GCSE Geology 2.2: Plate tectonics

The Earth has a concentric structure based on its chemical properties (crust, mantle and core) and mechanical behaviour (lithosphere and asthenosphere).

	Average thickness (km)	Composition	Density	Maximum age
Continental crust	35	Granitic	2.7	4,000 Ma
Oceanic crust	7	Basaltic	2.9	200 Ma
Mantle	2,900	Peridotite	3.3-5.5	4,500 Ma
Core	3,450	Iron and nickel	9.9-13.1	1,300-4,500 Ma

The **lithosphere** is the outer layer of the Earth which is made up of the crust (oceanic and continental) and part of the upper mantle. It is cold, rigid and brittle (earthquakes are common in this layer). It averages 100-120 km in thickness and is what tectonic or lithospheric plates are composed of. It is just a few km thick under mid-ocean ridges but can be up to 300 km beneath mountain ranges such as the Himalaya.

The **asthenosphere** is the layer immediately below the lithosphere, and the top of it is marked by a temperature of 1300˚C. This layer is hot, weak and capable of flowing slowly in a solid state. It can deform internally to allow the subduction of lithospheric plates into it. Mantle convection currents occur in this layer, and it averages from 100-700 km depth from the surface.

Tectonic plates move relative to each other by mechanisms that are not yet completely understood. Three different mechanisms have been suggested:
Mantle convection currents in the upper mantle drag the overlying plates with them as the currents move. Now considered not to be an important mechanism.

Ridge push involves the higher elevation of mid-ocean ridges allowing gravitational forces to move newly created lithosphere away from the site of formation.

Slab pull or slab drag involves cold, dense oceanic lithosphere descending back into the mantle at subduction zones. This 'sinker effect' helps to pull mid ocean-ridges apart, generate further partial melting of the mantle beneath and produce more oceanic lithosphere. Now regarded as the most important mechanism.

Evolution of plate tectonic theory – a number of scientists made contributions to our understanding of plate tectonic theory between 1915 and 1965.

1915: Alfred Wegener proposed the concept of continental drift based on six lines of evidence: jigsaw fit of opposing coastlines, fossil distributions, tectonic fit of old mountain belts, geological fit of rock types across continental boundaries, distribution of 300 Ma glacial deposits and the study of rock types through geological time that indicated different climatic belts. More recently, GPS has been used to monitor continental movements.

1960: Harry Hess proposed the concept of seafloor spreading based on echo-sounding results of a survey on the ocean floors of the world. It was found that the shallowest parts of oceans (1.5 km higher than the surrounding ocean floor) were in the middle (mid-ocean ridges) and the deepest areas lay at the edge adjacent to continents (ocean trenches 8-11 km deep). The flat areas between the ridges and trenches were an average of 4 km deep and termed 'abyssal plains'. Hess proposed that new oceanic lithosphere was created at mid-ocean ridges, moved away from the ridge and eventually destroyed in ocean trenches.

1963: Vine and Matthews studied the magnetic stripes on the ocean floor (normal and reversed polarities of the Earth's magnetic field) and discovered that the pattern was symmetrical across mid-ocean ridges. This showed that new oceanic crust was formed at mid-ocean ridges and spread away from a central point in opposite directions.

1965: J.Tuzo Wilson discovered a new structure which he termed a 'transform fault'. He used these to connect the mid-ocean ridges to the ocean trenches and build up a global map of interlocking tectonic plates. Later, these transform faults were classified as conservative plate boundaries.

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Plate boundaries are also where the majority of the Earth's volcanoes and earthquakes are located. Five types of tectonic plate boundaries have been identified and each one is characterised by different types of structures, topography, magma, and earthquake activity.

Divergent plate boundaries – e.g. Mid-Atlantic Ridge
Plates moving away from each other.
Basalt pillow lavas extruded onto sea floor.
Decompressive partial melting of upper mantle to form basaltic magma.
Ocean ridges (MOR) with high heat flow values.
Rift valley runs along centre of MOR (normal faults, tensional forces).
Shallow focus earthquakes <70 km deep.
Unequal rates of magma addition on MOR generates transform faults.
Symmetrical pattern of magnetic stripes.
Crust increases in age away from MOR in both directions.
Transform faults offset the ridge at 90°.
Ridge push due to ridge being 1.5 km higher than abyssal plain.

Convergent oceanic-continental plate boundaries – e.g. the Andes
Plates moving towards each other.
Subduction of older, colder oceanic lithosphere at ocean trench and slab-drag.
Benioff zone earthquakes at depths of 1-670 km.
Release of water from upper part of subducted oceanic lithosphere into overlying mantle, causing partial melting of mantle peridotite to form andesitic magma.
Volcanic mountain chain – explosive andesitic volcanoes.
Folding, thrust faulting.

Plate theory is continually being re-evaluated
Seismic tomography to reveal deep structure of mantle with evidence of subducted oceanic lithosphere at depths of >2000 km.
Ocean drilling discovered asymmetrical spreading along parts of divergent margins with mantle peridotite exposed on the seabed (now altered to serpentinite) as part of ocean core complexes.

Convergent oceanic-oceanic plate boundaries – e.g. Java/Sumatra/Caribbean
Plates moving towards each other.
Subduction of older, colder and denser oceanic lithosphere at ocean trenches and slab drag.
Benioff zone – deep, medium depth and shallow focus earthquakes at depths of 1-670 km.
Release of water from upper part of subducted oceanic lithosphere causing partial melting of overlying mantle to form andesitic magma.
Volcanic island – arc-explosive andesitic volcanoes.

Convergent continental-continental plate boundaries – e.g. the Alps, Himalaya
Formed after the closure of a former ocean.
Plates moving towards each other.
Compressive stress forms a fold mountain belt (the Alps/Himalaya).
Continental crust double the average thickness (70-90 km).
Partial melting of the base of the continental crust to produce granitic magmas, which rise and solidify as granite plutons.
Contact metamorphism – marble, metaquartzite.
Shallow focus earthquakes.
Regional metamorphism – slate, schist from sediments on former ocean floor.
No volcanic activity – continental crust too thick/ too cool to allow magma to rise and erupt.

Conservative plate boundaries – e.g. San Andreas Fault (transform fault)
Plates slide past each other horizontally (shear forces).
Join up divergent and convergent boundaries.
Movement is intermittent as plates locked together.
Stress builds up then sudden movement causes shallow focus earthquakes.
Movement can be to the right (right-lateral) or left (left-lateral).
No volcanic activity as no subduction/partial melting is taking place.