THE TIMES
CONCISE ATLAS OF THE WORLD

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Times Books

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Introduction

In presenting a further revision of an atlas which has proved to be extremely popular, we draw attention to an important change in this edition. Place-names in China are given in their Pinyin spellings, a step likewise taken in our larger atlas, the Comprehensive Edition. More is said on the subject below.

The preliminary section of the atlas is concerned with geography in its widest sense: as a science that has much to contribute to the understanding of the contemporary world. In these pages we first describe the origin and geology of the Earth and its physical nature, its resources of climate, vegetation and minerals. Then we examine major features of the geography of man, particularly his settlements and population patterns, his trade and industry, his use of energy, the development of tourism, and the effect of all these activities on the balance of his natural environment. The complex techniques of navigation, which have been central to the development of human history, are described, and the Earth as a whole is placed into its context in the expanding Universe. The present state of our knowledge of the Universe is described; two pages are devoted to maps of the Moon and one to star charts.

In the main body of the atlas the maps, with the exception of those covering the conurbation areas, have been compiled by John Bartholomew & Son Limited of Edinburgh, who have been associated with *The Times* in atlas-publishing since 1922. Several map projections are used, each for its own special properties. Without some adaptation the surface of the spherical earth cannot be transferred to a flat sheet of paper, any more than an orange can be wrapped in a sheet of paper without cutting and folding. Map projections are the means of adapting the round globe to the flat map.

How best to spell place-names, a matter of great complexity, has always been considered carefully in the preparation of atlases published by *The Times*. Difficulties arise from the diversity of writing systems in use in the world and the great number of languages, hundreds of which are inadequately written or have no writing system. In the absence of a uniform and internationally accepted method of recording and writing geographical names, conventional spellings established by long usage furnish us with Athens (English), Athènes (French), Azine (Spanish), etc. *The Times Concise Atlas* gives transliterations in English, e.g. Athinai, with the English conventional name, where appropriate, in parentheses: Athinai (Athens). In general, *The Times Concise Atlas* follows the rules recommended by the United States Board on Geographical Names and the Permanent Committee on Geographical Names for British Official Use.

In all previous editions names in China have been transcribed in terms of the Wade-Giles readings of Chinese characters. With increasing use of Pinyin within China as a roman alphabet equivalent of the Han characters and the recent availability of sufficient sources for names, the publishers decided to replace Wade-Giles by Pinyin in mainland China. In Taiwan, Wade-Giles is still in use and so is retained in this atlas. Neither is Pinyin applicable in Hong Kong where a local system is in use. A special section on the Transcription of Chinese Place-Names has been added to this edition (p.88).

With regard to the sensitive political implications of maps, *The Times Atlas* has always considered its task to be to show facts as they are and not to pass judgements. When delineating a frontier this atlas shows which authority is administering the area at the time the map goes to press. Our wish is to help the traveller, businessman, student or teacher who we hope will buy it. It also follows that place-names are, as far as possible, spelt according to the usage of those administering the region concerned. An atlas can show where a frontier is disputed, but it strays beyond its proper sphere if it tries to adjudicate between the rights and wrongs of the dispute rather than to set down the facts as they are.

The index section contains over 90,000 entries. Not every name on the maps appears in that index, but all towns and physical features other than the smallest are indexed. Place-names and their descriptions (such as Lake or River) are listed in strict alphabetical order, so that Haig L. (Lake) does not immediately follow the town of Haig, but is interrupted by Haiger. Each name is accompanied by its country or location and by the page number and grid reference by letter and numeral.

The information on states and territories which precedes the index section has been revised to accord with the latest information available.

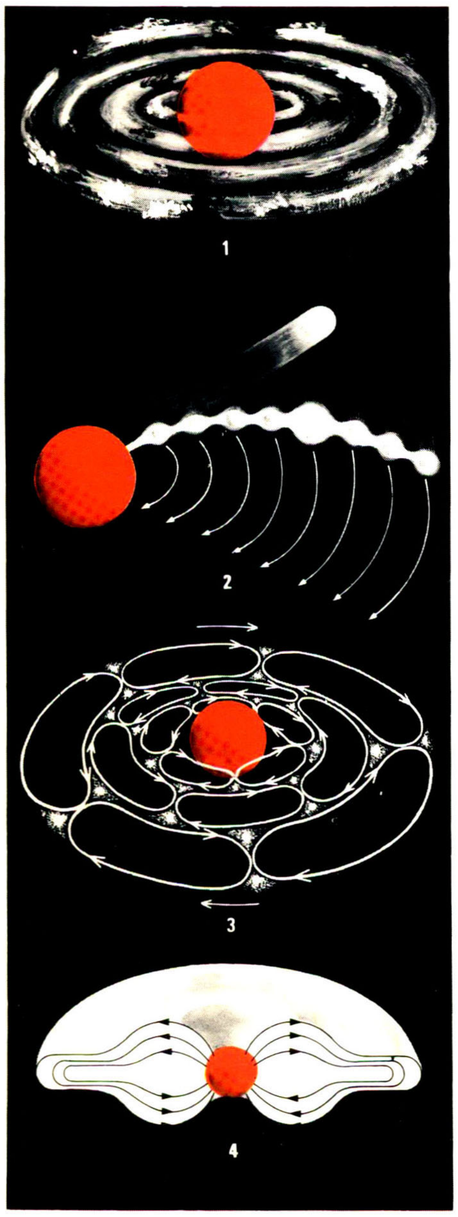
It is with pleasure that we issue this, our latest edition, and we hope the reader will find equal interest and pleasure from its use.

The Earth

The origin of the Earth

The Earth originated as part of the solar system about 4,700 million years ago, probably by the accretion of particles from a cloud of gas and dust (see *The origin of the planets*). Certainly it must have formed in a fairly cold state, for otherwise many of the more volatile elements still present in the Earth would never have been able to condense. On the other hand, the Earth must have warmed up quickly as it increased in size, heat being produced in three ways – by conversion of kinetic energy of the particles coming to rest on the surface of the new planet as the result of great compression in the body's interior, and from decay of radioactive elements.

This heat, which was produced more rapidly than it could escape, had a profound effect on the new Earth's structure. Without it, the Earth would have become a homogeneous globe of silicon compounds, iron and magnesium oxides and smaller quantities of all naturally-occurring elements. As it was, the planet very soon warmed up sufficiently to allow the separation of elements and compounds, to begin. The heavier materials such as iron sank towards the Earth's centre whereas the lighter ones, chiefly silicon compounds, rose towards the surface.



The origin of the planets

Most of the theories about the origin of the planets in the solar system may be divided into two broad types – those which attribute the creation of a solar system to gradual evolutionary processes and those which see it as the result of a catastrophic action.

Kant and Laplace *Nebular Theory*

The earliest theory of the first type was put forward in 1755 by Kant, who suggested that the solar system originated as a spinning disc of material which later separated out into the Sun and the planets. In 1796 this basic idea was developed by Laplace into the nebular theory. Laplace proposed that the Sun was originally a rotating gaseous nebula (1) which gradually contracted under gravitational forces and rotated more and more rapidly until gaseous material was thrown off at the edges to form a series of rings. Each ring then condensed into a separate planet.

Moulton, Chamberlin and Jeans *Tidal Theory*

By 1900 Laplace's theory in its original form had been abandoned, partly because it had proved to be inconsistent with the Sun's observed period of rotation and partly because scientists had shown that Laplace's rings would be too stable to coalesce into planets. So in 1905 Moulton and Chamberlin suggested a return to Buffon's idea of about 200 years before, namely, that the solar system resulted from the collision of the Sun with another body. Thirteen years later this proposal was modified by Jeans, who envisaged not a collision but a close encounter between the Sun and a star (2). As the star passed by the Sun its gravitational attraction drew out from the Sun's surface a long filament of gaseous matter which, being unstable, broke into separate zones. Each zone cooled and contracted into a planet.

Von Weizsäcker's Theory

By the 1930s, however, it had become clear that the sort of filament suggested by Jeans would be so unstable that it would be dispersed into space within a few hours. Moreover, planets such as the Earth are so different from the Sun in composition that they are unlikely to have formed directly from it. So in 1944 von Weizsäcker returned to, and modified, the nebular theory. He suggested that the Sun passed through a vast dense cloud of interstellar dust and gas which it attracted to itself in the form of a disc. The particles in the disc then gradually aggregated into larger and larger lumps which became the planets (3).

Hoyle's Theory

Although the broad outlines of von Weizsäcker's theory are now quite widely accepted, the theory is not entirely satisfactory in detail and so other scientists have proposed variations or even completely different theories. One of the most interesting of modern suggestions was put forward by Hoyle, who drew attention to the role of magnetism. Hoyle proposed that magnetic forces between the Sun and the dust-gas disc gradually move the disc outwards (4). As the disc spread away from the Sun it was capable of carrying smaller and smaller particles and so the larger particles gradually get left behind. This segregation into sizes also implies segregation into different compositions, which quite neatly explains why, when the particles aggregate into planets, the compositions of the planets vary considerably right across the solar system.

The position of the Earth in the Universe

The Earth is the third planet from the Sun and the largest of the group of inner, or terrestrial, planets, the other members of which are Mercury, Venus and Mars. The Sun, the inner planets and the group of outer planets (Jupiter, Saturn, Uranus, Neptune and Pluto – all of which, with the exception of Pluto, are much larger than the Earth) together make up most of the solar system. The solar system is completed by over 400,000 or so asteroids, or minor planets, most of whose orbits lie between Mars and Jupiter and the largest of which is Ceres with a diameter of 730 km. All the planets revolve around the Sun in the same direction and, with the exception of Pluto, their elliptical orbits lie almost in one plane.

Pluto, the outermost planet, is about 5,900 million kilometres, or about 5 light hours, away from the Sun. Yet vast as this distance is, the Sun and planets are but a speck in the universe. For a start, the solar system is but a very small part of the Milky Way, a lens-shaped galaxy which contains some 100,000 million stars like the Sun and vast clouds of hydrogen, helium and dust. The diameter of the Milky Way is about 100,000 light years and the Sun lies about two-thirds of the way from the centre.

The Milky Way, in turn, is only one of many thousands of millions of galaxies scattered throughout the universe. Galaxies tend to cluster; the Milky Way, for example, is but one galaxy in a local group of about 20 and is only about half the size of the largest galaxy in the group. The group itself has a spread of about 5 million light years.

Outside the local group, the furthest known ordinary galaxy is more than 8,000 million light years away, but beyond that are radio galaxies and quasars. Radio galaxies emit vast quantities of radio energy (more than a million times than that emitted by the Milky Way) and are believed to be the sites of gigantic explosions, possibly representing an early stage of galaxy formation. Quasars are very brilliant, but much smaller objects (less than 1 light year across), which are powerful emitters of radio waves and may be the nuclei of distant galaxies. The furthest known object, quasar OQ 172, lies 18,000 million light years away, at the very edge of the detectable universe.

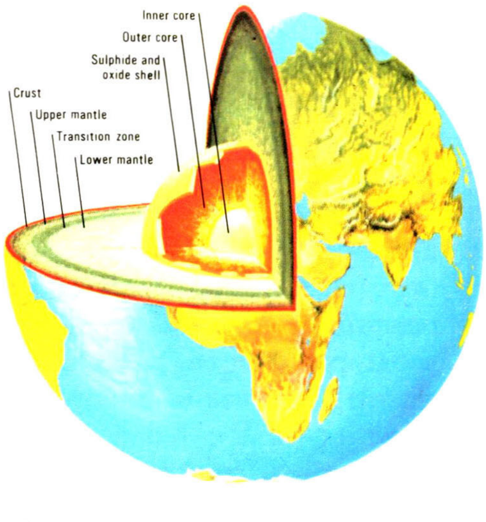
Physical characteristics of the Earth

The Earth is not perfectly spherical but has the shape of a spheroid, a sphere flattened at the poles. The average polar radius of 6,357 km is thus smaller than the average equatorial radius of 6,378 km. The overall average radius is 6,371 km, which is the radius of the sphere that has the same volume as the Earth.

The mass of the Earth is 6×10^{24} kg and its average density is about 5·5 grams/cm^3. But the average density of the surface rocks is only about 2·8 grams/cm^3. There must therefore be an increase in density towards the Earth's centre where the pressure exceeds that of $3\frac{1}{2}$ million atmospheres. The temperature at the centre is uncertain; but is probably no more than about 5,000°C.

More than 70 per cent of the Earth's surface is covered by ocean. Indeed, the Pacific Ocean alone, which with its adjacent seas accounts for more than 35 per cent of the Earth's surface, covers a larger area than that of all the continents combined. More than 65 per cent of the continental area lies in the northern hemisphere, although at the poles themselves this imbalance is reversed.

Metal-bearing rocks deep inside the Earth, contain crystals of ferro-magnetic materials revealed by production of local anomalous magnetism. As the rocks cooled and solidified, the magnetised molecules were aligned like small magnets in the direction of the magnetic poles, thus preserving as 'frozen magnetism' a permanent record of the magnetism at the place and time of their solidification.

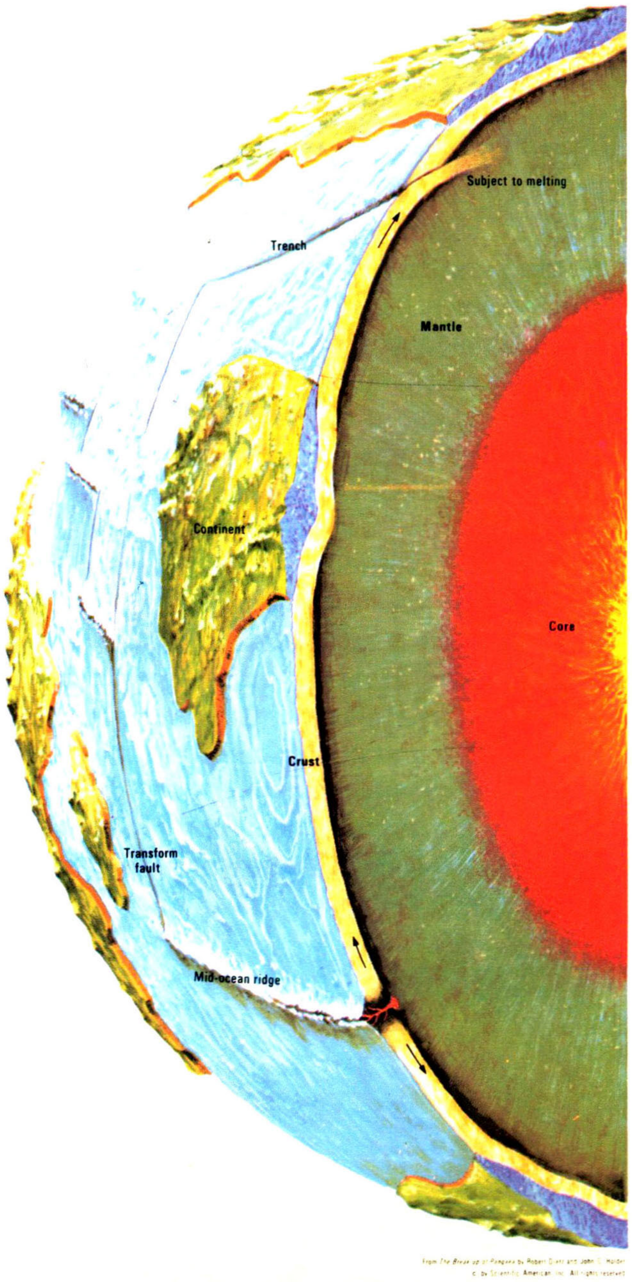


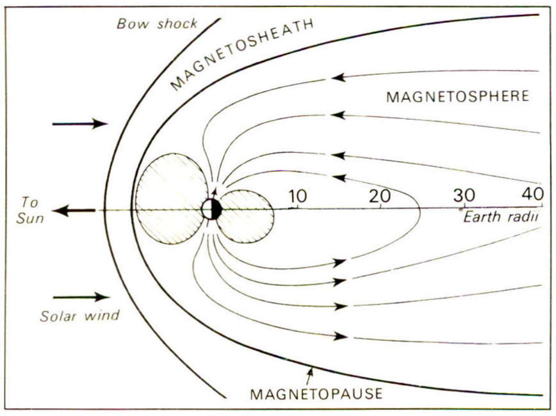
Structure of the solid Earth

The solid Earth consists of three shells: crust, mantle and core. The thin outer shell, the crust, is made up of different types of rock. Under continents it is about 40 km thick and is mostly granitic in composition. Under mountain ranges it may be thicker than 70 km. The oceanic crust is about 8 km thick and is basaltic. The mean crustal density is 2·8 (water = 1·0), and it is about 0·4% of the total mass of the Earth.

The base of the crust is marked by the Mohorovicic discontinuity (Moho or M–). At this level the velocity of the fastest seismic waves sent out by earthquakes rises rapidly from 6 km/sec to 8 km/sec. Below the Moho lies the mantle. Solid rocks brought up from the mantle by lava flows suggest that it is much less varied than the crust and consists mostly of the rock peridotite. The mantle has a thickness of 2,900 km, density of 4·5, and makes up 67·2% of the Earth's mass. The increase in pressure with depth causes the minerals in peridotite (mainly olivine and pyroxene) to change through a transition zone to new dense minerals unknown at the surface.

The innermost Earth shell is the core. The outer core, 2,200 km thick, is fluid. Motions in the fluid generate the Earth's magnetic field. The inner core, radius 1,270 km, is solid. The core density is 11·0 and contains 32·4% of the Earth's mass. Both cores are probably made of nickel-iron.





The magnetosphere

Ionized gas, or plasma, streams from the Sun in all directions, and is known as the 'solar wind'. The Earth's fluid iron-nickel core produces a magnetic field which extends beyond the Earth's surface into space. Where the solar wind comes into contact with this magnetic field there is a mutual interaction.

On the side of the Earth facing the Sun the solar wind compresses the Earth's magnetic field, whereas on the side of the Earth away from the Sun the field is greatly elongated. The field is thus confined to a zone known as the magnetosphere, the boundary of which is called the magnetopause. The position of the magnetopause changes a little as the intensity of the solar wind varies, but in the solar direction it lies at an average distance of about 10 Earth radii from the centre of the Earth, whilst in the anti-solar direction, it extends out to very large distances of at least 60 Earth radii.

The solar wind is travelling at almost 1000 km per second when it encounters the Earth's magnetic field. A shock wave is formed several Earth radii from the magnetopause in the direction of the Sun. The region between the magnetopause and the shock wave front is known as the magnetosheath, or transition region of the magnetosphere.

Earthquakes

An earthquake is a sudden release of strain energy at a point – or, more accurately, within a small zone – in the Earth's crust or upper mantle. Because many shallow earthquakes are obviously related to sudden fault movements, it was once thought that they were responsible for all earthquakes. But it seems likely that at depths greater than a few tens of kilometres the pressure would be too great to allow any fault slippage, whereas earthquakes are known to occur down to depths of about 700 km. The cause of the deeper shocks remains unknown.

Whatever their basic cause, however, most earthquakes are clearly related to plate tectonic processes and occur along plate boundaries – oceanic ridges, oceanic trenches and transform faults. The most intense belt of seismic activity lies around the margin of the Pacific Ocean where 75 per cent of all shallow earthquakes (0–70 km depth), 90 per cent of all intermediate earthquakes (70–300 km) and almost all deep earthquakes (greater than 300 km) occur. Most of the remaining large earthquakes take place along the Alpine-Himalayan chain. Earthquakes are also concentrated along the oceanic ridge system, but most of these are shallow and comparatively small.

There are two ways of specifying the size of an earthquake – by magnitude and intensity. Magnitude is denoted by a number on a logarithmic scale ranging up to about 9·0. It is an absolute measure of the energy released by the earthquake, and so each earthquake is specified by a single magnitude number. Intensity, on the other hand, is denoted by numbered grades on the Modified Mercalli Scale and is based on the damage caused by the earthquake at the Earth's surface as well as on people's reaction to the shock. As these effects decrease with distance from the focus, an earthquake is described by a series of decreasing intensity grades with the highest grade corresponding to the area immediately above the focus.

Earthquake waves

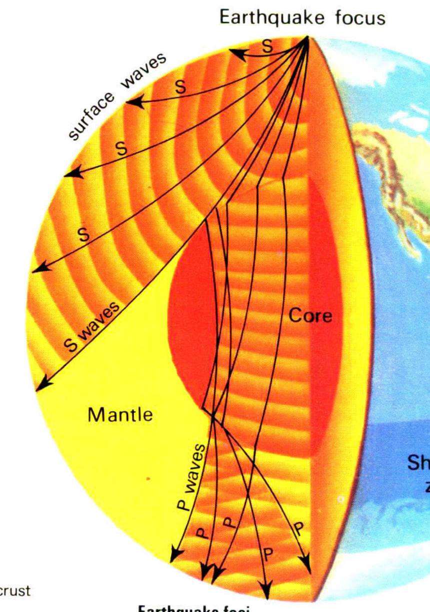
When an earthquake occurs, the shock gives rise to vibrations, or seismic waves, which radiate outwards in all directions from the earthquake's focus. Some of the waves, known as body waves, pass through the Earth's interior; but others, surface waves, travel close to the Earth's surface.

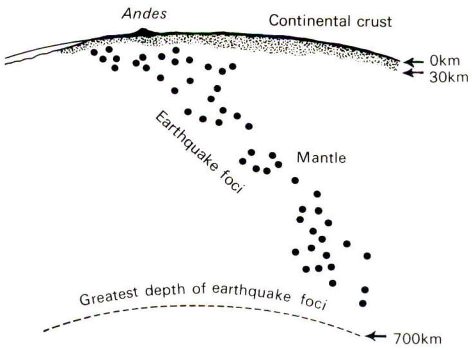
There are two distinct types of body wave. In P, or longitudinal waves the particles of the Earth vibrate backwards and forwards along the direction in which the wave is travelling. In S, or transverse waves the Earth particles move up and down at right angles to the direction of wave travel. Both P and S waves travel along the same paths, except that S waves do not pass through fluids. S waves therefore do not enter the Earth's fluid outer core. In solid materials, however, P waves travel about twice as fast as S waves; so where both P and S waves arrive at a distant measuring station, the P waves arrive first.

The velocities of body waves depend on the physical and chemical state of the material through which they are passing and they generally increase with depth in the Earth. Within any given zone (the mantle, for example), waves are refracted along curved paths which ultimately bring them to the surface. But where the physical properties in the Earth suddenly change, the waves change velocity and are refracted equally abruptly. This occurs chiefly at the crust-mantle and mantle-core boundaries at which there are sharp chemical changes; indeed, these discontinuities were first recognized from the study of seismic waves. The combined effect of refraction and the inability of S waves to travel through the outer core is to prevent most P and S waves reaching the Earth's surface at angles of 105°–142° from the earthquake, a region known as the "shadow zone"

Surface waves are slower than body waves, but they are responsible for most of the ground motion and hence most of the earthquake damage to buildings.

Seismic waves
Body waves, both Primary (P) and Secondary (S), pass through the interior of the Earth. Long waves are the slowest and the most damaging of waves, passing along the surface of the crust. The amplitude or strength of the waves is used to determine the magnitude of the earthquake. Magnitude is graded according to the Richter Scale which is logarithmic: a magnitude of 5 emits waves with a strength ten times that of 4 and one hundred times that of 3 etc.





Earthquake foci
The focus of an earthquake is the small zone from which the seismic waves and energy are released. More than 70 per cent of all foci lie within the Earth's upper 70 km, but some earthquakes occur down to depths of about 700 km. Along deep ocean trenches, where the ocean plate descends into the mantle, the downward path of the plate may be traced by plotting the positions of the associated earthquake foci. Along other types of plate boundary the foci are usually much shallower; along the San Andreas fault, for example, they all lie in the upper 20 km or so.

Modified Mercalli Earthquake Intensity Scale
The 12-point scale designed in 1935 grades shocks according to the degree of disturbance felt by ordinary citizens. The numerals I to XII define the categories.

- I Shock not felt except by a few people under special circumstances.
- II Shock felt by few people at rest. Delicately suspended objects swing.
- III Shock felt noticeably indoors. Stationary cars may rock.
- IV Shock felt generally indoors. People awakened, cars rock and windows rattle.
- V Shock felt generally. Some plaster falls, dishes and windows break and pendulum clocks stop.
- VI Shock felt by all. Many frightened, chimneys and plaster damaged, furniture moves and objects upset.
- VII Shock felt in moving cars. People run outdoors. Moderate damage to buildings.
- VIII General alarm, shock very destructive. Damage to weak structures, but little to well-built structures. Furniture overturned.
- IX Panic. Total destruction of weak structures and considerable damage to well-built structures, foundations damaged, underground pipes break and ground fissures and cracks.
- X Panic. All but the very strongest buildings destroyed, foundations ruined, rails bend and water slops over river banks.
- XI Panic. Few buildings survive, broad fissures form and underground pipes out of service.
- XII Panic. Total destruction, waves seen in ground and objects thrown in air.

Volcanoes

There are about 500 active volcanoes situated on tectonic plate margins (see page 8 Plate tectonics). Volcanic belts are of two major types; those at the crest of mid-ocean ridges and those at the convergence of plate boundaries. The most recent eruptions include an eruption at Tristan Da Cunha (1956), the birth of a volcanic island at Surtsey near Iceland (1963), and eruption at Eldfjell, Heimaey in Iceland (1973). Other volcanoes are continuously active but with less dramatic results. They include Cotopaxi and Chimborazo in Ecuador, Popocatepetl in Mexico, and Lassen Peak and Katmai in the USA.

Cinder cone

This is the simplest form of volcano. Material is ejected through the central pipe and each eruption produces new deposits to overlay preceding layers. Gradually the cone is built up with larger fragments remaining near the summit at the steepest angle, around 30 degrees, and the smaller deposits moving to the base of the cone where the angle of rest may be as low as 10 degrees. Cinder cones rarely develop more than a kilometre in diameter.

Shield volcano

If much liquid or viscous lava is produced then deposits slowly build up a shallow-sloped volcano which may stretch up to 20 kilometres across. The gentle slopes are rarely steeper than 10 degrees.

Composite cone

This is the most common type of volcano formed by the vent emitting both rocks and lava at different times. The deposits therefore alternate to form a strong bonded structure resistant to erosion. Examples are Etna in Sicily, Vesuvius by Naples and Fujiyama in Japan.

Caldera

Calderas are formed either as the result of eruptions when the upper part of the cone is destroyed, or else by the collapse of the unsupported rim following the ejection of large quantities of lava. The cone is reduced in height but increased in circumference. Collapse occurs when the reservoir of molten magma issues through a side fissure instead of the central vent. The unsupported floor collapses with the crater rim, considerably enlarging the crater. Crater Lake, Oregon, 6–10 km in diameter, is an example of a caldera.

Flood basalt

Long narrow fissures in the Earth's crust may leak lava and heated rocks spreading them over a vast area. Fissure eruptions have produced the Deccan in India which covers half a million square kilometres.

Gas emission

In periods between eruptions, volcanoes release steam and various gases. As volcanic extinction approaches, lava and ashes are no longer ejected, the leaking gases are not under sufficient pressure to cause a fracture of the lava crust. This is called the solfatara stage after the large crater near Naples in Italy. The gases include sulphuretted hydrogen, sulphur dioxide, carbon dioxide, hydrochloric acid and ammonium chloride.

Explosive volcanoes sometimes eject material mixed with hot gas and this is known as *nuée ardente* or glowing cloud emission.

Volcanoes which emit chiefly steam are called fumaroles. The best example is the Valley of Ten Thousand Smokes near Katmai Volcano in Alaska. Carbon dioxide emitting volcanoes are termed mofettes.

Geysers and mud volcanoes

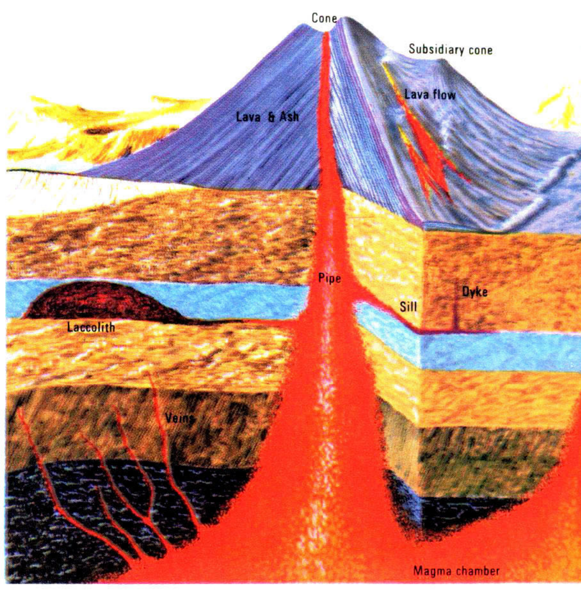
In certain parts of the world volcanic eruption expresses itself by the ejection of water at a high temperature. Geysers consist of clear water emission, but are called mud volcanoes if the water has a high content of solid matter. Both these mark the terminal phase of volcanic activity. The Waimangu geyser in New Zealand, active until 1904, had a jet fountain 500 feet high.

Volcanic prediction

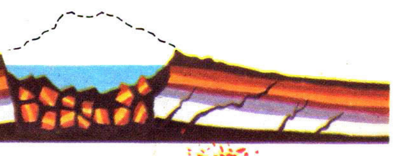
The monitoring and prediction of volcanic activity is linked to earthquake detection on the site of recently active volcanoes. Most of those close to populated areas have permanently staffed observatories, such as at Mt Etna in Sicily and Mauna Loa in Hawaii. Transportable seismometers at selected locations record the small movements of the magma within the volcano which precede an eruption. The probable point of eruption can then be calculated. Tiltmeters and distance measuring equipment are used to map the changes to the landscape during and after an eruption. On many volcanoes, the slopes tilt downwards after an eruption and then build up slowly towards the next peak of activity. Volcanic movement sometimes produces a change in the local magnetic field caused by a rise in temperature of the underlying magma.

Cross-section through composite volcano

Volcanic activity
Volcanoes are formed when magma or molten material from the mantle or atmosphere, is extruded through weak or fractured points in the Earth's crust. Magma reaches the surface from the magma chamber through a volcanic pipe, but in some instances side vents leak magma through horizontal sills and vertical dykes. When magma reaches the surface it may be in liquid, solid or gaseous form. A lacolith is sometimes formed where molten rock is unable to reach the surface but is under enough pressure before solidifying to distort the overlying strata into a dome.



Caldera

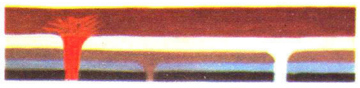


Calderas are large, basin-shaped depressions bounded by steep cliffs, like Crater Lake, Oregon, USA. They are usually formed when the magma chamber cannot support the cone above.

Shield volcano

Shield volcanoes, like Kilauea, Hawaii, repeatedly erupt highly fluid basalt lava that spreads out sometimes tens of kilometres.

Flood basalt



Flood basalt is an outflow of fluid lava from long and narrow fissures. The lava may spread out over vast areas to form extensive plateaux, like the Deccan in central India.

Nuée ardente

Nuée ardente (glowing cloud) eruptions are violent explosions of gas mixed with rock fragments which are ejected, sometimes to a considerable height, as at Mont Pelée in Martinique in 1902.

Plate tectonics

Earthquakes originate in well-defined zones of the Earth where rocks are actively being deformed. Earthquake zones separate large rigid areas free from active deformation known as tectonic plates. There are at least twelve such plates composing the Earth's outer shell, the lithosphere, and seven of them occupy a very large area, over 40 million square kilometres (see below Relative motions of tectonic plates). The lithosphere averages about 100 km in thickness and rests upon the asthenosphere, the semi-molten upper layer of the mantle. The detailed mechanism of plate movement is unknown but it is probably related to the transfer of heat energy deep within the Earth.

The idea of continual creation and destruction of the crust is seen in the movement of the ocean-floor plates forming mid-ocean ridges and deep trenches at the plate margins. Molten material from below the crust rises to the surface at the oceanic ridge where it forms new crust. To compensate for this additional material the leading edge of the moving plate is deflected downwards back into the mantle.

The theory of ocean-floor plate movement has been substantiated by dating of rock-core samples and comparison between magnetised rocks from either side of median ocean ridges. Deep ocean drilling has revealed that the oldest rock samples are in fact furthest away from the ocean ridge. Similarly, magnetised rock samples taken at an identical distance either side of a ridge show the same pattern of magnetic reversals. The oldest age of the rock samples appear to be about 200 million years, consistent with the estimate of the time when the Pangaea started to break up (see Continental drift).

There are three basic types of plate boundary identified by the differing movements of the plates in relation to one another.

Extensional plate boundary

At an extensional plate boundary new ocean floor is continuously created by the welling up of an oceanic ridge of hot basaltic crustal material from the underlying mantle. This material adheres to the plate edges as they move outwards from the median ridge. This process is known as ocean-floor spreading. The 40,000 km world-wide submarine mountain chain formed by ocean-floor spreading is the longest chain on Earth, but is visible only where exceptionally intense vulcanism, as in Iceland and Tristan da Cunha, raises it above sea-level. The usual ridge height is up to 5 km but widths may extend as far as 4,000 km. The forces of tension between the two diverging plates, cause rifts and transform faults where the fractured margins break up.

As the new ocean floor cools it acquires a weak magnetism. The older ocean floor moves away from the ridge at rates of between one and ten centimetres per year (see map below). The polarity of the Earth's magnetic field changes with time. Thus older ocean floors may be weakly magnetised in a differing direction to the present. The successive polarity changes or reversals, which occur at irregular intervals of a few hundred thousand years, give rise to a magnetic striping on the ocean floor by which older floors may be dated and the history of the oceans interpreted.

Translational plate boundaries

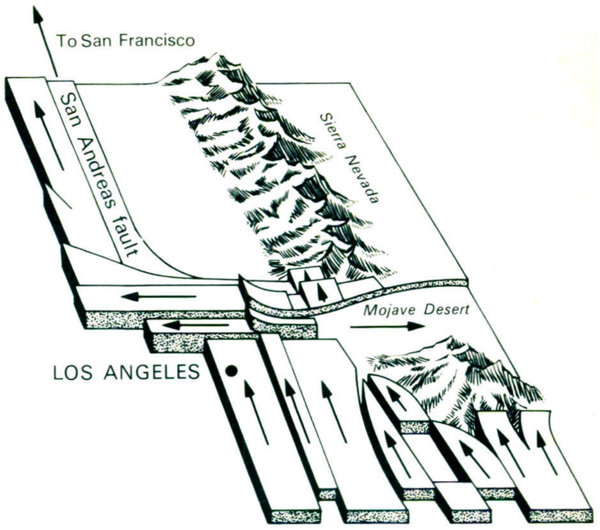
Crust is neither created nor destroyed at translational plate boundaries. The plates slide past each other along vertical faults or fractures known as transform or transcurrent faults. Best known as the San Andreas Fault in California (see diagram) and the Alpine Fault of New Zealand. Seismic activity is considerable along the numerous fracture zones which traverse the ocean ridge transform faults.

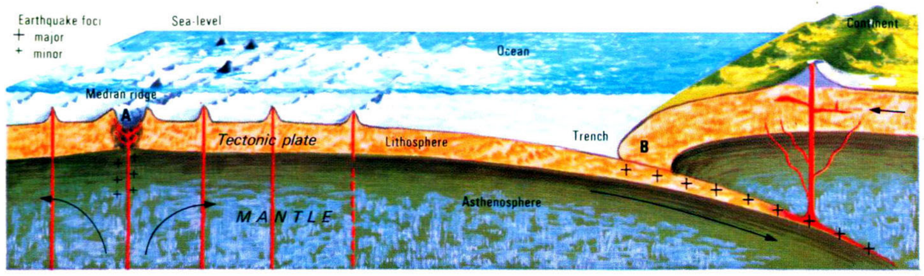
Compressional plate boundary

At compressional plate boundaries the older ocean floor sinks into the mantle at a subduction zone or steep zone of underthrust. This type of boundary is marked by ocean trenches where the edges of the crustal plates drop steeply into the mantle and become re-absorbed into the asthenosphere at depths of up to 600 or 700 km. Either plate could be pushed or subducted under the other, but usually, the less rigid and more flexible ocean-floor plate is deflected downwards by the continental plate. The descending plate carries crust material back into the under-lying mantle where it melts and breaks up. As it is less dense than the mantle it rises either towards the oceanic ridge and island arc or towards the continental lithosphere where it causes lava eruptions in a chain of volcanoes. The Aleutian, Japanese and Marianas islands are examples of such island arcs, and the South America Andes is an example of a subduction zone beneath a continental landmass. The sinking rate of one plate beneath its neighbour appears to be between 2 and 10 cm per year, resulting in intense seismic activity. The Earthquake foci in the subduction zone may be as deep as 700 km but they follow the subducted plate margin and give rise to severe disturbance.

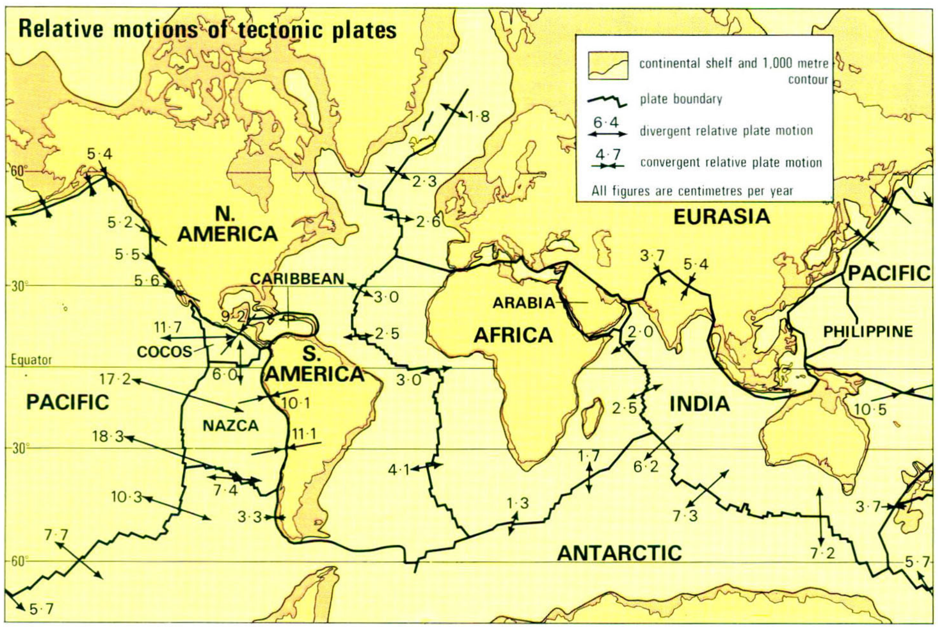
San Andreas fault

The fault is situated at the western margin of the North American plate which is sliding past the Pacific plate at an average speed of about 6 cms per year and setting up considerable stresses. In 1906, this vertical transform fault on a Translational plate boundary released its accumulated stress energy by a sudden sideways movement resulting in the San Francisco earthquake. Since 1906 the stresses have again been building up. Serious movement may again occur when the strength of the bonding of the two plates is exceeded by the stress.

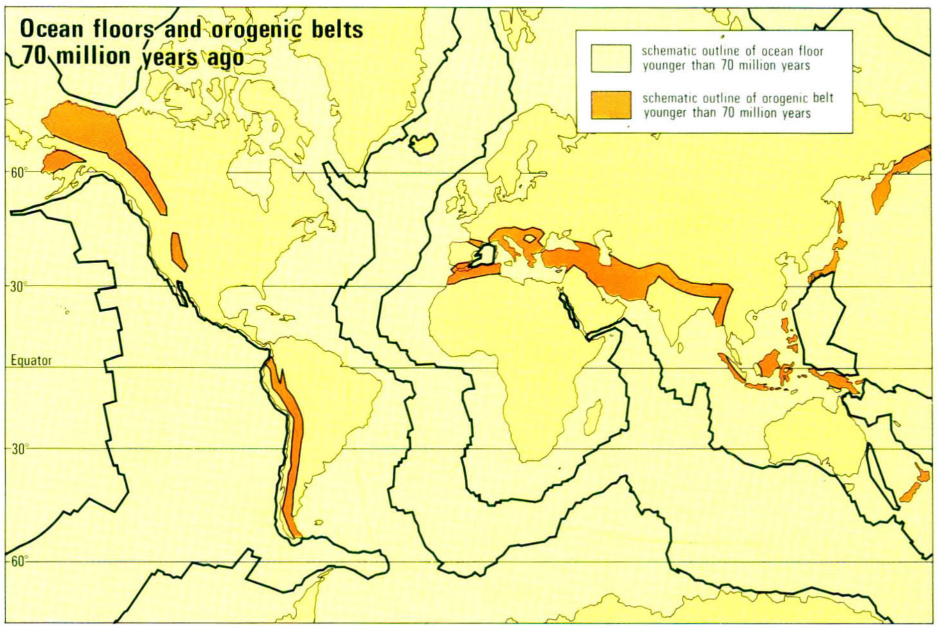




Volcanic activity and earthquakes are associated with plate tectonics. At A, an extensional boundary, magma from the upper mantle forms two parallel ridges. The rift between them broadens and new ridges are formed. At a compressional plate boundary, B, the ocean crust descends to perhaps 700 km, at which depth melting takes place.



At mid-ocean ridges, plates are diverging at up to 18 centimetres per year. Where a continental plate meets an ocean plate the less dense continental material "floats" over the descending ocean plate and is pushed up to form a mountain range. Where two continental plates converge the continental material of both plates is forced upwards.



Ocean-floor spreading during the last 70 million years has been particularly apparent in the eastern Pacific and in the mid-Atlantic ridge which extends east of Africa across the south Indian Ocean. In the Americas the active orogenic belts are close up against the spreading plate boundaries. The mid-Atlantic ridge is passive in comparison.

Plate movement

Crustal plate movement occurs continuously in all parts of the globe but varies in type and rate of movement. This movement is generated by the complex interaction of a number of elements; the continental lithosphere plates themselves; the mid-ocean plate boundary ridges; micro-continental plates; island arcs; small enclosed ocean basins; and inland seas.

Present-day plates

Plate	*Area*	*Continental area*
	(millions of sq.km)	
Pacific	**108**	**1·9**
Eurasia	**68**	**59·4**
N. America	**58·8**	**35·0**
S. America	**42·7**	**25·6**
India	**61**	**21·7**
Africa	**78·4**	**35·4**
Antarctic	**59·9**	**17·9**
Nazca	**16·4**	
Cocos	**3·1**	
Philippine	**5·7**	
Caribbean	**3·5**	**1·4**
Arabia	**4·9**	**4·2**

A variety of movements are therefore possible. The fastest rate of movement is the divergence of the Pacific plate from the Cocos, Nazca and Antarctic plates with a figure of 18·3 cms per year at latitude 30° South (see map above). The Mid-Atlantic Ridge marks the boundary between the American, African and Eurasian plates. This divergence remains fairly constant at between 2 and 4 cms per year. The African, Indian and Antarctic plates are diverging from each other at a rate between 2 and 7 cms per year.

The above map shows that convergent plate motion involves an ocean plate and a continental plate or two continental plates, but rarely two ocean plates. The fastest rate of convergence is between the Cocos and the Caribbean plate in Central America where the Guatemala Trench marks the edge where the Cocos plate is sliding downwards at over 9 cms per year. The Himalayas mark a collision zone between the Eurasian and the Indian plates; the rate of crustal compression here is over 5 cms per year.

Mountain building

Orogeny is the geological process of mountain-building. The two most important agents of orogeny are deformation of Earth's crust (diastrophism), which includes faulting and folding; and vulcanism. Orogeny usually occurs along narrow belts of the Earth's surface and can involve the uplift and deformation of great thicknesses of sedimentary and volcanic rocks. This process is called the orogenic cycle and is associated with the movement of an oceanic plate against a continental land-mass (see Compressional plate boundary above). At this margin many layers of sedimentary and volcanic rock deposited over millions of years become uplifted and deformed. Until recently mountain-building was thought to be more associated with ascending and descending currents within crustal rocks.

The Earth's orogenic belts lie between the stable continental plates and an ocean or inland sea (see map of orogenic belts above). The Andes and Rocky Mountains lie between the American plates and the Pacific Ocean; the Himalayas lie between the stable Eurasian plate and the Indian sub-continent.

The uplifted and deformed rocks formed as a result of plate collision may be mixed with molten igneous rock rising from the mantle as a result of the melting subducted crust. Youngerfold mountains less than 500 million years old consist of these rocks thrust upward and over-folded as in the Alps, or simply uplifted as the central Andes. The rate of uplift may be as much as one centimetre a year. Over-fold mountain ranges are the remnants of earlier folding cycles which have been stranded away from active plate collision margins.

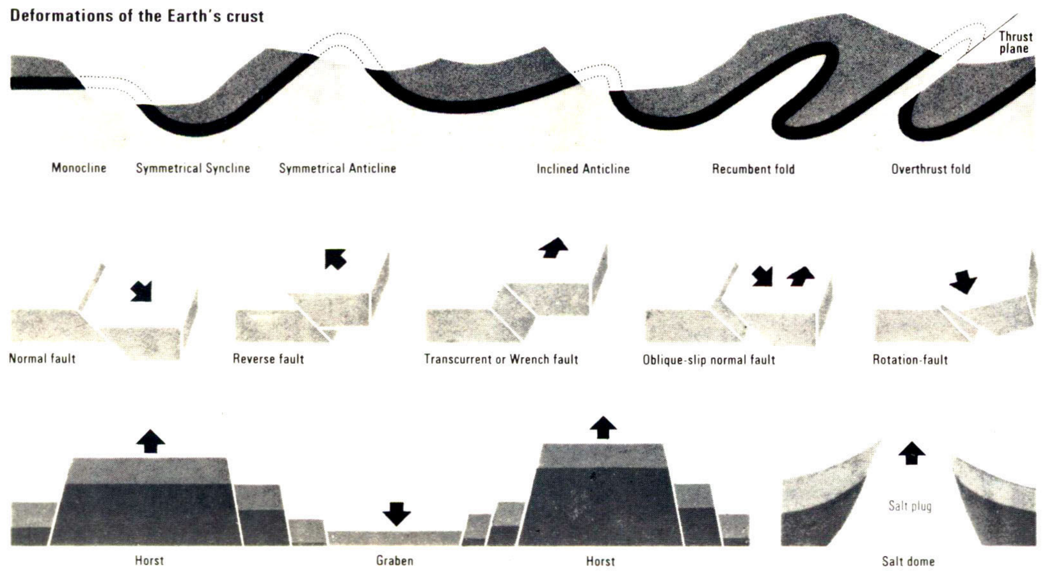
The map above was computed from the relative positions of dated sedimentary and metamorphic rocks plotted with reference to the trapped magnetism fields within them. Latest research reveals over one hundred and fifty magnetic field reversals during the last 70 million years. It is clear that the Earth's major orogenic belts have changed little during that time but the ocean floor areas have spread considerably.

Folding and faulting
When the Earth's crust bends under compression, folds develop. The simplest of these is the monocline, a one-sided fold, although downfolds (synclines) and upfolds (anticlines) are more usual. Increasing pressure steepens the side facing the pressure until one side is pushed under the other, forming a recumbent fold. Finally the fold may break along its axis, one limb being thrust over the other. Mountain chains often demonstrate intense folding, when sediments are crushed between converging plates.

Faults occur when the Earth's crust breaks, often causing earthquakes. When tension stretches the crust normal faulting occurs and the rocks on one side of the fault-plane override those on the other.

A horst is a block of the crust thrust up between faults; the reverse is called a graben or rift valley. Repeated horst and graben forms give basin and range topography as in Nevada, USA.

The upward movement of a roughly circular plug of salt, some thousands of feet in depth, may force up strata and the surface layers to form a salt dome. These are often associated with oil and gas.



Folding and faulting

In unstable regions of the Earth's crust stresses may cause folding, fracturing and distortion of sedimentary and volcanic rocks. This is termed crust deformation and is most apparent in the European Alps, South American Andes and the Himalayas. The causes of instability are multiple. Orogenesis or mountain-building deforms the crust, but larger more gentle movements may be caused by isostasy or natural adjustment of crustal levels. A basin accumulating sedimentary deposits may slowly sink under their weight, and weathering may lighten a mountain chain causing it to rise.

The processes and extent of folding and faulting depend on the type and magnitude of the stress; fast or slow, regular or irregular application of stress; the period of time of the stress; the constituency and type of rock or rocks; and relationship with adjacent rock strata. The interrelationships of these factors are so complex that the deformation may range from micro-scopic waves to vast folds tens of kilometres across, and from displacement of single crystals to giant faults.

Folding

Folds are of many types, classified according to the severity and shape of the fold. Basically a fold consists of two limbs or sides with a bisecting axis. If the limbs dip in opposite directions and are divided into two equal halves, the fold is symmetrical; if the axis does not bisect the fold it is asymmetric. An overturned fold has one limb lying partly under the other, and a fold is termed recumbent where one limb is wholly under the other. Folds are usually formed well below the surface and are only exposed by erosion. Anticlinal or synclinal stumps are typical of eroded folds – the ridges of the Appalachian Mountains in the eastern USA are the exposed limbs of folds.

Faulting

A fault is a fracture of the Earth's crust in which the rock on one side of the fracture moves in a different direction to the rock on the opposing side. The fracture and movement along the plane of the fault may be vertical, inclined or horizontal. A normal fault has the inclined plane of fracture exposed as one part of the crust slips downwards and away from another. A reverse fault occurs when compression causes a slab of the crust to slide under an adjacent block. Faults with horizontal rock movement are termed transcurrent or wrench faults, the best-known example of which is the San Andreas fault (see page 8). A combination of movements can produce a highly complex fault structure which creates problems of interpretation for the geologist. The block on one side of a normal fault may slip sideways as well as downwards, it may rotate about a fixed point, or both blocks may move in the same direction but one faster than the other.

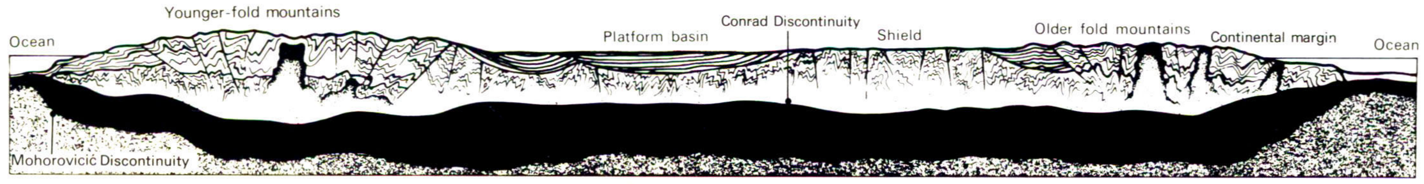
Rift valleys or grabens, are caused by the subsidence of elongated blocks of crust sometimes on such a scale that they are marked by chains of volcanoes. The East African Rift Valley System stretches from the coast of Africa opposite Madagascar northwards to the Red Sea and the Mediterranean. Crustal movements upwards produce horst scenery of uplifted blocks; typical examples are the Tien Shan mountains of central Asia, now heavily eroded, and the ranges of Nevada, USA.

Continental crust

A cross-section through the continental crust typically shows the following features: continental margins, younger and older-fold mountain chains, platforms and shields. The continental margin will either be passive as are most Atlantic margins, or active, as are the Pacific margins. Younger-fold mountains formed during the last 500 million years, such as the Rockies and Andes of America, and the Himalayas of Asia, mark the younger subduction zones and occur along most of the active continental margins. Older-fold mountains, like the Appalachians of eastern America and the Caledonian system of Britain and Scandinavia, are nearer to the older subduction zones across which two continents have been joined together. Platforms are areas on which flat-lying sediments have been laid down as in the central United States, Saharan Africa and the Arabian peninsula. Underneath the platforms are highly deformed pre-Cambrian rocks that emerge at the surface as shields. Most of north Canada, central Africa, South America east of the Andes, and Antarctica are shield areas.

The internal structure of the continental crust is known from monitoring seismic activity and from echo-sounding experiments. In most places the crust consists of an upper layer of less dense material over-lying a lower, more dense layer. The boundary between the two is termed the Conrad Discontinuity. The upper layer is 92 per cent igneous and metamorphic and 8 per cent sedimentary in composition. The lower layer is probably basaltic in character or a product of metamorphism called amphibolite, and is derived from partial melting of the mantle. The zone of transition between the continental crust and the underlying magma is called the Mohorovičić Discontinuity.

In comparison with the oceanic crust, the continental crust is less dense with a value of 2·7 as against 3·0; thicker reaching down to a depth of 70 km below mountain belts as opposed to 6 km; and older with some parts aged 3,500 million years and much over 1,500 million years compared with a maximum of 200 million years for the most ancient regions of the submerged oceanic crust.



Continental crust
The chemical composition of the crust down to 16 kilometres is: oxygen 46 per cent, silicon 28 per cent, aluminium 8 per cent, iron 5 per cent, calcium 4 per cent, sodium 3 per cent, potassium 2 per cent and magnesium 2 per cent.

Continental drift

Continental drift is a term used to describe the relative motions of the continents.

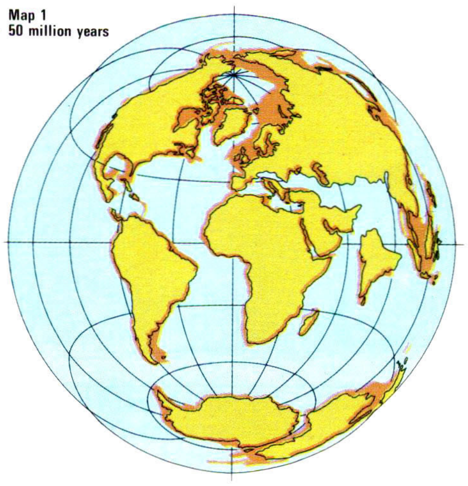
The relative positions of the continents as far back as 200 million years may be found from the magnetic anomaly maps of the Atlantic and Indian Oceans. The position of the geographic pole of past time may be found from studies of ancient magnetism on continents. From a knowledge of the relative positions and the geographic pole a map of the former positions of continents may be drawn.

Four such maps, drawn by computer, are shown opposite; the Earth 50, 100, 150 and 200 million years ago. By comparing the maps against each other one can see how the Atlantic and Indian Oceans shrank in size as the continents came closer together. As they shrank, a space opened between Eurasia on the one hand and Africa, Arabia, Iran and India on the other. This space is assumed to represent an old ocean, known as the Tethys, that has been completely subducted in the region east of the Mediterranean. The Alpine-Himalayan mountain chain is assumed to represent the final phases of a plate tectonic cycle involving the collision of continents that once bordered the Tethyan Ocean.

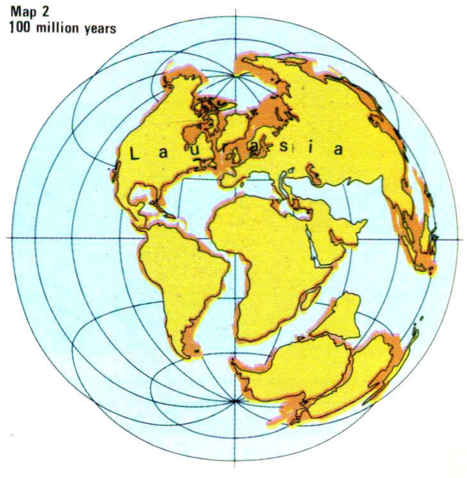
About 80 million years ago, Eurasia, Greenland and North America formed a single continent known as Laurasia. One hundred and forty million years ago the southern continents were joined together to form a single continent known as Gondwanaland. About 180 million years ago all the major continents formed a single supercontinent known as Pangaea, first postulated by Wegener over half-a-century ago. Pangaea was itself formed some 250–300 million years ago by the collision of Gondwanaland with Laurasia west of the Urals and of Asia east of the Urals. It is not yet possible to draw maps of the continents prior to about 350 million years ago because the distance between the fragments that collided to form Pangaea prior to their collision cannot be estimated.

Continental drift
Early evidence of break-up and drift of the continents away from the single Pangaea landmass, has been confirmed by recent studies of ancient magnetism. The evidence consisted of matching continental shapes, for example the 'bulge' of Brazil fits closely to the coast of West Africa; and the joining of geological strata across the fit, for example the coal deposits of Uruguay and South Africa. The distribution of certain species of flora and fauna worldwide in the Palaeozoic and Mesozoic eras can only be satisfactorily explained by supporting the theory of continental drift. Animal fossils from Antarctica match those discovered in Argentina and South Africa, and climatic changes to the British Isles during the last 200 million years can be explained by continental movement.

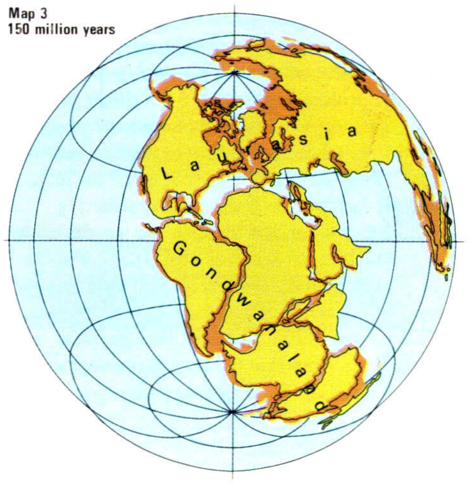
Map 1
50 million years



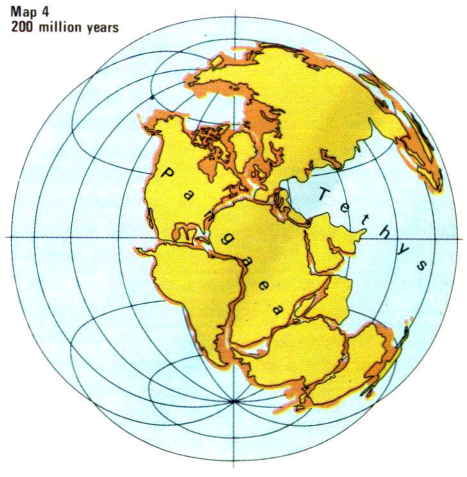
Map 2
100 million years



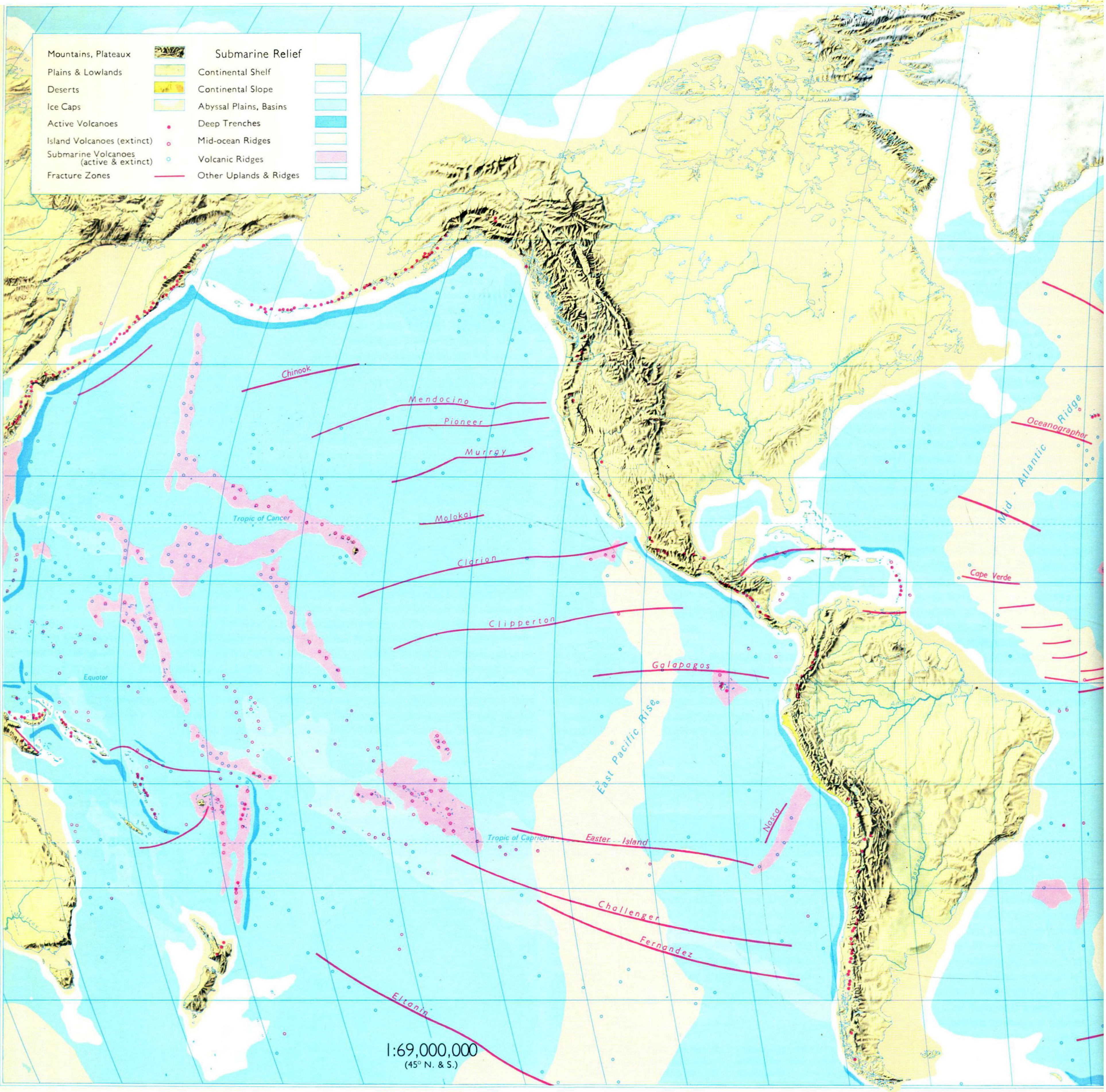
Map 3
150 million years



Map 4
200 million years



Land and sea forms



The simplest division of the surface of the Earth is into continents and oceans. All the evidence confirms that the ocean basins were never part of the continental areas and the oldest continental blocks were never part of the true ocean floor.

The rocks of the old continental blocks are markedly different from the young folded mountains. The former are the original blocks, granitic and among the oldest rocks formed in Pre-Cambrian times. The margins of the continents have been repeatedly covered by the sea and the true limit of the continents is the edge of the continental shelf, the physiography of the continents therefore consists basically of the old stable mountain masses, young folded mountain ranges and the coastal plains and continental shelf.

The fundamental difference between the physiography of the oceans and that of the continents arises from distinct geological processes involved in their formation. The granite rocks of the continental masses are lighter than the silica and magnesia (sima) rocks on which they rest, and thus 'float' on them. The floor of the ocean is therefore composed of material denser than that of the surface rocks of the continents.

Different chemical processes operate in the continental and ocean rocks because of their different composition and also because of the atmospheric as opposed to the aqueous environment. The continents are subjected to the severe erosional forces of the weather and to more rapid chemical processes resulting from direct contact with the atmosphere. A wide temperature fluctuation ranging from intense heat to extreme cold has transformed the land forms; but of all the meteorological factors rain is the most destructive.

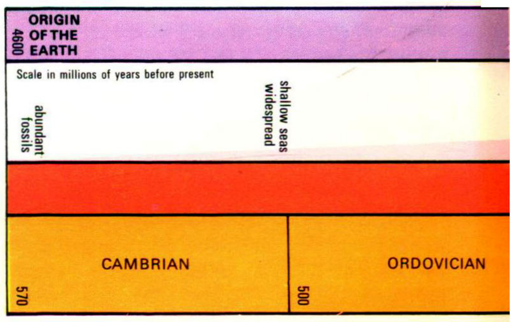
The Earth's surface features are produced by the interaction of internal and external forces. The former include mountain building, faulting, uplift, vulcanicity, and resistance, of the rocks. The external forces include the physical and chemical reactions that weather the surface rocks, and the main agents of erosion: running water, ice, sea and wind. Each of these gives rise to distinctive land forms, so that we can, for example, identify glaciated landscapes or desert landscapes, but always reflects the interaction of structure and the erosional process.

Running water is the most important sculptor of land forms, and the results of its work can be seen even in desert areas. Valleys are the work of the rivers that flow, or have flowed, through them. Most river systems flow into the sea but some empty into interior lakes, such as the Dead Sea, where water is lost by evaporation.

Glacier ice produced very distinctive land forms, such as trough-shaped valleys, pyramidal peaks and moraines; in the Pleistocene period glaciers were much more widespread than now.

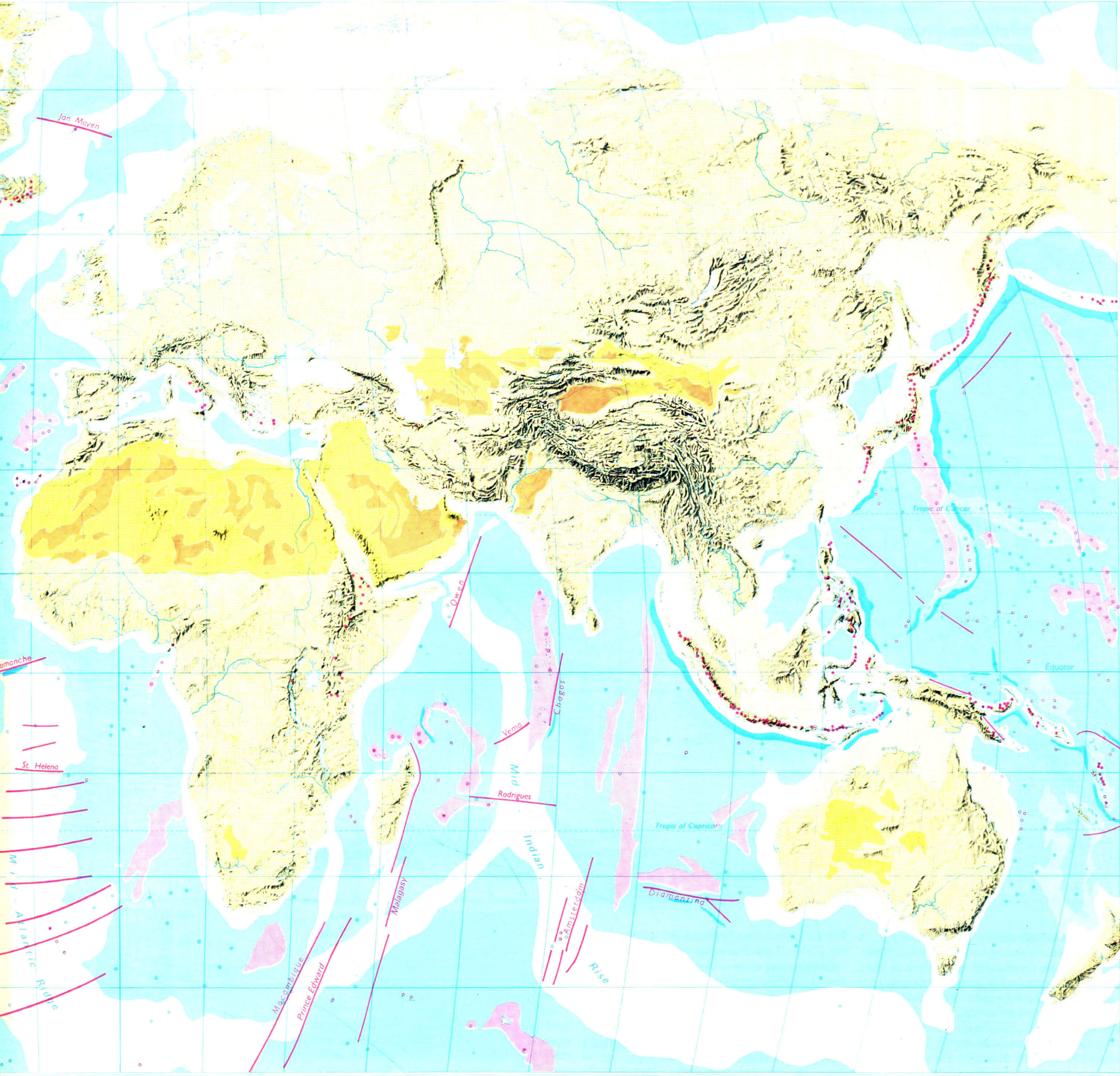
The wind is most effective in areas of sparse or absent vegetation. Only about 25 per cent of the area of the world's deserts are dune-covered. The rest is rocky or gravelly.

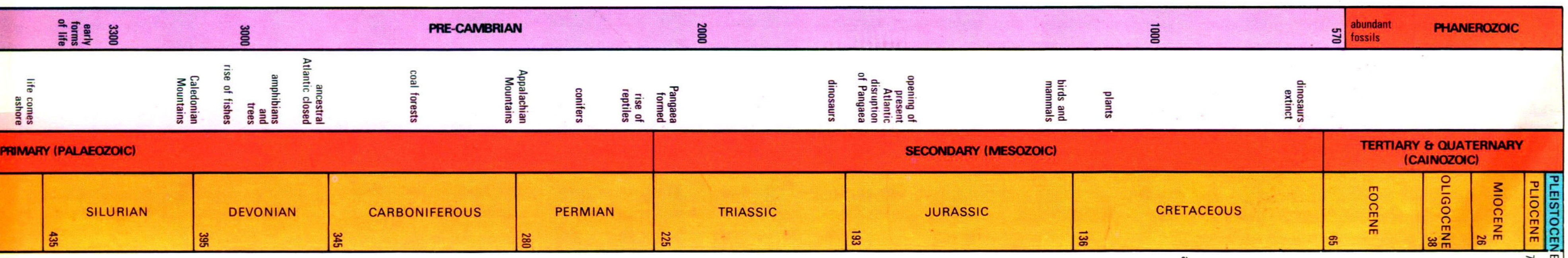
The oceans are not subject to the violent effects of heat and frost, wind and rain, only to the quiet forces of sedimentation and gravity. Near the continents the sediments are at their thickest; over the rest of the ocean floor they are seldom more than a few hundred metres thick.



Like the continents, the oceans can be divided into main physiographic categories: continental shelf and slope, continental rises, abyssal plains, ocean ridges and rises and trenches. If we exclude the continental shelf and part of the continental slopes the area of the oceans at 2,000 metres below sea level is about 320 million sq km.

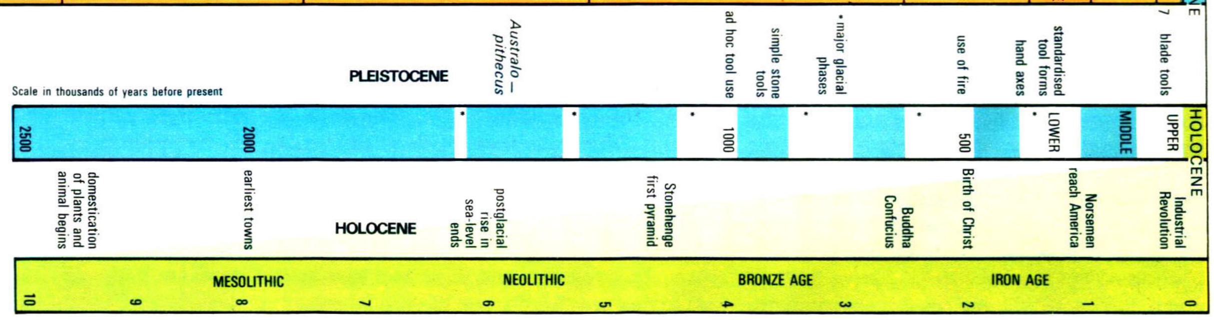
The abyssal plains extend over almost half this area and are below 2,500 metres. At this depth, temperature is never higher than 4°C (39°F).

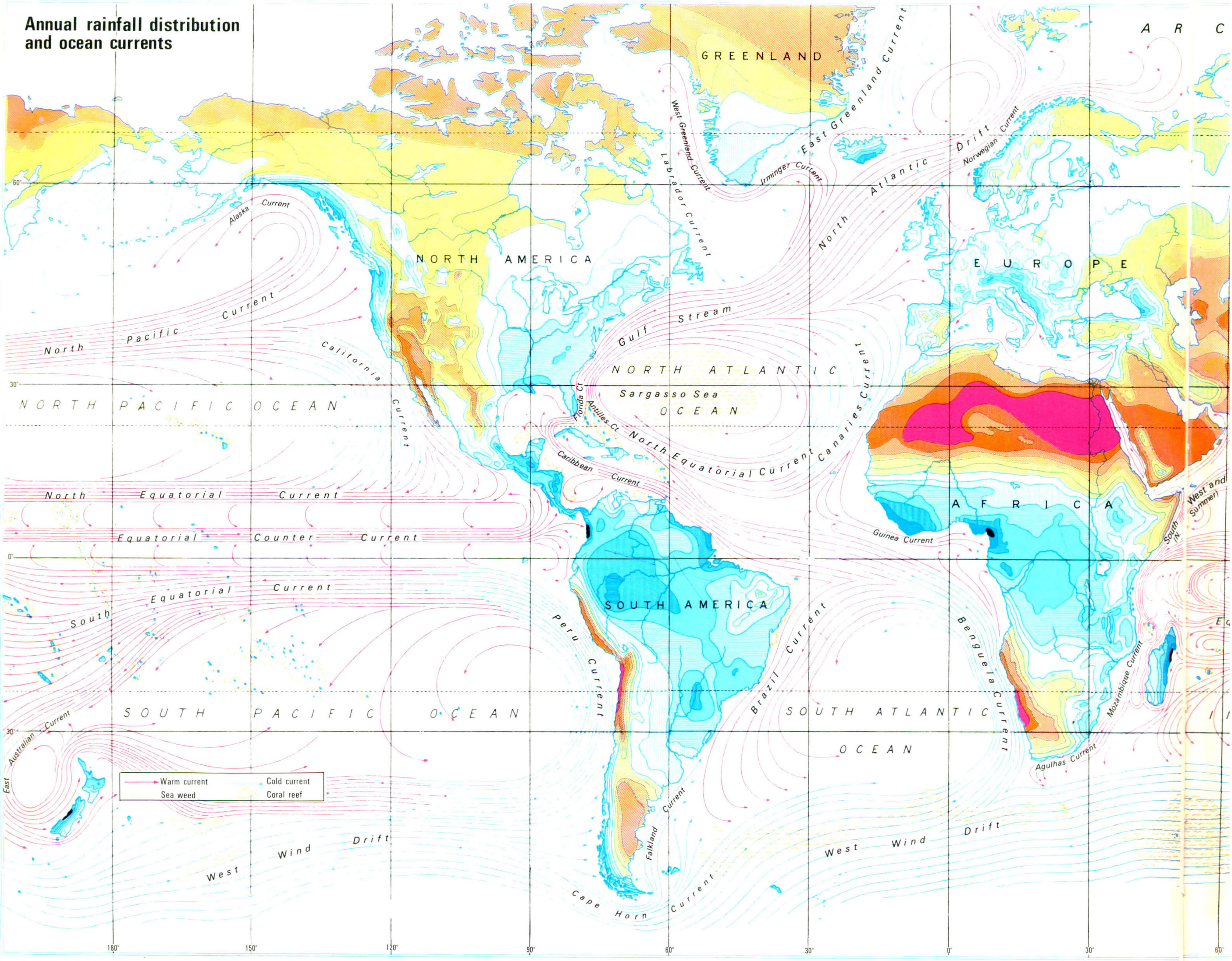




Geological periods and the emergence of Man

Modern man has inhabited the Earth for less than one millionth of the total period of its existence, now known to approach some 5,000 million years. Much of this enormous span of time (see top column) was the almost barren and relatively unknown Pre-Cambrian period. For only one eighth of its history has the Earth borne abundant life: the second column shows this Phanerozoic divided into stratigraphic periods, based originally on fossil evidence. The third column details the last two and a half million years, marked by at least seven ice ages and the period when many of the Earth's land forms were shaped. *Homo sapiens* appears only recently, and though he became a cultivator and developed urban living quite early in this final period covering the last 10,000 years, only in the last 250 years has he harnessed the world's power and mineral resources.





Evolution of the atmosphere

The Earth has an atmosphere because it is large enough for its gravitational pull to retain the gases surrounding it. Our present atmosphere is not the first. Most of the gases and probably all of the water in the oceans are the result of volcanic activity.

As the atmosphere lacks certain of the heavy gases it has been suggested that the Earth's original atmosphere was boiled away by a tremendous increase in the Sun's heat. At the same time the water and water vapour then present would also have evaporated. Studies of Mars from the Mariner and Viking spacecraft suggest that the same process happened there too, confirming the validity of this theory.

The Earth's atmosphere once largely consisted of hydrogen, combined with methane and ammonia. The hydrogen was gradually lost and free oxygen was slowly added.

In Cambrian times, between 570 and 500 million years ago, a much greater proportion of carbon dioxide was present in the atmosphere. Since life first appeared, the plants and rocks both on land and in the seas have competed for the carbon dioxide and the free oxygen. There is now a greater quantity of oxygen and carbon dioxide locked up in the rocks of the Earth than is to be found in the whole atmosphere. The balance of the atmosphere today is maintained by the constant erosion of limestone rocks and the decay of vegetable matter.

The composition by volume of the atmosphere is: nitrogen 78·09%, oxygen 20·95%, argon 0·93%, carbon dioxide, 0·03%, and smaller quantities of helium, krypton and hydrogen, 0·2% water vapour, traces of other gases and atmospheric dust.

Exactly what composition is necessary to support life and how far terrestial species can adapt by evolution to great changes in the composition of the atmosphere is not known. The basic essentials are oxygen, nitrogen, carbon dioxide and water.

The protective atmosphere

Apart from the atmosphere's role as the source of the gases necessary to life, it acts as a great shield against a perpetual bombardment of meteors and deadly rays and particles. Friction with the atmosphere causes all except the largest meteorites to burn themselves out before reaching the surface. Ultra-violet rays are absorbed in a layer of ozone present in the Stratosphere. Charged particles are prevented from reaching the Earth. Their contact with the atmosphere produces the aurora borealis and the aurora australis. Cosmic rays originating either from the Sun or from the outer reaches of space are likewise kept out.

Divisions of the atmosphere

For the first 80 kilometres above the Earth's surface the composition of the atmosphere is constant. Density decreases with height: at 16 kilometres it is only one-tenth of the density at sea level; at 32 kilometres it is one-tenth as dense as at 16 kilometres, and so on.

The terms Troposphere, Stratosphere, Mesosphere, Thermosphere and Exosphere have been used to describe the divisions of the atmosphere.

The Troposphere is the lowest division. Within it takes place nearly all the processes that produce weather and climate; evaporation, precipitation, movement of winds and air currents and the formation of the many types of storm etc.

Above 80 kilometres, oxygen and nitrogen molecules cannot remain associated and tend first to separate into atoms and then to be ionised into charged particles (ions) by the strong solar radiation. At the outermost limits of the atmosphere ionised helium and hydrogen dominate the very tenuous plasma (ionised gas), which, because of its electric charge, is controlled more by the Earth's magnetic field than by gravity.

The Ionosphere is the region of electrification which extends from the upper limit of the Stratosphere as far as the Thermosphere. It consists of a number of belts of radiation designated D, E, F_1 and F_2 which reflect radio waves back to Earth.

The outermost regions are now more commonly termed the Magnetosphere, the region dominated by magnetic fields. Beyond the Magnetosphere interplanetary space is dominated by the Sun's magnetic field and charged particles from the Sun – the solar wind.

Ultra-violet radiation produces concentrations of charged particles which are at their maximum in the upper part of the F_1 layer and the lower part of the F_2 layer.

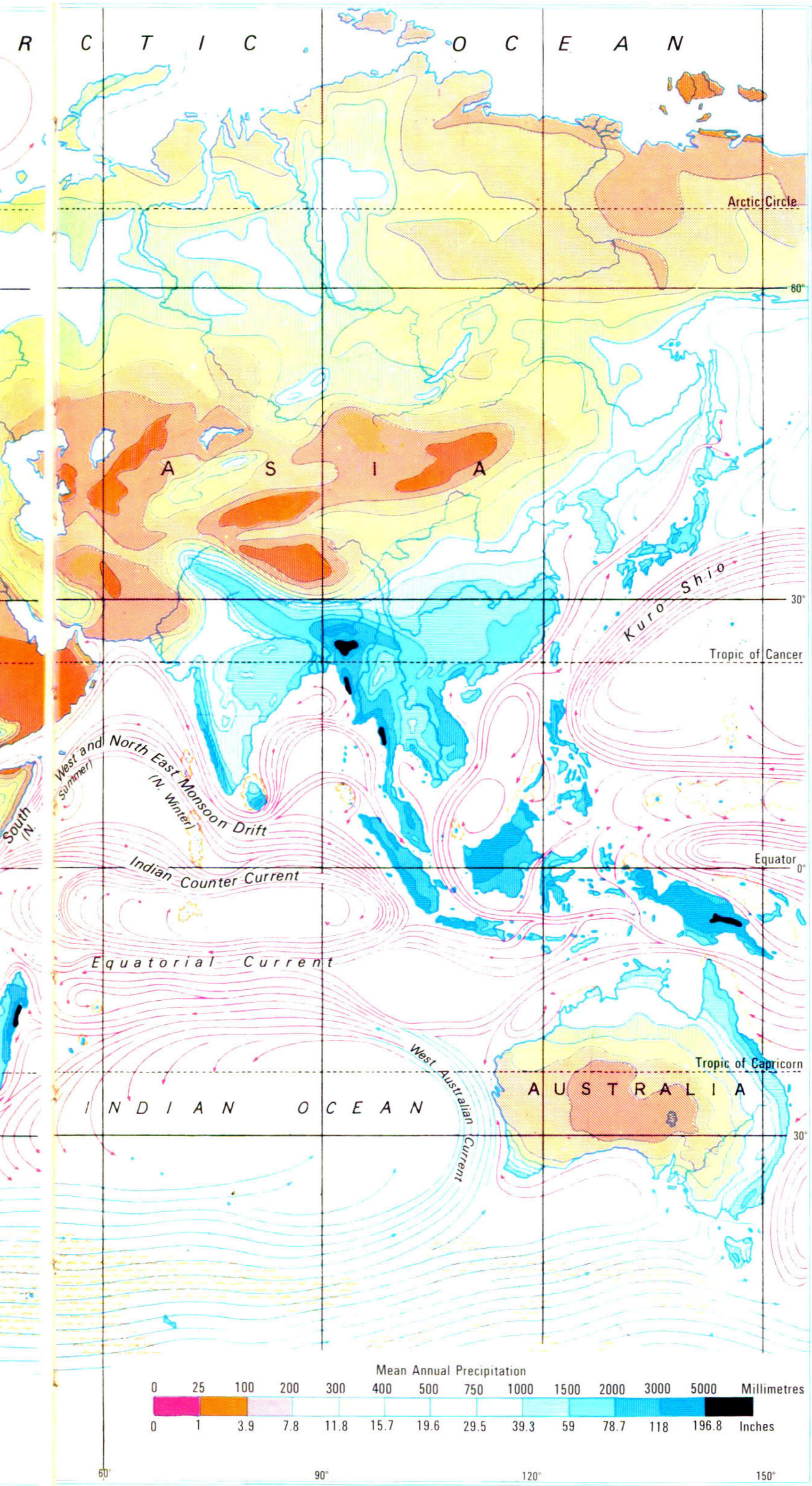
The electrification belts are not fixed at particular altitudes: light and darkness and other physical factors cause them to move up or down. At night the F layers combine to form a single layer.

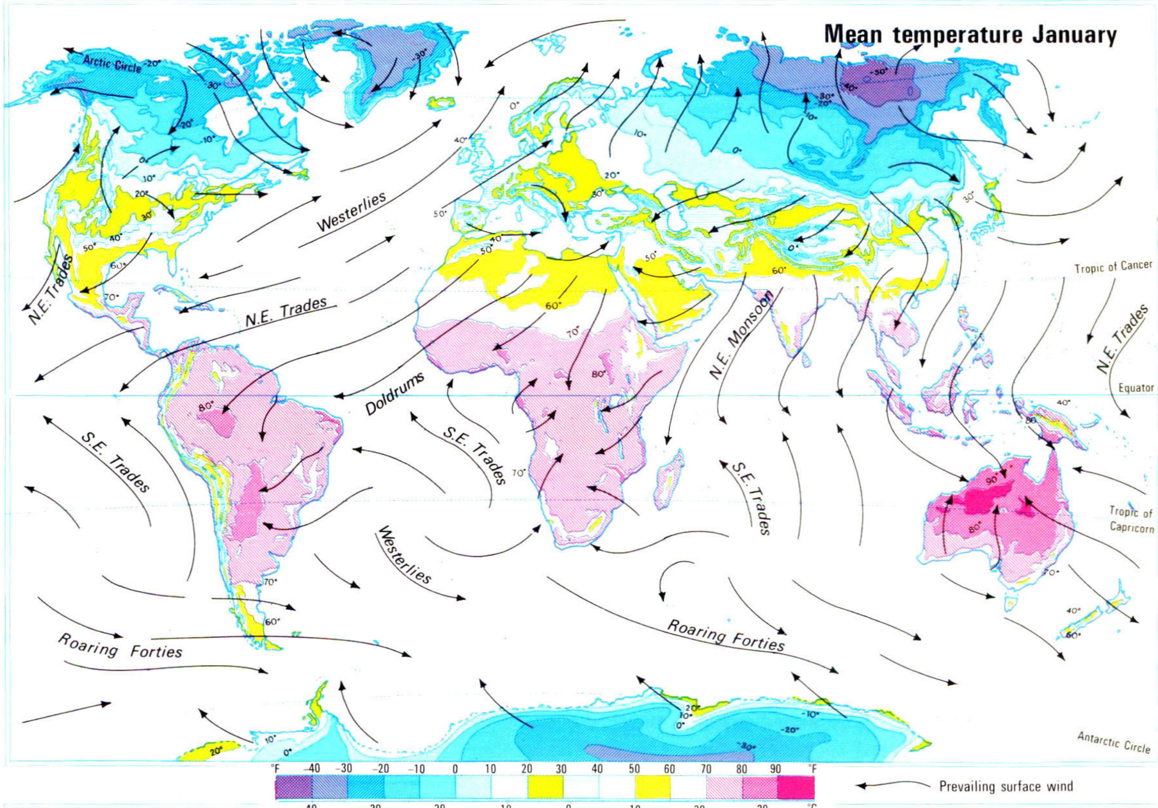
Atmosphere and the weather

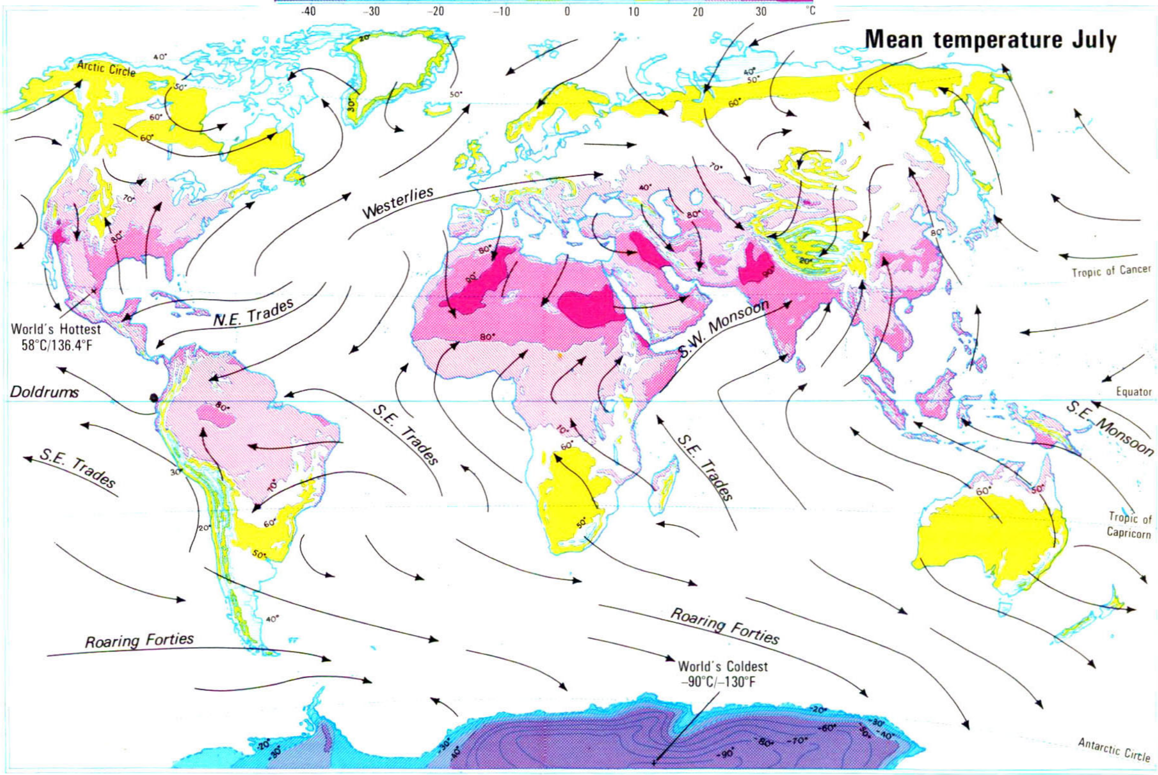
Climate of the Troposphere close to the Earth's surface may be affected by changing influences high in the atmosphere. The amount of energy that penetrates the Stratosphere appears to follow the Sun's 11 year cycle of activity by altering the percentage of ozone in the Stratosphere. It is probable that energy in the form of ultra-violet waves from the Sun produces a swing in the ozone balance changing the effectiveness of heat absorption by the atmosphere.

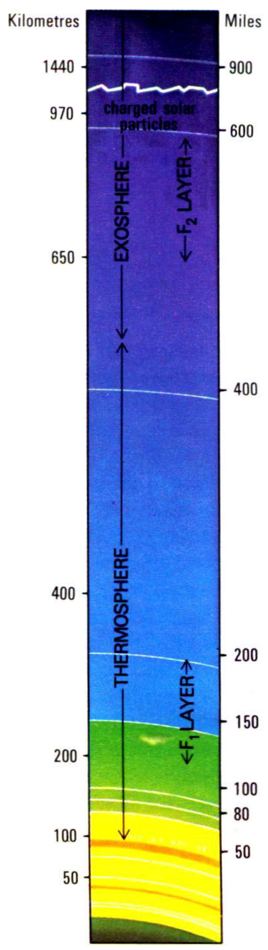
At 3,000 and 15,000 kilometres, the two Van Allen radiation belts consist of electrically charged particles which occasionally migrate into the atmosphere. These particles react with atmospheric gases to produce the auroras. There is a strong likelihood that weather patterns are thus affected in the polar latitudes.

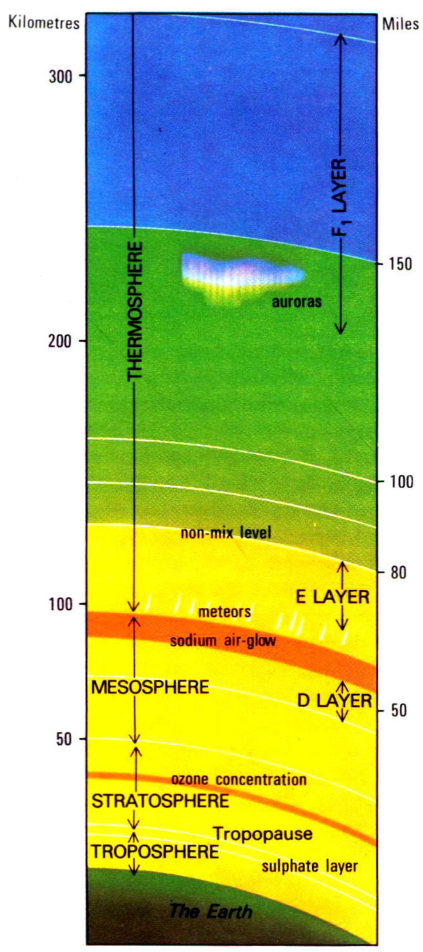
Changes in climate have been observed to coincide with changes in the Earth's magnetic field. The nature of the relationship is not known, but the extinction of species of fauna and changes in flora appear to have coincided with abrupt magnetic changes. These are identified by analysis of the direction of the magnetic field trapped within rocks on their formation.











Monitoring the World's weather

International meteorology has made great advances in the last twenty-five years profiting from technological enterprise, notably artificial satellites, high-speed computers and methods of statistical analysis.

In 1961 the United Nations recommended that the World Meteorological Organisation (WMO), undertake a study of two measures. To advance the state of atmospheric science and technology so as to provide greater knowledge of basic physical forces affecting climate and the possibility of large-scale weather modification; and to develop existing weather-forecasting capabilities and to help Member States make effective use of such capabilities through regional meteorological centres. The WMO quickly produced a report on the advance of the atmospheric sciences and application in view of space developments. After four years of discussion and study this report was accepted in the form of the World Weather Watch plan.

The idea of monitoring a global weather system requires world-wide data collection on the condition of the atmosphere and associated geophysical phenomena, its processing to establish likely future weather activity, and a telecommunications network for collection and distribution of processed information. The WMO therefore set up the Global Observing System (GOS), the Global Data-processing System (GDPS), and the Global Telecommunications System (GTS) to carry out these functions.

Details of the activities of these organisations are impressive. In 24 hours the GOS makes about 110,000 observations from 9,000 land stations, 3,000 aircraft and 7,000 merchant ships throughout the world. In remote areas automatic weather stations are being built, and special-purpose ships are being constructed to traverse data-sparse areas. The GDPS has developed its System to manage this huge amount of input information. Giant computers are installed at Melbourne, Moscow and Washington DC, and a model of global weather for the following 24 hours is produced twice a day. These analyses and forecasts are distributed visually and digitally to the 23 Regional Meteorological Centres and 100 National Met. Centres. The GTS uses telegraph, telephone, radio, cable and landlines to distribute the material at speeds of up to 7,200 words per second.

The WMO has also instigated a Global Atmospheric Research Programme (GARP), to extend the scope and accuracy of weather forecasts, and to better understand the physical basis of climate and climatic fluctuations. To do this GARP has set up a series of regional experiments, such as the Atlantic Tropical, Air-Mass Transformation, Monsoon and Polar Experiments. In late 1978 the largest experimental programme will start. Named the First GARP Global Experiment (FGGE), it will monitor the atmospheric condition of the entire globe for one year, and apply world-wide tests of existing climatic models.

Polar-orbiting and geostationary satellites will be used to collect the extensive data for this global experiment.

Water resources and vegetation

Water is essential not only to practically all forms of life but is required in enormous quantities to support our modern industrial society. The average daily consumption for each individual in the UK is about 1 cubic metre, and in the USA the figure approaches ten times this quantity. Domestic use accounts for 20 per cent of this total in the UK and 10 per cent in the US. The need to husband water supplies is obvious in arid climates, but it is only in recent years that the need to conserve water resources in areas of more abundant rainfall, has been appreciated.

Hydrological cycle

Fresh water forms only 2 per cent of the water available on the Earth's surface. Even so, this amount would be more than adequate were not the greatest reserves locked, inaccessibly, in the polar ice caps. The problem therefore, is to provide water where and when it is needed and to ensure that it is not used faster than it can be replaced. The oceans are nature's reservoirs. From them water is evaporated to fall as rain or snow over the land. From the land it returns, mostly through rivers, to the sea. This process is known as the 'hydrological' cycle (see diagram). The maximum water potentially available is therefore dependent on the amount precipitated on the land. Water conservation aims to preserve for subsequent use as much of this water as possible.

Water conservation

When rain falls over land a proportion is quickly evaporated back into the atmosphere. Apart from limited and local measures, not a great deal can be done to conserve this water, nor that which is taken up by plants and returned to the atmosphere by transpiration. Some water 'runs off' and finds its way into rivers. Here control can be exercised, by adopting agricultural methods that will prevent too rapid run-off of surface water, retaining it in the soil for the benefit of crops, or alternatively by constructing drainage channels, dams and reservoirs in which water can be stored for later use. The remainder of the rainfall will sink deep into the earth, where a proportion will be held in rock strata. Rocks with a capacity to hold water are known as 'aquifers'; water is recovered by sinking wells to them.

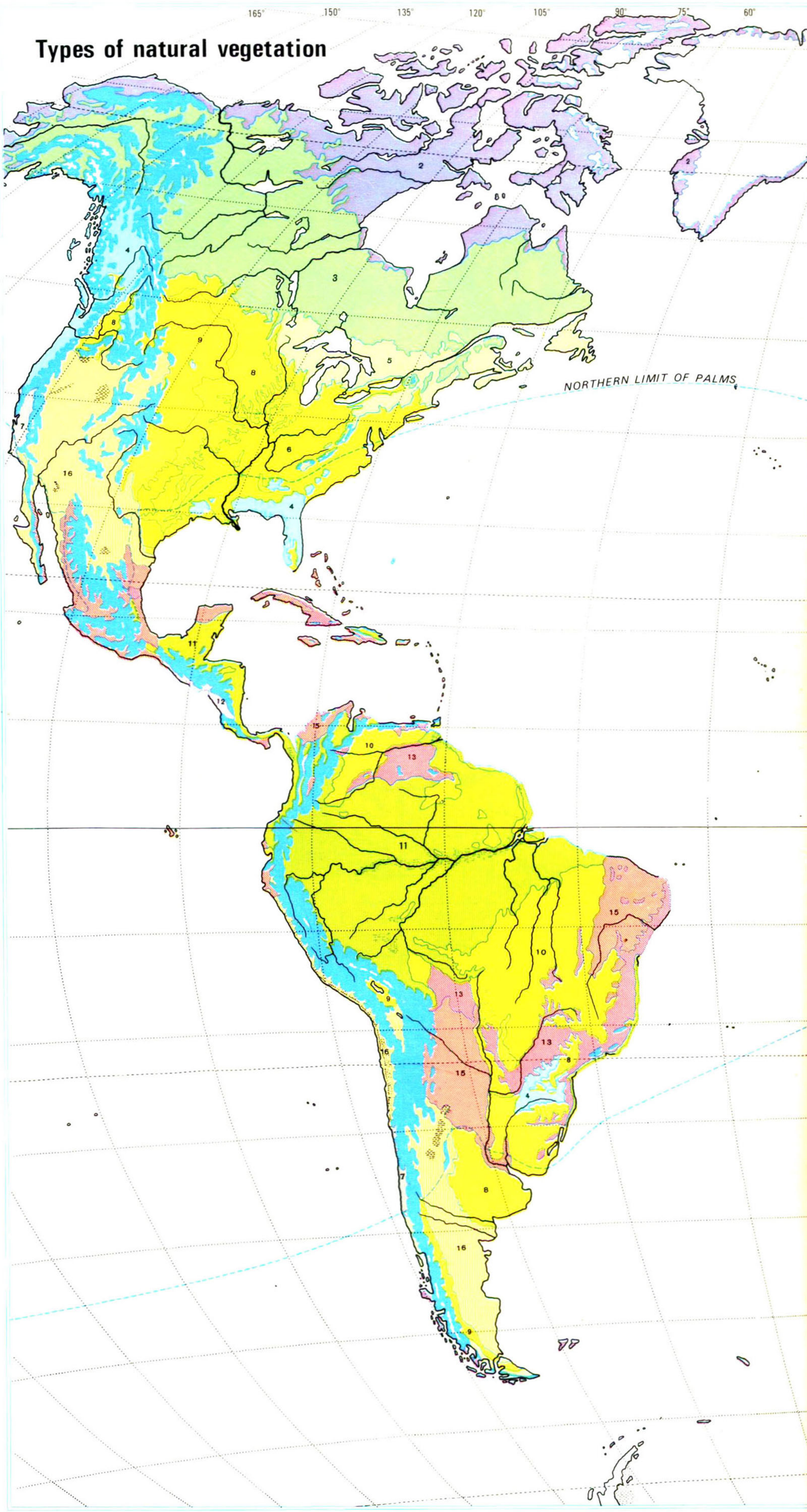
Elementary though these measures are, they provide the foundation of proper control of water resources. Modern treatments increase the water supply still further by providing for water to be re-used. Water taken for industry can be cleansed and returned to the river from which it came. Further downstream it may be taken into the public water supply, and so into a sewage system from which it is discharged clean for further use.

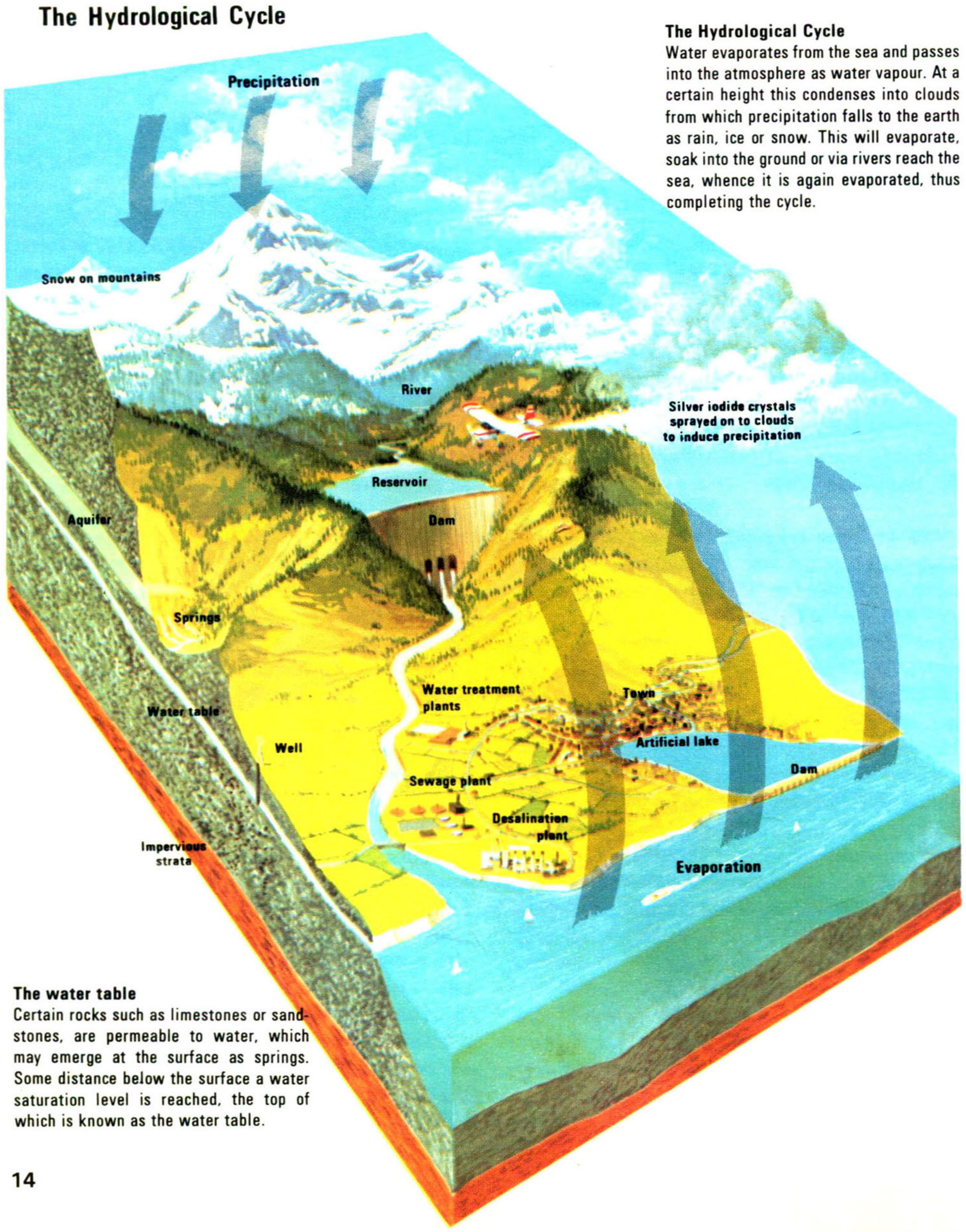
Simple water conservation techniques can assure adequate supplies for large cities situated on rivers or lakes. Thus London, Washington and Chicago rarely suffer from water shortage. For other cities, not so fortunately situated, methods must be found to bring water from elsewhere. Birmingham in the UK, for example, is supplied with water from central Wales. New York City cannot use the brackish water of the Hudson estuary, but relies on supplies from catchment areas in New York State, some of which are over 160 km (100 miles) away. This water is brought to the metropolis from 27 reservoirs through 640 km (400 miles) of aqueducts and tunnels.

Techniques similar to those used to reclaim land allow arms of the sea to be isolated for conversion into freshwater lakes.

Further possibilities of increasing the water supply bring some hope for the arid regions of the world. For many decades rain has been induced by 'seeding' clouds with silver iodide crystals. This technique has achieved success, but it is extremely costly and uncertain. It cannot succeed unless there are clouds (i.e. water vapour) in the air. More promising are schemes to obtain fresh water from the sea by desalination and this is most commonly done by distillation and freezing. Distillation plants are currently in commercial use, particularly in the Middle East, but the cost is high and the quantity of water produced is small. The use of solar energy to support distillation processes is attractive in that fuel costs are abolished. However, while solar stills have proved successful on a small scale, larger versions have not worked efficiently. Experimental desalination plants based on freezing processes are in operation in the United States, and in Britain a pilot plant of this type is to be constructed in East Anglia.

Oil-rich but arid states have also considered seriously the possibility of towing icebergs from Antarctica to serve as a water supply. Recent estimates show this operation to be comparable in cost with desalination processes.





The Hydrological Cycle
Water evaporates from the sea and passes into the atmosphere as water vapour. At a certain height this condenses into clouds from which precipitation falls to the earth as rain, ice or snow. This will evaporate, soak into the ground or via rivers reach the sea, whence it is again evaporated, thus completing the cycle.

The water table
Certain rocks such as limestones or sandstones, are permeable to water, which may emerge at the surface as springs. Some distance below the surface a water saturation level is reached, the top of which is known as the water table.

Natural vegetation

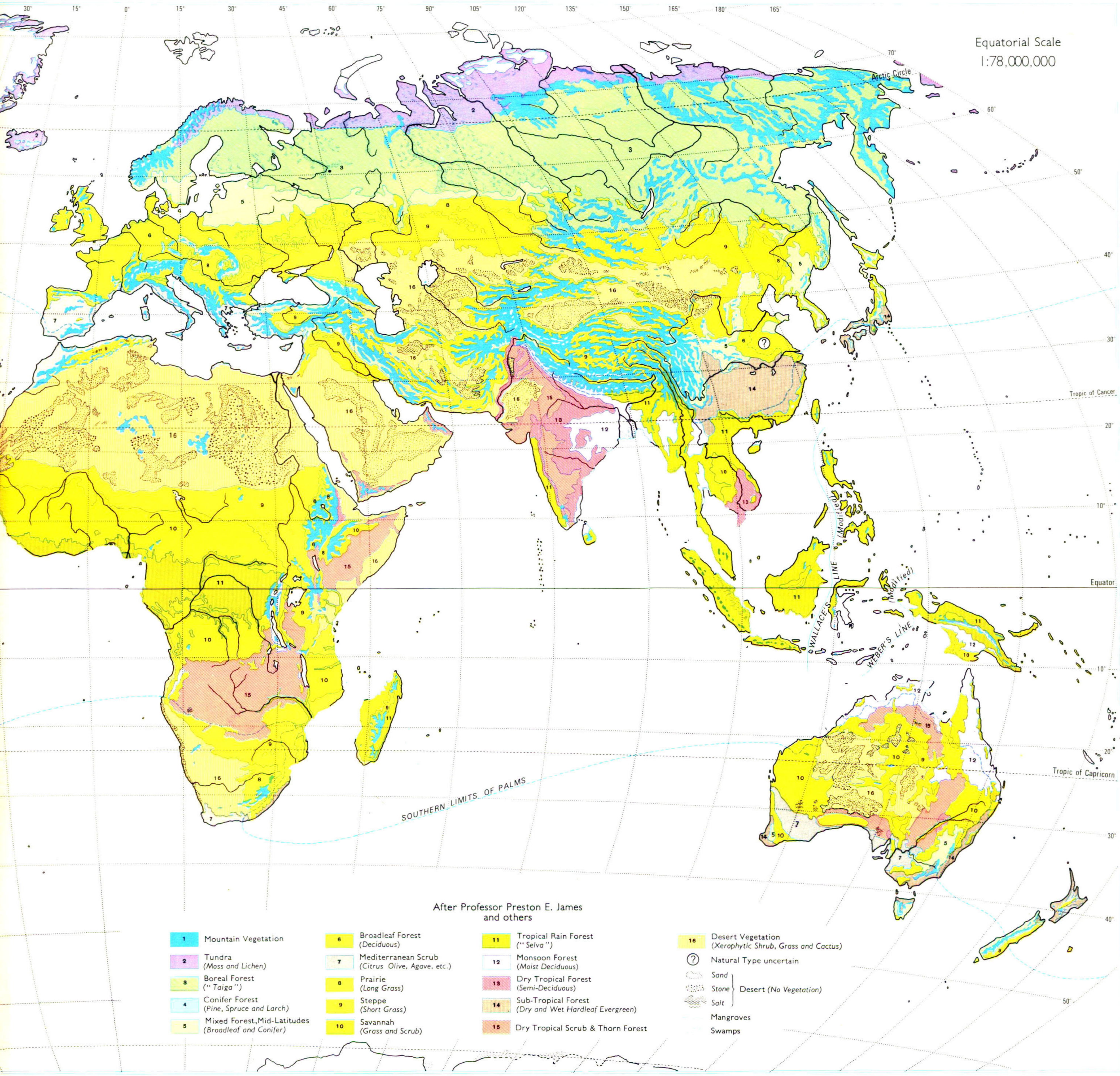
A remarkable feature of the earth's land surface is the extent to which it is covered with plant life. Though there are inhospitable areas – such as the peaks of great mountain ranges and polar ice caps – where plant life all but disappears, for the most part vegetation exists in great abundance. Natural vegetation means the type of plant cover that would occur naturally without man's interference. In western Europe, man's activities have over the centuries so altered the natural plant cover that practically nowhere does it exist in its original form. Yet there is no difficulty in defining the broad categories of plants that flourish in the conditions that prevail locally.

The map on this page displays the major categories of natural vegetation, each characterized by important features which transcend differences between individual species. These vegetation zones are in essence a response to climatic conditions, for although local conditions of soil, relief and micro-climate are all important in determining local particulars of plant cover, the temperature and rainfall conditions of climatic regions exercise substantial control over the nature of plant cover. Thus, since latitude largely determines climate, the vegetation regions north and south of the Equator tend to be a mirror image one of the other. The close relationship between climate and vegetation has provided geographers with a convenient division of the world into major regions, since the particular features of plant life of each region are distinctive.

Vegetation regions

Near the Equator climate varies little throughout the year with rainfall and temperature consistently high. The absence of seasons means that plants do not undergo a resting period, while the abundance of warmth and moisture ensures a particularly luxuriant growth. Thus the characteristic vegetation of areas such as the Amazon and Zaire basins and the islands of Indonesia is dense, almost impenetrable forest, with trees competing for light attaining great heights.

Further away from the Equator lie the tropical



grasslands. Here grass grows in abundance during the rainy season only to be withered by the sun in the ensuing drought. The sparse plant life of the world's deserts shows particular adaptations to drought conditions. Some species develop seeds which lie dormant for long periods and then, when rainfall comes, grow and complete their life cycle in the brief period in which moisture is retained in the soil. Many, including the cactus species' so typical of the arid regions of the western United States, are able to store water efficiently with little loss through transpiration.

The characteristic vegetation of much of Europe, including the British Isles, and the eastern half of the United States, is broad-leaved deciduous forest. In response to the clear climatic differences between summer and winter, trees have adapted to take fullest advantage of the favourable growing season. The broad leaf structure which allows maximum exposure to light and air means that the tree is an efficient starch-producing organ. This same adaptation renders the plant extremely sensitive to low temperatures and high winds, and thus these plants lie dormant during winter months. So precise is their adaptation that their activity is not dependent on average climatic conditions but on the likely variations from this average. In Britain the oak and ash are not tempted to unfold their leaves early in a mild spring yet imported species like the horse chestnut will do so. Most cultivated plants are imported or are 'artificial' cross-breeds and lack precise adaptation to prevailing climatic conditions. They need protection by shelter or irrigation or removal of other competitive plants if they are to flourish.

North of the regions of the broad-leaved deciduous forest flourish the conifer forests. In the United States they are developed particularly well in the north-western states. The trees that form these forests are much better adapted to withstanding unfavourable conditions and include the world's most magnificent specimens, in particular the giant redwood trees, which grow to greater heights than any other tree except the eucalyptus. These forests are of substantial economic importance and provide over 30 per cent of timber needed by the USA.

Climatic variations

We are now in an interglacial period within which minor climatic variations have occurred. Some 3,000 to 4,000 years ago climate in the British Isles was drier, with greater temperature variations between summer and winter so that hazel and birch flourished more than they do now. There is considerable evidence that land bordering the Sahara desert is drier now than it was 2,000 or so years ago, for plants grew more abundantly then, and in north Africa wheat was grown for the Roman Empire in regions which are now semi-desert. Some of this decline is undoubtably due to unwise farming methods, which have resulted in the loss of topsoil, or to clearance of the natural plant cover to grow crops. A wealth of evidence now shows that both Sahara and Gobi deserts spread towards the Equator when the climate cools slightly – as it has since the 1950s. This, plus overgrazing, is the cause of recent droughts in the Sahel (the region bordering the Sahara to the south), in Ethiopia, and in Somalia and north-east Kenya.

Although we are concerned mainly with the broad characteristics of the plant life of the major vegetation zones, we should not ignore the strange variations that occur, as species adapt to local conditions. The vegetation of the Everglades in Florida displays a remarkable adaption to the swampy conditions that prevail there, while along tropical coasts mangroves grow and with their preponderance of stilt-like roots keep a firm hold on the shifting ground beneath. These roots, the upper parts of which are exposed at low tide, have pores through which the plant can take oxygen, since there is little oxygen in the muddy water below, where organic matter is decomposing.

Precise adaptation of particular species to local conditions has been turned to economic advantage. A few species flourish abnormally well where certain minerals are present, and by study of these 'indicator plants', deposits of copper and other ores have been traced in many parts of the world.

Minerals and their uses

Gold

Precious metal and principal international reserve asset underwriting the means of exchange. Used in manufacture, medicine and fabrication for its special corrosive resistant properties. It does not tarnish and is unaffected by most acids. It weighs about two and a half times as much as steel and is very malleable and ductile. Thus it can be hammered to an extremely thin sheet or drawn into the finest of metal wires. Gold is an excellent conductor of electricity. Applications vary from jewellery and coinage to dentistry and electronic circuitry. Over 70 per cent of free world production comes from South Africa. Other producers include North America, USSR, Australia and central Africa. Non-communist output totals over 1,027,000 kilograms annually. For every million parts of ore about 13 parts of gold are extracted.

Silver

Precious metal of wide industrial usage and reusage. Mine production is around 9,230 tonnes of new silver, to serve both speculative and industrial markets, which include photography and the decorative arts as well as coinage. Main producers include North America, Mexico, Peru and Australia.

Platinum

Often a by-product of copper-nickel mining, a precious metal of catalytic properties in, e.g., making nitric acid. Provides long-lasting protective coatings which are used in chemical, electrical, petroleum, glass and electronic industries. Main producer is South Africa, with 70 per cent of output, in meeting world demand of 1·4m troy oz. USSR and Canada also substantial producers. Platinum metals include Iridium, Rhodium, Palladium, Osmium, Ruthenium. Future demand may be affected by anti-pollution use in reforming petroleum.

Diamond

Precious stone of pure carbon formed at depth under pressure and temperature and then extruded in Kimberlitic rock pipes and dykes – coveted for rarity and qualities such as hardness, cutting and abrasive properties. World output of diamonds for industrial purposes 32,400 metric carats. Gemstone production is just over 13,500 metric carats. Over twenty countries produce diamonds with the bulk of output coming from Zaire, South Africa and the USSR. World synthetic diamond output is over 45 million metric carats.

Copper

One of the oldest known and most exploited metals, the mineral in refined form is used widely through the whole spectrum of industry, half going to electrical and telecommunication sectors. Other big areas of consumption are in general engineering and building components. Its main properties are its capacity as a conductor of heat or electricity, its ductile nature which allows it to be drawn into fine wire, and its value in alloys with zinc and tin. Bronzes are largely copper-tin alloys. Brasses are alloys of copper, zinc and tin. Copper deposits occur in the oceans and promise to extend the life of copper when continental deposits are nearing exhaustion. Total refined output varies because of market conditions, but is now nearly 8 million tonnes. Top producers are USA, USSR, Chile, Zambia, Canada, Zaire, Peru and Australia, with about 20 other significant sources.

Tin

Soft silver-white corrosion-resistant metal used primarily as a coating for steel sheets used in food canning; has strong resistance to atmospheric tarnishing. Widely used in alloys, notably the brasses and bronzes, brazing materials and solder. World consumption is 197 million tonnes, mainly by USA, Japan, UK, Germany and France. Main sources are Malaysia, Bolivia, Thailand and Indonesia. Also mined in Australia, Nigeria, Zaire and Brazil. Total mined output is 181 million tonnes. Prices are subject to international marketing agreements because of importance of material (8 industrial countries account for 80 per cent of consumption).

Lead and Zinc

Major metals smelted from mines to meet consumption of more than 5·5 million tonnes of zinc and over 3·4 million tonnes of lead. Large stocks are kept in Europe, North America and USSR. Zinc is used in die castings for cars, and for brass and galvanizing iron and steel. Also used as a pigment in paints, chemical manufacture and metallurgical processes. Non-ferrous lead goes into production of batteries, and as additive for gasoline; main producers of refined lead are in North America and Europe, while mine production is led by the Americas, Oceania, USSR and Africa. Zinc production is dominated by North America, Europe and socialist countries.

Steel Metals

These include nickel, manganese, chromium, cobalt, molybdenum, tungsten, vanadium, columbium and tantalum, all offering specific qualities and properties for making special steels. Nickel, for example, is essential for making high quality stainless steel, which takes 40 per cent of consumption. Chromium is also necessary for the production of stainless steel. Tungsten is added to steel to produce high grade steels which can be hardened in air instead of water. Manganese is added to iron to produce castings which are not brittle. Base material of steel is iron ore, production of which rises steadily and in 1974 reached 507 million tonnes. The world's biggest producer of iron ore is USSR with around 123 million tonnes. Other big suppliers are Australia, Brazil, China, France, India, Liberia, Sweden and North America (90m tonnes). Ore is sold in lump, sinter and pellet forms for transportation to blast furnaces.

Aluminium

Primary aluminium (which, with titanium and magnesium, is a principal light weight metal) depends on production of bauxite amounting to 78 million tonnes annually. Nearly a fifth of bauxite comes from Jamaica. Other major sources are Australia, USSR, Surinam, Guyana, France, Guinea and Hungary. The USA accounts for about half of the Free World consumption; most primary aluminium goes into fabrication of industrial products made from plate, strip and wire. Alloyed with manganese or titanium, it offers tensile properties combined with lightness. World primary aluminium output is over 13 million tonnes led by North America, USSR, Japan and Norway.

Nuclear Metals

The most important of these is uranium. They include thorium, beryllium, zirconium and hafnium, caesium and ribidium, and rare earths. Development of nuclear power and related industries has expanded the search for and production of the various metals. Uranium production is around 18,500 tonnes a year.

Mercury

Liquid metal with volatile properties, known as quicksilver, derived from cinnabar. Mercury is used in scientific instruments and in chemicals, particularly in the production of chlorine and caustic soda. World mine output is 92 million tonnes. Leading sources are Spain, North America, Italy, Mexico, China, USSR and Yugoslavia.

Cadmium

A soft silvery-white metal occurs together with zinc. Mainly used in plating processes, as a pigment for plastics, for television phosphors and for nickel-cadmium batteries. It is also used for control rods in atomic nuclear reactors. The largest commercial producer is the USA. Total output is well over 10m lbs a year.

Rhenium

Derived from copper ores with molybdenite, this metal has a melting point exceeded only by tungsten. Its outstanding ductility, high temperature strength and corrosion resistance makes it an alternative for platinum as a petrochemical catalyst. Used for camera flash bulb filaments and for alloys. Main sources are Chile. USA, USSR and Sweden. Other electronic metals and minerals are indium, selenium, tellurium and mica.

Phosphate Rock

Universally mined phosphoric material with widespread usage in chemical processes. Output is in excess of 117 million tonnes.

Potash

An alkaline substance used for fertilizers and other chemical synthesis. World production is 24·2 million tonnes, with North America, USSR, Germany and France the leading sources.