A Resource Booklet for SACE Stage 1 Earth and Environmental Science

The following pages have been prepared by practicing teachers of SACE Earth and Environmental Science. The six Chapters are aligned with the six topics described in the SACE Stage 1 subject outline. They aim to provide an additional source of contexts and ideas to help teachers plan to teach this subject.

For further information, including the general and assessment requirements of the course see: https://www.sace.sa.edu.au/web/earth-and-environmental-science/stage-1/planning-to-teach/subject-outline

A Note for Teachers
The resources in this booklet are not intended for 'publication'. They are 'drafts' that have been developed by teachers for teachers. They can be freely used for educational purposes, including course design, topic and lesson planning. Each Chapter is a living document, intended for continuous improvement in the future. Teachers of Earth and Environmental Science are invited to provide feedback, particularly suggestions of new contexts, field-work and practical investigations that have been found to work well with students. Your suggestions for improvement would be greatly appreciated and should be directed to our project coordinator:: lenaltman9@gmail.com

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Chapter 3

TOPIC 3: Processes in the Geosphere

1.1 Uniformitarianism

1.2 Finding evidence of the Earth’s structure

1.3 Processes within the Earth’s interior

1.4 The Earth’s tectonic processes

1.1 Uniformitarianism

Observation of present-day processes can be used to infer past events and processes, by applying the principle of Unitarianism.

- Explain how features of sedimentary rocks can provide information about their history.

James Hutton was a Scottish doctor, geologist and intellectual and in the late 1700s founded one of scientific geology's fundamental principles - **uniformitarianism**. Hutton developed this principle by observing the geological relationships that were occurring around his home. Hutton noticed that geological processes such as sedimentation and erosion changed the shape of landscapes and that these processes occur continuously over time.

Figure 1.11 James Hutton

While working in Scotland and abroad Hutton realised that if given enough time ice could erode rock, streams can carve valleys and sediments can accumulate to create landforms. Hutton surmised that millions of years were required for Earth to become the shape that it is.

Fig 1.12 Hutton’s principle of Uniformitarianism

He believed that “the present is the key to the past”, suggesting that processes that can be viewed in modern landscapes have operated in exactly the same way throughout geological time. For example, layers of sandstone are formed in exactly the same way that sand is currently deposited on beaches and this theory can be used to help explain the formation of landforms through the evidence found in the geological record. Although strict uniformitarianist thinking is over-simplified, it is still useful to explain what we see in the rock record as often the simplest explanations are the correct ones. These ideas led to our understanding of the Rock Cycle as it is today

Use of Sedimentary features

All around us there are many geological features that can be interpreted by using the principle of uniformitarianism and modern sedimentary environments are one such example. High water energy like that found in a fast running stream or active shoreline usually has much finer sediments. When we see these types of distinctive features we assume that deposition of those sediments have been influenced by the environmental factors that can be seen in the current environment.

Example:

Ripple marks observed in Sandstone remind us of the ripple marks that can be observed in sand at the beach. Uniformitarianism suggests that when ripple marks are evident in rock that this rock has been formed in a similar environment to the beach. It is then assumed that when ripple marks are seen in a rock, that this view was formally the top surface of a sandy plain that has been exposed to a persistent current of water or wind.

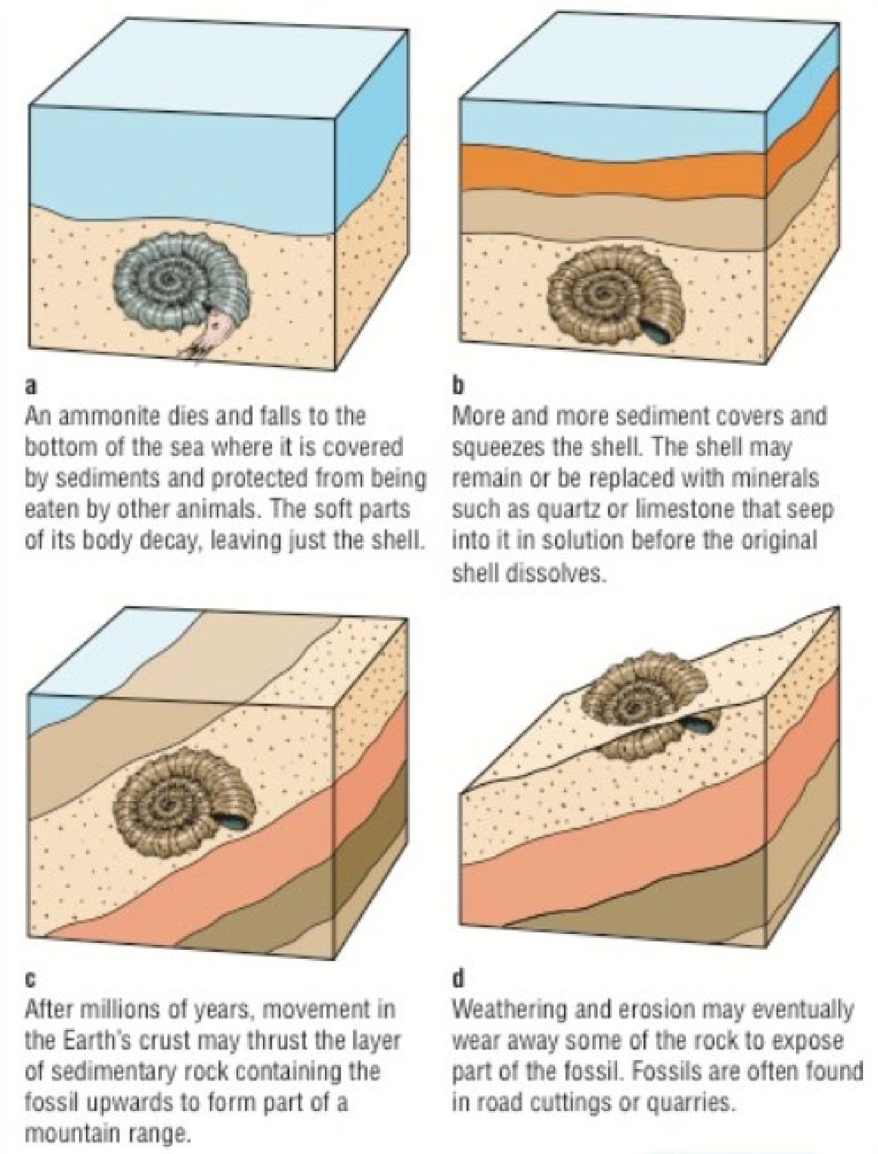
Figure 1.13 Ripple marks in Sandstone

Figure 1.14 Ripple marks on beach

Sedimentary Structure	Formation	Geological Interpretation
Mud Cracks	 Mud cracks are sedimentary structures formed as muddy sediment dries and contracts. Crack formation also occurs in clay-bearing soils as a result of a reduction in water content.	 When mud cracks are observed within sedimentary layers we assume we are looking at the top surface of deposited sediment and that this surface must have been exposed to air so that it can dry out.
Graded Bedding	 When sediment is carried by either wind or water, heavier sediments are dropped first and finer sediments are the last to be deposited.	 When graded bedding is observed in a sedimentary rock layer it is assumed that the depositional environment had high energy currents capable of carrying a range of sediment clast (grains of crystal) sizes, thus the heavier clasts will indicate the bottom of the layer.
Cross-bedding	 This is formed as a result of movement from wind/water currents.	 When cross bedding is observed within a sedimentary rock layer it means that the rocks were formed as a result of a consistent current.

Fossils

Because many sedimentary features can be formed through either wind or water currents it can sometimes be difficult to determine which of these is responsible for the formation of the observed features. This can be overcome by examining other evidence within the rock layer such as fossils which can indicate the environment in which sediments were deposited.



1.15 Formation of fossils

Organisms can leave traces of their existence in geological deposits in the form of fossils. Fossils are the remains or impression of a prehistoric plant or animal embedded in rock and preserved in petrified form. Using uniformitarianism we can say that if an organism lives in a particular environment today, any ancestors in the form of fossils must have lived in a similar environment in the past.

Example:

Marine fossils found within a sandstone layer indicate that the sediment has been deposited in a marine environment. Because these organisms live underwater, the environment under which the sediments have been deposited to form this rock must have been underwater.

Fig 1.16 Fossilised shells in sandstone

Fig 1.17 Fossilised fern leaves in sandstone

Likewise, fossilised fern leaves evident in sandstone indicate that the formation of this rock was most likely to have occurred in a terrestrial environment (on land), such as a forest. The specific species of fern can then provide further data as to the potential climate at the time of deposition.

Uniformitarianism and extra-terrestrial environments

Uniformitarianism is a concept that can also be applied to settings outside of the Earth. Observations of other planets within our solar system such as Mars indicate this principle can be used to determine past environments. High-resolution images taken from the orbit of Mars and other images from the Mars Rover *Curiosity*, suggest that the rocks forming Mount Sharp (a mountain on Mars) are sediments. Using Uniformitarianism, the lowest and oldest strata may have been deposited from a crater lake when conditions must have been warmer and wetter on Mars.

Figure 1.18 Strata at the base of Mount Sharp on Mars

Question 1

Uniformitarianism is used by geologists to help understand the depositional environments required to form the rocks we see today.

(a) In the Sturt Gorge of South Australia geologists have found solid rocks that are texturally similar to loose sediments that are now being deposited by active glaciers in the European Alps. Geoscientists have concluded that there must have been glaciers in South Australia in the past. State the principal used to make this conclusion.

____(1 mark) **KA1**

(b) Explain how the quote “the present is the key to the past” relates to the principal of uniformitarianism.

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(c) James Hutton was a Scottish philanthropist who is responsible for the introduction of the uniformitarianism principle. Describe the influence James Hutton had when forming his idea.

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(d) In recent geological history, some inland areas of Australia have been covered by sea. Explain what evidence could be used to form this conclusion.

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____(3 marks) **KA2**

(e) Sedimentary features found in rocks can help geologists to determine the type of environment at the time the rock was formed.

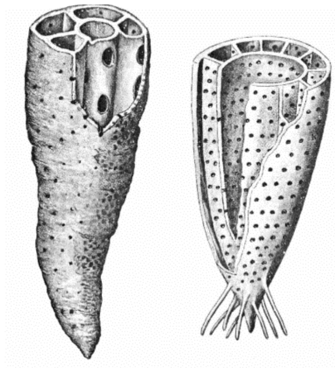
(1) In the table below, use the images provided to explain the depositional environment required to produce the features observed.

Image	Feature	Depositional Environment
		

(2 marks) **KA2**

(2) Brachina Gorge is a famous landmark in South Australia for its abundance of fossils. One such fossil that is commonly found is the archaeocyatha pictured below.



(3) Considering the archaeocyatha is a sea sponge found on coral reefs, explain the depositional environment required for the rock to form if these fossils are present inside it.

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(4) The image below is from the Mars Exploration Rover *Opportunity*. It shows layered rocks in a ledge named "Payson" on the edge of Erebus Crater on Mars.

Explain how this sedimentary feature suggests water was once present on Mars.

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1.2 Finding evidence of the Earth's structure

The study of seismic waves and meteorites provides evidence for the layered structure of the Earth.

- Explain how the presence of shadow zones provides information about the layered structure of the Earth.

When rocks suddenly break, an earthquake occurs and energy is produced. This energy radiates through the Earth and along the Earth's surface as wave fronts (known as seismic waves). Seismographs are machines that are used to detect these waves. There are 2 main types of waves; Surface waves and Body waves. Some seismic waves are able to travel only through the Earth's surface while others can travel through the crust and mantle, through to the other side of the Earth as seen in the table below.

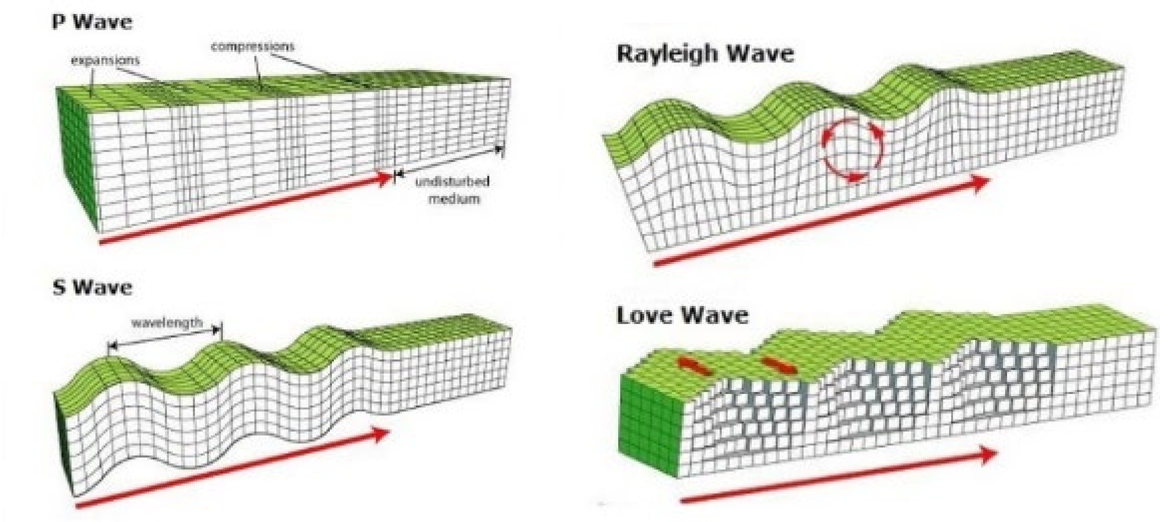

Figure 1.21 Different types of Seismic Waves

Type	Name	Relative Speed	Penetration
Body Wave	P-wave (Primary, Compressional)	Fastest wave, speed increases with depth in Earth (5-16km/sec)	Travels through solids and liquids
Body Wave	S-wave (Secondary, Shear)	Slower than P-waves	Travels through solids only
Surface Wave	R-wave (Rayleigh)	Slowest wave	Travels along the surface of the Earth
Surface Wave	L-wave (Love)	Slowest wave	Travels along the surface of the Earth

Refraction of Earthquake Waves

The speed a wave travels depends on the density of the medium the wave is travelling through. As a wave passes from one medium to another, the density changes, causing the wave to refract; changing its speed and the direction it is travelling in. This happens with all types of waves (not just seismic ones) and can especially be seen for both water and light waves.

Example:

Light waves are refracted as they pass from water into glass because the density of glass is much higher than the density of air. As light travels from air into glass, the speed and direction the light is travelling changes as well. This bend observed is called refraction.

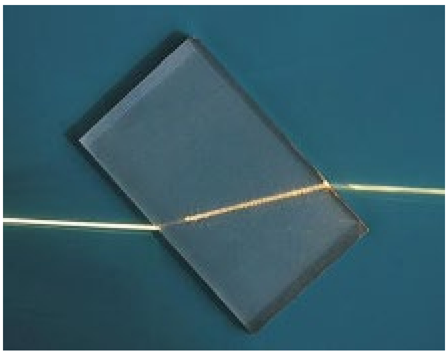

Figure 1.22 Refraction of light as it travels through glass

Because the density of Earth's mantle increases with depth, earthquake waves are gradually refracted towards the Earth's surface as they travel through the mantle.

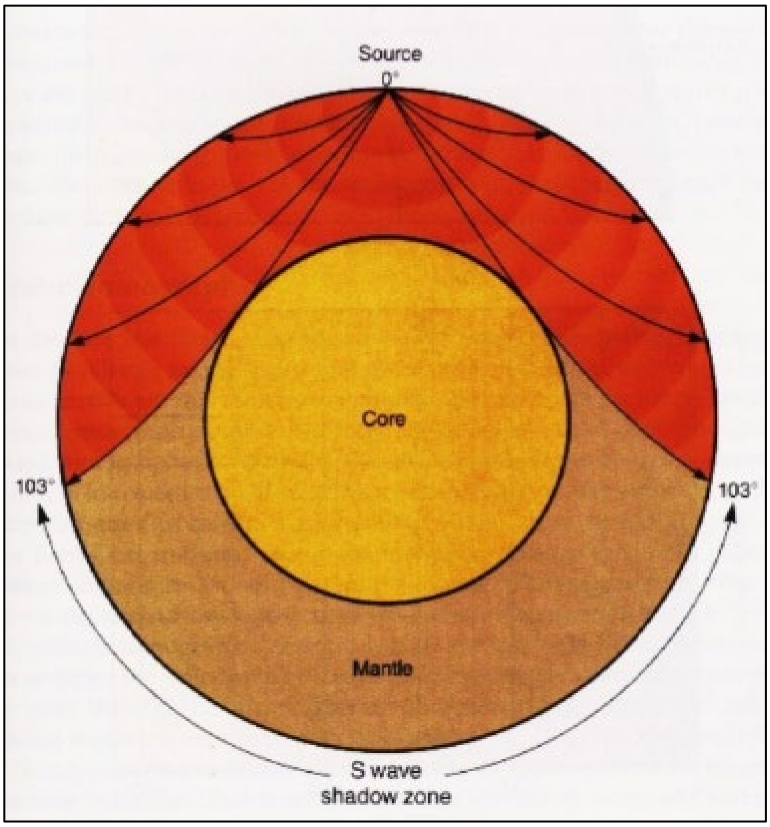

Figure 1.23 Refraction of seismic waves as they travel through the mantle

Shadow zones

At certain points of the Earth's surface, seismographs can only faintly detect earthquakes after seismic waves have passed; these points are known as Shadow Zones. During an earthquake, seismic waves radiate spherically from the point at which they originate (the Focus).

The P-Wave Shadow Zone

P-waves undergo refraction at the boundary between the mantle and the outer core. This means that P-waves are not received by seismic stations in a band around Earth extending between 103° and 145° from the earthquake's epicentre. This region is known as the P-wave shadow zone and it is the size of this zone that has enabled geologists to determine the depth of the mantle.

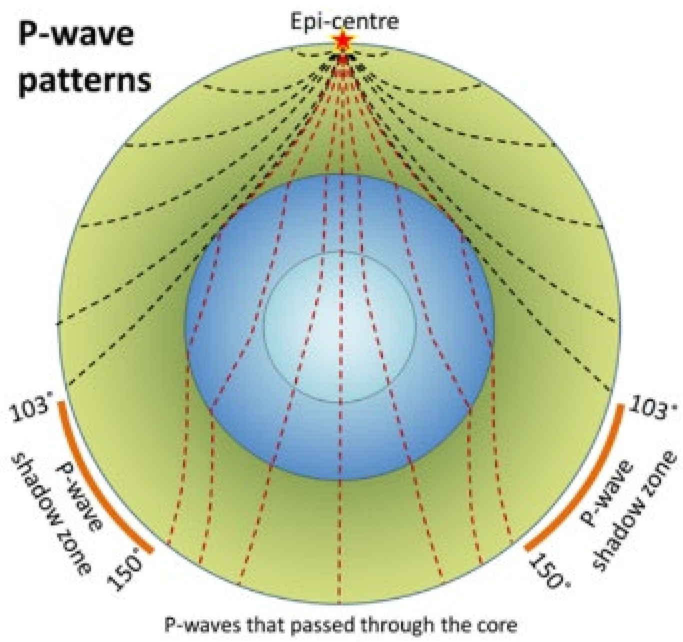

Figure 1.24 P-wave shadow zones

The S-Wave Shadow Zone

S-waves are different to P-waves as they cannot travel through liquids. The S-wave shadow zone therefore extends from 103° on one side of the earthquake to 103° on the other. This implies that the outer core of the earth is liquid.

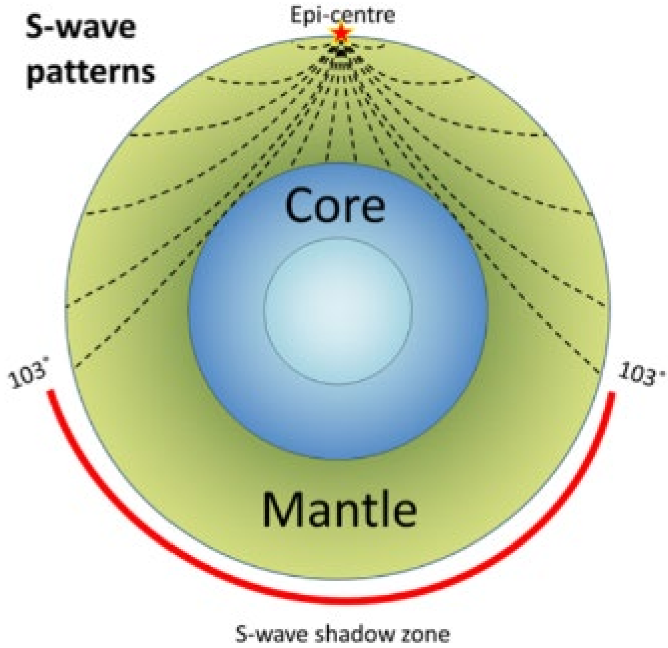

Figure 1.25 S-wave shadow zones

The diagram below shows the S-wave and P-wave shadow zones produced by an earthquake that occurred in North America. The S-wave shadow zone is much larger because of the liquid core.

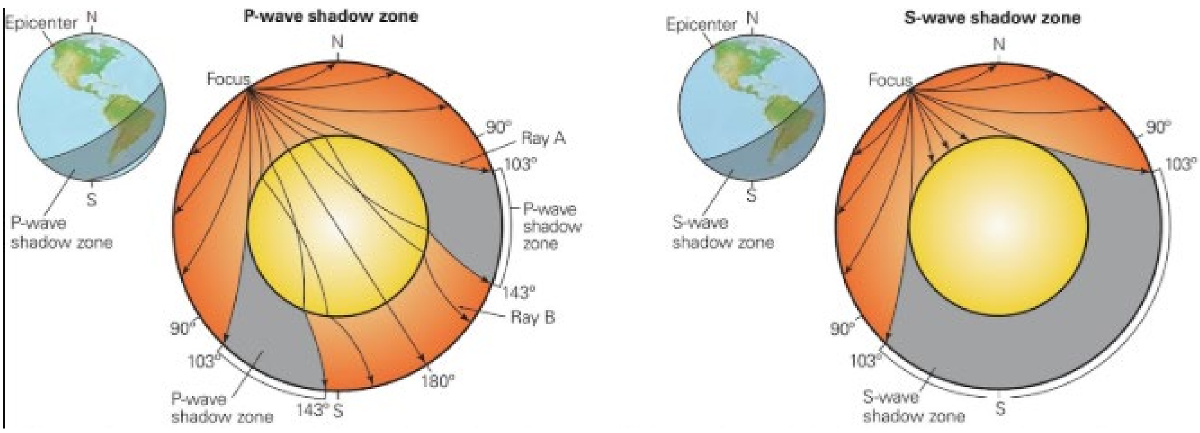

Figure 1.26 S-wave and P-wave shadow zones for Earthquake at the North Pole

Shadow zones and the Composition of the Earth

The deepest mine is currently 3.9km below the surface and the deepest drill hole is 12.3km; this is the deepest we have seen below the surface (only 0.19% of the Earth's radius). As such, physical observation has not provided enough indication of the internal structure of the Earth and geologists have therefore had to use several types of indirect measurements to gain a clearer picture of what lies beneath our surface, including the study of seismic waves and their shadow zones.

The study of seismic waves provides a measurement of how fast waves travel through the Earth and how they bend, reflect or refract as they travel. Researchers can determine the exact depth to the crust-mantle and mantle-core boundaries and can use this information to determine sub-layers.

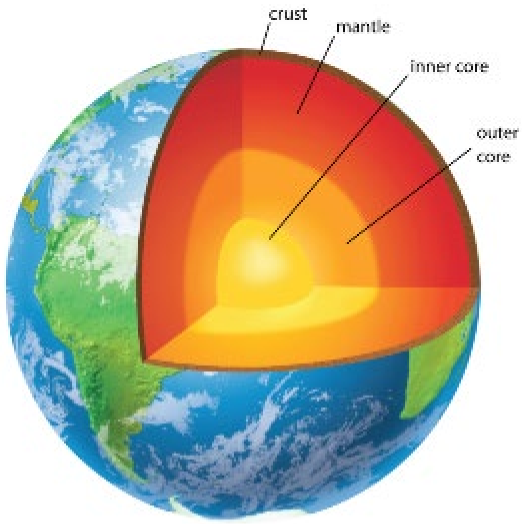

Figure 1.27 Internal structure of the Earth

If the density of the earth increased gradually all the way to the centre, P-wave shadow zones would not exist because waves passing into the interior would curve up and reach every point on the surface. The presence of P-wave shadow zones indicates there is a boundary within the Earth that changes density abruptly as the waves refract down at a sharp angle, known as the core-mantle boundary. The presence of an S-wave shadow zone implies there is a solid mantle and a liquid outer-core.

Question 2

Geologists have used the study of seismic waves to help determine the structure of the Earth.

(a) State the category each of the following seismic waves belong to (body or surface).

a. P-wave

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b. S-wave

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c. L-wave

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d. R-wave

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(2 marks) **KA1**

(b) Describe the motion of Love and Rayleigh waves.

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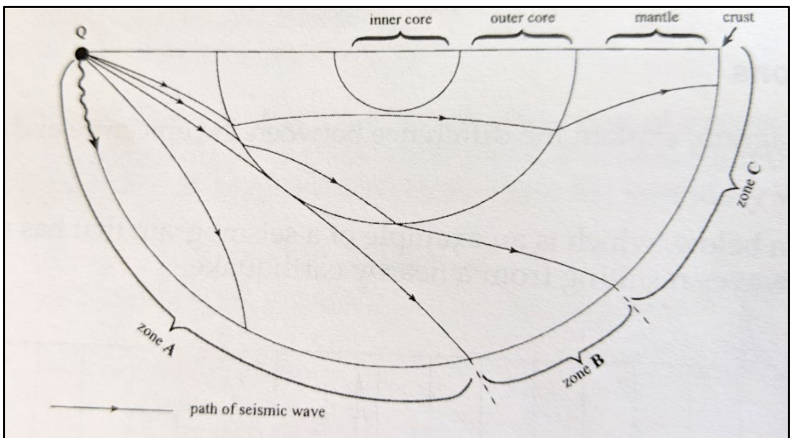
(c) The diagram below shows part of a cross-



section through the Earth and the paths of some of the P, S and L seismic waves that originated at point Q. Three different seismic zones are marked A, B and C.

(1) Name the scale used to measure the intensity of the seismic waves detected.

____ (1 mark) **KA1**

(2) State the term used to describe the zone around the Earth where neither P or S-waves can be received.

____ (1 mark) **KA1**

(3) Describe whether or not P and/or S-waves could be received in each of the zones, A, B and C on the cross-section diagram from an earthquake that originated at point Q.

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(4) Explain why some locations (in part (3)) could not receive P and/or S waves.

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_______________________________________(3 marks) **KA2**

(5) Explain what would happen to the size of the zone where no P or S-waves were detected if the size of the outer core were larger.

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_______________________________________ (2 marks) **KA2**

The study of seismic waves and meteorites provides evidence for the layered structure of the Earth.

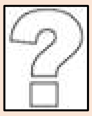
- Explain how the composition of a meteorite can provide evidence of the internal composition of the Earth.

Meteorites

Solid objects that strike the Earth from space are called meteorites. Most meteorites are asteroidal or planetary fragments and they are classified as iron (made of iron nickel alloy), stony (made of rock) or stony iron (rock imbedded in a matrix of metal). From their composition researchers have concluded that some meteors are asteroids that have differentiated into a metallic core and rocky mantle before shattering into fragments during collisions.

Figure 1.28 iron, stony and stony iron meteorites

Meteorites come from planetesimals (a minute planets) and protoplanets (a large body orbiting the Sun in the process of forming into a planet) similar to those from which the Earth formed 4.5 billion years ago. This means that to characterise the Earth’s mantle and core, Geologists can study meteorites because it can be considered that the average of meteorites is representative of the average composition of the whole Earth. The chemicals and minerals present within meteorites provide clues as to what was happening at the final stages of the formation of Earth and other bodies in our solar system. This has allowed geologists to make estimates of the proportions of different elements in Earth, without actually seeing the internal structure of our planet. Stony meteorites are most likely similar in composition to the mantle and iron meteorites are similar to the core.

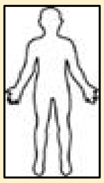
 Potential Field Trip:

If you wish to see examples of meteorites, there are a number of specimens on display in the TATE Museum at the University of Adelaide and the South Australian Museum.

Guides can be found on the following links:

www.adelaide.edu.au/uni-collections/unimuseums/UC_Tate_Museum_EMAIL.pdf

www.samuseum.sa.gov.au/Upload/files-education/text/seniormineralinvestigation.pdf

 Potential SHE task topics:

- The development of scientific investigation into determining the layers of the Earth’s interior.
- The collaboration that has occurred between different geologists/geophysicists across the globe in order to determine the layers of the Earth’s interior.
- The applications and limitations of seismographs when determining the layers of the Earth.
- The Influence seismographs have had in the classification of the layers of the Earth.

Question 3

Analysis of meteorites have been instrumental in the formation of a model of the Earth's structure.

(a) Explain how the composition of meteorites has influenced the development of our current model of the internal structure of the Earth.

(6 marks) **KA3**

(b) Discuss one limitation the use of meteorites may have on the validity of our model of the Earth's core.

(3 marks) **KA3**

(c) Research a major meteorite impact in Australia. Discuss when it occurred, the effect it had on the local environment and species at the time and what features remained from the time of impact.

(10 marks) **KA4**

The study of seismic waves and meteorites provides evidence for the layered structure of the Earth.

- Describe the structure, relative thickness, composition and state of each layer of the Earth's interior.
- Describe how continental crust is different from oceanic crust.

All of our knowledge about the interior of the Earth comes from indirect evidence but geologists are now very certain about the interior structure of the Earth. Studies into seismic waves have proven that the structure of the Earth is layered.

Professor Andrija Mohorovicic of the University of Zagreb (Croatia) was the geophysicist and meteorologist responsible for the identification of the boundary between the crust and the mantle in 1909.

Figure 1.29 Profesor Andrija Mohorvicic

He observed that certain seismic waves arrived at detecting stations sooner than predicted and from this, he deduced that the earthquake occurred in what had to be an outer layer of Earth (now known as the crust) and that the faster waves must have travelled through an inner layer (now known as the mantle). The boundary between these two layers is now known as the Mohorovičić discontinuity or the Moho. Much later observations by more sophisticated instruments have since confirmed his discovery.

The Earth's Interior

The layered structure of the Earth is believed to have been developed during the early formation of the Earth. When determining the layers, 2 methods are used; one recognising compositional differences due to material types and mineralogy and the second recognising mechanical transitions between materials.

Silicate minerals (SiO_2) make up 95% of the Earth's Crust because the Earth is made up of mostly oxygen (45.2%) and silicon (27.2%). Calculated by weight, the Earth is then made up of aluminium (8%), iron (5.8%), calcium (5.1%), magnesium (2.8%), sodium (2.3%), potassium (1.7%), titanium (0.9%), hydrogen (0.14%), manganese (0.1%) and phosphorus (0.1%); combining to form millions of compounds.

The materials making up the Earth are largely segregated into a number of compositionally distinct layers due to the changes in density of the materials. The internal structure of the Earth can be seen in more detail in the diagram below.

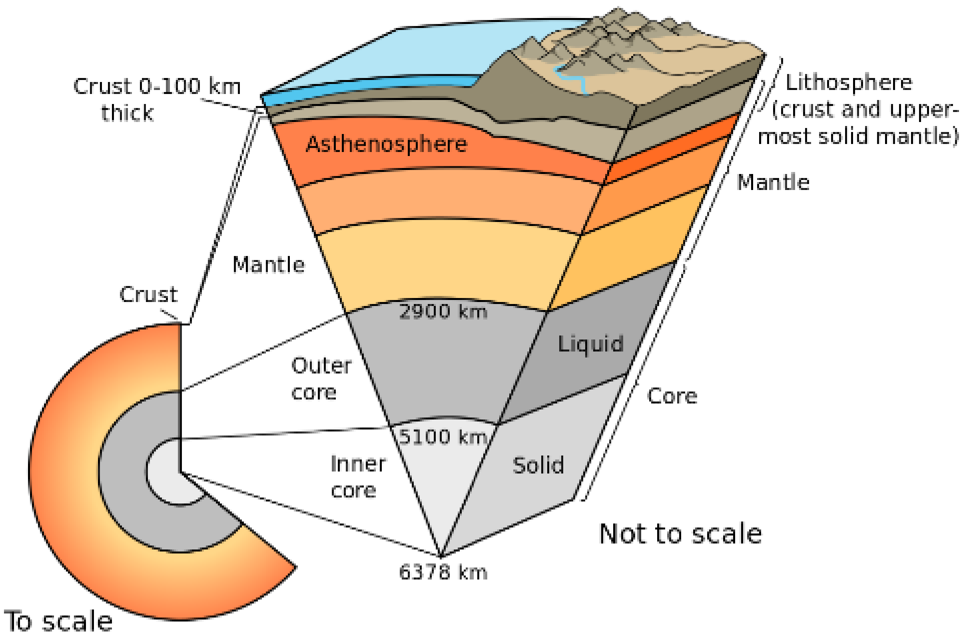


Figure 1.291 layers of the Earth with accompanying depths

The following table summarises the essential properties for each of Earth's layers.

Name of Layer	Thickness (km)	Physical state	Composition
Crust: Continental Oceanic	25 – 70 7-10	solid solid	granitic (sial) basaltic (sima)
Mantle	2885	solid	peridotite
Outer core	2100	liquid	alloy of Fe & Ni
Inner core	1400	solid	same as outer core.

The Crust

The surface of the Earth is actually its outermost layer, known as the crust. As it is the layer we are standing on, it is the layer we are the most familiar with. While it contains all of our resources the crust is the thinnest layer of the Earth, being only 0.1-1% of the Earth's radius. The exact thickness of the crust varies greatly however, depending on the location.

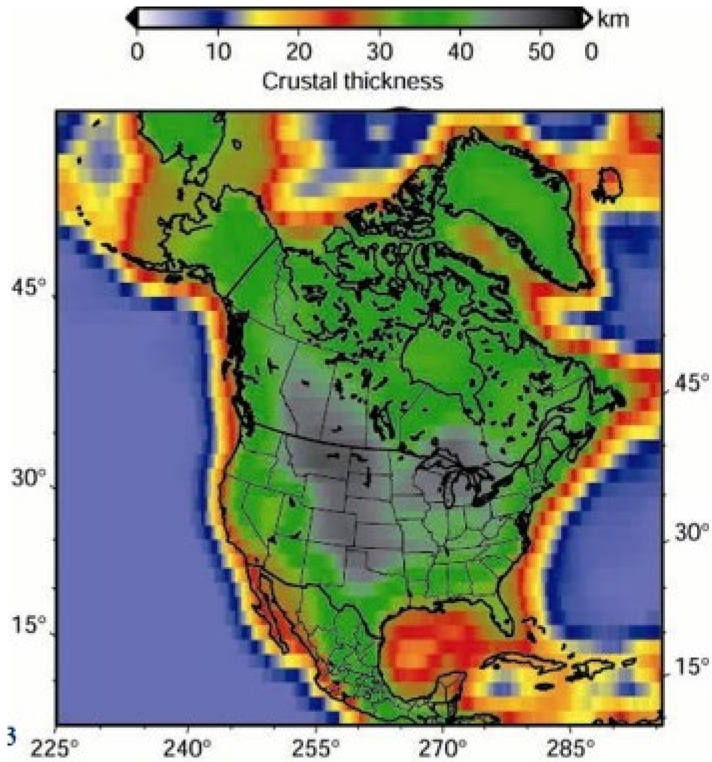


Figure 1.292 differences in thickness of the crust beneath North America

The map (Figure1.292) is compiled from measurements of seismic waves and gravity. Because crustal rocks have lower density than mantle rocks, the force of gravity tends to be slightly weaker over regions of thickened crust.

Geologists distinguish between two fundamentally different layers of the crust; continental and oceanic. These two layers are different in both composition and density. The continental crust averages 4-5 times the thickness of oceanic crust but is much less dense. Continental Crust is less dense as it is rich in silicon and aluminium (Si and Al; hence sial) and composed of more felsic igneous rocks such as granite. Oceanic crust is denser as it is composed of materials that are denser in composition; silicon and magnesium (Si and Ma; hence sima) and is made up of more mafic igneous rocks such as basalt.

The Mantle

The mantle of the Earth forms the thickest layer at around 2900km surrounding the core. This layer is made up of higher density silicate rocks such as olivine, pyroxene, garnet, spinel and peridotite but once the mantle is deeper than 660km, pressure becomes too high and these form into rocks that can only be seen at the surface from high pressure rock experiments. The mantle makes up 84% of the Earth by volume.

Because of this massive pressure difference at 660km, geoscientists have divided this layer into 2 sub-layers; the upper and lower mantle. Almost all of the mantle is solid rock but the temperature of this rock is so hot from a depth of 100-150km, that the rocks are soft enough to flow. The flow is extremely slow however, at a rate of 15cm per year. Though overall the temperature of the mantle increases with depth, the specific temperature also depends on the location as some areas are considered hot spots (for example Hawaii). This distribution of warmer and cooler temperature indicates that the mantle experiences convection currents similar to water, as cooler, denser material sinks while warmer, less dense material will rise. These convection currents are believed to be responsible for tectonic plate movement.

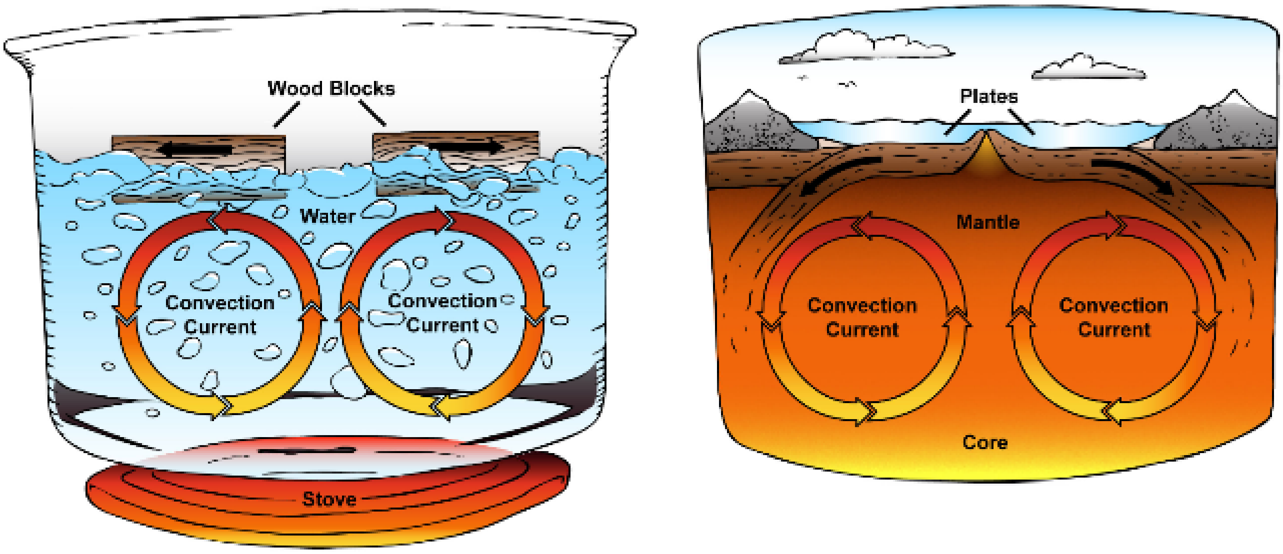


Figure 1.293 convection currents due to changes in temperature

The Core

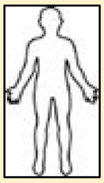
Suggested Activity: Demonstration of convection currents

<u>Apparatus:</u>

1 x large, glass, flat bowl	1 x blue food dye
2 x 250mL beaker	1 x red food dye
1 x kettle	1 x cup of ice
1 x stirring rod	

<u>Method:</u>

1. Fill the large bowl with tap water.
2. In one beaker, place a few ice cubes and 100mL of tap water with 2 drops of blue food dye and stir.
3. In the second beaker, add 100mL of boiling water and 2 drops of red food dye and stir.
4. Carefully lower both beakers into the large bowl of water, while slowly tipping each beaker onto its side.
5. Observe the movement of colour in the bowl.

 Potential SHE task topics:

- Explore the contributions (communication and collaboration) different scientists have made during the last century to form our current understanding of the structure of the Earth's interior.
- Discuss how the developments in technology over the last century have made understanding the interior of the Earth much easier.

Question 4

The interior of the Earth is made up of 3 main layers; the crust, the mantle and the core.

(a) Mohorovicic first identified the boundary between the crust and the mantle in 1909.

(1) The Moho was identified by mapping variations in the velocity of seismic waves within the rocky outer layers of the planet. State the physical feature of the planetary interior that this seismic discontinuity corresponds to.

____ (1 mark) **KA1**

(2) Explain how the development of technology has allowed geoscientists to state with more certainty the composition and layering of the Earth's interior.

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____ (3 marks) **KA3**

(b) Sima and sial are simplified compositional criteria used to subdivide the outer crust of the Earth.

(1) Describe what makes crustal rock either sima or sial.

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____(3 marks) **KA1**

(2) Explain why they are different from the terms oceanic and continental crust.

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(3) Explain how oceanic and continental crust are different.

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(3 marks) **KA1**

(c) In the space below draw a labelled infographic, with the relevant depths depicting the interior layers of the Earth.

(5 marks) **KA2**

1.3 Processes within the Earth's interior

Some processes within and between the Earth systems require energy that originates from the interior of the Earth.

- Interpret graphs of the Earth's geothermal gradient.
- Describe the transfer of geothermal energy from the decay of naturally occurring radioactive elements to rocks.

A gradient is a gradual change in some physical or chemical property and can be either sharp or shallow. Heat energy always moves down a temperature gradient from a warmer place to a cooler one. This is why heat from the Earth's hot centre flows outward towards the cooler surface, affecting rocks within each layer, from the core to the crust.

Measurements have been taken worldwide in underground mines or wells to harvest rock and measure properties such as temperature, radioactivity and porosity. These measurements have been useful in determining the Earth's temperature gradient and in demonstrating the increase of temperature with depth.

The geothermal gradient in the crust varies widely, depending on the topography (thickness of the crust). In the upper part of the crust the geothermal gradient averages 25°C per kilometre but at greater depths, the rate decreases to 10°C or less. Below 200km the gradient is thought to be only 0.5°C per kilometre. At approximately 700km below the surface the temperature can reach around 2000°C (see Figure1.30).

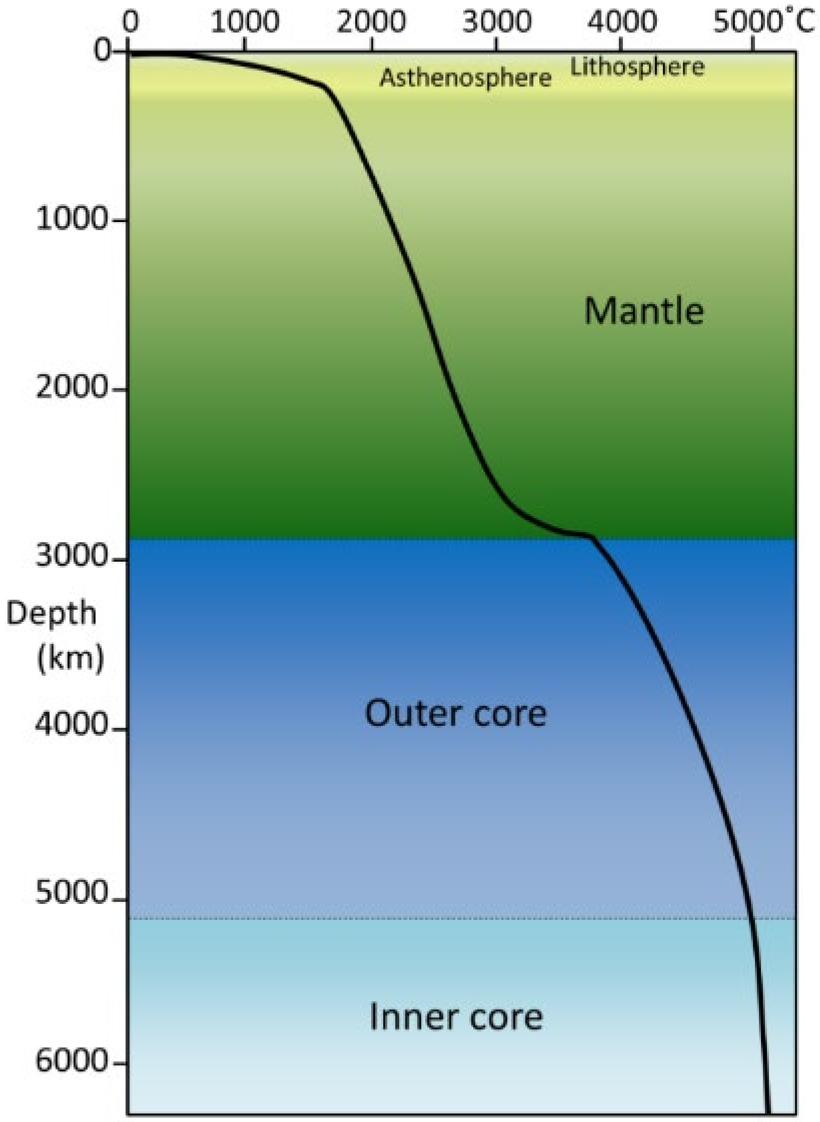


Figure 1.30 The Earth's geothermal gradient illustrates how temperature increases with depth.

Geothermal Energy

If the Earth was not hot inside, igneous processes would not occur. The heat in the Earth is a remnant of the Earth's formation. According to the Nebula Theory, Earth formed from the collision and merging of millions of planetismals and as each collision occurred, kinetic energy (from the motion of the planetimals) was transformed into thermal energy.

As the Earth grew gravity pulled matter inward, until the weight of over lying material squeezed the matter inside tightly together. The compression inside the Earth also made the Earth’s interior hotter. Once the earth had grown to become a planet, the Earth continued to be bombarded by colliding planetismals, adding increasing heat energy.

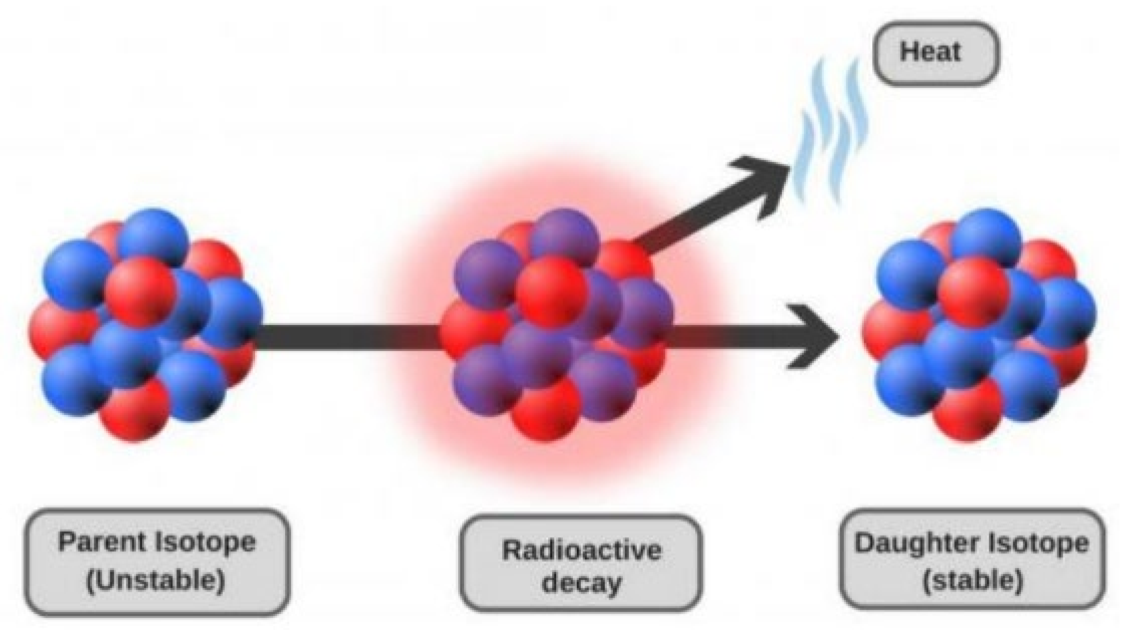
Figure 1.31 Early formation of the Earth

Eventually this process caused iron within the Earth to melt, increasing its density, allowing it to sink to the core. Friction between the sinking iron and its surroundings caused more heat. This process transformed gravitational potential energy into thermal energy.

These collisions and differentiations made the earth so hot, it is believed that it was made partially molten throughout and the surface was likely to have been an ocean of lava. Since then, the Earth has radiated heat into space, slowly cooling over the last 4.5 billion years and the sea of lava has solidified, forming igneous rock.

Radioactive Decay

While some of the Earth's internal energy dates from the Earth's early formation, some is also produced from radioactive decay in minerals. As there has been no external heat added since the end of the bombardment of planetismals, the fact that the Earth still has continuous igneous processes indicates that another source of heat energy must be present in the form of radioactive decay. If this was not the case, the planet would be too cool for igneous activity to occur. Decay of a single radioactive atom only produces a very small amount of heat, but the cumulative effect of radioactive decay throughout the Earth has been sufficient to slow down the cooling of the planet. This is why Earth is still hot today, reaching almost 1 300°C at the base of the lithosphere (crust and upper mantle) and 4 700°C within the core.



Many chemical elements in the earth are naturally radioactive includi**ng** radium, uranium and thorium, making them unstable. These elements emit radiation as they spontaneously break down into stable daughter elements such as lead and potassium. This process releases a small amount of thermal energy which then continues to heat the earth internally.

Suggested Activity: Transfer of kinetic energy to thermal energy.

Apparatus:

1 x hammer

1 x nail

1 x wooden block

Method:

1. Observe the temperature of nail using finger (or temperature probe).
2. Use a hammer to knock the nail into the wooden block.
3. After several strikes, observe the temperature of the nail using a finger (or temperature probe)
4. Compare the difference experienced before and after the collisions.

Potential Resources: Geothermal Gradient

Some interesting activities and presentations that breakdown the geothermal gradient can be found on the following website:

https://www.geolsoc.org.uk/Education-and-Careers/Resources/Activity-Sheets-And-Presentations

Question 5

Transfer of energy is responsible for the geothermal gradient within the Earth.

(a) Explain what a geothermal gradient is.

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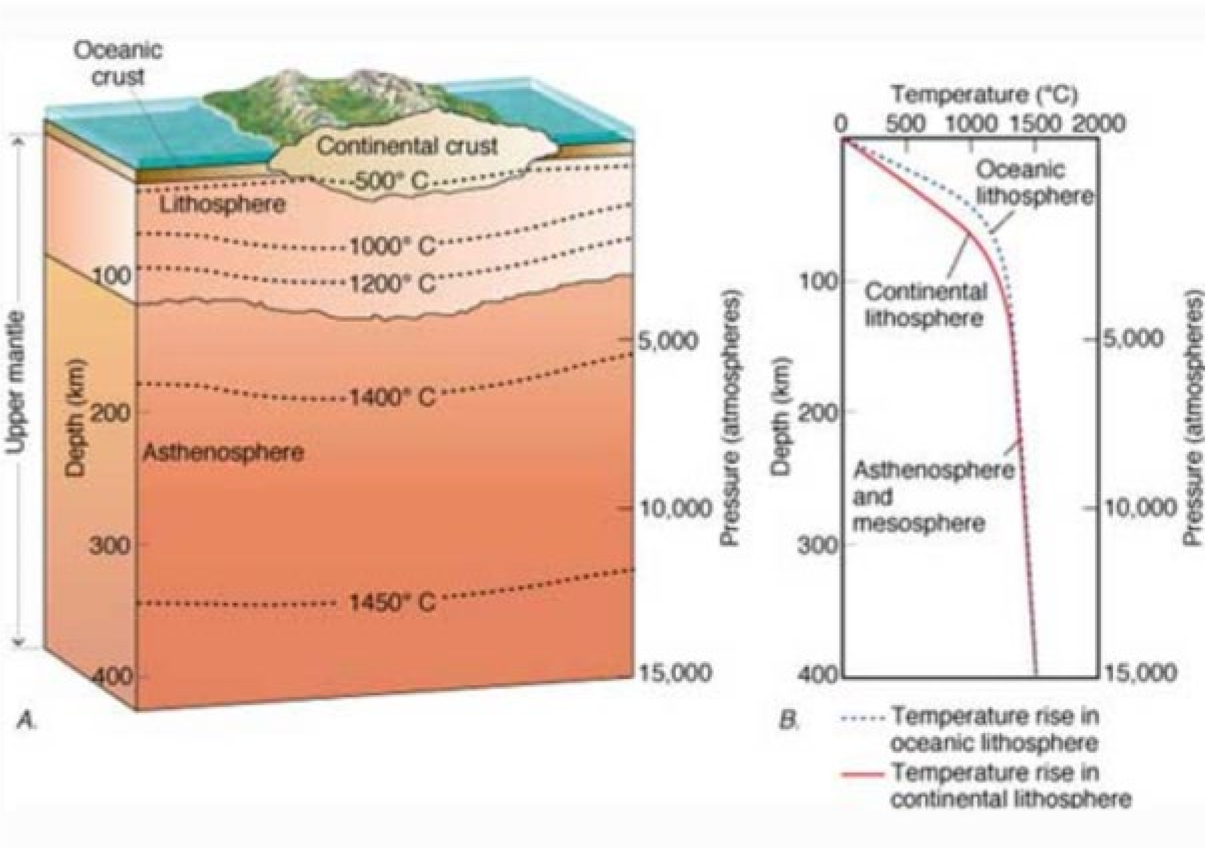
(b) The diagram below shows the Earth's geothermal gradient.



(1) Use the graph above to determine which crust (lithosphere) is cooler at a depth of 50m; oceanic or continental.

____(1 mark) **IAE3**

(2) Explain why this crust (as stated in (1)) would be cooler.

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____ (3 marks) **KA2**

(3) Explain whether or not the geothermal gradient is constant from Earth's surface to the centre.

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(c) Explain what is involved in the process of radioactive decay.

__________________________ (3 marks) **KA1**

(d) Discuss where the Earth's geothermal energy comes from.

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(e) Research the Geothermal Hot Rocks method for the production of electricity.

(1) Explain how geothermal hot rocks uses heat generated from radioactive decay to create electricity.

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(2) Discuss how this method of electricity is potentially more environmentally sustainable than other sources (application).

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(3) Discuss a limitation that this method may have for the generation of electricity in Australia.

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1.4 The Earth's Tectonic Processes

Transfers and transformations of energy in the Earth's interior cause plume formation and drive the movement of tectonic plates, through processes such as mantle convection, slab pull and ridge push.

- Describe how plumes from the mantle can transfer heat energy from the Earth's interior to produce 'hot-spot' volcanic activity and form an island chain.

Plate tectonics is a concept that is still fairly recent. The Canadian geophysicist John Tuzo-Wilson was initially sceptical of the theory of Plate Tectonics, but eventually became one of its most famous supporters, proposing two important ideas; the most famous of these being 'hot-spots'.

"much as I admired the elegance of physical theories which at the time, geology wholly lacked, I preferred a life in the woods, to one in the laboratory"


Figure 1.40 John Tuzo-Wilson

In 1915, the highly controversial theory of continental drift was first published by Alfred Wegener (the founder) but by the early 1950's the theory still didn't explain why active volcanoes are found many thousands of kilometres from the nearest plate boundary. In 1963, Tuzo-Wilson proposed that plates might move over fixed hots-pots in the mantle forming volcanic island chains like Hawaii. John Tuzo Wilson noted that active hot spot volcanoes occur at the end of the dead, volcanic islands and seamounts (extinct volcanoes). This theory filled in the gaps that were previously missing in ‘continental drift’.

Hot Spot Volcanoes

Volcanoes usually occur in volcanic arcs (above sea-level volcanoes next to the border of ocean trenches) or along mid-ocean ridges (often hidden underwater). Because these type of volcanoes are formed as a consequence of tectonic movement along a plate boundary, they are known as plate boundary volcanoes. Not all volcanoes on Earth are plate boundary volcanoes however. The most well-known of these are the islands of Hawaii (lying in the centre of the Pacific Plate) however, hot spots can also occur under land masses (Figure 1.41 below).

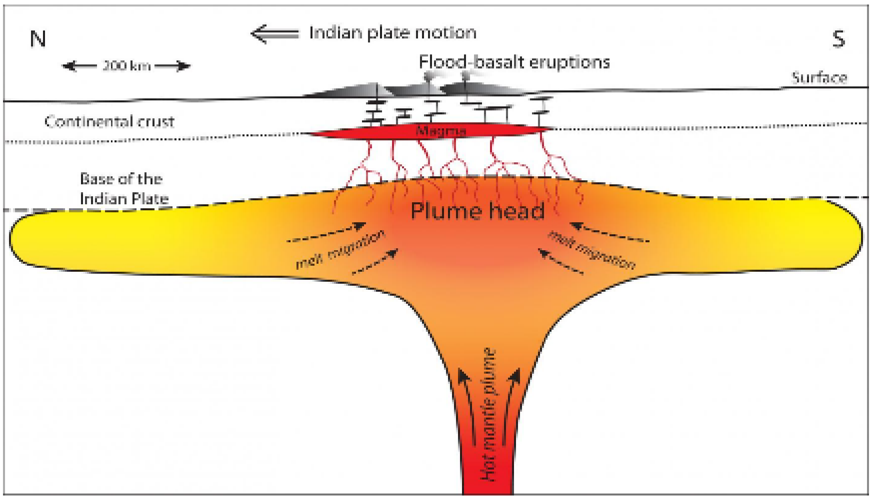


Figure 1.41 The hot spot under India

Hot spots are places within the mantle where rocks melt to generate magma. The magma generated by the hot spot rises up through the lithosphere, because it is less dense than the surrounding cooler rock. When it reaches the base of the lithosphere, the lithosphere partially melts and seeps up to the Earth’s surface forming an active volcano. This upwelling of magma from the mantle is known as a mantle plume; the hot spot develops above the plume.

After Tuzo-Wilson's research, it is believed that the heat source of the hotspot is in a fixed location. As can be seen (Figure 1.42 below), it is the plate that is moving, creating what is known as a volcanic arc. Movement of the plate slowly carries the volcano off the top of the plume, making it extinct and a new, younger volcano then grows above where the plume is still located. World-wide, there approximately 100 volcanoes that exist in isolated places away from plate boundaries due to hot spots.

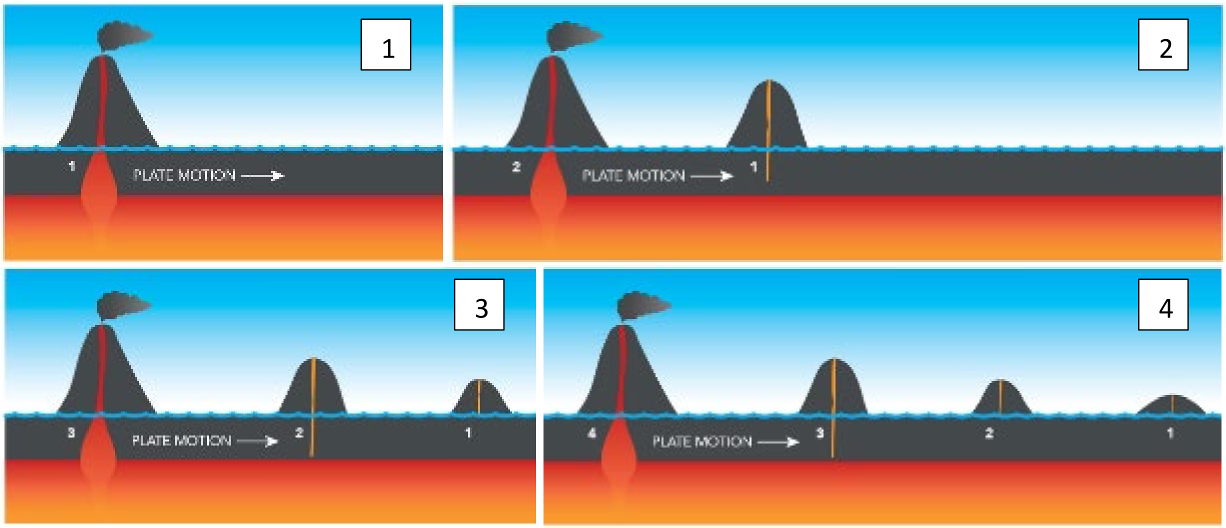


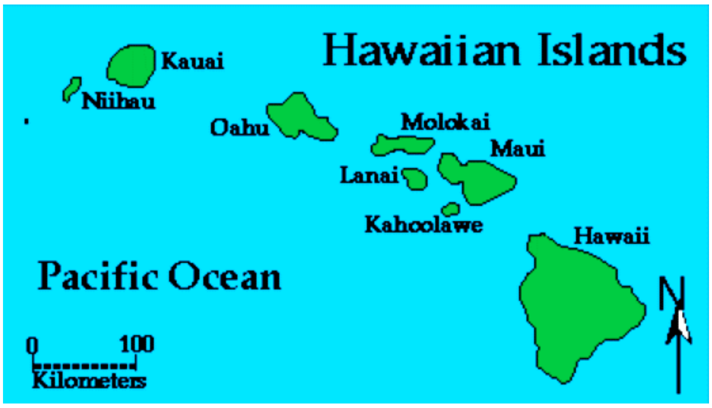
Figure 1.42 Formation of volcanic arcs

In 1965, Tuzo-Wilson followed this discovery with the idea of a third type of plate boundary; transform faults. Also known as transverse plate boundaries (and transform boundaries) these faults slip horizontally, connecting oceanic ridges (divergent boundaries) to ocean trenches (convergent boundaries) and allow plates to slide past each other without any oceanic crust being created or destroyed. At the time, transform faults were regarded as the missing piece in the puzzle of plate tectonic theory; the most famous of which is the San Andreas Fault between the North American and Pacific plates.

Question 6

The concept of hot-spots helped to explain gaps that were found in Wegener's continental drift theory.

(a) The islands of Hawaii have formed a hot-spot track as seen in the diagram below.



(1) If the active volcano is on Hawaii itself, draw an arrow on the diagram above that depicts the direction of tectonic plate movement. (1 mark) **KA2**

(2) Explain how hot-spot tracks can be used to track the past motion of a tectonic plates.

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____ (3 marks) **KA2**

(b) Explain how a hot-spot track is produced.

(3 marks) **KA1**

(c) Explain how a chain of islands caused from a hot-spot differ from a chain of islands caused by a subduction zone.

(3 marks) **KA2**

(d) Discuss the significance of scientific collaboration in the development of continental drift theory.

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____________________ (4 marks) **KA3**

Transfers and transformations of energy in the Earth's interior cause plume formation and drive the movement of tectonic plates, through processes such as mantle convection, slab pull and ridge push.

- Explain why new crust is pushed away from mid-ocean ridges.
- Explain why an oceanic plate is subducted in collisions with a continental plate.

Tectonic Plates

The movement of tectonic plates is the mechanism the Earth's continents have used to move across millions of years. The tectonic plates that we see on Earth today have not always existed in the way we see them today and are constantly changing. Plate motion due to convection currents in the mantle cause oceanic plates to form and later be consumed, while continents are merged and then split apart with this same motion. This is what has led to the formation and destruction of landmasses such as Gondwana as seen in the figure below.

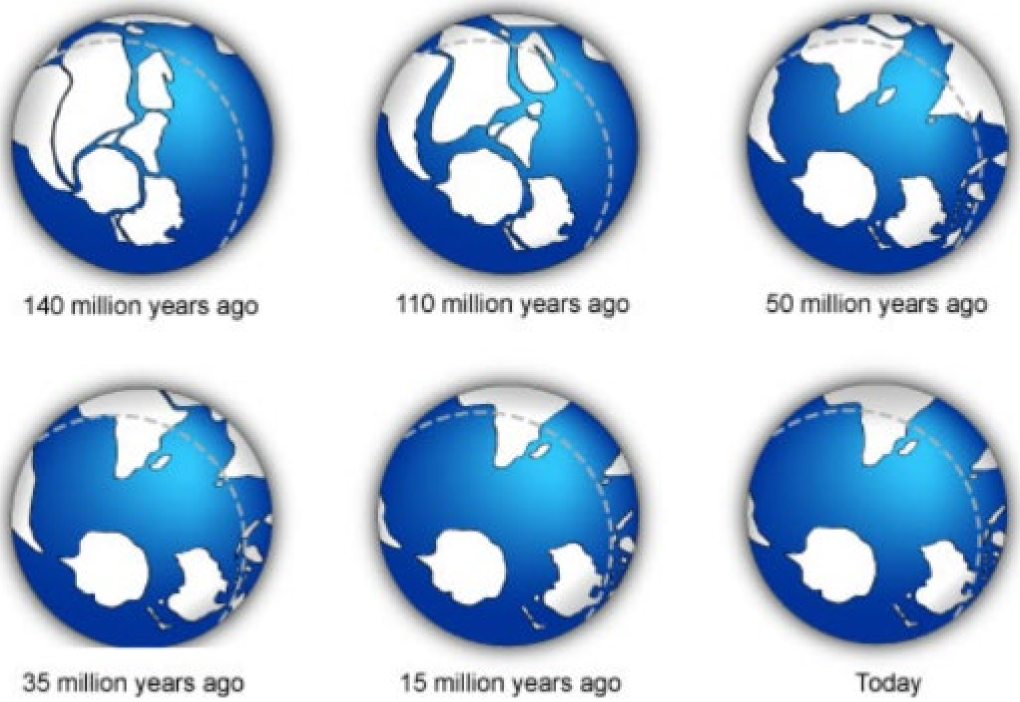

Figure 1.43 The transition from Gondwana to the continents we see today, over the last 140 million yeaars.

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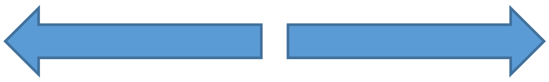
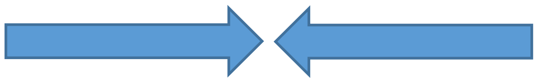
boundaries. Geoscientists have developed a good understanding of how plates move and how these movements relate to tectonic activity. Most movement occurs between narrow zones where the results of tectonic forces are most evident.

There are four types of plate boundaries:

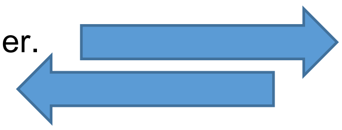
- Divergent boundaries – where new crust is generated as the plates pull away from each other.



- Convergent boundaries – where crust is destroyed as one plate dives under another (subduction).



- Transverse boundaries – where crust is neither destroyed or created as the plates slide past each other.



- Plate boundary zones – broad belts where boundaries are not well defined and plate interaction effects are unclear. *Not all plate boundaries are a simple as the boundaries above because the plate movement deformation occurs over a broad space and often several smaller plates (known as micro plates) are also involved in the plate interactions, leading to complicated geological structures and earthquake patterns.*

Exploration of the Sea Floor

Wegener's theory of continental drift was resurrected with the exploration of the sea floor by geoscientists including Harry Hess. During his time serving in the US Navy during World War II, Hess (later a professor of geology at Princeton University), became interested in the geology of the oceans. Using sonar while in the Navy, Hess identified the presence of Mid Ocean Ridges and noticed that they were raised up as much as 1.5km above the surrounding generally flat sea floor (abyssal plain). He also noticed that the deepest parts of the oceans (ocean trenches) extended down to depths over 11 km (in the case of the Marianas Trench off the coast of Japan) and that ocean trenches were very close to continental margins.

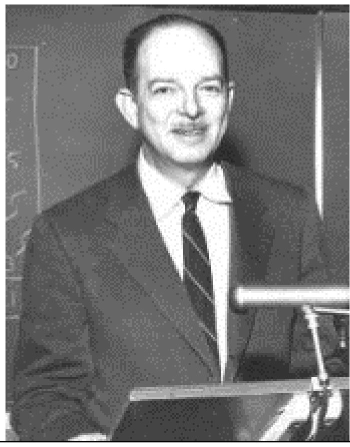


Figure 1.44 Professor Harry Hammond Hess

From his observations, Hess believed that oceans grew from their centres, with molten material (basalt) oozing up from the Earth's mantle along the mid ocean ridges. He suggested that this magma on the surface created new seafloor which then spread away from the ridge in both directions and the reason the ridges were higher than the sea floor was due to thermal expansion (heat).

The Forces Acting on Tectonic Plates

Early geoscientists originally believed that convection currents within the mantle was solely responsible for the movement of tectonic plates however it is now accepted that while convection flow does occur, it does not directly drive motion. Hot magma definitely rises and sinks in some locations because of difference in temperature and this does influence plate motion but the local directions of this flow does not always align with the overall direction of plate movement. This is because the plates are a huge landmass, of substantial weight and other forces are also involved (such as momentum). Geoscientists hypothesise that two forces (ridge-push forces and slab-pull force) strongly influence the motion of individual plates.

Ridge-push force develops due to differences in elevation. The oceanic crust (lithosphere) at the ridge is at a higher point (elevation) than the oceanic crust in the abyssal plains below. The height contrast creates a gravitational force that pushes the crust on the ridge into the crust below (Figure 1.44). As the crust along the ridge moves away, new magma rises up from the mantle and cools at the surface to form new crust. This tectonic interaction is known as a divergent plate boundary.

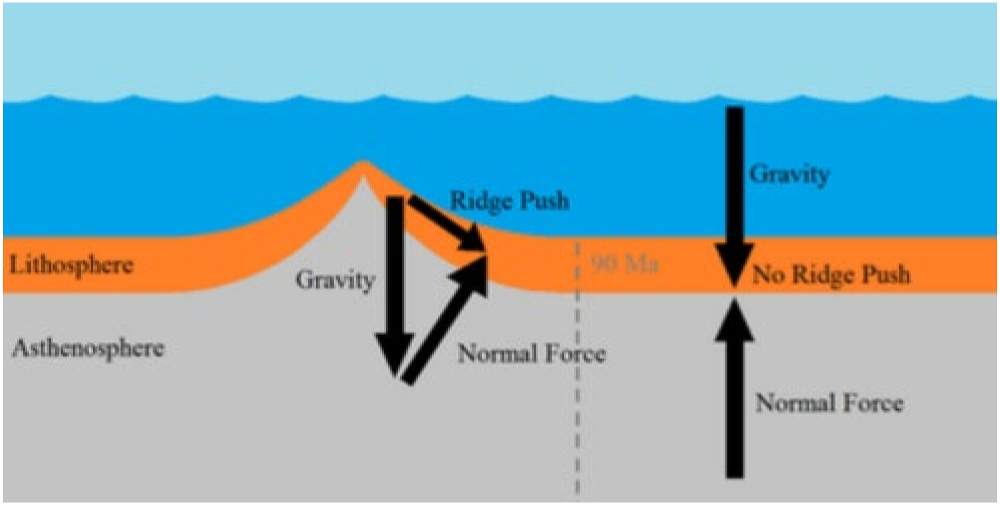


Figure 1.45 Ridge push occurring at an oceanic ridge, due to gravity.

Slab pull f e) formed millions of years ago is much denser than the mantle (asthenosphere) causing it to sink into the mantle below pulling the rest of the plate along behind it. This force is much more evident in subduction zones when 2 plates are converging on each other. The denser oceanic plate slides below the less dense continental plate and then the oceanic crust sinks into the mantle causing the slab pull force to continue to pull it down. This type of boundary often results in the formation of volcanoes in the continental crust above. One notable example of this is Mount St Helens in North America.

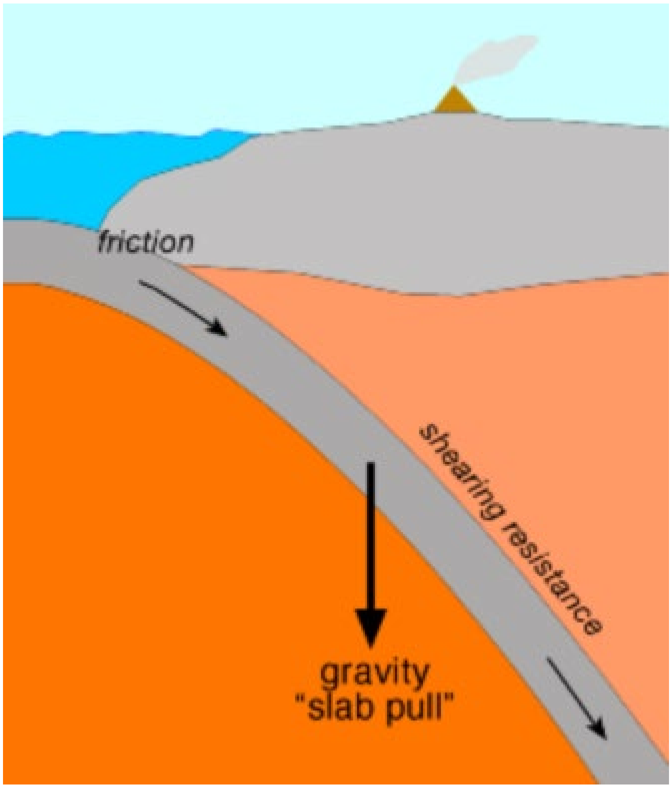


Figure 1.46 Slab pull occurring at subduction zones due to differences in density

Question 7

Tectonic plate movement is responsible for landscape we see on the surface today.

(a) Identify the driving force behind the push-pull model.

____ (1 mark) **KA1**

(b) Describe the evidence that supports the model of ridge push.

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____ (3 marks) **KA2**

(c) Explain how slab pull works.

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____ (3 marks) **KA1**

(d) There are four main types of tectonic plate boundaries.

(1) State which plate boundary is most likely to occur between two plates that are made of oceanic and continental crust.

____ (1 mark) **KA1**

(2) Describe the interaction that would occur at this boundary.

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____________________ (2 marks) **KA2**

(3) Explain why this interaction occurs.

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____ (3 marks) **KA2**

(4) Give one geographic example of where each of the following boundaries can be observed at the surface of the Earth.

Divergent:

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Convergent:

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Transverse:

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(3 marks) **KA1**

(e) The map below is of the Western Pacific Ocean.

Examine the position of Japan with respect to mainland Asia. Given Japan's older crust contains rocks similar to those of eastern Asia, and there are many active volcanoes along the length of Japan, explain how the Sea of Japan has formed.

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(4 marks) **KA2**

Potential Field Trip:

If you want to introduce students to a university environment, The Institute for Mineral and Energy Resources;

Centre for Tectonics, Resources and Exploration at Adelaide University runs TRaX Seminars weekly on Fridays at 12.10pm-1.00pm, in the Mawson Lecture Theatre.

Information about the sessions and contact details to book a class can be found at the following location:

https://www.adelaide.edu.au/trax/

Potential SHE task topics:

- Explore the contributions (communication and collaboration) different scientists have made during the last century to form the modern theory of plate tectonics.
- Discuss the influence technology from World War II has had in understanding geological processes.

Potential Activity: What's the angle

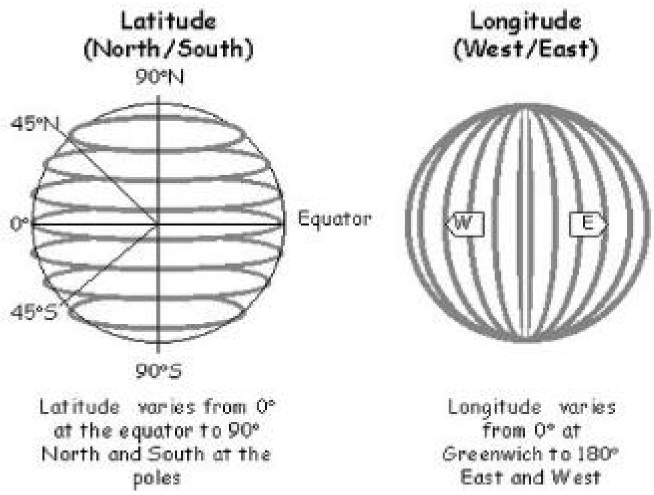
Activity kindly provided by;

Earthquake data is recorded by seismometers all around the world. With three or more good sets of data from a scatter of seismometers it is possible to establish the location of the earthquake at the surface (called the epicentre) and the depth of the earthquake's origin below the epicentre (called the foci).

In this exercise there is real data for 22 earthquakes that have occurred in South America between 1993 and 1994 (Table 1). The epicentre for each earthquake is given by the latitude and longitude coordinates and the foci are given by the depth.

EXTRA INFORMATION:

Latitude and Longitude



Latitude and *longitude* are a global coordinate system that allows scientists to give any point on the Earth's surface a unique coordinate pair. The Equator (0°) divides the Earth into Northern and Southern Hemishpheres; latitudes in the Southern Hemisphere are followed with an S (for example 19.8° S) or in digital systems Southern Hemisphere latitudes are prefixed with the minus symbol (for example -19.8°). Likewise the Prime Meridien (0° at Greenwich) divides the Earth into Eastern and Western Hemispheres. Longitudes east and west are suffixed with an E or W accordingly. Western longitudes are prefixed with a minus symbol in digital systems.

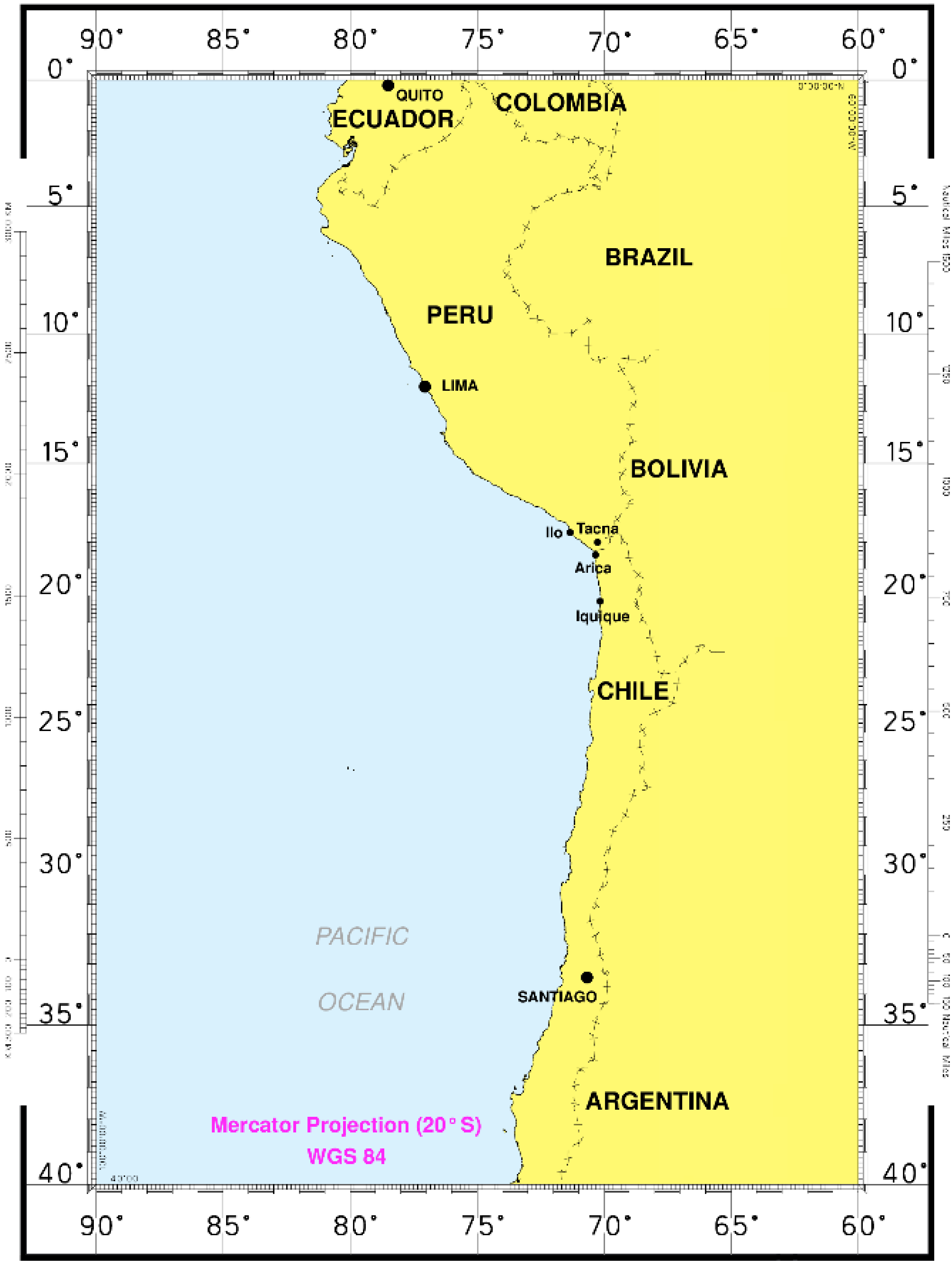
Activity:

1. In the table below, colour the shallowest (50 km or less) in blue and deepest earthquakes (500 km or more) in red.
   (2 marks) **KA4**

2. Plot the 5 shallowest and 5 deepest (not necessarily red and blue) epicentres listed in Table 1 onto the map provided below.
   Use the number provided in the table to label each epicentre on the map. (5 marks) **KA4**

TABLE 1. Table with data from actual earthquakes in South America from 1993-1994.

Station	Latitude (S)	Longitude (W)	Depth (Km)	Magnitude
1	19.8	66.6	259	4.6
2	27.8	63.2	513	5.1
3	26.2	63.3	550	4.8
4	31.2	71.5	33	5.0
5	23.2	66.4	200	4.8
6	23.5	71.0	25	5.0
7	24.5	70.8	33	5.0
8	21.3	68.2	122	4.7
9	23.6	70.0	42	5.0
10	23.5	70.5	50	NA
11	22.9	68.3	115	4.8
12	34.1	69.8	45	NA
13	22.3	66.1	274	5.0
14	23.2	69.3	67	4.9
15	22.5	67.4	168	4.5
16	19.5	65.8	305	4.5
17	21.4	68.1	123	5.1
18	27.0	63	500	4.9
19	27.2	67.1	155	4.7
20	20.4	66.0	300	4.5
21	25.6	66.0	385	5.0
22	22.2	64.5	440	4.8



Map 1: Partial map of the west coast of South America. Adapted from: https://commons.wikimedia.org/wiki/File:ICJ_Peru_Chile_judgment_map1.png

3. Describe any trends that can be inferred from the data you have plotted.

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_____________________________ (5 marks) **KA2**

4. This earthquake zone on the map represents the San Andreas fault line. State the type of earthquake zone it is.

____ (1 mark) **KA1**

5. Explain which type/s of crust is involved in this earthquake zone.

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____ (3 marks) **KA1**

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