PLATE TECTONICS

by John Edwards

WE BELIEVE the Earth to be about 5 billion years old. That long ago it would have been a mass of gas and molten rock. As the Earth cooled, different materials began to separate out. More dense materials such as iron started to form the core of the Earth. Lighter materials such as silicates floated to the surface.

Distinct layers began to form in the Earth, which are still present today. The outer or surface layer, the **crust**, is on average only 20 km in depth. The zone of rock beneath the crust is the **mantle**. This is composed mainly of nickel and iron, and is approximately 3,000 km in depth. The layer beneath the mantle is the **core**. Much of the core is iron and nickel, which is liquid because it is so hot. This is called the **outer core**. The centre of the Earth is called the **inner core**, which is also made of iron and nickel. The inner core is solid because the rocks are under so much pressure, even though the temperature is 5,000°C.

The theory of plate tectonics

The crust is not continuous over the surface of the Earth, but is broken into a series of massive **plates**. Although it is not apparent, these plates are in constant motion (Figure 1). The average rate of movement is between 1 and 10 cm per year. The North American and Eurasian plates, for example, are moving apart, while the African and Eurasian plates are colliding.

Until the mid-19th century, we had little knowledge about the dynamic nature of the Earth. Then scientists began to investigate the possibility that the continents moved across the surface of the Earth. The main initial reason for this was the apparent 'fit' of the coastlines of South America and Africa. It was a German meteorologist, Alfred Wegener, who proposed the theory of **continental drift**. He suggested that all the continents had originally been joined together as one landmass, after which they had separated and slowly drifted along the ocean floors to their current locations.

Wegener investigated the apparent match of the coastlines of South America and Africa. The evidence was supported by the rocks in the two continents. The mountains running across South Africa appeared to match those in Argentina, and there were many similarities in the types of rock found in the two locations. In addition to this, similar fossils were found on either side of the Atlantic Ocean.

Despite the strength of the evidence, Wegener's ideas were not generally accepted at the time. It was not until later that new evidence was found to support and develop the theory of continental drift. Scientists by now had a much better understanding of the structure of the ocean floors. It was clear that new ocean crust was continually being created in zones in the middle of the oceans. **Sea-floor spreading** was used to modify Wegener's

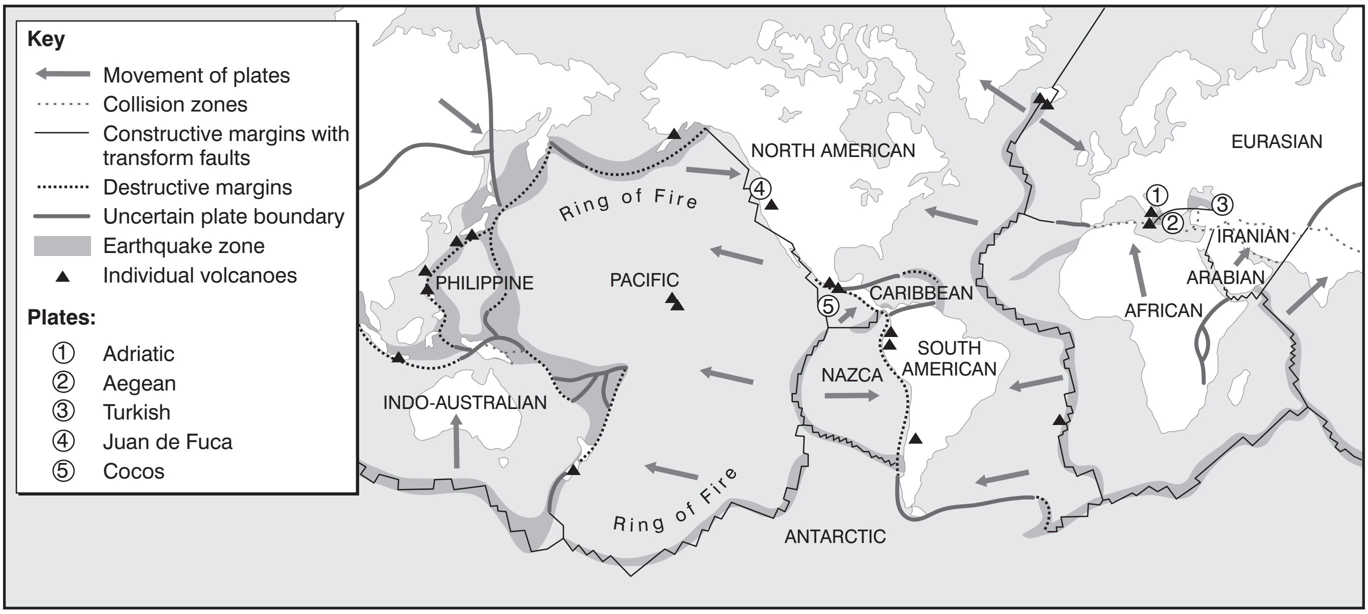

Figure 1: **The Earth's plates**

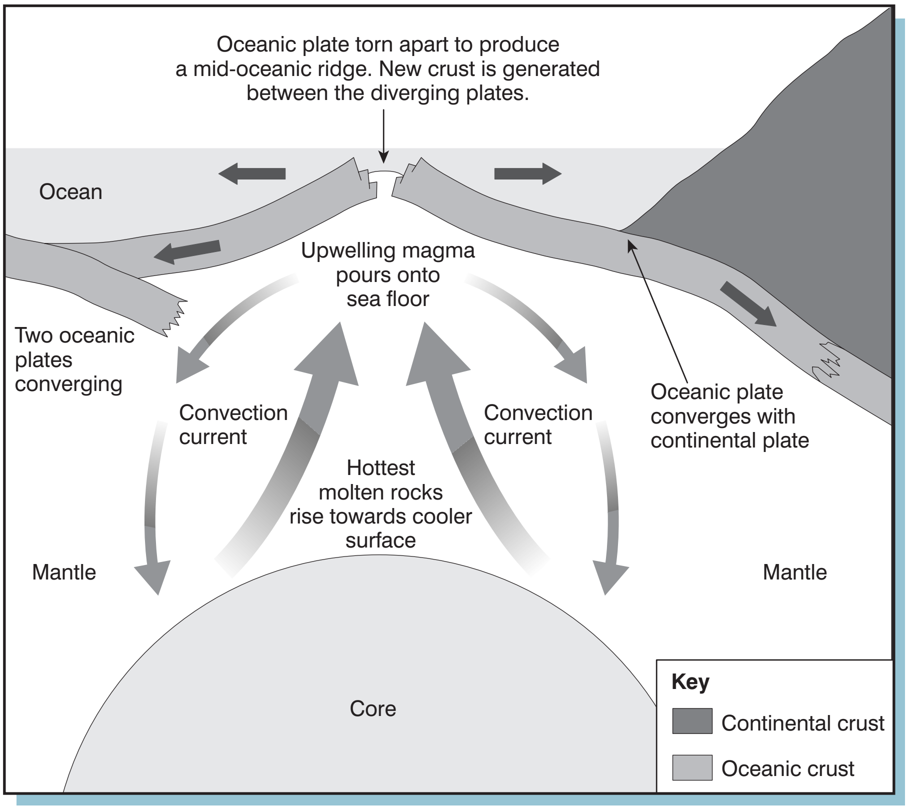

Figure 2: **Convection currents provide the driving force for movement of the Earth's plates**

Figure 3: **The super-continent of Pangaea, 250 million years ago**

Figure 4: **Laurasia and Gondwanaland**

original ideas. The continents were moving, but the creation of crust along mid-ocean ridges was the driving force, rather than the continental landmasses floating on the ocean floors. The **theory of plate tectonics** had been established.

It is heat from within the Earth that powers the movement of the plates on its surface. At temperatures of over 1,000°C, the rocks of the mantle near to the core become 'plastic' and start to flow towards the surface. It is only the high pressure of rocks in the crust above that stops them from melting in the heat. Nearer the surface the rocks cool, flow sideways and then return towards the core. The rocks of the Earth's mantle form giant **convection currents** (Figure 2).

The sideways movement of rocks just beneath the crust causes the plates on the surface to move. Although this may be as little as 1 cm per year, over millions of years this movement has completely changed the pattern of land and sea on the Earth's surface.

Break-up of a super-continent

The theory of plate tectonics suggests that, working backwards from the present day, it is likely that all of the continents were once joined as a huge super-continent called **Pangaea**. This was surrounded by a giant ocean called the **Panthalassa Ocean**. Figure 3 shows the positions of present-day continents within Pangaea. Notice how little Africa has altered in all this time, but how far India had to travel before it became a part of Asia.

Pangaea broke into two new continents called **Laurasia** and **Gondwanaland**, shown in Figure 4. Europe, Asia and North America were all joined together as Laurasia. Gondwanaland was made up of Africa, Australia, South America and Antarctica. Until 150 million years ago, India still remained a part of this landmass.

After Laurasia and Gondwanaland broke apart, the continental landmasses started to drift further apart. By 130 million years ago, the shape of our present-day continents was beginning to be recognisable. The Atlantic Ocean had started to develop as Europe and North America drifted apart. Antarctica was moving south towards its current location, and India was on its way to crash into Asia.

Plate boundaries

The Earth's plates may move very slowly in human terms, but it is this movement that is responsible for some of the most spectacular landscapes and hazards on our planet. It is at the edges of the plates, where two or more meet, that these processes take place.

There are three types of plate boundary. These are:

1 **Divergent** (or **constructive**) **boundaries:** this is where plates move apart.

2 **Convergent** (or **destructive**) **boundaries:** this is where plates collide.

3 **Transform** (or **conservative**) **boundaries:** this is where plates slide horizontally past one another.

Divergent boundaries

Divergent boundaries occur where two plates move away from each other. They are pushed apart by molten rock, or **magma**, rising from the mantle beneath the crust

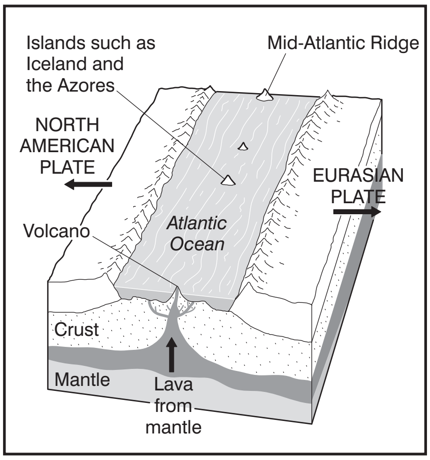

Figure 5: **A divergent plate boundary**

(see Figure 5). As soon as the magma reaches the surface it solidifies, forming new crust. This is why this type of plate boundary is sometimes called a **constructive** boundary.

Convergent boundaries

Convergent boundaries occur where two or more plates collide. The type of collision depends on the nature of the plates involved. However, a part of the Earth's crust is 'lost' during this process, this plate boundary is called a **destructive** boundary.

- **Where ocean and continental plates collide**

The Nazca plate to the west of South America is an oceanic plate. It is colliding with the South American plate, which is a continental plate. As it does so, the Nazca plate is forced down underneath the South American plate (see Figure 6). This is called a **subduction zone**, and the destruction of the crust is why this type of boundary is sometimes called a **destructive** plate boundary. As the plates meet, a deep trench forms at the bottom of the ocean. These **ocean trenches** form the deepest parts of the oceans. The Peru–Chile trench, for example, runs for thousands of kilometres along the eastern Pacific Ocean where the Nazca and South American plates meet. It ranges from 8 to 10 km in depth.

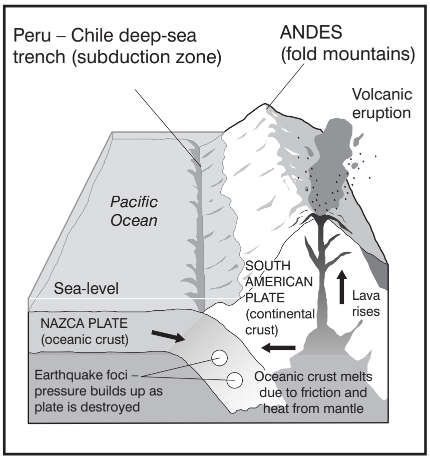

Figure 6: **A destructive boundary where oceanic and continental plates meet**

As the oceanic plate is forced downwards, violent collisions take place between the two plates. These are earthquakes. When the crust carries on descending it melts, due to friction and the higher temperatures as it enters the Earth's mantle. Some of this newly formed magma rises to the surface in the form of volcanoes. The continental plate is also forced upwards as the oceanic crust is forced underneath. In the case of the South American plate, this has resulted in the formation of the Andes Mountains.

- **Where ocean plates collide**

Where two oceanic plates meet, one is usually pushed underneath the other. The processes are the same as when oceanic and continental plates meet. A subduction zone is formed, along with an ocean trench. There are earthquakes as the plates collide, and the melting crust rises to the surface to form a line of volcanoes. This time, there is no landmass and so the volcanoes end up forming a string of volcanic islands called an **island arc**. The islands of the Caribbean, and the Aleutian Islands near Alaska, were formed in this way.

- **Where continental plates collide**

When two continental plates meet, they collide and are buckled upwards to form **fold mountains**. Neither plate is pushed downwards, or subducted (see Figure 7).

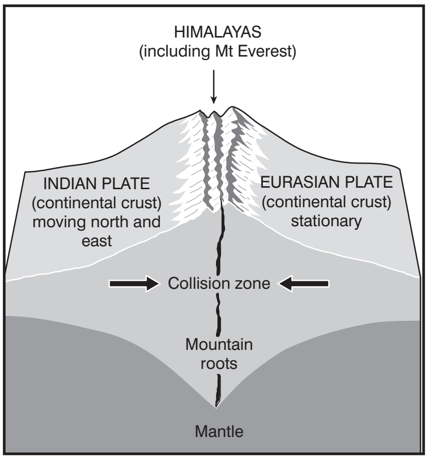

Figure 7: **The collision of two continental plates**

Transform boundaries

Not all of the Earth's plates are moving apart or crashing into one another. Some plates slide horizontally against each other, at transform boundaries. No crust is created or destroyed at these boundaries, which is why they are sometimes called **conservative** plate boundaries (see Figure 8).

This means that there are no volcanoes at these boundaries. Earthquakes do occur, however, as the plates tend to stick then slip violently rather than sliding smoothly against each other.

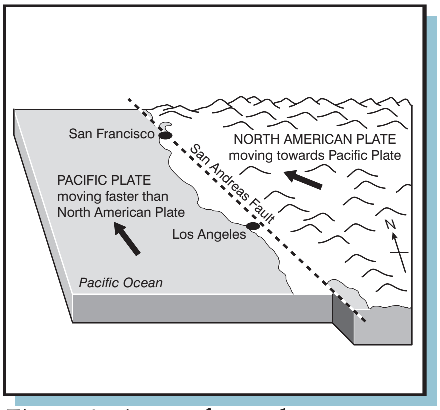

Figure 8: **A transform plate boundary**

Activities

1 On a copy of Figure 9, label the following:

- Crust
- Mantle
- Core
- Oceans
- Continents

Make your labels as descriptive as you can (eg give depths, temperature of the core).

2 Give a definition of each of the following:
(a) divergent plate boundary
(b) convergent plate boundary
(c) ocean trench.

3 Describe how convection currents drive the movement of the Earth's plates.

4 (a) What did Alfred Wegener suggest happened to the plates, in his theory of continental drift?
(b) What evidence supported his theory?
(c) Why do you think his theory was not generally accepted at the time?

5 How was the theory of continental drift developed and refined to become the theory of plate tectonics?

6 The islands of Hawaii are composed of volcanoes, yet they are not situated at plate boundaries. Find out why this is.

Figure 9: **A simple structure of the Earth (partly in cross-section)**

Date	Latitude	Longitude	Magnitude	Place
18 Sep 1901	57.43	-4.32	5.0	Inverness
24 Mar 1903	53.05	-1.70	4.6	Derby
19 Jun 1903	53.02	-4.39	4.9	Caernarfon
27 Jun 1906	51.62	-3.81	5.2	Swansea
14 Jan 1916	52.85	-2.19	4.6	Stafford
30 Jul 1926	49.17	-1.62	5.5	Channel Islands
15 Aug 1926	52.31	-2.66	4.8	Ludlow
24 Jan 1927	59.68	2.10	5.7	North Sea
17 Feb 1927	49.17	-1.62	5.4	Channel Islands
7 Jun 1931	54.08	1.50	6.1	Dogger Bank
12 Dec 1940	52.90	-4.40	4.7	North Wales
30 Dec 1944	53.86	-2.02	4.8	Skipton
11 Feb 1957	52.82	-1.33	5.3	Derby
12 Feb 1957	52.82	-1.33	4.2	Derby
9 Feb 1958	53.75	1.01	5.1	North Sea
3 Nov 1976	53.41	-2.69	4.5	Widnes
26 Dec 1979	55.03	-2.82	4.7	Carlisle
19 Jul 1984	52.96	-4.38	5.4	Lleyn Peninsula
2 Apr 1990	52.43	-3.03	5.1	Bishop's Castle

Figure 10: **Britain's 20th-century earthquakes**

7 Iceland is located at the boundary of the Eurasian and North American plates. The island is part of the Mid-Atlantic Ridge, and is a living case study of plate tectonics in action.
Find information about Iceland and compile a case study about the physical geography of the country. You should refer to the following in your answer:

- location on the Mid-Atlantic Ridge
- movement of the Eurasian and North American plates
- the geological development of the island – relate this to sea-floor spreading and the growth of the Atlantic Ocean
- Surtsey
- Thingvellir.

8 Earthquakes, like volcanic eruptions, occur near the boundaries of plates. Look at Figure 10. This shows the earthquakes recorded in the British Isles during the 20th century.
(a) Do you expect the British Isles to have earthquakes? Why is this?
(b) Mark the earthquakes on an outline map of the British Isles.
(c) Describe the distribution of earthquakes on your map. How does this compare with a map showing earthquake zones at plate boundaries?
(d) Why do you think there have been so many earthquakes in the British Isles?

