

Topic 17: *Plate Tectonics*

Stage 5 Earth & Space Sciences

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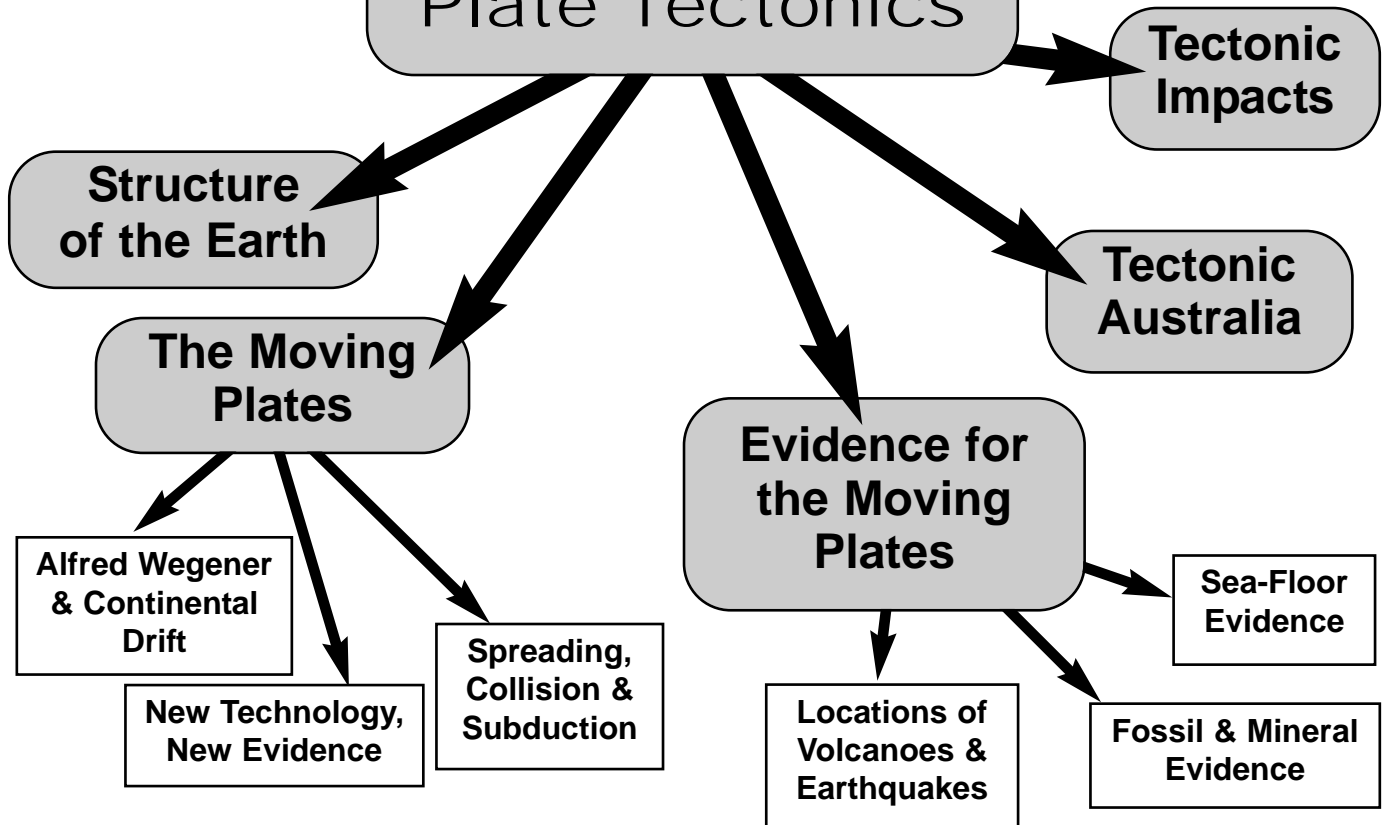
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*Worksheets begin on p19.
Answer Section begins on p25.*

Topic Outline

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Plate Tectonics



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We begin with revision of some things covered before...

The Structure of the Earth

You already know that the Earth has a layered structure.

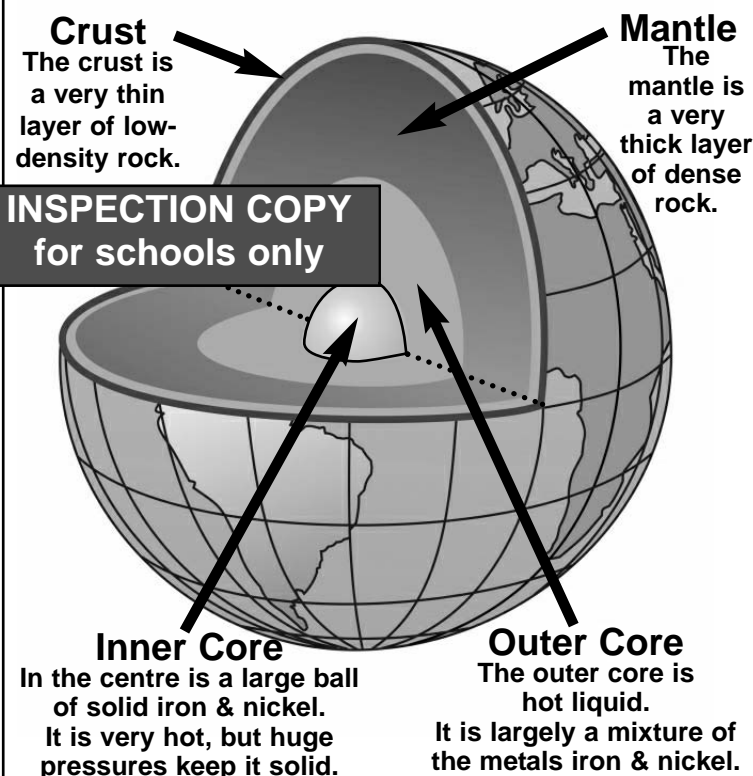
Inside the Solid Earth

Scientists have always been interested in earthquakes. By learning about earthquakes it was hoped that we might learn to predict them, and so avoid some of the deaths and destruction that they cause.

About 100 years ago, the study of earthquakes (called "Seismology") ("size-mol-ogee") became advanced enough that scientists began studying the way that earthquake shockwaves travel through the Earth.

From this, it became clear that the solid Earth is not totally solid, and has a layer structure, as shown.

Later, it was discovered that the outer layer is not a one-piece "shell", but is broken up into a dozen or so "plates" which slowly slide around on the layers underneath. As they slide, the plates move apart, or collide, creating earthquakes, mountain ranges, the ocean basins and even the continents themselves.



The Lithosphere

Although the Crust and Mantle are separate layers and have different density and composition, the boundary between them is not as simple and clear cut as the previous diagram suggests.

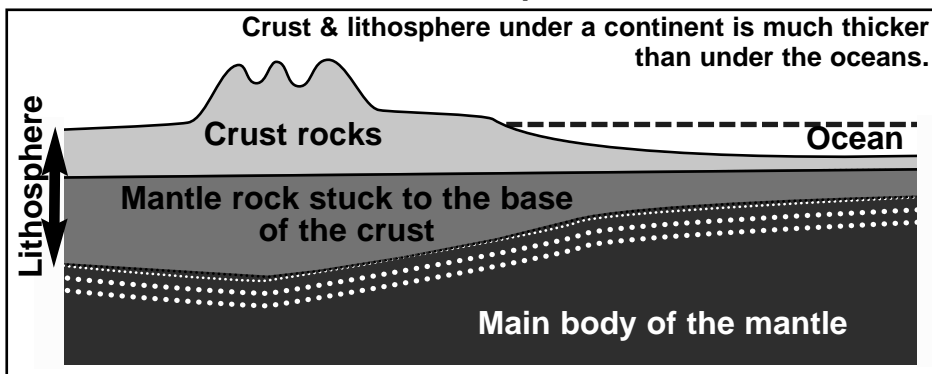
Attached to the bottom of the crust is a layer of mantle rock which has "welded" itself to the crust rocks above.

This 2-part layer is called the lithosphere.

The thickness of the lithosphere varies.

Under the oceans, it can be about 5 km thick and is mostly crust rocks with very little mantle rock attached. Under the continents the lithosphere is over 100km thick.

100km of rock sounds like a lot, but compared to the 6,400 km diameter of the Earth, the lithosphere layer is an extremely thin shell on the outside.



Below the lithosphere is a "slippery layer" of the mantle. We now know that the lithosphere "floats" on the main body of the

mantle, and is broken up into large pieces called tectonic plates.

The plates are pushed around by huge, relentless forces caused

by heat energy upwelling from the Earth's Core.

In this topic you will learn about the tectonic plates and how they create and change the continents, oceans and mountain ranges over hundreds of millions of years.

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Seismology

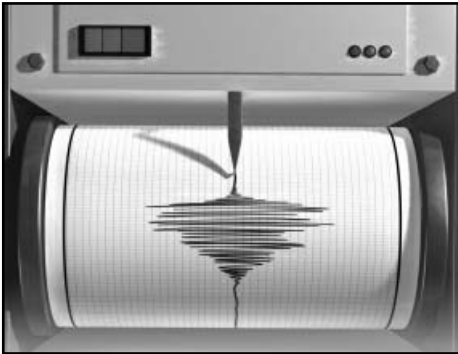
(Greek, "seismo"= shaking)

Seismology is the study of earthquakes and their shock waves.

Earthquakes

Earthquakes are caused by sudden movements in the Earth's crust. The sudden release of enormous energies sends out shock waves which radiate out from the "focus" of the 'quake.

The shock waves are detected and recorded by a seismometer.



The photo shows an old-fashioned seismometer recording the vibrations on paper. Modern seismometers use electronic detectors and record data digitally for computer analysis.

Seismic Waves

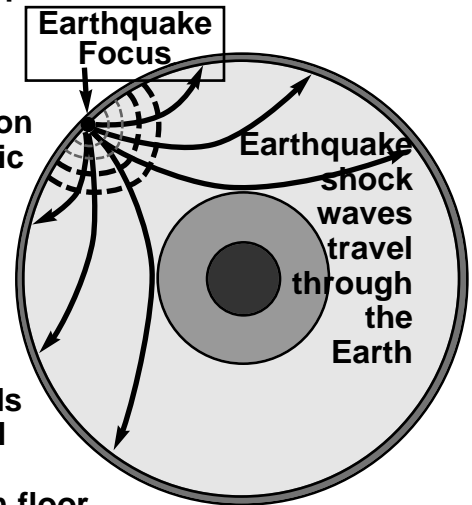
The shock waves are refracted by different density rocks, and some types of waves cannot pass through the liquid Outer Core.

Our understanding of the structure of the Earth is based on studying the seismic waves and how they behave as they pass through the different layers.

There are thousands of seismometers all over the world, including the ocean floor.

Most are automatic stations sending data to central computers by radio or phone links.

Many are warning systems to alert people to possible volcanic eruptions or tsunami waves in the oceans.



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Locating an Earthquake

Within minutes of an earthquake occurring, modern seismometers can tell you exactly where it occurred. Here is a simplified explanation of how.

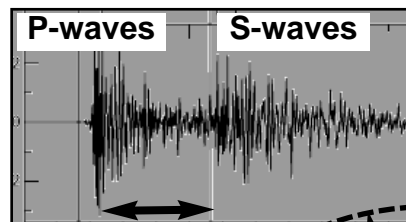
P and S Waves

Earthquakes give off several types of shock wave which have different properties and travel at different speeds.

The fastest waves, called "Primary" (P) waves always arrive at a seismometer first, followed by "Secondary" (S) waves.

The time-gap between them gives the distance from seismometer to earthquake. Each 1.0 second P-S gap equates to a distance = 7 km.

If 3 or more seismometers record the earthquake, it can be located by triangulation. Study the diagram to get the idea.

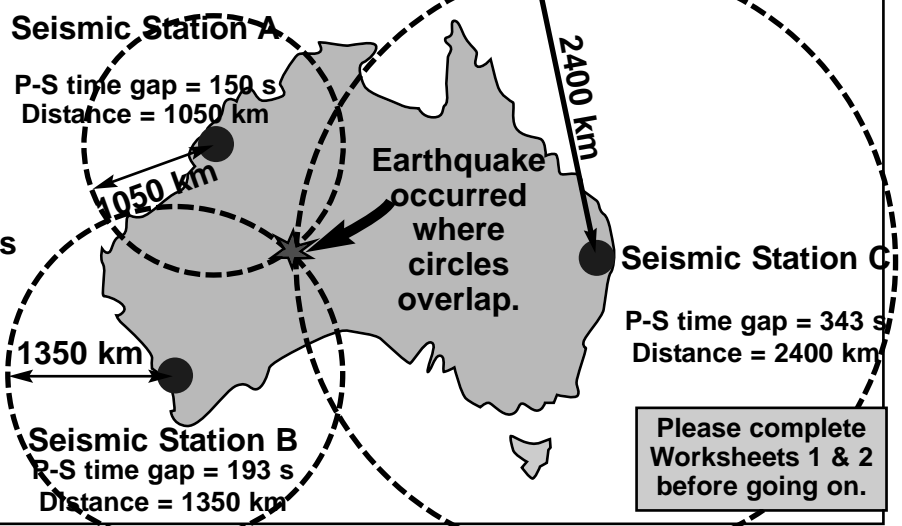


Record of seismic shock waves, showing time gap (arrow) between S & P waves.

Seismic Station A
P-S time gap = 150 s
Distance = 1050 km

Seismic Station B
P-S time gap = 193 s
Distance = 1350 km

Seismic Station C
P-S time gap = 343 s
Distance = 2400 km



Please complete
Worksheets 1 & 2
before going on.



A Little History: "Continental Drift"

As soon as accurate maps of the World appeared, some people noticed that the shapes of some of the continents fit together like jig-saw pieces.

One man took this idea further.

Alfred Wegener

(German, 1880-1930) (pron: "vague-ner")

Wegener was trained in astronomy, but became interested in Earth Science.

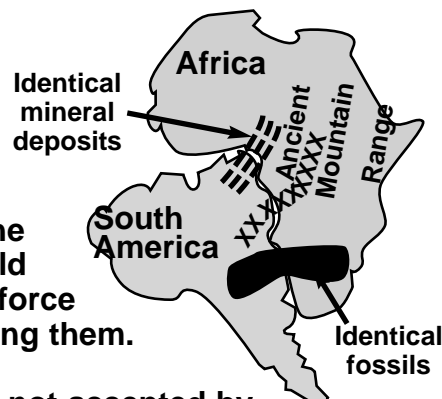
Intrigued by the shapes of the continents, he studied the rocks and fossils on either side of the Atlantic Ocean.



He found many examples of identical, same-age minerals, fossils and geological features which are on separate continents, but in exactly the locations which fit the "jig-saw" idea.

In 1915, he published a theory of "Continental Drift" which proposed that the continents had once been joined together and had moved to their current locations.

He put forward a lot of geological evidence, but could not suggest how the continents could move, or what force might be pushing them.



His theory was not accepted by many other scientists.

Wegener died in a snow blizzard while doing climate research in Greenland.

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New Technologies, New Evidence, New Theory

During World War II, sonar was developed for submarine warfare. In the 1950's it was used to accurately map the deep ocean floor for the first time. The demand for petroleum led to new techniques for deep-sea drilling from ships into the rocks under the sea. Sensitive "magnetometers" could be towed by a ship to map the magnetism in the rocks under the deep oceans. These new technologies led to new discoveries.

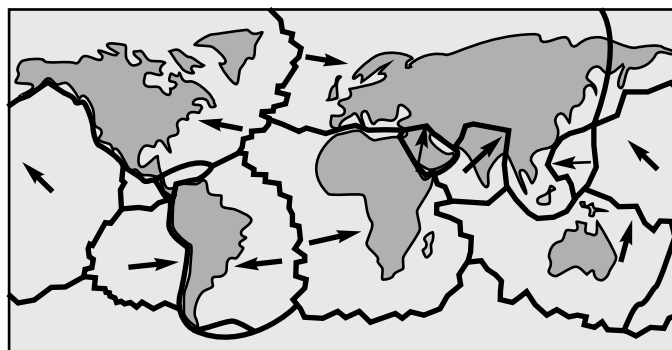
Plate Tectonic Theory

During the 1950's through 1970's a huge amount was learnt about the crust of the Earth, especially under the deep oceans.

New ocean-floor maps, magnetic data and rock samples from deep-sea drilling built up a body of evidence which showed that Wegener was right... the continents move!

Additional evidence came from seismology and studies of volcanoes. Details of the evidence will be presented later in this topic.

This led to a new theory called "Plate Tectonics". According to this theory, the lithosphere is not a simple "skin" like an egg shell, but is broken up into about a dozen pieces, or "plates".



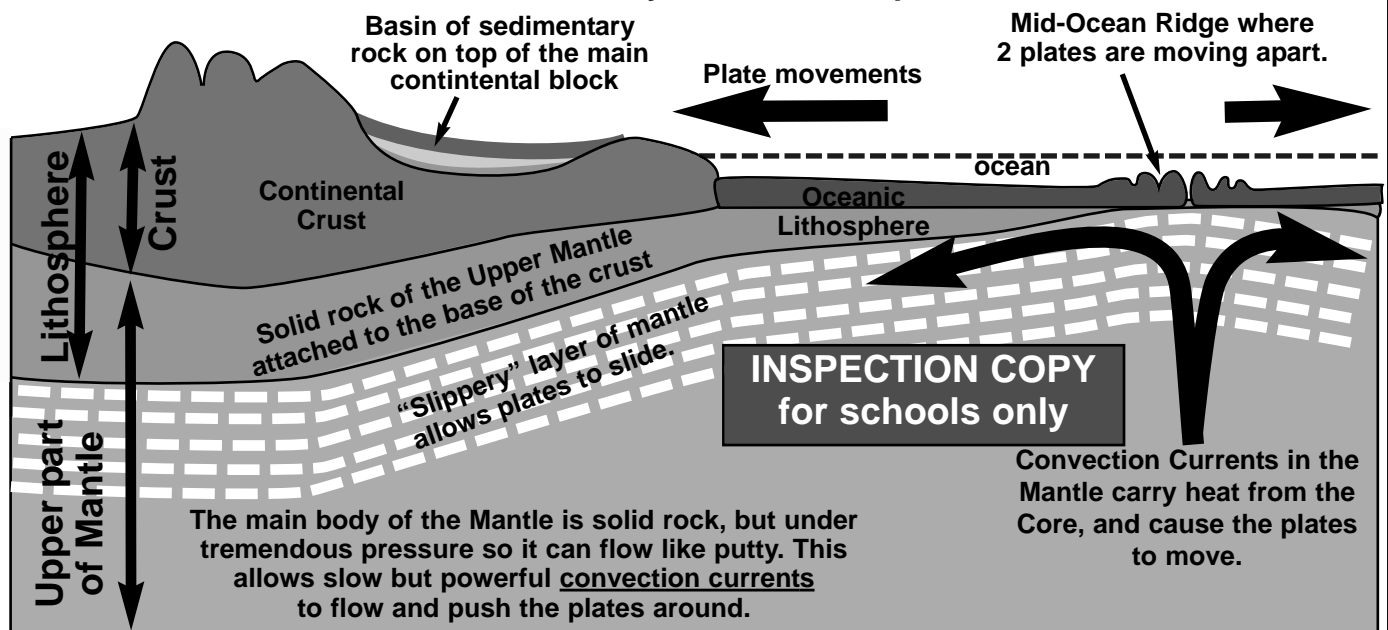
The plates slowly move around, sliding on the mantle layer below. Adjoining plates must either move apart, or crash together, or slide sideways past each other.

These movements cause earthquakes and volcanoes, create mountain ranges and volcanic islands and enlarge or destroy the ocean basins.



The Structure of a Tectonic Plate

Most of the major Tectonic Plates include a thick “block” of a continent plus a thin layer of lithosphere under an ocean. A few plates (such as the Pacific Plate) have no continent and are entirely made of lithosphere under an ocean.



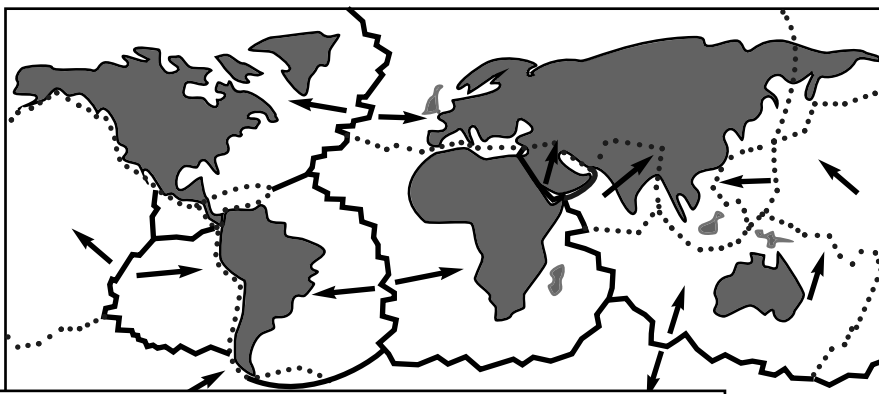
Each plate can slide sideways on a “slippery” layer of the Mantle. The movement is caused mainly by huge, slow convection currents which carry heat out from the Earth’s core. The average rate of movement is about 5 cm per year, but movements are not slow and steady. Instead, the plate might not move at all for many years, then suddenly lurch forward by several metres.

It is these sudden movements which cause earthquakes. Plates have many cracks and fissures (faults) around the edges because the whole plate might not move all at once. As different sections lurch forward, the plate develops many cracks and offsets. Over millions of years, a plate not only moves sideways, but can rotate and/or change its shape.

When Plates Move Apart

When plates move away from each other, molten rock immediately billows up from underneath to fill the gap and create a new, thin layer of crust. This is occurring mainly on the floor of the oceans.

Hidden deep underwater there are about 70,000 km of plate boundaries which frequently move (creating many small earthquakes) and erupt new oceanic crust.



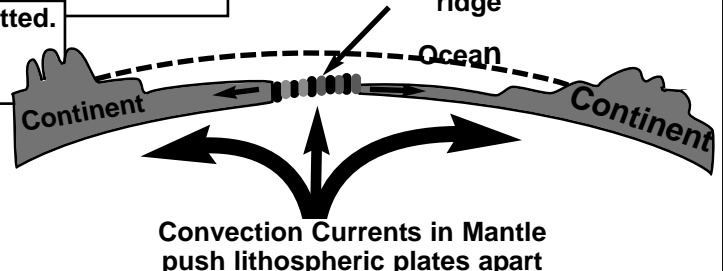
On this map, plate boundaries are shown solid or dotted. The solid boundaries are where plates are moving apart, mostly at the Mid-Ocean Ridges.

The “Mid-Ocean Ridges” are chains of underwater mountains with a central “rift valley” where the plate edges are. In some places, such as Iceland, the eruption of new crust has built up high enough to reach the ocean surface, forming islands.

About 250 million years ago, the American continents were joined to Europe and Africa. As they have moved apart, the Atlantic Ocean has grown wider and wider by “sea-floor spreading”.

SEA-FLOOR SPREADING

As plates move apart, new rock fills the gap, creating a “mid-ocean ridge”





When Plates Collide

The tectonic plates cover the surface of a sphere. If they are moving apart in some places, then they have to be colliding somewhere else. Exactly what happens in a collision zone depends on what type of lithosphere is involved.

Subduction

If one of the colliding plates is made of oceanic lithosphere it will be pushed down under the other plate and destroyed by being re-melted into the Mantle. This is called "Subduction".

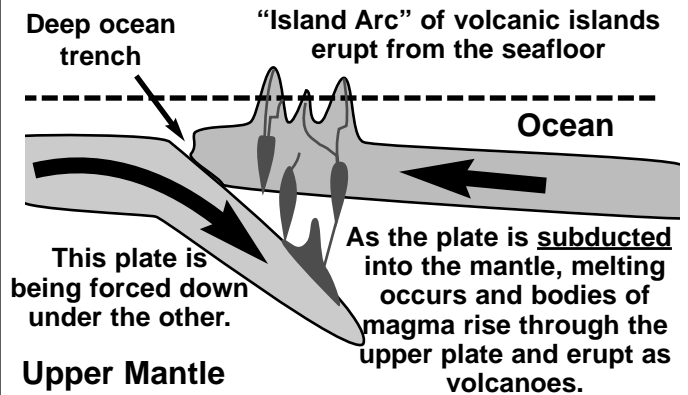
This type of collision is occurring north of Australia where the plate under the Pacific Ocean is being destroyed. The many volcanic islands of the western Pacific have formed in chains along the subduction zones. Deep ocean trenches occur where the plate is bent sharply downwards.

Each time a plate lurches forward, an earthquake occurs. Large under-sea 'quakes can set off a tsunami, or seismic water wave, in the ocean. The Boxing-Day tsunami of 2004, which killed over 200,000 people, was caused by a 'quake in the subduction zone north-west of Australia.

In March 2011, a huge earthquake near the coast of Japan (where the Pacific Plate is being subducted) set off a tsunami which devastated parts of Japan and killed thousands more.

Composite photo of a fictitious tsunami about to destroy a coastal city. Real tsunamis are more like a "wall of water" rather than a giant surf wave.

Colliding Oceanic Plates



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If one of the colliding plates is carrying a continent things happen differently. The crust rocks in a continent are too thick & low in density to be subducted.

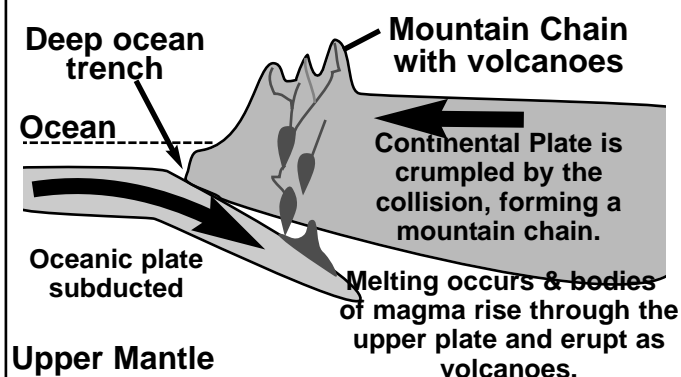
The South American plate is colliding with the plate under the eastern Pacific Ocean. There are deep ocean trenches just off the coast and a massive mountain range (the Andes) along the western edge of the continent.

The mountains are formed by the "crumpling" of the continent's crust in the collision. There are also many volcanoes and earthquakes.

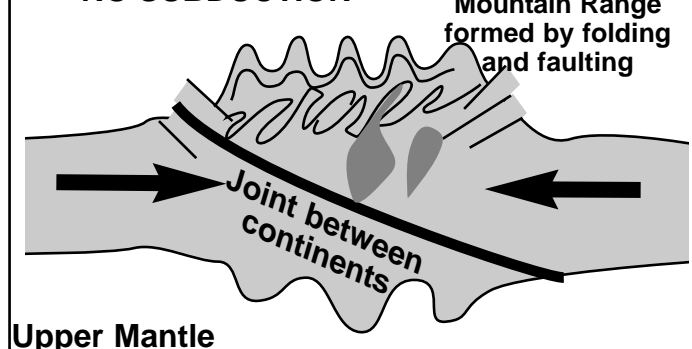
Mountain Building

If both colliding plates carry the thick lithosphere of a continent, neither plate is subducted. Instead, the continents are crumpled by the collision. The crumpling effect folds and fractures the crust rocks and pushes them up to form a chain of mountains. The Himalaya mountains formed this way as the plate carrying India has collided with Asia. Rocks which were once under the sea are now 9 km high.

Oceanic-Continental Collision



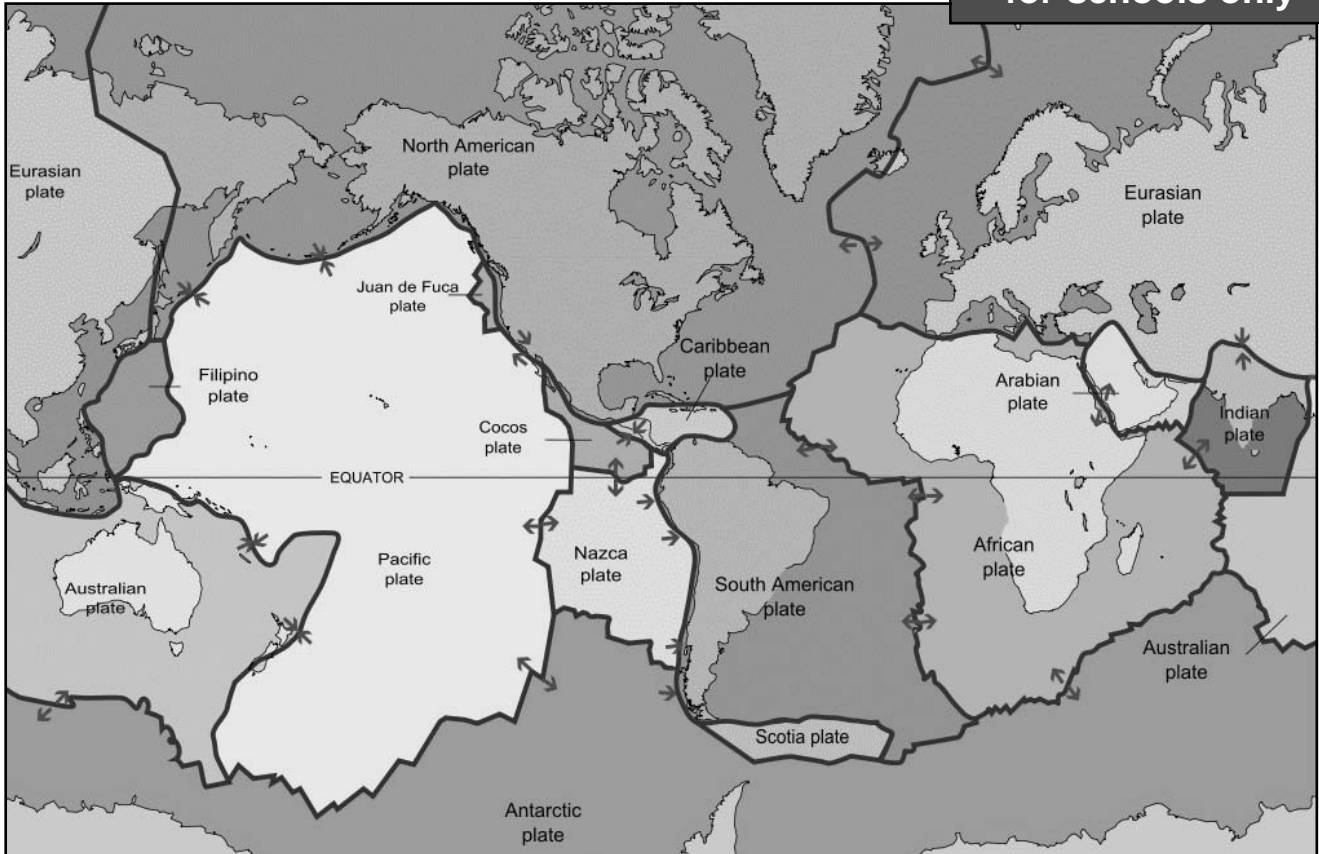
Continent - Continent Collision...



More Images

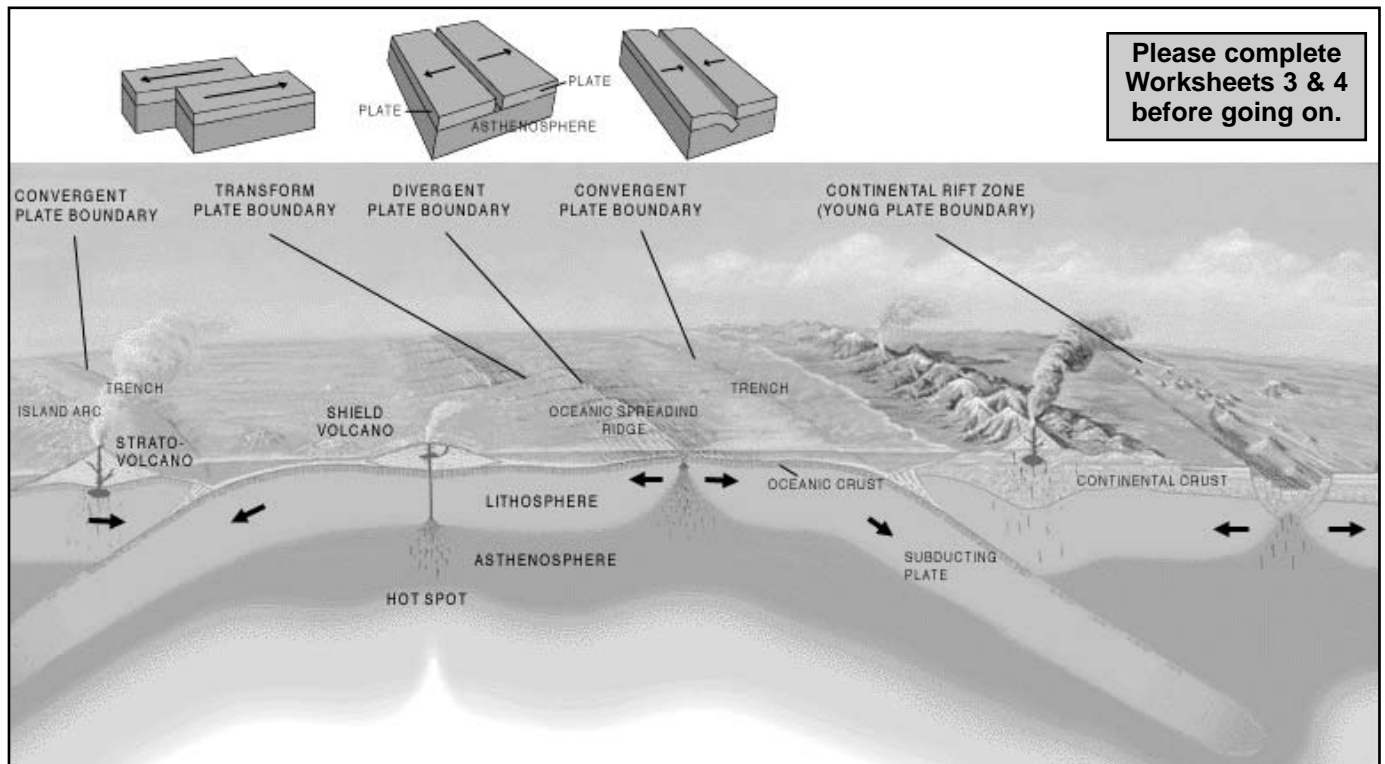
Study these for a greater understanding.

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The diagram above is a more detailed and accurate map of the tectonic plates than the earlier sketches.

The diagram below shows all the types of plate boundaries at once. Of course, there is no place on Earth exactly like this.



Please complete
Worksheets 3 & 4
before going on.



What Makes the Plates Move?

Each tectonic plate can be thousands of kilometers long and wide and 100 km thick. Made of solid rock, each plate weighs billions of billions of tonnes.

What forces can make it move?

Convection Currents in the Mantle

We believe that the Earth's core is very hot due to the energy released from radioactive decay.

It is so hot down in the core (around 6,000°C) that the iron-nickel metal mixture should be completely molten. However, the immense pressure forces the Inner Core to be solid, despite the heat.

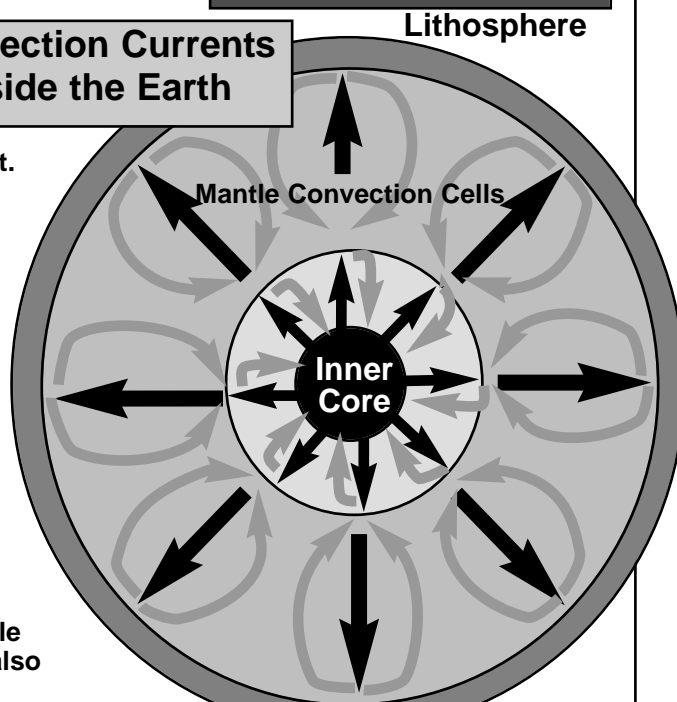
Since the outer core is liquid, convection currents flow in the liquid and carry the heat outwards.

This heat transfers into the mantle rocks. Although these are thought of as "solid" rock, the mantle is really a thick, semi-liquid. The immense heat and pressure forces the rock to flow like putty in huge convection "cells".

The flow is so slow that it takes many millions of years for the heat to flow from the core to the crust.

These huge, slow-flowing currents hit the base of the lithosphere and flow sideways. The currents drag on the bottom of the tectonic plates causing them to move. Mantle convection current are the "prime movers", but there are also other forces acting...

Convection Currents inside the Earth

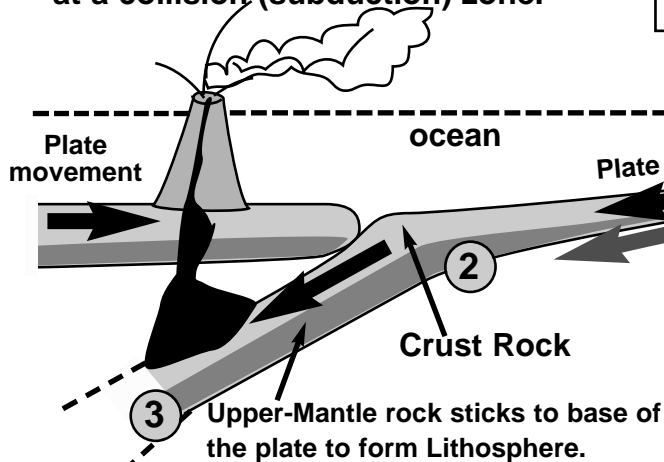


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1 "Convection Drag"

As the convection currents reach the top of the mantle they flow sideways before cooling and descending again. Friction pulls on the plates, dragging them sideways.

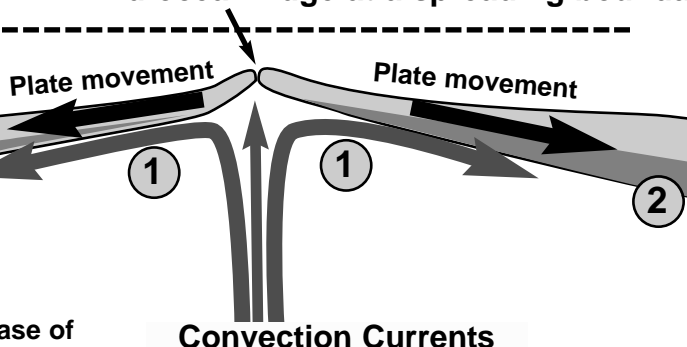
Volcanic islands & deep ocean trench at a collision (subduction) zone.



3 "Slab Pull"

At a subduction zone, the descending plate is sinking into the mantle because of its high density. As it descends, it pulls the rest of the plate behind it. It is probably the increased density of an old oceanic plate which first fractures it and creates a new subduction zone. Density increases because mantle rock keeps solidifying onto the base of the plate. By the time an oceanic plate is "old" (about 200my) it may be too dense to stay "afloat" any longer.

Mid-ocean ridge at a spreading boundary.



2 "Ridge Push" Gravitational Sliding

When new crust material forms at the mid-ocean ridge it is only a relatively thin layer of crust rock. As the plate moves outwards from the ridge it becomes thicker because upper mantle rock solidifies onto the base to form complete "lithosphere". Its density increases, so the plate sinks lower into the underlying mantle. This causes the plate to slope like a dinner plate on a tilted table... gravity exerts a force which makes it slide sideways across the "slippery layer" underneath.

The "tilting" of plates is a fact... the sea floor at a Mid-Ocean Ridge can be several kilometres higher (closer to the sea surface) than the sea floor 500km away from the ridge.



Evidence for Moving Plates

The Tectonic Plate Theory explains many things such as earthquakes & volcanoes, mountain ranges, island chains & deep ocean trenches. But is it really true? We believe it is true because there is a huge body of evidence to say so. Some evidence was noted by Alfred Wegener almost 100 years ago, but a lot was only discovered after the 1950's when new technologies allowed us to study the ocean floor, accurately measure the age of rocks and so on.

The Shape of the Continents

The continents of the Earth are like jig-saw puzzle pieces... they fit together quite well, especially along the lines of the “continental shelf” rather than the actual coastline.

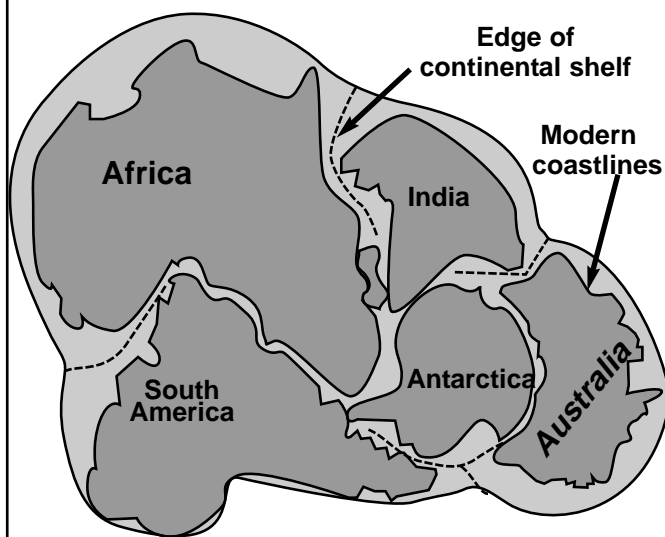
The continental shelf is the true edge of each continent. In most cases it is under water today, but has been mapped using sonar.

When the continents are fitted together along their continental shelf margins, the fit is almost perfect.

This cannot be just coincidence! It strongly suggests that the modern continents were once joined together.

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THE ANCIENT SOUTHERN CONTINENT GONDWANA



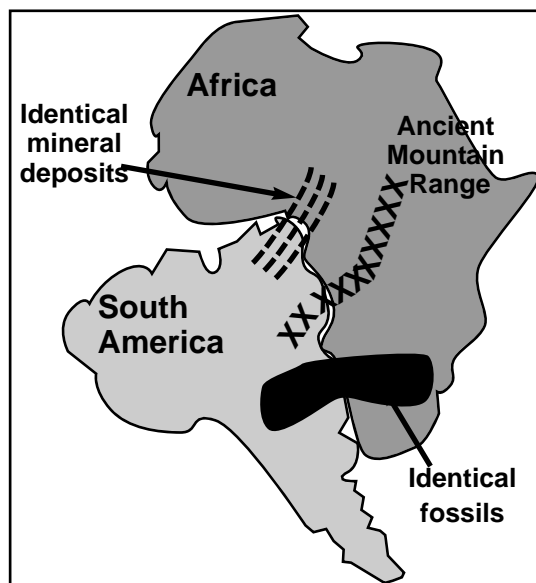
The Fossil & Mineral Evidence

Alfred Wegener discovered some of this evidence and used it to support his “Continental Drift” idea. Since his time, many more discoveries have been made of this same type of evidence.

Fossils

There are many examples of fossil plants and animals that are found on separate continents. These were land plants, or freshwater animals which could not have crossed an ocean.

The fossils are the same age, and identical specimens are found across (for example) Africa, South America, India, Australia and Antarctica. They must have evolved and lived right across an ancient continent. The moving plates later separated the fossil deposits.



Geological Evidence

There are many examples of rock layers and mineral deposits on different continents which are identical and are in locations which fit the “jig-saw” pattern.

Wegener noted evidence of the eroded “stump” of an ancient mountain range which is present in South America and Africa.

Scientists have even found scratch marks on rocks caused by ancient glaciers which gouged the rocks. The pattern of the scratches line up perfectly across what are now different continents. Of course, when the glaciers were doing the scratching, the continents were joined together.



Evidence From the Ocean Floor

When scientists began mapping the ocean floor with sonar, they quickly discovered that there is a "Mid-Ocean Ridge" of underwater mountains running for 70,000 km through the world's oceans. New deep-water drilling equipment allowed rock samples to be collected, and new methods involving radio-activity allowed the age of rocks and sediments to be measured.

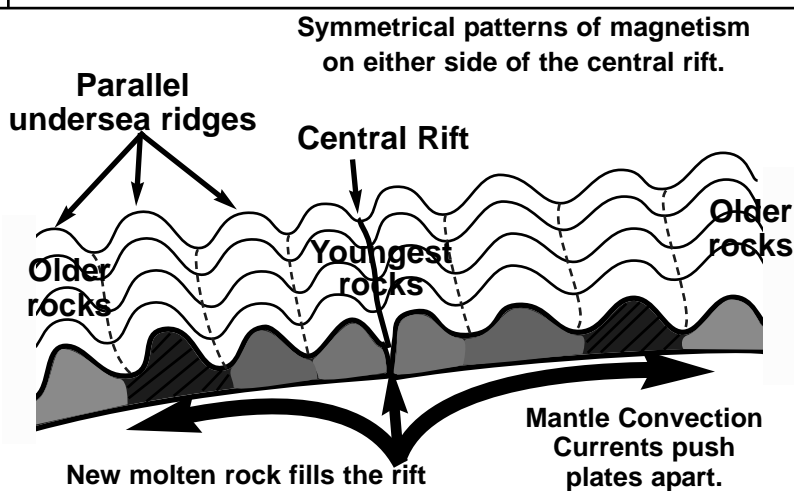
New magnetic equipment allowed the magnetism in the rocks to be measured accurately. The picture which emerged was clear evidence for the moving plates.

Mid-Ocean Ridges

The rocks of the parallel ridges are youngest in the middle and get progressively older as you move outward. The sediments which settle on top of the rock are thinnest at the mid-ocean ridge and get thicker as you move away from it.

The "residual magnetism" in the rocks (which was aligned as the rock hardened from molten lava) shows a symmetry on either side of the central ridge. Each matching band of magnetism represents a line of new rock formed as the crust plates moved apart.

Later, these bands were split and separated by even newer rock injected in the middle as the crust plates continued to be pushed apart.



While some rocks on the continents are billions of years old, the rocks of the oceanic crust are all relatively young. This is because oceanic crust is created where plates move apart, and then destroyed again by subduction within a few hundred million years. There is no really ancient rock under the oceans.

Please complete Worksheets 5 & 6 before going on.

Evidence From Seismology

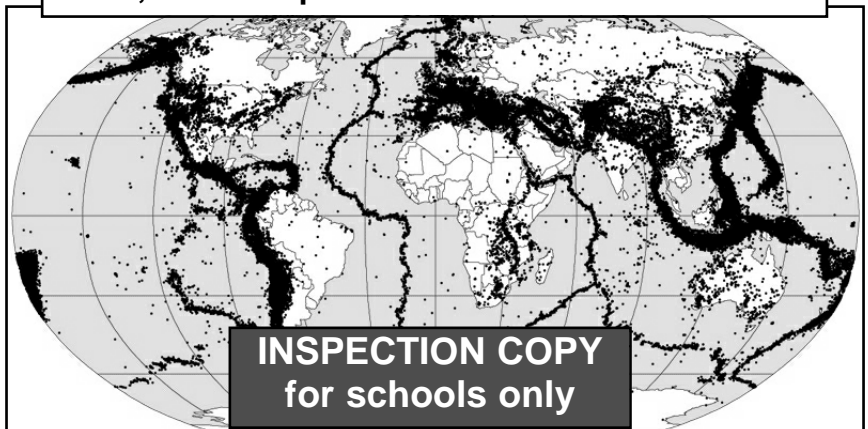
Even several hundred years ago, it was realised that earthquakes and volcanic eruptions occur most often in certain "active zones", such as the edge of the Pacific Ocean which is called the "Pacific Ring of Fire".

When data from modern seismology is analysed a clear pattern emerges.

The vast majority of earthquakes (and volcanoes) are located along the boundaries of the tectonic plates.

On this map you can clearly see the line of the mid-ocean ridges and the heavy concentration of earthquakes where the plates are colliding.

Each dot on this map is the focus of one of the 350,000 earthquakes that occurred 1963-1998.

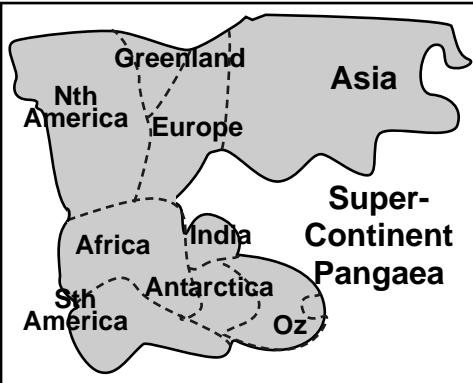


Notice that, while Australia has relatively few earthquakes, there is a very active region to our north. In 2004 and 2011, massive earthquakes in this region caused tsunamis.



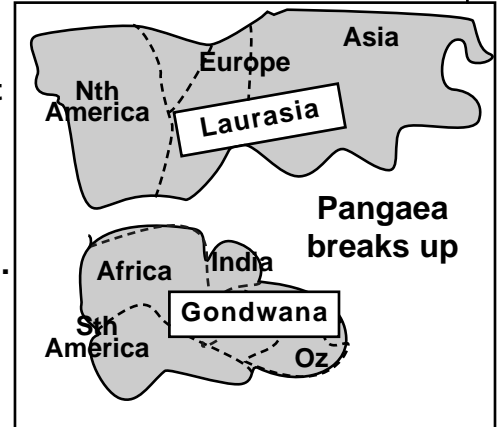
A Changing Map of the World

Supercontinent Pangaea



The evidence indicates that 200 million years ago, all the continents were joined together in one “super-continent” called Pangaea, which means “whole Earth”.

About 180 million years ago, Pangaea split into 2 parts as shown. Later, North America separated from Europe, creating the Atlantic Ocean as it moved away.

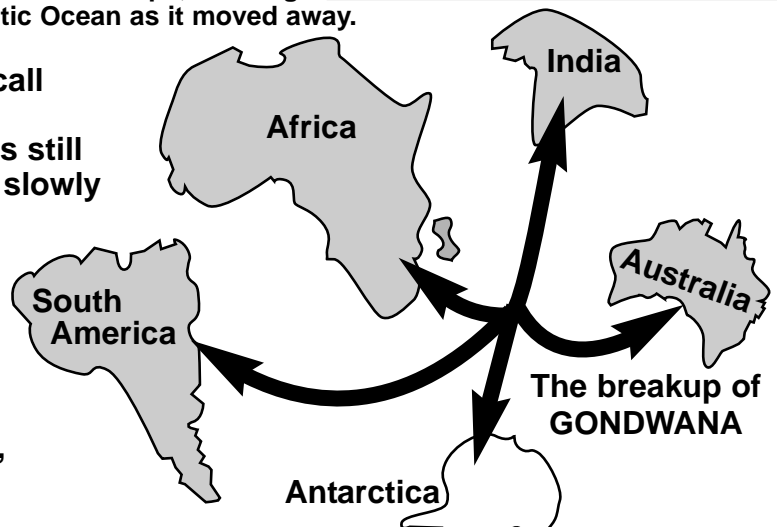


In the south, the ancient continent we call Gondwana also began breaking up. Until 45 million years ago Australia was still joined to Antarctica. Today Australia is slowly moving north.

If all the tectonic plates keep moving the way they are now (no guarantees!) we can predict what the world might look like in 100 million years time:

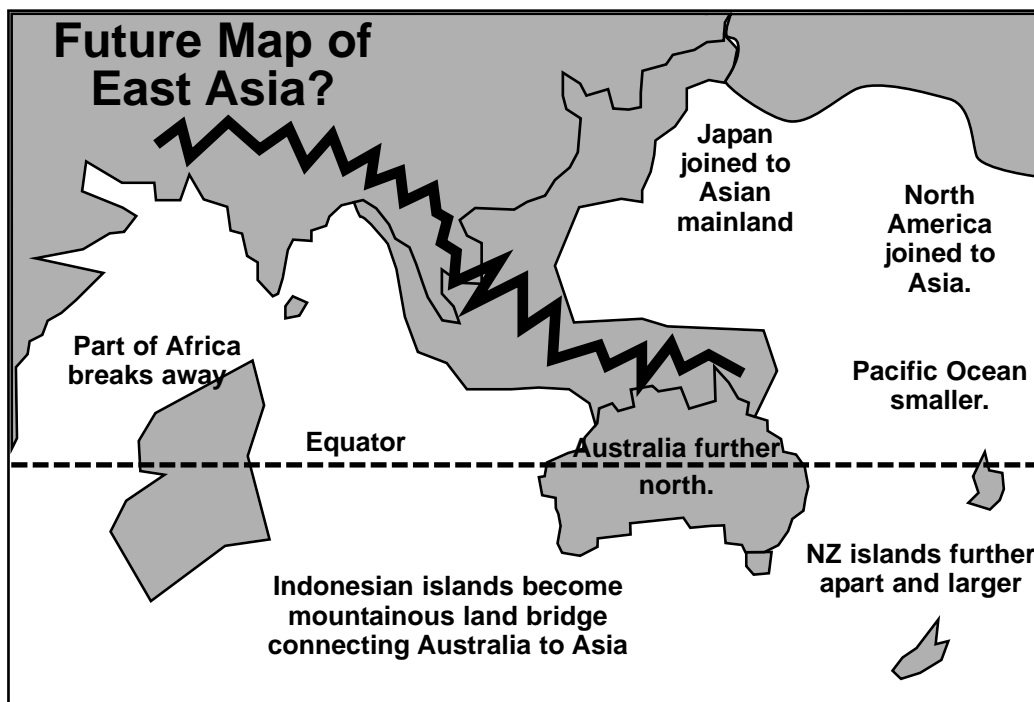
Africa will join completely onto Europe, destroying the Mediterranean Sea.

The eastern one-third of Africa will split-off to form a separate continent.



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North America will connect to Asia and the north Pacific Ocean will shrink.



Eventually, all the continents may collide and join together to form a new “super-continent” like Pangaea, but with all the parts in different places. The new supercontinent might later crack up into new fragments.

This cycle has occurred over and over in the past. Western Australia was once joined to

Canada in a previous super-continent long before Pangaea was formed.



Evolution of the Continents

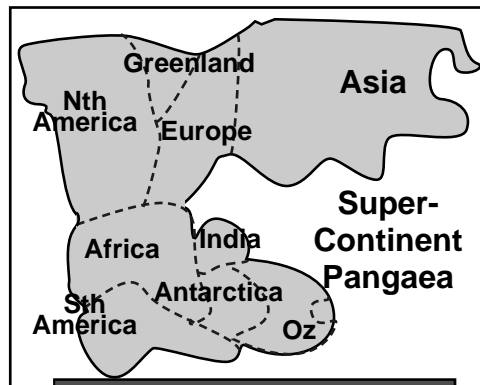
Supercontinents & Supercycles

We now know that all the modern continents were once joined together in one “supercontinent” called **Pangaea** (= “whole Earth”). The rest of the Earth was covered with a global ocean called **Panthalassa** (= “whole ocean”).

But how did Pangaea form in the first place?

It is thought that Pangaea formed from the collisions of previously separate continents. Those previous continents were totally different to the modern ones.

Those pre-Pangaea continents are thought to have come from the breakup of another previous supercontinent, and so on... a continuous cycle of forming and breaking up of supercontinents... a “supercycle” of Plate Tectonics.



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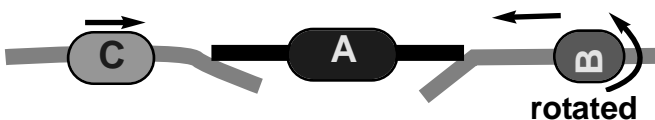
1. Oceanic Lithosphere

Original Supercontinent

2. Supercontinent splits apart. Sea-floor spreading creates new oceans as continents move apart.

3.

Eventually, continents approach each other again... possibly on the other side of the world. Subduction shrinks the old, previous oceans, until the continents collide.



4.

New Supercontinent forms

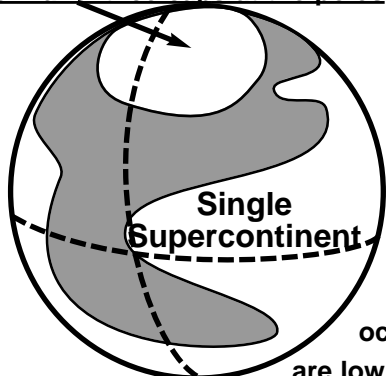


The entire “supercycle” is thought to take approximately 400-500my and has major impacts on global climate.

Global Climate & Plate Tectonics

As scientists have gathered information about ancient plate movements and the “continental supercycle” they have noticed an interesting general correlation with global climate.

Permanent ice caps at the poles

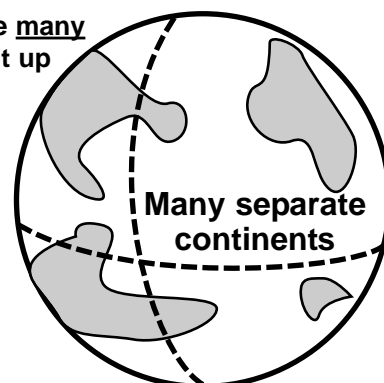


When there is a single supercontinent, the world climate is colder and drier, with lower sea levels.

This is because volcanic activity is at a minimum (less rifting and subduction occurring) and CO₂ levels are low. A reduced greenhouse effect lowers the average world temperature.

Low temperature means less evaporation, and lower rainfall. Formation of a permanent ice-cap lowers sea levels for many millions of years.
The world becomes cold & dry.

When there are many continents split up all over, there must be more rifting and subduction going on, and so volcanic activity increases CO₂ levels.



The Greenhouse Effect increases global temperatures, so there is more evaporation and more rainfall. Unless a continent drifts over a pole it is unlikely there are ice caps, so sea levels are higher.

At the moment, we are somewhere in-between these situations.

There is evidence that our ice-caps are melting. If they melted completely, sea-levels would rise by 60m or more.

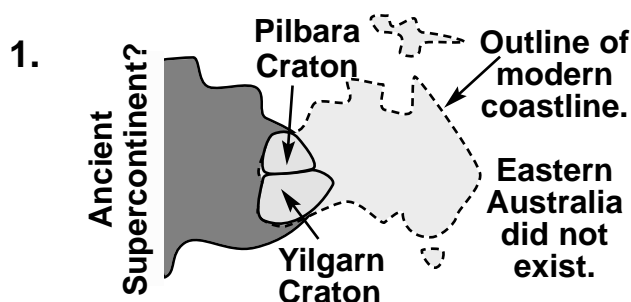
Tectonic History of Australia

Cratons

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A “craton” is a mass of continental rock which is ancient & stable. A craton rarely seems to be broken up by tectonic movements, probably because it is too thick. It is a chunk of lithosphere which has survived many “supercycles” and been part of many “supercontinents”, but still manages to stay in one piece. Australia contains some of the oldest cratons on Earth. Parts of Western Australia have probably been through many continental supercycles, although we have little knowledge of events more than 2 cycles back.

Evolution of the Australian Continent



The diagram above shows the most ancient part of Australia that we know about. The Pilbara and Yilgarn Cratons were already ancient when they joined together about 2,300 mya, possibly as part of the formation of a new supercontinent.

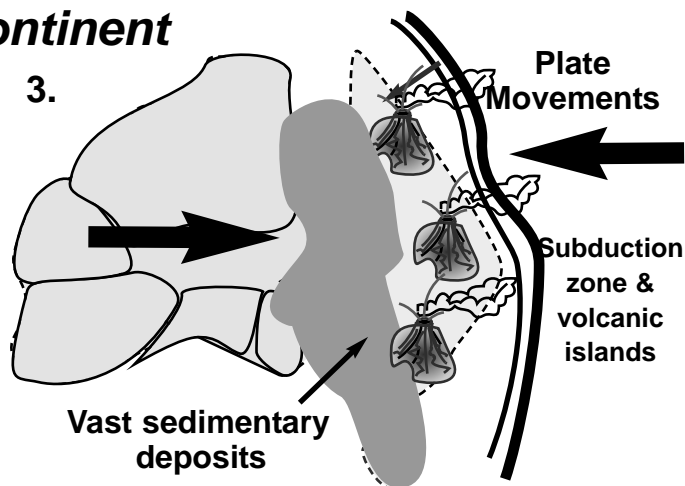
Over the following billion years, several younger cratons were added to the east to make a larger, stable continental mass. Presumably, these additions occurred during successive periods of collisions to form new supercontinents.



As supercontinent “Rodinia” broke up, the area that is now the eastern states of QLD, NSW, Vic and Tassie became a collision zone.

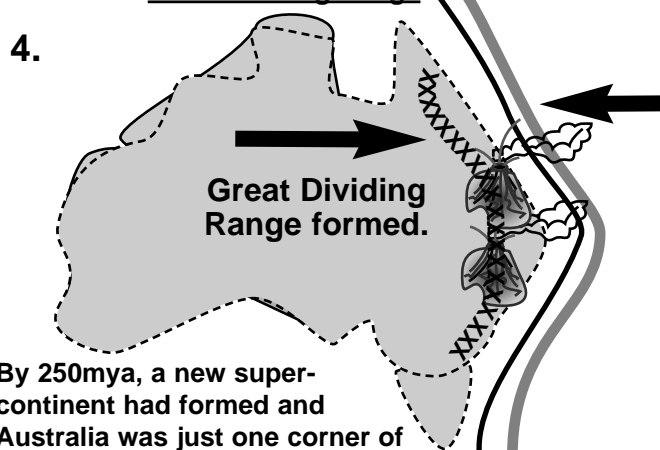
By 500mya, the Australian cratons were colliding with another plate, so that a subduction zone formed.

By 400mya, volcanic island arcs erupted from the sea floor. Huge amounts of sediments were deposited in the shallowing sea, from erosion of the continent and islands. (diagram 3, above right)



Sea levels were higher than today, so many areas of the continent were under shallow seas.

Vast sedimentary deposits formed in eastern Australia, including the great coal seams of QLD, NSW & Victoria, and the great “Hawkesbury” sandstone deposits around Sydney. The collision also created the Great Dividing Range.



Later, Pangaea broke apart. Later still, the southern portion “Gondwana” split up as described earlier.

For the past 200 million years or so, Australia has been a very quiet place tectonically. The main geological process operating has been erosion, so our land is broad and flat. Sediment washed from the mountains has formed the coastal plains where most Australians live.



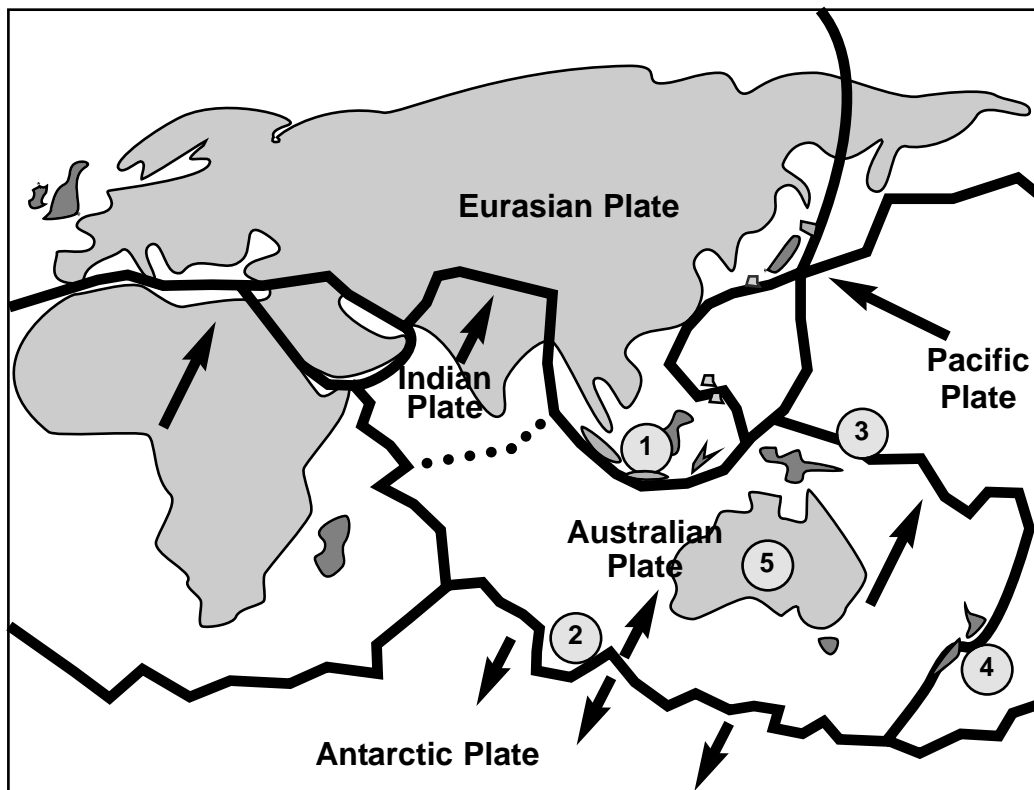
Tectonic Australia Today

Australia seems to be a very quiet place in terms of tectonic activity. We have no volcanoes and only a few, mostly small, earthquakes. Why?

The Australian Plate

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The diagram shows the approximate position of the “Australian Plate” and its neighbours. The arrows show the plate movements.



1 Indonesia

Many active volcanoes. Earthquakes are common. On Boxing Day 2004, an under-sea ‘quake made a tsunami which killed an estimated 200,000 people. This is a Subduction Zone.

2 Southern Ocean Floor

Mapping of the ocean floor reveals a Mid-Ocean Ridge with many small earthquakes. Sea-Floor Spreading is pushing Australia and Antarctica further apart.

5 Australia

We are surrounded by tectonic activity, but we experience almost none. That’s because we are in the quiet centre of our tectonic plate. All the exciting, but dangerous and violent things happen at the edges where 2 plates meet.

3 Pacific Island Chains

Look at a map of this region. There are many Deep Ocean Trenches and hundreds of Volcanic Islands. Another Subduction Zone.

4 New Zealand

They aren’t called the “Shakey Isles” for nothing! Many earthquakes & active volcanoes. NZ sits on the edge of our plate where it slides sideways past the Pacific Plate.

Please complete
Worksheet 7
before going on.



Impacts of Tectonic Events

What effects do the movements of Tectonic Plates have on people & on the Earth?

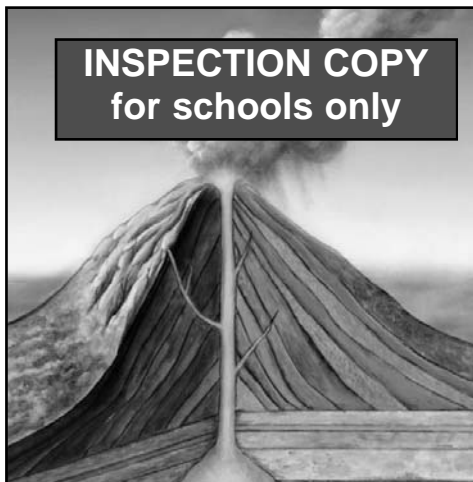
Effects of Volcanoes on Earth Climate

Volcanic Eruptions release huge CO_2 and Greenhouse

amounts of gases, ash and dust. Most of the solid particles fall quickly and blanket the surrounding area, but some fine particles can be injected into the high atmosphere and remain there for years.

These fine particles reflect light & heat from the Sun. This has a cooling effect which can last for years.

Volcanoes release a lot of acidic gases such as sulfur dioxide. This can cause "acid rain" which damages ecosystems.



Although fine dust particles can have a short-term cooling effect, the longer-term effect of volcanoes can be the opposite.

Volcanic eruptions release huge amounts of CO_2 gas. This is a "greenhouse gas" which traps heat which would otherwise radiate back into space. This has the effect of raising global temperatures.

One volcano has little impact, but there have been times in the Earth's history when widespread activity caused major climate changes. We believe that, about 250 million years ago, 95% of all life on Earth became extinct. The cause seems to have been sudden climate changes due to huge volcanic eruptions which first cooled, then heated the Earth.

Volcanoes & People

Lava Flows

When people think of volcanic eruptions, they usually think of lava. Although a lava flow can destroy property, it is seldom a danger to people. The big killers are "Pyroclastic Flows" and "Lahars".

Pyroclastic

Flow is a cloud of red-hot ash and poisonous gases which can pour down a volcano at 100km/hr. Nothing survives.



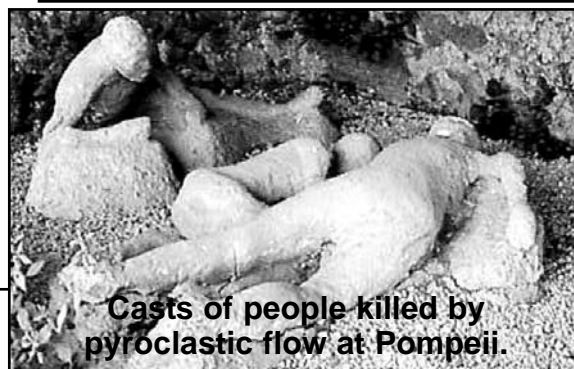
Lava flow over a road in Hawaii

Lahar is a flow of mud, ash, water and debris from a melted glacier or burst lake on a volcano. Lahars simply bury everything in their path.

Despite these dangers, people have chosen to live near volcanoes throughout history because the soil is usually fertile and excellent for farming.



Artist's impression of the destruction of Pompeii, in 79 CE



Casts of people killed by pyroclastic flow at Pompeii.



Earthquakes & People

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In a severe earthquake the ground heaves so that you cannot stand upright. However, this ground motion is not the main hazard to people. The big killers in any earthquake are collapsing structures, fires & tsunamis.

When major earthquakes hit large cities, the death toll can be enormous. Most casualties result from collapsing buildings. Multi-storey apartment blocks can “concertina” downwards: each floor is a block of concrete which can fall onto the next in a downward “domino effect”.

Knowing the danger, many people rush out into the streets and are then showered with falling roof tiles and broken glass from buildings that have not collapsed, but are shaking violently.

As the ground moves, pipes carrying water, power & gas are ruptured. Fires break out, & broken water mains make it difficult to fight the blaze. In the great San Francisco earthquake of 1906 large areas of the city survived the ‘quake but were destroyed by uncontrollable fires.

In hilly or mountainous areas, earthquakes can trigger landslides which can bury entire villages. When the earthquake occurs under the sea, the crust movements can cause destructive water waves called “tsunamis”. In recent years there have been 2 major tsunamis in the Asian region.

Indonesia, Boxing Day 2004

A massive undersea earthquake in the subduction zone near Sumatra, Indonesia set off a tsunami which killed about 200,000 people in Indonesia, Thailand, Malaysia, Sri Lanka and other nations around the Indian Ocean.

In many places there was no warning before a wall of water wiped out entire towns, beach resorts and rural farming communities.

Japan, March 2011

One of the largest earthquakes ever recorded occurred in the subduction zone just off the Japanese east coast. There was considerable earthquake damage, then within an hour a 30m tsunami washed up to 10km inland. About 15,000 people died. This death toll was considered to be quite low due to Japan having excellent building codes, warning systems, tsunami defences and emergency refuges.

Despite all defences, the tsunami damaged the Fukushima Nuclear Power Plant. This led to a later explosion and leakage of radioactivity from the reactors.



San Francisco 1906. Massive ‘quake, then fire.



A tourist took this photo as the 2004 Asian Tsunami hit the coast of Thailand. Moments later, most of these people died.



The day after the tsunami:
Sendai International Airport, Japan



Impacts of Tectonic Events (cont.) Effects on World Geography

Over hundreds of millions of years, the moving plates totally change the size and arrangements of the continents and the oceans. As the oceans change, so do the ocean currents. This has major impacts on the Earth's climate and on plants & animals.

Sea-Floor Spreading

Where plates move apart, new crust is created at the mid-ocean ridges. This widens the ocean basins.

200 million years ago, the Atlantic Ocean did not exist because North America was joined to Europe. As the lithosphere fractured into separate plates which moved apart, the Atlantic Ocean was created, and is still growing wider.



Mountain Building

Mountain chains are formed where plates collide. The crust is buckled, folded and faulted.

Earthquakes thrust the crust upwards to form the great mountain chains of the world. Erosion then forms valleys and plains. All our landscapes result.

Subduction destroys oceanic lithosphere and shrinks oceans. Near subduction zones, volcanic islands grow from the ocean floor. The Pacific Ocean is shrinking as Nth America approaches Asia.

Metamorphism

The high temperatures and pressures caused by tectonic forces changes the rocks themselves. Shale turns to slate, and limestone becomes marble.

Please complete
Worksheet 8.

Effects on Living Things

We tend to think that earthquakes and volcanic eruptions always cause destruction of ecosystems and death of living things. However, there is a positive side as well.

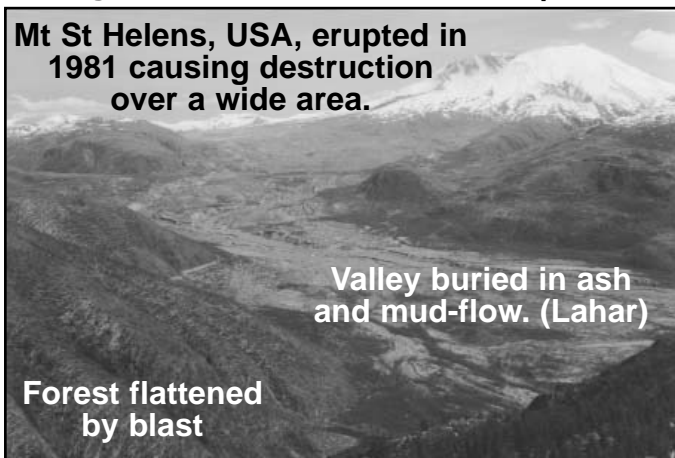
Mass Extinctions

At a local level, a tsunami can destroy coral reefs or coastal mangrove ecosystems. A volcano can destroy forests, or bury entire ecosystems under hot ash. Locally, the living communities can be devastated.

It can also be global. It was already mentioned that volcanic activity almost completely wiped out life on Earth by causing huge climate change about 250mya.

However, we know from the fossil record that after every mass extinction, life always "bounces back" with greater variety and numbers than before.

Mt St Helens, USA, erupted in 1981 causing destruction over a wide area.



New Habitats

Tectonic events create new places to live. For example, coral reefs thrive around volcanic islands created by subduction zones. Many new species evolve on the islands themselves.

Mountain ranges and the rivers, valleys and plains that form from them, all become habitats for living things.

Recycling Chemicals

Ancient farmers knew that volcanoes create fertile soil. An eruption can destroy, but fresh lava brings minerals which fertilise the soil.

Globally, plate tectonics is essential for cycling vital chemicals, such as carbon, calcium and phosphorus. Scientists now realise that without tectonic activity, the Earth's biosphere could not evolve and thrive as it has done.

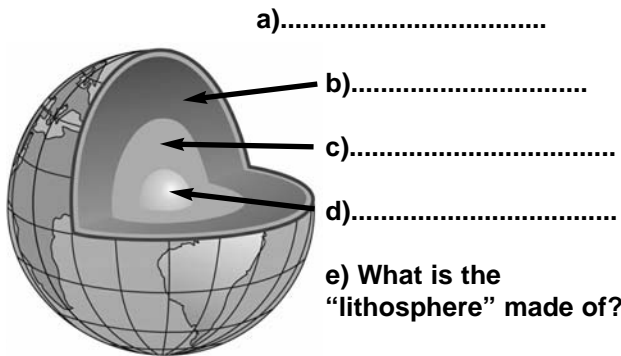


Worksheet 1

Earth & Lithosphere

Student Name.....

1. Label this diagram to identify the layers of the Earth.



3. Give an outline of how we know about the layer structure of the Earth.

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4.

a) What does a "seismometer" measure?

b) What are "P" & "S" waves & how can they be used to find the distance to an earthquake?

2. What is the major difference between lithosphere under a continent compared to under the ocean floor?

c) Apart from learning about the Earth itself, what is a practical reason for seismology?

Worksheet 2

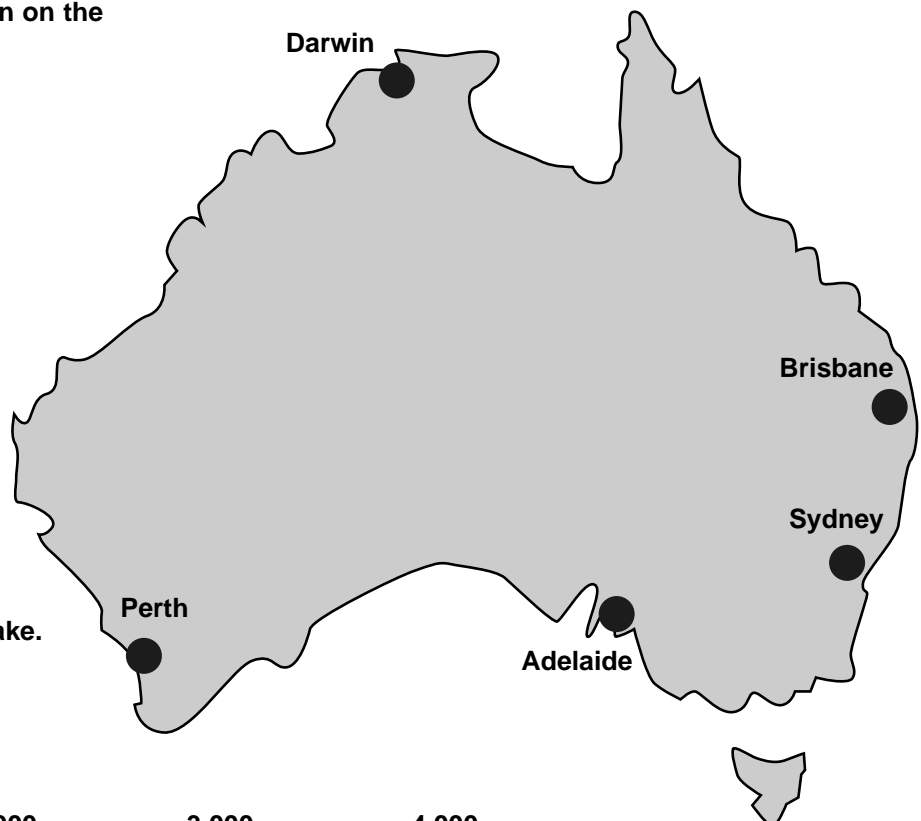
Locating an Earthquake

Student Name.....

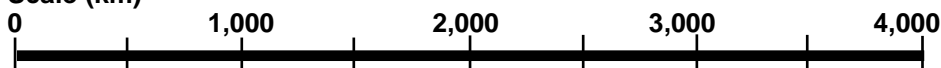
Earthquake shock waves were detected by seismometers in all the cities shown on the map. Here are data from 3 stations.

City	P-S time gap	Distance (km)
Adelaide	271s
Brisbane	238s
Darwin	137s
Sydney
Perth

- Each 1 sec gap between the P and S waves = 7km. Calculate the distance from the 3 stations to the earthquake.
- Use compasses to locate the earthquake epicentre.
- Complete the missing data for Sydney & Perth.



Scale (km)





Worksheet 3

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Plate Tectonics

Fill in the blank spaces.

The theory of "a)..... Drift" was proposed by Alfred b)..... in 1915. He thought that the continents had once been joined together and had moved apart. His evidence included identical c)..... and rock formations which are now separated by oceans. His theory was not well accepted, mainly because he could not explain d).....

During 1950-1970's new technologies produced new evidence. e)..... allowed mapping of the f).....

Deep-sea drilling allowed g)..... to be collected, and the h)..... in the rocks could be measured by magnetometers.

From the accumulation of evidence we now believe that the lithosphere is made up of a number of separate i)..... which slide across the j)..... being pushed by slow-moving k)..... which carry heat from the earth's l).....

Two adjoining plates must either m)....., or n)....., or slide sideways past each other.

It is the sudden movement of a plate which causes most o).....

Worksheet 4 When Plates Move

Fill in the blank spaces.

If 2 plates move apart, a)..... immediately erupts to fill the gap and create new b).....

This occurs mainly along the "c)....." ridges on the ocean floors. Many small d)..... occur as the plates move apart. In a few places the erupting material builds up enough to form an e).....

Where plates collide, different things can occur depending on the plate types. When "oceanic plates" collide, one of them will be pushed down into the mantle, or "f).....". When the plate bends down sharply there is a g)..... trench. As rock melts and moves upwards, a chain of volcanic h)..... may form.

Student Name.....

The plate movements may be irregular and sometimes produce huge i)..... Since these occur under water, they may set off a j).....

Subduction also occurs if the collision is between an oceanic plate and one carrying a k)..... The continent edge is l)..... forming a m).....

If 2 continents collide neither one can be n)..... Both are o)..... and, creating a mountain range such as the p)..... range.

We believe that 200 mya, all the continents were joined together in a "supercontinent" called "q)....."



Worksheet 5

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Evidence of Moving Plates

Fill in the blank spaces.

The most obvious evidence is the a)..... of some continents which seem to fit together like a jig-saw. This is especially true along the "b).....", rather than the coastlines.

There are many examples of identical c)..... of plants and animals found on different continents. Similarly, there are identical d)..... and mineral deposits now on separate continents.

Many pieces of evidence have come from studies of the deep ocean floor, especially along the "e)..... Ridges".

There are a series of parallel ridges, with a central f)..... The rocks in the centre are the g)..... (age) and they get progressively h)..... as you move further from the ridge.

The ocean sediments are very i)..... at the ridge and get j)..... as you move outwards.

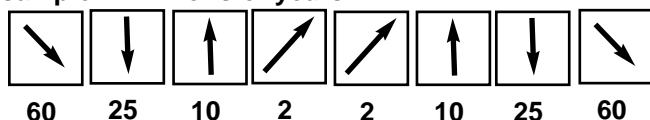
There are a series of matching "bands" of k)..... in the rocks on either side of the rift. All these facts point to the oceanic crust being created and spreading from the central rift.

Seismology patterns give more evidence. The vast majority of l)..... and occur along the plate m).....

Worksheet 6 Plate Tectonics

Student Name.....

1. This data was collected from rocks on either side of a mid-ocean ridge. The arrows show the magnetic field direction of each sample and the numbers are the approximate age of the rock sample in millions of years.



a) How would you explain the patterns in this data?

b) Where, in this sequence of samples, would you expect to find the thickest layers of sediments on top of the rock? Explain.

2. Fossils of a plant called *Glossopteris* have been discovered in Sth America, Africa, India, Australia and Antarctica. This plant lived about 180 million years ago. It had soft seeds without a seed case, so it is unlikely that seeds could survive drifting across an ocean. Explain the distribution of the fossils.

3. Most of the active volcanoes in the world occur in the "Ring of Fire" around the perimeter of the Pacific Ocean. Why?

4. Australia has no active volcanoes and experiences few earthquakes. Why is that?



Worksheet 7

Student Name.....

The Changing Map of the World

1. Describe the supercontinent we have called "Pangaea".

3. a) Which parts of Australia are the most ancient?

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b) What sort of tectonic events caused the formation of much of eastern Australia?

2. About 180 mya, Pangaea split into 2 parts, called "Laurasia" & "Gondwana".

a) List the modern continents which comprised Laurasia.

c) What has been the main geological process in Australia for the last 100 my?

b) List the 5 major "chunks" of the modern world that were once Gondwana.

d) Why is modern Australia a fairly quiet place, tectonically?

Worksheet 8

Tectonic Impacts

Volcanoes can have major effects on the atmosphere. Some eruptions can inject

a)..... into the high atmosphere. This b)..... sun-light and can c)..... the Earth for several years.

Gases released also have effects. Sulfur dioxide can cause d).....-rain. Huge amounts of e)..... gas are released and this can cause "f)..... warming".

Effects on the hydrosphere include g)....., caused by under-water earthquakes. Long-term changes to the ocean basins and positions of the continents cause h)..... changes. In an "ice-age" the sea-level i)..... If ice-caps totally melt, the sea-levels rise by over j)..... metres.

Student Name.....

There are many impacts on the lithosphere as the plates move around. k).....-

..... spreading widens the oceans.

At a l)..... zone, m)..... islands grow from the ocean floor, and n)..... ranges are created along the edge of a continent.

The biosphere can be affected both negatively and positively.

Volcanic eruptions can destroy a local ecosystem, but global climate change can cause a o)....., such as when 95% of living things died out about 250 mya.

Tectonic events also create new p)....., such as q)..... around volcanic islands. Many important chemicals are r)..... by the creation and subduction of the tectonic plates.



Topic Test (2 pages)

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Plate Tectonics

**Answer all questions
in the spaces provided.**

1. (6 marks)

Match each description to an item from the list. To answer, write the letter (A,B,C, etc) of the list item beside the description.

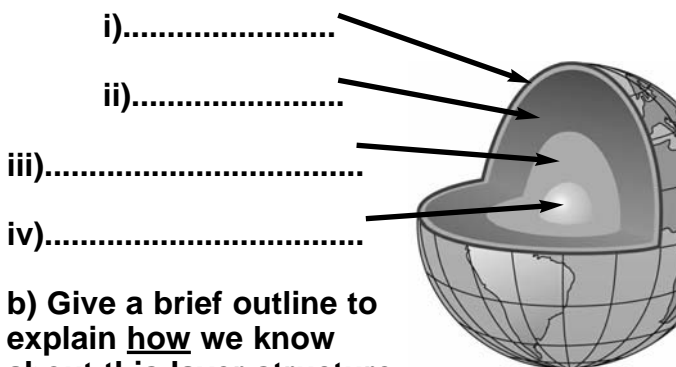
Description	matches with	List Item
a) Layer of crust with mantle rock attached.	
b) Study of earthquakes and their shock waves.	
c) Scientist who first proposed "Continental Drift".	
d) Zone where a tectonic plate is destroyed.	
e) Result of 2 continental plates colliding.	
f) Seismic wave created by underwater earthquake.	

List Items Not all will be used.
Some may be used more than once.

- | | |
|-----------------|-------------------|
| A. subduction | E. Wegener |
| B. island chain | F. mountain range |
| C. lithosphere | G. seismology |
| D. tsunami | H. Einstein |

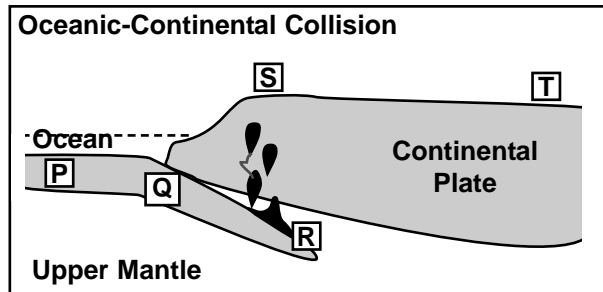
2. (6 marks)

a) Label the layers of the Earth



3. (5 marks)

This diagram shows a collision between 2 tectonic plates. Answer the following by using the positions P,Q,R,S & T.
(may be used more than once, or not at all)



In which position:

- a) would there probably be a mountain range?
- b) would there be a deep-ocean trench?
- c) might there be a volcano?
- d) would be the focus of an earthquake?

e) Name a place on Earth where a collision like this is occurring.

4. (5 marks)

a) Describe a piece of evidence from sea-floor studies which supports the theory of Plate Tectonics.

b) Describe some fossil evidence which supports the theory.

c) Describe the pattern of earthquakes which helps us locate plate boundaries.



Topic Test (cont.)

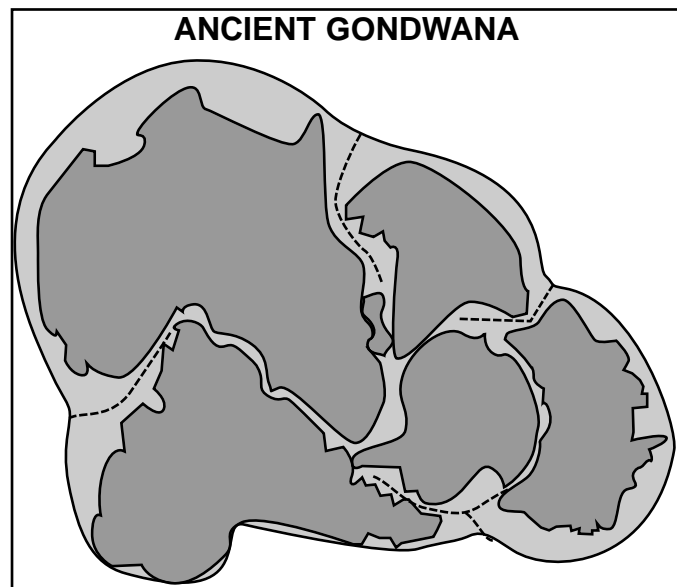
5. (4 marks)

a) What is meant by the “supercontinent supercycle”?

b) Scientists have found that there is a connection between the “super-cycle” of the continents and world climate. Give an outline of this general connection.

6. (5 marks)

a) The diagram shows the ancient continent called “Gondwana”. Label the modern names of its parts.



7. (5 marks)

a) What is a tsunami and what causes it?

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b) What is a “pyroclastic flow”?

Comment on whether this is dangerous to people.

c) What is a “lahar”?

8. (4 marks)

a) Explain how a lot of volcanic activity can cause the Earth’s climate to cool.

b) Explain how volcanic activity can also cause the Earth’s climate to warm up



Answer Section Topic 17. Plate Tectonics

Worksheet 1

1.
 - a) crust
 - b) mantle
 - c) outer core
 - d) inner core

2. Thickness. Very thick under a continent, much thinner under the ocean floor.

3. Knowledge has come from seismology, from studying the way that earthquake shock waves behave as they pass through the Earth.

4.
 - a) Earthquake shock waves.
 - b) They are different types of shock waves which travel at different speeds. P waves always arrive before S waves. The time difference allows measurement of distance to the 'quake.
 - c) To predict possible tsunamis or volcanic eruptions and allow evacuation of danger areas.

Worksheet 4

- a) molten rock
- b) crust
- c) mid-ocean
- d) earthquakes
- e) island
- f) subducted
- g) deep ocean
- h) islands
- i) earthquakes
- j) tsunami
- k) continent
- l) buckled/folded
- m) mountain range
- n) subducted
- o) folded & faulted
- p) Himalaya
- q) Pangaea

Worksheet 5

- a) shape
- b) continental shelf
- c) fossils
- d) rocks
- e) mid-ocean
- f) rift valley
- g) youngest
- h) older
- i) thin
- j) thicker
- k) magnetism
- l) earthquakes & volcanoes
- m) boundaries

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Worksheet 2

1. Distances (nearest 10km)

Adelaide	1900 km
Brisbane	1670 km
Darwin	960 km

2. Epicentre is on southern coast of Gulf of Carpentaria.

3. Missing data (approx)

Sydney	295 s	2060 km
Perth	410 s	2860 km

Worksheet 3

- a) Continental
- b) Wegener
- c) fossils
- d) what could make the continents move.
- e) Sonar
- f) ocean floor
- g) rock samples
- h) magnetism
- i) plates
- j) mantle
- k) convection currents
- l) core
- m) move apart
- n) collide
- o) earthquakes

Worksheet 6

1.
 - a) The crust keeps splitting open in the middle and new crust rock forms in the gap. This is why the rock is youngest in the middle and gets older outwards. This also explains the symmetrical pattern of magnetism on either side of middle.
 - b) Furthest away from the centre, because the oldest rocks have had more time for sediments to settle.
2. The plant grew all across the super-continent and fossils formed. Later, the fossil deposits have been separated by movements of the plates.
3. There are plate boundaries all around the ocean perimeter. Volcanoes occur (mostly) near the edges of plates.
4. Australia is not near the edge of a plate, so there is little tectonic activity.

Answer Section (cont.)

Worksheet 7

1. Pangaea was made up of all the world's major continents joined together.
2.
 - a) Nth America, Greenland, Europe, Asia.
 - b) Africa, Sth America, India, Antarctica & Australia.
3.
 - a) Western Australia.
 - b) A subduction zone formed where 2 plates were colliding. This caused mountain building and volcanoes creating eastern Australia. Erosion into shallow seas built vast sedimentary deposits.
 - c) Erosion. (That's why Aust. is so low and flat)
 - d) Because it is in the centre of a tectonic plate. Volcanoes and earthquakes tend to occur at the boundaries, not in the middle.

Worksheet 8

- a) fine dust particles
- b) reflects
- d) acid
- f) greenhouse
- h) climate
- j) 100
- l) subduction
- n) mountain
- p) habitats
- r) recycled
- c) cool
- e) carbon dioxide
- g) tsunamis
- i) falls.
- k) sea-floor
- m) volcanic
- o) mass extinction
- q) coral reefs

Topic Test

1.
 - a) C b) G c) E d) A e) F f) D
2.
 - a) i) crust
 - ii) mantle
 - iii) outer core
 - iv) inner core
- b) Seismology studies.
Layer structure figured out from the way earthquake waves behave as they travel through the Earth.

3.
 - a) S b) Q c) S d) Q or R
 - e) Pacific coast of Sth America.
(Andes Mtns)

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4.
 - a) Rocks are youngest at the mid-ocean ridges and get older as you move away in each direction. This is evidence for "sea-floor spreading".
 - b) Fossils are found on different continents which match the "jig-saw" idea. The plant/animal lived all over an ancient super-continent, and fossils have been separated by plate movements.
 - c) Most earthquakes occur along the plate boundaries.

5.
 - a) The Earth's continents periodically join together in one vast continent, then split apart separately, then join up again.
 - b) When there is one super-continent the world climate is generally cold and dry. When there are many continents the climate is warmer and wetter.

6. (Clockwise from top left) Africa, India, Australia, Antarctica, Sth America.

7.
 - a) A large, destructive ocean wave caused by an undersea earthquake.
 - b) A red-hot mixture of poisonous gases and ash which may pour down the slopes during a volcanic eruption. Extreme danger; nothing can survive.
 - c) A flood of water, mud, ash & debris from a collapsed lake or melted glacier on a volcano.

8.
 - a) Ash flung into the upper atmosphere can reflect so much radiation from the Sun that less heat gets through and the Earth cools.
 - b) Volcanoes can produce vast amounts of CO₂ gas. This can increase the "green-house effect" and cause the Earth to warm up.