Basic Processes in Physical Geography

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Introduction

Over the past 15 years or so new ideas and techniques in Geography have been filtering downwards to the secondary school level. Many textbooks on the so-called 'New Geography' have appeared on human aspects of the subject, but it seemed to us that there was a need for a textbook in Physical Geography which introduced new techniques and covered processes in a more scientific way.

The book is aimed principally at the 'O' Level courses and as such includes material which traditional syllabuses demand. However, it is hoped that the inclusion of processes will make the book useful for the first-year Sixth as well as perhaps giving a little impetus to syllabus change.

Descriptive text has deliberately been kept to a minimum. The inclusion of questions and exercises within the text is aimed at encouraging pupil involvement. Different methods of enquiry like hypothesis testing and correlations are introduced. There are many data response exercises based upon data given in the book, but pupils should have ready access to a good secondary school atlas. Some of the questions are for the lower ability pupil, but others are rather more difficult and may well need the help and guidance of the teacher in answering them. It is hoped that the layout of the book will enable a wide range of different teaching methods to be used.

P.M.E.
G.J.G.

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Processes and Forms in the Crust 1

In the autumn of 1980, two devastating earthquakes hit the Mediterranean region. One destroyed El Asnam in Algeria, a city the size of Oxford. The other laid waste a large area around Potenza in southern Italy. Earthquakes are well known in the Mediterranean region: Skopje, Yugoslavia, was destroyed in 1963 killing over 1000 people, and in eastern Turkey nearly 2500 were killed four years later.

Many earthquakes are recorded every year around the world, but only those that cause damage and destruction to towns and villages actually hit the headlines. Volcanoes receive a good deal of publicity, especially when they explode with the force of a ten megatonne bomb as Mount St. Helens did in May 1980, or when they create a completely new island as at Surtsey, off Iceland, 1963–67.

As with many features in physical geography, we need to study the **distribution pattern** of earthquakes and volcanoes in order to understand how they arise. In understanding their cause, scientists are in a better position to predict when they will occur. Then the terrible effects can be lessened by evacuating people and livestock away from the danger zones.

Volcano	Location
Mt. Wrangell	61° 40′N 143° 0′W
Katmai	58° 17′N 154° 56′W
Shasta	41° 20′N 122° 20′W
Baker	48° 50′N 121° 49′W
Mt. St. Helens	46° 12′N 122° 11′W
Paricutin	19° 28′N 102° 15′W
Popocatepetl	19° 10′N 98° 40′W
Cotopaxi	0°30′S 78° 30′W
Volcán Corcovado	22° 57′S 43° 13′W
Mauna Loa	21° 08′N 157° 13′W
Asama Yama	36° 24′N 138° 31′E
Fuji-San	35° 22′N 138° 44′E
Kokuritsu-Koen	31° 50′N 130° 55′E
Krakatoa	6° 07′S 105° 24′E
Ruapehu	39° 18′S 175° 35′E
Mt. Erebus	77° 32′S 167° 09′E
Etna	37° 46′N 15° 00′E
Vesuvius	40° 49′N 14° 26′E
Stromboli	38° 48′N 15° 13′E
Surtsey	63° 16′N 20° 32′W
Tristan da Cunha	37° 15′S 12° 30′W
Elgon	1° 08′N 34° 33′E
Kilimanjaro	3° 04′S 37° 22′E

Table **1.1** Major volcanoes

The Distribution of Earthquakes and Volcanoes

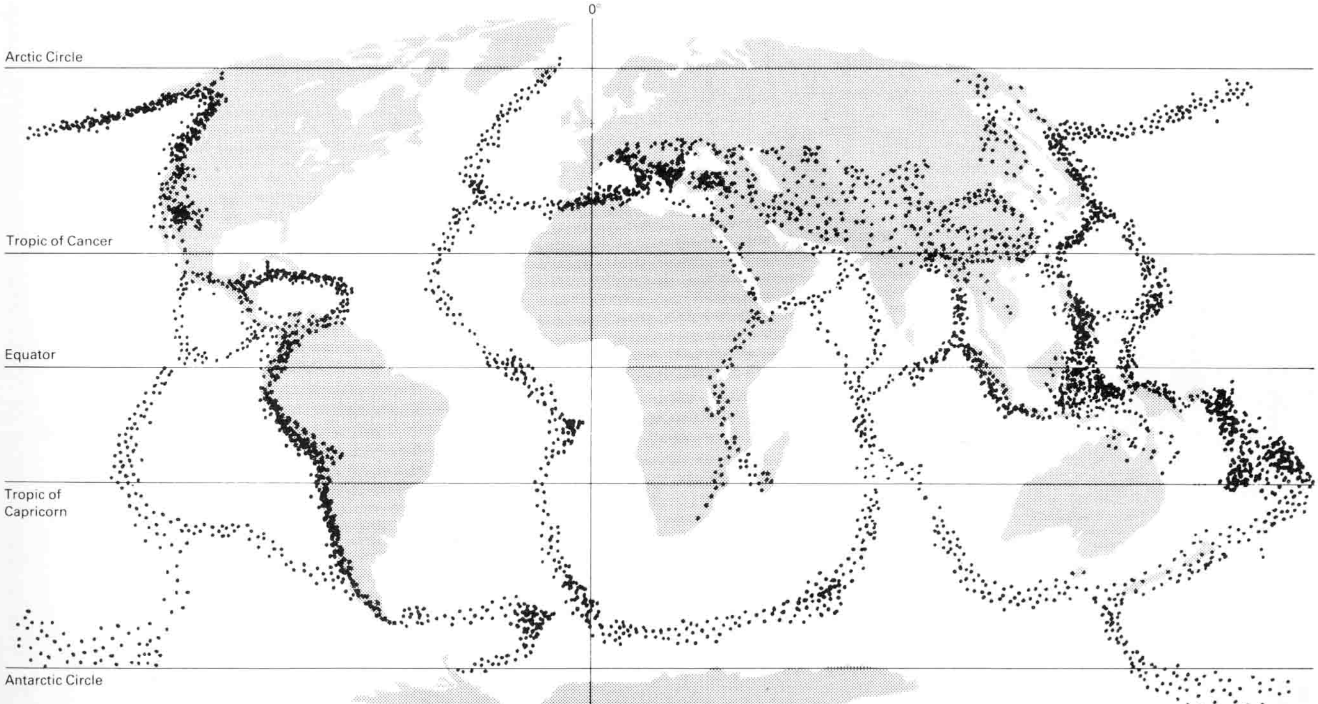


Fig. **1.1** World distribution of major earthquake zones

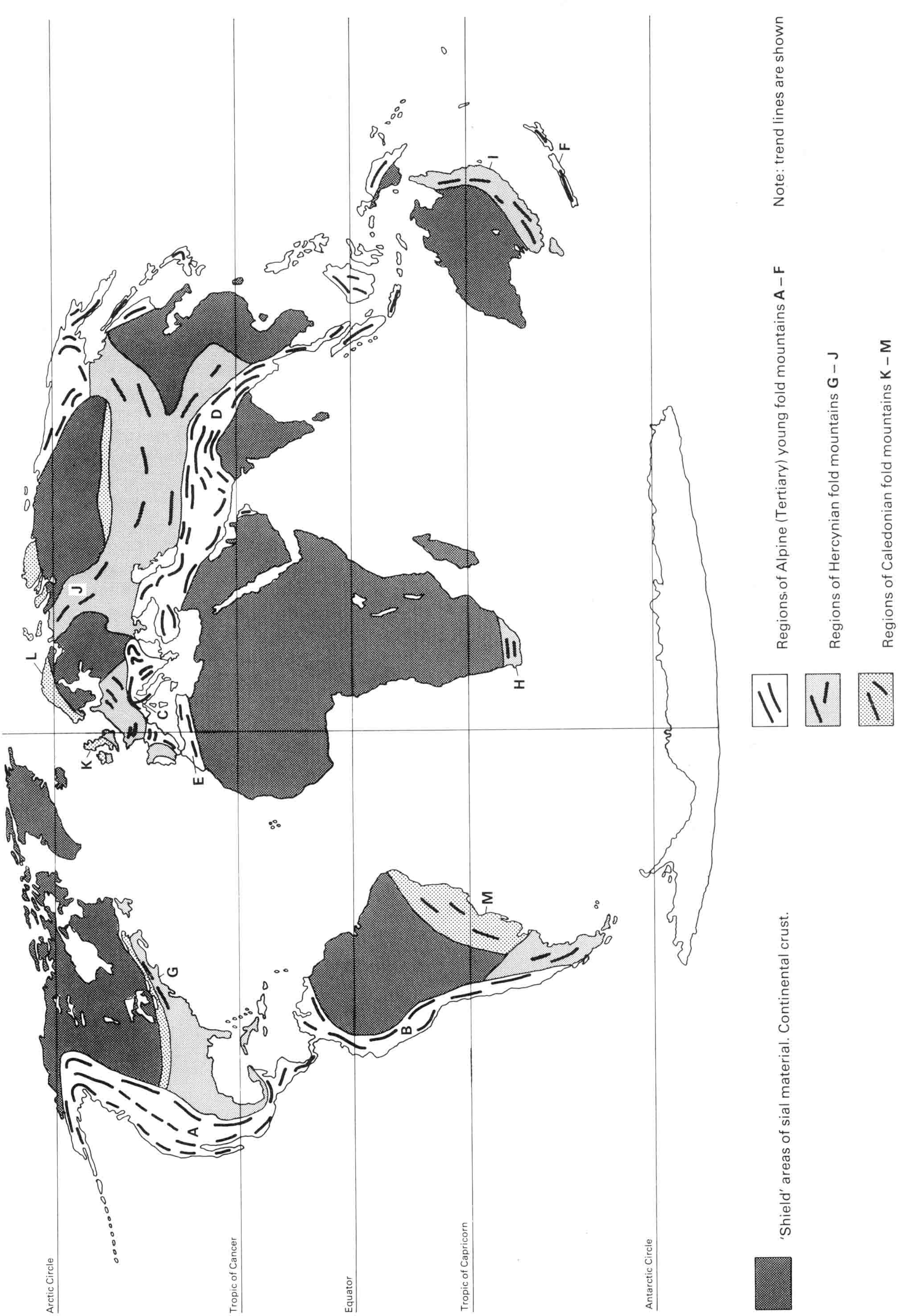


Fig. 1.2 World distribution of fold mountains and continental crust areas

1 a) Place a piece of tracing paper over the world map, Fig. 1.1. With the help of your atlas, plot the volcanoes listed in Table 1.1 as accurately as you can.

b) Describe the relationship between the distribution of the volcanoes on your map and the distribution of earthquakes shown in Fig. 1.1.

2 Study a map of world relief in your atlas. From Fig. 1.2 identify the ranges of **young fold mountains.** How is the distribution of these related to the distribution of volcanoes and earthquakes?

We have now seen how the important physical phenomena of the world occur together in belts. Their distribution patterns are said to be **correlated**. This important correlation is due to the way in which the Earth is constructed and to the processes that go on inside the structure.

The Structure of the Earth

Fig. 1.3 is a model showing how geophysicists think the Earth is constructed. The information for this is obtained from a number of different sources, but particularly from the patterns made by earthquake shock waves as they pass through different types and densities of material.

The **crust** of the Earth is so thin that we need to enlarge the scale considerably to see how it is made, as in Fig. 1.4. In fact, if the Earth were reduced to the size of an apple, the crust would be thinner than the skin, and the Himalayas would hardly show as wrinkles.

3 Study Fig. 1.4 carefully. What zones can the crust be divided into? What is the approximate thickness of each of these zones?

ZONE	COMPOSITION	DENSITY g/cm³	TEMP °C
Crust	granite basalt	2.8 3.0	
Upper Mantle	magnesium + iron silicates	4.3	800
Lower Mantle	magnesium + iron silicates	5.5	1600
Outer Core	liquid nickel + iron	10.0	3000
Inner Core	solid metal	13.6	5000

Note: the density of water is 1 g/cm³

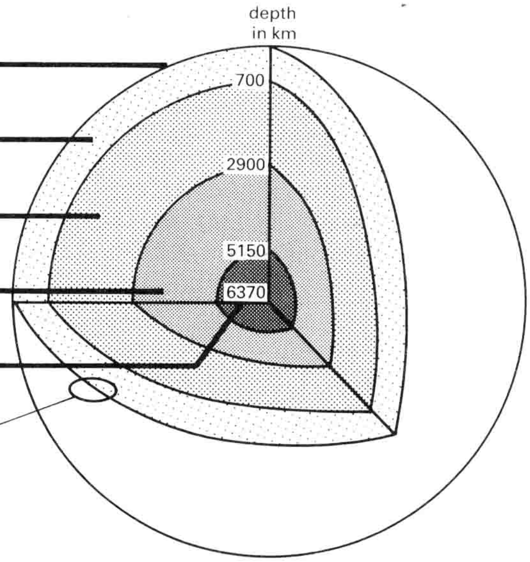


Fig. **1.3** The structure of the Earth

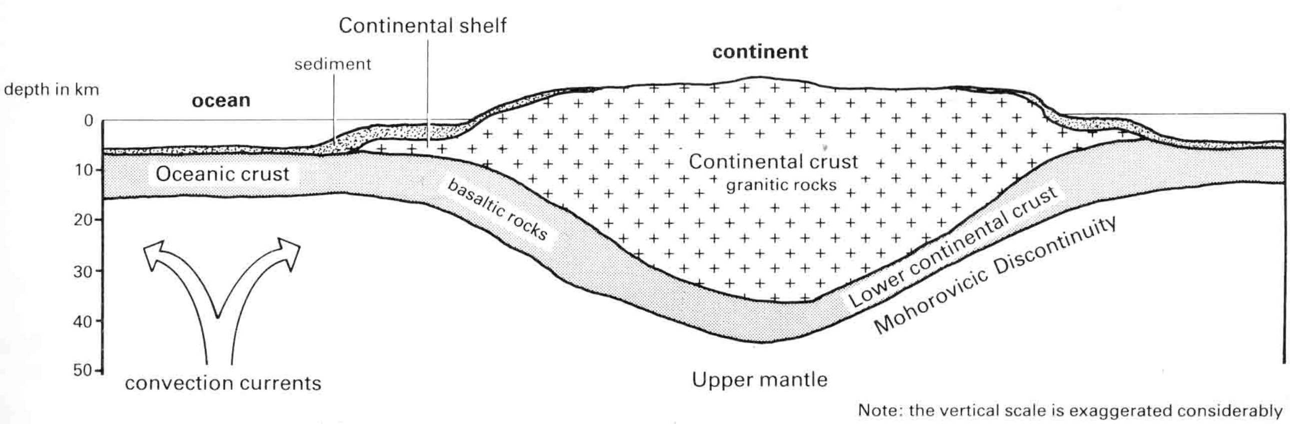


Fig. **1.4** The structure of the crust

The **continental crust** is made up of **granitic rocks** which consist largely of complicated aluminium silicates (silica is an oxide of silicon). This part of the crust is often termed the **sial** (*si*licon + *al*uminium) layer because of its composition (see Table 1.2 on page 12).

On top of the continental crust is a very thin veneer of **sediments**. These are produced by the breakdown of the granitic rocks under the effects of the weather (see page 24).

4 On what part of the continental crust are the sediments the thickest?

The **oceanic crust** is made up of **basaltic rocks** which consist of the silicates of iron and magnesium. It is often called the **sima** (*si*licon + *i*ron + *ma*gnesium) layer. It extends below the continental crust as the lower continental crust, although the chemical and physical composition may be changed by the weight of the material above it.

The crust represents the lightest material of the Earth. It settled out on the surface of the planet after its formation from a mass of gas some 4600 million years ago. As it cooled, the crust solidified. It can be described as *floating* on the **mantle** beneath.

The **upper mantle** is very hot and behaves more like a liquid than a solid. It is thought to have **convection currents** rising through it: these have a very important role in the formation of the features of the crust. Materials will expand as they are heated; as they expand, they become less dense and lighter. The mantle material is hot near the core of the Earth. It expands, becomes less dense, and rises towards the surface. As it does so, it cools down because it reaches a cooler zone. This cooling causes the material to contract, become denser and heavier, and it spreads horizontally and descends to be heated again. This results in a roughly circular movement of mantle material, known as convection.

A model of this can be made in the chemistry laboratory. Take a flask of water. Drop a small piece of potassium permanganate onto the bottom of the flask. Place the flask over a bunsen flame and observe the patterns made by the purple streaks as the water heats up. These patterns are, in simple form, similar to those that may exist beneath the crust (Fig. 1.5).

5 Study the information given in Figs. 1.3 and 1.4.

a) Why has the crustal material risen to the surface?

b) Why do you think that the crustal material split into the continental and oceanic layers?

c) **Mohorovicic** was a Yugoslavian geologist who discovered an important boundary, or **discontinuity.** Where is this?

d) What do you notice about the thickness of the continental crust above and below sea level?

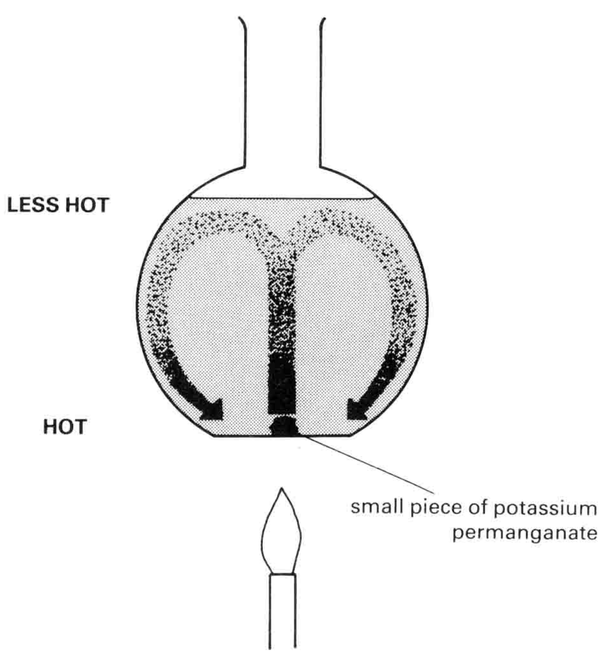


Fig. **1.5 (a)** Convection currents in a flask

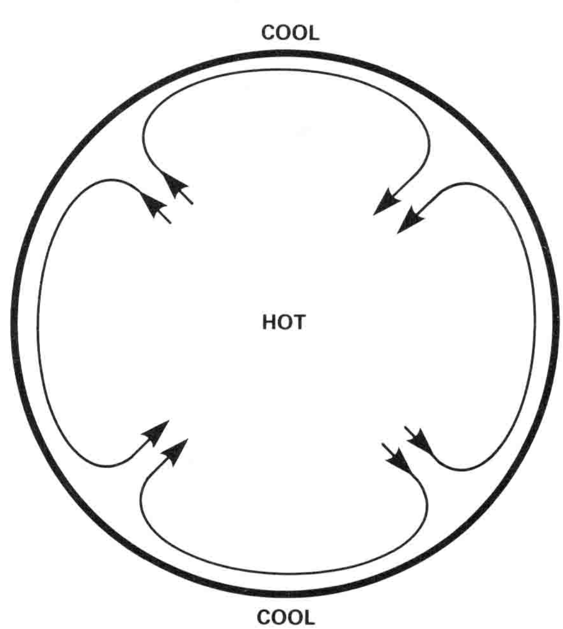


Fig. **1.5 (b)** Convection currents in the Earth. (This is purely diagrammatic and should not be taken to mean that there are four currents under the crust.)

The answer to the last question has a lot to do with balance. Icebergs have 90% of their mass below sea level so that they float in a stable manner without toppling over: the same principle applies to the continents, and is known as **isostasy.** The mass of the mountain chains extends downwards in order to maintain balance: this mass is known as the **roots** of the mountains.

Crustal Plates

We have seen that the crust is made of a thin layer of granite (the continental crust) and basalt (oceanic crust) which floats on the mantle beneath. However, the crust is not a continuous, unbroken layer: it is split into a number of segments known as **plates**. Fig. 1.6 shows the distribution of these plates and the boundaries along which they meet. The cross-section in Fig. 1.7 shows their distribution around the Equator.

6 Describe any correlations you see between the pattern made by the plate boundaries and the distribution of earthquakes, volcanoes and young fold mountains.

These plates are not stationary but are moving slowly over the mantle in the directions shown by the arrows in Figs. 1.6 and 1.7. The speed of movement varies from place to place, but it is estimated that the American Plate and the Eurasian Plate are drifting apart at the rate of 1 cm a year.

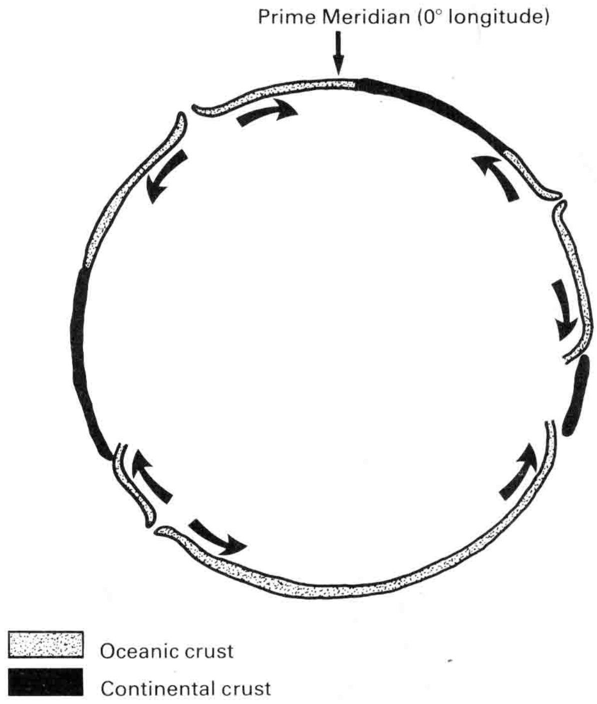


Fig. **1.7** Cross-section through the Equator showing distribution of plates

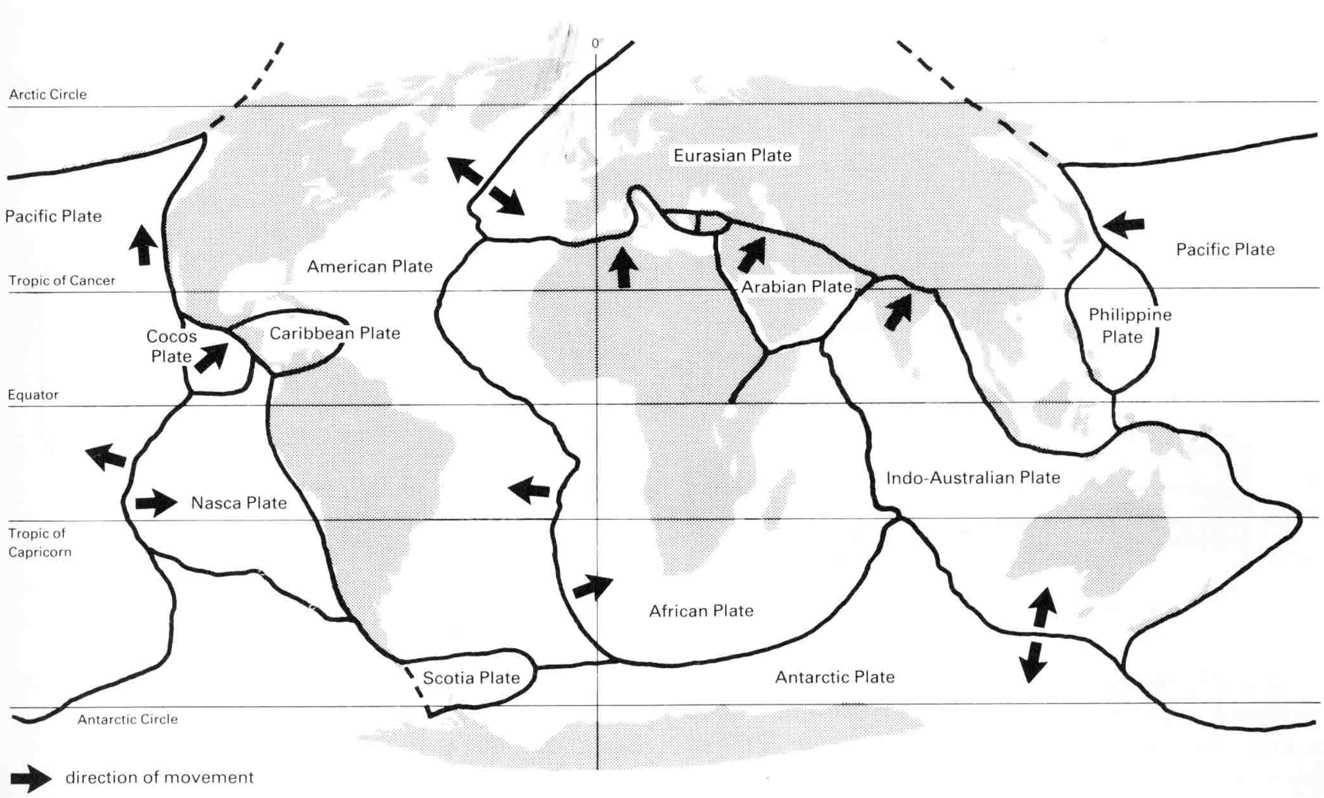


Fig. **1.6** The distribution of crustal plates

7 Study together Figs. 1.6 and 1.7. Moving eastwards from the Prime Meridian (0° longitude), identify the continental crustal plate sections and the oceanic crustal plate sections on a copy of Fig. 1.7.

Plates which Move Apart (Divergent Plates)

Fig. 1.8 shows in diagrammatic form what is thought to be happening on the bed of the mid-Atlantic. Here, the hot mantle material is rising upwards and spreading outwards, causing the crustal plates to move apart and the edges to buckle upwards into a series of **ridges**. Between the ridges on either side of the gap, the mantle material cools as it spreads. This cooling causes changes in the chemical composition of the rock, which solidifies to become new oceanic crust. The whole process is called **sea floor spreading**. More explosive mantle activity causes the formation of volcanoes which may protrude above the surface of the ocean as islands.

8 Identify as many volcanic islands as you can in the mid-Atlantic, using your atlas.

9 Find other mid-ocean regions that also have ridges as a result of neighbouring plates moving apart.

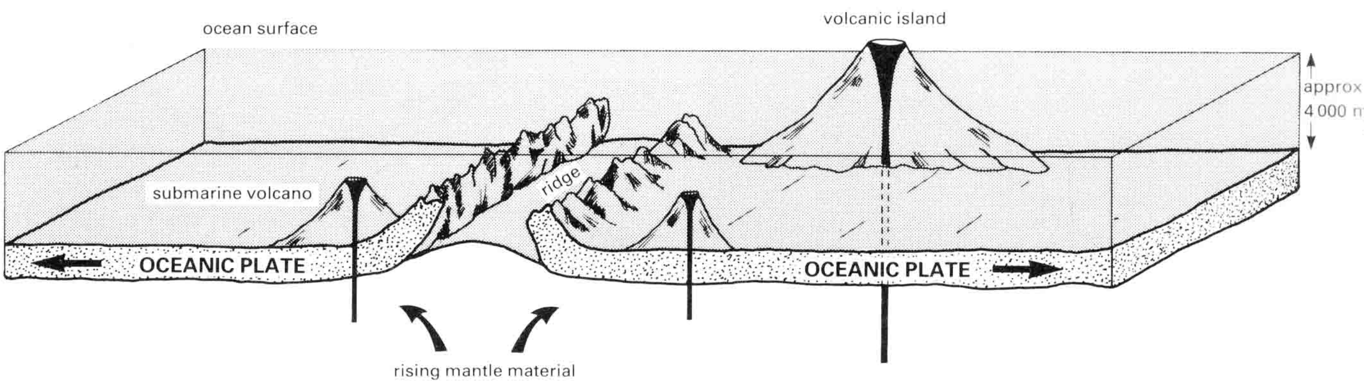


Fig. **1.8** A diagrammatic cross-section through the mid-Atlantic ridge

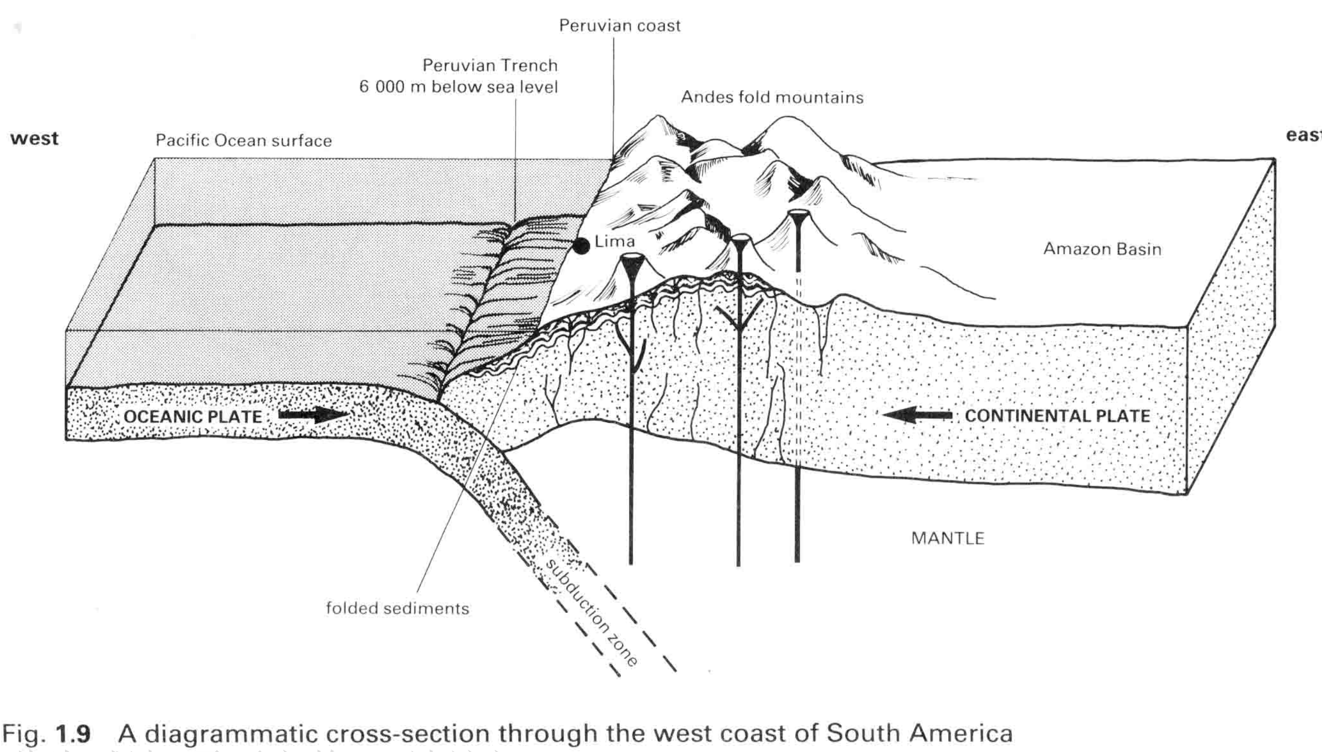


Fig. **1.9** A diagrammatic cross-section through the west coast of South America

Plates which Move Together (Convergent Plates)

10 Fig. 1.9 shows what is thought to be happening along the coast of Peru on the western side of South America. Name the two plates involved.

The oceanic plate is forced down into the mantle, where it breaks up and melts in what is known as the **subduction zone.** Masses of molten oceanic material well upwards through the mantle.

11 Why should the oceanic material melt in the subduction zone? Explain why it rises upwards (Fig. 1.3 gives a clue).

12 When this molten material finds its way through cracks and weaknesses in the continental crust above, what feature may be formed at the surface?

The movement of the plate in the subduction zone is neither smooth nor regular. It can in fact be sharp and violent, sending shock waves through the Earth: these are **earthquakes**. Earthquakes also occur as the continental crust, being lighter than the oceanic crust, rides above the plate boundary. The granitic rocks and the sediments get crumpled and folded. This contortion and uplift creates chains of fold mountains. A similar situation to that of the west coast of South America occurs along the east coast of Asia, where the Pacific Plate is dipping under the Eurasian Plate.

13 Refer to Fig. 1.30 on page 22. How young are the young (Alpine) fold mountains?

These mountains are also referred to as **Tertiary** fold mountains because they were built up in the Tertiary era of the Earth's history. Fig. 1.30 shows that they are also the youngest. Mountain building is called **orogenesis**, and has occurred several times during the Earth's evolution.

Looking at Fig. 1.4 you will notice that the continental plate does not end at the coast but extends some way beneath the ocean as the **continental shelf**. These shelf regions have very important implications for mankind. As the ocean is relatively shallow, sunlight can penetrate, encouraging marine life: continental shelves are the world's most valuable fishing grounds. They are also potential sources of minerals: North Sea oil is a good example of a shelf resource which is already being exploited.

14 Find a physical map of the world in your atlas. Where are the widest continental shelves to be found?

Where plates are moving together, the continental shelf has an outer margin that dips down steeply to a **marine trench**.

15 How deep is the Peruvian trench? (Fig. 1.9). Find in your atlas where the deepest marine trenches are to be found.

Plates which Move Sideways (Transform Plates)

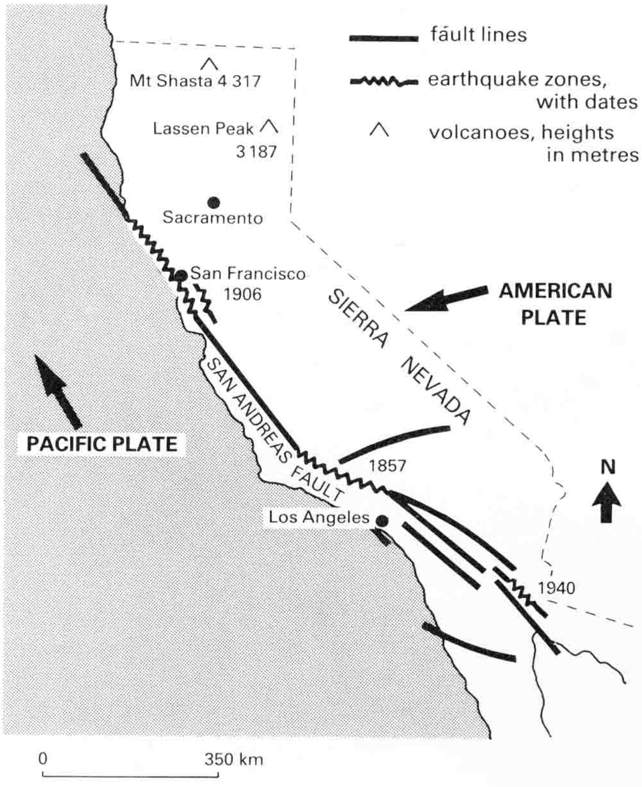


Fig. **1.10** The San Andreas fault zone

Along the western coast of North America, the Pacific Plate is moving northwards in relation to the American Plate, along the San Andreas Fault. This movement is being studied closely in California because it could cause an earthquake like the one that led to the devastation of San Francisco in 1906. The complexity of

faults (lines of weakness in the crust) in this region tends to lock the plates together, preventing them from moving smoothly. Stress and tension build up in the crust which can suddenly give way, causing severe earthquakes. In 1864, 1898 and 1900 there were severe quakes, but the greatest so far occurred at 5.13 a.m. on 18 April 1906. The earthquake itself did less damage than the fire which followed it. Up to 700 people are thought to have died and 250 000 were made homeless. Ten square kilometres of the city centre were completely destroyed. However, the local distillery survived, which prompted a newspaper reporter from the East Coast to write:

> 'If, as they say, God struck the town
> For being over frisky,
> Why did He burn the churches down
> But spare Hotaling's whisky?'

Seismologists (those who study earthquakes) and geologists warn that another earthquake can be expected with reasonable certainty before the end of the century, although it is very difficult to accurately predict such things. With the number of modern tower blocks that now dominate San Francisco, the next quake could have far more disastrous effects than the one in 1906.

Fig. **1.11 (a)** Folding in sedimentary rocks, Lulworth Cove, Dorset

Tokyo is another city that has been badly damaged by an earthquake in recent times, in 1926. It lies on the margin of the Eurasian and Pacific Plates. In this case the mechanics of the cause of the quake are slightly different. Read again page 7 to see why.

The situation on the west coast of North America is made more complicated by the fact that not only is the Pacific Plate moving laterally northwards, but the American Plate is moving westwards against it. This is causing the rocks of the continent to buckle and fold, and volcanoes are forming in a similar way to those along the west coast of South America.

16 It has been said that one day Los Angeles might lie opposite Sacramento. If the average rate of movement of the Pacific Plate is 5 cm a year, calculate approximately when this might happen (Fig. 1.10).

The Folding and Faulting of Rocks

We have seen that the rocks of the continental crust become contorted and crumpled at the plate boundaries, the shock waves that result from these movements causing earthquakes. Distortions of rocks can be divided into **folding** and **faulting.** Figs. 1.11 and 1.12 illustrate the simplest kinds of folding and faulting, but it must be realised that such features occur in complex arrangements and in a wide range of scales from the immense folds of the Alps to the merest buckle and crack in a coal seam only centimetres across.

17 From the information in Fig. 1.11, describe in your own words the following terms: **anticline**, **syncline**, **crest**, **trough**, **dip**, **strike** and **limb**.

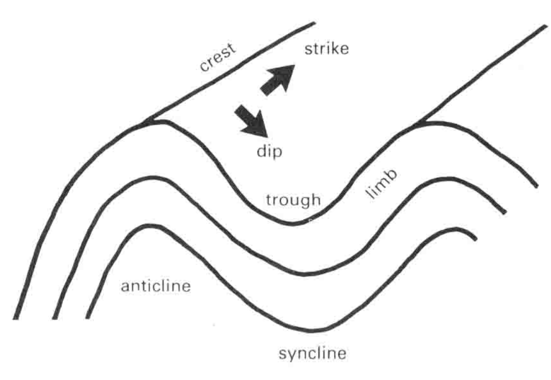


Fig. **1.11 (b)** Simple folding in rocks

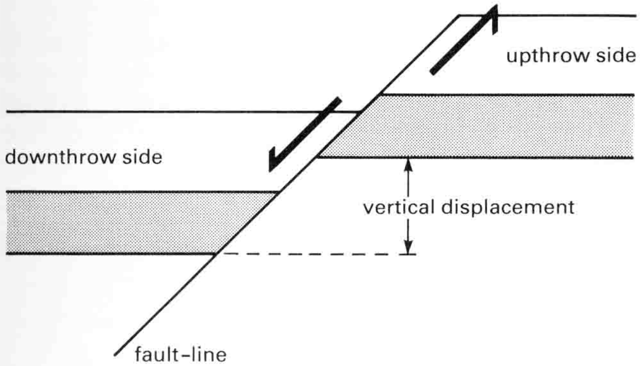


Fig. **1.12** Cross-section through a normal fault

Simple folding can cause gentle relief with hills on the crests and valleys in the troughs. Such an arrangement can be seen in the Jura Mountains on the border between Switzerland and France. These were folded about 50 million years ago during the formation and uplift of the great Alpine mountain chain. Folding in the Alps is extremely complicated. Fig. 1.13 gives only a very simplified version of it. A variety of different types of fold are seen in great fold mountain chains like the Alps, the Himalayas and the Andes. Fig. 1.14 illustrates the types of folding that may be found. Notice that a **nappe** also involves faulting as a mass of rock is thrust horizontally.

In Fig. 1.13 you can see that the surface relief bears little or no resemblance to the folding beneath. This is because the surface has been severely eroded (worn away) by the action of mountain glaciers (see Chapter 6).

The Faulting of Rocks

The San Andreas Fault is a very long **lateral fault** at the junction of two plates, but faulting on a smaller scale occurs frequently within plates themselves. Apart from sideways, faulting displaces rocks upwards or downwards along a crack, or **fault-line**, in the crust.

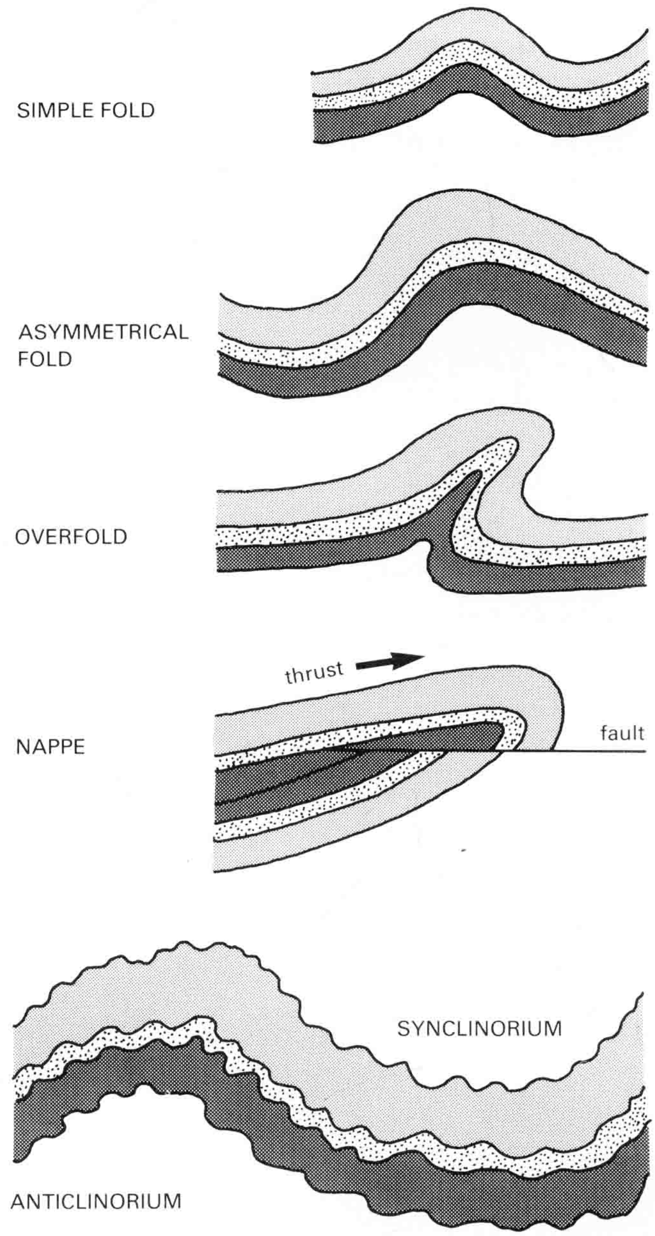


Fig. **1.14** Types of folding

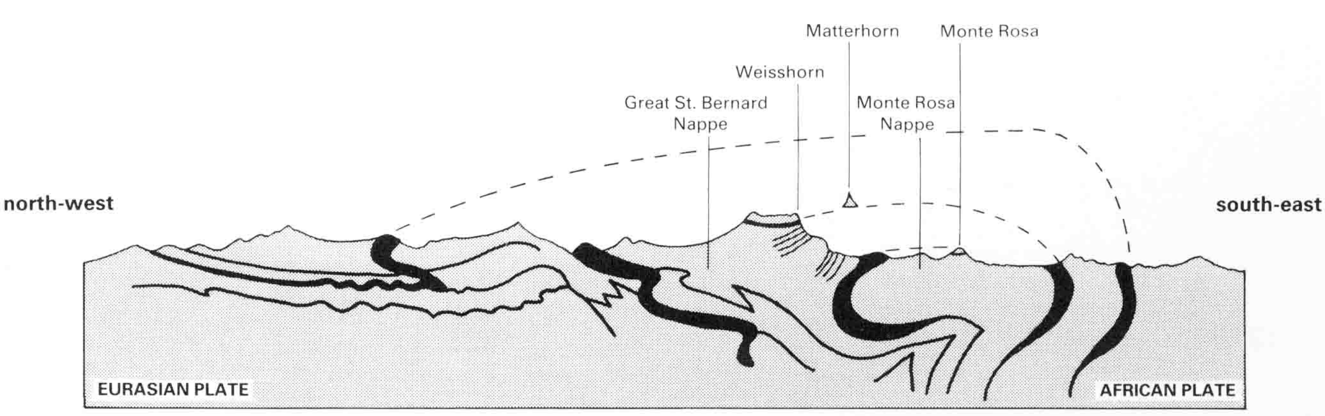


Fig. **1.13** Complex folding in the western Alps. Broken lines indicate rock masses that have been eroded away. The Matterhorn lies off the line of section to the south.

Fig. 1.15 is a photograph of a fault in a quarry in the Forest of Dean, Gloucestershire.

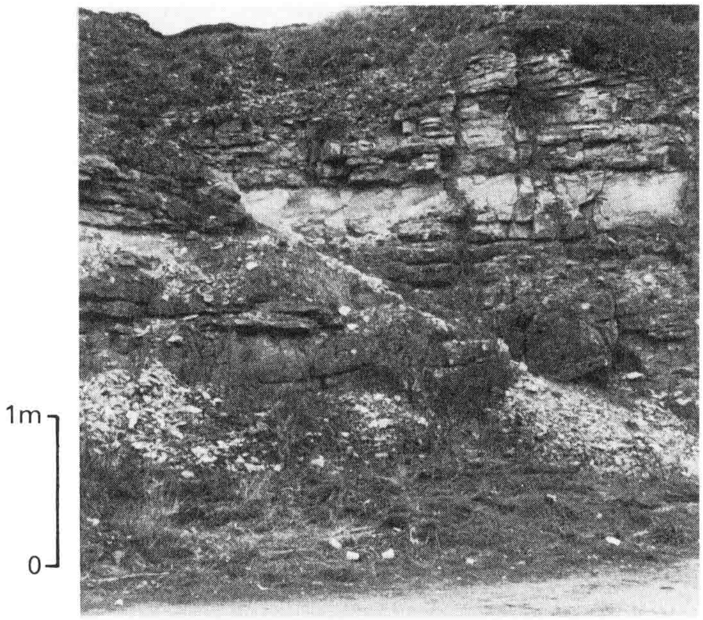


Fig. **1.15** A reverse fault, Forest of Dean

18 Draw a sketch of this photograph and label it in a similar way to the fault shown in Fig. 1.12. What is the difference between the two faults illustrated?

Fig. 1.12 is an example of a **normal fault**, where the surface has been lengthened. Fig. 1.15 is an example of a **reverse fault**, where the surface has been shortened.

19 Measure the amount of vertical displacement in Fig. 1.15.

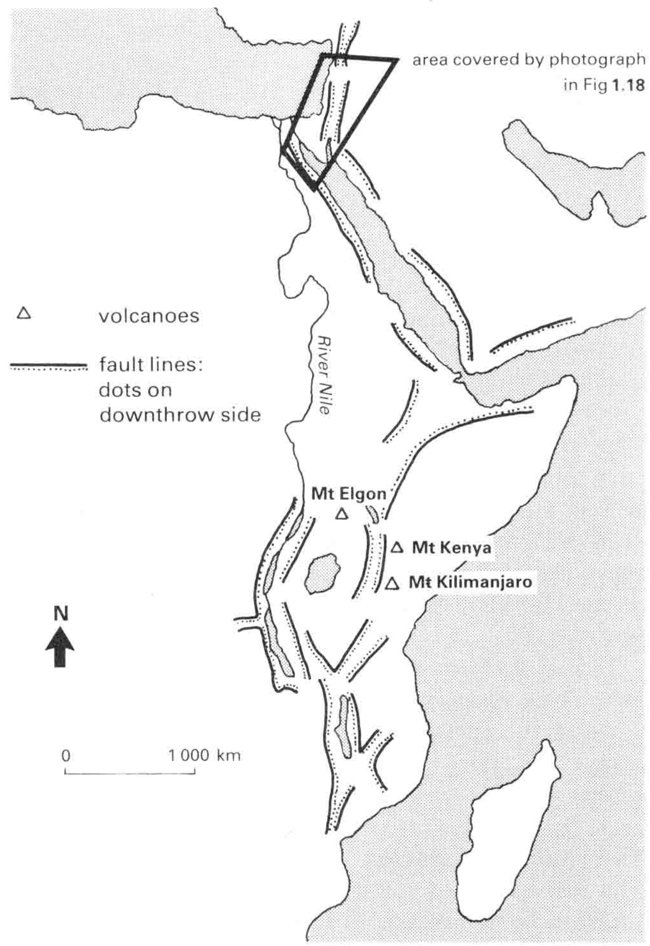


Fig. **1.17** The East African rift system

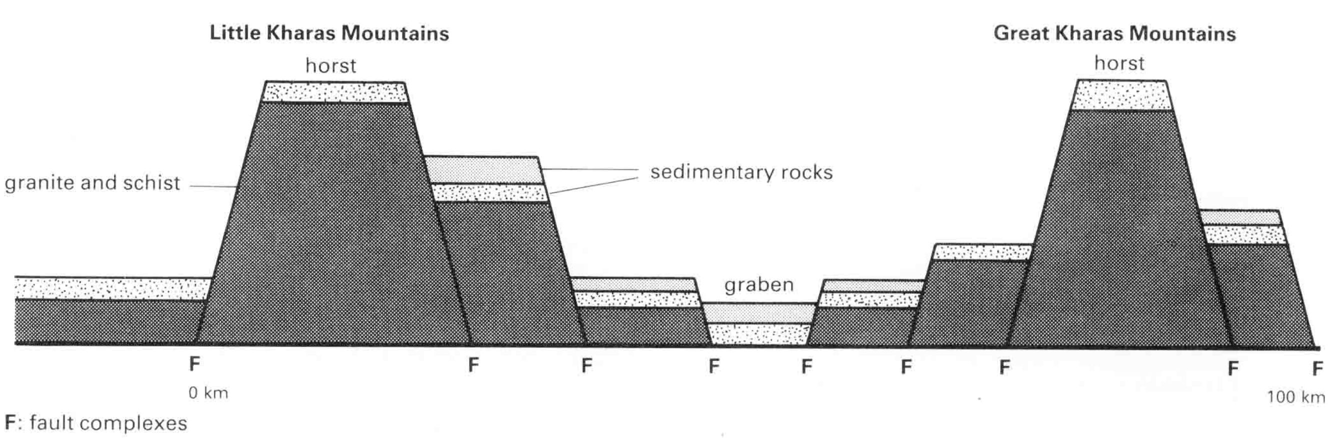


Fig. **1.16** Simplified cross-section through the Kharas mountains, Namibia

Faults often occur in groups with blocks being thrust upwards to form **horsts** or downwards to form **graben**, as shown in Fig. 1.16. Elongated graben form **rift valleys**, such as the Rhine Rift Valley between Mainz and Basle.

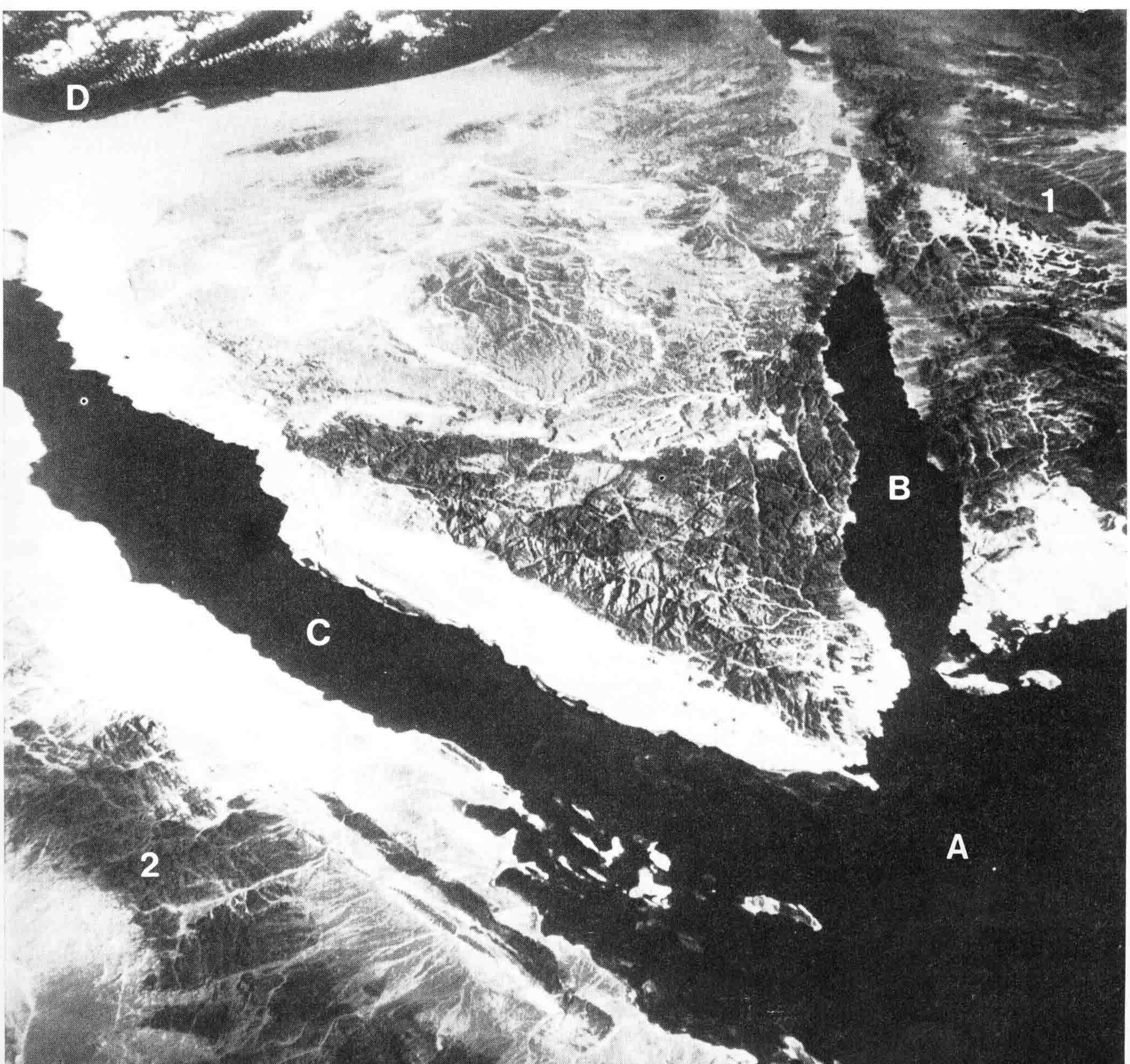
20 Locate the Rhine Rift Valley in your atlas.
a) What is its length and average width?
b) The hills to the east and west at the southern end are examples of horst blocks: name them. How high are they above the valley floor?
c) Draw a profile through the valley at Colmar. The boundaries between the shades on your atlas map are the contour lines. Label the Rhine and the hills to either side.

Fig. 1.17 shows a rift system on a scale similar to that of the San Andreas Fault. Fig. 1.18 shows a satellite photograph of part of the system.

21 Make a tracing of Fig. 1.18 and mark on it the plate boundary (see Fig. 1.6), the names of plates 1 and 2 and sea areas A, B, C, and D.

The section in East Africa itself is thought to be due to the plate splitting under internal tensions. Note that volcanoes are found in this region. The Rhine Rift Valley at one time also had volcanic activity, but the volcanoes are now extinct, e.g. the Krehberg, 35 km north-east of Mannheim.

Fig. **1.18** Satellite photograph of the Sinai Peninsula, part of the East African rift system



Rock Types

Igneous Rocks

Rocks are aggregates, or mixtures, of **minerals.** Minerals are composed of the atoms of chemical **elements.** There are about 92 elements, but fortunately the most common rocks can be described in terms of a dozen or so.

Name	Symbol	Percentage
Oxygen	0	46.71
Silicon	Si	27.69
Aluminium	Al	8.07
Iron	Fe	5.05
Calcium	Ca	3.65
Sodium	Na	2.75
Potassium	K	2.58
Magnesium	Mg	2.08
Titanium	Ti	0.62
Hydrogen	H	0.14

Table **1.2** The main chemical elements which make up the crustal rocks

Oxygen combines readily with the other elements to form oxides, the most common being **silica** (silicon oxide), SiO_2. This mineral is very common in rocks and is known as **quartz**. **Sand** is made up of quartz grains. Silica in turn combines with other elements to form silicates, the most common being the **felspar** group made up of potassium, aluminium and calcium silicates. These are important constituents of granite.

During the time when the Earth was a molten ball, the lighter elements floated to the surface. As the surface cooled, so the elements combined and crystallised into minerals to make up **igneous rocks**: granite of the continental crust, basalt of the oceanic crust. Volcanic outpourings throughout geological time have also contributed to the Earth's stock of igneous rocks. Hot gases and liquids crystallising within the crust have given us important mineral resources of the precious and semi-precious type as well as non-ferrous metals, e.g. gold, silver, tin, lead, zinc and copper.

Granite consists of three major mineral groups: felspar, mica (both of which are silicates of aluminium, potassium and calcium) and quartz. If you have access to a piece of granite, try to identify these minerals. Quartz is glassy, felspar creamy and in some cases pink, and mica is black or silver. The grains are of measurable size, often up to several millimetres across.

Basalt is a much finer grained rock and is much darker in colour due to the presence of minerals containing iron and magnesium, such as the **pyroxene** group and biotite (a form of mica).

Granite and basalt are thus very different in content and appearance. One major difference lies in the amount of quartz. Granite has a lot of quartz and as such is classified as an **acidic** igneous rock. Basalt, on the other hand, has little or none, and is classified as a **basic** igneous rock. This difference has important effects upon the landforms they produce. Between granite and basalt is a wide range of **intermediate** rocks whose chemical composition is intermediate between acidic and basic.

The difference in grain size between granite and basalt is the result of different rates of cooling of the molten rock, or **magma.** Magma deep in the crust cools slowly, producing large grains. Such rocks are sometimes referred to as **intrusive** or **plutonic**. On the surface, the material will cool quickly, resulting in small grains which can be so minute that they are invisible to the naked eye. Such rocks are called **extrusive** or **volcanic**.

Igneous rocks form a complex group, but matters can be made easier to understand if you remember the simple two-fold classification: a) acidic or basic b) extrusive or intrusive.

22 Find a geological map of Britain in your atlas.
a) On an outline map, shade on the distribution of igneous rocks. Pay attention to the way in which the rocks have been classified.
b) Describe the distribution you have mapped. What is the relationship between the rocks and the height of the land?

Sedimentary Rocks

Igneous rocks exposed on the surface will be broken down both physically and chemically by the weather elements (weathering) and worn away by streams, the sea and glaciers (erosion). The weathered and eroded material will be deposited on the floors of lakes, on river flood plains and, most of all, on the bed of the sea. These **sediments** will build up in layers, or **strata**, and become compressed and cemented to form **sedimentary rocks**. The quarry face shown in Fig. 1.15 clearly shows sedimentary rock strata. The strata are also called **beds**; the boundary between each bed is called a **bedding plane**.

The composition of the sedimentary rock depends very much upon the nature of the original igneous rock. Granite decomposes to form **sand** (the quartz grains) and **clay** (from the decomposition of felspars). Basalt produces clay as well as many soluble (dissolvable) products. Sand grains cemented together by silica or calcite form **sandstones**, which tend to be hard and resistant to weathering and erosion. Clay, on the other hand, and **shale** (a coarser kind of clay) are soft.

The sea is home to millions of creatures with shells made of calcium carbonate. These accumulate to considerable depths as the creatures die and sink to the