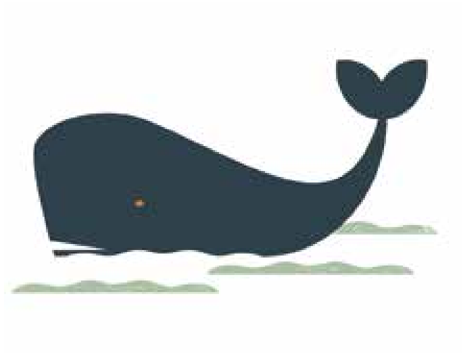

Biology and Geology

4

Biology and Geology 4 is a collective work, conceived, designed and created by the Secondary Education department at Santillana, under the supervision of **Teresa Grence Ruiz**.

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Do not write in this book. Do all the activities in your notebook.

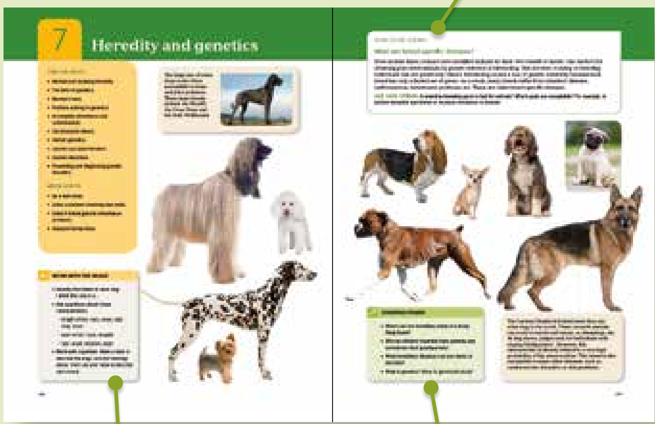
SANTILLANA Richmond

FIND OUT ABOUT

KEY COMPETENCES

- Linguistic competence
- Competences in Mathematics, Science and Technology
- Digital competence
- Learning to learn
- Social and civic competence
- Cultural awareness and expression
- Initiative and entrepreneurship

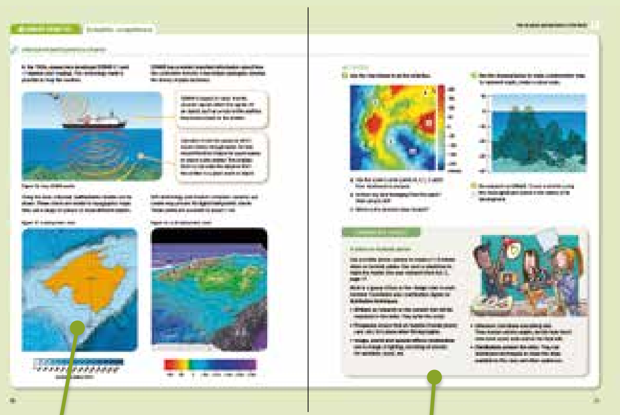
How do we know?



Work with the image

Starting points

Apply what you know



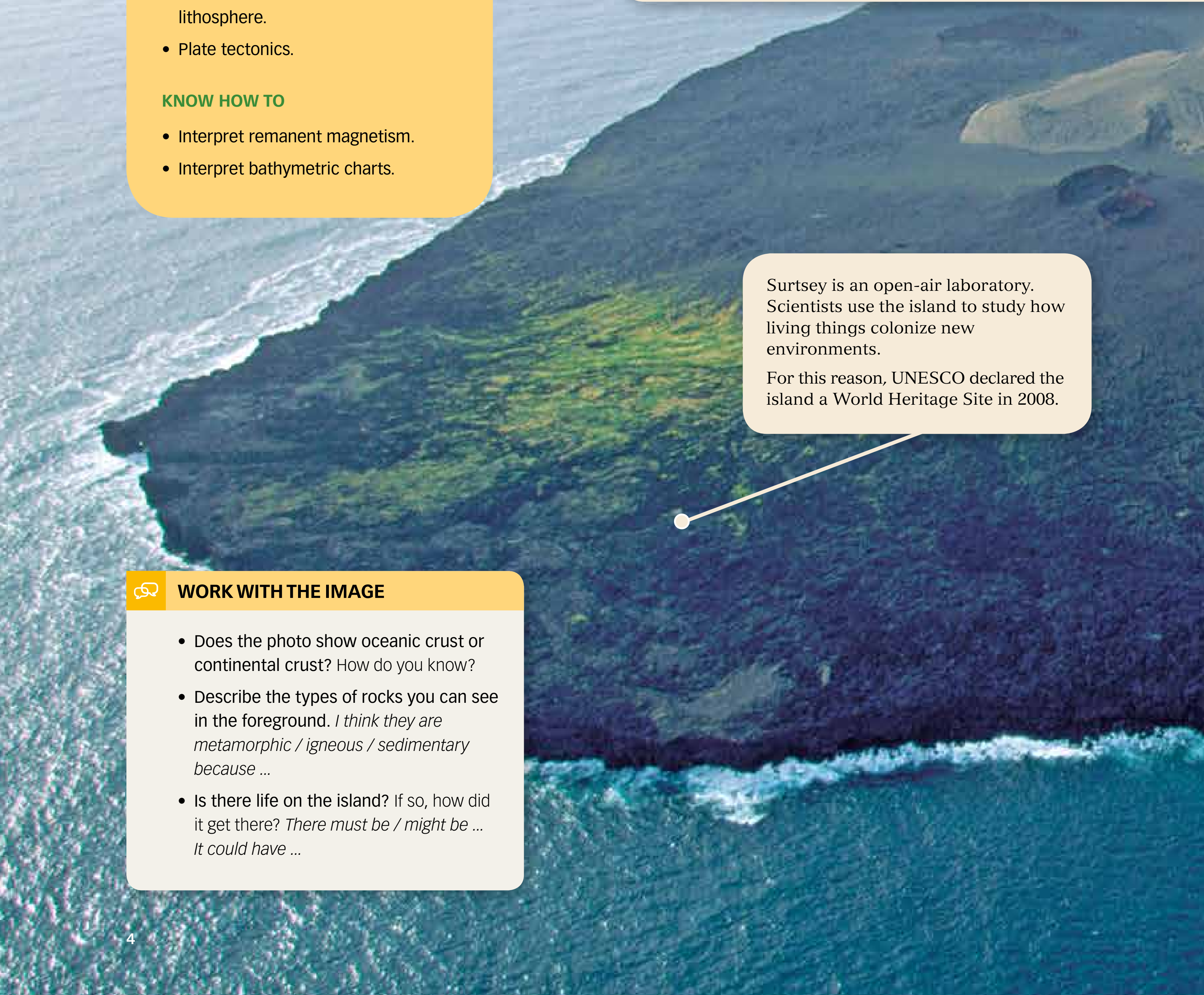
Activities, listening comprehension, simple projects

Scientific analysis

Know how to

Cooperative project

1 The structure and dynamics of the Earth



FIND OUT ABOUT

- The origin of the solar system and the Earth.
- The internal structure of the Earth.
- The geodynamic model.
- The internal engine of the Earth.
- Vertical movements of the lithosphere.
- Horizontal movements of the lithosphere.
- Plate tectonics.

KNOW HOW TO

- Interpret remanent magnetism.
- Interpret bathymetric charts.

The eruption began at a depth of more than 100 m below sea level. A volcanic cone formed that took several months to reach the surface.

The island continued to grow for three and a half years. It reached a maximum surface area of almost three square kilometres (km^2). Its maximum height was 150 m above sea level. However, the island was quickly eroded and is now smaller.

Surtsey is an open-air laboratory. Scientists use the island to study how living things colonize new environments.

For this reason, UNESCO declared the island a World Heritage Site in 2008.

WORK WITH THE IMAGE

- Does the photo show oceanic crust or continental crust? How do you know?
- Describe the types of rocks you can see in the foreground. *I think they are metamorphic / igneous / sedimentary because ...*
- Is there life on the island? If so, how did it get there? *There must be / might be ... It could have ...*

HOW DO WE KNOW?

Is it possible to watch an island form?

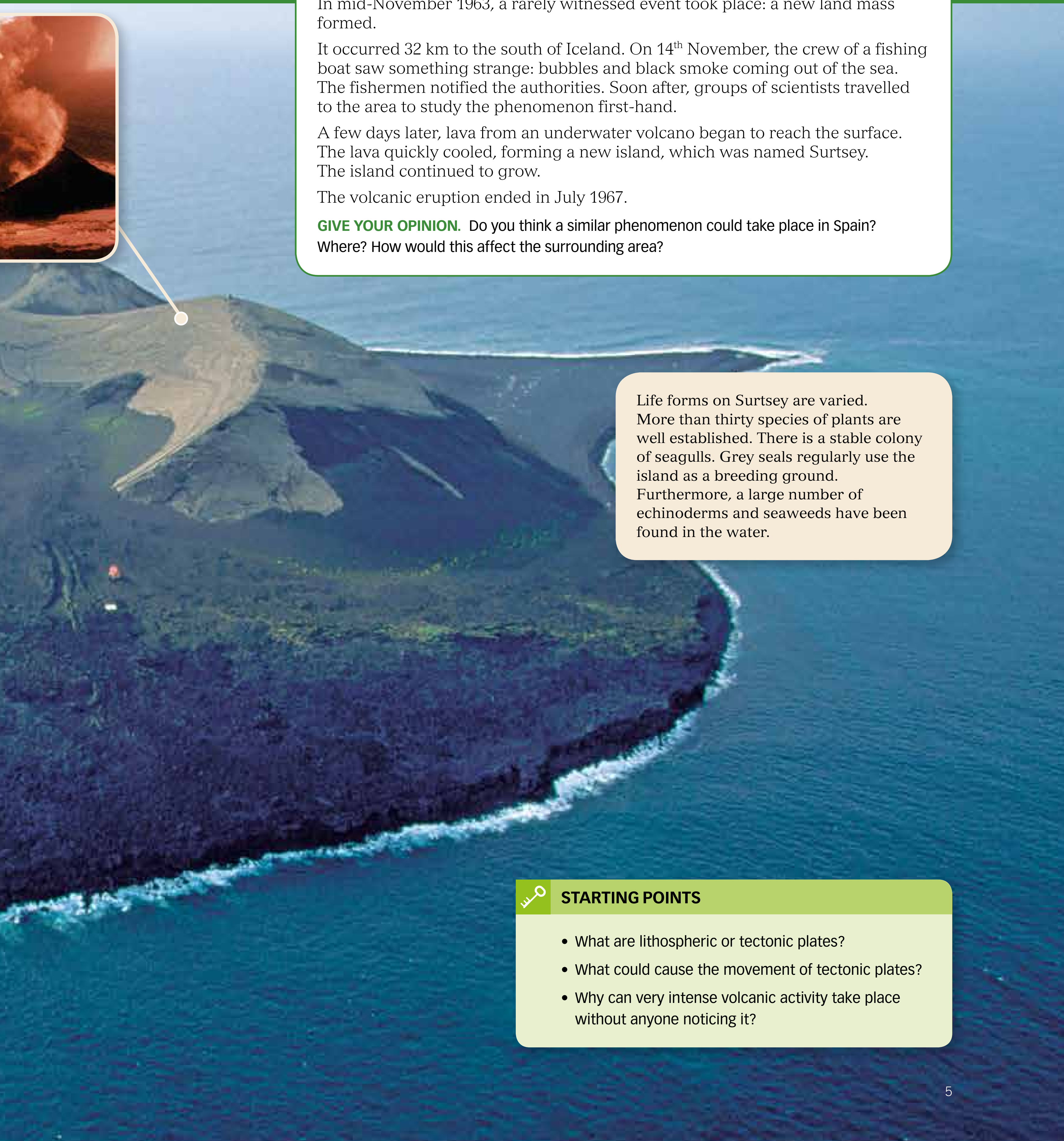
In mid-November 1963, a rarely witnessed event took place: a new land mass formed.

It occurred 32 km to the south of Iceland. On 14th November, the crew of a fishing boat saw something strange: bubbles and black smoke coming out of the sea. The fishermen notified the authorities. Soon after, groups of scientists travelled to the area to study the phenomenon first-hand.

A few days later, lava from an underwater volcano began to reach the surface. The lava quickly cooled, forming a new island, which was named Surtsey. The island continued to grow.

The volcanic eruption ended in July 1967.

GIVE YOUR OPINION. Do you think a similar phenomenon could take place in Spain? Where? How would this affect the surrounding area?



Life forms on Surtsey are varied. More than thirty species of plants are well established. There is a stable colony of seagulls. Grey seals regularly use the island as a breeding ground. Furthermore, a large number of echinoderms and seaweeds have been found in the water.

STARTING POINTS

- What are lithospheric or tectonic plates?
- What could cause the movement of tectonic plates?
- Why can very intense volcanic activity take place without anyone noticing it?

LEARNING OBJECTIVES

- Explain the origin of the solar system and the planets.
- Describe the spheres of the Earth and their origin.

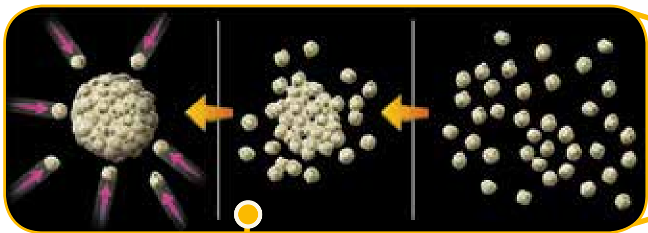
1 The origin of the solar system and the Earth

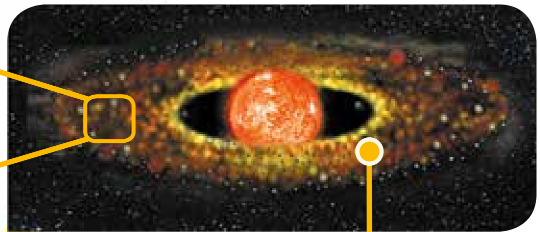
Astronomers calculate that the solar system began to form about 5 billion years ago. It began to form deep inside a nebula located at the end of one arm of our galaxy, the Milky Way. The nebula was a large cold cloud of cosmic dust and gases, mainly hydrogen and helium. The most widely accepted hypothesis about the formation of the solar system is **planetesimal accretion**. See Figure 1. In this process, gas and dust coagulate or accrete, creating solid objects.

Figure 1. Planetesimal accretion in our solar system.

As the nebula rotated around its axis, it began to contract and flatten. It became disk-shaped.

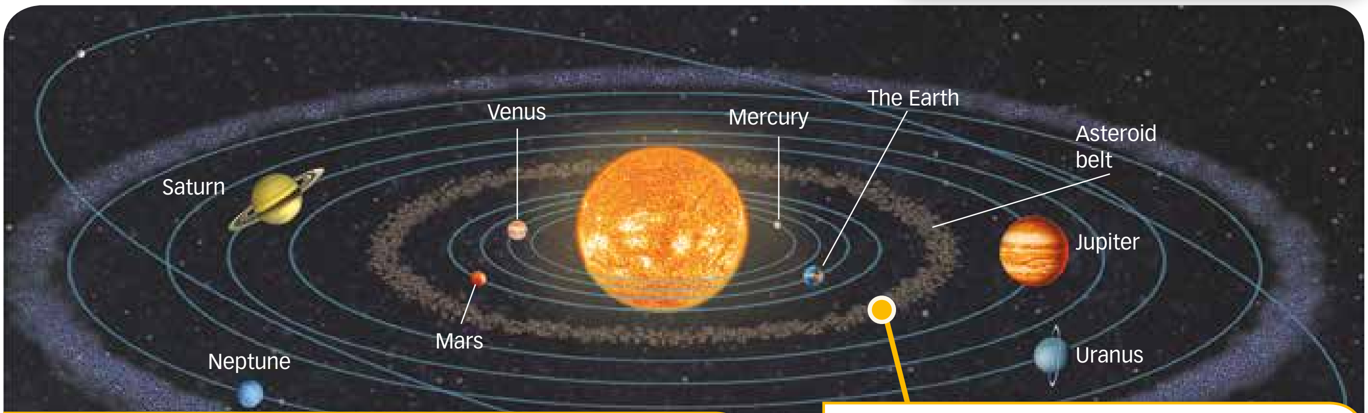
Gravity caused a huge mass of hydrogen and helium to accumulate in the centre of the disk. The temperature of these gases increased until thermonuclear fusion reactions occurred, creating the Sun.





These particles collided with each other due to the effects of gravity. The collision led to the formation of structures called **planetesimals**, which gradually increased in size.

Large quantities of solid particles began to revolve around the primitive Sun. These particles were primarily elements like iron and silicon.



Over the course of 400–450 million years, the planets formed from the remains of the nebula:

- Four rocky planets: Mercury, Venus, the Earth and Mars.
- Four gas giants: Jupiter, Saturn, Uranus and Neptune.

An asteroid belt lies between the two groups of planets. It contains numerous minor planets. Most meteorites that collide with the Moon, the Earth and other planets come from this belt.

The Earth and its spheres

The Earth can be divided into four systems or *spheres*: geosphere, atmosphere, hydrosphere and biosphere. Although each sphere is separate, they all interact very closely with each other. Matter and energy are constantly being exchanged between the four spheres. See Figure 2.

- **Geosphere.** Scientists theorize that about 4.5 billion years ago the Earth was a large ball of molten rock. The molten state was due to three processes that generated heat:
  - The continuous impacts of planetesimals during accretion.
  - The decay of radioactive isotopes such as potassium-40 and uranium-235.
  - The differentiation of materials, due to gravity, into three layers of increasing density:
    - Crust: a thin top layer formed of aluminium silicates.
    - Mantle: a layer of iron and magnesium silicates, floating on the core.
    - Core: a metallic centre formed of the heaviest elements, primarily iron.
- **Atmosphere.** During the **gravitational differentiation** process, large quantities of gas were emitted. The lighter gases, hydrogen and helium, escaped into space. Others, such as carbon dioxide and water vapour, were trapped in the crust. From there, they escaped through fissures. This resulted in intense volcanic activity which caused a primitive atmosphere to form.
- **Hydrosphere.** Later, the water in the atmosphere condensed. Heavy rainfall flooded the depressions on the solid surface, forming the hydrosphere.
- **Biosphere.** Life on the Earth was made possible by two factors:
  - The distance between the Earth and the Sun.
  - The physical and chemical conditions on the Earth, such as temperature and the presence of liquid water.

  Biological activity on the Earth has influenced many processes including:
  - The oxygenation of the atmosphere.
  - The formation of soil.
  - The creation of thick bands of rock such as limestone. Limestone is formed by the accumulation of calcium carbonate from shells, corals and skeletons.

ACTIVITIES

5. **What caused the geosphere to be made up of layers?** Briefly describe the process that took place: *First, next, then, later, finally,* etc.
6. **Differentiate the four spheres.** Write an eight-sentence summary in your own words: main characteristics, formation process, etc.
7. **Find out which processes lead to the formation of coral reefs, coal and petroleum.**

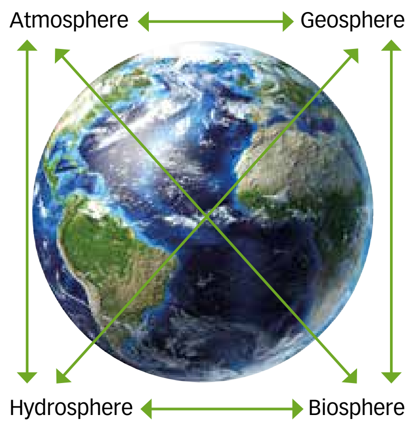


Figure 2. Directions in which energy and matter are constantly being exchanged.

WORK WITH THE IMAGE

1. **Why are the planets closest to the Sun denser than those that are farther away?**
2. **Does the amount of water that makes up the hydrosphere remain constant, or does it tend to increase over time?** Refer to Figure 2 to explain your answer.
3. **Give examples of the exchange of energy between these spheres.** Biosphere / geosphere; atmosphere / biosphere; hydrosphere / geosphere.
4. **What does the eruption of the Eyjafjalla volcano tell you about the process of degassing the Earth?**

LEARNING OBJECTIVES

- Explain how seismic waves are used to understand the interior of the Earth.
- Understand the geochemical model of the Earth.

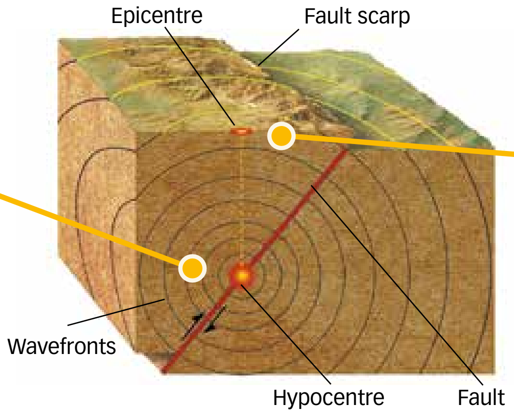
2 The internal structure of the Earth

Geologists study earthquakes to understand the interior of the Earth.

Earthquakes are violent shaking events caused by sudden movements of the crust. See Figure 3. They occur when large masses of rock located at fault lines suddenly slip past one another, releasing energy. See Figure 4.

Figure 3. Earthquake features.

The **hypocentre** is the point within the Earth where an earthquake originates. From here, oscillations (vibrations) travel through the inner layers of the Earth as **seismic waves: P-waves** and **S-wave.** These waves form spherical wavefronts.

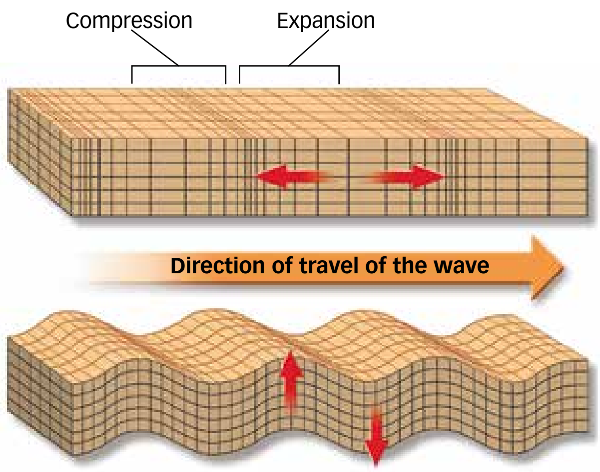


The point on the surface that the waves reach first is called the **epicentre**. It is directly above the hypocentre. **Surface waves** spread from the epicentre, sometimes with catastrophic effects.

Figure 4. P-waves and S-waves.

Primary or pressure waves (P-waves)

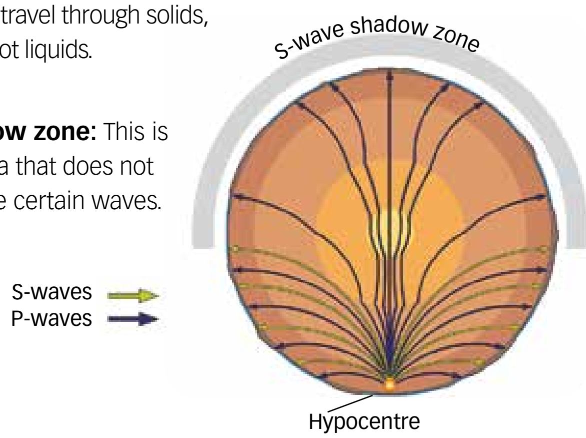
- These are the fastest waves and therefore the first to reach the seismograph, a machine that records seismic waves.
- There are areas of compression and expansion, oscillations, in each wave.
- As it travels, the wave shakes the ground backwards and forwards.
- Waves can travel through solid and liquid materials. However, they travel through liquids more slowly.



Secondary waves (S-waves)

- These are slower, so they are detected by seismographs after the P-waves.
- The oscillations are at right angles to the direction of travel.
- They travel through solids, but not liquids.

Shadow zone: This is an area that does not receive certain waves.



The layers of the Earth vary in chemical composition and mechanical behaviour. As seismic waves travel through each layer, they can be reflected or refracted. This causes the waves to change speed or direction.

Seismologists analyse seismic waves to deduce the physical state of each layer: rigid, malleable or fluid. They also detect the depth of seismic **discontinuities** or boundaries between layers.

Geochemical model of the internal structure of the Earth

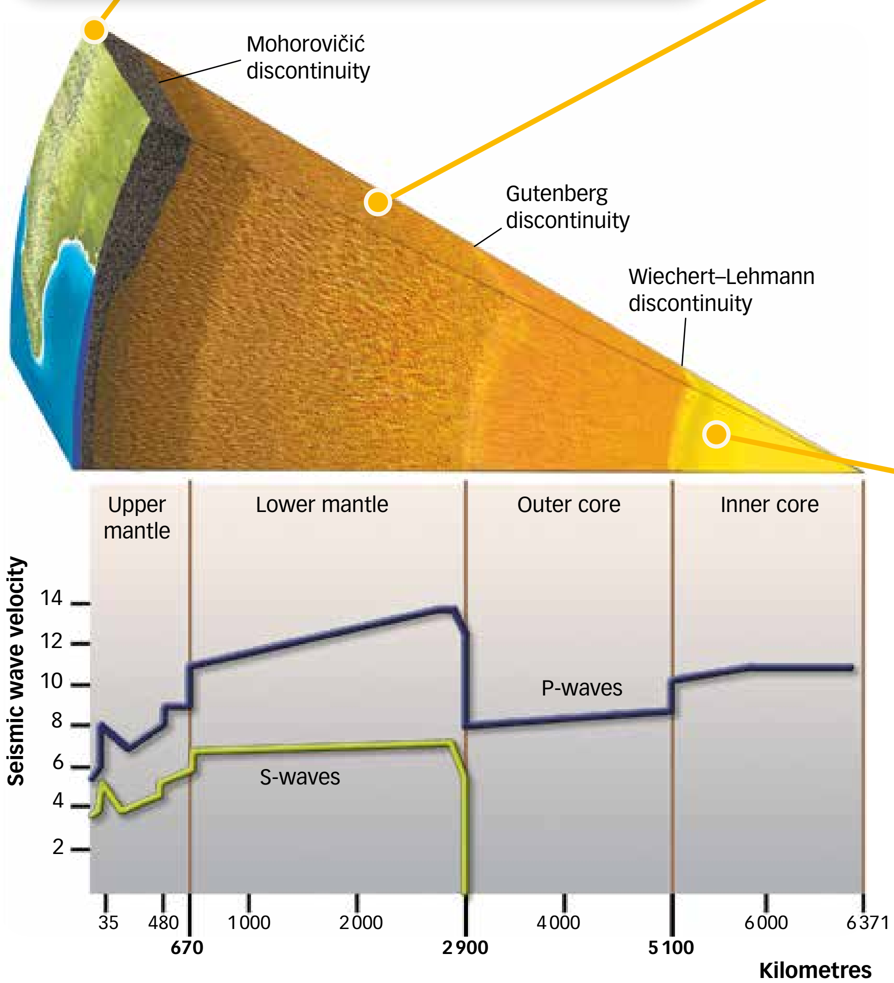
Seismologists have defined two models of the internal structure of the Earth: the geochemical model and the geodynamic model. Although both are based on the behaviour of P-waves and S-waves, there are important differences. The **geochemical model** is based on the chemical composition of the internal layers of the Earth. It divides the Earth into three layers: **crust**, **mantle** and **core**. Within these layers are three seismic discontinuities, each one named after its discoverer. See Figure 5

WORK WITH THE IMAGE

1. Summarize facts about P- and S-waves. Make a table.
2. How does Figure 5 help you to know there is a discontinuity?

Figure 5. Geochemical model of the Earth's interior.

Crust. This layer consists primarily of aluminium silicates. There are two types: **continental crust** and **oceanic crust.**



Mantle. This layer is made up of igneous rocks rich in iron and magnesium silicates. One is peridotite, which consists primarily of the mineral olivine.

The mantle is divided into parts:

- The upper mantle, a layer of igneous rocks, sometimes considered part of the crust.
- The transition zone, made up of denser materials than the upper mantle. The higher density is caused by higher temperature and pressure in this zone.
- The lower mantle.

Core. This consists of almost pure iron mixed with a small percent of iron sulphides and nickel.

It is divided into two parts, each in a different physical state:

- The **inner core** is solid.
- The **outer core** is liquid. It has a consistency similar to water. Violent convection currents here generate the Earth's **magnetic field** or **magnetosphere**.

ACTIVITIES

3. **Model P- and S-waves with a slinky.** Students 1-2 hold each end of the slinky on the floor 2 m apart. Student 3 times each wave and draws its movement. The group compares wave duration.
P-waves: pull the slinky a little, then push it. [3x]
S-waves: shake one end up and down once. [3x]

4. **Draw the structure of Mercury.** Crust: 100–200 km thick. Mantle: 600 km thick. Liquid outer core: 700 km thick. Solid inner core: 1 100 km thick. Indicate any discontinuities. Then make a graph like Figure 5..

LEARNING OBJECTIVES

- Understand the geodynamic model of the Earth.

Figure 6. Drawing of the geodynamic model.

WORK WITH THE IMAGE

1 Look at the images in Figure 7, pages 10 and 11. Listen and choose the correct answer.

3 The geodynamic model

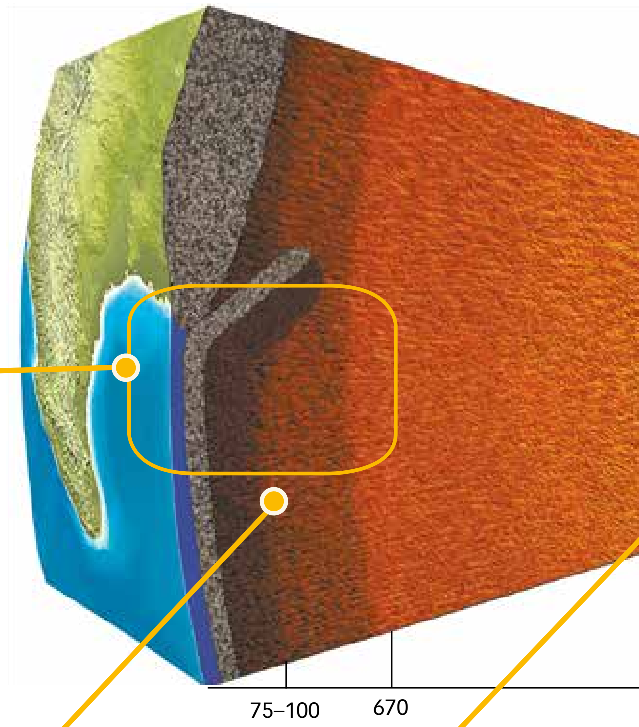
The **geodynamic model** of the internal structure of the Earth (see Figure 6) is based on:

- The physical state of the layers: plasticity, rigidity and density.
- The mechanical properties of the layers; that is, how they respond to changes in pressure and temperature.

According to the geodynamic model, the Earth is a heat engine. See Figure 6. Within it, temperature changes cause atoms and molecules to agitate. This agitation modifies the structure and composition of materials, generating movement and pressure. This pressure can be released slowly or quickly, transforming heat energy into mechanical energy.

Like the geochemical model, this model divides the Earth into layers. In contrast, however, the geodynamic model identifies five layers. From the surface inwards, they are: the **lithosphere**, **asthenosphere**, **mesosphere**, **D" layer** (pronounced *D-double prime*) and the **core**.

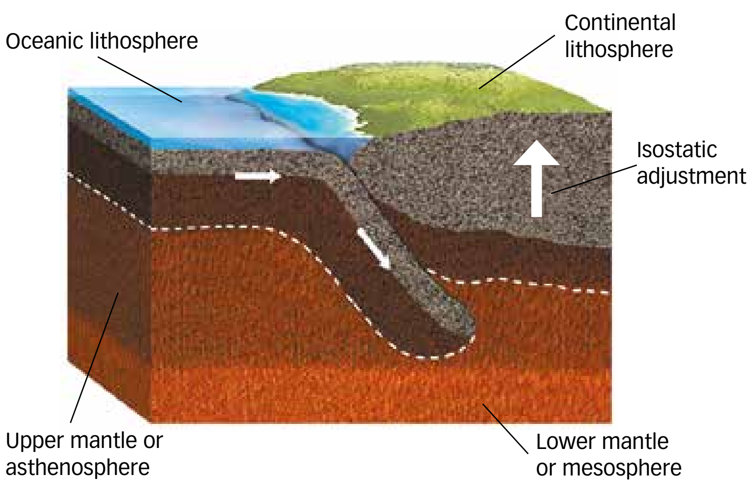
Figure 7. Geodynamic model of the Earth.



Lithosphere

The lithosphere is dragged along by the movement of the mantle underneath. As a result, it has been fractured into large blocks called **lithospheric plates**. These plates fit together like a jigsaw puzzle, and are subjected to two types of movement:

- Horizontal movements due to **plate tectonics**.
- Vertical movements due to **isostatic adjustment**.



Asthenosphere or sublithospheric upper mantle

This layer lies between the lithosphere and the mesosphere. It is a plastic malleable layer with a tendency to flow as the lithosphere moves.

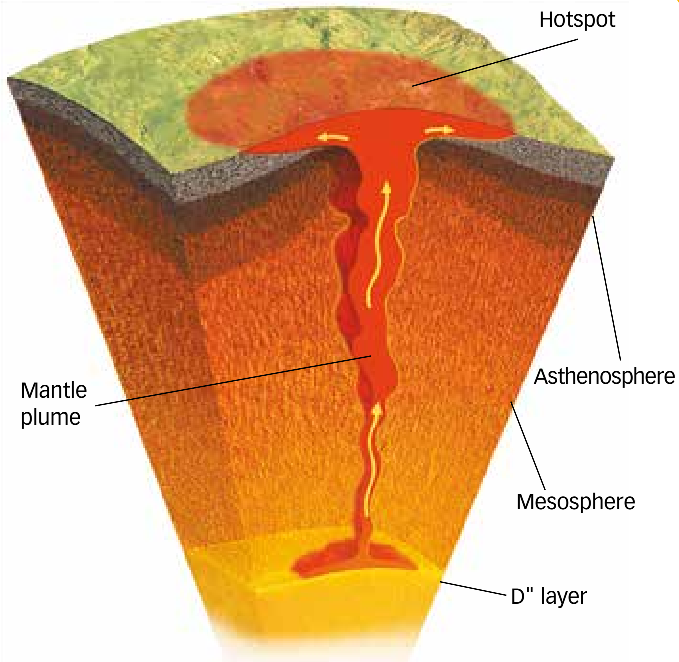
Mesosphere

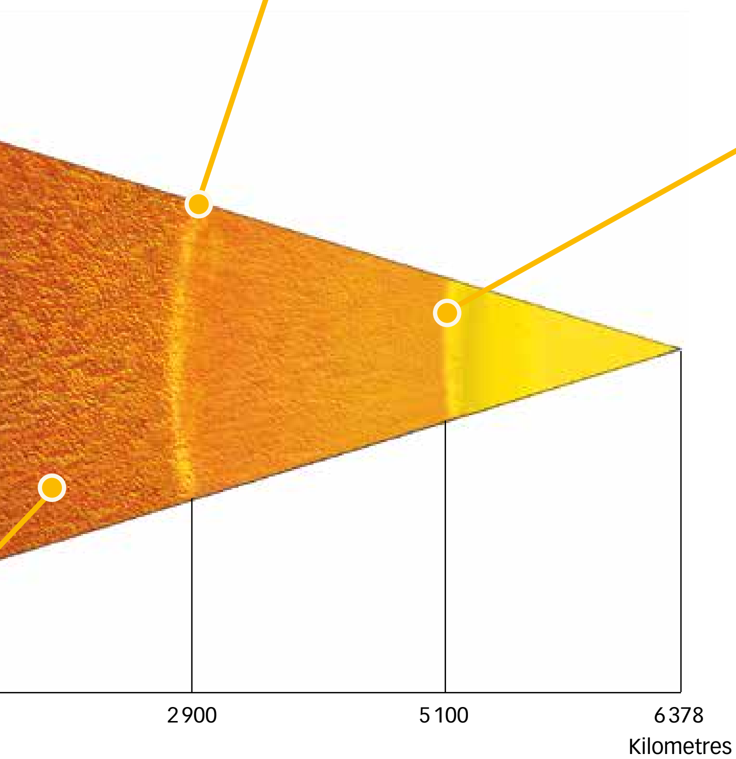
The mesosphere is the lower mantle. It extends from a depth of 670 km to the D" layer. Although it is solid, the mesosphere is not static. For example, it flows, but very slowly: a few centimetres per year. Cold lithospheric plates from subduction zones can descend into it. Mantle plumes can enter it from the D" layer underneath.

The D" layer

The D" layer is one of the most dynamic layers of the Earth. Heat from the outer core accumulates here, and hot magma escapes from this layer as **mantle plumes.** The plumes break through the lithosphere, creating **hotspots**: areas of intense volcanic activity, such as the Hawaiian Islands.

Eruption of the Kilauea volcano.



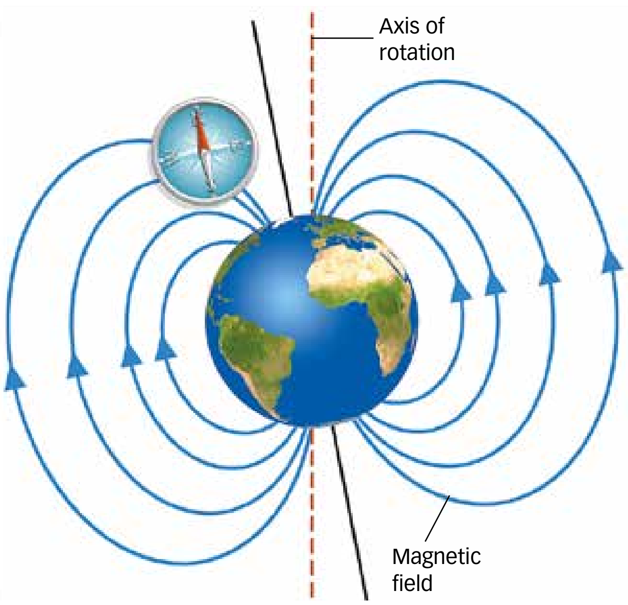


The core

In both the geochemical and the geodynamic models, the core consists of two parts: inner and outer. The heat in the solid inner core spreads to the liquid outer core. This generates convection currents that push heat out of the core into the D" layer, where it accumulates.

These convection currents also generate the Earth's magnetic field.

The magnetic field consists of invisible dynamic lines of force. These lines cross the Earth between two magnetic poles. Unlike the geographical poles, the magnetic poles are not fixed. The distance between them varies over time.



ACTIVITIES

2 How is heat moved up to the lithosphere?

3 Describe the geodynamic model in a table: *Layers, Thickness, Composition, Phenomena.*

4 What criteria are the basis for each theory: geochemical and geodynamic?

LEARNING OBJECTIVES

- Describe the mechanisms responsible for the internal dynamics of the Earth.
- Identify what causes the vertical movements of the crust.

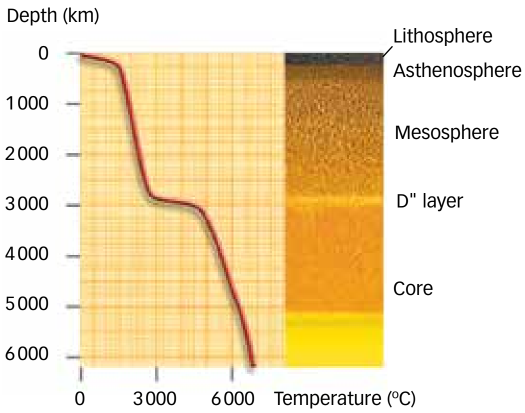


Figure 8. Geothermal gradient: correlation between depth and temperature.

WORK WITH THE IMAGE

1. Test a classmate on Figure 8. *What's the temperature at a depth of ...?*
2. If the geothermal gradient were the same from the surface to the core, 1 ºC/33 m, what would the temperature of the core be? Make a graph to show this geothermal gradient. Then compare your graph with Figure 8.

ACTIVITIES

3. Define *convection current.*
4. Is *heat flow* the same as *geothermal gradient*? Explain your answer.

4 The internal engine of the Earth

The internal dynamics of the Earth depend on two factors: internal energy in the form of heat and the force of gravity.

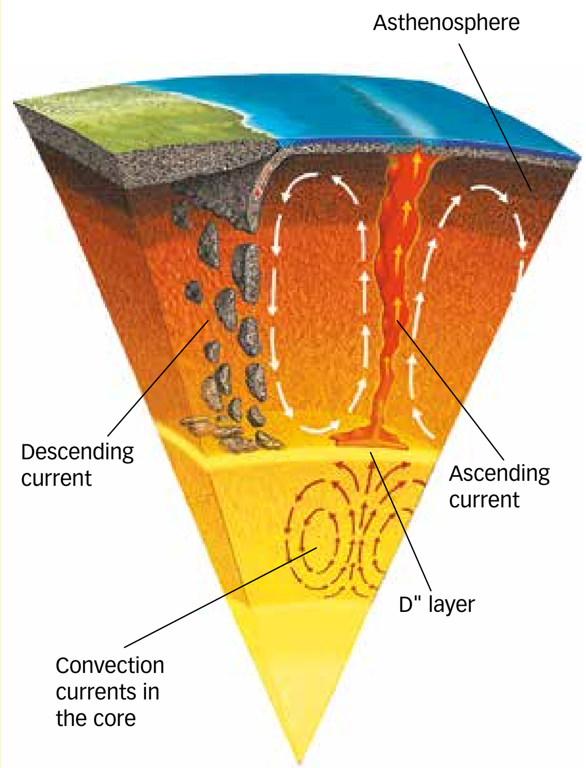
The internal temperature of the Earth increases as the distance from the surface increases; that is, the greater the depth, the higher the temperature. This is called the **geothermal gradient**. See Figure 8. In the crust, the average geothermal gradient is 3 °C per 100 m. In volcanic areas, it can be as high as 10 °C per 100 m.

Heat flow in the geosphere

Heat travels from the hot interior of the Earth up to the surface. See Figure 9. The amount of heat energy that reaches the surface is called the **heat flow**. This heat may be transmitted by **conduction**, but rocks have low conductivity. As a result, transmission takes place very slowly.

The real engines driving the internal dynamics of the Earth are **convection currents**. Hot materials, which are less dense and therefore lighter, ascend to the surface. As they cool, these materials become denser and sink again. This continuous flow is generated by high temperature variations between the lithosphere and the D" layer.

Figure 9. Ascending and descending heat currents in the mantle.



In the mantle, hot magma plumes from the D" layer generate an **ascending current**.

Gravity acting on the lithospheric plates generates a **descending current**.

If the layers have different densities, like the metallic core and the rocky mantle, they cannot mix. As a result, independent convection currents are generated.

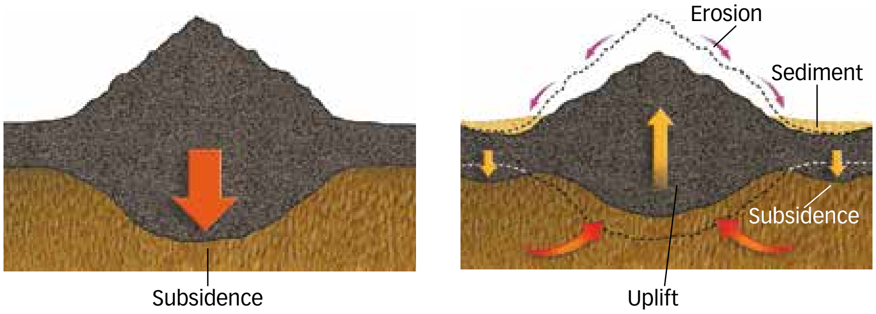
5 Vertical movements of the lithosphere

The rigid lithosphere 'floats' on top of the sublithospheric mantle. The state of gravitational equilibrium between the two layers is called **isostasy**.

This equilibrium is altered by dynamics of internal and external origin. Blocks or sections of the lithosphere move up or down to re-establish isostasy. This is similar to the vertical movements of boats being loaded and unloaded. See Figure 10.

An increase in weight on top of the lithosphere can cause it to sink. This is called **subsidence**. Ice accumulation during glaciation or sediment accumulation in sedimentary basins can cause subsidence. In contrast, both ice thaw and erosion reduce the weight on top of the blocks. This results in **uplift**; that is, the lithosphere rises.

Figure 10. Subsidence and uplift.

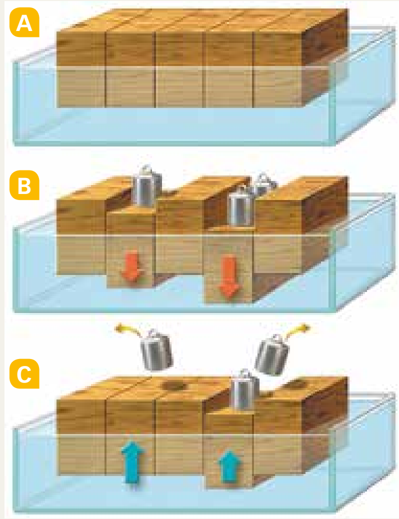


The weight of the materials forming the mountain causes the crust below to sink.

Erosion reduces the weight of the mountain. Internal dynamics cause it to rise.

WORK WITH THE IMAGE

5 Describe *isostasy* using Archimedes' principle of buoyancy. *In image A, all the blocks weigh the same, so they ... In contrast, when weight is added ...*



6 What is the difference between *subsidence* and *subduction*?

THINK ABOUT IT

An ice cap once covered the Scandinavian Peninsula. It melted 10 000 years ago. Since then, the peninsula has risen. Uplift occurs at a rate of 1–10 mm/year depending on the area.

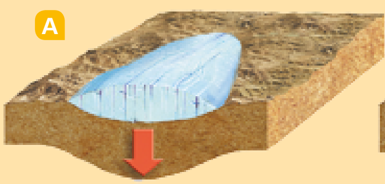
Can you explain the phenomena that cause this uplift?

ACTIVITIES

7 A homeowner wants to install geothermal heating. In this area, the geothermal gradient is 3 ºC/100 m. At what depth will the temperature be 150 ºC?

8 Look at Figure 10. What happens to the sediment produced by the erosion of the mountain?

9 Image A represents a cross-section of a glacier tongue. Image B represents the same area years after the tongue has disappeared. Explain what happened.



LEARNING OBJECTIVES

- Summarize the two main hypotheses regarding the movement of plates.

ACTIVITIES

1. What was Pangaea and what happened to it?
2. Why was Wegener's theory called unifying?
3. Find biogeographic and paleomagnetic proof of continental drift. For example, research theropods. Make a map.

WORK WITH THE IMAGE

4. **Role-play.** Wegener supporters and fixist scientists. Use facts from Figure 11: ... *observed that ... demonstrated / suggested that ...*

6 Horizontal movements of the lithosphere

Until the beginning of the twentieth century, most scientists believed that the continents had always been **fixed** in the same positions.

Wegener and the continental drift theory

Various theories about the horizontal movements of the continents were developed. However, the most complete and significant was proposed by **Alfred Wegener** in 1912: the **theory of continental drift.** It explained numerous phenomena observed in fields such as palaeontology, palaeoclimatology, petrology, geodesy and geography.

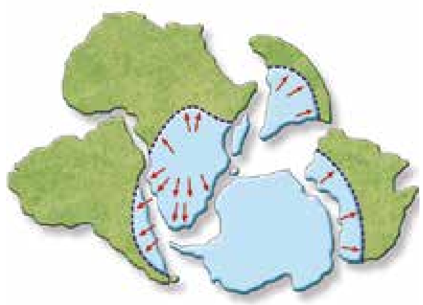
Wegener believed that the continents could move. He theorized that 300 million years ago they were joined together in a single supercontinent he called **Pangaea**. Then the supercontinent gradually began to break up. The different parts moved horizontally across the seabed like icebergs in water. Eventually they formed the current continents.

Wegener presented considerable evidence to support his theory. See Figure 11. However, he was unable to name a force strong enough to move the continents. He suggested that the rotation of the Earth could have been responsible.

In the mid-1920s, the continental drift theory fell into disrepute. Almost thirty years passed before scientists began to re-evaluate it.

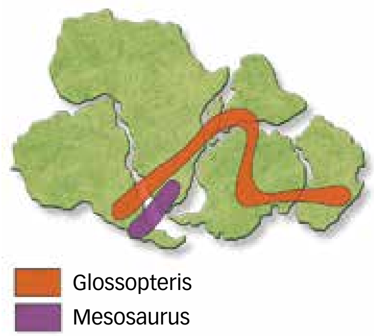
Figure 11. Evidence for the theory of continental drift.

Geographical evidence. Several people realized that some continents, like Africa and South America, seemed to fit together. Benjamin Franklin in the 18th century and Alexander von Humbolt in the 19th century were among them.



Palaeoclimatic evidence. Examples include traces of glaciation that occurred 300 million years ago.

The red arrows indicate the direction in which the ice eroded the land.



Palaeontological evidence. Fossils of very similar animals and plants were found on different continents. The only explanation was that those continents had been very close to each other in the past.

Seafloor spreading hypothesis

After the Second World War, an intense period of ocean exploration began. SONAR technology made it possible to create detailed maps of the seabed. Researchers perfected new methods by studying radioactivity and the **remanent magnetism of rocks**. The development of computers also led to more efficient data processing.

Geological and geophysical discoveries relating to the seabed led to a new theory. The **seafloor spreading hypothesis** was proposed by Harry Hess in 1962. See Figure 12.

According to Hess's theory, the seafloor spreads apart at mid-ocean ridges and new oceanic crust is formed by:

- Volcanic activity.
- The gradual movement of the seabed away from the ridge.

ACTIVITIES

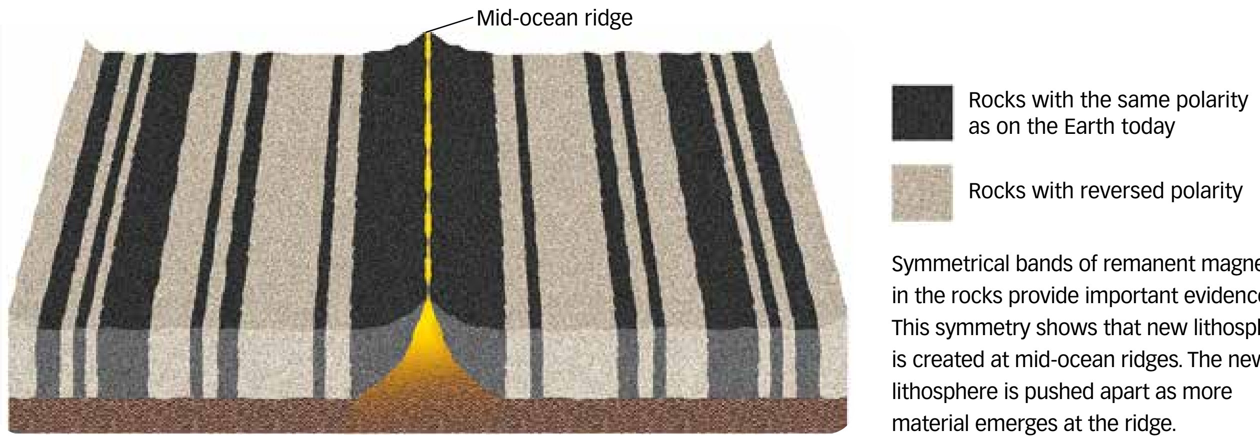
5 Describe Hess's hypothesis.
Hess argued that ...

6 Do all the rocks on the seafloor have the same magnetic polarity? Explain.

7 Look at Figure 12. Which rocks are the oldest? And the youngest?

8 Make a dynamic paper model to show seafloor spreading. Get instructions on the Internet.

Figure 12. Diagram showing the seafloor spreading hypothesis.



Symmetrical bands of remanent magnetism in the rocks provide important evidence. This symmetry shows that new lithosphere is created at mid-ocean ridges. The new lithosphere is pushed apart as more material emerges at the ridge.

KNOW HOW TO

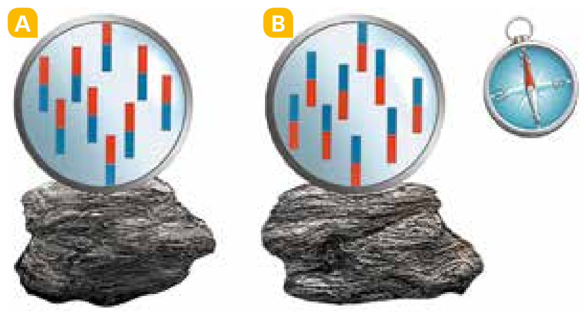
Interpret remanent magnetism

Magnetite is a mineral that forms in lava. As it cools, magnetite crystals align with the Earth's magnetic field.

However, the polarity of the Earth reverses periodically due to the instability of the magnetic field. These reversals in polarity are recorded in rocks in a phenomenon called **remanent magnetism**. The last magnetic field reversal occurred about 780 000 years ago.

Magnetite crystals act like compasses. To show their orientation, geologists use red and blue like a compass needle. Red points towards the North Pole at the time the crystals cooled.

Geologists use remanent magnetism to identify rocks that formed in periods when the Earth had the same or the opposite polarity.



ACTIVITIES

9 What do the red and blue lines in images A and B indicate?

10 Samples A and B were found near an oceanic ridge. Which one is the most recent? How do you know?

LEARNING OBJECTIVES

- Explain the basic principles of plate tectonics.

WORK WITH THE IMAGE

1 Look at Figures 13 and 14.

a) Why do you think sediment deposits are so thin at mid-ocean ridges?

b) Why are the oldest rocks on the seafloor only 185 million years old?

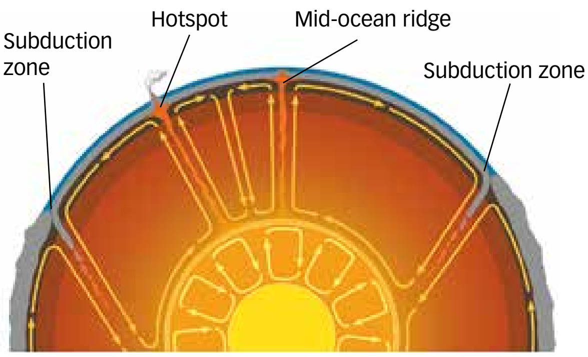


Figure 13. Activity at trenches, ridges and hotspots.

7 Plate tectonics

Hess's seafloor spreading hypothesis led to a new theory: **plate tectonics**. It is a comprehensive theory of geological processes. The concept of *plates* was developed by Canadian geologist, **John Tuzo Wilson**, in 1965. It was based on his study of the global distribution of earthquakes and volcanoes. See Figures 13 and 14. There are two main types of plates:

- **Oceanic plates**, which consist entirely of oceanic lithosphere.
- **Mixed plates**, which consist of a mixture of continental lithosphere and oceanic lithosphere.

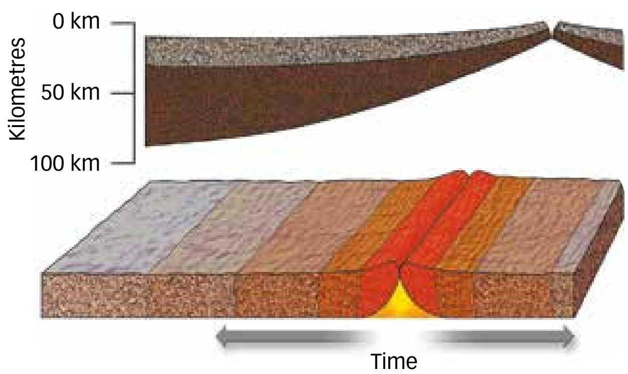
Principles of plate tectonics

- The lithosphere is divided into **plates**. These plates are separated by unstable boundaries characterized by intense seismic and volcanic activity. All the plates fit together like pieces of a giant jigsaw puzzle.
- **Oceanic lithosphere** is thinner and denser than continental lithosphere. It is generated continuously at **mid-ocean ridges**. When oceanic lithosphere is generated, an equal amount is destroyed in **oceanic trenches** or **subduction zones**. As a result, the diameter of the Earth is always the same. See Figure 13.
- Gravity and the internal heat of the Earth generate **convection currents**. These currents move the tectonic plates with respect to one another, changing the position of the continents.
- Tectonic plates interact. This interaction creates large **relief features** and related phenomena, such as earthquakes and tsunamis.

Figure 14. Evidence of plate tectonics.

- Maps of the seafloor show mid-ocean ridges, oceanic trenches and large underwater faults.
- Direct measurements have demonstrated that the plates are moving. They also indicate the direction of plate movement.

- Sediment deposits are thicker at continental margins, but almost non-existent at mid-ocean ridges.



- The newest crust is found at the centre of mid-ocean ridges. The age of the crust increases with distance from the ridge towards the continents. No rocks older than 185 million years old have been found on the seafloor.

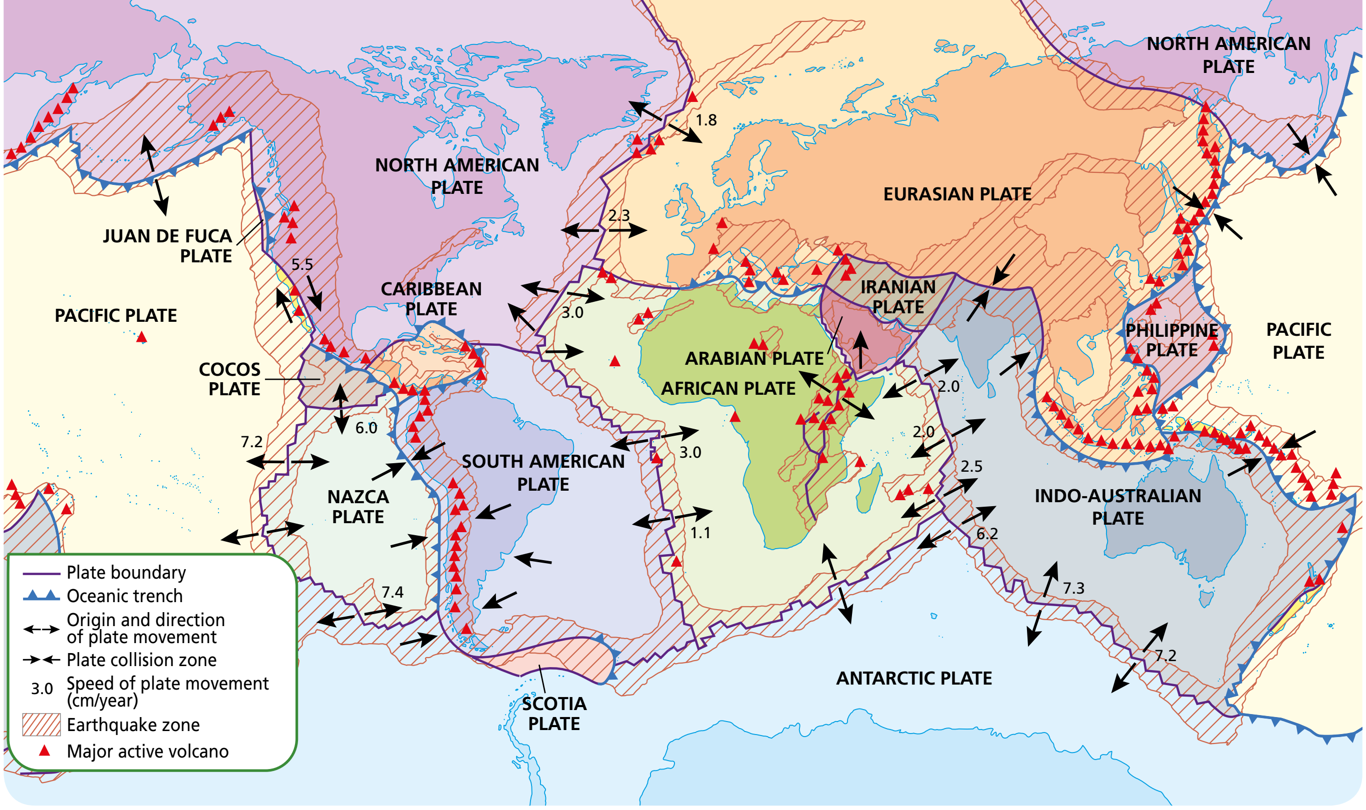


Figure 15. Movement, direction and boundaries of tectonic plates.

Relative movements of plates

The place where two plates meet is called a **boundary**. There are three types of plate boundaries. Each moves and interacts differently, and each creates specific geological structures. Various geological phenomena occur at these boundaries. See Figure 15. For example, lithosphere can be created, destroyed or conserved. Other intense phenomena, such as earthquakes, volcanic activity and subsidence also occur.

WORK WITH THE IMAGE

2 Research a tectonic plate. Find out about the area, location, movement, speed, important structures. Present your findings as a fact file with illustrations.

Boundary type	Events	Geological structures generated
Convergent	Continents collide.	Orogens / orogenic belts: mountain ranges, etc.
	Oceanic lithosphere is destroyed.	Subduction zones
Divergent	Oceanic lithosphere is created.	Mid-ocean ridges
Transform	Plates slide past each other.	Transform faults

ACTIVITIES

3 What relationship is there between convection currents in the mantle and lithospheric plates? What role do trenches and oceanic ridges play in the theory of plate tectonics?

4 Draw transversal cuts of each type of plate boundary. Show the structures each generates. Label your drawings.

5 Can you show plate movement with a model? Choose materials to represent each type of plate and the asthenosphere they rest on. Do some research.

6 Complete the sentences.

- *According to the theory of plate tectonics, …*
- *The boundaries of a tectonic plate can be …*

REVISE BASIC CONCEPTS AND FACTS

1 **Briefly summarize the main concepts.** Copy and complete the sentences.

a) The hypothesis of planetesimal accretion states that ...

b) The main differences between *P–waves* and *S–waves* are ...

c) The geochemical model states that the Earth ...

d) The geodynamic model states that the Earth ...

e) Convection currents are ...

f) Continental drift and seafloor expansion are ...

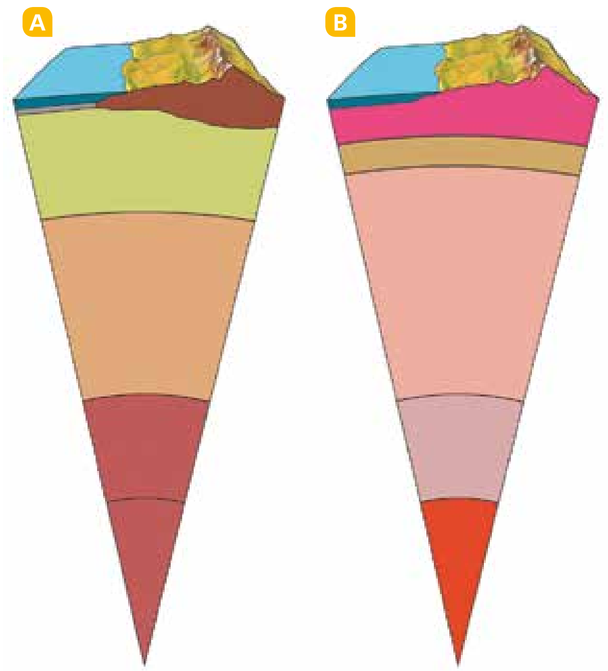
g) Isostasy is ...

2 **Define *geothermal gradient*.**

3 **Compare the layers of the Earth with respect to temperature and depth.** Use forms of *hot* and *dense*. For example: *The inner core is hotter and denser than the outer core.*

4 **Look at Figure 5, page 9 and Figure 7, pages 10–11.** What differences do you see between the *geochemical* and the *geodynamic* models?

5 **Make large copies of these drawings.** Then follow the instructions below.



a) Label each drawing with the name of the model that it represents. Label the parts of the structure of the Earth in each one.

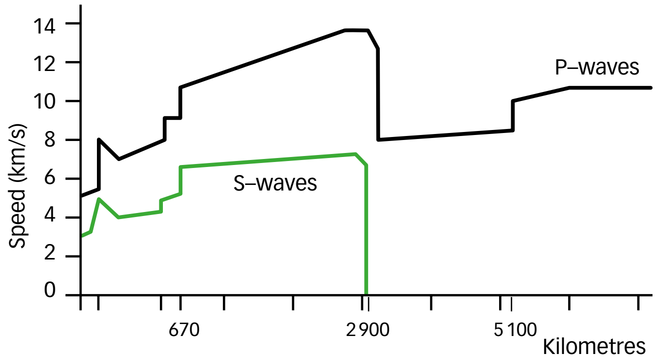
b) Label the discontinuities and the depth at which each is located.

6 **Mercury's core makes up 75% of the planet.** If the Earth had a similar core, how thick would the other layers be?

7 **This graph compares P- and S-waves in the geosphere.** Copy the graph and include the following labels:

a) The Mohorovičìc, Gutenberg and Wiechert–Lehmann discontinuities.

b) The crust, the mantle and the inner and outer cores.



8 **Describe Wegener's theory of continental drift and Hess's theory of seafloor spreading.** Use words like: *argued / demonstrated / proposed / hypothesized that ...* Relate their theories to the plate tectonics theory.

9 **What evidence was Wegener missing to prove his theory of continental drift?** What subsequent discoveries proved his theory?

10 **How do bands of magnetic polarity prove Hess's theory?**

11 **Make simple drawings showing the contact between these plates. Use arrows to show plate movement.**

a) Pacific and North American plates – San Andreas fault.

b) Eurasian and Pacific plates near Japan.

c) Nazca and South American plates.

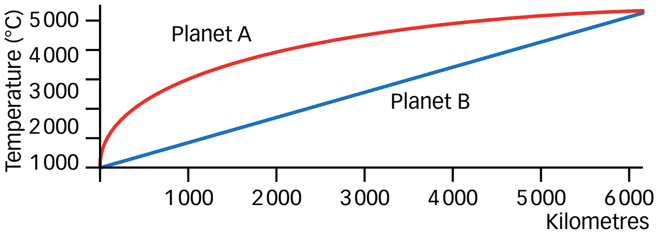
d) Indoaustralian and Eurasian plates.

e) South American and African plates.

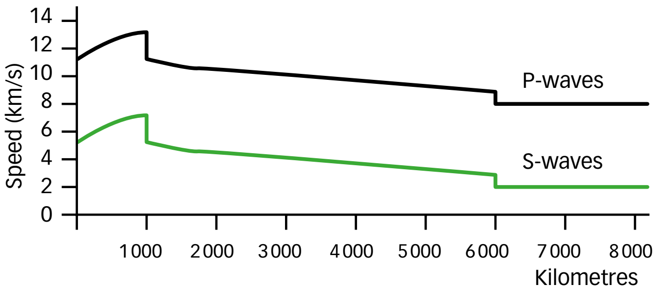
12 **Make a three-slide presentation about a hotspot.** Work in a group. Include this information: location of the hotspot, name of the tectonic plate it is on; speed, name and ages of islands, etc.

APPLY WHAT YOU KNOW

13 **These graphs show the geothermal gradient of two different planets.** Which planet would be the best for exploiting geothermal energy?



14 **This graph shows P- and S-waves on an imaginary planet.** Find and label the discontinuities. Then examine each layer. Describe the most important characteristics of each one.



15 **Make a model to show how hotspots form.** Get ideas from the Internet.

16 **Could there be a connection between global warming and isostatic phenomena?** Explain your answer.

17 **Make the model below in order to carry out this experiment.** Put two identical pieces of cork, A and B, in water. Put some sand on piece A. Then use a spoon or scoop to remove sand from piece A and place it on piece B. Observe what happens and answer these questions:

a) What happens to piece A as you remove weight?

b) What happens to piece B as you add weight?

c) Which geological processes are being shown?

d) Which areas of the surface of the Earth does each piece of cork represent? Hint: think about erosion and sedimentation.

e) Summarize your work. Use words like *observe*, *hypothesize, demonstrate, although, in contrast*.

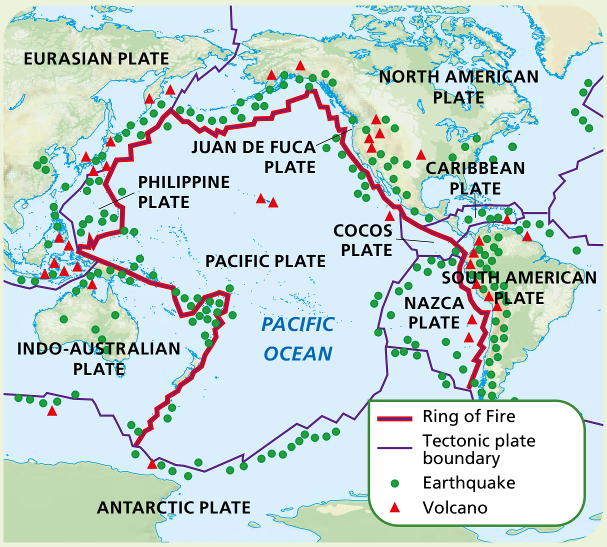
SCIENTIFIC ANALYSIS

The Pacific 'Ring of Fire'

The Ring of Fire is an area of intense seismic and volcanic activity. It is located around the edges of the Pacific Ocean. The intense activity is due to the movement of tectonic plates.

The eastern section is the result of subduction. The Nazca and Cocos Plates are sliding under the South American Plate. Subduction also occurs where the Pacific Plate collides with the North American, Philippine and Indo-Australian Plates.

This enormous, complex system is an important piece of evidence confirming the theory of plate tectonics.



18 **Which geological phenomena related to plate boundaries are mentioned in the text?**

19 **Is the Pacific Ocean getting bigger?** Apply information from this text and the unit to answer.

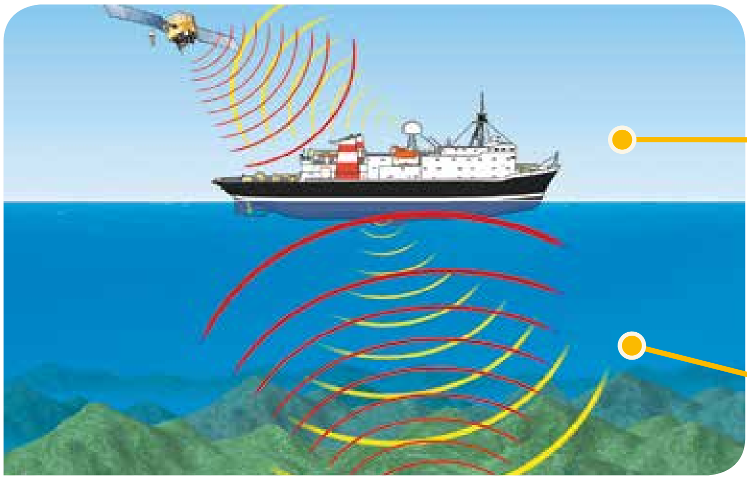
20 **Volcanoes are not located randomly across the surface of the Earth.** Why not?

21 **Explain how the Ring of Fire can be used as proof of plate tectonics.**

Interpret bathymetric charts

In the 1940s, researchers developed SONAR (SOund NAvigation and Ranging). This technology made it possible to map the seafloor.

SONAR has provided important information about how the continents formed. It has helped geologists develop the theory of plate tectonics.



SONAR is based on radar: it emits acoustic signals. When the signals hit an object, such as a rock on the seafloor, they bounce back to the emitter.

Operators know the speed at which sound travels through water. So they record the time it takes for sound waves to return to the emitter. This enables them to calculate the distance from the emitter to a given point or object.

Figure 16. How SONAR works.

Using the data collected, **bathymetric charts** can be drawn. These charts are similar to topographic maps: they use a range of colours to show different depths.

GPS technology and modern computer systems can create very precise 3D digital bathymetric charts. These charts are accurate to about 1 cm.

Figure 17. A bathymetric chart.

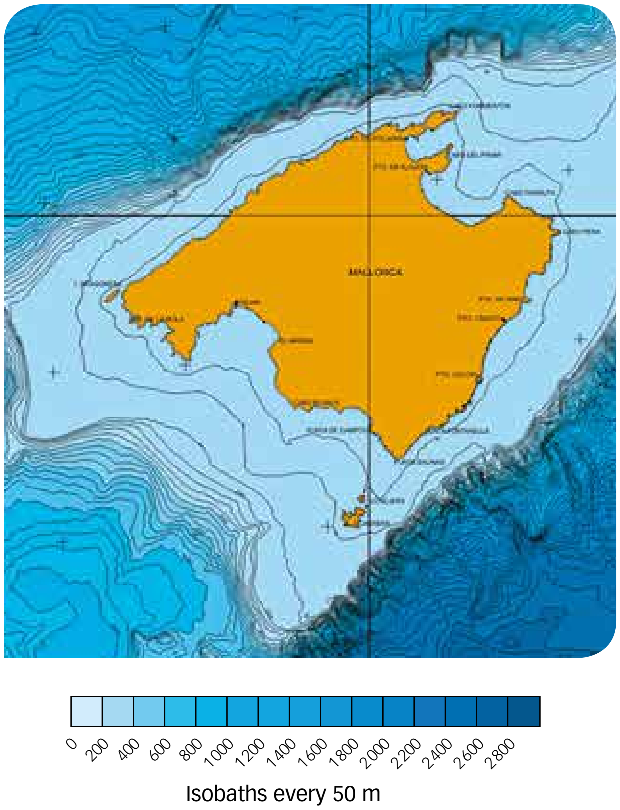
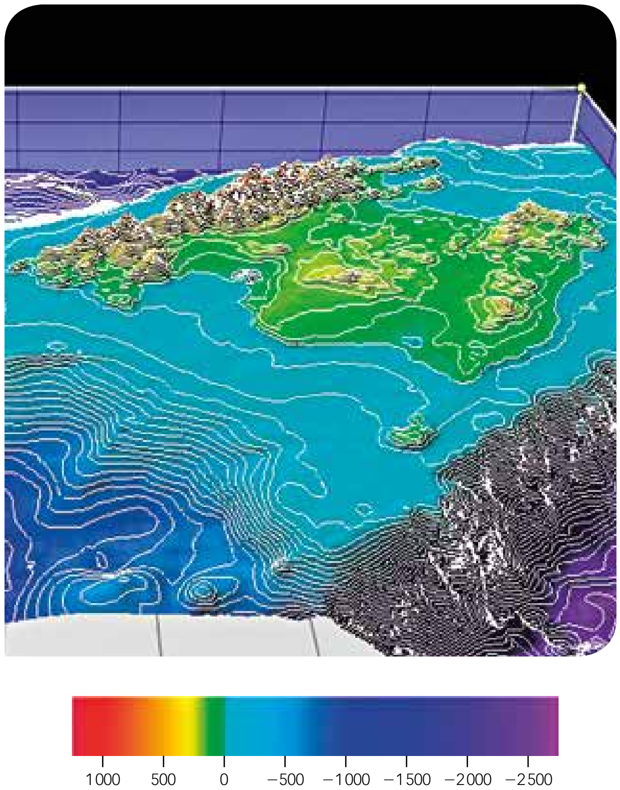
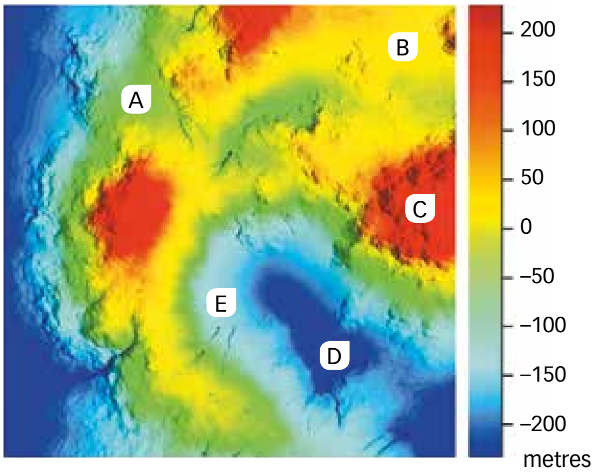


Figure 18. A 3D bathymetric chart.



ACTIVITIES

1 Use the map below to do the activities.

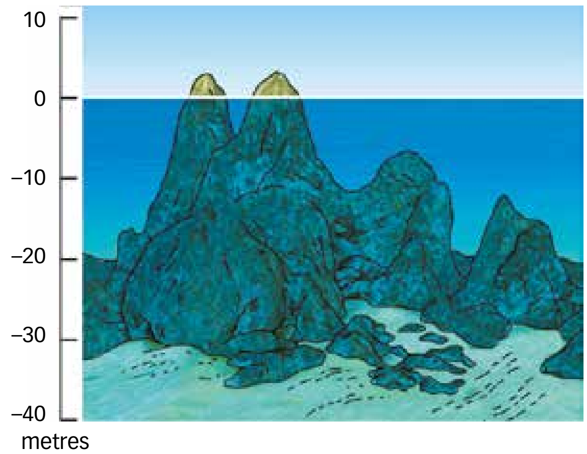


a) Use the scale to put in order points A, B, C, D and E from shallowest to deepest.

b) Is there any land emerging from the water? How can you tell?

c) Where is the steepest slope located?

2 Use the drawing below to make a bathymetric map. To represent depth, create a colour scale.



3 Do research on SONAR. Create a timeline using the most significant events in the history of its development.

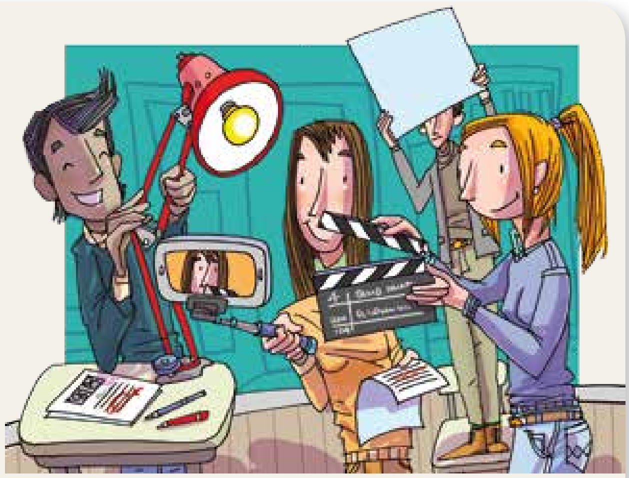
COOPERATIVE PROJECT

A video on tectonic plates

Use a mobile phone camera to create a 1–2 minute video on tectonic plates. Use card or plasticine to make the model. Use your research from Act. 5, page 17.

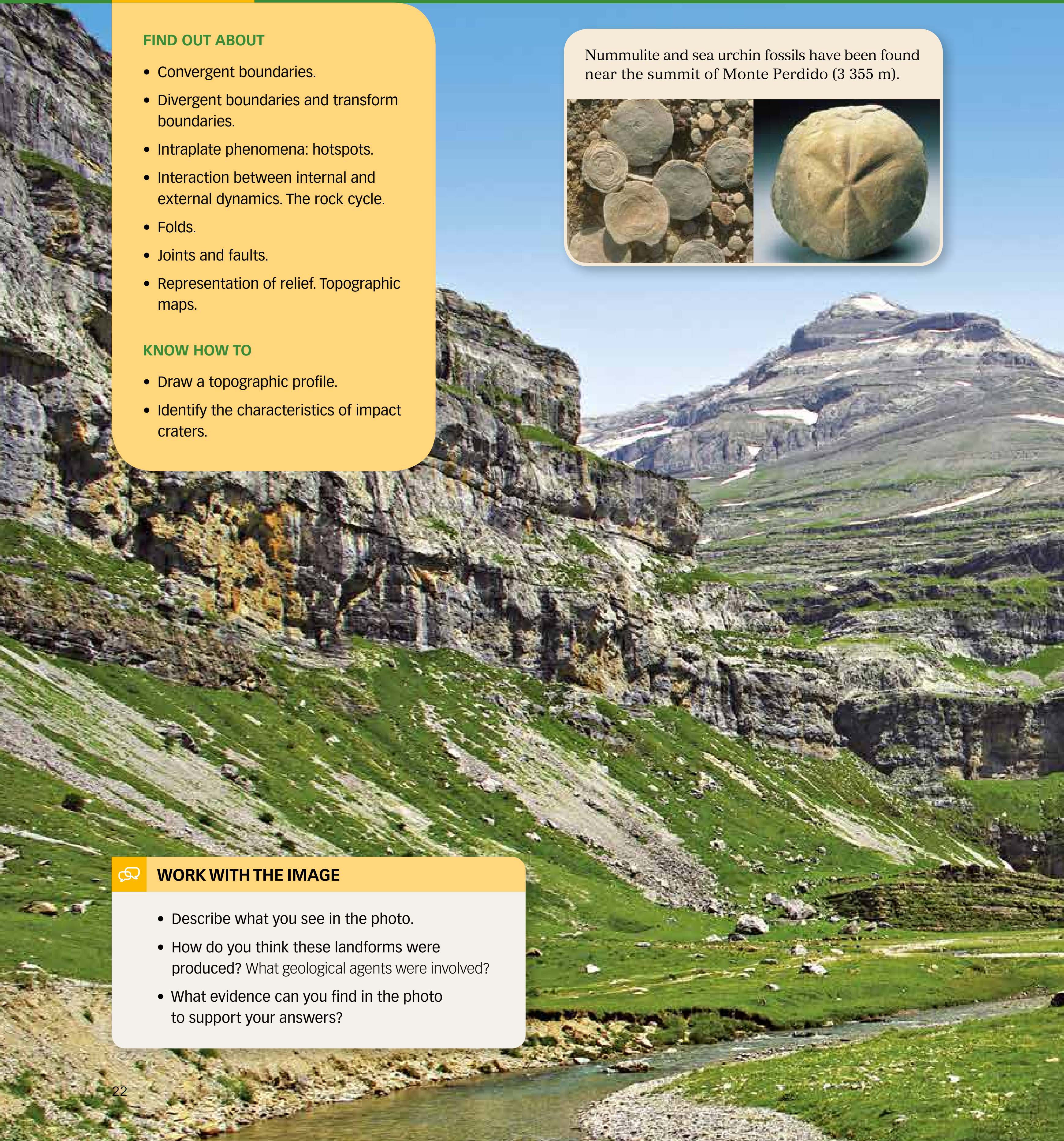
Work in a group of four or five. Assign roles to each member. Coordinate your contributions. Agree on distribution techniques.

- **Writers** do research on the content that will be explained in the video. They write the script.
- **Producers** ensure that all material (mobile phone, card, etc.) is in place when filming begins.
- **Image, sound and special effects technicians** are in charge of lighting, recording of voice(s) for narration, music, etc.



- **Directors** coordinate everything else. They choose camera angles, decide how much time each scene lasts and do the final edit.
- **Distributors** present the video. They use distribution techniques to make the video available to the class and other audiences.

2 Tectonics and relief



FIND OUT ABOUT

- Convergent boundaries.
- Divergent boundaries and transform boundaries.
- Intraplate phenomena: hotspots.
- Interaction between internal and external dynamics. The rock cycle.
- Folds.
- Joints and faults.
- Representation of relief. Topographic maps.

KNOW HOW TO

- Draw a topographic profile.
- Identify the characteristics of impact craters.

Nummulite and sea urchin fossils have been found near the summit of Monte Perdido (3 355 m).

WORK WITH THE IMAGE

- Describe what you see in the photo.
- How do you think these landforms were produced? What geological agents were involved?
- What evidence can you find in the photo to support your answers?

HOW DO WE KNOW?

Why are there marine fossils on mountain tops in the Pyrenees?

Some mountains in the Pyrenees are made of rocks formed from sediment deposited on an ancient seafloor. Monte Perdido, in the Ordesa National Park, is one example. A large part of the sediment was formed from the remains of living organisms like algae, corals, fish and molluscs. Many of these were fossilized.

About 80 million years ago, the Iberian and European plates started to collide. The collision pushed the seafloor up, forming the Pyrenees. As a result, the remains of sea shells are now found as high as 3 000 m above sea level.

GIVE YOUR OPINION. Why do you think it is useful to know how landforms were created?

This impressive fossil is the jaw of a 57-million-year-old marine crocodile. The jaw was found in the Añisclo gorge in the Ordesa National Park.

STARTING POINTS

- How are landforms created and destroyed?
- What are ocean trenches and mid-ocean ridges?
- What is a fold? And a fault?

- Understand the phenomena that occur at convergent boundaries.

1 Convergent boundaries

Convergent boundaries are areas where lithospheric plates are destroyed. Two types of phenomena are associated with convergent boundaries: **subduction zones** and **continental collision zones**.

Subduction zones

Oceanic lithosphere forms at mid-ocean ridges. See Figure 1. As this lithosphere moves away from the ridge, it cools and gets denser. When the lithosphere collides with another plate, it sinks or **subducts** into the mantle. Subduction occurs at an angle, at a rate of 10–15 cm per year. Parts of the lithosphere may reach the D" layer as a result of gravity.

The subducting plate is always oceanic because oceanic lithosphere is denser. However, the overlying plate, which stays on the surface, can be oceanic or continental. Similar processes occur in both cases:

- Oceanic lithosphere is destroyed.
- Intense seismic and volcanic activity is generated.
- Magmatism occurs as the basalt in the subducting plate melts.
- Metamorphism and deformation occur due to increased pressure and temperature.

Subduction can last more than 200 million years. It generates two types of orogens: **island arcs** and **volcanic arcs**.

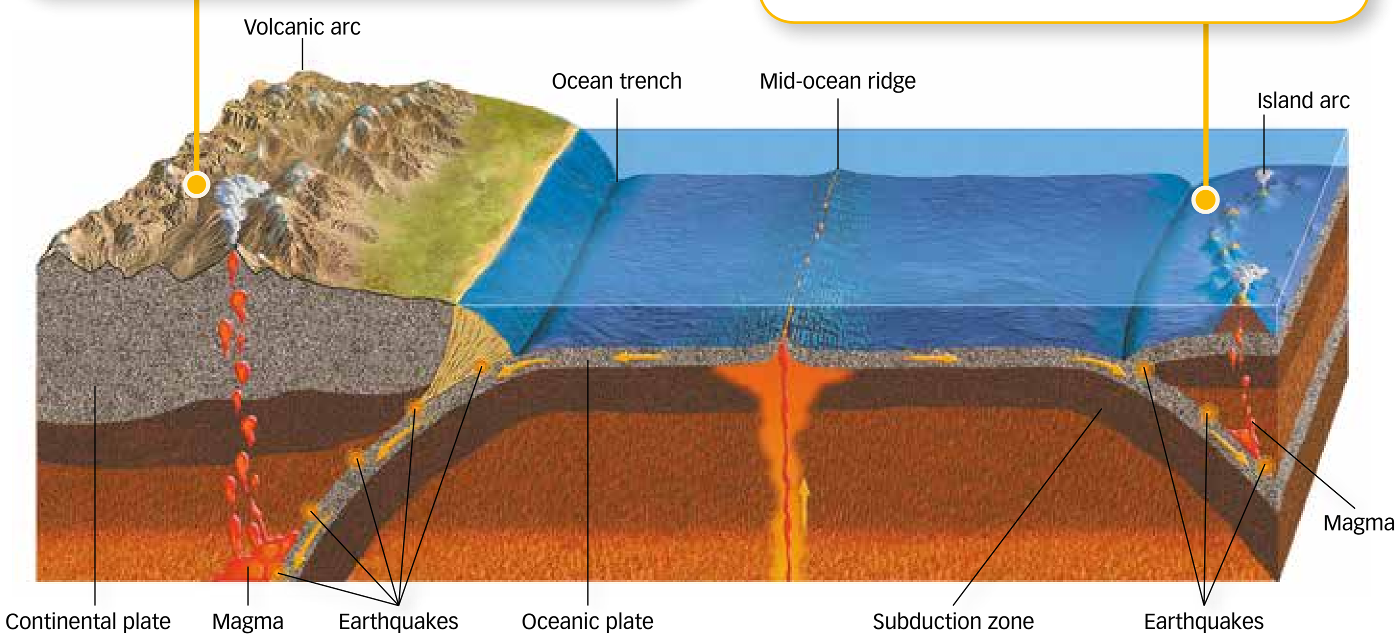
WORK WITH THE IMAGE

1. What are the most important geological events that take place in subduction zones?
2. Choose three features from Figure 1. Describe them in your own words; for example, the collision of oceanic plates.

Figure 1. Formation of subduction zones.

When a continental plate collides with an oceanic plate, a volcanic arc is formed. For example, the Andes were formed when the South American and Nazca plates collided.

When two oceanic plates collide, an archipelago of volcanic islands called an island arc is formed. Island arcs are very common in the Pacific Ocean, for example, Japan and the Philippines.



Continental collision zones

As continental blocks move towards each other, these processes occur:

- The oceanic lithosphere between the blocks subducts under the continental lithosphere.
- Over time, the ocean water disappears. Most of the sediment on the seafloor is compressed and uplifted.

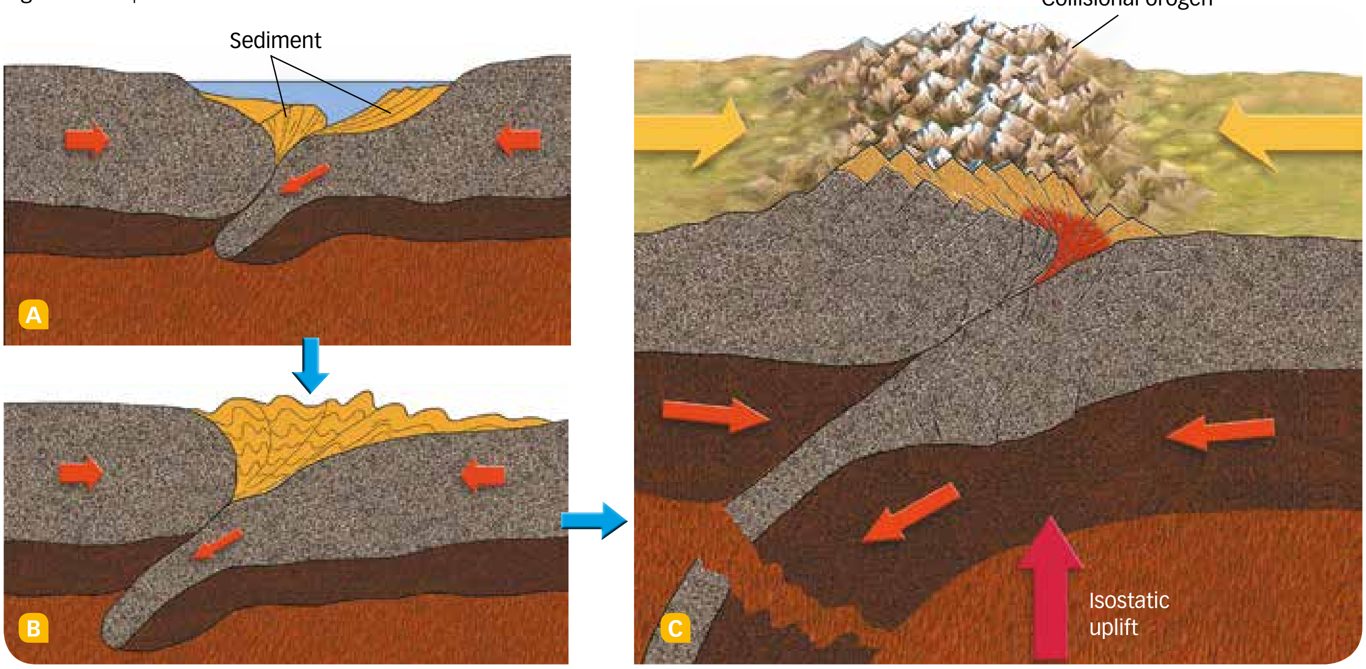
When continental blocks collide, the plates do not subduct because continental lithosphere is too light to sink into the mantle. Instead, compressional forces cause one plate to be thrust over the other until the convergent movement stops. The two plates are joined by a suture formed by a new mountain range. See Figure 2. In this way, continents increase in size.

- The thickness of the continental lithosphere doubles as one plate is thrust over the other.
- A mountain range or **collisional orogen** forms. Examples include the Himalayas, the Pyrenees and the Baetic System in Spain. The highest parts of these mountains usually consist of sedimentary rocks formed on the seafloor. These rocks are rich in marine fossils including molluscs, echinoderms and fish.
- Isostatic uplift of the orogen occurs because the mantle pushes on the thickened lithosphere.

DID YOU KNOW?

The Iberian Plate, when pushed by the African Plate, began to collide with the European Plate 80 million years ago. This collision formed the Pyrenees.

Figure 2. The process of continental collision.



WORK WITH THE IMAGE

3 Describe the processes shown in Figure 2. The arrows will help you. Use the words in the images and others like *form, double, thrust, first, next,* etc.

ACTIVITIES

4 Explain these phenomena.

a) The thrusted plate can be oceanic or continental, but the subducted plate is always oceanic.

b) Sediments are trapped and deformed during the collision of these plates. Where do they come from?

LEARNING OBJECTIVES

- Understand the phenomena that occur at divergent and transform boundaries.
- Study intraplate phenomena caused by hotspots.

2 Divergent boundaries and transform boundaries

Divergent boundaries

Oceanic crust is generated at divergent boundaries as plates move apart. Divergent boundaries have the following characteristics:

- They are fracture zones thousands of kilometres long. Hot material from the mantle rises to the surface, causing intense volcanic activity through fissures. Over millions of years, **mid-ocean ridges** or **underwater mountain ranges** are formed. See Figure 3.
- Volcanism in this area produces large volumes of basalt. In other words, new oceanic crust is formed. This crust adheres to the surface of the mantle, forming a thin lithosphere. See Figure 4.
- Convection currents generate forces that tend to separate the two sides of the fracture. As a result, the fracture stays open and basaltic magma continues to emerge. The depression that is occupied by the fracture is called a **rift**.

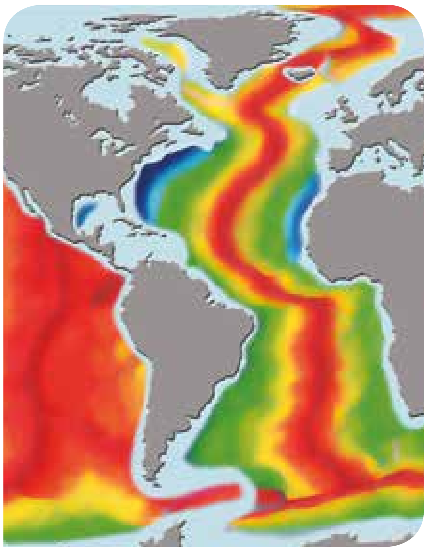
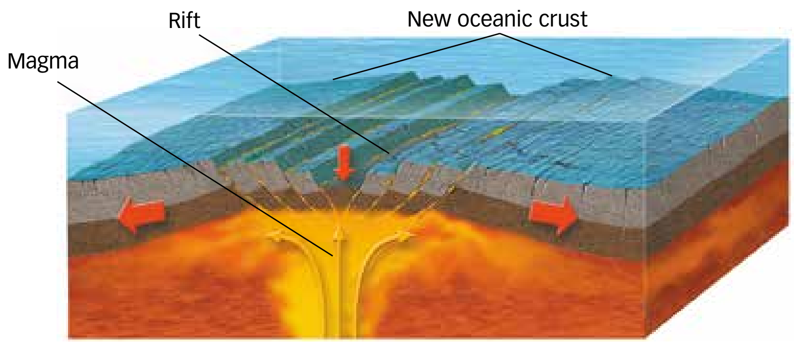


Figure 3. The Mid-Atlantic Ridge. The dark blue areas represent the oldest materials; the red areas the youngest.

Figure 4. Generation of oceanic crust.



Transform boundaries

Transform boundaries are also called conservative or passive boundaries because crust is **neither created nor destroyed**.

Transform boundaries are formed when two plates slide past each other horizontally in opposite directions. See Figure 5. This movement generates **transform faults**. These faults cause earthquakes because of the friction generated between the plates. Most transform faults are located on the seafloor. They cut across mid-ocean ridges perpendicularly and can be thousands of kilometres long. They also occur on continents; for example, the San Andreas Fault between the Pacific and North American Plates.

Figure 5. The San Andreas Fault causes earthquakes that affect California (USA).

ACTIVITIES

1 Look at Figures 3 and 4. Is Iceland increasing or decreasing in size? Explain your answer.

2 Compare divergent and transform boundaries.

3 Design a model to show one type of plate movement. You can use materials like styrofoam, wood and plasticine.

3 Intraplate phenomena: hotspots

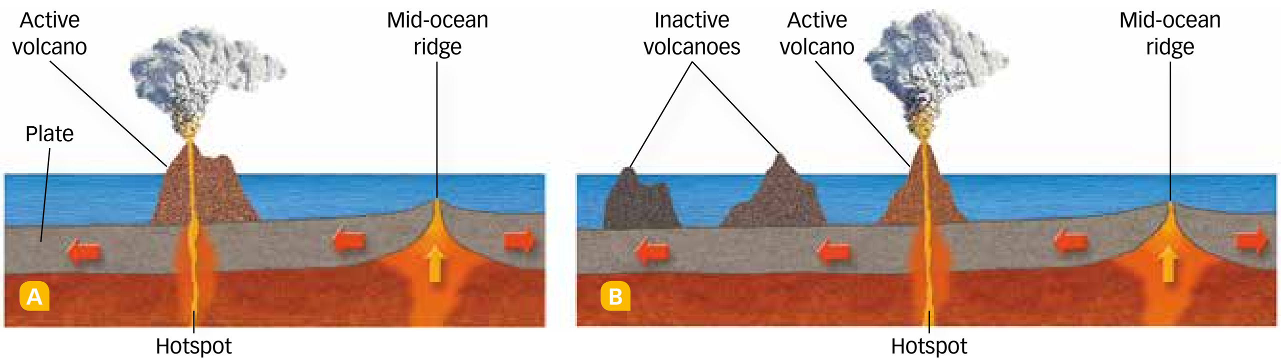
When mantle plumes from the D" layer perforate the lithosphere, they cause hotspots and other phenomena.

- **Formation of volcanic islands.** Islands such as Hawaii and the Canary Islands were formed this way. The islands furthest away from the hotspot are older than the ones nearest it. See Figure 6.

WORK WITH THE IMAGE

4 Complete the sentence. *The age of a volcanic island … as its distance from the hotspot increases.*

Figure 6. How volcanic islands are formed.

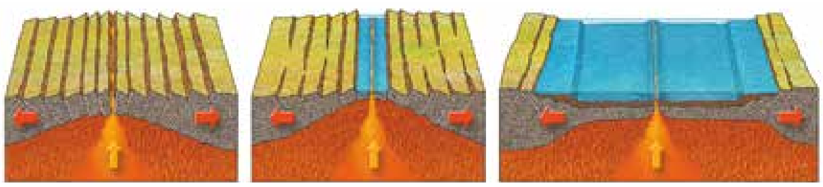


A mantle plume generates a hotspot and causes an underwater volcano to form. The magma accumulates until the volcano rises out of the water, forming a volcanic island.

The hotspot does not move, but the overlying plate does. The magma finds different escape routes and forms new volcanoes. Volcanic activity decreases as the plate moves away from the hotspot.

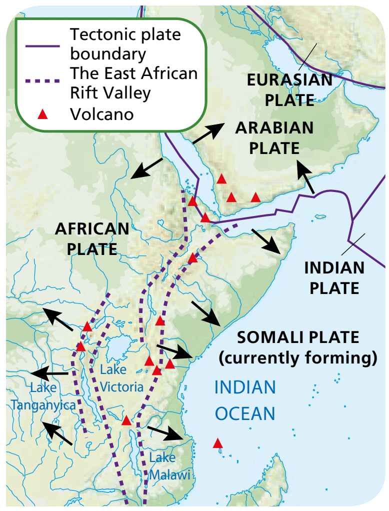
- **Formation of rifts.** Hotspots can generate rifts or deep cracks. Continents can start to break apart as a result of a rift. See Figure 7. This is the case with the Great Rift Valley in East Africa.

Figure 7. How rifts are formed.



Heat from a mantle plume starts to break up the continental lithosphere, forming a rift. New oceanic lithosphere begins to form between the two sides of the rift. Seawater floods the valley, enabling the new ridge to form.

THINK ABOUT IT



Seismic and volcanic activity along the Great Rift Valley is forming a new plate, the Somali Plate. Eventually, it will separate from the African Plate.

ACTIVITIES

5 Do research on the world's most prominent hotspots. Make a map.

6 Show how volcanic islands and rifts are formed. Make models. Materials like a screen, plasticine or toothpaste may be helpful.

LEARNING OBJECTIVES

- Understand how the interaction between internal and external geodynamic processes creates landforms.
- Understand how rocks are transformed, resulting in the rock cycle.

WORK WITH THE IMAGE

1 Look at Figure 8.

a) How are magmatic rocks transformed into sedimentary rocks? Use your own words.

b) What is the difference between *magma* and *magmatic rocks*?

c) Which processes in the rock cycle modify rock composition and appearance? Which take place in the Earth's interior? And on the surface?

4 Interaction between internal and external dynamics. The rock cycle

The Earth has an efficient system for recycling lithospheric plates. On the surface, interactions occur between the atmosphere, biosphere, hydrosphere and geosphere. A combination of internal and external forces generates, shapes and eventually destroys landforms.

The steps in this process can be summarized as follows:

- **Creation of landforms.** Convection currents in the mantle cause material from deeper layers to rise to the surface. This internal process results in volcanism, and causes tectonic plates to move and collide.

  At collision zones, orogenesis generates mountains. The new landforms may sink or rise as a result of isostasy.
- **Modelling of landforms.** External agents, including wind, water, ice and living things, shape the land. These agents modify the landforms and generally flatten the surface of the Earth. That is, areas of high relief are eroded away. These eroded materials fill lower areas called **sedimentary basins**.
- **Destruction of plates.** Subduction occurs in ocean trenches, where gravity causes plates to sink to deeper layers. However, plate tectonics generates new landforms in other places.

The rock cycle

The rock cycle takes place throughout the process of landform building and destruction.

Rocks can be classified into three types: *sedimentary, metamorphic* and *igneous*. See Figure 8.

Figure 8. The rock cycle.

The rock cycle involves the combined action of internal and external dynamic agents.

Materials are transformed into the various rock types through physical and chemical processes, such as the cooling of magma, diagenesis and metamorphism.

Rocks eventually fragment into finer materials due to weathering and erosion. These fragments are transported by external agents, like wind and water. They accumulate in sedimentary basins as layers (sedimentation).

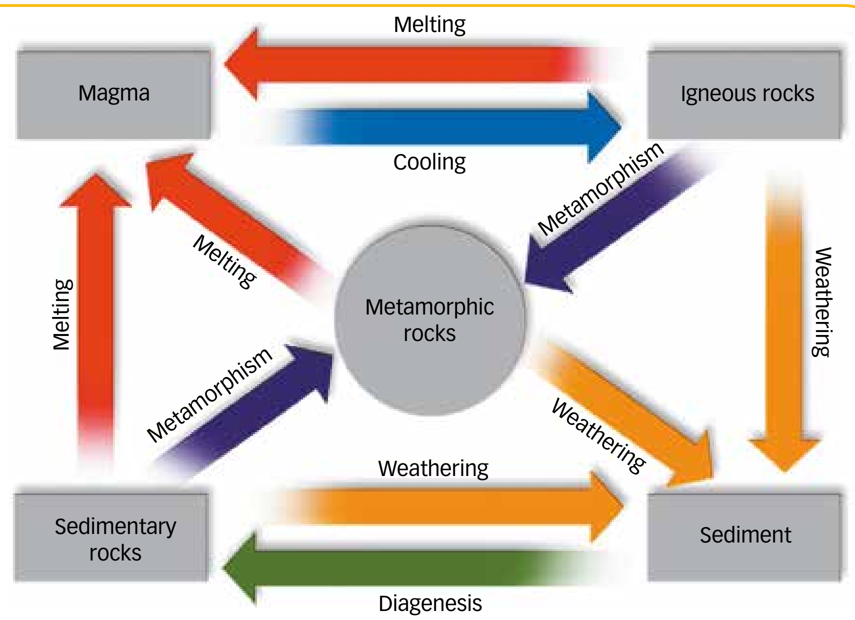
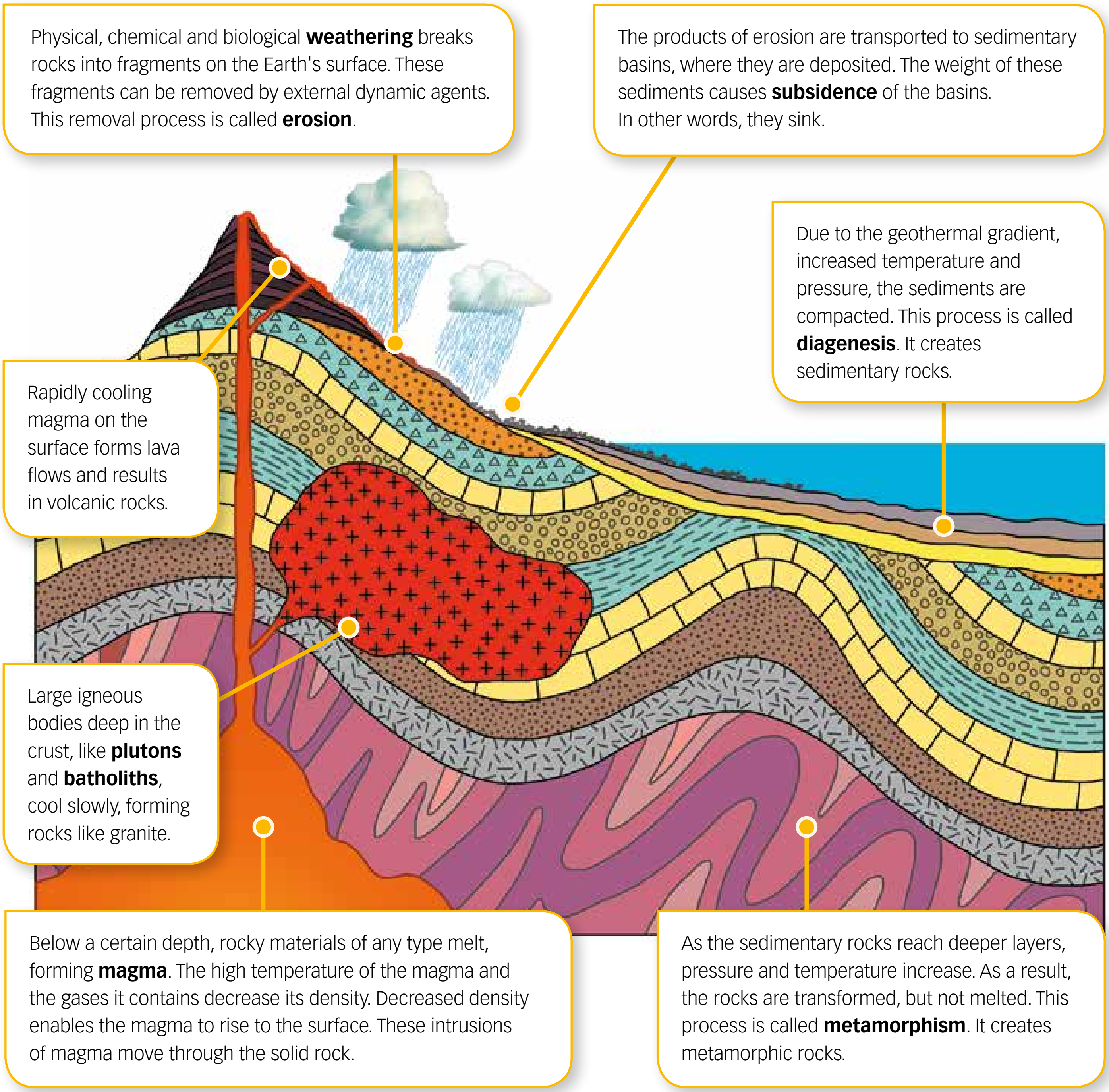


Figure 9. How rocks are formed and altered.



WORK WITH THE IMAGE

2 Look at Figure 9. How is the origin of granite different from that of a sedimentary rock? And from a metamorphic rock?

3 Look at Figure 9. What processes bring materials down from the Earth's surface to its interior? And from the interior up to the surface? In which areas does each process take place?

4 Define these concepts in your own words. *Diagenesis, magma, metamorphism, plutons* and *weathering.*

ACTIVITIES

5 Simulate the rock cycle in your classroom. What materials and equipment would you need?

LEARNING OBJECTIVES

- Identify the different types of deformation that rocks undergo.
- Understand what folds are and identify the basic types.

5 Folds

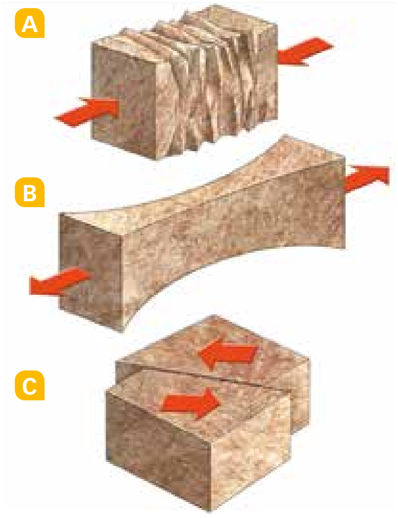
The rocks in the crust of the Earth are constantly subjected to stress generated by tectonic plates. There are three types: *compression*, *tension* and *shear*. See Figure 10. Each type of stress deforms the rocks. The type of deformation depends on the:

- Duration and intensity of the stress.
- Pressure and temperature.
- Rock composition and physical and chemical characteristics.

There are three types of deformation:

- **Elastic deformation** is reversible. When the stress stops, the material returns to its initial shape. Seismic waves caused by earthquakes produce this type of deformation.
- **Brittle deformation** is irreversible and can be caused by compression or tension. Sometimes the stress exceeds the elastic or ductile capacity of rigid rocks. As a result, the stress causes the rocks to break.
- **Ductile deformation** occurs when rocks are subjected to intense compressional stress over millions of years. This type of deformation is irreversible.

Figure 10. Types of stress.

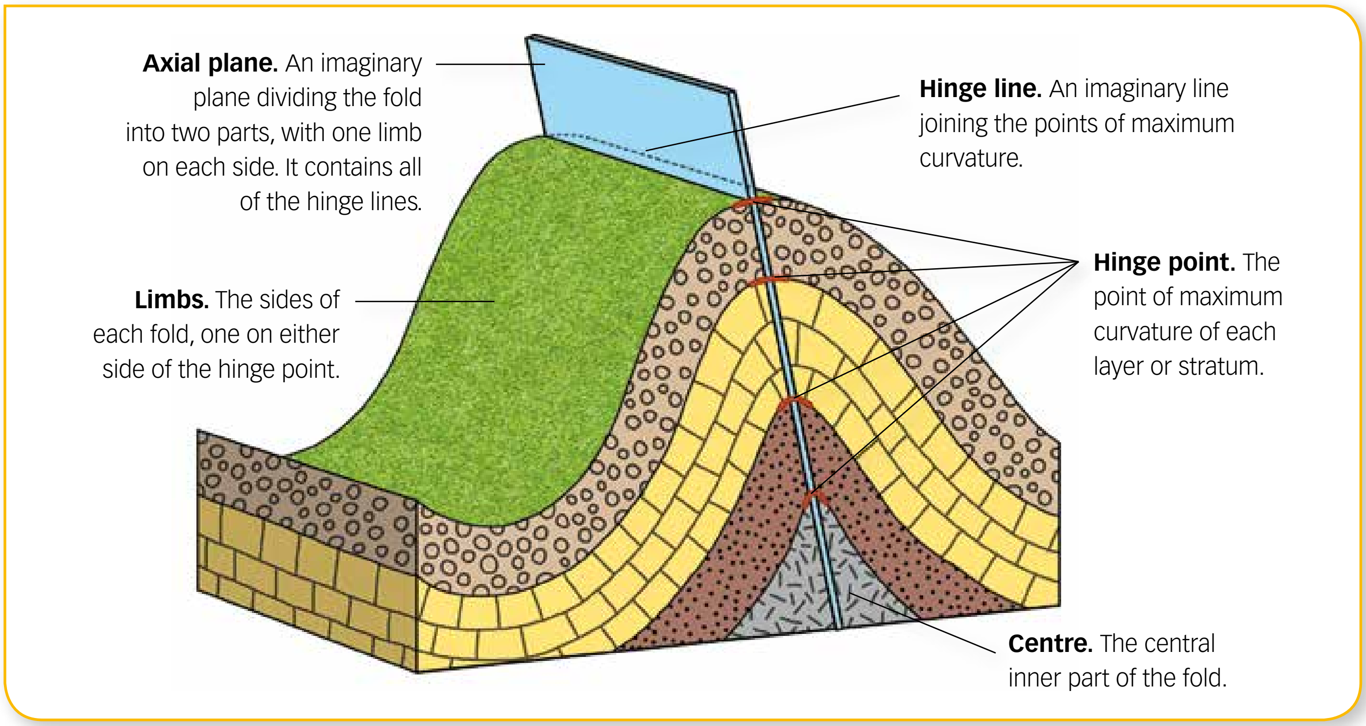


The movement of tectonic plates can cause different types of stress.
A. Compression. B. Tension. C. Shear.

Folds

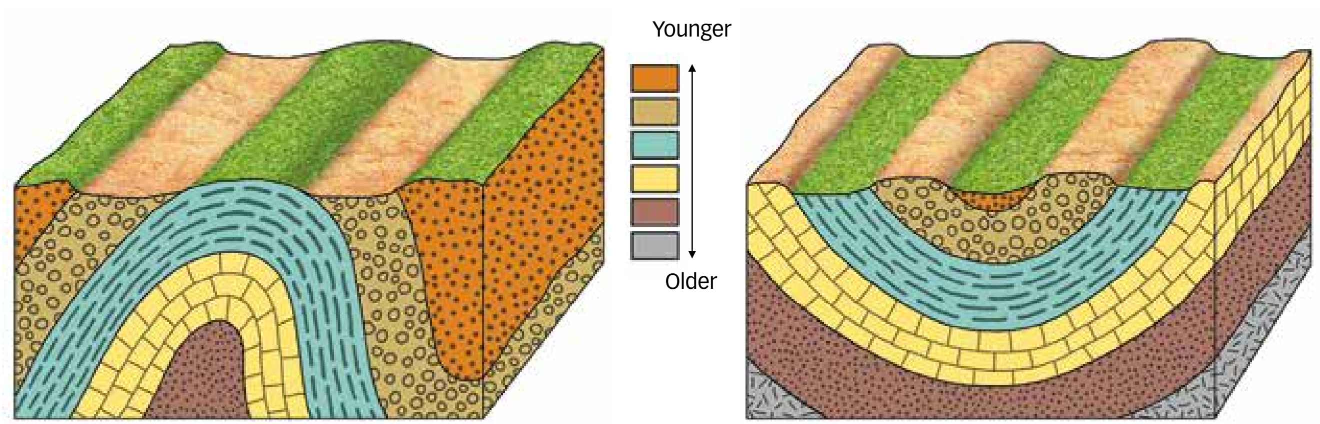
A **fold** is a bend or an undulation in rock. It is the result of ductile deformation. To understand how folds form, it is important to recognize their components. See Figure 11.

Figure 11. Components of a fold.



Types of folds

Figure 12. Anticlines and synclines.

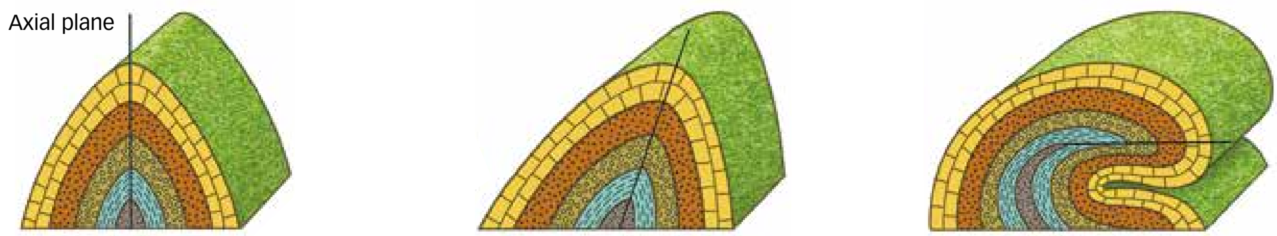


In **anticlines**, the oldest layers are at the centre and the younger ones surround the other layers. Anticlinal folds are concave down, or A-shaped.

In **synclines**, the youngest layers are at the centre. The older ones surround the other layers. Synclinal folds are concave up, or V-shaped.

There are different types of anticlines and synclines depending on the position of the axial plane. See Figure 13.

Figure 13. Types of folds.



Upright (symmetrical). The axial plane is vertical, so the two limbs are symmetrical.

Inclined (asymmetrical). The axial plane is moderately inclined: between 90º and 0º.

Recumbent. The axial plane and the limbs are almost horizontal.

ACTIVITIES

1. Look at Figure 10. What materials could you use to simulate each type of stress?
2. Look at Figures 10–12. Listen and choose the correct answer.
3. Summarize the information on folds in a table. Use these headings: *Name, Axial plane, Limbs*.
4. Draw this fold. The arrow points to the oldest strata. Is it anticline or syncline? Label its main parts. Find more photos. Make a slide show.

LEARNING OBJECTIVES

- Distinguish between different types of brittle deformation and describe how they occur.

WORK WITH THE IMAGE

1 Look at Figure 14. Which types of faults form when the lithosphere stretches?

2 Make models of the faults in Figures 14–17. Use clay or coloured plasticine.

6 Joints and faults

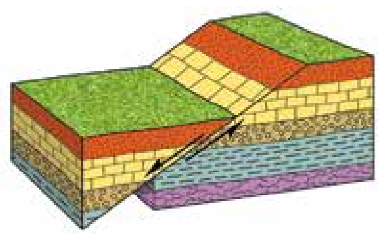
When rocks cannot absorb the stress to which they are subjected, they fracture or break. Fracturing is brittle deformation. It can be caused by any type of stress: *compression, tension* or *shear*. Fractures range in length from a few millimetres to thousands of kilometres.

There are two main types of fractures:

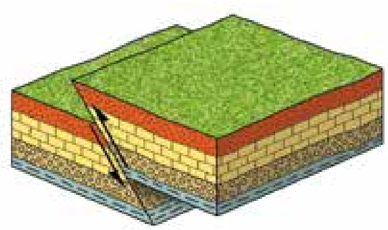
- **Joints.** The rock fragments remain in their initial position. Tectonic joints usually occur in well-consolidated rocks subjected to stress.
- **Faults.** There is displacement of one block with respect to the other. These fractures are usually accompanied by earthquakes.

The dislocation of the two blocks, or **fault walls**, generates three basic types of faults: *normal, reverse* and *strike-slip*. See Figure 14. They differ with regard to the angle of the fault (the dip) and the direction of the slip along the fault.

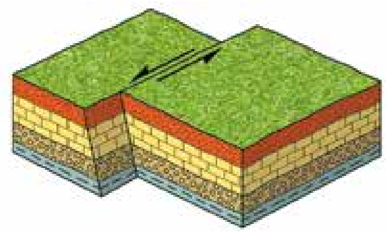
Figure 14. Types of faults.



Normal faults are formed by tensional stress. One of the blocks moves downward.



Reverse faults are formed by compressional stress. One block is pushed above another.



Strike-slip faults are formed by shear stress. The sides move horizontally relative to one another.

Areas with many fractures are called **fault zones** or **fault systems**. These often generate complex structures, such as depressed blocks of terrestrial crust called **grabens** and raised fault blocks called **horsts**. See Figure 15.

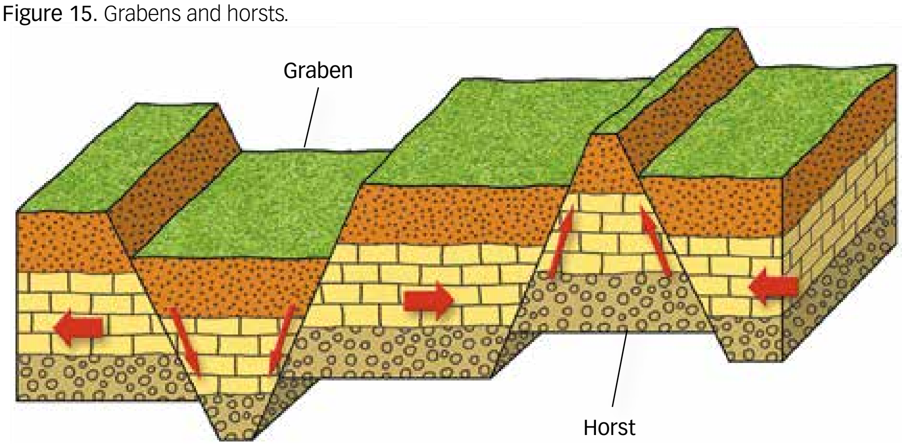
WORK WITH THE IMAGE

3 Look at Figure 15.

a) Define *graben* and *horst*.

b) Find examples of both structures on the Iberian Peninsula, such as the River Tajo valley.

Figure 15. Grabens and horsts.

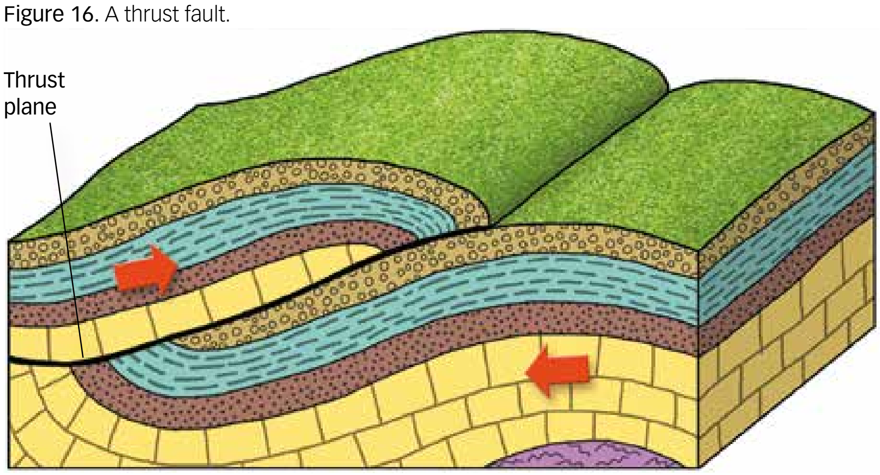


Thrust faults and thrust sheets

These brittle deformations are more complex.

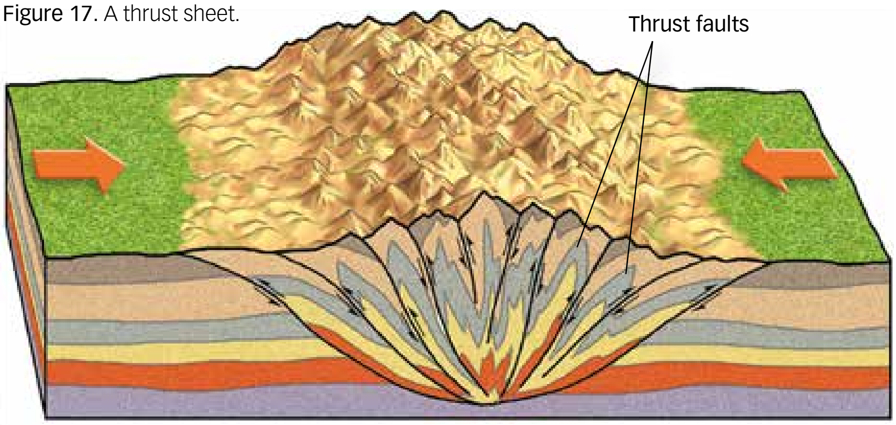
- A **thrust fault** is a combination of an almost horizontal fold and a reverse fault. One block is pushed over another. See Figure 16. Older strata in the upper block lie on top of the younger strata in the lower block.

Figure 16. A thrust fault.



- A **thrust sheet** is a series of reverse faults covering a large area. See Figure 17. Thrust sheets usually form during collisional orogenies when material between plates is subjected to high compressional stress.

Figure 17. A thrust sheet.



WORK WITH THE IMAGE

4 **Look at the photo.** What does the red line represent? And the red arrow? Where are the oldest materials? And the youngest?

ACTIVITIES

5 **Make a drawing of the fault shown in this photo.**

a) What kind of fault is it? How do you know?

b) Draw arrows to indicate the direction of the forces that caused this fault.

c) Find two more photos. Repeat steps *a* and *b*.

6 **Summarize the information on faults.** Make a table with these headings: *Type of fault, Type of stress, Movement.*

LEARNING OBJECTIVES

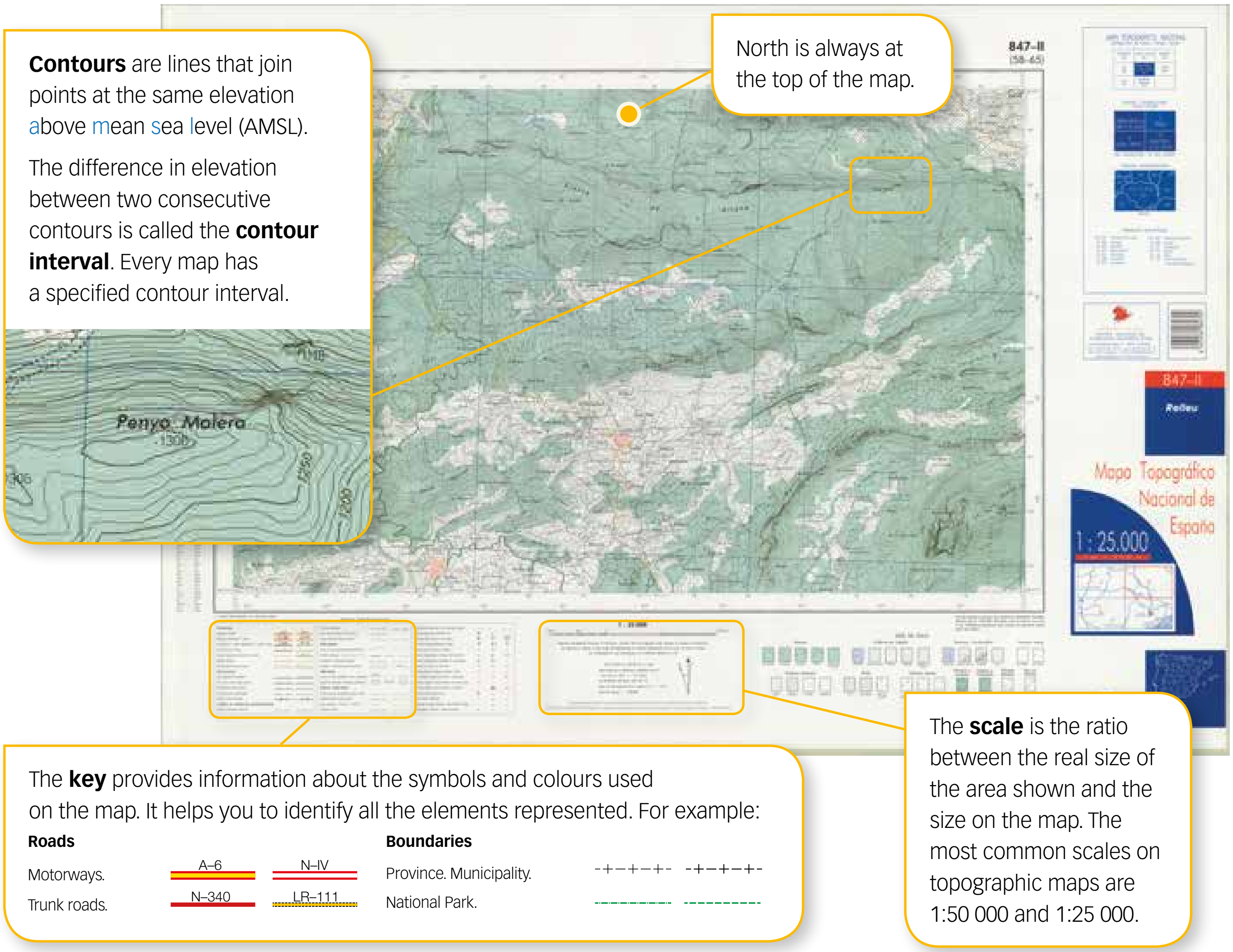
- Describe the most important elements of a topographic map.
- Draw and interpret topographic profiles, and understand their usefulness.

7 Representation of relief. Topographic maps

Topographic maps are two-dimensional maps. They show the relief in an area projected onto a plane. They are basic tools used for many activities: deciding on hiking routes, designing civil engineering projects, land use planning and predicting geological risks.

Topographic maps contain various elements. Each provides different information. See Figure 18.

Figure 18. A topographic map.



ACTIVITIES

1 Use this formula to calculate scale, real distance and distance on the map. *Scale = Map distance / Real distance.*

a) Two points are 8 km apart on the ground and 10 cm apart on the map. What is the map scale?

b) Two points are 10 cm apart on the map. The map scale is 1:20 000. How far apart are the points on the ground?

c) Two points are 2 km apart on the ground. How far apart are they on a map with a scale of 1:50 000?

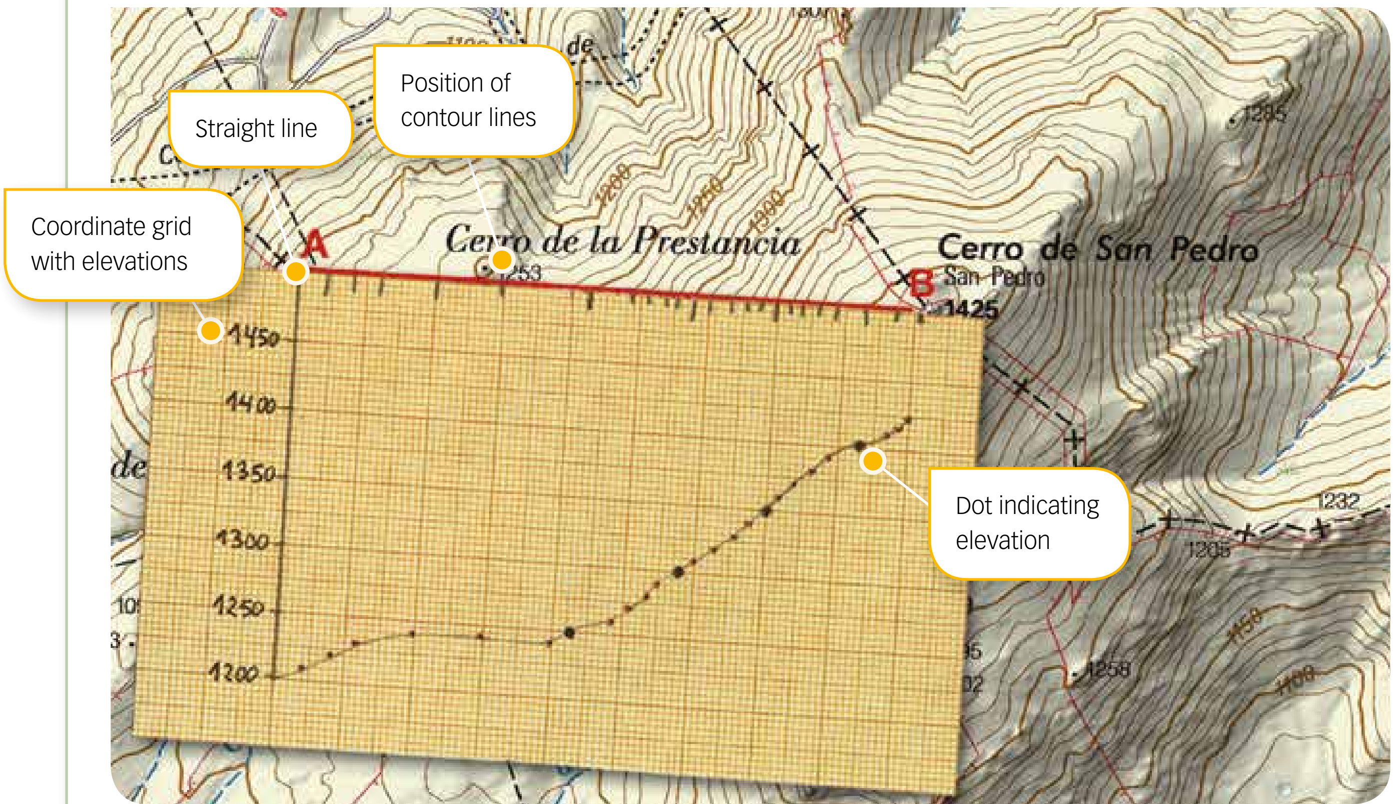
KNOW HOW TO

Draw a topographic profile

Topographic profiles between two or more points make it possible to visualize relief. Topographic profiles are very useful when planning routes.

To draw a topographic profile, you will need a contour map, graph paper, a ruler and a pencil.

- Place the graph paper on the map. Position the top edge between the two points you want to study. Draw a straight line between the points, here A and B.
- On the edge of the graph paper, mark the position of each contour line between the two points. Indicate the elevation of each contour as a dot.
- In the space below the line, draw a coordinate grid with the values of the elevations you need to represent. Mark the positions of the contours on the x-axis. Mark the elevations on the y-axis.
- Connect the contour points with a line.



ACTIVITIES

2 Use the map on the right to do the activities.

a) List points A, B, C and D from greatest elevation to least elevation.

b) What difference in altitude is there between *Casa del Chaparral* and the highest elevation?

c) Draw these profiles: A–C and B–D.

d) **Role-play.** Choose a hiking route: A–C or B–D. Refer to the profile to support your choice.

3 Make a 3D model of this map. Materials: card and an enlarged photocopy of the map. Trace each contour line on the card and cut it out. Superimpose the layers using silicone to create more thickness.

ACTIVITY ROUND-UP

REVISE BASIC CONCEPTS AND FACTS

1 Summarize the unit by answering these questions.

a) What geological phenomena occur at the boundaries of tectonic plates?

b) What intraplate phenomena and what type of formations do they produce?

c) How does the rock cycle take place?

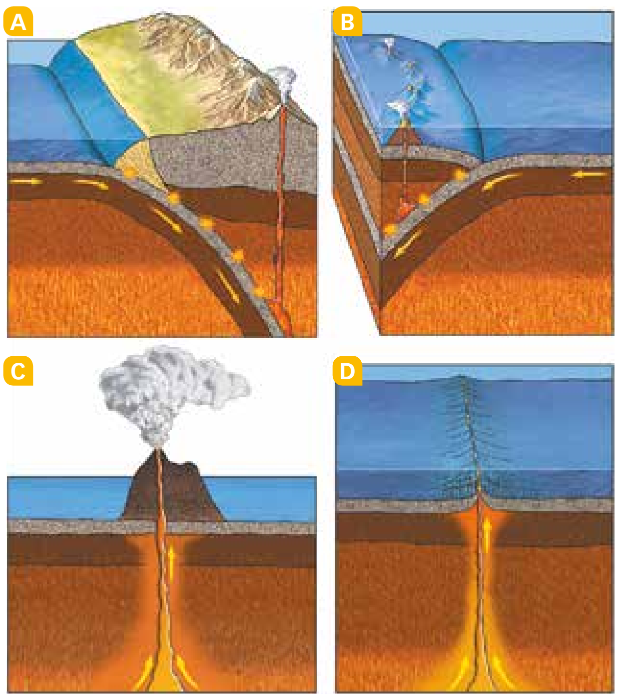
d) What type of deformations can rocks undergo?

e) What are the different types of folds like? Name and describe them.

f) What types of faults are there?

g) What are the main elements on a topographic map?

2 Look at the diagrams. Explain the geological phenomena shown in each.



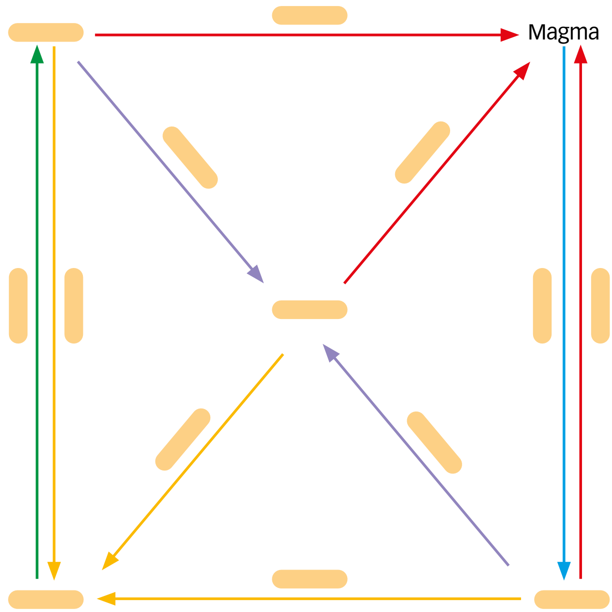
3 Explain the difference between each pair.

a) Island chains and volcanic islands.

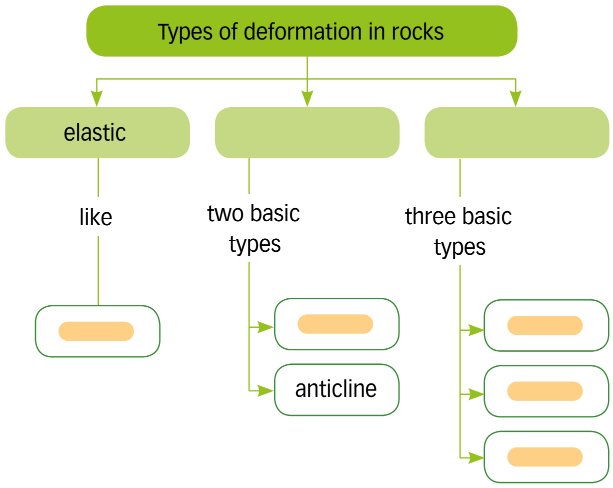
b) Continental rifts and mid-ocean ridges.

4 Explain the interaction between *internal geological phenomena* and *external geological agents*. Summarize what happens from the moment landforms are created until they are destroyed.

5 Copy and complete the diagram of the rock cycle.



6 Copy and complete this concept map.



7 Define these concepts. Draw or find photos to illustrate your definitions:

- *Thrust sheet.*
- *Reverse fault.*
- *Subduction.*
- *Transform fault.*
- *Hinge point.*
- *Batholith.*
- *Syncline.*
- *Graben.*
- *Scale.*

8 Make 3D models of folds. Use plasticine in a different colour to represent each layer and card for the axial plane.

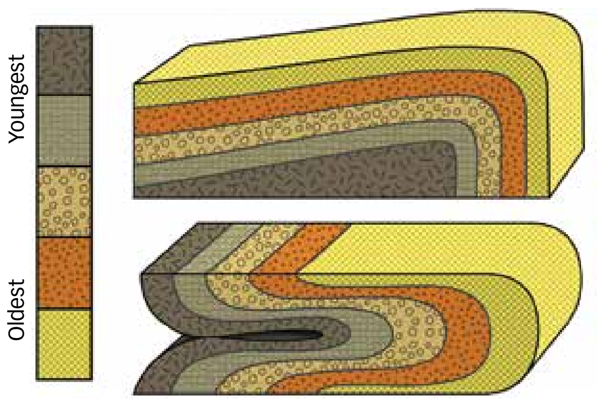
9 When would you use a topographic map? Describe its main features.

10 Compare anticline and syncline folds. Make a Venn diagram.

APPLY WHAT YOU KNOW

11 Look at the photos. Name each geological structure. Explain how each was formed.

12 Look at the drawings. Which represents an anticline? Which represents a syncline? Use the key on the left to decide. Describe the formation process of each.



SCIENTIFIC ANALYSIS

The atoll mystery

An atoll is an island that apparently consists entirely of coral. Atolls are generally ring-shaped with a lagoon in the middle. Most are found in the open sea, far from the coast. Until recently, the origin of atolls was a mystery. Why did the coral grow in a circle?

In the 1830s, British naturalist Charles Darwin proposed a theory to explain atoll formation:

- Coral began to grow on a volcanic island.
- Eventually, the coral grew up to the surface.
- The island gradually disappeared due to erosion or the effects of other geological agents.
- The coral continued to grow, forming the atoll.

In 1947, scientists exploring the base of the Bikini Atoll in the Pacific Ocean confirmed Darwin's theory.

13 Describe the process of atoll formation. What geological phenomenon causes this formation?

14 Illustrate Darwin's atoll formation theory. Make a comic strip with four vignettes.

15 Explain this phenomenon. As volcanic rocks cool, their density increases. How, then, could the volcanic islands disappear as atolls formed?

16 Many species in danger of extinction inhabit coral atolls. Write a tweet encouraging people to protect them and stop trading coral illegally.

Identify the characteristics of impact craters

Impact craters are formed when two solid bodies collide. These collisions usually involve a smaller body, such as an asteroid or comet, and a larger body, such as a satellite or planet.

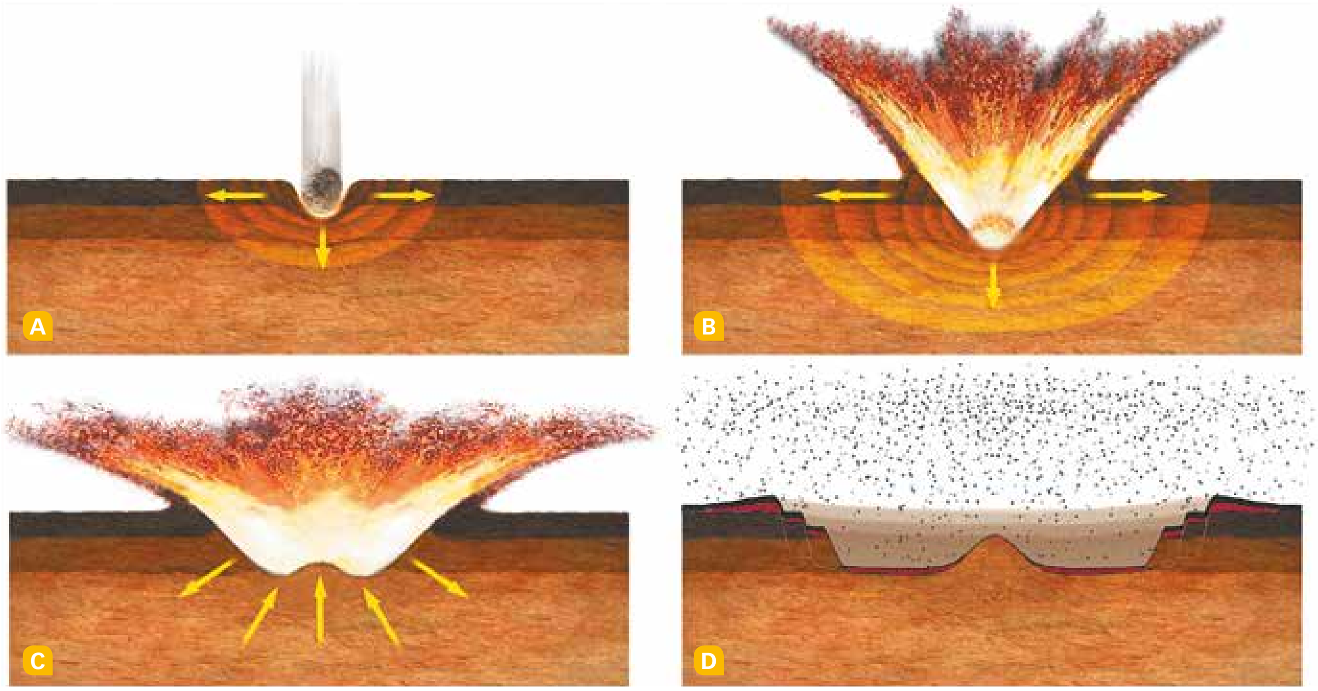
When these collisions occur, the impacting body is completely vaporized, leaving no traces behind. The impacted body also changes. One part undergoes intense metamorphism and melts. The other part fragments into finer particles.

The fragments, collectively called **ejecta**, are expelled from the crater. The distance the ejecta travels depends on its mass. Ejecta is deposited around the crater.

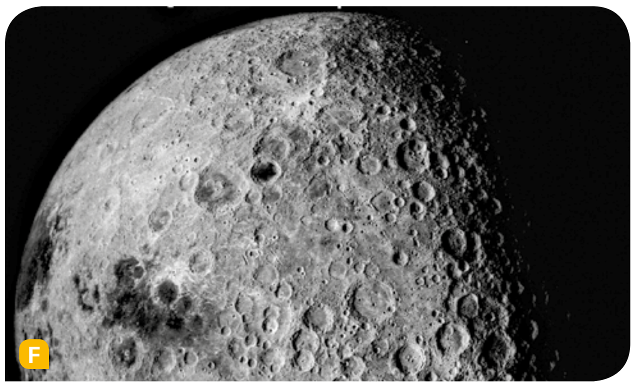
Craters with diameters of more than 2 km experience more intense change. The rebound of the shock wave causes the centre of the crater to uplift.

Impact craters are given this name to differentiate them from craters of volcanic origin. Volcanic craters form in a very different way.

Figure 19. Formation of an impact crater.



Around 130 impact craters have been recorded on the Earth. Others may have disappeared over time as a result of erosion.



It is estimated that there are more than 300 000 impact craters on the Moon. The Moon has no atmosphere, so these craters have not been eroded.

ACTIVITIES

1 How can you differentiate between an *impact crater* and a *volcanic crater*?

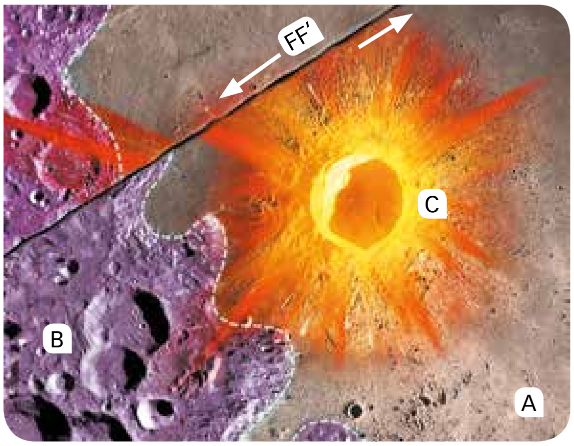
2 Look at the photo of craters on the Moon. What criteria could you use to decide which are the oldest and which the youngest?

3 Find and print a photo of an impact crater on the Earth. Label it: *geographical coordinates, elevation* and *diameter*.

4 Look at the drawing of the Moon's surface. Explain the order in which these structures were created:

- A – structure with no craters.
- B – structure with craters.
- C – crater with ejecta.
- FF' – fault.

Remember: a structure is younger than the ones that it affects.



COOPERATIVE PROJECT

Make a model of an impact crater

Create a model that shows how impact craters are formed by meteorites.

- Work in groups of two or three. Meet with your teacher to decide where you will carry out the experiment.
- Think of the materials you need. For example, a slingshot to propel the 'meteorite'. What materials can you use to represent a meteorite? And the impacted surface? Remember that this surface must reflect the impact.

Experiment with fine sand or flour. Use different coloured layers so that you can see which are impacted. Ejecta may vary in size depending on the velocity of the impact.

- Make a list of the materials you need. Decide which group member will be responsible for each one.
- Carry out the experiment and record the results. Results will vary depending on the angle of impact, the size and type of material used for the meteorite, and the surface.
- Take photos of the craters. Make a poster to explain your results.