Collins

Cambridge Assessment International Education

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Cambridge International AS & A Level
Geography

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3 Rocks and weathering

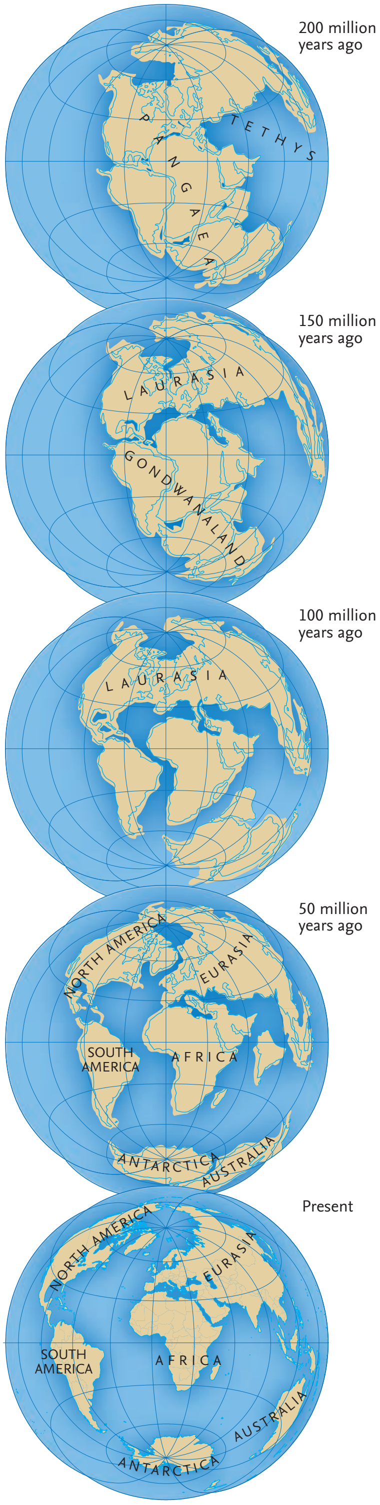


FIGURE 3.1 Pattern of continental drift from Pangaea to the present day.

It is estimated that the Earth was formed about 4.6 billion years ago (4600 million years ago) by mass planetary movements in space. It is believed that the explosive energy resulting from the birth of our Sun was the momentum needed for space debris to combine for over 20 million years before forming the planets we now recognise in our solar system. A complex process of meteor showers, gravitational movements and volcanism would then slowly help to sculpt a home for life.

Most of what we recognise on Earth today is the result of the last 600 million years with human life only identified as existing within the last 195 000 years. The Earth and its features have been in constant evolution being continually grown, shaped and eroded through many physical processes that are still operating today.

The continued movement of the Earth and corresponding shifts in climate and global position have resulted in varying characteristics. The characteristic formed at a particular time or period has been given a name based on modern interpretation and discovery. Through each time period the Earth's creatures have lived and died.

Plate tectonics

The notion of plate tectonics was first instigated in 1912 by German meteorologist Alfred Wegener whose work included the theory of continental drift. Though many people had professed to notice the similar shapes and jigsaw-like fit of some continents and land masses, Wegener sought to find evidence from a variety of sources to prove his theory that the continents were slowly drifting across the surface of the Earth. Many were sceptical, seeing no clear mechanism for such large scale movements.

From the evidence outlined below, Wegener deduced that at one time the Earth was one land mass – a super continent known as Pangaea. Pangaea later split into Gondwanaland and Laurasia before breaking into additional landmasses over time. Now it is widely accepted that the continents are indeed moving in different directions under the influence of large thermic currents under the surface of the Earth. Wegener's pioneering discoveries have led to greater depth of study and more comprehensive evidence.

Evidence for plate tectonics

- Geology: Many rocks of a similar age, structure and composition have been found on land masses now thousands of miles apart. For example, the Blue schist of North Wales were formed with those of the east coast of the USA.
- Fossils: Fossils have been found of key species in Africa, India and Antarctica. Fossils of the fern *Glossopteris* have been found in all southern continents as well as Lystrosaurus – a large mammal-like dinosaur that was not known to swim or fly.

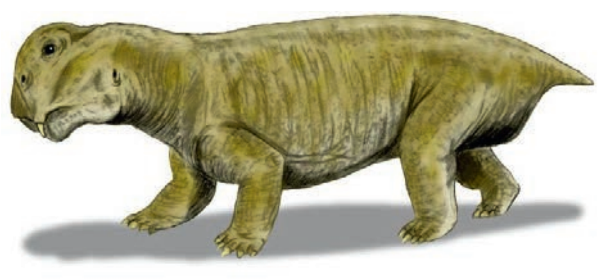


FIGURE 3.2 Lystrosaurus, fossil evidence for plate tectonics

- Climatic evidence: Evidence of ice sheets and glaciers has been found in the tropics. Even during the Earth's coldest periods it was impossible for ice to be formed there unless these areas were once closer to the poles. Coal has been found in Antarctica. Coal forms in tropical conditions. This means that Antarctica must have been closer to the equator at some stage.
- Sea floor spreading: In 1962 Harry Hess studied the age of rocks across the Atlantic. He determined that as new rock is created from plate movements widening the Mid-Atlantic Ridge older rocks are pushed to the edges. Estimates suggest that the Atlantic is widening by an average of 2 cm each year.
- Paleomagnetism: During underwater volcanic eruptions, basaltic lava is intruded into the crust and cools. Every time new rock or minerals are created, the magnetic orientation of the time is imprinted in them. Experiments have shown a periodic reversal of the magnetic field showing a pattern of alternating north-south aligned sediments.

The structure of the Earth

The Earth is often classed as spherical though its equatorial diameter is slightly wider than its polar diameter. It is composed of a series of layers ranging in density and thickness to its centre. Each layer has specific characteristics that are fundamental to the mechanisms of plate tectonics and continental drift. Many comparisons are made to the structure of an egg, which clearly defines three parts – the shell, white and yolk corresponding to the crust, mantle and core respectively. Whilst this is useful as a visual aid, the true nature of the complex interactions can only be explained with a more detailed understanding.

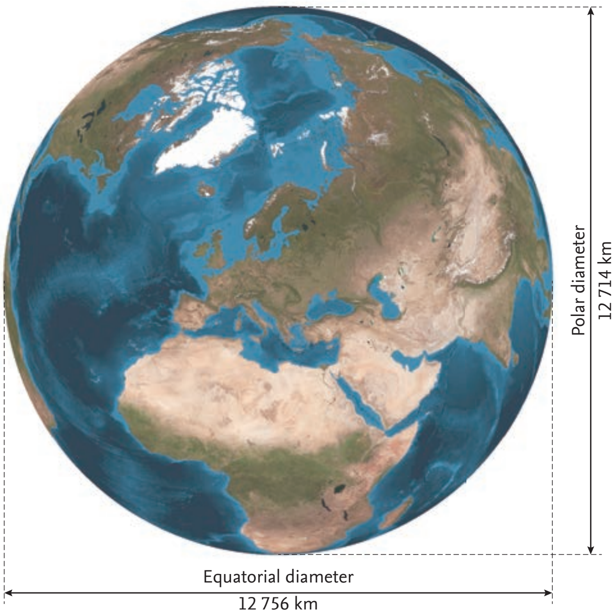


FIGURE 3.3 Earth's dimensions

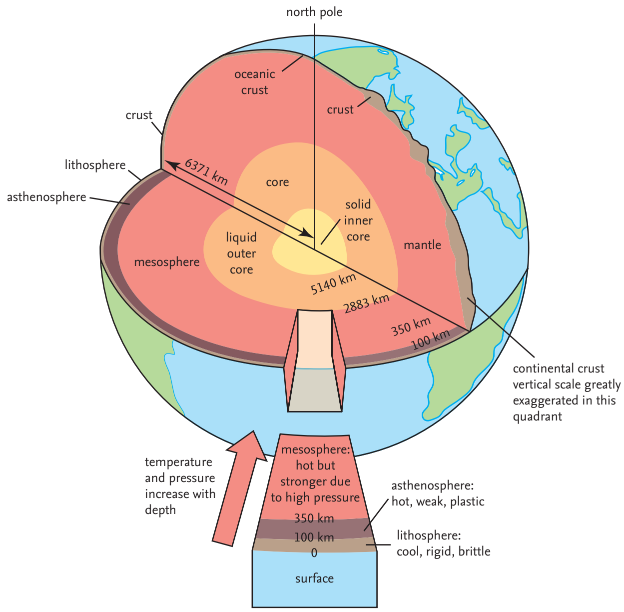


FIGURE 3.4 Structure of Earth

The lithosphere

The lithosphere is the outermost layer composed of the crust (the Earth's outer layer) and the rigid upper part of the mantle. It is the lithosphere that was 'cracked' into tectonic plates during the Earth's formation. There are seven major plates, eight minor plates and a number of smaller fragments known as micro plates. These plates are rigid and sit on the semi-molten mantle below known as the **asthenosphere**. The largest plates are the Antarctica, Eurasian and North American plates.

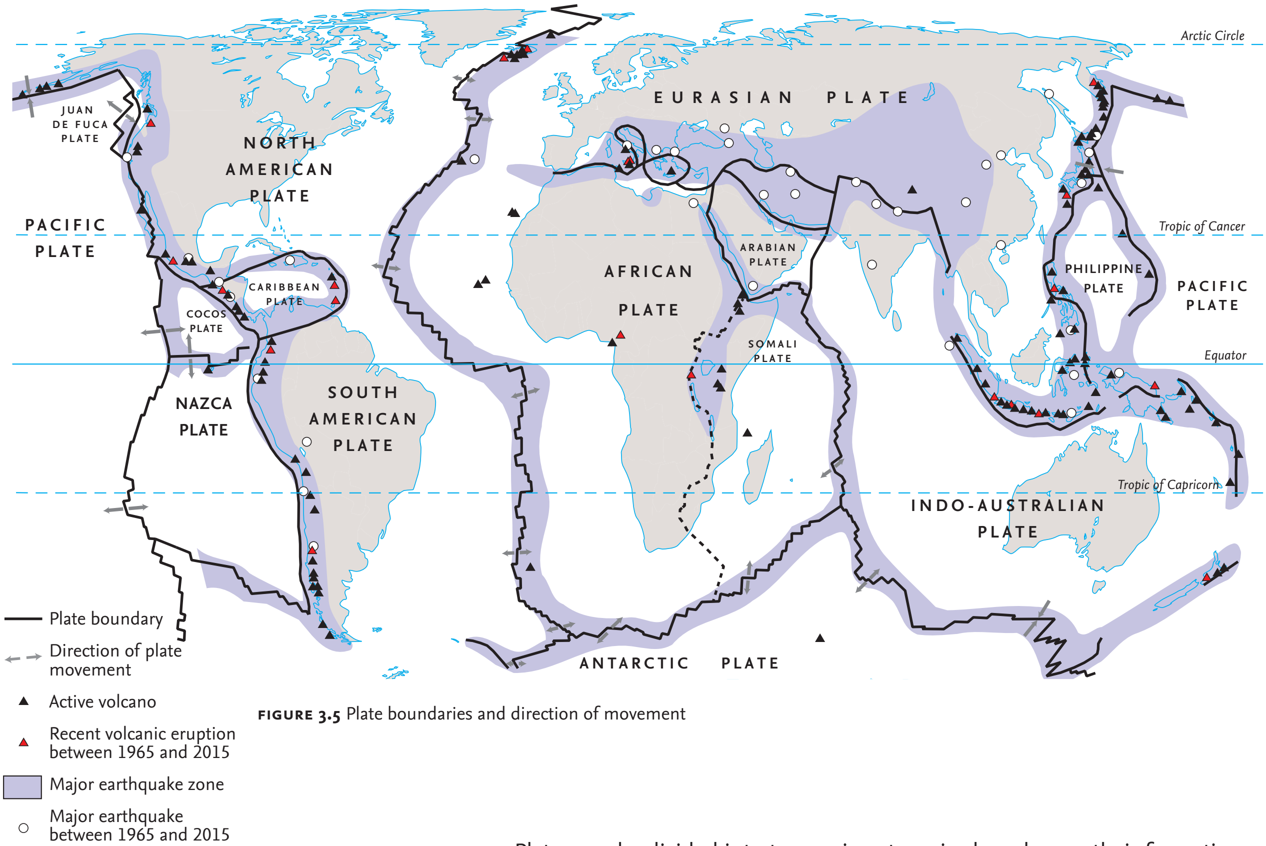


FIGURE 3.5 Plate boundaries and direction of movement

Plates can be divided into two main categories based upon their formation and the composition of the rocks or crust they are made up of.

Continental plates are on average 125 km thick, reaching their greatest thickness at large mountain ranges. The continental crust (known as sial) is composed of older lighter granitic rock that is rich in minerals such as silica and may range from 5–70 km thick.

Oceanic plates are thinner than continental plates, only reaching a thickness of 50–100 km thick, of which the upper 5–10 km may be crust. They are composed of younger and denser rock of balsaltic origin. The boundary between the crust and the mantle is known as the Mohorovičić Discontinuity or Moho for short.

Plate movement and boundaries

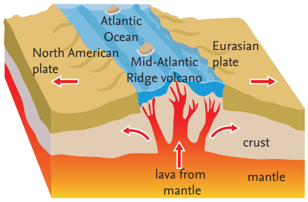
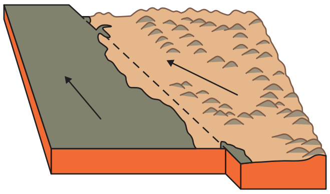
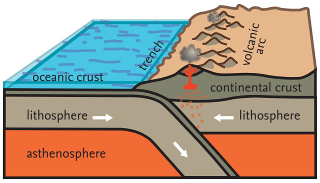
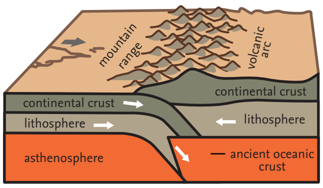
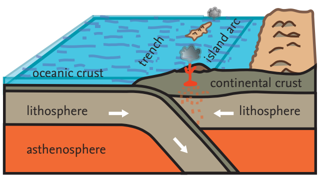
The Earth's core still retains much of its radioactive heat from its early formation. As the radioactive isotopes break down, the immense heat generated creates convection currents within the mantle. The hot molten, viscous rock is then forced to rise and older rock descends creating a cycle that allows the overlying plates to drift along. However this process is impossible to verify, even with modern technology, and as a result several additional theories have been sought to explain continued plate movements.

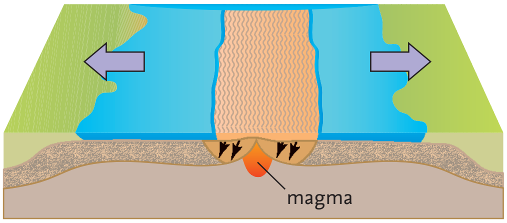
The **slab-pull mechanism** is also referred to as **dragging theory**. In this scenario the oldest edge of a plate furthest from the molten magma becomes cooler and more solid. This solid denser material descends at a **subduction zone**. **Hotspots** are vertical plumes of magma that can be found both at plate boundaries and within the middle of a plate. Hotspots occurring within a plate, such as Hawaii which is centrally located in the Pacific Plate, are referred to as intraplate hotspots and are characterised bu volcanic activity. As the tectonic plates move, upsurging magma will continue to be extruded creating a trail of volcanic islands.

The mechanism for plate movement is still a subject of debate.

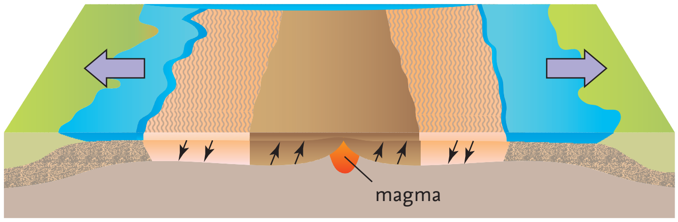
The edge of a plate is called its boundary or margin. Plates interact with each other as they move. This movement is largely restricted to three main directional motions – **convergent** (together), **divergent** (apart) and **transform** (side-by-side) – but there are four associated margin types, which are summarised in Table 3.1.

TABLE 3.1 Types of plate boundary

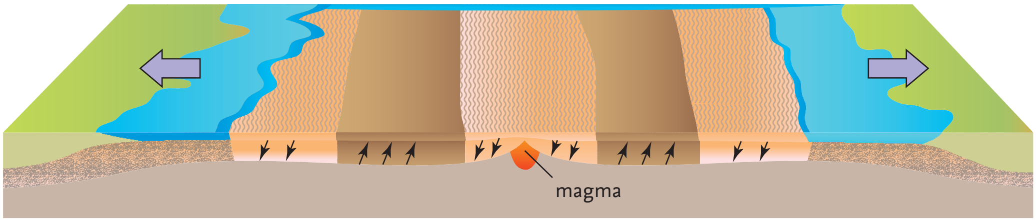
	Name	Image	Explanation	Example
Divergent	Constructive plate boundary		A constructive plate boundary occurs when tectonic plates move apart creating an upwelling of magma from beneath. As the plates rarely move rapidly and with little contact with each other, seismic activity is less. Volcanic activity may be present.	The North American and Eurasian plates are moving away from each other along the line of the Mid-Atlantic Ridge. Iceland lies on this divergent boundary and has formed due to this and a hotspot.
Transform	Conservative plate boundary	Conservative margin 	A conservative or transform boundary is characterised by two plates moving side by side. Often plates will move at different rates or in different directions, which puts increased stress between the two 'slabs'. As friction increases so too will the potential for earthquakes.	A classic example is the San Andreas fault in California. The Pacific plate is moving more rapidly northwest than the North American plate by an average of 30 mm a year. The fault is 1300 km long, extends to at least 25 km in depth, and has a northwest-southeast trend.
Convergent	Destructive plate boundary		A destructive plate boundary results from a convergence of oceanic and continental plates. As they are forced into each other the denser oceanic plate subducts under the thicker less dense continental plate. The subducting plate becomes increasingly magmatic due to intense heat and pressure as it is destroyed. Volcanic activity may result along with seismic activity.	The Andes have been created by the eastward movement of the Nazca plate towards the South American plate by 79 mm each year. The descending Nazca plate is forced down beneath the South American plate causing it to fracture and deform. This results in shallow focus earthquakes and a deep ocean trench. Explosive andesitic magma creates **volcanoes** such as the stratovolcano Láscar in Chile.
	Collisional plate boundary	 continental-continental convergence	A collisional plate boundary occurs when plates of equal thickness and densities collide. Though this may be at a relatively slow rate, the extreme pressure is great enough to develop huge mountain chains. Continental crust is thickest here and as a result magmatic intrusions are rare.	The Himalayan mountain range and Tibetan plateau formed as a result of collision between the Indian plate and the Eurasian plate. The Himalayas are still rising by more than 1 cm per year as India continues to move northwards into Asia, which explains the occurrence of shallow focus earthquakes in the region. According to seismological data, the ground beneath Kathmandu may have moved about 3 m southward as a result of the 2015 earthquake.
	Ocean plate-ocean plate boundary	 oceanic-oceanic convergence	Subduction zones may also be formed at an oceanic-oceanic convergence zone. In this situation the melted subducting plate may result in submarine volcanoes that may eventually breach the surface to form islands. As these islands occur along a boundary several chains may be formed and are referred to as Island Arcs. Oceanic-oceanic subduction results in seismic and volcanic activity.	The islands of Japan and the Philippines sit at the junction of several plates, the Eurasian plate, the Philippine plate and the Pacific plate. The Ryukyu Islands are an island arc created by the Philippine plate subducting below the Eurasian plate.



(a) Period of normal magnetism



(b) Period of reverse magnetism



(c) Period of normal magnetism

FIGURE 3.6 (a), (b) and (c) Divergent plate boundaries, sea floor spreading.

Sea floor spreading

Divergent plate boundaries occur more commonly in the oceans and are responsible for creating large oceanic ridges and, in combination with other factors, islands such as Iceland.

It was not until the early 1960s that the concept of sea floor spreading was considered one of the mechanisms of continental drift. In the Atlantic this constant 'conveyor belt' motion is creating enough new ocean floor to widen the Atlantic ocean by 2 cm a year, meaning continental North America and Europe are slowly moving further apart.

Since the 1960s, sea floor spreading has been investigated extensively. When lava cools on the sea floor magnetic grains in the rock align themselves in accordance with the Earth's magnetic field at the time of cooling. This effect of paleomagnetism can be seen in Figure 3.6.

Subduction zones

Subduction zones occur at collisional plate margins where there is a difference in plate density. In oceanic-continental plate collisions they are generally formed where denser oceanic plates descend under a continental plate into the hot molten layers of the upper mantle. Subduction usually takes place at angles of 30–70°, experiencing an increase in gradient with depth. The dip of the subducting plate is inversely proportional to the speed at which the plates converge. There are several features associated with subduction zones:

- **Oceanic trenches** or deep-sea trenches are long narrow depressions in the surface of the seafloor along a plate boundary formed as a result of the descending oceanic plate. Oceanic trenches form the deepest parts of the ocean and range between 6000 and 11 000 metres deep where the Mariana trench lies to the east of the Pacific Ocean.
- A **Benioff zone** (sometimes referred to as a Wadati-Benioff zone) is a planar zone of seismicity corresponding to a subducting plate. A planar zone is a zone along a line or plane within the rock structure. Wadati–Benioff zone earthquakes develop along the boundary between the two plates as friction dictates (Figure 3.7).

- **Fold mountains** and folded sediments are formed by the compression of marine sediments trapped between the converging lithospheric plates at a convergent boundary. These marine sediments are distorted under extreme pressure and thrust upward creating a chain of mountains and volcanoes. The Himalayas are a fine example of fold mountains created by sediments in the Tethys Sea that are now influenced by orographic uplift and continue to shape the greatest mountain range and highest mountain on Earth, Mount Everest.

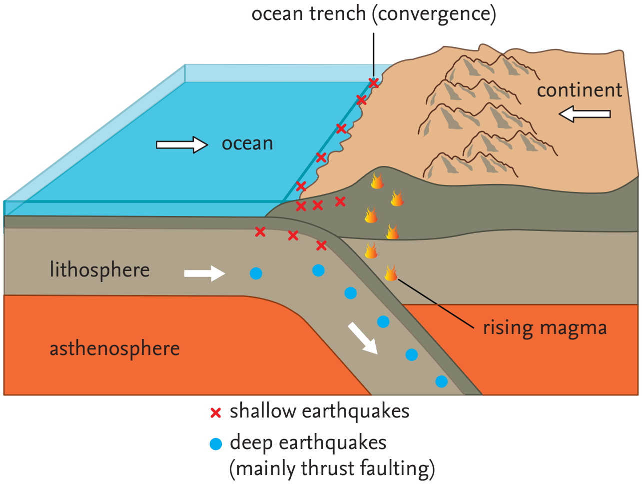


FIGURE 3.7 Benioff zone

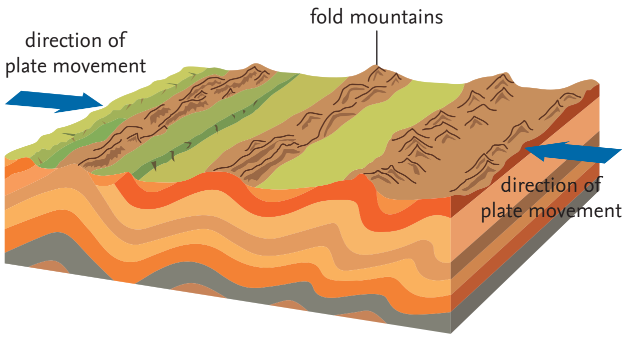


FIGURE 3.8 Formation of fold mountains

FIGURE 3.9 Mount Everest and nearby Himalayan peaks including Nuptse and Lhotse.