Earth’s structure

Introduction

This topic explores the key concepts of Earth’s structure as they relate to:

- the structure of Earth
- movement of Earth’s crust
- earthquakes
- tsunamis • volcanoes
- rocks.

Key concepts of Earth’s structure

The activities in this topic are designed to explore the following key concepts:

- Earth is made up of layers: the core, mantle and crust.
- Earth’s crust is divided into plates that move like bricks over freshly laid mortar.
- Earth’s plate movements are responsible for earthquakes, tsunamis and volcanoes.
- Earth’s plate movements are responsible for the creation of mountain ranges.
- Soils on Earth are the result of weathering of rocks.
- There are three main categories of rock: igneous, metamorphic and sedimentary.
- Igneous rocks are formed through the cooling of magma.
- Sedimentary rocks are formed through compaction of sediment over an extended period of time.
- Metamorphic rocks result through the transformation of other rocks by heat and pressure processes that occur below Earth’s surface.
- Minerals are the building blocks of rocks.

Students' alternative conceptions of Earth's structure

Research into students' ideas about this topic has identified the following non-scientific conceptions:

- The location of earthquakes is random.
- Continents don't move.
- Earth is molten, except for its crust.
- Most of the world's most spectacular scenery was created by cataclysmic events.
- An earthquake measuring 6.5 on the Richter scale is one time more powerful than an earthquake measuring 5.5.
- Rocks stay the same forever.
- Earthquakes cannot happen where I live.
- The biggest danger of a volcano such as Mount St Helens is the hot lava.
- Any crystal that scratches glass is a diamond.
- Rocks must be heavy.
- Soil must have always been in its present form.
- Mountains are created rapidly.
- Earth's gravitational attraction is drastically reduced on mountaintops.
- Boiling or burning radioactive material can reduce the radiation emanating from the material.
- All radioactivity is man-made.

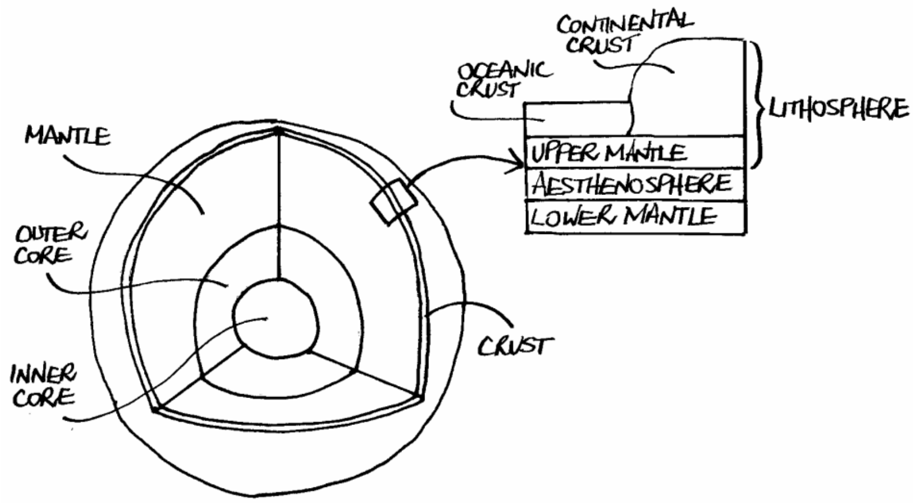
The structure of Earth

Earth's inside structure is quite different to its hard, crusty shell. We sometimes get a glimpse of Earth's interior through the action of active volcanoes. Earth's rocky crust is by no means stationary and we regularly see evidence of crust movement in the form of earthquakes. Earthquakes in ocean regions produce destructive ocean waves called 'tsunamis'.

The universal acceptance of plate tectonic theory is recognised as a major milestone in the earth sciences. It is comparable to the revolution caused by Darwin's theory of evolution or Einstein's theories about motion and gravity. Plate tectonics provide a framework for interpreting the composition, structure and internal processes of Earth on a global scale.

Earth is made of three concentric layers: the core, mantle and crust. Each layer has its own chemical composition and properties (see Figure 1).

FIGURE 1: INTERIOR STRUCTURE OF EARTH

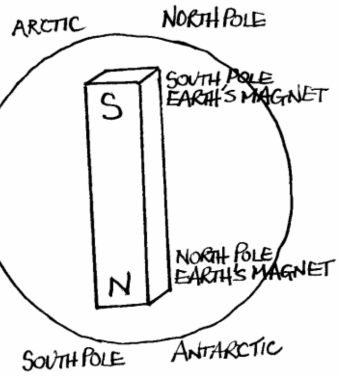


Core

The core has two layers: an inner core that is solid and an outer core that is liquid. The core is mostly iron, with some nickel and takes up 16% of Earth's total volume. The metallic core accounts for Earth's magnetic field. Earth behaves as though it has a simple straight bar magnet at its centre, with the 'south' pole just below Canada and the 'north' pole opposite, not quite coincident with the geographical poles (see Figure 2). A compass needle's 'north' pole points northwards; because 'unlike' poles attract, Earth's magnetic pole in the Arctic must be the opposite type, 'south'. It is thought that streams of liquid metal within the outer core, combined with Earth's rotation, cause the magnetism. The strength of the magnetism may change from decade to decade and, over the period of 500 000 years, the magnetism reverses completely. This means that over the next 500 000 years, compasses will point south!

Evidence of Earth's change in magnetic polarity (direction of north–south line of magnetism) is found in the rocks. Scientists have found that rocks within Earth's crust formed at different times. Within some rocks there are small particles of magnetite that are magnetic and, when the rocks were formed, these magnetite particles aligned themselves with Earth's magnetic field. As the rocks cooled, the direction of the particles' magnetic polarity was fixed. Therefore, by knowing the age of a rock and the magnetic polarity of the magnetite particles within it, we can determine the magnetic polarity and Earth's strength in times past.

FIGURE 2: EARTH AS A MAGNET



Mantle

The mantle is the thickest of Earth's layers and takes up 83% of Earth's volume. It extends down to about 2900 km from the crust to Earth's core and is largely composed of a dark, dense, igneous rock called 'peridotite', containing iron and magnesium. The mantle has three distinct layers: a lower, solid layer; the asthenosphere, which behaves plastically and flows slowly; and a solid upper layer. Partial melting within the asthenosphere generates magma (molten material), some of which rises to the surface because it is less dense than the surrounding material. The upper mantle and the crust make up the lithosphere, which is broken up into pieces called 'plates', which move over the asthenosphere. The interaction of these plates is responsible for earthquakes, volcanic eruptions and the formation of mountain ranges and ocean basins. The section on plate tectonic theory later in this topic explains the occurrence of these events further.

Crust

The Earth's crust is the outermost layer, consisting mainly of the chemical elements silicon and aluminium. The crust has two types: a continental crust that varies in thickness between 20 km and 90 km, and an oceanic crust that varies in thickness between 5 km and 10 km. The oceanic crust is denser than the continental crust.

The following activity provides a picture of the relative size of Earth's interior and atmospheric components.

ACTIVITY: FROM THE CENTRE OF EARTH TO OUTER SPACE

This activity creates a linear model to help you get some idea of the size of Earth, the thickness of its interior layers and the various layers of its atmosphere.

You will need:

- **a roll of toilet paper**
- **some Post-it notes.**

In this activity, 1 cm on the toilet paper represents a distance of 10 km. A sheet of toilet paper is about 11 cm long, so this represents a distance of 110 km.

Lay the toilet paper out on the floor. At one end of the paper place a label for the centre of Earth. Place labels along the paper according to the table below.

Layer of Earth	Distance (km)	Distance (sheets of toilet paper)
centre of Earth	0	0
edge of inner core	635	6
edge of outer core	2200	20.5
edge of mantle	2900	25
surface of Earth	2940	25 + 4 cm
edge of troposphere	2955	25 + 5.5 cm
edge of stratosphere	2990	25 + 9 cm
edge of ionosphere	3640	33
edge of exosphere	4290	39
outer space	> 4290	place next to last note

The space shuttle and the international space station orbit Earth at a height of about 700 km above Earth's surface. Are these spacecraft in outer space? I find it surprising that the thickness of Earth's crust and atmosphere are quite small in comparison to the size of Earth.

The temperature of the material in Earth's interior increases with depth, as the table below illustrates. Heat is transferred to Earth's surface by convection (liquid layers) and conduction (solid layers). Convection is where the hot material, in this case the liquid magma, moves from a lower layer to a higher one. Conduction is heat transfer where the actual hot material, in this case the rock, does not move. For example, conduction occurs along a metal bar if one end is held in a flame.

Section	**Depth (km)**	**Temperature (°C)**
upper mantle (top)	50	800
upper mantle (bottom)	1000	3300
lower mantle	2000	2225
mantle core boundary	2900	2500

centre	6371	3000

Movement of Earth's crust

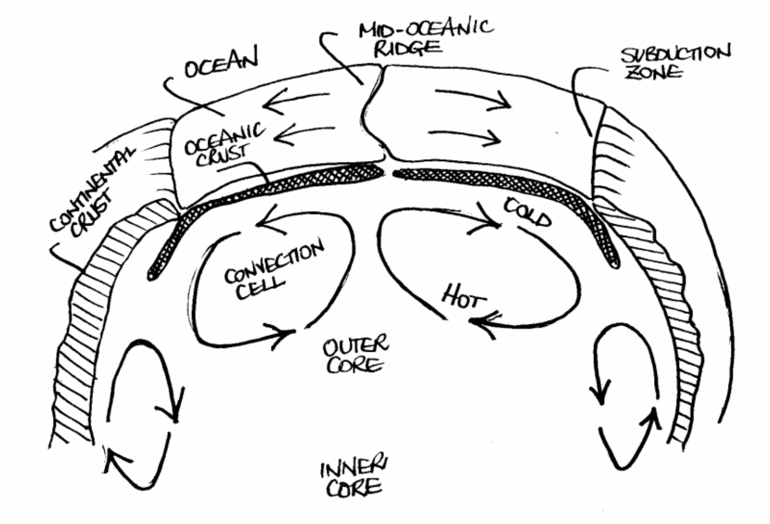
Plate tectonic theory

Plate tectonic theory is a theory developed in the 1910s by a German meteorologist, Alfred Wegener, who amassed a tremendous amount of geological, paleontological and climatological data that indicated continents moved through time. He proposed the hypothesis of 'continental drift' to explain his data. However, Wegener's theory was not accepted at the time because it could not account for a mechanism by which the huge continental masses move; evidence of a possible mechanism was not found until the 1950s and 1960s. Plate tectonic theory is now universally accepted. The significance of this theory is enormous when you consider that it can account for many seemingly unrelated geological features and events.

According to plate tectonic theory, the lithosphere is divided into about a dozen rigid sections, called 'plates', which move over the asthenosphere, the part of the mantle that behaves plastically and flows slowly (imagine bricks moving over freshly laid mortar). Refer to one of the websites listed in the section 'Resources' in this topic to view how Earth's surface divides into plates and why they are referred to as 'continental plates'.

The mechanism responsible for the movement of Earth's plates is thought to be convection cells within Earth's mantle. Convection cells are convection currents that occur when warm material from deep within Earth rises towards the surface, cools, and then, upon losing heat, descends back into the interior. Hot material rises because it is less dense (amount of material per volume) than the colder material. The cycle then begins again with hot material rising. This results in loops of moving material that form convection cells. The direction of the top of the convection current determines in which direction the overriding plate moves (see Figure 3).

FIGURE 3:
CONVECTION CELLS BENEATH EARTH'S PLATES



Zones of volcanic activity, earthquake activity, mountain ranges and oceanic ridges mark plate boundaries. Along these boundaries, plates diverge, converge, or slide sideways past each other. Based on adjoining convection cells (see Figure 4) we can see how plates can sometimes converge and other times diverge (see Figure 4).

Divergent plate boundaries

Plates move apart as magma rises to the surface from the asthenosphere. These boundaries occur in the oceans at oceanic ridges. As the plates separate, the gap is continually being filled by magma (molten rock), which solidifies to form rock and then attaches to the moving plates. The phenomenon of sea-floor spreading occurs at different rates. For example, in the Atlantic the spreading is at a rate of 2 cm per year, whereas in the east Pacific the rate is 4 cm of new crust every year.

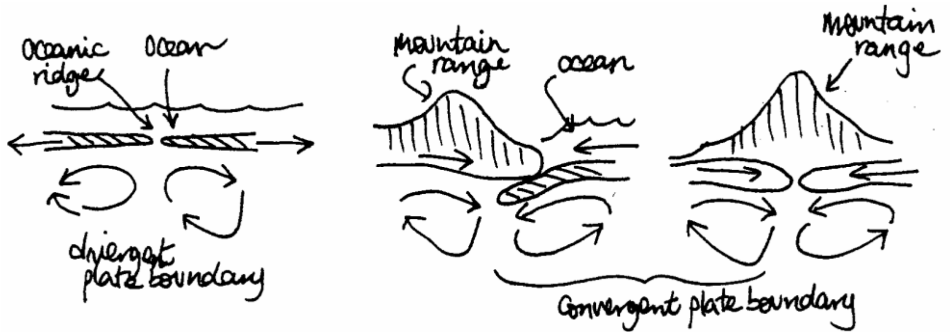
Convergent plate boundaries

One plate sinks beneath another plate (called 'subduction') along a subduction zone. The leading edges of the colliding plates may both be oceanic, or one plate may be oceanic (and will be the sinking plate) and the other continental, or both plates may be continental. Where oceanic plates collide, deep trenches in the ocean occur. As the plate descends it melts to generate magma. As this magma rises, it may erupt at Earth's surface, forming a chain of volcanoes. Where continental plates collide, mountain ranges such as the Himalayas arise. Mountain chains are also formed where one of the plates is continental and the other is oceanic.

Transform plate boundaries

Plates slide sideways past each other. The San Andreas Fault in California is a transform plate boundary separating the Pacific plate and North American plate. Sliding plates build up pressure in certain places, causing the sudden movement of plates to release the pressure. The sudden movements of plates are earthquakes.

FIGURE 4: PLATE BOUNDARIES



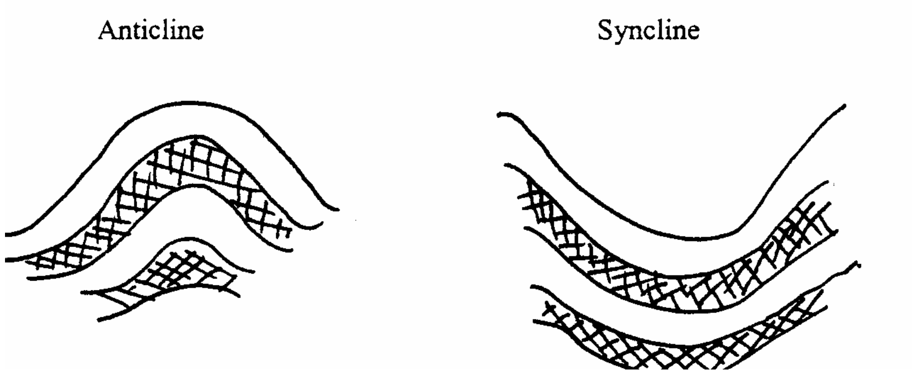
There is a substantial amount of evidence in support of plate tectonic theory. This includes the following facts:

- Shorelines of different continents fit together.
- The same type of rocks and fossils are at different places on Earth.
- The age of rocks can be determined; rocks in the ocean ridges are young and get older with distance from the ridges.
- The rock bed of the oceans has magnetic material imprinted with the magnetic polarity of Earth in ancient times.
- Precise measurements of continental positions by satellites have verified continental drift.

Folds and faults

The movement of Earth's crust creates pressures in certain regions of rocks. Where pressure is slowly applied to rocks, they bend. If the temperature and pressure are high, as at great depths, the rocks bend fairly easily. The bending in the rocks creates folds. There are two main types of folds: upward folds and downward folds. The upward folds are called 'anticlines' and the downward folds are called 'synclines' (see Figure 5).

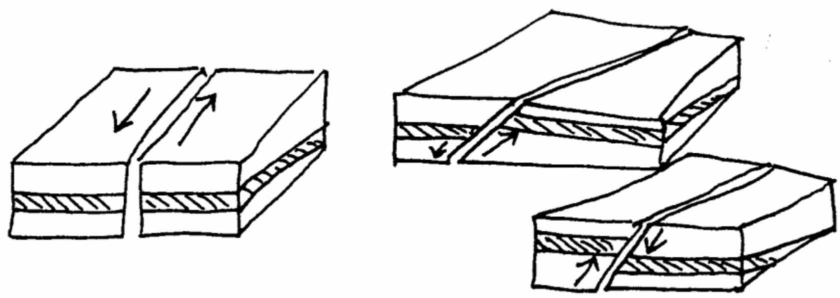
FIGURE 5:



TYPES OF FOLDS

Under different conditions, instead of bending, rock can break and change position. Continued pressure causes movement along some cracks. Such cracks, along which the rocks move, are called ‘faults’. Faults can vary in the way blocks of earth move relative to each other. Blocks can move over or under each other, or move sideways to each other (see Figure 6).

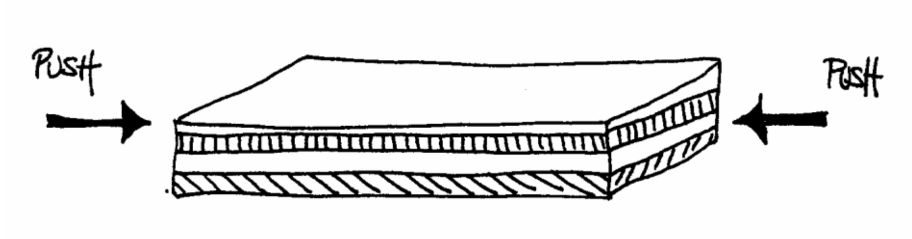
FIGURE 6: TYPES OF FAULTS



ACTIVITY: MAKING A FOLD MOUNTAIN

Mountains are formed when plates slowly push together and cause layers of rock to fold upwards. You will need three or four flat rectangles of modelling clay (alternatively, you could use layers of dishcloths). Press the rectangles of clay on top of each other. Now push the ends inwards and observe what happens (see the figure below). What mountain ranges of the world do you think formed when tectonic plates bumped into each other?

FIGURE:
MOUNTAIN
MODEL



Earthquakes

The earthquake in India in 2001 demonstrated the immense destructive power earthquakes can have. More than 900 000 earthquakes are recorded around the world each year. While scientists have found out a lot about earthquakes, they have not as yet been able to predict the precise location, time or intensity of an earthquake. Most earthquakes (almost 95%) take place in belts where stresses between plate boundaries occur.

An earthquake is the vibration of Earth caused by the sudden release of energy, usually located at a fault that involves the movement of blocks of rock along fractures. Following an earthquake there are usually adjustments along a fault line, which generate a series of smaller earthquakes called ‘aftershocks’. Aftershocks usually continue for a few days after the initial earthquake but may persist for months.

ACTIVITY: WHERE ON EARTH DO EARTHQUAKES OCCUR?

You will need a photocopied map of the world. Based on an Internet search (try some of the sites listed in the section 'Resources' in this topic), mark the location of earthquakes from last year on your map in blue. Mark in the location of current earthquake activity using the colour red. What similarities and differences do you find? Do you find any relationship between the occurrence of earthquakes and the location where continental plates meet (refer to the section on plate tectonic theory earlier in this topic). Outline maps suitable for hand plotting earthquake locations can be obtained at <http://wwwneic.cr.usgs.gov/neis/education/maps.html>.

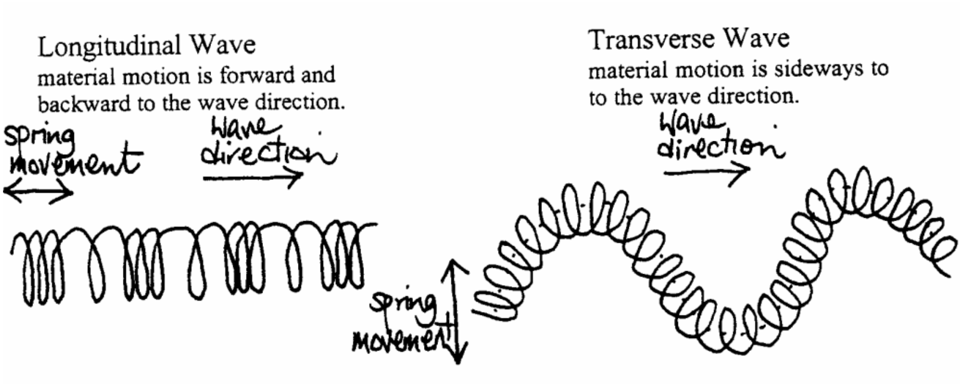
Seismic waves

Earthquakes send out vibrations, called 'seismic waves', within Earth in all directions. Some vibrations can be detected many kilometres away, even on the other side of Earth. There are three main types of travelling disturbances, or waves, that travel out from the site, or epicentre, of an earthquake: surface waves, P (primary) waves and S (secondary) waves. A wave is a disturbance, or vibration, that travels through a material (solid, liquid or gas) without the actual material moving along with the travelling disturbance. Waves in a material can be generated in two basic ways: as a longitudinal wave and a transverse wave. In a longitudinal wave the material in which the wave travels moves forwards and backwards to the direction of the wave. In a transverse wave the material moves perpendicularly to the wave direction (see the activity *Investigating waves on a slinky*).

ACTIVITY: INVESTIGATING WAVES ON A SLINKY

You will need a long helical spring, sometimes called a 'slinky'. On a linoleum or wooden floor, stretch the slinky between two people. One person holds the slinky steady and the other person makes a vibration. The vibration can be either a sideways motion or a forwards-and-backwards motion. Observe the different types of waves that travel along the spring. Where a sideways movement occurs in the spring the wave is a transverse wave. Where the movement of the spring is forwards and backwards, the wave produced is a longitudinal wave (see the figure *Types of waves*). Sound is a phenomenon that produces longitudinal waves, whereas waves on the surface of water are transverse waves.

FIGURE:
TYPES OF WAVES



P waves

These waves are longitudinal waves and are similar to sound waves. P waves can move through solids, liquids and gases. P waves are primary waves and are the fastest of the seismic wave types.

S waves

These waves are transverse waves. S waves are slower than P waves and can only move through solids. S waves are secondary waves, as they are slower than primary waves.

Surface waves

As their name suggests, these waves travel on the surface of a material rather than through it. They are transverse waves. There are several types of surface waves; the most common are called ‘R (Raleigh) waves’ and ‘L (Love) waves’. R waves travel like surface water waves, where the material moves up and down (vertically) as the wave passes, whereas in L waves material moves sideways (horizontally) to the wave motion. Surface waves are slower than both P waves and S waves.

The speed of seismic waves varies according to the pressure and elasticity (or springiness) of the material they move through. For example, seismic waves travel slower through rocks of greater density, but faster through rocks of greater elasticity.

ACTIVITY:
MAKING SHOCK WAVES

This activity demonstrates how shock waves travel through solid materials.

You will need:

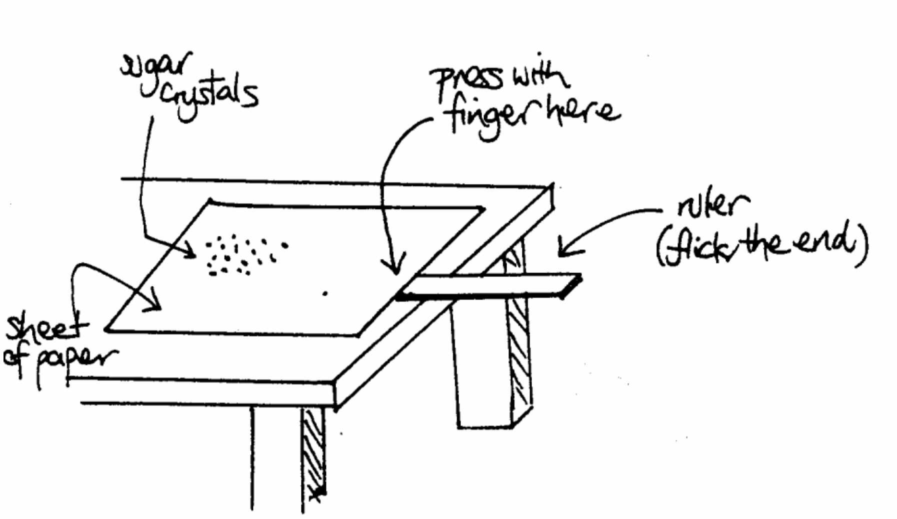
- **a large sheet of paper**
- **sugar**
- **a ruler.**

Place the paper on a table near the edge. Put a little sugar near the centre of the paper and slip the end of the ruler under the paper (see the figure *Making shock waves*). Hold

the ruler gently to the table and flick the end. Observe what happens to the sugar when you flick the ruler.

To demonstrate that even small vibrations can travel long distances in solids, find a long length of wood or metal such as the top railing of the school fence. Have one person tap the fence with a stick. Have another person move some distance along the fence and place his/her ear on the railing. How far along the fence can the vibration be heard?

FIGURE:
MAKING SHOCK WAVES



Measuring and detecting earthquakes
There are two popular earthquake scales: the Richter Magnitude Scale and the Modified Mercalli Intensity Scale.

The Richter Magnitude Scale measures the total amount of energy released by an earthquake at its source, or epicentre. The Richter Magnitude Scale is an open-ended scale that begins with 1. The largest magnitude recorded is 8.6 (the earthquake in India in 2001 registered 7.9).

The Modified Mercalli Intensity Scale measures the kinds of damage done by an earthquake. Table 1 gives some of the Modified Mercalli Intensity Scale.

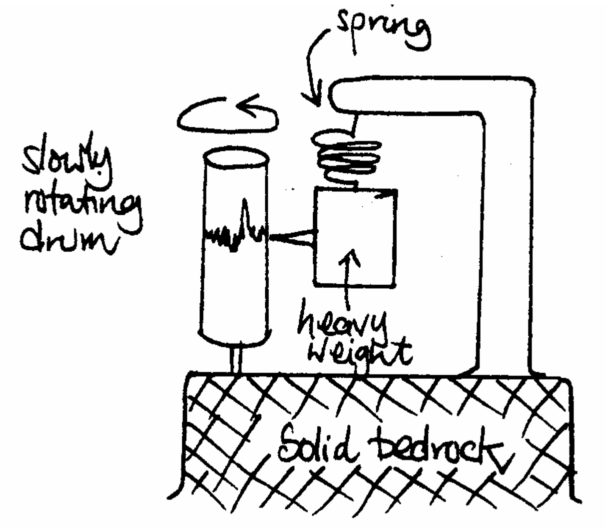
TABLE 1:

PART OF THE MODIFIED MERCALLI INTENSITY SCALE

Scale	Damage
I	Not felt except by a few people under especially favourable conditions
III	Noticeable indoors, especially in upper rooms. Standing cars rock noticeably.
V	Felt by nearly everyone. Some dishes, windows broken, maybe cracked plaster. Disturbance of trees, poles and tall objects noticeable.
VII	Everybody runs outdoors. Damage negligible in good design buildings but considerable in poorly built structures; some chimneys broken. Noticed by people driving cars.
IX	Buildings shifted off foundations. Underground pipes broken.
XI	Few masonry structures standing. Bridges destroyed. Underground pipelines completely out of order.
XII	Damage total. Objects thrown into the air.

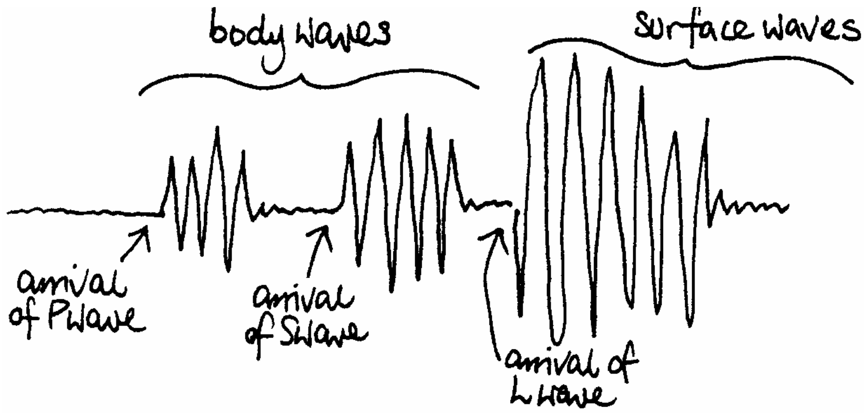
Scientists use an instrument called a ‘seismograph’ to detect seismic waves generated by earthquakes. A seismograph is built so that part of it is attached to solid rock and part of it is not (see Figure 7). When Earth shakes, the part of the seismograph attached to solid rock shakes too. The other part, a heavy suspended weight, moves very little. A pen records the relative movement between the two parts on a slowly rotating drum. An earthquake is recorded as a wiggly line on what is called a ‘seismogram’. What has been described, and shown in Figure 7, is an early model of a seismograph. Modern versions use electronic motion detectors that are connected to solid rock. Electrical signals are sent to a pen that marks a graph on a rotating drum.

FIGURE 7:
EARLY-MODEL SEISMOGRAPH



An earthquake produces different types of seismic waves that travel at different speeds. Because of this the seismograph shows different sets of vibrations from the one earthquake (see Figure 8).

FIGURE 8:
SEISMOGRAM OF AN EARTHQUAKE



Seismograms can be used to locate the epicentre of earthquakes. This is done by comparing seismograms from at least three separate locations on Earth. From one particular site scientists can determine the time difference between the P and S seismic waves. Based on the speeds of these waves, scientists can determine the distance to the epicentre. Therefore, each site constructs a circle on a map for the probable location of the earthquake. The intersection of the three circles (one from each detection site) is the location of the earthquake.

This method of detecting the location of earthquakes is also used to monitor explosions from nuclear bombs. A country cannot secretly test a nuclear bomb without the rest of the world knowing about it. Information from seismograms can also be used to determine the structure of the centre of Earth. Waves travel at different speeds and reflect off boundaries between the different layers of Earth's interior. By knowing the speeds of seismic waves in different materials, scientists can build up a picture of Earth's interior.

ACTIVITY: MODEL OF A SEISMOGRAPH

A seismograph consists of a slowly rotating drum that is firmly connected to Earth's crust. A pen draws a continuous line on the drum, which has a piece of graph paper attached. When earthquakes occur, the pen vibrates, making wiggly lines on the graph paper. The larger the earthquake, the larger the amplitude of the wiggles.

To model a seismograph you will need:

- **a table, preferably with four separate legs**
- **a partner**
- **a pen or pencil**
- **sticky tape**
- **strips of graph paper.**

Tape a strip of graph paper to the table. Now slowly move your pen down the central line of the graph paper strip while keeping your other hand off the table. Have your partner bump or shake the table from the side, first gently and then harder as you are drawing the line.

The line drawn on the graph paper strip becomes your model seismogram.

Tsunamis

Tsunamis are sometimes called 'tidal waves', but they have no connection with the tides. Tsunamis are caused mainly by earthquakes, but also by underwater landslides and volcanic eruptions. They are seismic ocean waves that travel at hundreds of kilometres per hour over very long distances. These seismic waves have enormous energies. While in deep water the crest of the waves is low at sea (ships may not even notice them in the other waves) but they travel at fast speeds. As these seismic waves reach shallower water, their speed slows and their energy is converted into an increase in the height of the wave. The waves, on reaching shore, may be 38 m or more in height and can therefore be very destructive.