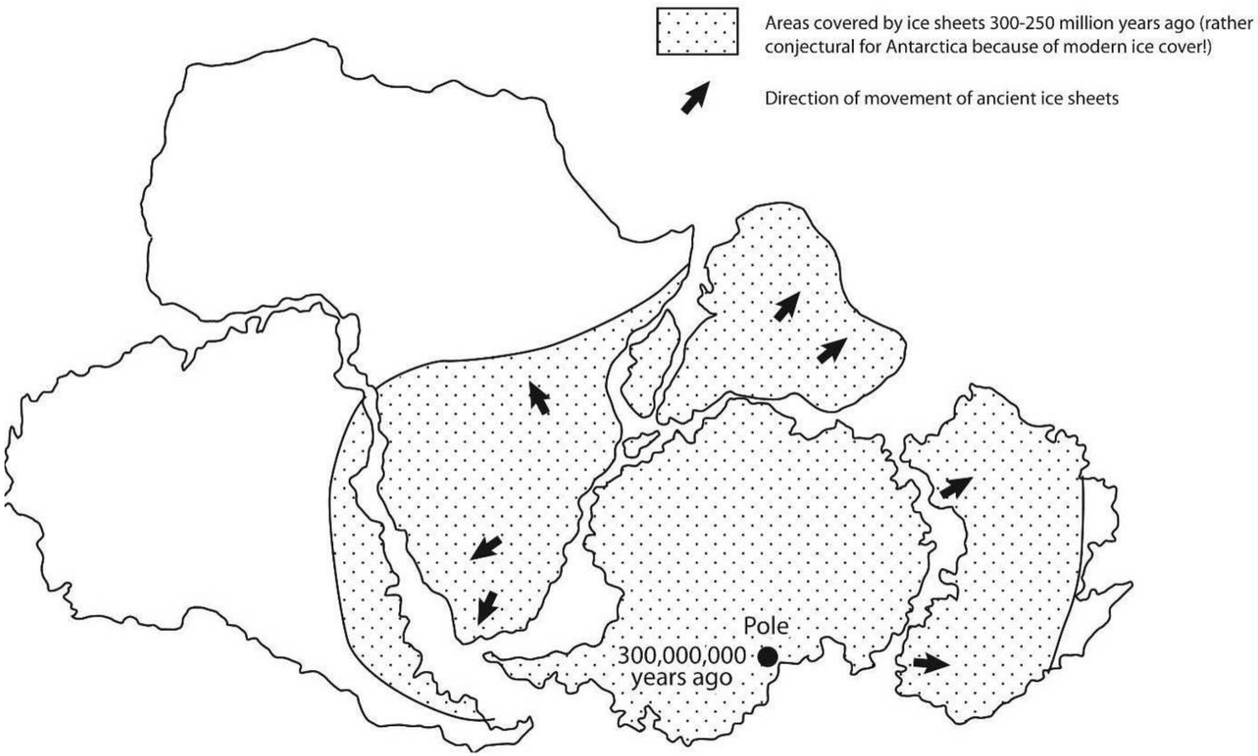
**The outlines of the Gondwana Continents**



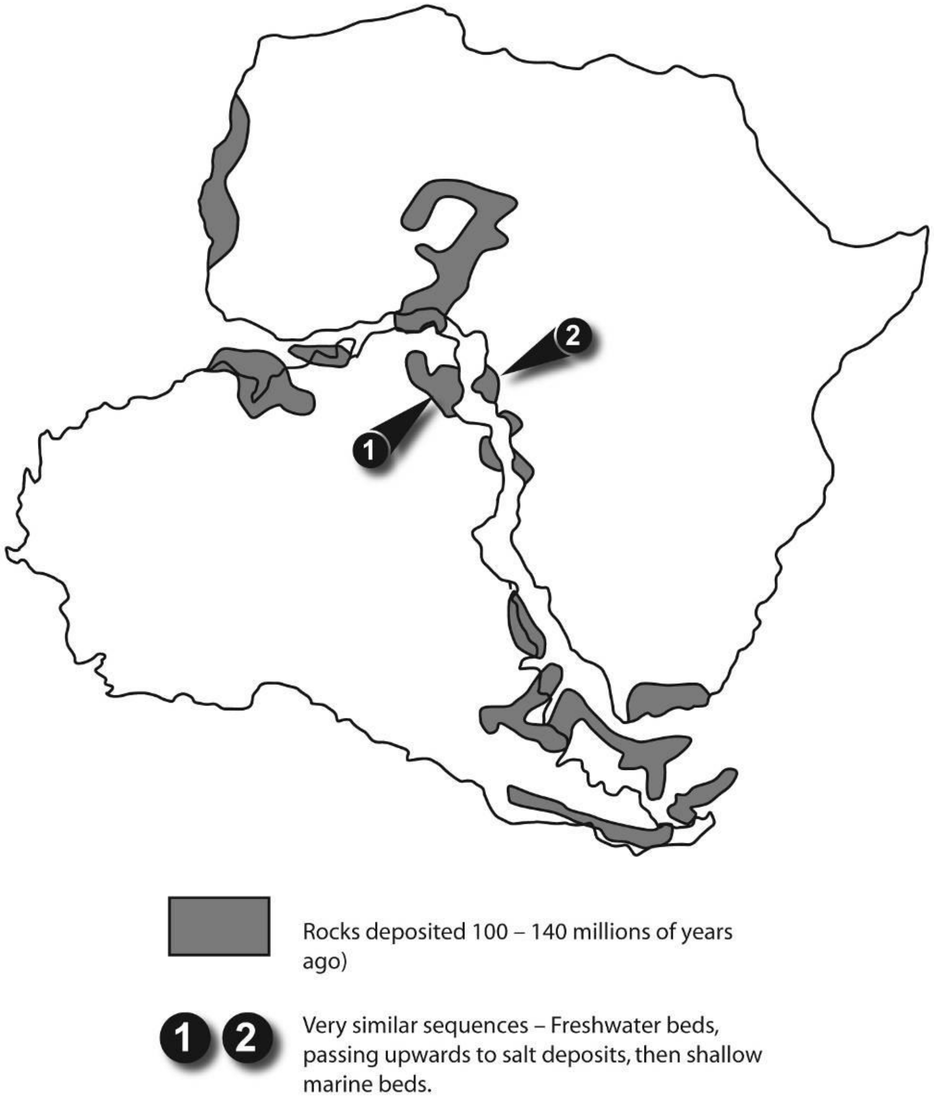
**The fit of continental shelves**


At 1000m below sea level the continental rock types give way to oceanic ones. Using this depth for a reconstruction gives a better fit than the present coastlines. Areas of overlap are mostly where features such as deltas have added to the continental margins since break-up.

**Former distribution of ice across the Gondwana continents**

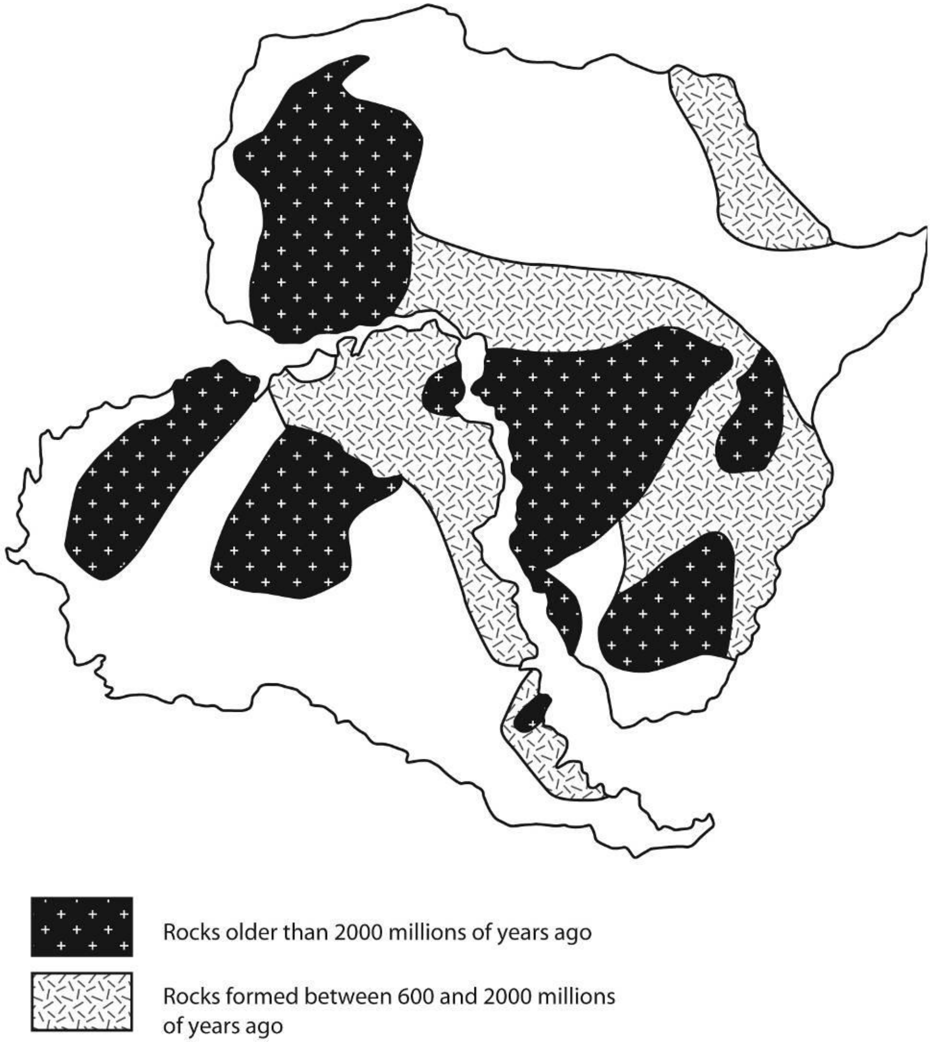


**Distribution of ancient rocks across South America and Africa**



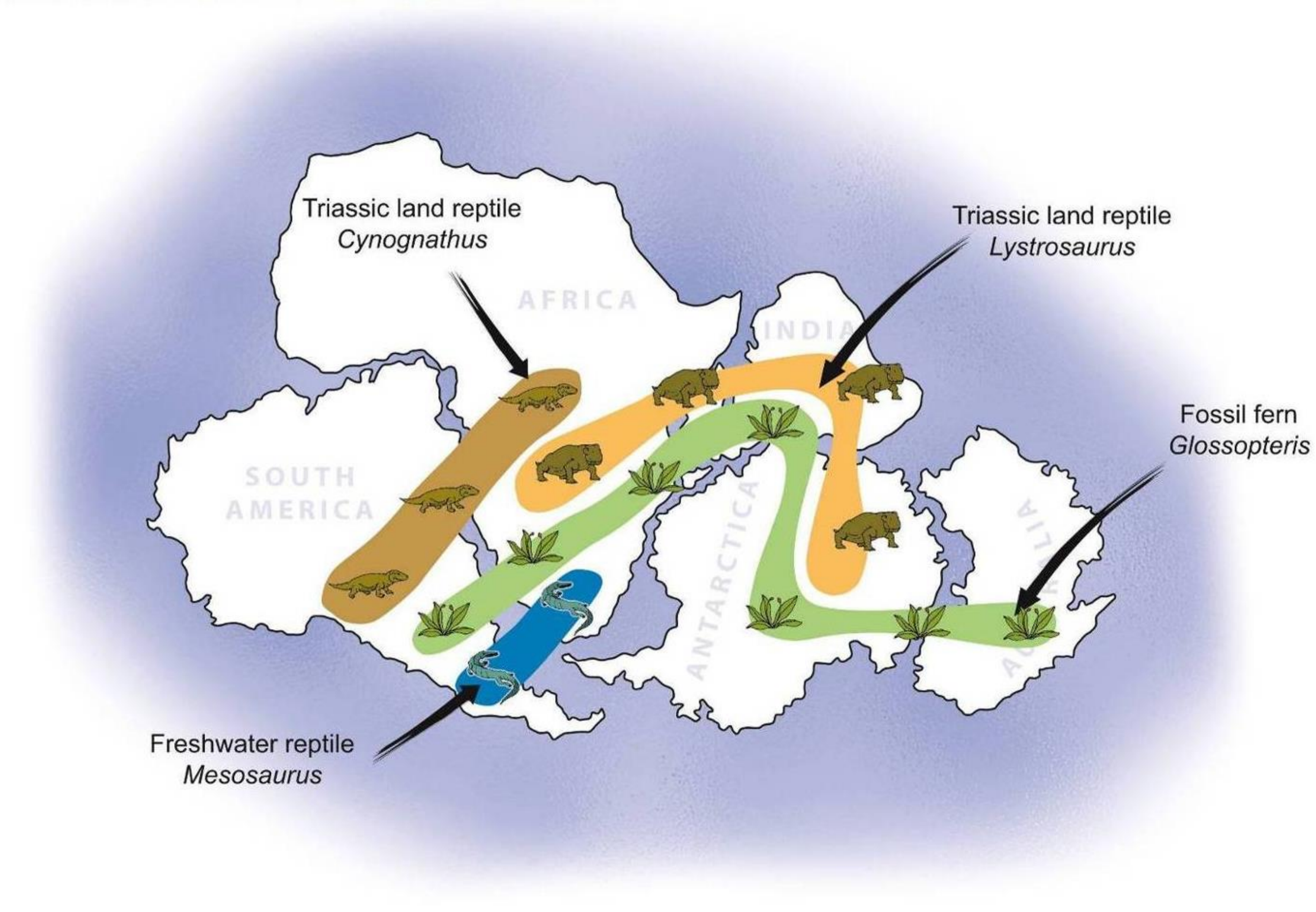

Author/origin unknown © redrawn by ESEU

**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**



# Model Earth – Plasticine™ spheres

**Activity:**
Students explore and discuss the differences between two identical–looking Plasticine™ spheres – one with a ball bearing inside.
Carry out a risk assessment (see page 65 at the end of this document).

- Groups of students are given a pair of Plasticine™ spheres, of equal size, as above.
- Students are asked to compare the spheres and say how they might work out what is inside using either the 'low tech' facilities of the laboratory or 'high tech' methods of industry or university labs, including sticking a pin into them.
- When they have worked out a range of ideas, these are applied to the Earth, to consider if they could be used to provide evidence on the Earth's structure. The relative density of the Earth is around 5.5, but the average relative density of surface rocks is only about 2.8, so the interior must be considerably denser. A typical igneous rock of the continents is *granite*, with a relative density of about 2.7. [This activity is described in more detail in: King, C. (2002) The secrets of Plasticine™ balls and the structure of the Earth: investigation through discussion. *Physics Education,* 37 (6), 485 – 491].

**Student learning outcomes:**
**Students will be able to:**
- identify which of the two balls is heavier;
- describe different hypotheses that could account for one ball being heavier than the other;
- explain different ways of testing these hypotheses, using equipment from low tech to high tech;
- explain which of these hypotheses could also be used on the Earth to find out whether or not the Earth has a heavy metal core.

**Pupil practical or teacher demonstration:**
Pupil practical

**Time needed to complete the activity:**
5 minutes

**Preparation and set-up time:**
The spheres need making up in advance but can be kept for succeeding lessons, for which no preparation time is then required.

**Resources:**
- a pair of Plasticine™ spheres per group of students. Each sphere should be 2 cm to 3 cm in diameter. One has a ball bearing at the centre, occupying about half the diameter of the sphere
- one pin per group
- a sample of granite
- optional balance, density can, or callipers - if quantitative work is planned

**Ideas for leading into the activity:**
Any discussion which requires knowledge of the Earth's interior, e.g. how plates can move; where magmas come from; why seismic waves change in velocity with depth, etc.

**Ideas for following up the activity:**
The Earth can be "weighed" and the size has been known since about 250 B.C., so the overall density can be calculated.
Boreholes can only penetrate a few kilometres, so the Earth cannot meaningfully "have a pin stuck in it" to the mantle/core boundary at nearly 3000 km depth! Seismic work provides the detail about the depth of the core and the other layers.

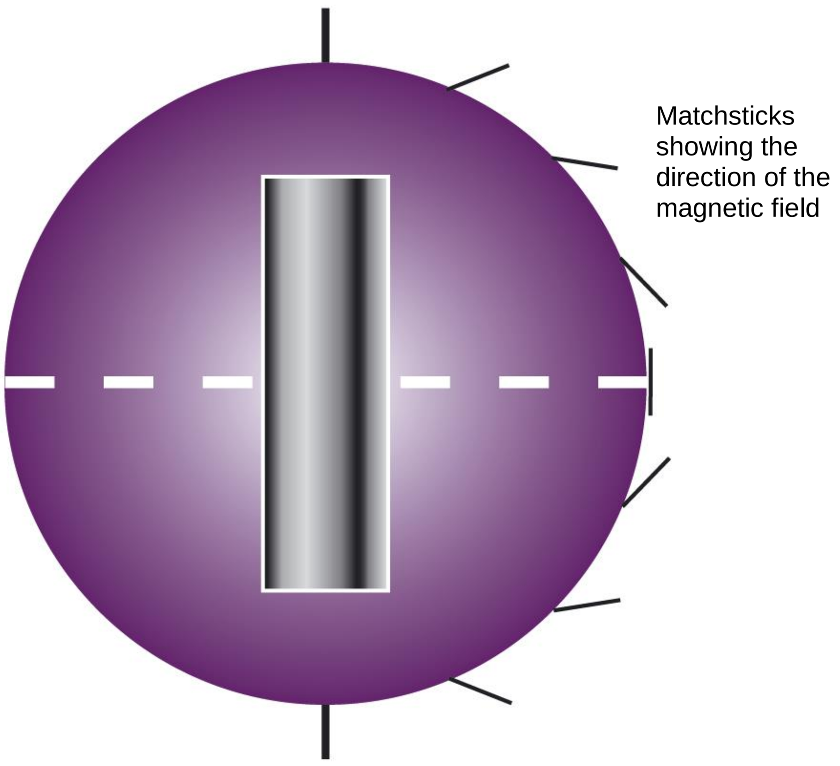
**Source of activity:**
Earth Science Education Unit, Keele University.

# From Magnetic Globe to Magnetic Rock Evidence

**Activity:**
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.
- 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!

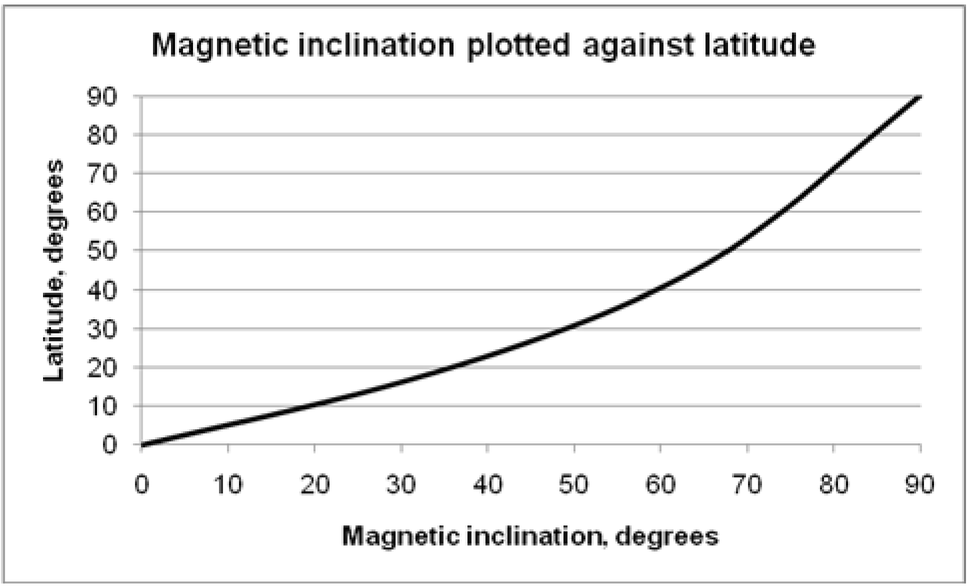



Model of the Earth's magnetic field
© Chris King, ESEU

**b) Preserving remnant 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 'remnant 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 **remnant 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 remnant magnetisation with a vertical inclination, where must it have been formed? *(At one of the two poles.)* Then ask, if it had a horizontal inclination, where must it have formed? *(At the equator.)*
- Ask the students the meaning of this data from outcrops of rock in the UK:
    - 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 60ºN (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 70º.)*





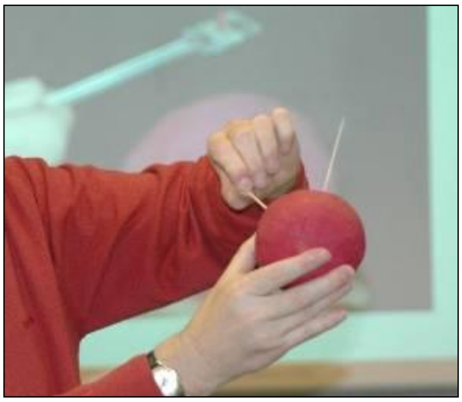
 

**Student learning outcomes:**
Students will be able to:
- describe how a Magnaprobe™ can be used to detect and mark a magnetic field;
- describe how a Plasticine™ ball with a magnetic field indicated shows magnetic field lines in three dimensions;
- explain how the ball provides an analogy with the magnetic field of the Earth;
- explain how the magnetic field of the time can be 'fossilised' in cooling magnetic rocks;
- explain how remnant 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.

**Student practical or teacher demonstration:**
Teacher demonstration

**Time need to complete the activity:**
10 – 15 minutes

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



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

**Resources:**
**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 remnant 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.

**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? *(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 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? *(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? *(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.)*

**Ideas for 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? *(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 of activity:**
Taken from 'Model Earth – Plasticine™ balls' in the ESEU workshop publication 'The Earth and plate tectonics', and from 'What is the Earth's magnetic field like?' in the 'Through the lab window to the world: teaching KS3 physics through an Earth context' ESEU workshop publication.

# Geobattleships

**Activity:**
Students 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 students into pairs. Issue a volcano sheet to one student and an earthquake sheet to the other. Tell them that there are at least 32 volcanoes or earthquake epicentres shown on the maps.
Students play “battleships”, taking it in turns to “fire” at their opponent’s maps. (Students 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.

Students 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.

Students 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.

**Student learning outcomes:**
Students will be able to:
- 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.

**Pupil practical or teacher demonstration:**
Pupil practical (on paper)

**Time needed to complete activity:**
10 minutes

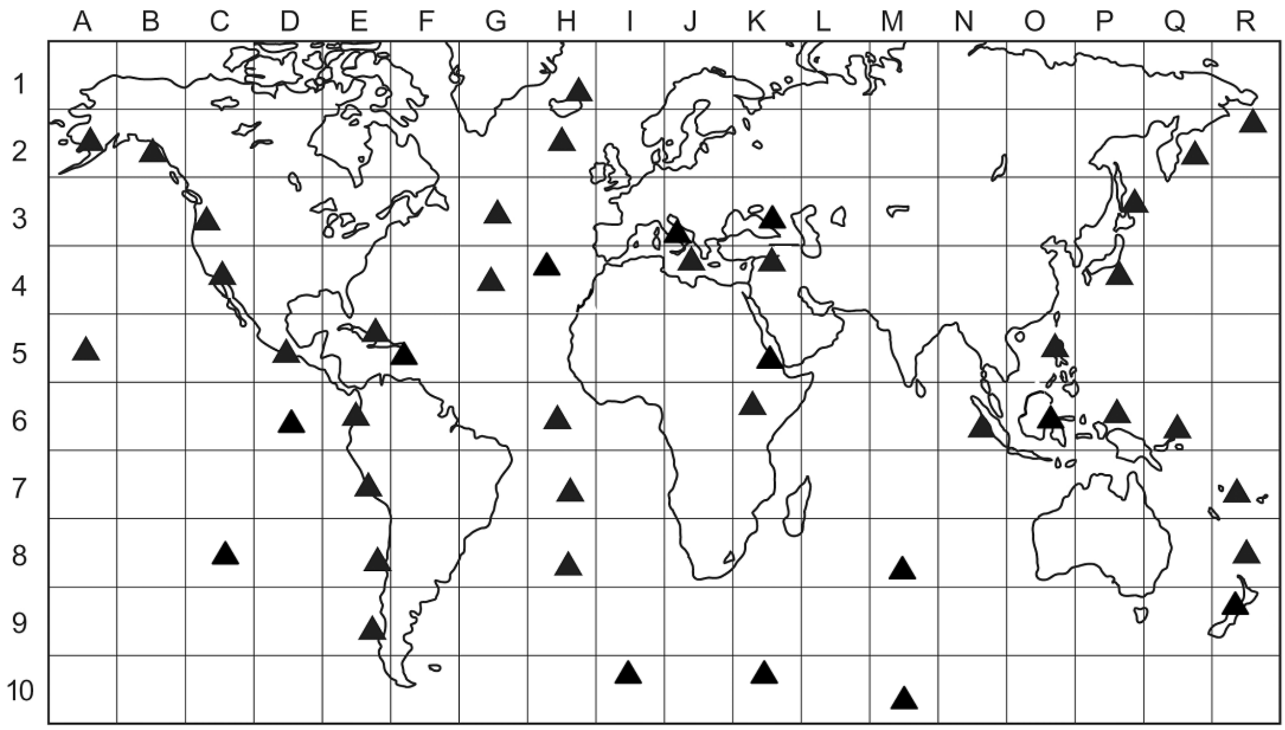
**Preparation and set-up time:**
None

**Resources:**
- Sets of sheets for pairs of students. One set shows the distribution of volcanoes plus a blank map: the other shows the distribution of major earthquakes plus a blank map. These are best printed onto different coloured card.

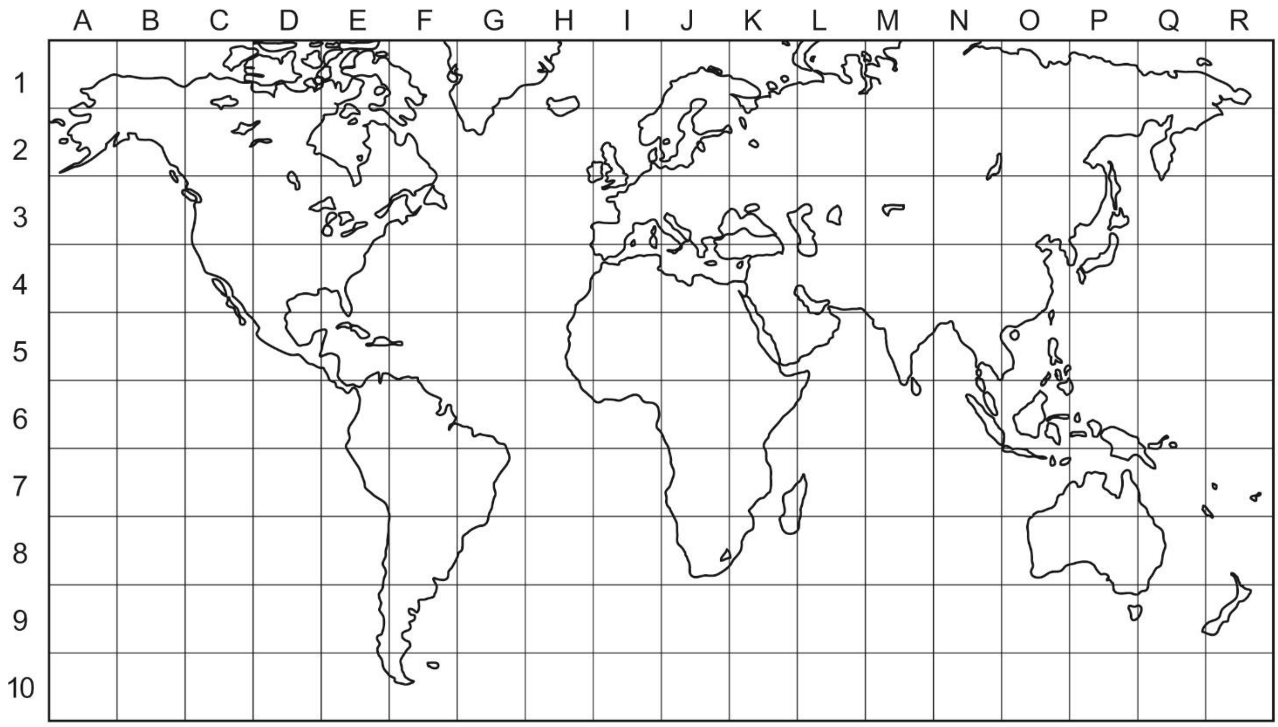
**Ideas for leading into the activity:**
The activity should be used **before** students are made aware of the detail of the surface distribution of earthquakes and volcanoes. This will then help them to understand the evidence for the location of the plate boundaries, rather than simply being told where they are. It could be used as a revision of their existing understanding from Key Stage 3.

**Ideas for 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! The Geological Map of the World, produced by the Open University/ESSO is available from the Earth Science Teachers’ Association (ESTA), or a free copy is given to centres where the ESEU conducts INSET workshops. Sources on the web include http://www.usgs.gov

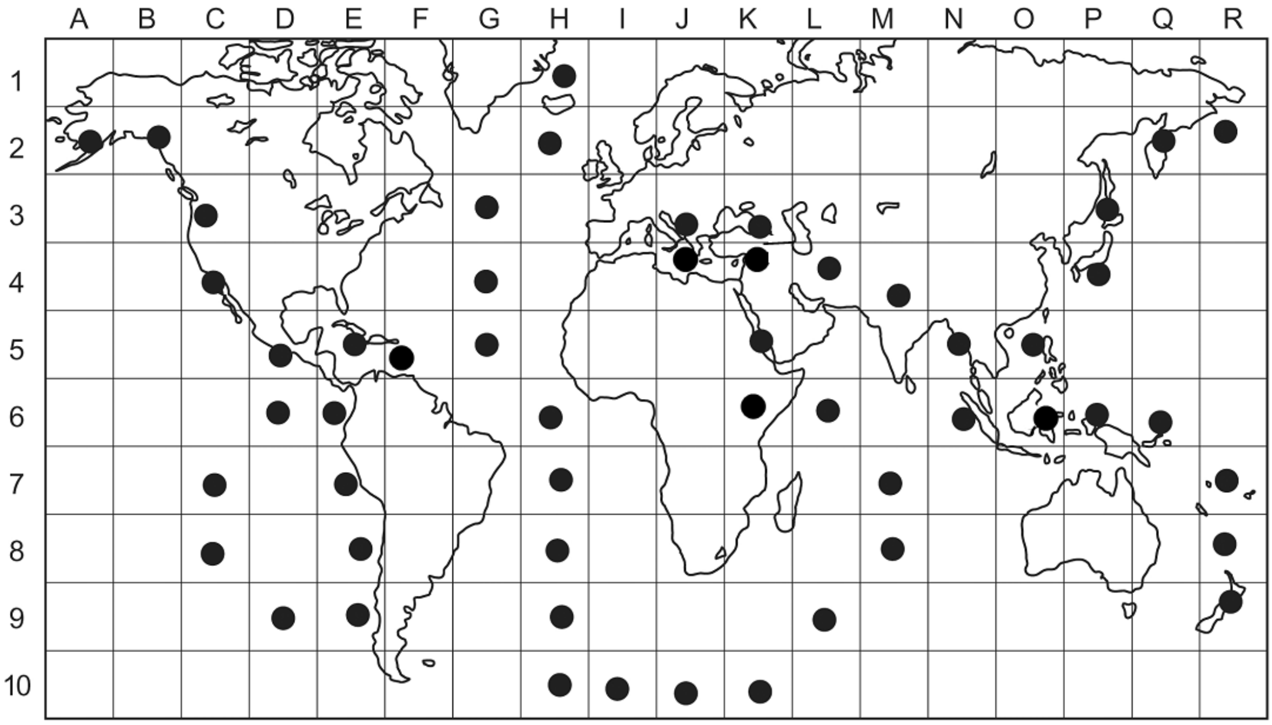
Continue with other evidence for plate tectonics.



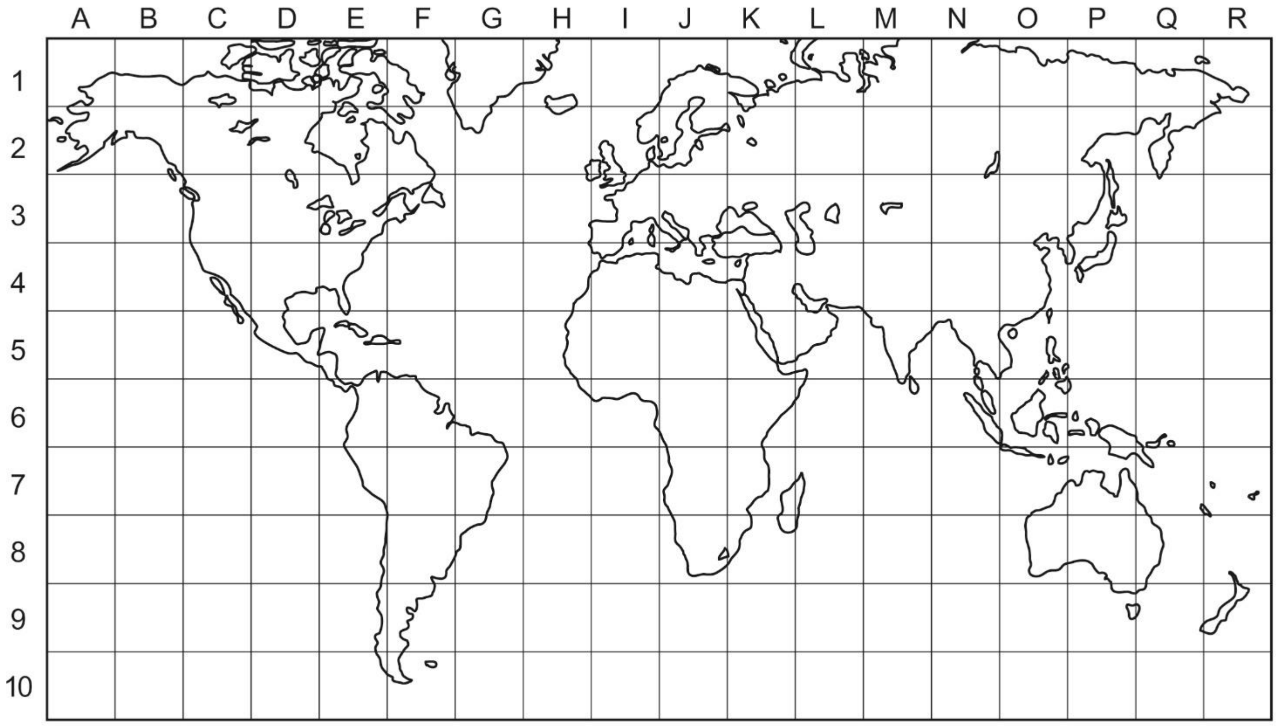

**Main Volcanoes / Volcanic Activity map**




**Map for plotting Earthquake locations**




**Main Earthquake Activity map**




**Map for plotting Volcanoes / Volcanic activity locations**

# The earthquake distribution evidence

**Activity:**
The PowerPoint slide 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.

**Student learning outcomes:**
Students will be able to:

- 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.

**Student practical or teacher demonstration:**
Teacher demonstration.

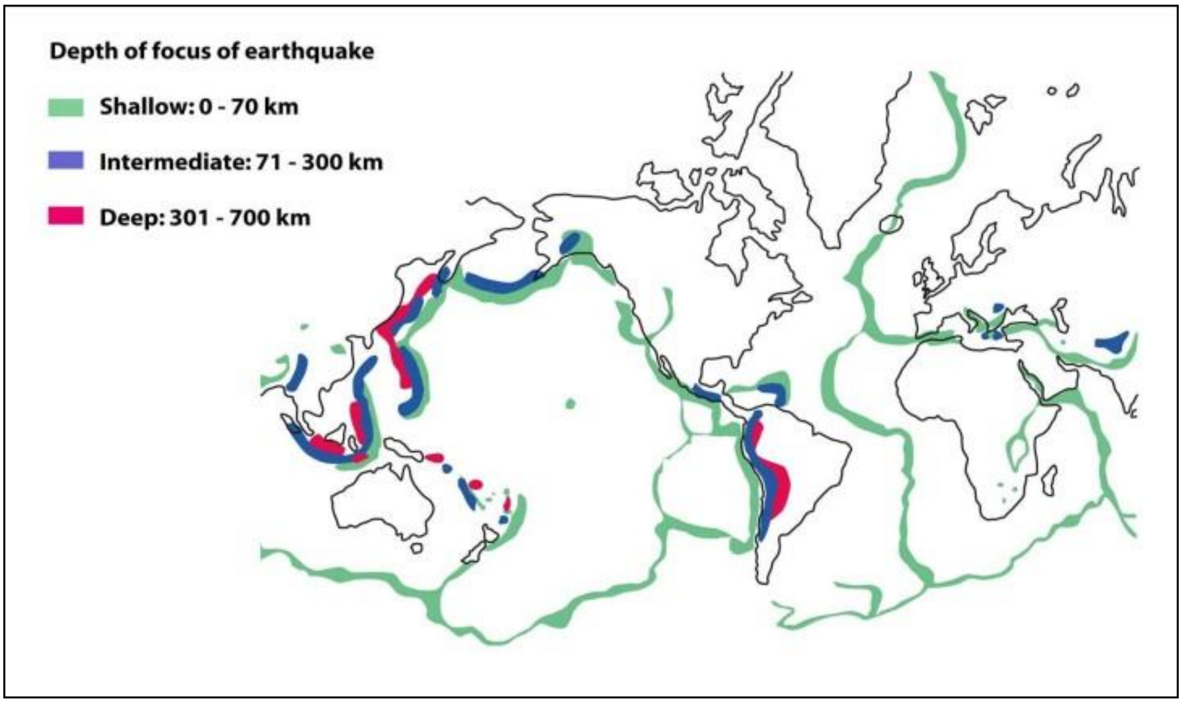
**Time needed to complete the activity:**
5 minutes.

**Preparation and set-up time:**
None, once the computer and PowerPoint are running.

**Resources:**

- **'The Earth and plate tectonics' PowerPoint presentation.**

**Source of activity:**
Earth Science Education Unit, Keele University.



# Earthquakes - the slinky simulation

**Activity:**
The transmission of P- and S-waves can be demonstrated using a slinky spring.

- Extend the slinky on the bench top and ask a student to hold the other end.
- Giving the slinky a sharp push-pull motion produces a longitudinal wave (known as a P or Primary wave (since it travels faster than other types of wave and arrives before the S or Secondary wave); also a Push/Pull or comPressional wave.
- Ask students to note the movement of the spots on the central coils; they move backwards and forwards in the direction of the wave as compression and rarefaction passes along the spring, as molecules vibrate in solids, liquids and gases during passage of a P-wave.
- Giving the slinky a sharp sideways shake produces a transverse wave (known as an S or Secondary wave; also a Sideways, Shake, Shear or Slow wave).
- The students should note the movement of the spots, this time, at right angles to the path of the waves; these simulate the shear movement of molecules as S-waves pass; since fluids (liquids and gases) cannot shear, they cannot transmit S-waves.
- Both P-waves and S-waves travel through the Earth and are known as body waves.
- Surface waves, which produce an undulation of the surface and cause most of the damage in an earthquake, are akin to sea waves and are impossible to imitate with the slinky.

**Student learning outcomes:**
Students will be able to:

- describe how slinky springs can simulate P- and S-waves
- explain how the movement of the spring simulates the movement of the material it passes through, by the movement of the molecules;
- explain why P-waves are transmitted by solids, liquids and gases, but S-waves by solids only.

**Student practical or teacher demonstration:**
Teacher demonstration

**Time needed to complete activity:**
5 minutes

**Preparation and set-up time:**
None

**Resources:**

- A slinky spring.
- If possible, glue a few coloured spots on the central coils, or paint white spots on with Tippex™ to emphasise the movement of the spring.

**Ideas for leading into the activity:**
How do we find out about the Earth's interior?

**Ideas for following up the activity:**
Wave motion – student 'molecules' activity.

**Extension ideas for more able or faster pupils:**
See student 'molecules' activity

**Source of activity:**
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.

'P-wave' © ESEU

'S-wave' © ESEU

# Wave Motion – student molecules

**Activity:**
This activity simulates the ways in which seismic waves are transmitted in different states of matter.

- Students line up with straight arms, holding the shoulders of the person in front. The rear student (the most trustworthy!) applies a gentle push/pull motion, which ripples through the line, imitating a P-wave (primary wave) being transmitted by a solid.
- Shaking the students from side to side imitates an S-wave (secondary wave) in a solid.
- Students drop their arms. The trusted student waggles the one in front of him/her from side to side, but no motion passes down the line: an analogy for an S-wave not being transmitted through a liquid.
- Students close up together with arms down. A gentle push at the rear causes a P-wave to travel through a ‘liquid’, although the analogy breaks down when the front student falls over and the pulse is not sent back again!

**Student learning outcomes:**
Students will be able to:

- describe how a line of students can simulate P- and S-waves
- explain how the movement of the students simulates the movement of material as the waves pass through, by the movement of the molecules;
- explain why P-waves are transmitted by solids, liquids and gases, but S-waves by solids only.

**Student practical or teacher demonstration:**
Teacher demonstration with participation by selected students.

**Time needed to complete the activity:**
5 minutes

**Preparation and set-up time:**
None

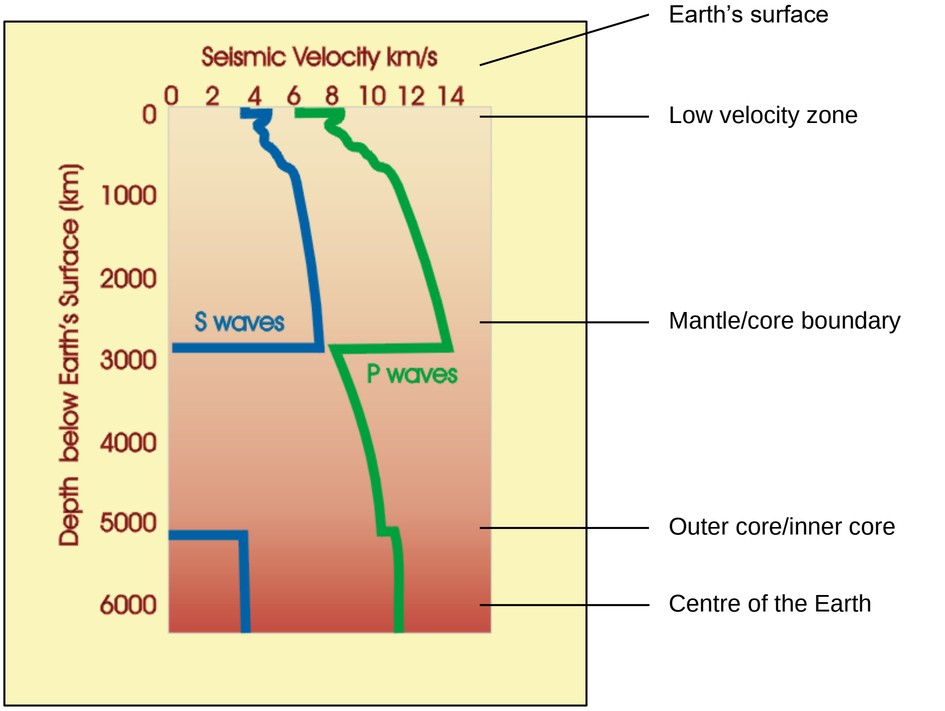
**Resources:**
4 or 5 willing students!

**Ideas for leading into the activity:**
Demonstration of P- and S-wave transmission using a slinky.

**Ideas for following up the activity:**
Present the graphs of P and S seismic wave velocities through the Earth. Point out: solid mantle: liquid outer core: solid inner core. The crust is too thin to show on this scale, but the Low Velocity Zone (LVZ) in the upper mantle (asthenosphere) can usually be picked out where the velocities of the P and S waves dip. The crust and the part of the mantle lying above the LVZ are called the lithosphere. Plates are made of lithosphere and not crust alone.

**Source of activity:**
Earth Science Education Unit, Keele University.

Student ‘molecules’ © ESEU




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 seismic evidence for the structure of the Earth

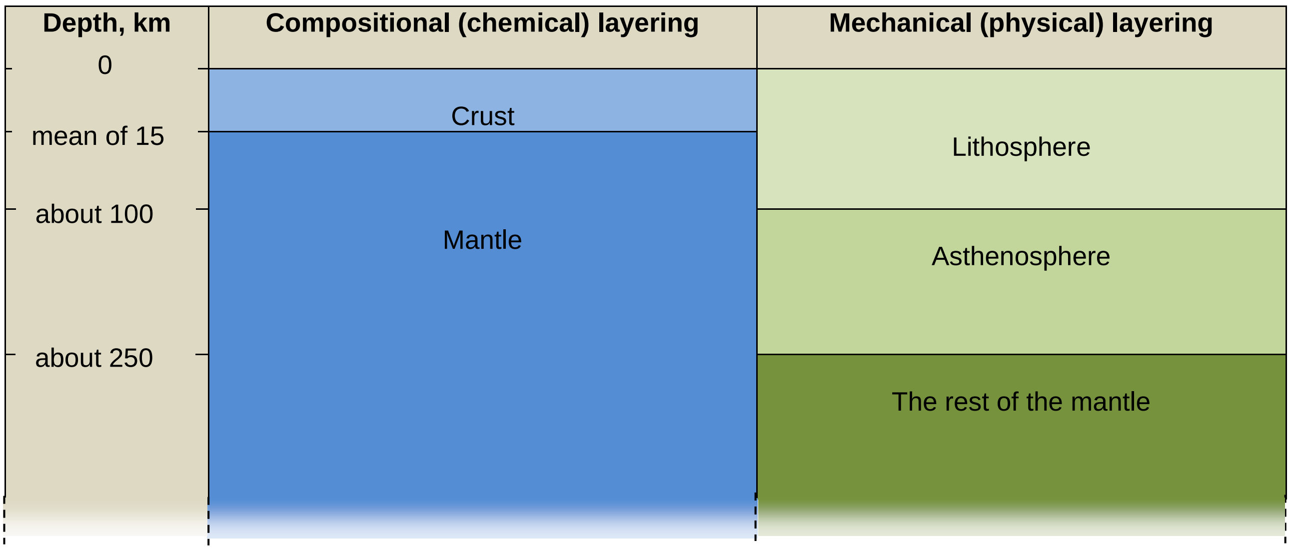
**Activity:**
The PowerPoint slides show a plot of the velocities of P- and S-waves as they penetrate the Earth. Note that it is an unusual graph in the depth increases downwards. This can be used, through discussion, to show:

- there are no S-waves in the outer core – so this must be a fluid (as 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, since it transmits S-waves must be solid;
- 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 1 – 5% liquid, or 95 – 99% solid; This is able to flow, over geological time.

The following slide 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 partially liquid asthenosphere (1 – 5% liquid) 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.

The composition and structure of the outer Earth is summarised in the diagram below.




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

The outer part of the Earth can be simulated by a student on a skateboard.

**Student learning outcomes:**
Students will be able to:

- describe the structure of the Earth;
- explain how the seismic evidence can be used to interpret the internal structure of the Earth.

**Student practical or teacher demonstration:**
Teacher demonstration.

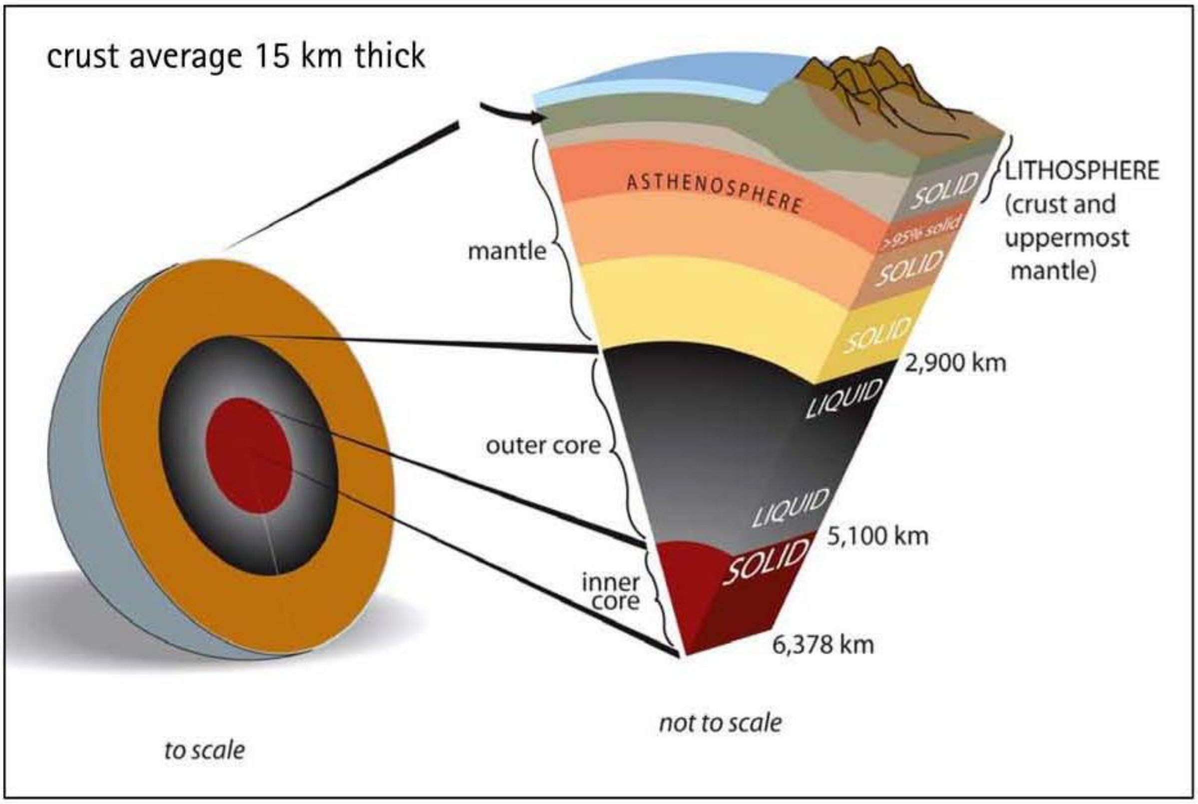
**Time needed to complete the activity:**
5 minutes.

**Preparation and set-up time:**
None, once the computer and PowerPoint are running.

**Resources:**

- **'The Earth and plate tectonics' PowerPoint presentation.**

**Source of activity:**
Earth Science Education Unit, Keele University.





# Why are the Earth's tectonic plates called 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.

**Student learning outcomes:**
Students will be able to:
- describe the main features of the Earth's plates;
- Explain how a china plate provides an analogy for the Earth's plates.

**Student practical or teacher demonstration:**
Teacher demonstration.

**Time needed to complete the activity:**
5 minutes.

**Preparation and set-up time:**
Nil – apart from finding a plate.

**Resources:**
- A chipped china plate

**Ideas for leading into the activity:** Aspects of plate tectonic theory, notably the concentration of most seismic activity at the edges of plates in contrast to the aseismic interior of the plate. Establish the nature of the lithosphere, and its thickness (100-200 km or so), which is very thin in relation to its surface area.

**Source of activity:**
Earth Science Education Unit, Keele University.

©Peter Kennett, ESEU

# Properties of the Mantle – potty putty™

**Activity:**
A demonstration of 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!)
- 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 (*plastic*) and what is causing the stress (*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!

**Student learning outcomes:**
Students will 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.

**Student practical or teacher demonstration:**
Either

**Time needed to complete the activity:**
5 minutes

**Preparation and set-up time:**
2 minutes

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

***'Recipe for making 'Potty putty'***
*Apparatus:*

- 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. This will wash off eventually, but not very easily!

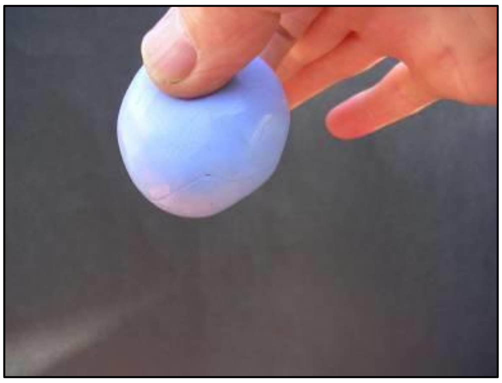
**Ideas for leading into the activity:**
Any discussion of the mantle:

- 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.

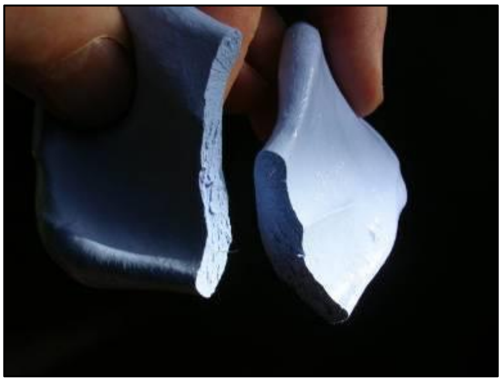
**Ideas for following up the activity:**
Discussion of the rate of movement of plates: convection of the mantle is slow, but possible even though mantle is NOT liquid.

**Source of activity:**
Earth Science Education Unit, Keele University.



Bounce it (elastic deformation)
© Peter Kennett

Bend it (plastic deformation)
© Peter Kennett



Snap it (brittle deformation)
© Peter Kennett

Shatter it (brittle deformation)
© Peter Kennett

# The heat flow evidence

**Activity:**
The PowerPoint slide 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 not only does the rising mantle convection current bring heat to the surface, but partial melting and the rising and eruption of magma also releases large amounts of heat;
- the plate cooling as it is moved away form 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.

**Student Learning Outcomes:**
Students will be able to:

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

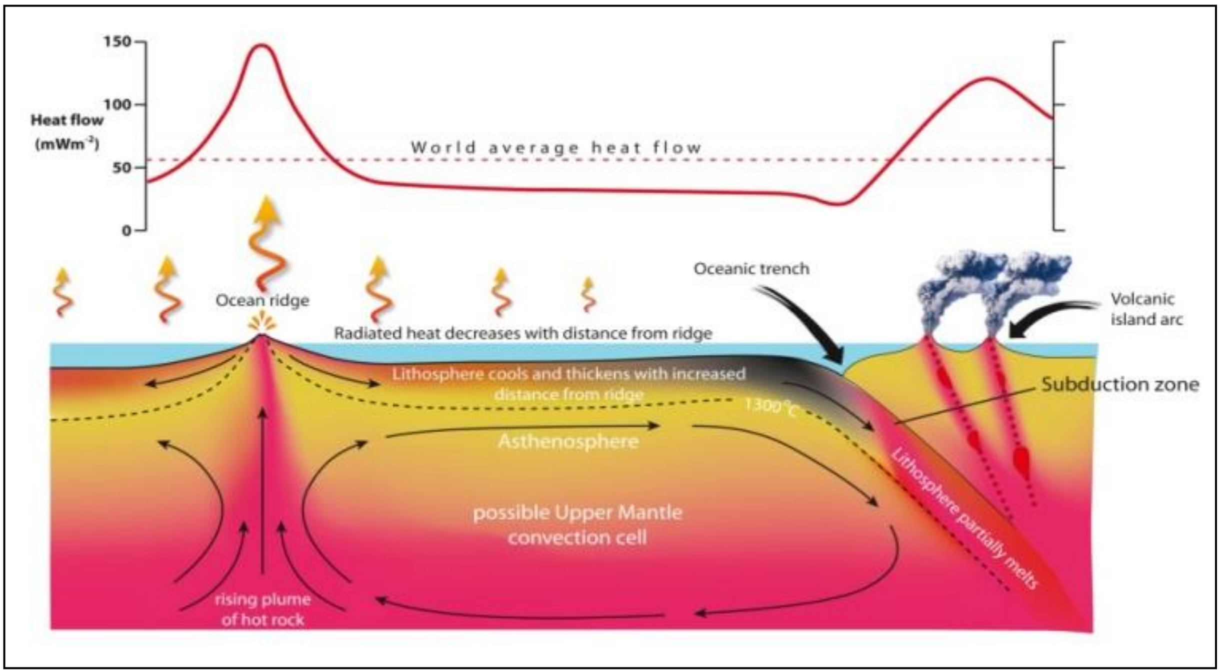
**Student practical or teacher demonstration:**
Teacher demonstration.

**Time needed to complete the activity:**
5 minutes.

**Preparation and set-up time:**
None, once the computer and PowerPoint are running.

**Resources:**
**'The Earth and plate tectonics' PowerPoint presentation.**

**Source of activity:**
Earth Science Education Unit, Keele University.





# Evidence from the age of the sea floor

**Activity:**
The PowerPoint 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*)
- Why there is so little old ocean (blue) (*A. It has mostly been subducted*).
- How you could work out rates of spreading from this map. (*A. Measure the distance from the centre of a red area (the spreading centre) to the edge of a dark blue area (which is 154 Ma old); then use the equation: speed = distance/time to calculate the spreading rate*).

**Student learning outcomes:**
Students will be able to:

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

**Student practical or teacher demonstration:**
Teacher demonstration.

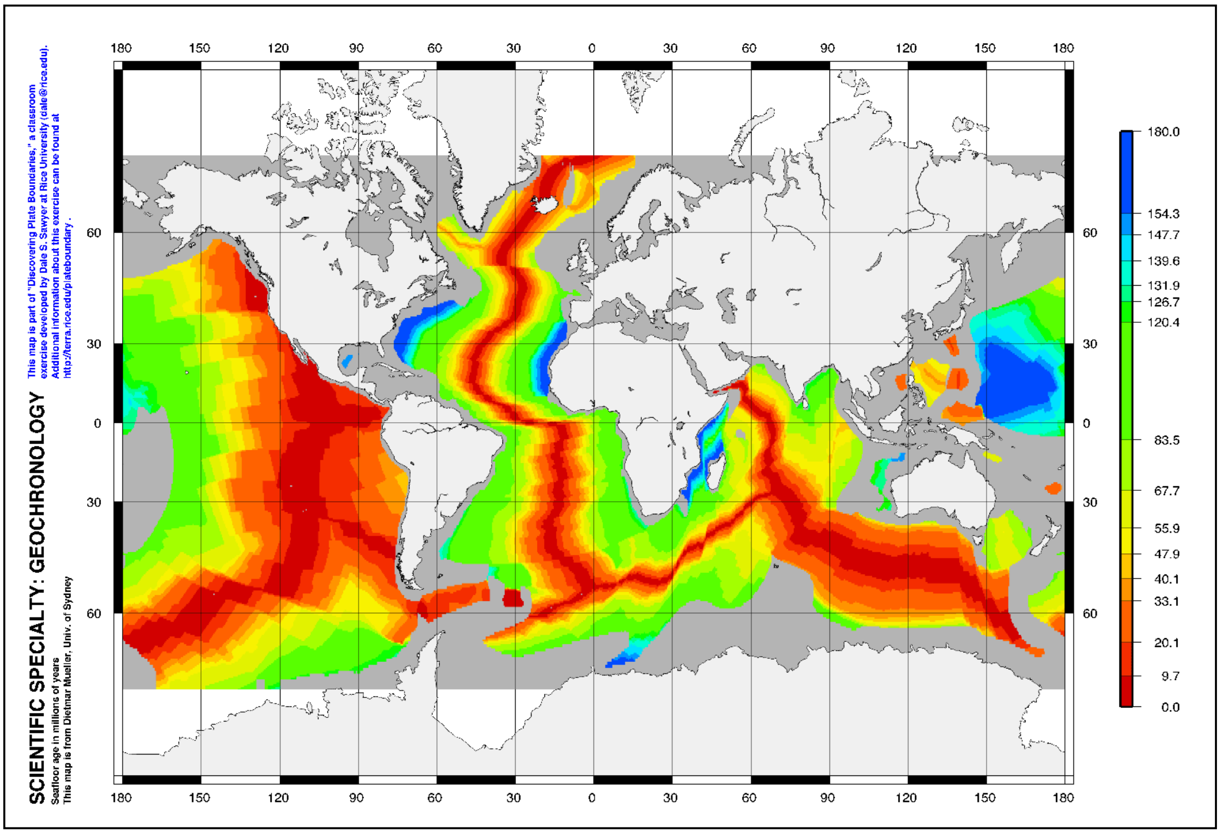
**Time needed to complete the activity:**
5 minutes.

**Preparation and set-up time:**
None, once the computer and PowerPoint are running.

**Resources:**

- **'The Earth and plate tectonics' PowerPoint presentation.**

**Source of activity:**
Earth Science Education Unit, Keele University.



# Constructive plate margins - adding new plate material

**Activity:**
The series of PowerPoint slides shows the processes active at a constructive (divergent) plate margin. The diagram shows:

- a rising mantle convection current;
- heating near the surface causing partial melting and magma to form;
- 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 in a topographic map of the Atlantic Ocean floor.

The following slides 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.

**Student learning outcomes:**
Students will be able to:

- explain the processes active at constructive plate margins.

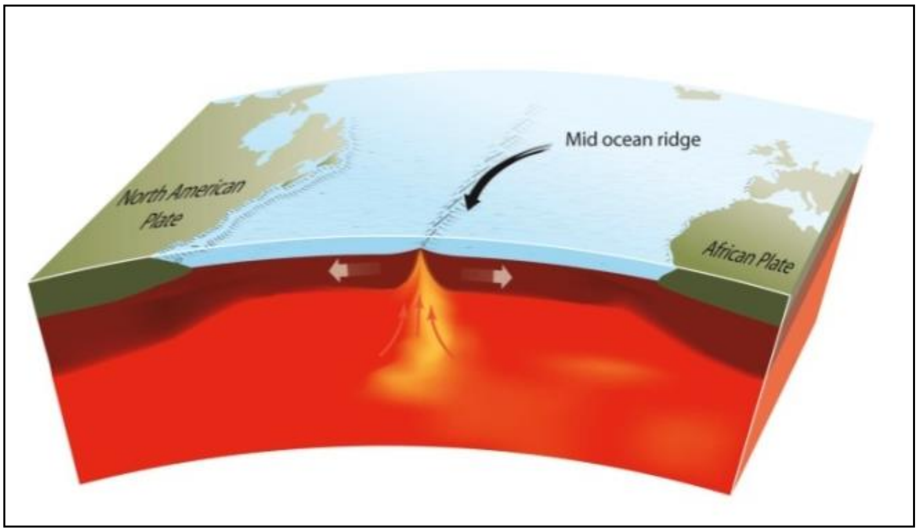
**Student practical or teacher demonstration:**
Teacher demonstration.

**Time needed to complete the activity:**
5 minutes.

**Preparation and set-up time:**
None, once the computer and PowerPoint are running.

**Resources:**
**'The Earth and plate tectonics' PowerPoint presentation.**

**Source of activity:**
Earth Science Education Unit, Keele University.





# Faults in a Mars™ Bar

**Activity:**
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.

**Student learning outcomes:**
Students will be able to:
- 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.

**Student practical or teacher demonstration:**
Teacher demonstration

**Time needed to complete the activity:**
2 minutes

**Preparation and set-up time:**
None

**Resources:**
One Mars™ Bar (any size!)

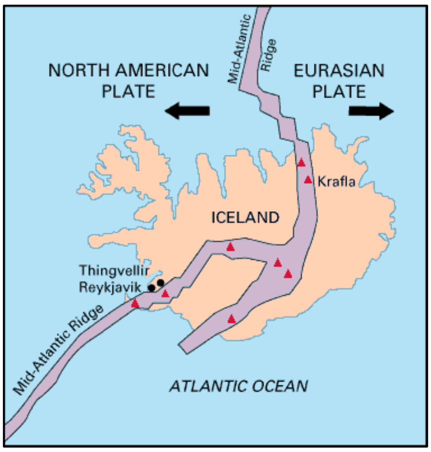
**Ideas for leading into the activity:**
Establish the layered nature of the Earth – crust, mantle, core, from seismic wave evidence. Explain that the crust and outermost mantle act together, to form the lithosphere and that it is the lithosphere which moves and not the crust alone. This brief activity 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.

**Ideas for following up the activity:**
Continue with other evidence for plate tectonics.

**Source of activity:**
Earth Science Education Unit, Keele University.

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

**Activity:**
Iron filings are used to demonstrate how a rock may be able to “hold” a magnetisation. A cardboard 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 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 page 65 at the end of this document).

Students 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 thin card or paper (e.g. 50 x 20cm) as shown in the diagram. This can be done by hand by drawing and colouring alternate stripes symmetrically 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 alternately, 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 as shown. 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. Continue *ad nauseam*.

Put the magnet well out of reach, 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 shaded sections are magnetised in the opposite direction to those in the un-shaded sections. This is analogous to the reversed polarity of magnetisation, acquired when the Earth’s magnetic field periodically reverses. (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).

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.

**Student learning outcomes:**
Students will be able to:
- 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.

**Pupil practical or teacher demonstration:**
Teacher demonstration

**Time needed to complete the activity:**
10 minutes

**Preparation and set-up time:**
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.

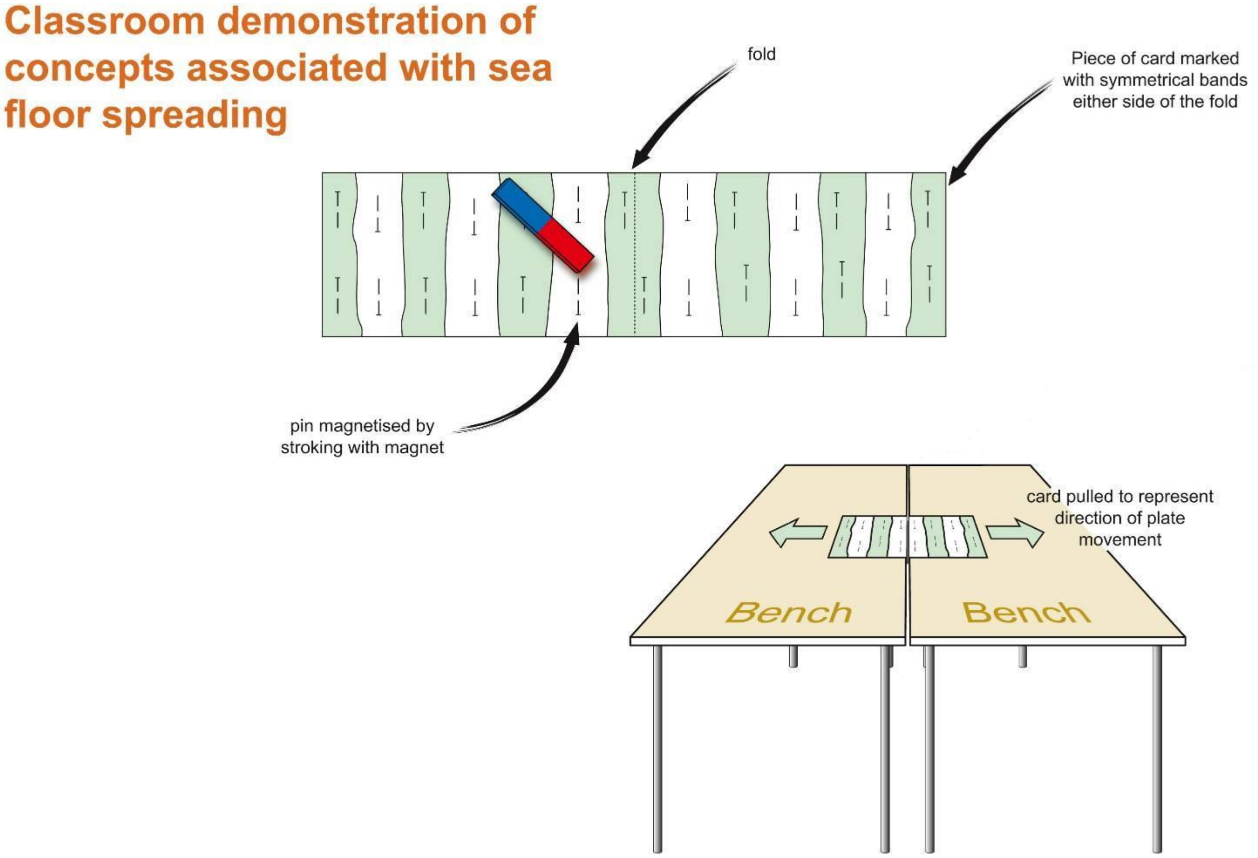

 

**Resources:**

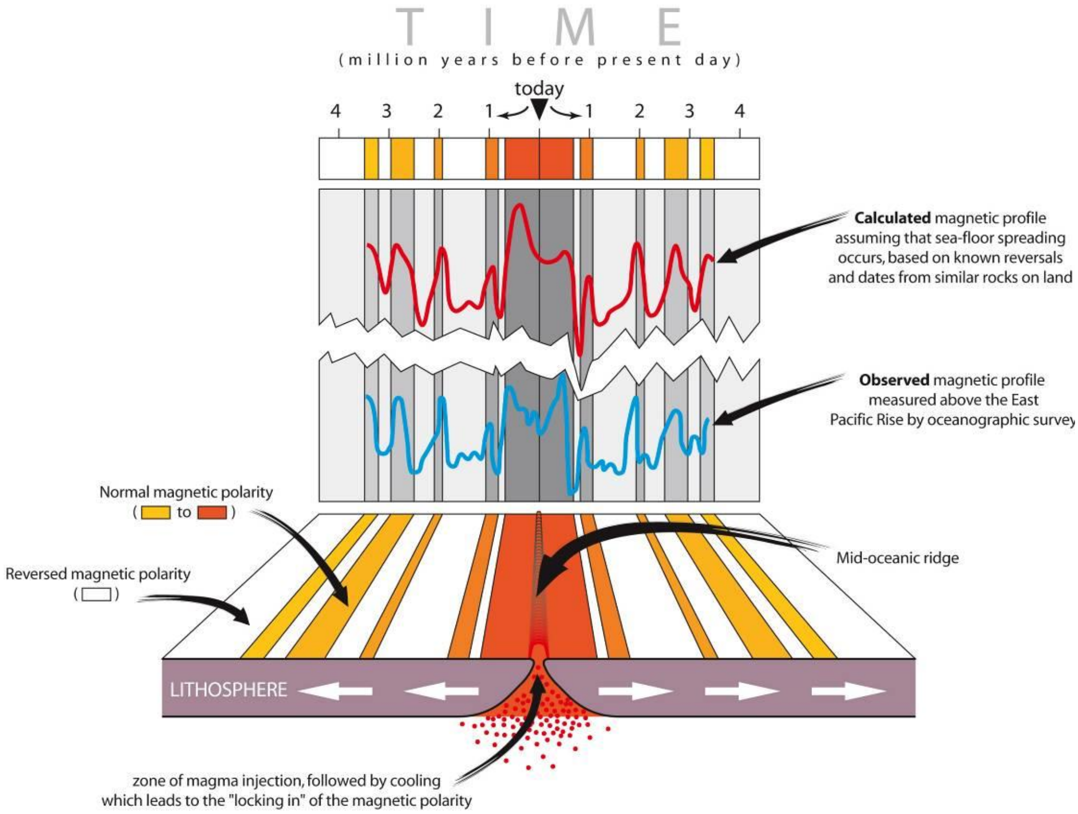
- bar magnet
- iron filings, *either* set in magnetic field orientation in wax in a petri dish, *or* in spray-on glue on paper
- sample of naturally magnetised, dark, igneous rock (e.g. gabbro, known as "black granite", from the waste skip at a worktop manufacturer or churchyard mason - optional).
- compass, eg. orienteering compass
- pins
- strip of paper with stripes
- access to a gap between two benches/desks, or piles of books etc. (see diagram)

**Ideas for leading into the activity:**
This can follow any other aspects of the nature of the oceanic ridges. It can also form part of the story of "How Science Works", in the context of Vine and Matthews' original hypothesis of 1963.

**Ideas for following up the activity:**
Continuing the story of the development of plate tectonics.

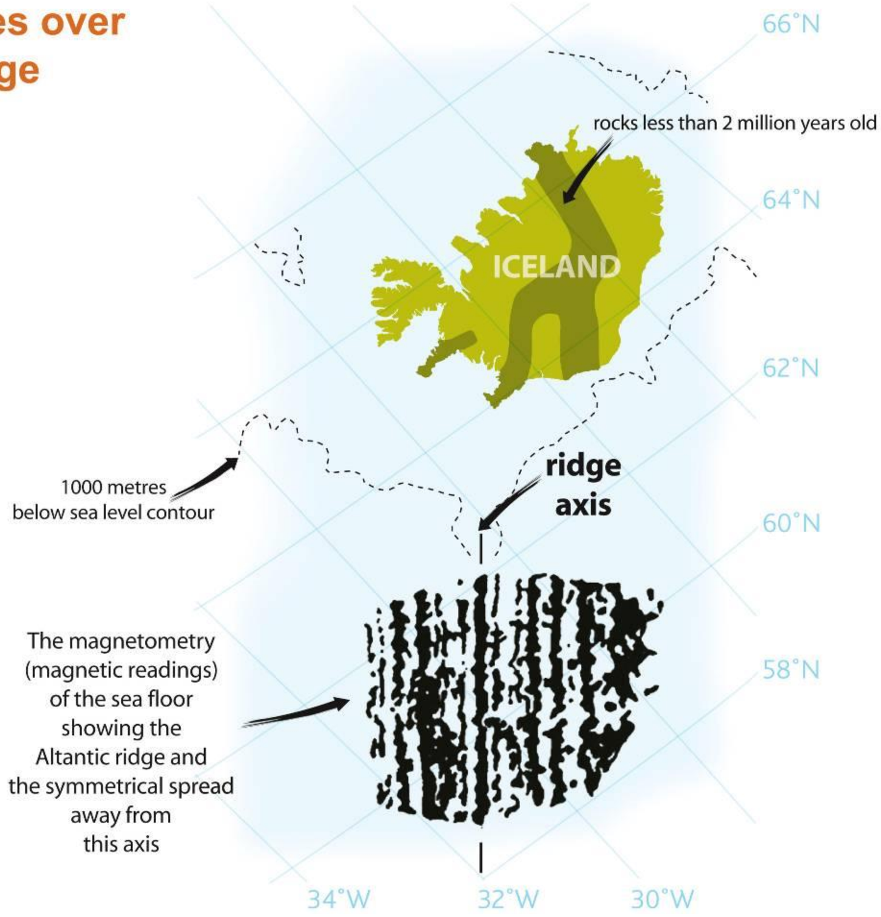


## Magnetic evidence for ocean floor spreading




## Magnetic anomalies over the Reykjanes Ridge

Black = positive anomaly
White = negative anomaly



# Destructive plate margins - recycling material

**Activity:**
A PowerPoint slide 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.

**Student learning outcomes:**
Students will be able to:

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

**Student practical or teacher demonstration:**
Teacher demonstration.

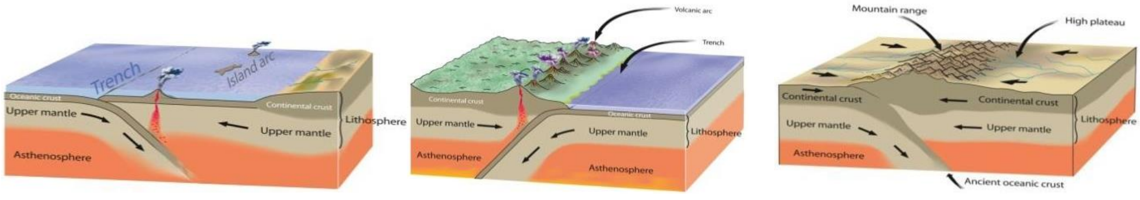
**Time needed to complete the activity:**
5 minutes.

**Preparation and set-up time:**
None, once the computer and PowerPoint are running.

**Resources:**

- **'The Earth and plate tectonics' PowerPoint presentation.**

**Source of activity:**
Earth Science Education Unit, Keele University.



# Partial Melting

**Activity:**
The partial melting processes is illustrated by a series of PowerPoint slides accompanied by a small beaker containing a mixture of a material that will melt (chopped candle wax) and a material that won't (gravel). The beaker is heated and the molten wax rises to the top to form a separate layer. In this way, the mixture has been chemically fractionated (the material of the top layer is different from the material of the bottom layer) due to the partial melting process.

Carry out a risk assessment (see page 65 at the end of this document).

Pour some gravel and some chopped wax into each beaker. Then gently heat one beaker, so that the wax melts and rises above the gravel, and allow it to set.

The beaker with the uniform mixture represents the rocks of the Earth's upper mantle, with a range of minerals of different melting points.

Raising the temperature of rocks causes the minerals with lower melting points to melt first, and to rise, producing igneous rocks with a different composition from the original material, as imitated in the second beaker. This happens at oceanic ridges where iron and magnesium-rich (silicon-poor) mantle rocks produce basaltic magmas. These have proportionately lower ratios of iron and magnesium (and more silicon) than the parent mantle rock. If the magma reaches the surface, it produces fine-grained *basalt* lava. If it sets just below ground, it produces medium-grained *dolerite*: cooling at greater depths results in coarse-grained *gabbro*.

Further partial melting of basaltic rocks at destructive margins and a range of other complex processes produces rocks which are even more deficient in iron and magnesium (and richer in silicon), called *andesites*. The eruptive style tends to be more violent and potentially catastrophic.

When oceanic plates are subducted beneath continents, not only does partial melting of the basaltic rocks produce andesitic magmas, but the base of the continents also partially melts, producing magmas even richer in silica. These are granitic magmas which, if they crystallise at depth, produce coarse-grained granite batholiths. If they rise to the surface, they cause very violent eruptions producing much silica-rich volcanic ash.

The sequence of slides illustrates these processes by reference to a square block of 100 squares, representing the mineral compositions of the different melts and rock types involved.

The partial melting of the wax versus gravel may be done in front of the class, or prepared in advance as a demonstration.

**Student learning outcomes:**
Students will be able to:
- describe how heating the wax/gravel mixture simulates partial melting of rocks;
- explain how partial melting produces magmas of different compositions from the original rocks;
- explain how different phases of partial melting produces rocks which are progressively richer in silica and poorer in iron and magnesium.

**Student practical or teacher demonstration:**
Teacher demonstration

**Time needed to complete the activity:**
a) if prepared in advance – about three minutes to explain what has happened.
b) if done in front of a class – about 15 minutes

**Preparation and set-up time:**
If prepared in advance – about 15 minutes.

**Resources:**
- two beakers, (250ml or smaller)
- chopped candle wax (preferably coloured) and gravel of roughly equal sizes with a ratio of 2 wax:1 gravel, enough to fill one-third of each beaker.
- demonstration samples of:
  • peridotite • basalt • dolerite • gabbro
  • andesite, if available.

**Ideas for leading into the activity:**
Consideration of plate boundaries – constructive beneath oceanic ridges and destructive beneath oceanic trenches.

**Ideas for following up the activity:**
Differences between magma types and styles of eruption at a range of plate boundaries.

'Partial Melting' © Chris King

**Source of activity:**
Earth Science Education Unit, Keele University.

**SCIENTIFIC ACCURACY**

- Whilst partial melting plays a major role in forming iron-rich magmas from mantle peridotite,
- and silica-rich magmas from lower crustal melting beneath continents,
- recent research has confirmed that the formation of andesitic magmas (neither silica nor iron-rich) is much more complex, and partial melting only plays a small part in the formation of some of them.

# Volcano in the Lab

**Activity:**
Demonstrate an eruption in a beaker, as follows. Carry out a risk assessment (see page 65 at the end of this document).
The beaker and its contents are placed on a tripod (with gauze) and heated fairly strongly over a Bunsen burner. Students watch attentively from behind a safety screen. They must not lose concentration, because the "eruption" often happens without much warning, other than an ominous crackling sound as the wax melts! The Bunsen is removed whilst there is still some wax left on the bottom of the beaker.

**Pupil practical or teacher demonstration:**
Teacher demonstration

**Time needed to complete the activity:**
10 minutes

**Preparation and set-up time:**
About 10 minutes to melt the wax into the bottom centimetre of the beaker and wait for it to cool and set, add another centimetre of clean sand, top up with cold water (and place in the fridge before the lesson - optional).

**Resources:**
- one 500ml glass beaker
- coloured candle wax
- clean sand
- cold water
- Bunsen, tripod, gauze, heatproof mat, gas supply, matches
- eye protection, or safety screen.

**Ideas for leading into the activity:**
Ask students what they expect to happen to the wax as it is heated. They are usually uncertain as to whether it will rise, or convect; how high it will rise; whether it will all reach the surface, or some set below it, etc.

**Ideas for following up the activity:**
- The sand and the water represent the crust of the Earth.
- The wax layer represents a layer deep in the Earth (the lower crust or mantle.)
- The mantle/lower crust is solid. It is being heated at a point source.
- When the wax melts, it rises, because of its lower density. It represents molten rock, known as **magma**.
- Some of the wax rises rapidly to the surface, imitating a volcanic eruption. It is very runny and spreads out evenly over the surface of the water (usually). This represents the way in which some **lavas** arising from fissure eruptions may cover huge areas, which are quantitatively more important than the better known individual volcanoes.
- Some of the wax can be seen rising through "tubes" of wax, which insulate it from the surrounding cold water and enable it to reach the surface. These conduits or feeder pipes form naturally too.
- Some of the wax sets very quickly in the cold water, forming grotesque shapes. These represent **intrusive igneous** rocks. Once the wax has all set, the top "lava layer" may be removed and the water poured off, in order to study the shapes of the "intrusions". This is equivalent to the removal of upper layers of rocks by weathering and erosion.
- Pupils can be challenged to say which aspects of the model are <u>not</u> consistent with the natural world. The most important one is that the surface eruption sets very slowly, whilst the "intrusion" sets very quickly. In reality, the reverse would be true, because of the higher ambient temperatures at depth and the insulating properties of several kilometres of overlying rock. Lavas may become solid within days, months or years, whereas a deep-seated intrusion of several tens of cubic kilometres may take millions of years to cool to the ambient temperature. Of course, the wax merely sets: it does not form crystals.
- Relate the model to plate tectonic theory.
- In reality, complete melting of rocks below ground is seldom achieved. Rocks partially melt, and the minerals of lowest melting points are the ones which melt first and rise (they are also the least dense minerals). See the activity "Partial melting".
- The properties of seismic waves in the Earth show that the mantle is generally solid. Within the upper mantle, the asthenosphere or 'weak layer' contains around about 5% of liquid, between the crystals of the rocks. Localised heating, and/or reduction in pressure, leads to partial melting, but the magma chambers which form are only tens of kilometres across, not mantle wide.
- Studies of the chemistry of igneous rocks show that partial melting of rocks produces three main types of magma, depending upon the nature of the tectonic plate boundary.

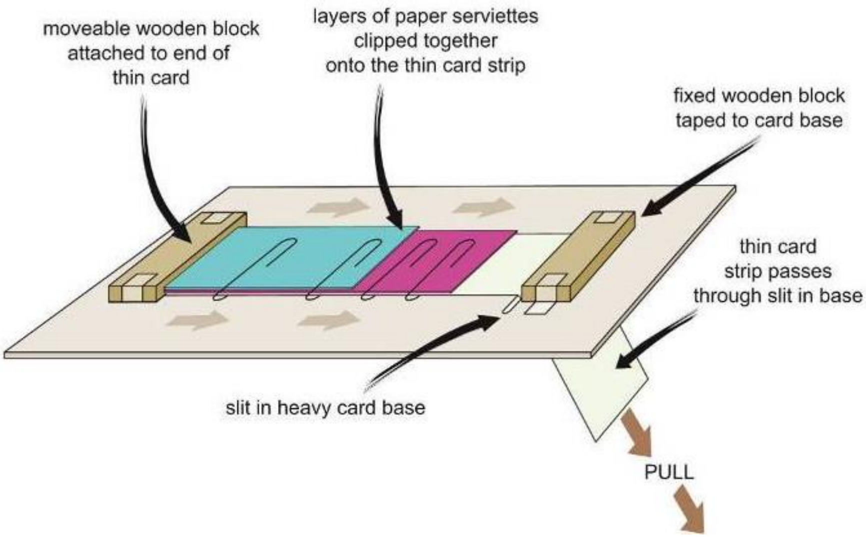
**Acknowledgements:**
The original idea for the wax volcano model came from Mike Tuke and is described in his *Earth Science Activities and Demonstrations*, published by John Murray.

The wax “volcano” after an eruptive event

# Plates in Motion – cardboard replica

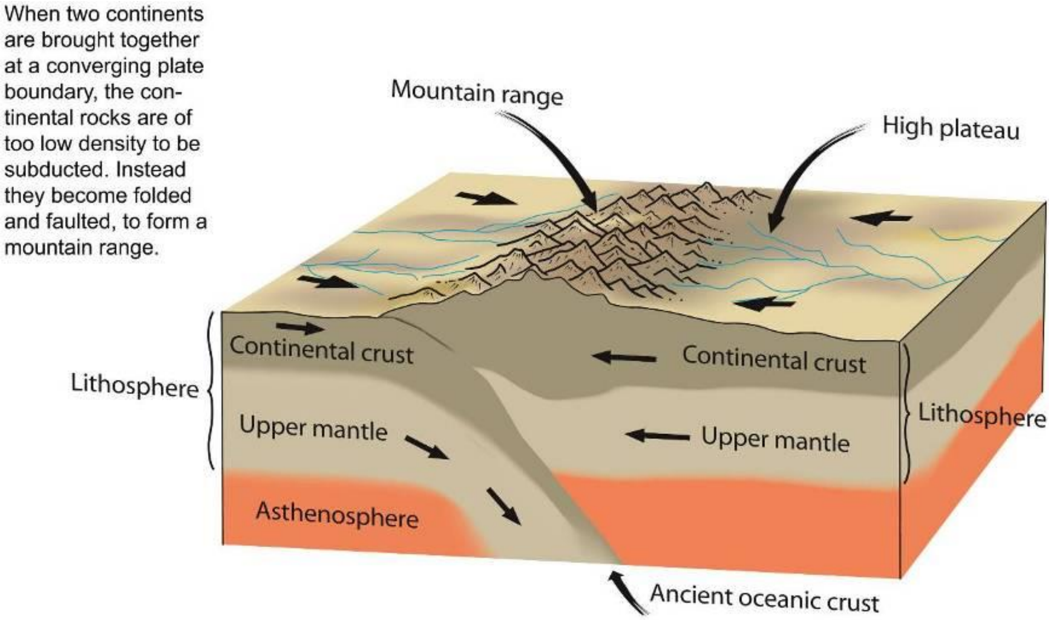
**Activity:**
**a) Subduction**
In this activity, subduction of a plate is modelled using cardboard.

Pulling on the thin card tag below the model causes 'subduction' of the card (of 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!).




© originally from the Earth Science Teachers' Association, SoE 2, Activity E7 'Plates in Motion', redrawn by ESEU

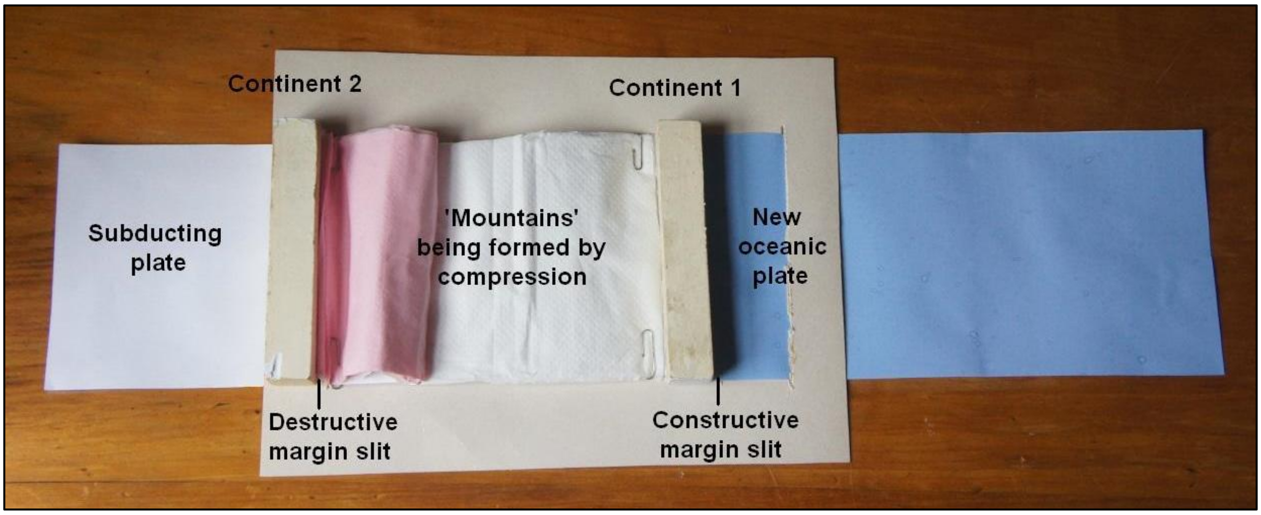
**Details of a continent to continent destructive plate boundary**

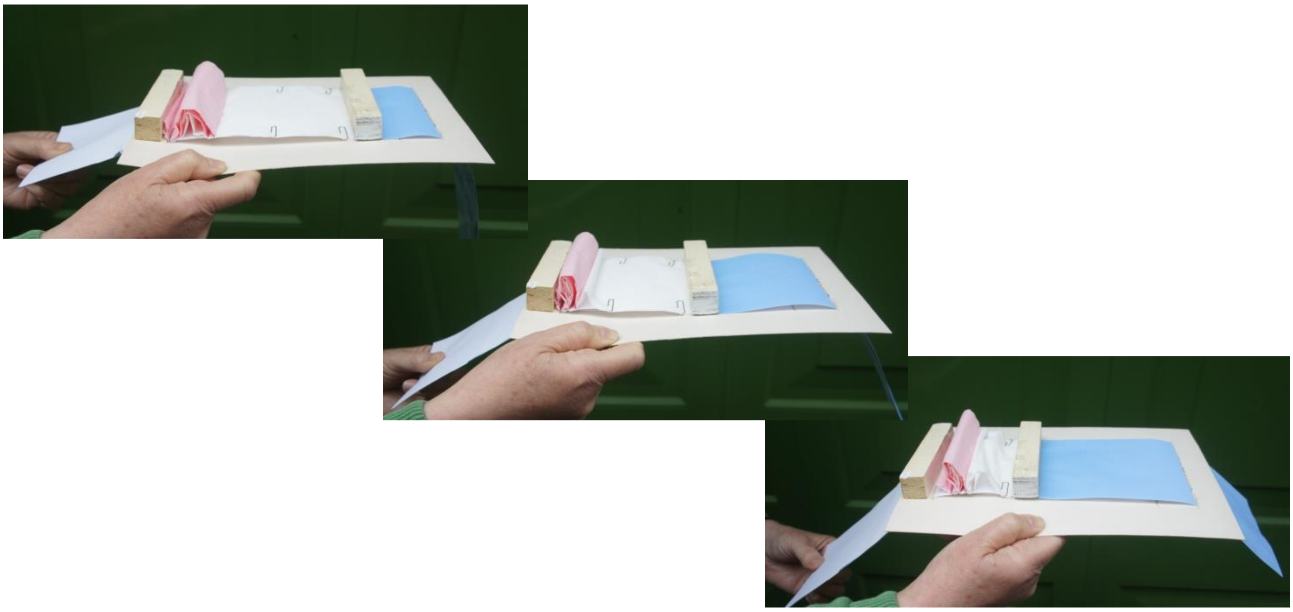



© originally from 'This Dynamic Earth: the Story of Plate Tectonics' by USGS redrawn by ESEU

**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.



**Student learning outcomes:**
Students will be able to:
- 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.

**Student practical or teacher demonstration:**
Student practical

**Time needed to complete the activity:**
3 minutes plus discussion

**Preparation and set-up time:**
30 minutes (made before the lesson, using diagram for guidance). No set up time in the lesson itself.

**Resources:**
'Plates in motion' model (see diagram), made from:

- cardboard
- A4 paper
- paper serviettes
- two small wooden blocks
- paper clips

**Ideas for leading into the activity:**
Outline of plate tectonic theory, leading to the nature of destructive plate margins.

**Ideas for following up the activity:**
Searching for plate margins on a world geological map.

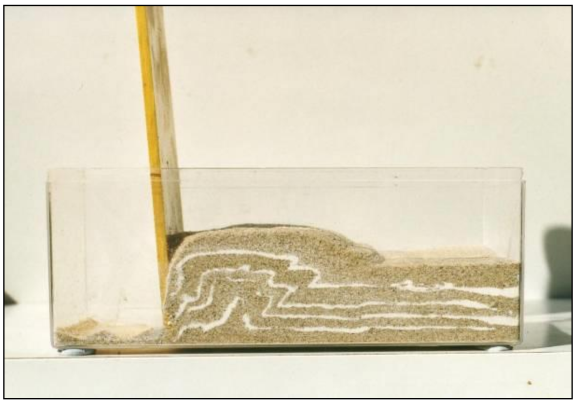
**Extension ideas for more able or faster pupils:**
Low density ocean floor sediments cannot go very far down a subduction zone into the mantle. Instead, they become 'welded' on to the continental margins. Such accretion has been estimated to take place at about 1.3 $km^3$ per year. Although much of 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.

**Source of activity:**
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.

# Fold Mountains in a Chocolate Box

**Activity:**
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 and allow the sand to be re-used more often before separating out the 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

**Student learning outcomes:**
Students will be able to:
- 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.

**Pupil practical or teacher demonstration:**
Either approach is possible, preferably as a student activity, involving about eight sets of materials. This activity is adapted from ESEU’s “Dynamic Rock Cycle” workshop, where more details are given.

**Time needed to complete the activity:**
10 minutes

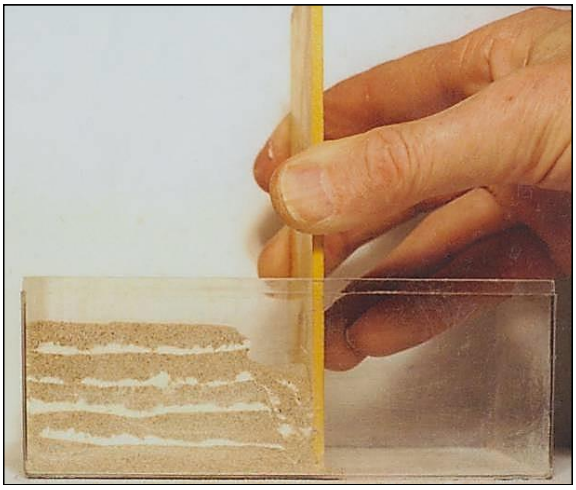
**Preparation and set-up time:**
Allow time to dispose of 8 boxes of Ferrero Rocher chocolates! Sand needs to be well dried out, and a piece of board must be cut for each box. All the materials can be used again, with the flour winnowed or sieved out of the sand after a few uses.

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

**Ideas for leading into the activity:**
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.

**Ideas for 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 cause by tension at spreading margins, as shown in the photograph below.


The “squeezebox” set up for tensional forces

**Source of activity:**
Earth Science Education Unit, Keele University

# Rate of Plate Movement

**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.

**Pupil practical or teacher demonstration:**
Student practical (paper)

**Time needed to complete the activity:**
10 minutes

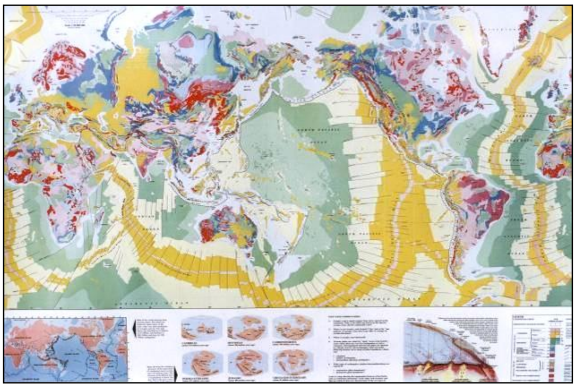
**Preparation and set-up time:**
None

**Resources:**
- Calculator
- Rule measuring in millimetres
- Geological map of the World, (1000mm x 660mm) published by The Open University. A copy of this map is left, free at each venue where the Earth Science Education Unit delivers a ‘The Earth and plate tectonics’ INSET session, thanks to a grant from the Curry Fund of the Geologists’ Association. Alternatively it may be purchased from ESTA at: contact@esta-uk.net Price £6.50 plus p&p. About three pupils can work on the map at one time, so the activity is best used as part of a circus, unless multiple copies of the map are available.

**Ideas for leading into the activity:**
Any aspect of the sea-floor spreading hypothesis

**Ideas for following up the activity:**
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.



The Geological Map of the World (O.U.)

# Plate Riding – how is the plate you live on moving now?

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

**Student learning outcomes:**
Students will be able to:

- relate plate tectonics to the environment in which they live.

**Student practical or teacher demonstration:**
Teacher or student demonstration**.**

**Time needed to complete the activity:**
5 minutes

**Preparation and set-up time:**
None

**Resources:**
None

**Ideas for leading into the activity:**
Presentation of plate tectonic theory

**Ideas for following up the activity:**
Considering how answers might differ for people riding different plates.

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

# Prediction of Earthquakes – 'Brickquake'

## a) a qualitative 'brickquake' demonstration

**Activity:**
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 (see page 65 at the end of this document).

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.

**Student learning outcomes:**
Students will be able to:
- describe how tension increases until the brick suddenly moves;
- explain how this related to similar processes causing earthquakes.

**Student practical or teacher demonstration:**
Teacher demonstration

**Time needed to complete the activity:**
10 minutes

**Preparation and set-up time:**
4 minutes

**Resources:**
- 4 clean house bricks, (one with string tied around it end to end)
- Newton meter, (e.g. 50N)
- elastic 'bungee' about 40 cm long (e.g. luggage bungee)
- G-clamp
- ruler

## b) a quantitative 'brickquake' demonstration

**Activity:**

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.

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

Carry out a risk assessment (see page 65 at the end of this document).

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.

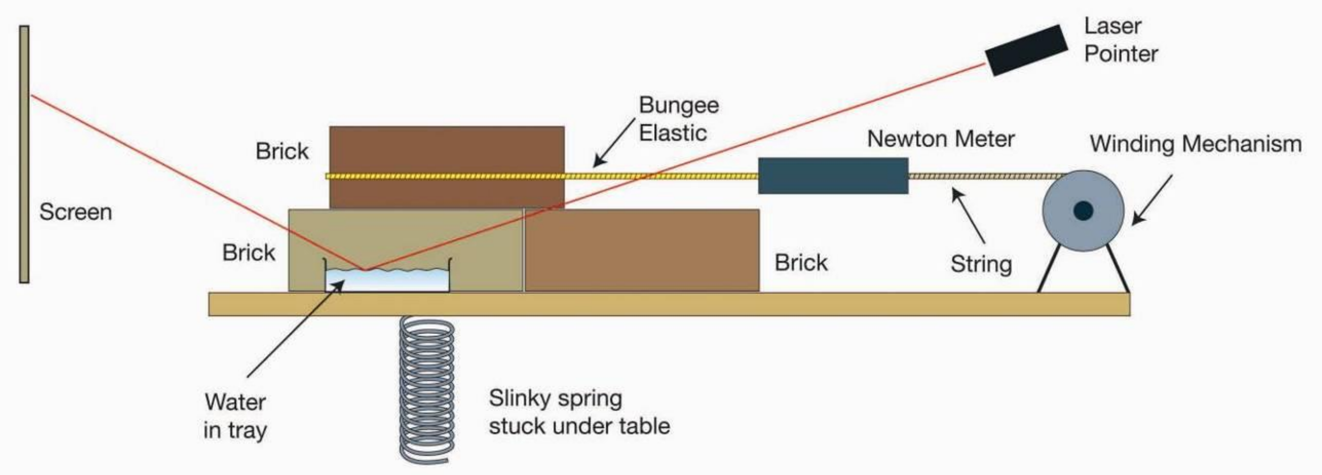


Diagram of apparatus for Brickquake © ESEU

**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 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.

**Student learning outcomes:**
Students will be able to:
- describe how 'earthquake' ruptures transfer energy to the surroundings in all dimensions;
- plot histograms of maximum force and slippage size and relate to different magnitudes of earthquakes;
- explain how difficult it is to predict exactly when an earthquake will occur and how big it will be.

**Student practical or teacher demonstration:**
Teacher demonstration mainly, or could be student practical, dependent on numbers and resources.

**Time needed to complete the activity:**
20 minutes

**Preparation and set-up time:**
20 minutes

**Resources:**
- 4 clean house bricks
- string, about 3 m long
- elastic ‘bungee’ about 40 cm 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
- a winding mechanism (e.g. pulley block) clamped to the table with a G-clamp (optional)
- slinky spring (optional)
- sticky tape (optional)

**Ideas for leading into the activity:**
The effect of earthquakes may have a worldwide impact (e.g. 2004 Boxing Day tsunami) but what is the underlying physics? This activity simulates earthquake movements and illustrates that energy is transferred.

**Underlying principles:**
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 ‘earthquake’ initiates forced oscillations of both P- (longitudinal) and S- (transverse) waves.

**Ideas for following up the activity:**
Carry out a web search into the frequency of earthquakes in known earthquake areas, e.g. http://tsunami.geo.ed.ac.uk/local-bin/quakes/mapscript/home.pl

**Extension ideas for more able or faster students:**
Investigate variations using more bricks in different arrangements e.g. piled on top of each other to discover the effect of increased vertical pressure. This relates to earthquakes generated at different depths within the crust.

Other variables can be changed, such as variations to the surface on which the bricks move.

**Source of activity:**
Based on the ESEU Brick Earthquake from ‘Prediction of Earthquakes’ in the ESEU workshop publication ‘*The Earth and Plate Tectonics’*.

# Tsunami – making waves

**Activity:**
This activity investigates the relationship between the velocity of the wave and the water depth in a "tsunami" created in a tank.

Students should:
- cover the bottom of the tank with water to a depth of about 10mm (use coloured water if possible);
- lift one end of the tank a few centimetres;
- put the end down again, returning the tray to the horizontal to make a wave;
- watch the wave and time how long the waves take to travel the full distance of the tray (start timing after the first reflection – more accurate readings are obtained by timing the travel time of several reflections and dividing by the number of reflections);
- take several readings;
- change the depth to, for example, 20 mm, and repeat the observations.

They will find, often to their surprise, that the deeper the water, the faster the wave. This is critical to the impact that tsunamis have on gently shallowing coastlines. As the wave approaches the coastline, fast-moving waves are slowed as the water shallows, causing them to build higher and higher, thus becoming more and more dangerous.

**Student learning outcomes:**
Students will be able to:
- describe how the speed of a tsunami-like wave depends upon the depth of water;
- explain how this affects the impact of tsunamis on shallowing coastlines.

**Pupil practical or teacher demonstration:**
Either

**Time needed to complete the activity:**
15 minutes

**Preparation and set-up time:**
A few minutes to assemble the materials.

**Resources:**
- flat-bottomed (ideally transparent) tank (or tray), e.g. a "wave tank" as used in other physics investigations in schools
- water (coloured if possible)
- prop to give the tray a slope (one end about 10cm off the desk)
- stop clock
- tape measure or ruler
- modelling clay (for extension work)

**Ideas for leading into the activity:**
Remind students of the disastrous tsunami in the Indian Ocean on Boxing Day, 2004 and its origins (sudden slippage along a major fault at the destructive plate margin displaced millions of tonnes of sea water, setting off a wave that crossed the Indian Ocean at speeds of several hundred kilometres per hour).

Students may be interested to hear the story of the 11 year old English girl on holiday with her parents in Phuket, Thailand when the Boxing Day tsunami struck. Two weeks before, her geography teacher had shown a video about the tsunami in Hawaii in 1946. She noticed that the sea was 'frothy' as she had seen in the video, realised the danger and managed to persuade her family and other tourists to leave the beach. Her story is told on the BBC News website:
http://news.bbc.co.uk/1/hi/uk/4229392.stm

Also remind students of the devastating tsunami that followed a major earthquake off Japan in March 2011. The earthquake was related to subduction of an oceanic plate beneath Japan.

**Ideas for following up the activity:**
Why were the effects of the tsunami worst when the wave hit sloping beaches, in contrast to cliffed coastlines? Use some modelling clay in the wave tank to find out.

Modelling a tsunami in a wave tank

# How to survive an earthquake

**Activity:**
This activity focuses on advice given to citizens on how to survive an earthquake in earthquake-prone areas.

Ask students what they think they should do if an earthquake should strike the area where they are sitting now.

What to do in an earthquake - The California Office of Emergency Services recommends:
- If indoors, bend down or lie on the floor, taking cover under a sturdy desk, table or other furniture. Hold on and be prepared to move with it, remaining in position until the ground stops shaking and it's safe to move. Avoid windows, fireplaces, wood stoves, heavy furniture or appliances. In a crowded area, take cover and stay put.
- If outside, get into the open, away from buildings, trees, lamp posts, power lines or signs.
- If driving, remain in your car. Stay away from bridges, tunnels, overpasses. Move your car out of traffic, but avoid stopping under trees, lamp posts, power lines or signs.
- In a mountainous area, or near unstable land, be alert to falling rock and debris that could be loosened by the earthquake.
- If you are at the beach, move to higher ground.

**Student learning outcomes:**
Students will be able to:
- describe the likely impact of an earthquake on the environment in which they are sitting;
- describe what to do, if the area is struck by an earthquake.

**Student practical or teacher demonstration:**
Teacher-led discussion

**Time needed to complete the activity**:
5 minutes

**Preparation and set-up time:**
None

**Resources:**
- The check list recommended by The California Office of Emergency Services, above.

**Ideas for leading into the activity:**
Ask if anyone has ever experienced an earthquake, e.g. on holiday.
Ask what students think kills people in an earthquake (they will usually mention falling into cracks in the ground, but this is rarely the case).

The main causes are falling roofs and other masonry, especially in developing countries with heavy clay bricks and tiles: fire resulting from ruptured gas pipes; lack of water to extinguish fires because of broken mains; spread of diseases such as cholera and typhoid through contaminated water supplies. Coastal areas can be devastated by tsunamis, generated by earthquakes, e.g. the Indian Ocean quake on Boxing Day 2004. These probably account for a bigger death toll than any other single cause.

**Ideas for following up the activity:**
Hold an “earthquake drill” in the classroom (This would be commonplace in schools in Japan).

Students may be interested to hear the story of the 11 year old English girl on holiday with her parents in Phuket, Thailand when the Boxing Day tsunami struck. Two weeks before, her geography teacher had shown a video about the tsunami in Hawaii in 1946. She noticed that the sea was ‘frothy’ as she had seen in the video, realised the danger and managed to persuade her family and other tourists to leave the beach. Her story is told on the BBC News website:
http://news.bbc.co.uk/1/hi/uk/4229392.stm

Carry out a web search for more details e.g. from UNIS (International Strategy for Disaster Reduction) website http://www.unisdr.org, or from http://www.doityourself.com/stry/duringearthquake

# Bulging Volcanoes

**Activity:**
This activity simulates the use of tiltmeters to measure the rise of magma within a volcano and the resulting bulging/tilting of the ground surface, as an aid to the possible prediction of an eruption.

Ask a student to inflate the balloon, gently!
Invite another student to measure the angle of tilt of the boards with reference to the water surface, whilst the boards are still tilted.

**Student learning outcomes:**
Students will be able to:
- describe how a tiltmeter made from a liquid lying horizontal in a container can be used to show the change in angle of the side of a volcano as it bulges prior to eruption.

**Pupil Practical or Teacher Demonstration:**
Either

**Time needed to complete the activity:**
5 minutes

**Preparation and set-up time:**
5 minutes.
Tape two boards together along one edge, and place near the edge of the bench.
Pour about 1cm depth of water into each container and add a few drops of colouring.
Place one container on each board, equidistant from the join, held in place by Blu Tac™. Place a balloon under the axis of the boards.

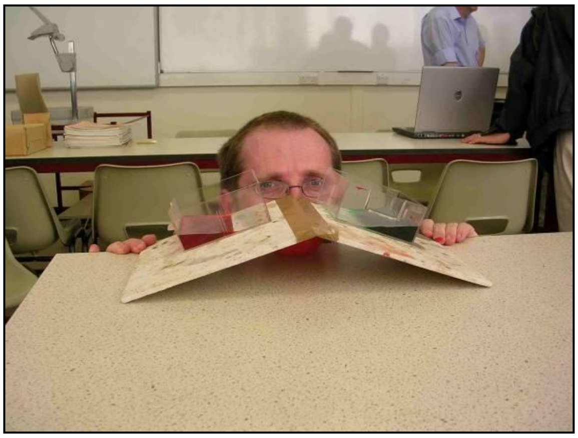
**Resources:**
- 2 heatproof mats, or similar rigid boards
- sticky tape
- balloon, preferably a long thin one
- 2 small containers for water, preferably rectangular in shape e.g. plastic component drawers. Glass beakers would do, but measurement of tilt angle is more difficult.
- Blu Tac™
- food colouring, or indicator
- protractor

**Ideas for leading into the activity:**
Introduce in the context of assessing geological hazards at any point in the study of plate tectonics and related topics.

**Ideas for following up the activity:**
Websearch for real data, try:
http://hvo.wr.usgs.gov/kilauea/update/main.html


Tilt meter in use in Montserrat

Discuss the reliance on one source of observations alone compared to using several different techniques, e.g. disaster on the Galeras volcano when gravity and gas emission data were being monitored at the summit of the volcano during a volcanological conference. Seismic tremors were not being interpreted (because the seismologist was away). The volcano erupted violently, killing Professor Geoff Brown of the Open University and several colleagues.


Imitating the inflation of a volcano with a balloon

# How Predictable are Volcanic Eruptions? – party popper simulation

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

Carry out a risk assessment (see page 65 at the end of this document).

Set up the party poppers in four clamp stands, as shown in the photograph, with books or pads of paper beneath the masses to catch them when they fall. Then invite four students 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 2000g 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

**Student learning outcomes:**
Students will be able to:
- reflect on the unpredictability of some natural processes in the light of the activity.

**Student practical or teacher demonstration:**
A teacher/student demonstration

**Time needed to complete the activity:**
10 minutes

**Preparation and set up time:**
3 minutes

**Resources:**
- 4 x clamp stands
- 4 x clamp bosses and arms
- 4 x party poppers
- 4 x mass hangers, each with 15 100g (1N masses)
- 4 x books or pads of paper for the masses to fall onto when the party poppers 'erupt'

Note: Be wary of falling masses.

**Ideas for leading into the activity:**
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.

**Ideas for 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 of activity:**
Earth Science Education Unit, Keele University.

# Resource List

Note: The activities that require no apparatus and materials are not included in this list.

| **Continental Jigsaws** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| "Jigsaws" | ✓ | |

| **Model Earth – Plasticine™ spheres** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| a pair of Plasticine ™ spheres per group of students | ✓ | |
| one pin per group | ✓ | |
| a sample of granite | ✓ | |
| optional balance, density can, or callipers - if quantitative work is planned | | ✓ |

| **From Magnetic Globe to Magnetic Rock Evidence** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| 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); <u>or</u> a magnetised needle suspended by thread | ✓ | |
| cocktail sticks or matchsticks (for extension) | ✓ | |

| **Geobattleships** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| Sets of sheets showing the distribution of volcanoes plus a blank map | | ✓ |
| Sets of sheets showing the distribution of earthquakes plus a blank map | | ✓ |

| **Earthquakes – the slinky simulation** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| A slinky spring | ✓ | |

| **Why are the Earth's tectonic plates called plates?** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| A chipped china plate | ✓ | |

| **Properties of the Mantle – potty putty™** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| Potty Putty™ (Silly Putty™) | ✓ | |

| **Faults in a Mars™ Bar** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| One Mars Bar ™ (any size!) | ✓ | |

| **The Magnetic Stripes Evidence** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| bar magnet | ✓ | |
| iron filings, *either* set in magnetic field orientation in wax in a petri dish, *or* in spray-on glue on paper | ✓ | |
| sample of naturally magnetised, dark, igneous rock | ✓ | |
| compass, e.g. orienteering compass | ✓ | |
| pins | ✓ | |
| strip of paper with stripes | ✓ | |
| access to a crack between two benches/desks, or piles of books etc. (see diagram) | | ✓ |

| **Partial Melting**<br>**Resource list:** | **Supplied By**<br>**Facilitator** | <br>**Institution** |
|---|---|---|
| two beakers, (250ml or smaller) | ✓ | |
| chopped candle wax (preferably coloured) and gravel of roughly equal sizes with a ratio of 2 wax:1 gravel, enough to fill one-third of each beaker | ✓ | |
| demonstration samples of: | | |
| basalt | ✓ | |
| dolerite | ✓ | |
| gabbro | ✓ | |
| andesite, if available | ✓ | |

| **Volcano in the Lab**<br>**Resource list:** | **Supplied By**<br>**Facilitator** | <br>**Institution** |
|---|---|---|
| one 500ml glass beaker | ✓ | |
| coloured candle wax | ✓ | |
| clean sand | ✓ | |
| cold water | | ✓ |
| Bunsen, tripod, gauze, heatproof mat, gas supply, matches | | ✓ |
| eye protection, or safety screen | | ✓ |

| **Plates in Motion – cardboard replica**<br>**Resource list:** "Plates in motion" model (see diagram), made from: | **Supplied By**<br>**Facilitator** | <br>**Institution** |
|---|---|---|
| cardboard | ✓ | |
| paper serviettes | ✓ | |
| two small wooden blocks | ✓ | |
| paper clips | ✓ | |

| **Fold Mountains in a Chocolate Box**<br>**Resource list:** | **Supplied By**<br>**Facilitator** | <br>**Institution** |
|---|---|---|
| transparent plastic box (e.g. Ferrero Rocher chocolate box or a component drawer) | ✓ | |
| spatula or dessertspoon | ✓ | |
| tray | ✓ | |
| a piece of board to fit snugly into the box eg. of hardboard or rigid plastic | ✓ | |
| 500g of dry fine sand | ✓ | |
| 25g of flour | ✓ | |
| a photograph of faulted rocks (optional) | ✓ | |

| **Rate of Plate Movement**<br>**Resource list:** | **Supplied By**<br>**Facilitator** | <br>**Institution** |
|---|---|---|
| Calculator | | ✓ |
| Rule measuring in millimetres | | ✓ |
| Geological map of the World (1000mm x 660mm) published by The Open University | ✓ | |

| **Prediction of Earthquakes – 'Brickquake'**<br>**Resource list:** | **Supplied By**<br>**Facilitator** | <br>**Institution** |
|---|---|---|
| a) | | |
| 4 house bricks, (one with string tied round it) | | ✓ |
| Newton meter | | ✓ |
| elastic rope (e.g. luggage bungee) | ✓ | |
| b) | | |
| 4 clean house bricks | | ✓ |

| | | |
|---|---|---|
| string, about 3 m long | | ✓ |
| elastic ‘bungee’ about 40 cm 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 | | ✓ |
| a winding mechanism (e.g. pulley block) clamped to the table with a G-clamp (optional) | | ✓ |
| slinky spring (optional) | | ✓ |
| sticky tape (optional) | | ✓ |

| **Tsunami – making waves** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| flat-bottomed (ideally transparent) tank (or tray), e.g. a “wave tank” as used in other physics investigations in schools | | ✓ |
| water | | ✓ |
| indicator liquid or food colouring | ✓ | |
| prop to give the tray a slope (one end about 10cm off the desk) | ✓ | |
| stop clock | | ✓ |
| tape measure or ruler | | ✓ |
| modelling clay (for extension work) | ✓ | |

| **How to Survive an Earthquake** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| The check list recommended by The California Office of Emergency Services | ✓ | |

| **Bulging Volcanoes** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| 2 heatproof mats, or similar rigid boards | | ✓ |
| sticky tape | | ✓ |
| balloon, preferably a long thin one | | ✓ |
| 2 small containers for water, preferably rectangular in shape e.g. plastic component drawers. Glass beakers would do, but measurement of tilt angle is more difficult. | | ✓ |
| food colouring, or indicator liquid | | ✓ |
| protractor | | ✓ |

| **How Predictable are Volcanic Eruptions?** | **Supplied By** | |
|---|---|---|
| **Resource list:** | **Facilitator** | **Institution** |
| 4 x clamp stands | | ✓ |
| 4 x clamp bosses and arms | | ✓ |
| 4 x party poppers | | ✓ |
| 4 x mass hangers, each with 15 100g (1N masses) | | ✓ |
| 4 x books or pads of paper for the masses to fall onto when the party poppers ‘erupt’ | | ✓ |

# Teaching points of ESEU Workshop activities

| Activity | Pattern (construction) | Challenge (cognitive conflict) | Explanation of thinking (metacognition) | Relevance (bridging) | Practical teaching points |
|---|---|---|---|---|---|
| What Wegener knew – and what he didn’t know | Recognising the pattern that Wegener saw | Seeking new hypotheses for the pattern seen<br>Considering why Wegener wasn’t believed | Explaining why Wegener wasn’t believed | Links between Wegener’s work and plate tectonics | |
| Continental Jigsaws | Reconstruction of the Pangaea map (or part of it) (based on movement from map of the world today) | How to use the information given on the various cut-outs | Discussion in groups | Where else do we find slabs of solid material moving about like this? (eg. solid lava on a lava lake, ice flows) | If you photocopy different jigsaw versions on to different colours of paper – they are much easier to sort afterwards. Cut out acetate versions can be used on an OHT. |
| Model Earth - Plasticine™ spheres | Formulating ideas to explain the mass/density difference | Developing ideas to ‘probe’ the ball to discover the reason for the differences in mass/density | Discussion with probing by teacher | Relating Plasticine™ ball ideas to real Earth ideas:<br>• probing with needle ≡ coring (≡ mosquito bite on an elephant)<br>• ultrasound ≡ seismic (shock) waves<br>• X-ray – not possible on Earth<br>• using a magnet – like using a compass to detect Earth’s field | Use different colours of Plasticine™ for different balls to make it easier to sort them later. |
| From Magnetic Globe to Magnetic Rock Evidence | Recognition of the magnetic pattern shown by the matchsticks/cocktail sticks | Finding the ‘Equator’ | | Linking between model and real Earths | Be sure to explain that the ‘bar magnet in the middle’ idea, although an early hypothesis, is on longer tenable |
| Geobattleships | Recognition of global earthquake/ volcano patterns | Seeking of patterns from incomplete data | | Link of global earthquake/ Volcano data to plate margins | Do not continue this after the patterns have been recognised |
| The earthquake distribution evidence | Recognition of global earthquake/ volcano patterns | | | | Two PowerPoint slides |

| Activity | Pattern (construction) | Challenge (cognitive conflict) | Explanation of thinking (metacognition) | Relevance (bridging) | Practical teaching points |
|---|---|---|---|---|---|
| Earthquakes – the slinky simulation | | Why can't S (shear) waves be transmitted through liquids? | | | White spots (Tippex™) on slinky show movement directions of individual particles. S-waves not transmitted through liquids because when the particles move sideways (shear) they don't bounce back. |
| Wave motion – student molecules | Recognition of the link between the model and reality | | | | |
| The seismic evidence for the structure of the Earth | The link between seismic velocities, as shown by a graph, and the Earth's structure | | | | PowerPoint slides |
| Why are the Earth's tectonic plates called plates? | | What are the similarities? | Discussion | | Both are broad but thin, rigid, brittle and curved with chipped 'active' edges. |
| Properties of the mantle – Potty Putty™ | | What affects how a solid responds to stress? | Discussion | What other solids behave like this (ice – tap with a hammer = rebound (elastic) hit harder – fracture, flows under pressure (glacier)) | The two controlling factors are amount of stress and amount of time. Temperature also has an effect |
| The heat flow evidence | How the heat flow evidence can be used to support plate tectonic theory | | | | PowerPoint slide |
| Evidence from the age of the sea floor | The pattern of ocean floors being younger at the centre and older at the margins | | | | PowerPoint slide |
| Constructive plate margins – adding new plate material | The features found at constructive plate margins in oceanic areas | | | | PowerPoint slides |
| Faults in a Mars™ Bar | Recognition of the similarities between the Mars Bar™ model and constructive plate margins | | | | |
| The Magnetic Stripes Evidence | | Why don't the 'real' magnetic stripes south of Iceland look like the black and white stripes of the model? | Discussion | | Stripes are formed by magnetism of lava flows |

| Activity | Pattern (construction) | Challenge (cognitive conflict) | Explanation of thinking (metacognition) | Relevance (bridging) | Practical teaching points |
|---|---|---|---|---|---|
| Destructive plate margins – recycling material | The features found at destructive plate margins | | | | PowerPoint slides linked to the effects of partial melting |
| Partial Melting | Understanding of the similarity between the wax/gravel model and partial melting of rocks | | | | |
| Volcano in the lab | Recognition of the link between the model and igneous activity | Considering similarities and differences | | Linking of the wax shapes produced to igneous processes and features | This works best if the water is cold from the fridge, but also works at room temperature |
| Plates in motion – cardboard replica | Recognition of the similarities between the cardboard replica model and destructive plate margins | What are the differences between the model and reality? | Discussion | | |
| Fold mountains in a chocolate box | Compression and tension produce different styles of faults | | | Similar things found in N. Wales with E-W axes. Explanation? Scotland hitting England and squeezing Wales. Gives some idea of the pressures involved. | Dry sand needed |
| Plate Animation - Britain's journey | | | | | |
| Rate of plate movement | | | | | |
| Plate riding – how is the plate you live on moving now? | | Linking the individual to a global pattern of movement | | | |
| Prediction of earthquakes – 'Brickquake' (3 bricks) | Recognition of the link between the model and how earthquakes occur | The unpredictability of the movement | Discussion of earthquake unpredictability | | |
| Tsunami – making waves | Spotting the pattern between depth and speed | | | Understanding of the effect a shallowing coastline will have on tsunami height and power | |
| How to survive an earthquake | | Linking to a real earthquake scenario | Discussion | | |
| Bulging volcanoes | Recognition of the link between the model and volcanic activity | | | | |
| How Predictable are Volcanic Eruptions? – party popper simulation | Anticipation that the greater the applied mass become, to more likely the party popper is to 'blow' (erupt) | The unpredictability of this activity | | Links from the party popper activity to the unpredictability of volcanic eruptions | |

# Risk Assessments

The ‘The Earth and Plate Tectonics ‘ activities not listed below have no recognised hazard associated with them.

| Potentially Hazardous Activity | Who/What may be Harmed? | Hazard Rating (A) | Likelihood (B) | Risk (AxB) | Further Action Required? |
|---|---|---|---|---|---|
| Model Earth - Plasticine™ spheres | If students push a pin into a Plasticine™ sphere, be sure they don’t do this on the palm of their hand, as the pin can go right through – then: | 1 | 1 | 1 | Ensure the students don’t push the pin into the Plasticine™ sphere while it is on the palm of their hands |
| The Magnetic Stripes Evidence | The pins used might stick into the students hands – then: | 1 | 1 | 1 | Ensure the pins used are covered by sticky tape |
| Partial melting | If done as a demonstration in class, there is the hazard of spillage of molten wax and of fire and burns from the gas burner – then: | 2 | 2 | 4 | Keep observers at least 2 m away, follow general advice on the use of gas burners: CLEAPSS Laboratory Handbook, section 9.10.2 |
| Volcano in the lab | If done as a demonstration in class, there is the hazard of spillage of water and molten wax and of fire and burns from the gas burner – then: | 2 | 2 | 4 | Keep observers at least 2 m away, follow general advice on the use of gas burners: CLEAPSS Laboratory Handbook, section 9.10.2 |
| Prediction of earthquakes – ‘Brickquake’ | There is a hazard that the brick might fall onto the demonstrator / students’ foot - then: | 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 |
| How Predictable are Volcanic Eruptions? – party popper simulation | The cardboard disk/contents from the party popper could fly into someone’s eye - then: The masses could fall onto the floor – then: | 1 | 1 | 1 | 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