Planet Earth in a Nutshell

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Biman Basu

VIGYAN PRASAR

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Foreword

Earth is the only planet we know of with life on it. Animals, Plants and microorganisms maintain a delicate balance with a variety of life forms we call Biodiversity. Each species depends on other species for its existence. When we talk of life on earth, we also talk about the human species. If we need to understand and preserve our environment, we shall need to understand the interdependence of the species on each other and the importance of natural resources like air, water and soil for living beings.

Life has continued to evolve on this earth over millions of years adapting to changing environment. Only those species have survived that have adapted to the changing environment. This change could be due to natural causes like earthquakes, eruption of volcanoes, cyclones, and so on. It even could be due to climate change. However, quite often this change is brought about by the species higher up in the ladder of evolution that tries to control environment to suit its needs and for development. This is precisely what human species has done to our fragile planet.

We need energy for development; which we traditionally obtain by burning natural resources like firewood, coal and petroleum. This is what we have been doing for centuries. Today there is consensus that human activities like burning of fossil fuels and consequent pumping of gases like carbon dioxide into atmosphere have been responsible for the earth getting hotter and hotter. Today, there are threats to our planet arising from climate change, degrading environment, the growing rate of extinction of species, declining availability of fresh water, rivers running dry before they can reach sea, loss of fertile land due to degradation, depleting energy sources, incidence of diseases, challenge of feeding an exponentially growing population, and so on. The human population is now so large that the amount of resources needed to sustain it exceeds what is available. Humanity's environmental demand is much more that the earth's biological capacity. This implies that we are living way beyond our means, consuming much more than what the earth can sustain.

To draw the attention of the world to these aspects and in an attempt to establish that environment is where we live; and development is what we all do in attempting to improve our lot, within that abode, the United Nations has declared the year 2008 as "The Year of the Planet Earth". It is hoped that with the cooperation of all we shall be able to save the biodiversity and the life on this planet. A host of activities and programmes are being organized all over the world for this purpose. One of the important aspects is to make people aware about the challenges we face and the possible solutions to save this planet from heading towards catastrophe. It is with such thoughts that Vigyan Prasar has initiated programmes with activities built around the theme "The Planet Earth". The activities comprise of development and production of a series of informative booklets, radio and television programmes, and CD-ROMs; and training of resource persons in the country in collaboration with other agencies and organizations.

It is expected that the present series of publications on the theme "The Planet Earth" would be welcomed by science communicators, science clubs, resource persons, and individuals; and inspire them initiate actions to save this fragile abode of ours.

Vinay B. Kamble
Director, Vigyan Prasar
New Delhi

Preface

Of all the planets of the Solar System, our Earth is unique. It is the only planet known to harbour life of a wide variety – from the simplest one-celled organisms to the most complex ones like human beings. The origin of Earth has always been a mystery for humans. According to the currently accepted theory our Solar System began as a spinning cloud of gas and dust – with an initial mass only 10 to 20 percent larger than the present mass of the Sun – sometime between 5,000 million and 4,600 million years ago. As the cloud contracted under force of gravity, the atoms got closer together and became denser. The spinning cloud eventually flattened out, with a bulge in the middle from which the Sun was born. Over time, materials in the disc around the Sun turned into solid, dust-like particles, which grew in size by accretion and eventually formed the planets.

After formation some 4,500 million years ago, the Earth has undergone several upheavals in its structure to come to its present shape. The continents that we see today were not there always; they have been in constant motion for hundreds of millions of years. The violent activities inside Earth also gave rise to many of our most valuable resources like coal, oil, and natural gas.

The first life forms – bacteria-like organisms – appeared on Earth some 3,500 million years ago. The blue-algae, or cyanobacteria, were the first photosynthesising organisms that brought life-giving oxygen to Earth's atmosphere making proliferation of life possible and leading to the appearance of the first modern humans some 120,000 years ago.

In this book an attempt has been made to present an overview of Planet Earth, from its origins to its evolution over aeons and the impact of humans on Earth's biosphere and natural resources and looks at the possibilities of stopping further degradation of Earth's ecosystems with effective use of the new knowledge of natural and human history.

I am grateful to Dr. V.B. Kamble and Shri B.K. Tyagi for giving me the opportunity to write this book. I am also indebted to Shri Pradeep Kumar for making an excellent job of page layout for the book.

Biman Basu

1

Third Rock from the Sun

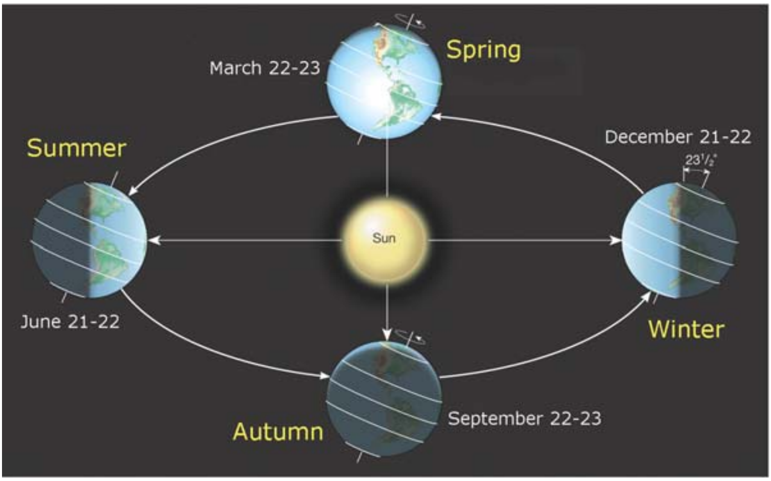
Of all the planets of the Solar System, our Earth is unique. It is the only planet known to harbour life of a wide variety – from the simplest one-celled organisms to the most complex ones like human beings. All the planets of the Solar System have now been explored by spacecraft and we know that nowhere else does liquid water, which is essential for life, exist. Nowhere else can one enjoy the scenic beauty that we see on this planet. There are mountains and volcanoes on other planets, but they do not evoke the joy and awe as they do on Earth. What makes our planet so different from the others?

At the root of all this is a singular combination of factors not found in case of any other planet. Our Earth happens to be at just the right distance from the Sun; it is neither too close nor too far away. Had it been a little closer to the Sun it would have been too hot for life. On the other hand, if it were a little farther away it would have been too cold. Distance from the Sun is also the key factor that makes Earth the only planet with liquid water on the surface. Water is vital not only for the biosphere – the part of the Earth where life exists – but also for the geologic processes of erosion, transport, and deposition that shape the Earth's surface. Yet, if the Earth were closer to the Sun, the water would have vaporized; if it were farther, water would turn to ice.

Earth from space. Earth is the only planet that has liquid water.

Earth's orbit is not a perfect circle, rather it is oval shaped. The average distance of Earth from the Sun is 150 million kilometres, but the Earth comes closer to the Sun in early January (when it is winter in the Northern Hemisphere) and moves about 5 million kilometres farther away in July. Earth travels in its orbit at 107,000 kilometres an hour, or 30 kilometres a second, taking 365 days 6 hours 9 minutes 9.54 seconds to circle the Sun once.

The Earth also spins on its axis that causes the cycles of day and night, but it does not spin on a vertical axis. The Earth's rotational axis is tilted by about 23.5 degrees to the orbital plane. It is because of this tilt in axis that we have change of the seasons as the Earth goes around the Sun, and the heating and cooling caused by the tilt of Earth's axis has greater effect on the seasons than the distance from the Sun.



The tilt of Earth's axis produces the seasons, as it goes round the Sun.

The distance of Earth from Sun is crucial for its evolution as an abode of life, but merely being at the right distance would not be not enough. Even at the present distance our planet would have been freezing cold were it not for the presence of an atmosphere containing carbon dioxide and water vapour. These are the gases that by trapping heat create greenhouse effect to keep Earth at a temperature comfortable enough for living organisms to evolve and survive. As the saying goes, too much of anything is bad, and the danger that our planet is facing today is due to too much of greenhouse effect, which is making the Earth hotter and threatens to jeopardise the climate system with serious long-term consequences. But that is not the topic of this book. Here we shall talk mainly about the Earth, from where it came, its structure, the geological processes that shaped it, and, of course, the origin and spread of life.

When did the Earth form?

There have been many theories about the origin of the Earth. One of the earliest theories was put forward by the German philosopher Immanuel Kant in 1755, which was later revised by French mathematician Pierre-Simon Laplace. Known as the 'Nebular hypothesis', it proposed that the planets were formed out of a cloud of material as it collapsed under the force of gravity and started spinning into a flattened disc. The Sun and the planets formed out of these spinning disks.

Around 1900, American astronomer Forest Ray Moulton and geologist Thomas Chrowder Chamberlain, along with Sir James Jeans and Sir Harold Jeffreys of England, independently developed a theory according to which the planets were formed 'catastrophically'; that is, by the close encounter of the Sun with another star. According to them, when a star ten times bigger than the Sun passed near the Sun, a cigar-shaped mass of material was drawn out from the solar surface. As the passing star moved away, the material separated from the solar surface continued to revolve around the Sun and over a period of time, slowly condensed into planets.

All of these theories of the origin of Earth explained some observations of the objects in our Solar System and their motions, but all of them had shortcomings. Some predicted a Sun that spins much faster than our Sun really does. Others relied on the extremely unlikely chance encounter of a massive star. Some could not account for the positions of the planets or their roughly circular orbits.

The next significant development occurred during the middle of the 20th century, as scientists better understood the processes by which stars formed and learnt more about the behaviour of gases under the conditions prevailing within stars. This knowledge led to the realization that hot gases stripped from a stellar atmosphere would simply dissipate in space; they would not condense to form planets. Hence the basic idea of Solar System having been formed as a result of stellar encounters was physically impossible.

It was around this time that scientists who were developing theories about the origin of the Solar System began to have a new source of data: the chemical composition of cosmic objects. The Nobel prize-winning chemist Harold Urey studied the chemicals that made up meteorites and concluded that these objects contained material that had changed very little since the early history of the Solar System. Most of the evidence that scientists have been gathering for more than 50 years about the Sun and the planets related to the chemical composition of these objects. The scientists believed that very specific chemical information could provide clues to how the planets were formed. This awareness prompted scientists to reconsider certain basic processes that were similar to some of the earlier notions of Kant and Laplace.

Born in a cloud of gas and dust

The currently accepted theory of the origin of the Sun and the planets is based on the data gathered over the last four centuries. According to this theory our Solar System began as a spinning cloud of gas and dust – with an initial mass only 10 to 20 percent larger than the present mass of the Sun – sometime between 5,000 million and 4,600 million years ago. This cloud was mostly made of atoms of hydrogen and helium with very small amounts of heavier elements from debris of older stars. As the cloud contracted under force of gravity, the atoms got closer together and became denser. The spinning cloud eventually flattened out, with a bulge in the middle. Gravity caused the material in the centre of the disc to keep contracting and it began to heat up because potential energy was converted into kinetic energy. Scientists estimate that this process continued for about 50 million years until the temperature at the centre was high enough – a few million degrees Celsius – for the nuclear fusion of hydrogen into helium to begin. It was at this stage that the Sun was born.

Birth of the Solar System 4,600 million years ago. The Earth was born some 100 million years or so after the birth of the Sun.

The early Sun still had material falling into it. This process caused temperatures near the centre of the disc to reach very high levels. After a few thousand years, the Sun and the rest of the disk began to cool off. Of course, as you would have guessed, the edge of the disk would have been much cooler than the centre of the disc because of its great distance from the hot Sun.

Over time, materials in the disc around the Sun turned into solid, dust-like particles. These first dust grains were fluffy, like snowflakes. As they moved around the Sun, they occasionally bumped into each other and stuck together by chemical and physical forces. Eventually, enough of the particles stuck together to form small chunks. These chunks attracted each other due to gravity and clumps of them coalesced together to form large objects. Through continued collisions and gravitational effects, these objects gradually grew into the planets we see today. Rocky dust particles containing metals and other heavier elements formed closer to the Sun and created the terrestrial planets – from Mercury to Mars – our Earth being the third from the Sun. Icy particles containing water and frozen gases such as ammonia and methane formed nearer the outer edge of the Solar System where the temperatures were lower. Scientists estimate that this process took a few hundred thousand years.

According to present estimates, formation of the inner planets, including the Earth and the Moon, was essentially complete within 100 million years after the interstellar cloud collapsed. So, according to the modern theory our Earth was formed some 4,500 million years ago; that is, some 100 million years or so after the birth of the Sun.

Early Earth

The early Earth was very different from the world we know today. There were no oceans, no oxygen in the atmosphere, and no living beings. Rocks and other material left over from the formation of the Solar System were constantly raining down from sky. As a result of this bombardment and heat generated from radioactive decay within the Earth, and from the pressure of contraction, Earth at this stage was extremely hot and fully molten. Heavier elements sank to the centre while lighter ones rose to the surface, producing Earth's various layers.

Earth's early atmosphere was most probably made up of gases from the solar nebula, especially light gases such as hydrogen and helium, but the solar wind and Earth's own heat would have driven off this atmosphere.

As the Earth cooled and shrunk, gravitational attraction became strong enough to retain an atmosphere which included water vapour. The surface cooled quickly, forming the solid crust within a span of some 100 million years. Between 4,000 million and 3,800 million years ago, as the Earth underwent a period of heavy bombardment by asteroids, steam escaped from the crust while more gases were released by volcanoes, making up an atmosphere made up mostly of nitrogen, carbon dioxide, carbon monoxide, and water vapour, possibly, with small amounts of methane and ammonia. Any free oxygen in the atmosphere at this stage would have been bound by hydrogen or minerals on the surface. As the temperatures dropped further, clouds formed and condensed and fell as rain. In some places the surface remained so hot that the rains kept evaporating back into water vapour as quickly as they fell.

The early Earth was so hot that the rains kept evaporating back into water vapour as quickly as they fell.

As time passed rocks on the surface absorbed most of the first rains. As torrential rains continued, waters collected in vast basins and became the first seas. According to some planetary scientists, comets impacting the Earth during its first few hundred million years could have deposited enough water to cover the Earth's surface to a depth of 6 metres. This happened some 3,800 million years ago. But without oxygen and an ozone layer to shield against ultraviolet radiation, the Earth was not yet fit for life.

Comets impacting the Earth during its first few hundred million years could have deposited enough water to cover the Earth's surface to a depth of 6 metres, forming the earliest seas.

Dynamic planet

After its birth some 4,500 million years ago, the Earth has not remained the same. It has undergone several upheavals in its structure to come to its present shape. The continents that we see today were not there always; they have been in constant motion for hundreds of millions of years. The world's tallest mountain range, the Himalayas, rose from under the sea some 50 million years ago. Volcanic activity, earthquakes, winds and tidal waves have been constantly acting, shaping and reshaping Earth's surface.

The violent activities inside Earth also gave rise to many of our most valuable resources like coal, oil, and natural gas. Rocks formed by geological processes form a key ingredient of our economy. They provide mineral resources, building materials, and the raw materials for industrial processes and for pottery. Valuable gemstones and the rare elements needed for high-tech applications are also extracted from rocks.

The enigma of the atmosphere

One of the unique features of our planet is its life-sustaining atmosphere. A key ingredient of Earth's present atmosphere is oxygen on which the majority of the living organisms depend for existence. None of the other planets of the Solar System has enough free oxygen in its atmosphere to be measurable. On Earth also, free oxygen was not always present in the atmosphere although it is now known that oxygen was present in rocks as oxides from the time of their formation, thousands of millions of years ago. Free oxygen came into the atmosphere only about 700 million years ago, after the appearance of green plants. The presence of plants is believed to have altered Earth's climate and paved the way for the evolution of land animals. According to data now available, green plants would have been growing on land well before the sudden appearance of many new species of animals that occurred about 530 million years ago, an event called the 'Cambrian Explosion'. The apes and humans appeared on Earth much later.

2

Layers of the Earth

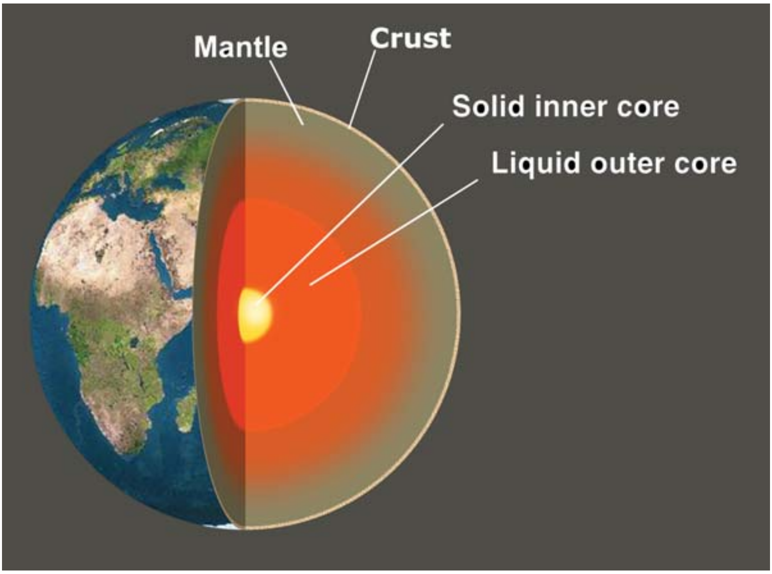
In his 1864 adventure classic *Journey to the Centre of the Earth*, the French writer Jules Verne narrates a thrilling travelogue of a professor, his nephew, and a guide down an extinct volcano to the interior of the Earth, their encounter with strange animals and natural hazards, and their ultimate return to the surface again somewhere in southern Italy. Of course, the story is pure fiction – there are no prehistoric animals in the Earth's interior and human beings would not withstand the heat – but the story did raise public curiosity to know about the interior of our planet.

Most people picture Earth as a sphere with the North Pole at the top and the South Pole at the bottom. But our Earth is not perfectly round; its spin causes it to bulge slightly at its middle, the equator. The diameter of Earth from North Pole to South Pole is some 12,713 kilometres; it is slightly more than 12,756 kilometres across at the equator. The difference is too tiny to be easily seen in pictures of Earth from space, so the planet appears round. Earth's bulge also makes the circumference of Earth larger around the equator than around the poles. The circumference around the equator is some 40,075 kilometres, whereas around the poles it is about 67 kilometres less.

Earth ranks fifth in size among the eight planets of the Solar System. Jupiter, the largest planet, is about 11 times larger in diameter than Earth. Mercury, the smallest planet, has a diameter a little over one-third that of Earth.

Earth's spheres

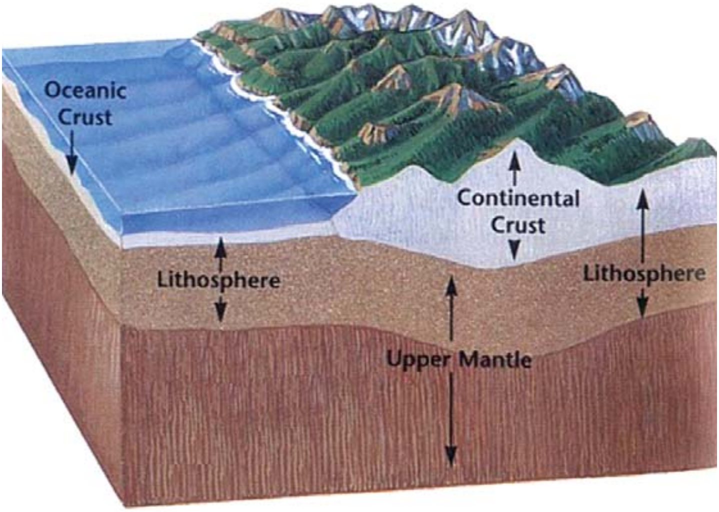
More than 90 percent of the Earth's mass is composed of iron, oxygen, silicon, and magnesium – elements that can form the crystalline minerals known as silicates. Although the Earth beneath out feet appears like solid rock, it is not like this all the way down to the centre. In fact, the Earth is composed of several layers, or spheres, somewhat like the layers of an onion. Each of these layers has its own properties. The outermost layer of the Earth is the crust, composed mainly of compounds of aluminium and silicates. The next layer is the mantle, which is composed mainly of rocks containing iron and magnesium



The Earth is composed of several layers, or spheres, somewhat like the layers of an onion.

silicates. The crust and the upper portion of the mantle are together known as the 'lithosphere'. The innermost layer is the core, which is separated into the liquid outer core and the solid inner core, made up of mostly iron and nickel.

On the surface, much of Earth is covered by a layer of water or ice called the 'hydrosphere'. The thin layer of air that surrounds the Earth is the 'atmosphere'. The portion of the hydrosphere, atmosphere, and solid land where life exists is together known as the 'biosphere'.



The crust and the upper portion of the mantle are together known as the lithosphere.

If the Earth were reduced to a tabletop globe 50 centimetres in diameter, the greatest depth which scientists have been able to reach for direct observation would be the equivalent of less than 1 millimetre thick. It is therefore not surprising that scientific investigators did not develop a picture of the Earth's interior until well into the 20th century, and only since the 1960s have they come to understand the dynamic processes that shape the Earth's surface.

The crust

The Earth's crust is like the skin of an apple. It is very thin in comparison to the other three layers. The crust is up to 10 kilometres thick under the oceans (called oceanic crust). The crust under the continents (called continental crust) extends down to 35 kilometres on average, but below the Himalayas it extends up to some 75 kilometres below. Most of the Earth's oceanic crust was made through volcanic activity. That is why, rather than being flat plains eroded by millions of years of water action, the ocean floors exhibit many of the same features, such as valleys and mountains that occur on land. The mid-oceanic ridge system, a 40,000-kilometre long network of volcanoes and fissures, generates new oceanic crust at the rate of 17 km^3 per year, covering the ocean floor with an igneous rock called basalt. Hawaii and Iceland are two examples of the accumulation of basalt islands.

Continental crust is composed essentially of crystalline rocks. These are low-density buoyant minerals dominated mostly by quartz (SiO_2) and feldspars (a kind of silicates). The temperature of the crust varies from air temperature on top to about 870 °C in the deepest parts of the crust where rocks begin to melt.

The Earth's crust is composed of two basic rock types – granite, which is hard and crystalline, and basalt, which is much denser, solidified lava. The continental crust is composed mostly of granite, while oceanic crust mostly consists of basalt. Because basaltic rocks of the ocean plates are much denser and heavier than the granite rock of the continental plates, the continents actually 'float' on the denser oceanic plates.

The crust of the Earth is broken into many pieces called 'plates'. The plates 'float' on the soft, plastic mantle that lies below the crust. The layer below the rigid lithosphere is a softer zone of asphalt-like consistency called the 'asthenosphere'. The asthenosphere is the part of the mantle that flows and moves the plates of the Earth. These plates usually move along smoothly but sometimes they stick and build up pressure at the boundaries where they meet. When the pressure becomes too high the rock bends until it snaps, causing an earthquake.

The mantle

The mantle is the layer beneath the crust which extends about half way to the centre. It is about 2,900 kilometres thick and is made of solid rock but behaves like an extremely viscous liquid. The mantle is where most of the internal heat of the Earth is located. It also forms the bulk of the Earth, accounting for two-thirds of our planet's mass. Scientists divide the mantle into two layers separated by a wide transition zone around a depth of about 480 kilometres. The lower mantle lies below that zone.

Unlike the crust, which is mostly hard rock, the mantle is a highly viscous plastic-like material that can flow. It is made of molten silicate rocks rich in iron and magnesium, and can be compared with a boiling cauldron. In fact, the molten mass in the mantle is in constant motion. There are cooler and warmer sections of the mantle that are in constant flux with one another, setting up powerful upward convection currents in the molten mass. It is these currents that make the continental plates move, in a process known as 'continental drift'. More of that later.

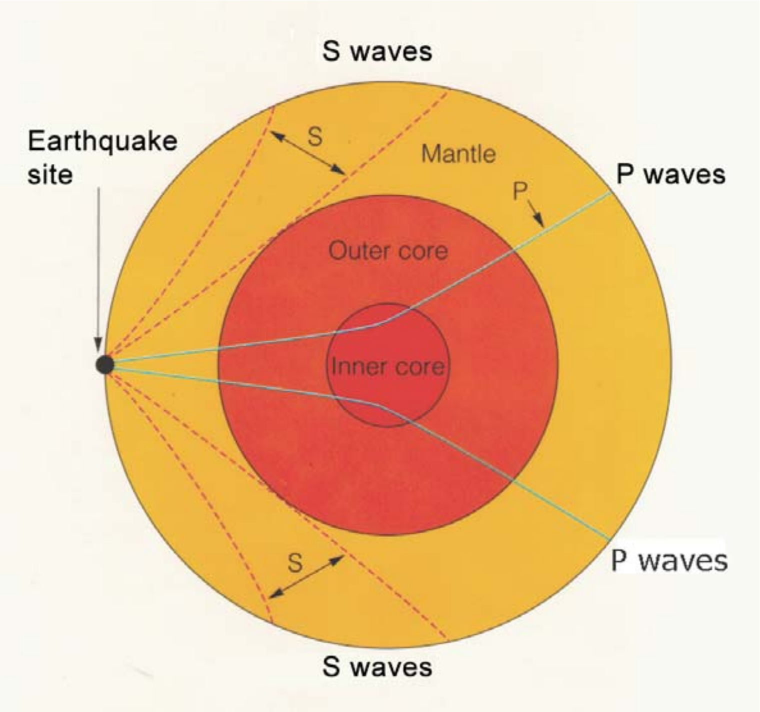
The mantle is also the place where most gemstones such as diamonds and garnets are formed. Diamond is nothing but pure carbon; the high pressures found at depths greater than

150 kilometres create diamond's compact crystal structure, making it the hardest material known. Rapidly rising magmas (molten rocks) carry diamonds to the surface, where they are found embedded in rocks. After separating from rocks diamond is cut and polished into gems.

One may ask at this stage, how do we know so much about the Earth's interior? Of course, the simplest way to find out what lies in deep interior of our planet would be to drill a hole and send robots to explore. But that is easier said than done. In 1990, the world's deepest drill hole penetrated to a depth of 12.3 kilometres beneath Russia's Kola Peninsula. But that was no more than a pinprick. More than 99 percent of the distance to Earth's centre still lay beneath the drill bit. So geologists use indirect methods; they gather clues from meteorites, rocks, diamonds, and earthquake waves.

Raw diamond as it comes embedded in rock.

Seismologists (scientists who study earthquakes) have learned that seismic waves slow down when they pass through hot molten rocks and speed up while passing through cold solid rocks. When an earthquake occurs it sends out vibrations called seismic waves in all directions that can be detected and measured at different locations. By measuring the arrival times for seismic waves generated by thousands of earthquakes seismologists can make three-dimensional images of the mantle's temperature in the same way as a medical CAT scan reveals the body's internal organs. Thus from the earthquake data geologists can work out the shape and depth of the mantle.



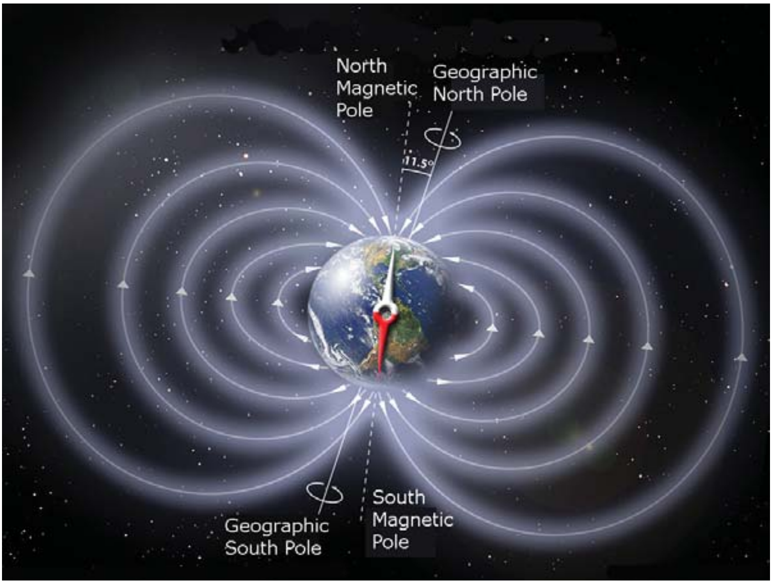
Some seismic waves cannot pass through hot molten rocks and by studying these waves the internal structure of Earth can be revealed.

The metallic core

Below the mantle, about 2,900 kilometres below the surface, lies the innermost part of the Earth – the core. About one-third of the Earth's mass is contained in its core, most of which is liquid iron alloyed with nickel and some lighter elements such as sulphur or oxygen. Scientists know it is liquid because seismic waves do not pass through it. However, a small central part of the core, below 5,150-kilometre depth, is solid. Temperatures in the core are extremely hot, ranging from 4,000 to 5,000°C at the outer part of the core to 5,500 to 7,500°C in the Earth's centre – probably hotter than the surface of the Sun.

The core is divided into two layers, the outer core and the inner core. The outer core is about 2,200 kilometres thick. It mainly consists of iron, some nickel and about 10% sulphur and oxygen, and is so hot that the metal is always in a molten state. The inner core – which we can call the 'centre of Earth' – is solid and about 1,250 kilometres thick. It consists mainly of iron, nickel and some lighter elements. At 5,500 to 7,500°C it is hotter than the outer core, but here the pressures are so high that it cannot melt.

The outer core and the inner core together are responsible for Earth's magnetism. It was the English physicist William Gilbert who, in 1600, first put forward the idea that the Earth behaves like a huge magnet in his book *De Magnete, Magneticisque Coporibus*, but he did not explain where the magnetism came from. Early 19th century experiments with simple batteries showed how magnetic forces are generated by electric current and it became evident that magnetism was a function of electrical forces. In case of our Earth, the rotation of the liquid outer core is believed to cause the molten iron-nickel to circulate. This produces a kind of dynamo effect and causes the Earth behave like a huge magnet, which makes it



The Earth behaves like a giant magnet, making it possible for us to use a magnetic compass as a direction finder.

possible for us to use a magnetic compass as a direction finder. If the Earth were not like a magnet we would have no means to find direction apart from the Sun, Moon and the stars. The Earth's magnetic field also acts like a shield around Earth, protecting us from energetic particles from the Sun carried by streams of particles called 'solar wind'.

3

Continents on the Move

If you look at the world map you will notice that the eastern coast of South America and the western coast of Africa seem to fit together like a jigsaw puzzle. The British scientist Sir Francis Bacon first noticed this peculiarity in the 17th century. Was it mere coincidence or was there something else for this similarity of shape? But Bacon did not have an answer. The correct explanation was first proposed by a German meteorologist named Alfred Wegener in 1912. According to him in the distant past the world's continents were joined together in a giant supercontinent which he called 'Pangaea' (which means 'all lands' in Greek). Then, sometime around 200 million years ago, Pangaea broke up and the fragments began to move away from one another, forming the present-day continents we see today.

It is now accepted that several times in Earth's history, collisions between continents have created huge supercontinents. Although the crust of the continents is thick, it breaks more easily than oceanic crust. As supercontinents broke into smaller pieces, material from Earth's mantle filled the gaps, creating new oceanic crust. As the continents moved apart, new ocean basins formed between them. About one-third of Earth's surface is covered by continental crust, so the pieces cannot move far before colliding. As two continents collide, an old ocean basin is destroyed. The continents have probably been in motion for at least the past 2,000 million years or more.

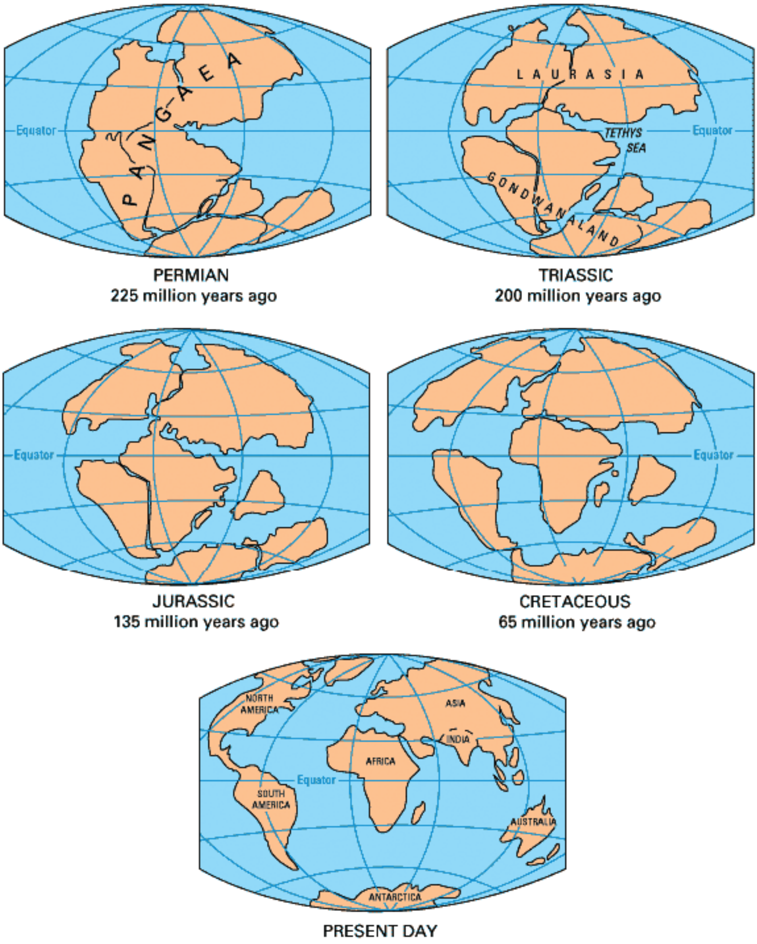
Around 800 million years ago, the continents were assembled into a large supercontinent called Rodinia. What is now North America lay at the centre of this supercontinent. Rodinia broke up some 750 million years ago into many pieces, which collided again between 500 million and 250 million years ago. Collision between what is now North America, Europe, and Africa caused the uplift of the Appalachian Mountains in North America, while collisions between part of present-day Siberia and Europe created the Ural Mountains.

The supercontinent of Pangaea.

By 250 million years ago, the continents reassembled to form another supercontinent called Pangaea. A single, worldwide ocean, called Panthalassa, surrounded Pangaea. In 1937 Alexander L. Du Toit, a South African geologist, modified Wegener's hypothesis by suggesting that eventually, Pangaea split into two halves, with the northern continent of Laurasia and the southern continent of Gondwanaland, sometimes called Gondwana (after Gondwana, a region of central India known for the Gond tribes), separated by the Tethys Sea. In course of time, Laurasia split to form North America, the Eurasian land-mass with the exception of the Indian subcontinent, and Greenland. Gondwanaland also split, forming the major southern landmasses of the world: Africa, South America, Antarctica, Australia, and India.

Pangaea broke up into Laurasia and Gondwanaland, separated by the Tethys Sea.

Today, scientists have amassed impressive geologic evidence to support the theory of moving continents. The phenomenon is known as continental drift and the process



PERMIAN
225 million years ago

TRIASSIC
200 million years ago

JURASSIC
135 million years ago

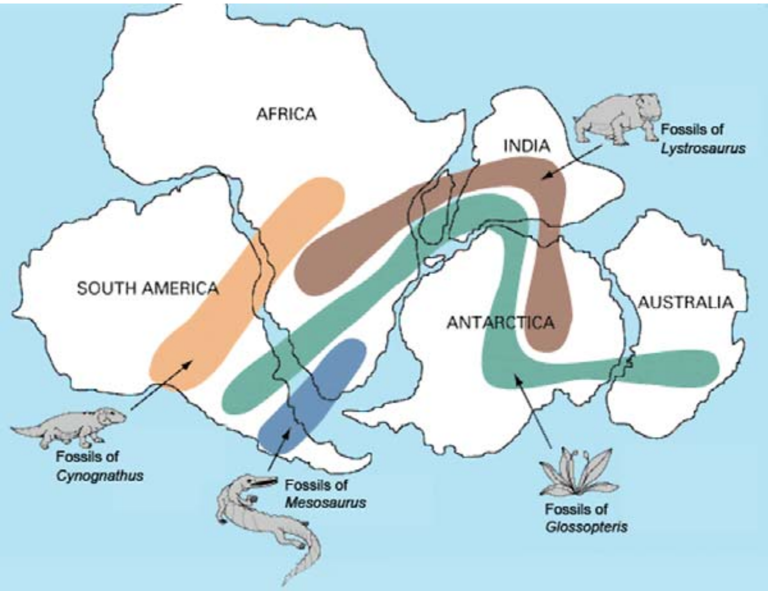
CRETACEOUS
65 million years ago

PRESENT DAY

Break up of Laurasia and Gondwanaland to form the present-day continents.

has been going on for hundreds of millions of years – at rates measured in only a few centimetres per year. For example, there is evidence of widespread glaciation from 380 to 250 million years ago in Antarctica, southern South America, southern Africa, Australia, and India, which can be only explained if these continents were once joined together around the South

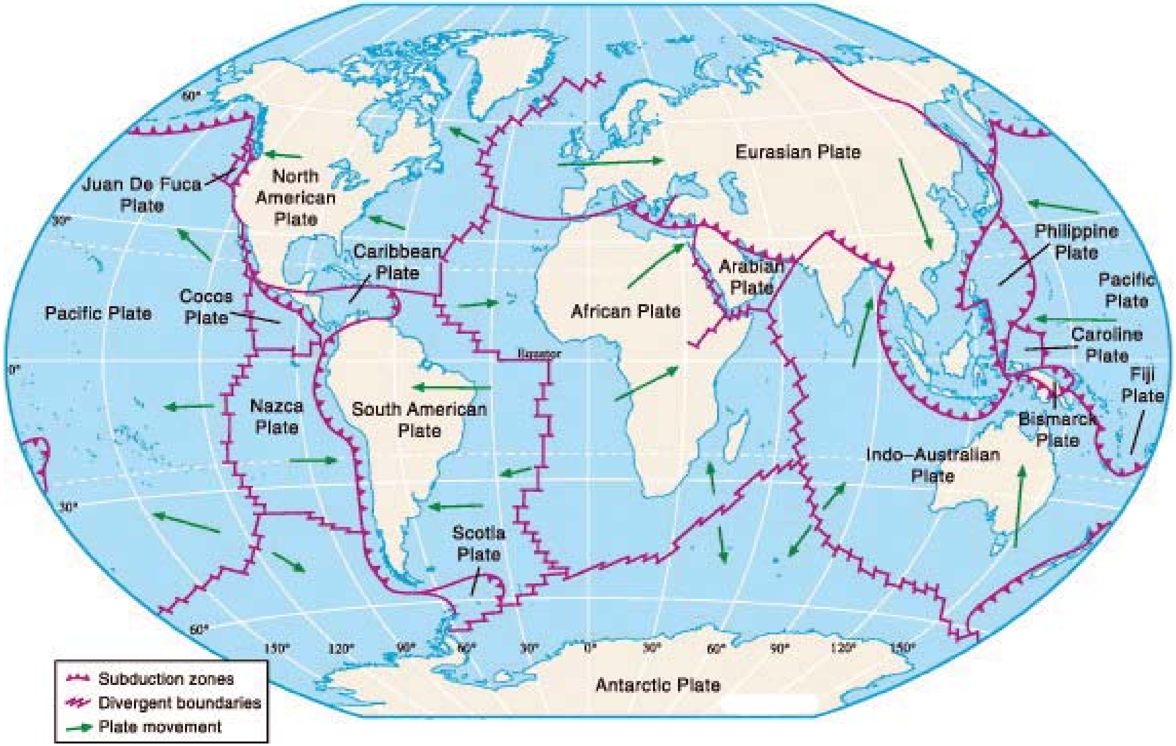
Polar Region. Also, fitting the Americas with the continents across the Atlantic brings together similar kinds of rocks and geologic structures. A belt of ancient rocks along the Brazilian coast, for example, matches one in West Africa. Moreover, the earliest marine deposits along the Atlantic coastlines of either South America or Africa are only 208 to 144 million years old, suggesting that the ocean did not exist before that time.



Fossils of similar animals and plants found in different continents provide strong evidence for continental drift.

Plate tectonics

Continental drift is based on the idea that the position of continents on the globe was once different than it is today, that some of the individual landmasses of today once were joined in other continental forms, and that the landmasses later moved to their present locations. But there was a problem here. A continent is too large a thing simply to float away; even an



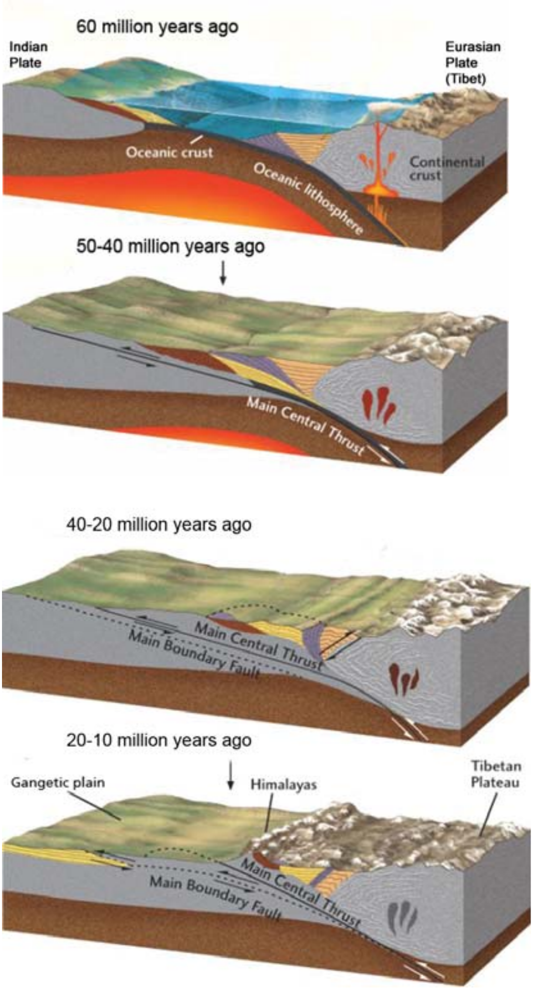
The Earth's outermost layer is fragmented into a dozen or more large and small plates.

aircraft carrier, which is many millions of times lighter, has to weigh less than the water it displaces, or it would sink like a stone. In any case, Wegener never claimed that continents floated; he only suggested they had moved. The question was: How, then, did they move?

The answer to this riddle was provided by plate tectonics, the branch of geology that studies the folding and faulting of the Earth's crust. Plate tectonics could explain the processes that have shaped Earth in terms of plates – which are nothing but large movable segments of the lithosphere – and their movement. It has provided explanations to questions that scientists had speculated upon for centuries – such as why earthquakes and volcanic eruptions occur in only certain regions around the world, and how and why great mountain ranges like the Alps and Himalayas formed.

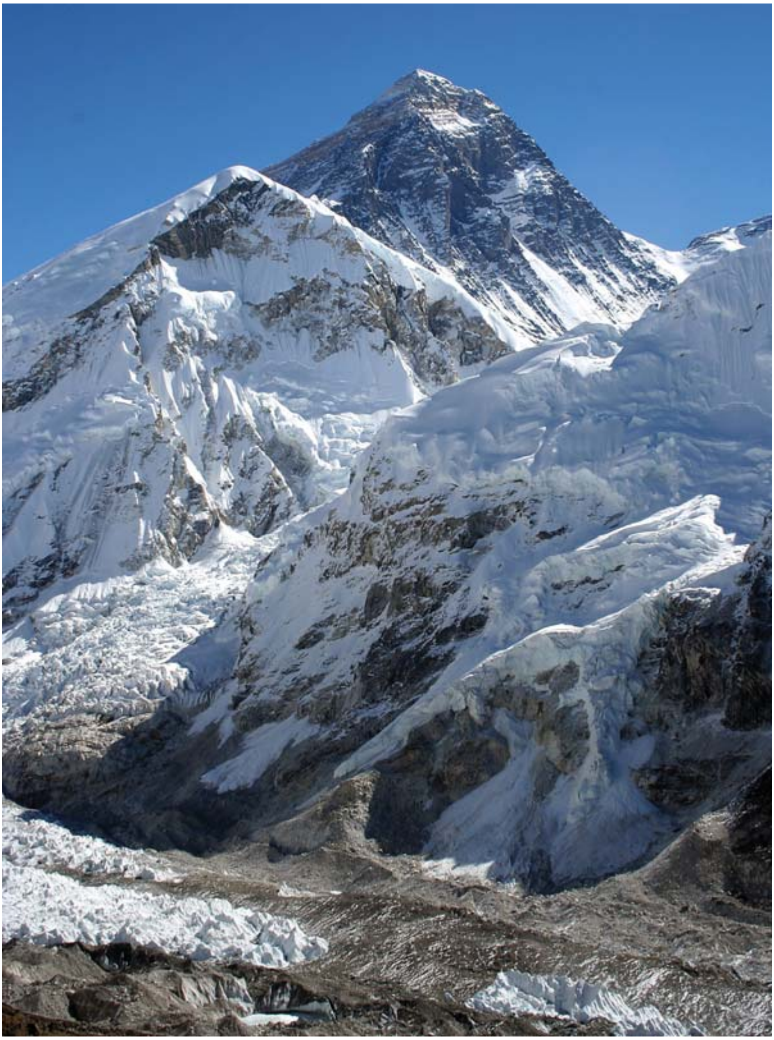
In geologic terms, a plate is a large, rigid slab of solid rock. The word tectonics comes from the Greek root "to build." Putting these two words together, we get the term plate tectonics, which refers to how the Earth's surface is built of plates. The theory of plate tectonics states that the Earth's outermost layer is fragmented into a dozen or more large and small plates that are moving relative to one another as they ride atop hotter, more mobile material.

The plate tectonics theory is elegantly simple. As we have already seen, the Earth's lithosphere, composed of a set of large and small continental plates, rests on and slides over an underlying, softer layer of partially molten rock known as the asthenosphere. While the interior of the moving plates remain essentially undeformed, their boundaries are subject to extreme pressures and are the sites where violent processes like earthquakes and volcanic eruptions occur. Where two plates collide the resulting pressure is often so great that it deforms



The Himalayan mountain range and the Tibetan plateau were lifted up by the collision of the Indian Plate with the Eurasian Plate over a period of some 50 million years beginning about 60 million years ago.

the surface into folds leading to formation of high mountain ranges. The world's highest mountain range, the Himalayas, is believed to have risen from the prehistoric Tethys Sea by a similar process when the Indian plate collided with the



Mount Everest, the highest point on Earth, was lifted from below the Tethys Sea by tectonic forces.

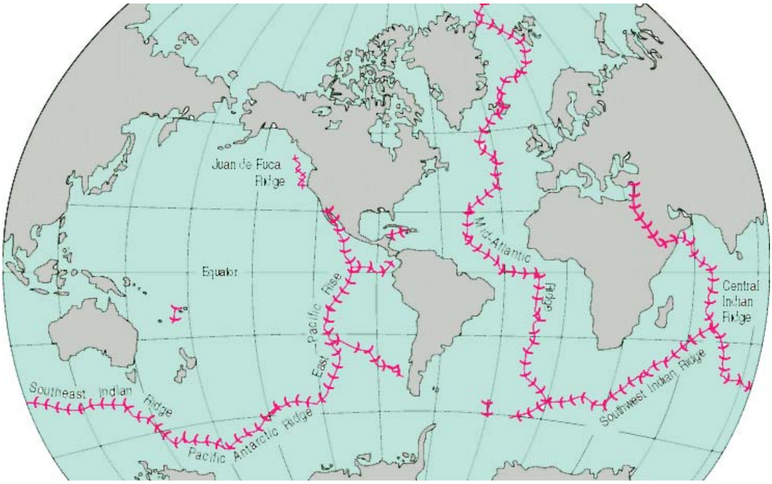
Eurasian plate some 50 million years ago. As the plates collided, it created a series of long, parallel folds in the Earth's crust, and in this stupendous upthrust was created a mountain range that contains all the worlds mountains over 7,000 metres in height. Fossils of marine organisms found on Himalayan peaks provide clear evidence of their rise from the sea . The Himalayas are also classified as 'young fold mountains' because they are among the youngest mountains on the globe.

Spreading seafloor

As we know, more than two thirds of the Earth's surface is covered by the oceans. Before the 19th century, the depths of the open ocean were largely a matter of speculation, and most people thought that the ocean floor was relatively flat and featureless. However, as early as the 16th century, a few intrepid navigators, by taking soundings with hand lines, found that the open ocean can differ considerably in depth, showing that the ocean floor was not as flat as was generally believed.

In 1947, seismologists on the U.S. research ship *Atlantis* made a surprising discovery. They found that the sediment layer on the floor of the Atlantic was much thinner than originally thought. Scientists had previously believed that the oceans have existed for at least 4,000 million years, and had expected the sediment layer to be very thick. So the thin sediment layer was quite puzzling. Why was there so little accumulation of sediments and debris on the ocean floor? The answer to this question, which came after further exploration, would prove to be vital to advancing the concept of plate tectonics.

The American geophysicist Harry H. Hess had first proposed in 1960 that the bottom of the world's oceans could be spreading and that could account for the movement of the continental plates. He also provided a plausible mechanism. On the basis of new discoveries about the deep-ocean floor, Hess postulated that molten material from the Earth's mantle continuously wells up along the crests of the mid-oceanic ridges that wind for 40,000 kilometres through all the world's oceans. The mid-oceanic ridge is the longest continuous mountain system on Earth, but found on the ocean floor. It is the region where Earth's crustal plates are moving apart. It is also the region where volcanic and earthquake activities occur frequently.



The mid-oceanic ridge is a 40,000 kilometre-long chain of low undersea mountains that spans across all the world's oceans.

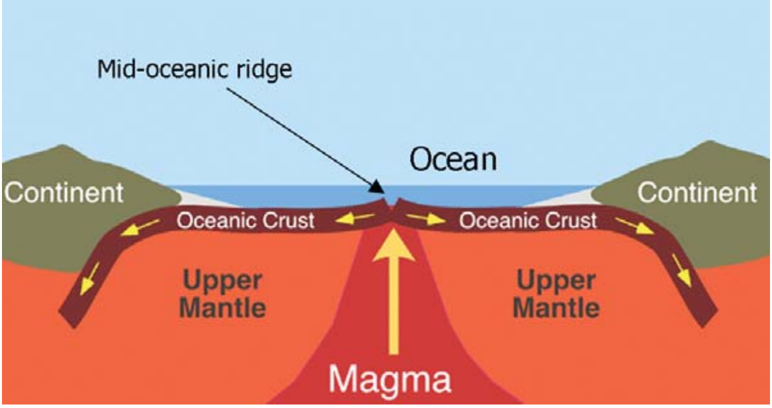
Along the mid-oceanic ridge, as the magma cools in contact with sea water, it is pushed away and spreads in both directions from the ridge system. This spreading creates a successively younger ocean floor of solidified basalt. It is estimated that this process generates new oceanic crust at the rate of 17 km^3 per year and the outward flow of magma is thought to bring about the migration, or drifting apart, of the continents. The continents bordering the Atlantic Ocean, for example, are believed to be moving away from the Mid-Atlantic Ridge at a rate of 1–2 centimetres per year, thus increasing the breadth of the ocean basin by twice that amount.

But the ocean floor certainly cannot go on spreading indefinitely. Indeed it does not; and there is a mechanism by which oceanic crust is also being destroyed continuously. Destruction of ocean floor occurs at plate boundaries, along areas called 'subduction zones' where oceanic crust goes under either continental crust or oceanic crust, as it happens along the western coast of South America, where it plunges downward, ultimately re-entering and dissolving in the Earth's mantle from which it originated. So we have new ocean floor being created continuously along the mid-oceanic ridges and old ocean floor being continuously destroyed along subduction zones. As a result although the ocean floor is constantly spreading, it is never able to collect enough sediment.

Scientists have measured the thickness of marine sediments and determined the absolute age of such bottom material, which provides additional evidence for seafloor spreading. The oldest sediments so far recovered by a variety of methods, including coring, dredging, and deep-sea drilling, do not exceed 208 million years in age, which is far less than the period for which the oceans have been in existence.

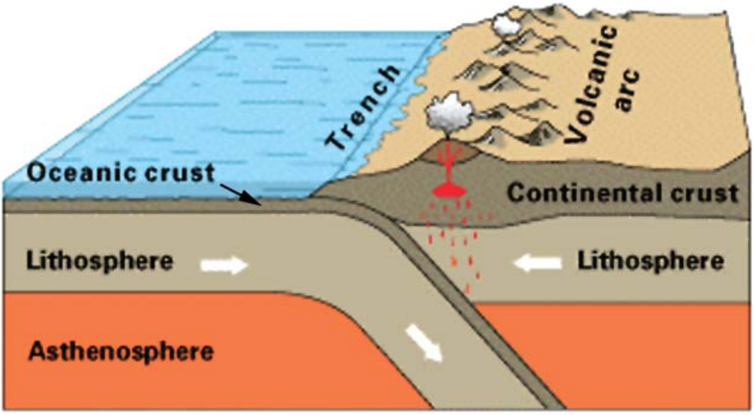
Magnetic anomalies

The most convincing evidence supporting the concept of seafloor spreading comes from the study of the magnetism of the ocean floor. In the late 1950's, when scientists mapped the present-day magnetic field generated by rocks on the floor of the Pacific Ocean, they found the intensity of the magnetic field to be very different from the intensity they had calculated. These measurements showed that there are numerous magnetic anomalies (or differences in the magnetic field from place to place) in the ocean basins. Such anomalies are positive if the magnetic field is greater than average, and they are negative if the field is less than average.



Molten magma coming out along the mid-oceanic ridge spreads and solidifies to create new ocean floor continuously.

The reason behind the magnetic anomalies in seafloor rocks is believed to be the periodic reversals of Earth's magnetic field, which happens once every 200,000 years or so on average. In fact, geological records show that the Earth's magnetic field has flipped many times over the last billion years. The volcanic rocks that make up the seafloor have magnetization because, as the hot magma cools, magnetic minerals within the rock



At the subduction zones, oceanic crust goes under the continental crust, which makes these regions prone to earthquakes and volcanic activity.

acquire the strength of the existing magnetic field of the Earth at the time and also align itself with the same. So the strength and orientation of the magnetic field of rocks that had cooled at different times would naturally be different.

Positive magnetic anomalies are induced when the rock cools and solidifies with the Earth's north magnetic pole in the northern geographic hemisphere. The Earth's magnetic field is enhanced by the magnetic field of the rock. Negative magnetic anomalies are magnetic anomalies that are weaker than expected. Negative magnetic anomalies are induced when the rock cools and solidifies with the Earth's north magnetic pole in the southern geographic hemisphere. The resultant magnetic field is less than expected because the Earth's magnetic field is reduced by the magnetic field of the rock. Magnetic surveys over the crests of mid-oceanic ridges indicate that magnetic anomalies occur in long bands parallel to the axis of the ridges and that the anomalies appear symmetrically on both sides of the ridges. Thus the differences in magnetic fields in rocks of the ocean floor provide sufficient evidence of the spreading of the ocean floor.

Ring of Fire

At the subduction zones, when oceanic crust collides with continental crust, continental crust being less dense usually rides up over the oceanic crust. As a result oceanic crust and the upper mantle lithosphere sink deep beneath the continent, becoming melted at some depth by the tremendous heat and pressure. When some of this molten rock or magma returns to the surface under pressure, melting some continental crust in the process, volcanic eruptions and lava flows occur. These volcanic activities, which are seen mostly above subduction zones, also lead to the formation of spectacular mountain ranges. This is how the continuous mountain chain around the Pacific Ocean known as the 'Ring of Fire' came to be. It is a long arc of subduction zones where magma chambers are formed in the upper mantle leading to high volcanic activity, stretching from the tip of South America north to the Cascade Mountains and the Aleutian Islands of Alaska, then running south through Japan, Southeast Asia, and continuing as far south as New Zealand. More than half of the world's active volcanoes above sea level are part of the ring, and 81% of the world's largest earthquakes occur along the Ring of Fire.

Earthquakes occur when rocks on opposite sides of a break in the crust, called a fault, push against each other or slide past each other. The boundaries between plates are faults, but there are faults within plates as well. Sometimes, even away from faults, forces within the plates cause rocks to fracture and

The 'Ring of Fire' is the continuous mountain chain around the Pacific Ocean. The red triangles indicate locations of earthquakes and volcanic activity.

slip. The boundaries between two plates sliding past each other are called transform faults. The San Andreas Fault in California, USA is a transform fault, where a portion of crust called the Pacific Plate is carrying a small piece of California northwest past the rest of North America. Faults along the boundary where the Indian Plate is pushing against the Eurasian Plate are responsible for the frequent earthquakes seen in north-eastern India and along the Himalayan belt in north India.

So, we now know that our Earth is a dynamic planet. We now know that, directly or indirectly, plate tectonics influences nearly all geologic processes, past and present. Indeed, the notion that the entire Earth's surface is continually shifting has profoundly changed the way we view our world.

Not only that. The knowledge of plate tectonics has given us the power to understand violent geological phenomena like earthquakes and volcanic eruptions that unleash bursts of energy far more powerful than anything we can generate. While we have no control over plate-tectonic processes, we now have the knowledge to learn from them and to devise ways to safeguard against loss of life and property during the occasional violent displays of the Earth's awesome power.

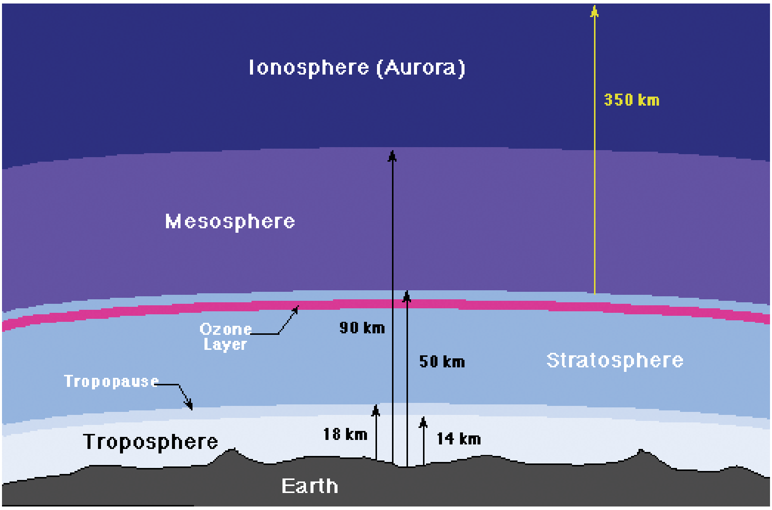
4

Air, Water and Rocks

The distinctive feature that distinguishes our Earth from all other planets of the Solar System is its environment that can support life. But, as we have seen, it was not always so. The Earth has reached its present state from a hot molten state over a period of several thousand million years during which it has seen violent changes leading to mountain building, seafloor spreading, and other geological processes in action. And the result of all this is the planet we see today – with its blue oceans, green forests and grasslands, dry deserts, wetlands, lofty mountains, the icy expanses of the polar regions, and the myriads of life forms that thrive in almost every nook and corner.

The atmosphere

One of the most vital components of Earth's immediate environment is its atmosphere, which plays a crucial role by protecting us by blocking out dangerous rays from the Sun and keeping us warm. The Earth's atmosphere is about 480 kilometres thick, but most of the atmosphere (about 80%) is within 16 kilometres of the surface of the Earth. Most people find it difficult to breathe more than three kilometres above sea level. About 160 kilometres above the surface, the air is so thin that satellites can travel without much resistance although detectable traces of atmosphere can be found as high as 600 kilometres above Earth's surface. There is no exact place where the atmosphere ends; it just gets thinner until it merges with the near-vacuum of outer space.



The atmosphere is one of the most vital components of Earth's immediate environment.

The Earth's original atmosphere was formed by a process in which gases like carbon dioxide, water vapour, sulphur dioxide and nitrogen were released from the interior of the Earth from volcanoes and other processes. It had no oxygen. Oxygen came into the atmosphere only after the appearance of green plants that released oxygen as a by-product of photosynthesis. Life forms on Earth have since modified the composition of the atmosphere to its present state. At present Earth's atmosphere is composed of nitrogen (78%), oxygen (21%), and other gases (1%).

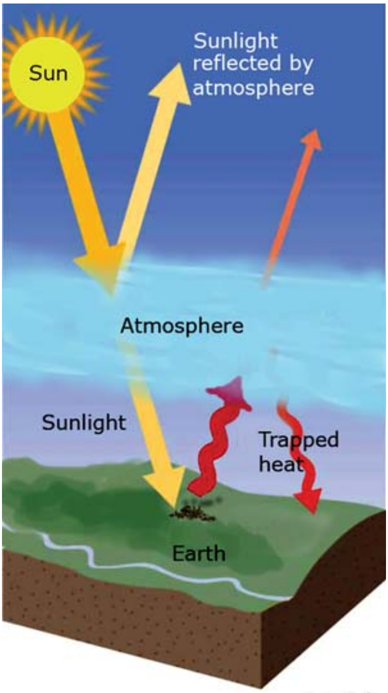
The presence of oxygen is crucial not only because it supports life and allows us to breathe, but also for the creation of the ozone layer in upper atmosphere that filters out the Sun's harmful ultraviolet rays. The atmosphere also protects the Earth from freezing by keeping heat inside the atmosphere through greenhouse effect. It there were no atmosphere the average surface temperature on Earth would be well below the freezing point of water!

The atmosphere is divided into five layers depending on how temperature changes with height . Most of the weather and clouds are found in the lowest layer called the troposphere. The troposphere extends from ground level up to a height of about 17 kilometres. All the weather phenomena – clouds, rain, lightning, thunderstorms – occur in the troposphere. Here the temperature generally decreases as altitude increases. The tropopause is the boundary zone between the troposphere and the stratosphere. It is characterized by little or no change in temperature altitude increases.

The stratosphere is characterized by a slight temperature increase with altitude and the absence of clouds. The stratosphere extends between 17 to 50 kilometres above the Earth's surface. It contains the Earth's ozone layer. Ozone, a form of oxygen, is crucial to our survival; this layer filters out harmful ultraviolet rays from the Sun. Only the highest clouds – cirrus, cirrostratus, and cirrocumulus – are seen in the lower stratosphere. The stratosphere is followed by the mesosphere, which extends from 50 to 85 kilometres above the Earth's surface. Roughly, it lies between the maximum altitude for most aircraft and the minimum altitude for most spacecraft. Here temperatures decrease rapidly as height increases. Millions of meteors burn up daily in the mesosphere as a result of collisions with the gas particles contained there, leading to a high concentration of iron and other metal atoms.

The ionosphere begins at a height of between 70 and 80 kilometres and extends up to some 640 kilometres. This layer contains free charged particles called ions and also free electrons, which makes it a good reflector of radio waves of certain wavelengths. The ions are created when sunlight hits atoms and tears off some electrons. The ionosphere makes long-distance wireless communication possible. Auroras occur in the ionosphere.

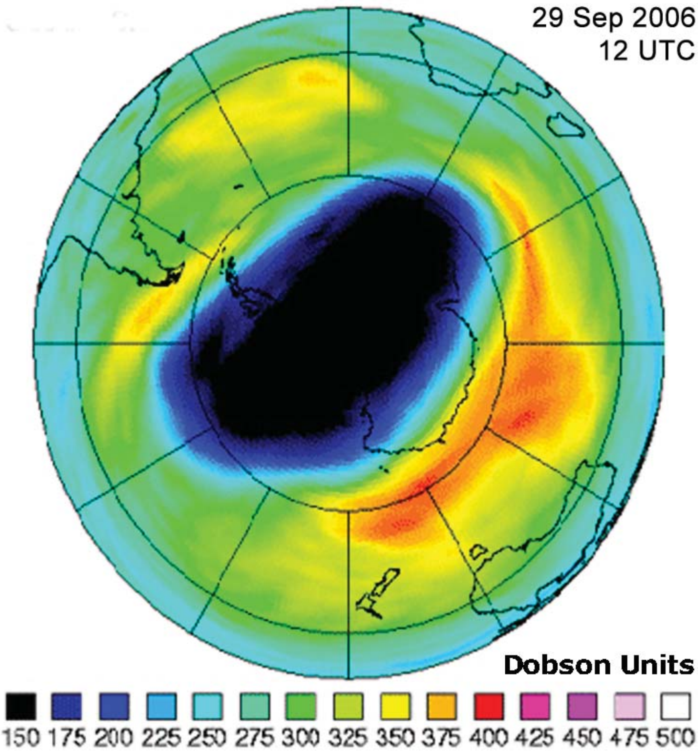
The exosphere is the outermost layer of the Earth's atmosphere. It begins at around 640 kilometres and extends up to about 1,280 kilometres. The lower boundary of the exosphere is called the critical level of escape, where atmospheric pressure is very low (the gas atoms are very widely spaced) and the temperature is very low. The main gases within the exosphere are the lightest gases, mainly hydrogen and helium.



Heat trapped by carbon dioxide and water vapour in the atmosphere causes the greenhouse effect, which keeps the Earth warm.

Threats to the atmosphere

Although the atmosphere is vital to our survival on this planet, some of our actions are posing a serious threat to its well-being. Increasing emission of carbon dioxide due to burning of fossil fuels by industry and use of petroleum powered vehicular traffic has upset the carbon dioxide balance in the atmosphere, leading to enhanced greenhouse effect. This is causing the Earth to get warmer, with consequent disruption in weather patterns around the globe.



The ozone hole over Antarctica as recorded in 2006.

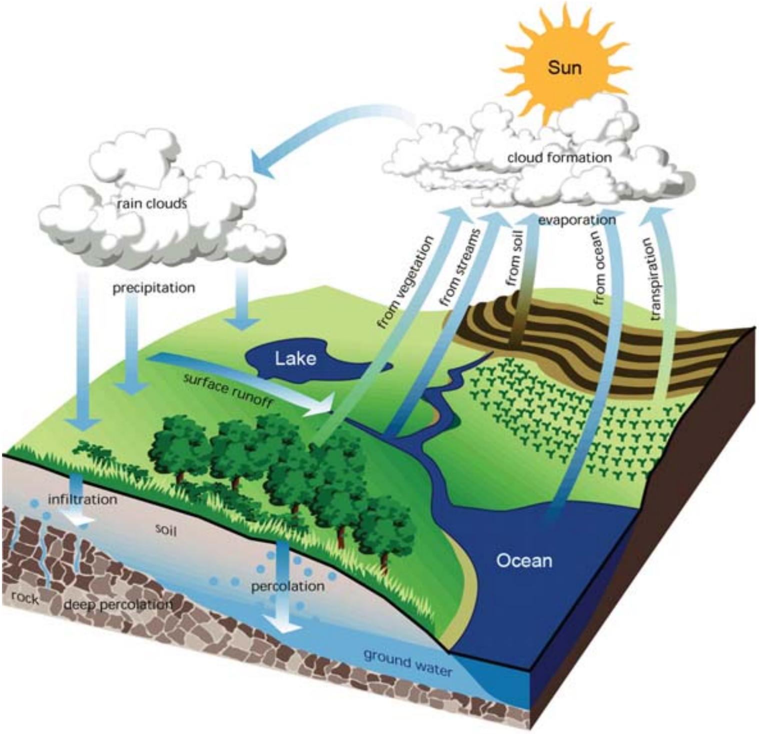
Increasing carbon dioxide levels is not the only threat. Even the protective ozone layer in the upper atmosphere is at risk. A unique class of industrial chemicals called chlorofluorocarbons (CFCs) were developed in the 1930s. Being non-toxic, non-flammable, and non-reactive with other chemical compounds, CFCs were found to be ideal for many applications such as coolants for commercial and home refrigeration units, aerosol propellants, electronic cleaning solvents, and blowing agents. After depletion of ozone levels in the stratosphere and formation of an 'ozone hole' over Antarctica were confirmed in 1984, CFCs were implicated as the culprit. Fortunately, the world community was quick to respond to the threat and steps were taken to ban the production and use of CFCs.

The hydrosphere

Liquid water makes the Earth a special place. Our planet is unique in that it has a temperature range that allows water to remain in its liquid state. If we were a colder planet like Neptune, it would not matter how much water there was on the planet; it would all be frozen. On the other hand, if we were on a very hot planet like Venus or Mercury, all of the water would be in a gaseous state. Water vapour and solid water are useless to the living organisms found on Earth.

More than 70% of the Earth's surface is covered by water, in either the liquid or solid state. In addition to the oceans, there is water in lakes and streams, subsurface water, the ice of glaciers and polar ice sheets, and water vapour in the atmosphere, which together make up the Earth's hydrosphere. Only a small portion of the Earth's water is freshwater, suitable for drinking. This includes water in rivers and lakes, and groundwater. Freshwater is needed for drinking, farming, and washing. Without water, life as we know it would not exist.

The water of the hydrosphere is not static; it is in constant motion. Heated by the Sun, water evaporates from both the land and seas. Transpiration by plants also releases water vapour into the atmosphere. On cooling, the water vapour in the atmosphere condenses to form clouds and falls as rain or snow. Rain or snowmelt from land is carried, eventually, to the sea to begin the cycle anew. This is the 'hydrologic cycle'. Although the total amount of water stored in rivers, lakes, and the atmosphere is comparatively small, the rate of water circulation through the rain–river–ocean–atmosphere system is relatively rapid. The amount of water discharged each year into the oceans from the land is approximately equal to the total mass of water stored at any instant in rivers and lakes.



The hydrologic cycle.

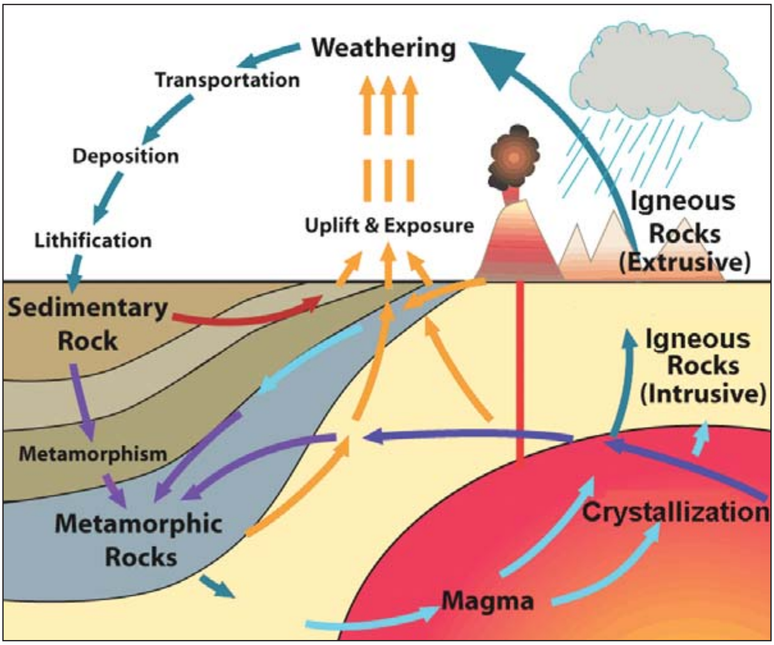
The waters of the hydrosphere are important in many ways. Plants, animals, and human beings need water to live and grow. Water also wears away rocks and slowly turns them into soil, which is necessary for growing crops. The unique chemical properties of water make it an effective solvent for many gases, salts, and organic compounds. Circulation of water and the dissolved material it contains is a highly dynamic process driven by energy from the Sun and the interior of the Earth. Oceans and other large bodies of water also help control the Earth's weather and climate.

In recent times this vital resource has been under threat from human activities. The reckless acts of modern human society are having a severe impact on the hydrologic cycle. The dynamic steady state is being disturbed by the discharge of toxic chemicals, radioactive substances, and other industrial wastes and by the seepage of mineral fertilizers, herbicides, and pesticides into surface and subsurface aquatic systems. Inadvertent and deliberate discharge of petroleum waste, improper sewage disposal, and thermal pollution also are seriously affecting the quality of the hydrosphere.

The lithosphere

The Earth's surface is made up of layers of rocks. As we have seen, the crust and the upper layer of the mantle together make up a zone of rigid, brittle rock called the lithosphere. Rocks of the lithosphere are mainly of three types – sedimentary, metamorphic, and igneous. The three types are constantly cycled through a geological process known as the 'rock cycle'. The process depends on temperature, pressure, time, and changes in environmental conditions in the Earth's crust and at its surface.

The rock cycle is an ongoing process, beginning as rocks that are pushed up by tectonic forces and eroded by wind and rain. The forces of weather break rocks into small particles that are carried away by wind and water and deposited elsewhere. These small particles are often deposited in shallow seas or lakes as sediments. As the layers of deposits pile up, perhaps over millions of years, pressure from the weight of the



The different types of rocks are formed, altered, destroyed, and reformed through the rock cycle.

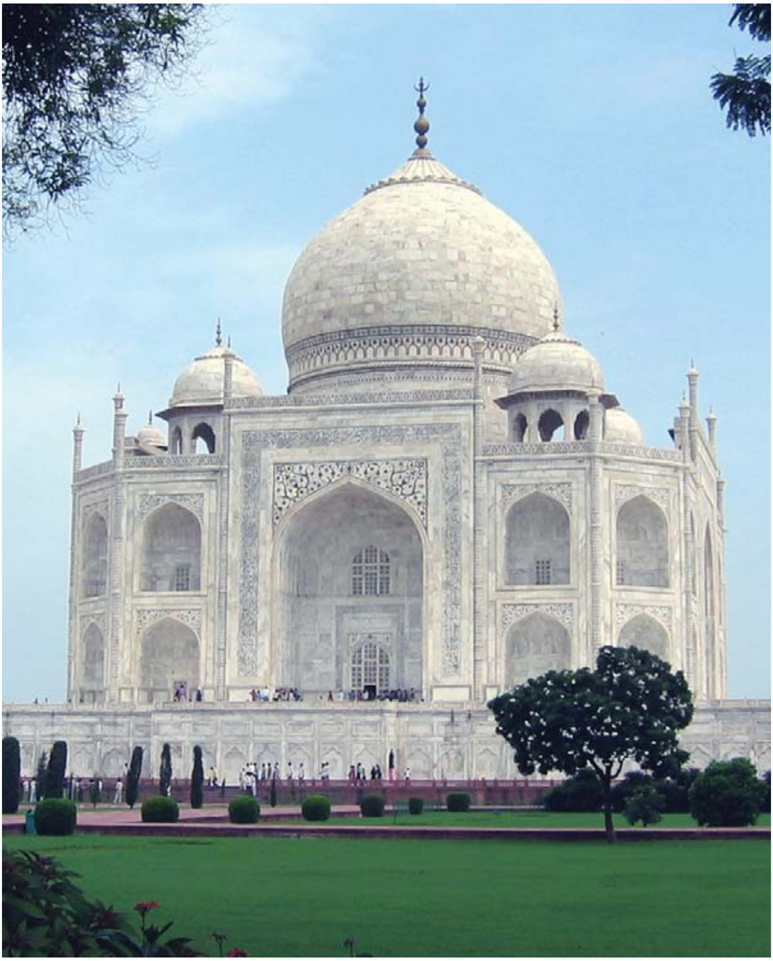
sediments above turns the lower layers into solid rock. Such rock, made of sediment, is called sedimentary rock. Sand may turn into sandstone; silt and clay become shale. Most fossils are found in sedimentary rocks.

Sedimentary rocks cover about three fourths of the Earth's land area, and most of the ocean floor. Large areas of buried sedimentary rock may be exposed where the Earth's crust is deformed or eroded. In some places, such as the mouths of rivers, the sedimentary rock may be up to 12,000 metres thick.

Metamorphic (which means 'change of form') rock is rock that has been altered by heat or by heat and pressure inside Earth without melting. Rocks change when mountain-building

The sandstone of which the Red Fort in Delhi is built is a sedimentary rock.

forces apply a great deal of pressure and heat on them. These rocks are formed from other rocks when solid-state changes in mineral content and textures takes place as a result of chemical



The marble of which the Taj Mahal at Agra is built is a metamorphic rock.

or physical changes that occur in solid rock buried in the Earth's crust. These rocks have new minerals and structures; some of the minerals in rock are broken down and new minerals are formed. The grains that make up the rock may become larger. Common examples of metamorphic rocks are marble, gneiss, and slate.

Igneous rock is rock formed by the hardening and crystallization of molten material that originates deep within the Earth. The word 'igneous' comes from the Greek word for fire. Rocks that have hardened from magma, the hot liquid beneath the Earth's crust, are igneous rocks. Granite is one of the most common igneous rocks of the Earth's crust; it forms a major part of the continental crust. It is a coarse-grained rock, formed by the cooling of magma. Granite has been used since ancient times as a building material. Many large Hindu and Buddhist temples in India were made of granite. Today granite is extensively used as flooring tiles in public and commercial buildings and monuments. With increasing amounts of acid rain in parts of the world, granite has begun to supplant marble


The granite rock out of which the Ellora temples at Aurangabad were cut is an igneous rock.

Landslides often occur as a result of illegal quarrying and deforestation on hill slopes.

as a monument material, since it is much more durable. Polished granite has been a popular choice for kitchen countertops due to its high durability and aesthetic qualities.

But indiscriminate quarrying of sandstone, granite, and marble often leads to serious damage to the environment, as seen in many places in India. Quarrying is often preceded by removal of forest cover and topsoil, which on hilly terrains has an adverse impact on the stability of the ground and slopes, leading to frequent landslides. Unscientific quarrying also disrupts groundwater sources, often leading to drying up of wells and tube wells in nearby areas.

5

The Dawn of Life

The Earth is the only planet of our Solar System known to be home to a myriad of life forms. But the origin of life on Earth still remains shrouded in mystery. We know that early Earth was extremely hot, with an atmosphere filled with poisonous gases. When and where did, then, the first living forms appear? What were they like? Although the exact time when life first appeared on Earth cannot be dated exactly, there is evidence that bacteria-like organisms lived on Earth some 3,500 million years ago. It is possible that some life forms may have existed even earlier, when the first solid crust formed, almost 4,000 million years ago. These early organisms must have been simpler than the organisms living today. What we know about primitive life on Earth is mainly from the study of fossils, which are traces of those organisms or their impressions left behind in sedimentary rocks.

Of course, we cannot go back in time to find out how life first appeared on Earth, but scientists have carried out innovative experiments to find out how the first living cells may have been created. According to one of the earliest theories of the origin of life on Earth, the first living cells were probably created in the primordial seas by the action of lightning. In

1953, Stanley L. Miller and Harold C. Urey, working at the University of Chicago, conducted an experiment which would change the approach of scientific investigation into the origin of life. Miller took molecules which were believed to represent the major components of the early Earth's atmosphere and put them into a closed system. The gases they used were methane (CH_4), ammonia (NH_3), hydrogen (H_2), and water (H_2O). Next, he ran a continuous electric discharge through the system, to simulate lightning storms believed to be common on the early Earth. At the end of one week, Miller observed that as much as 10-15% of the carbon was now in the form of organic compounds, as tested by chromatography. Perhaps most importantly, Miller's experiment showed that organic compounds such as amino acids, which are essential to cellular life, could be made easily under the conditions that scientists believed to be present on the early Earth.

But there were doubts about the validity of Miller's experiment because it is now believed that carbon dioxide was a major component of early Earth's atmosphere, which Miller had not taken into account. Another objection was that his experiment required a tremendous amount of energy. While it is believed lightning storms were extremely common on the primitive Earth, they were not continuous as the Miller/Urey experiment portrayed. Thus it has been argued that while amino acids and other organic compounds may have been formed, they would not have been formed in the amounts which this experiment produced.

Origin in hot springs

Currently many scientists think that life may have begun on Earth not on the surface but in the vicinity of deep-oceanic, hydrothermal vents. These submarine hot springs are chimney-like structures often up to 55 metres tall that were first discovered in 1979. Hydrothermal vents represent discharges of hot, mineral-laden water, onto the ocean floor deep beneath the ocean surface. They are found close to mid-oceanic ridges. It is thought that the water is heated from contact with the hot, newly-formed oceanic lithosphere in the vicinity of the ridges.

Currently many scientists think that life may have begun on Earth not on the surface but in the vicinity of deep-oceanic, hydrothermal vents like these.

These vents were found to release hot gases like hydrogen sulphide and mineral-rich water from the Earth's interior at temperatures above 300°C, which was considered too hot to support life. But scientists were surprised to find thriving ecosystems comprising various types of fish, worms, crabs, bacteria and other organisms around these vents where sunlight never reaches. Because life had been found to exist where it was previously thought unable to, many scientists began to ask questions as to whether or not this was where life may have originated on the Earth.

They had reasons to believe in such a possibility. The gradients of temperature and pH around these submarine vents would have provided energy and opportunity, and the minerals dissolved in water flowing out from such a vent would have provided a constant source of chemical nourishment for the first living cells to take shape. Laboratory experiments had shown that the iron sulphide found around such undersea hot springs would precipitate initially to form a gel with pores and bubbles that could provide enclosed sites for chemical reactions. The somewhat flimsy membranes between pockets would then have trapped and concentrated organic molecules, and the small volume of each bubble would have encouraged more complex reactions, as goes on in living cells. So the possibility was certainly there.

If life did originate at hydrothermal vents, the process may have been something like this: volcanic gases and water around the hydrothermal vents combine with elements of the Earth's crust to form acetic acid. With the addition of carbon, pyruvic acid is formed. When pyruvic acid reacts with ammonia, it forms amino acids, which then link up into proteins.

That this is not mere speculation was demonstrated in a series of experiments carried out by researchers at the Carnegie Institution in USA during 1998-99. They replicated the harsh vent conditions and came up with pyruvic acid – an organic chemical vital for cellular metabolism. The researchers used a recipe of iron sulphide (one of the ingredients of the Earth's crust), formic acid (detected even today in thermal vents), and alkyl thiol (a sulphurous compound similar to alcohol that is produced by the combination of iron sulphide and carbon monoxide). These chemicals were enclosed in a small gold capsule, and then subjected to high temperatures and pressures similar to the conditions found at hydrothermal vents.

Even if born around submarine thermal vents, however, it was not a cake walk for the Earth's earliest living cells. Not many of the early living cells born in the deep ocean would have survived in the open ocean, which at that time was an ultra-dilute broth exposed to dangerous ultraviolet radiation from the Sun. Most of them would have been safer on the ocean floor and in the sediments around the vents, subsisting on a meagre diet of hydrogen and carbon dioxide, which was in steady supply.

The first primitive life forms may have remained confined to the ocean bed for millions of years till tectonic movement of rocks within the Earth's mantle transported a few colonies of these early living cells to the surface. Some must have been placed in locations which were deep enough to be protected from harmful solar rays, but shallow enough to use radiation at longer wavelength to make more organic molecules from carbon dioxide. That is how the first living organisms – possibly bacteria – may have got a foothold on Earth, and over time, made it a living planet.

Panspermia theory

While any theory of the origin of life on Earth would be speculative, there is another school of thought according to which 'seeds' of life were brought to Earth by extraterrestrial bodies such as comets and asteroids. Among the strong proponents of this theory, commonly known as 'panspermia,' were the British astrophysicists Fred Hoyle and the Sri Lankan-born Chandra Wickramasinghe. But theory of panspermia does not answer the riddle of the origin of life; it only shifts the location beyond Earth. Few scientists today subscribe to this theory.

6

Life Unlimited

By 3,500 million years ago, the Earth's oceans were populated by one-celled organisms called prokaryotes. These are primitive forms of organisms which do not have a distinct, membrane-bound nucleus or membrane-bound organelles. The DNA in prokaryotes is not organised into chromosomes. They are the ancestors of present-day bacteria and cyanobacteria. In course of time, higher forms of life evolved and today living forms occupy almost every nook and corner of the globe. Whether you are at the bottom of the deepest ocean, or in the hottest desert, the coldest mountain tops, or even a few kilometres into the atmosphere, you will find life everywhere. There are several million known kinds, called species, of living things, and scientists believe that there are far many more species not yet discovered. And together they form the Earth's biosphere.

The oxygen givers

The atmosphere of early Earth did not have oxygen, which appeared only after organisms called cyanobacteria, commonly known as 'blue-green algae' appeared. As the blue-green algae grew in the Earth's oceans, they began to fill the atmosphere with oxygen. The oxygen that blue-green algae produced made it possible for other types of organisms to develop. It took about 300 million years between the time oxygen production from photosynthetic organisms started, and the carbon dioxide-rich atmosphere of the early Earth to change to the present-day oxygen-rich atmosphere we breathe.

Cyanobacteria or blue-green algae were the first organisms use photosynthesis and give off oxygen.

As the oxygen level in atmosphere increased, organisms, known as eukaryotes, appeared. These were organisms that, unlike prokaryotes, had a cellular nucleus with chromosomes and a nuclear membrane. Gradually, by 500 million years ago, there was an explosion of multi-cellular organisms. A large variety of them – jellyfish, worms, trilobites, molluscs with spiral shells, starfish, sea urchins, clams, snails, corals, sponges, and jawless fish – proliferated in the oceans, and by 435 million years ago the early vertebrates had appeared in the ocean. Vertebrates are animals having a bony or cartilaginous skeleton with a segmented spinal column and a brain enclosed in a skull or cranium. By about

A trilobite fossil. Trilobites had a segmented body divided by grooves into three vertical lobes and were among the earliest multi-cellular organisms to appear on Earth.

430 million years ago, primitive life forms including plants and insects appeared on land followed by spiders, mites, amphibians, and a group known as synapsids appeared. Often called mammal-like reptiles – they looked like a cross between a dog and a lizard – the synapsids were Earth's first great dynasty of land vertebrates. The first true reptiles appeared around 300 million years ago.

But the spread of animal species was not without breaks. Several times in Earth's history, species were wiped out by mass extinctions. Between 290 million and 250 million years ago, over 90% of the marine species and 70% of the terrestrial species died out during the worst ever mass extinction in Earth's history. Many species of shellfish and coral, crinoids, brachiopods, bryozoans, and fish disappeared. It is not known what caused this mass extinction, but it appears from fossil records that it happened over a rather short span of time – may be only a few million years.

The age of dinosaurs

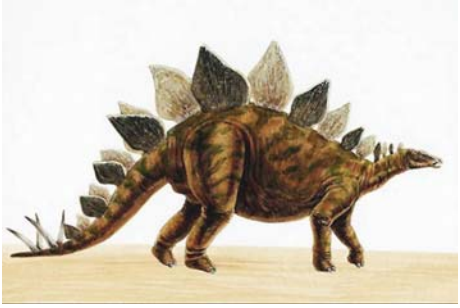
It took tens of millions of years to repopulate the Earth. Dinosaurs emerged by about 240 million years ago. They were reptiles and most of them hatched from eggs. Small dinosaurs such as icthyosaurs and plesiosaurs were fish eaters. Big fishes like sharks and rays continued to evolve and the first land mammals appeared. By 150 million years ago huge dinosaurs and flying pterosaurs – oldest known birds –

A Triceratops.

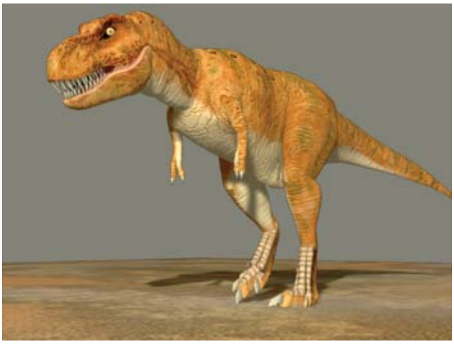
appeared. First squids, frogs, and turtles also appeared around this time.


Pterosaurs were huge flying dinosaurs that lived 150 million years ago.

The name 'dinosaur' means 'most fearsome lizard'. However, dinosaurs were not lizards, though related to them. Some scientists think that dinosaurs were more closely related to birds. Dinosaurs ruled the Earth for almost 170 million years. They lived in many different habitats, from open plains to forests to the edges of swamps, lakes, and oceans. Some dinosaurs were as tall as a five-storey building, and there were others no bigger than a chicken. In between the largest and the smallest, there were dinosaurs of all shapes and sizes. The largest dinosaurs may have grown as long as 45 m and weighed as much as 77 tonnes. The dinosaurs had tough skin covered in scales. Some were armour-plated and covered with spikes.


The Stegosaurus was a dinosaur with armour-plated body covered with spikes.

Some dinosaurs were carnivores – they ate meat. They had sharp teeth and claws. *Tyrannosaurus rex*, *Allosaurus*, and *Baryonyx* were carnivores. Most dinosaurs were, however, herbivores and ate plants. They had teeth designed to grind their food. They had larger intestines than carnivores because plants had less



The Tyrannosaurus rex *had sharp teeth and was a carnivore.*

nutrition than meat, so they had to eat huge quantities. Because of their sheer size and the predatory nature of species like the *Tyrannosaurus rex*, few other land species could proliferate freely.

But even the mighty dinosaurs fell to nature's wrath and were wiped out of Earth's face in one stroke. It happened around 65 million years ago, when it is believed that a huge meteor hit the Earth, causing enormous clouds of dust to block the Sun's rays. As a result the Earth

The dinosaurs were wiped out after a huge meteor hit the Earth 65 million years ago, causing enormous clouds of dust to block the Sun's rays that kept the Earth dark and cold for many years.

remained dark and cold for many years. Huge tidal waves flooded low-lying land and acid rain fell. Small animals could find shelter and enough warmth and food, but the huge dinosaurs could not. They died out.

The age of mammals

Mammals appeared about 190 million years ago, and became dominant after extinction of dinosaurs some 65 million years ago. Mammals are warm-blooded, hairy animals with backbones, possessing four-chambered hearts and diaphragms to help breathing. Most give birth rather than laying eggs, and all feed their young from milk-producing mammary glands unique to the class Mammalia.

The demise of the dinosaurs saw mammals growing bigger, more ferocious, and finally becoming the dominant predators, occupying the ecological niches vacated by dinosaurs throughout the world. Flying mammals replaced the flying reptiles, and swimming mammals replaced the swimming reptiles. Within ten million years after the death of the dinosaurs, the world was filled with rodent-like mammals, medium-sized mammals scavenging in forests, and large herbivorous and carnivorous mammals, which hunted other mammals, birds, and reptiles.

Around 35 million years ago two new groups of mammals appeared. They were the odd-toed hoofed animals like the ancestors of the modern horses, rhinoceroses, and tapirs, and the even-toed hoofed animals, which included the ancestors of deer, cattle, and sheep. It was also around this time that two completely marine mammal groups, the cetaceans, which include the whales, porpoises, and dolphins; and the sirenians – predecessors of the modern manatees and dugongs –

appeared. The first elephant-like animals and the early bats also first appeared during this period.

Between 35 million and 24 million years ago, elephants, cats and dogs, monkeys and the great apes made their debut on Earth. During the subsequent 15 million years, large apes roamed Africa and southern Europe. By five million years ago, the first Australopithecines – distant ancestors of modern humans that showed similarities to both apes and humans – appeared in southern and eastern Africa.

The woolly mammoth probably originated in north-central Eurasia around 1.8 million years ago.

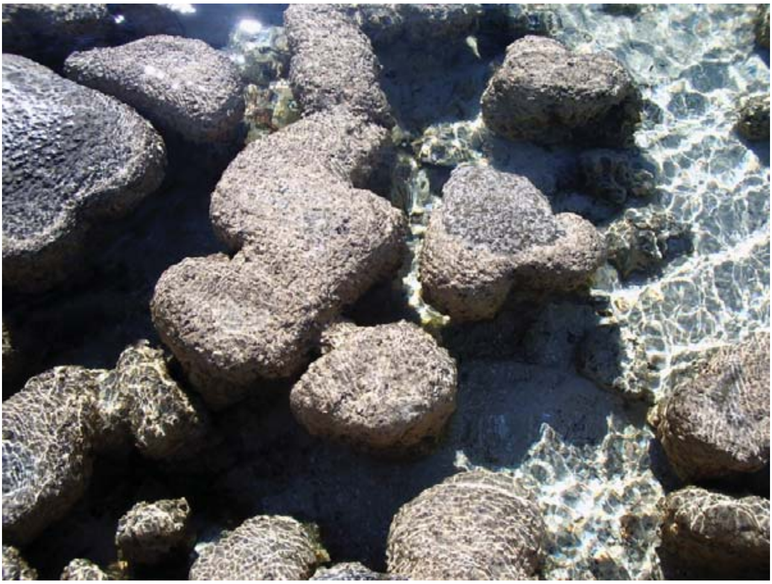
The woolly mammoth probably originated in north-central Eurasia around 1.8 million years ago, spreading westward to England and Spain and eastward via the Bering Isthmus to the tundra-like regions of North America from Alaska to the Atlantic Coastal Shelf. We know a great deal about its appearance due to the discovery of several well-preserved carcasses in frozen ground in Siberia and from the study of many detailed carvings, engravings and murals by Stone Age (Palaeolithic) artists. It was also around this time that the earliest direct ancestors of modern humans appeared in Africa.

7

Greening of the Earth

No one knows when exactly one-celled bacteria – the earliest living organisms – started using sunlight to make food, the characteristic of green plants. It was the development of chlorophyll which was responsible for putting free oxygen into the atmosphere. From fossil evidence, it appears that the earliest chlorophyll-using organism were the cyanobacteria, commonly known as blue-green algae, which appeared almost 3,500 million years ago. Although called 'blue-green algae', cyanobacteria are not algae. But they were the first organisms to synthesise their own food by photosynthesis and give off oxygen as a waste product. From this, we may say that cyanobacteria, although not true plants, were one of the first plant-like organisms to appear on Earth. This primitive plant is the ancestor of many current day plants.

Direct evidence of cyanobacteria being the first living organisms to colonise the Earth is found in fossils known as stromatolites found in rocks 3,000 to 3,500 million years old. Stromatolites are layered deposits, mainly of limestone, formed by the growth of layer upon layer of cyanobacteria and are usually characterized by thin, alternating light and dark layers, found in typically 'mushroom-shaped' rocks.



Stromatolites are layered deposits, mainly of limestone, formed by the growth of layer upon layer of cyanobacteria.

First land plants

The earliest evidence of land plants and fungi appears in the fossil record around 435 million years ago. Before that, only the water – the oceans, shallow seas, and lakes, teeming with simple aquatic plants, invertebrates, and primitive jawless fishes – held the secret of life. Fungi and lichen – a mixture of algae and fungi – possibly helped green plants move on to land. That momentous step, which may have happened in many places in various ways, made possible the world we know. We owe our existence to the land plants that evolved subsequently – to the oxygen release into the atmosphere, the nutrients they make and store, the soil they build, the animals they feed and shelter.

But coming on to land from water was not an easy proposition. First, once on land the plants had to hold up against gravity, had to find a way to prevent drying out, and also devise a mechanism for moving water and chemicals around in the body to survive and grow.

The earliest land plants that were able to overcome these problems were the tiny mosses, liverworts, and hornworts. Collectively called bryophytes, they are a large group of seedless green plants found on every continent except Antarctica. Being tiny, they remain close to the ground, absorbing water and nutrients directly through their cells. Skinny threads called rhizoids, precursors of root systems, anchor them to the soil.

Among the earliest land plants were the tiny mosses.

It was only after plants evolved true root systems and veins to transport water and nutrients around could they grow very big. Giant tree ferns lifted their fronds up to the Sun; rush-like horsetails and club mosses developed tall spore-bearing cones. These new types of plants, collectively called pteridophytes (Greek for “fern plants”), changed Earth’s landscape dramatically.

Ferns changed the Earth’s landscape dramatically.

Bryophytes and pteridophytes may have conquered the land, but they still relied on a film of water for reproduction. It was only after the evolution of seed-bearing plants, some millions of years later, that plant species freed themselves from the need for water to get sperm and egg together for reproduction. Seed plants – the trees, flowers, and grasses so familiar to us – developed a novel way of packaging sperm in pollen that could be carried by wind to enable them also to reproduce at a distance.

Primary producers

Plants play the most important part in the cycle of nature. They are the primary producers that sustain all other life forms on Earth. This is so because plants are the only organisms that can make their own food. Animals, including humans, depend directly or indirectly on plants for their supply of food. All animals and the foods they eat can be traced back to plants.

Plants are also the source of oxygen that we breathe. Plants take energy from the Sun, carbon dioxide from the air, and water and minerals from the soil and turn them into food by photosynthesis. In the process they give off water and oxygen. Animals and other non-producers take in the oxygen and release carbon dioxide during respiration, thus completing the cycle. The cycles of photosynthesis and respiration help maintain the Earth's natural balance of oxygen, carbon dioxide, and water.

Sequoia tress of California can grow up to 88 metres tall and 9 metres in girth.

Diverse forms

By about 360 million years ago, there were already a wide variety of shapes and sizes of plants around. Today, more than 250,000 species comprise the Plant Kingdom, which includes all land plants: mosses, ferns, conifers, flowering plants, and so on. Some plants are so small they can barely be seen. Others are taller than skyscrapers. The sequoia trees of California, USA are among the largest living plants on Earth. Some stand over 88 metres high and measure over 9 metres wide.

The early green plants – mosses and ferns – did not produce seeds for reproduction. The earliest seed-bearing plants were the gymnosperms – non-flowering plants in which the seeds were not enclosed in an ovary. The first flowering plants – also called angiosperms – appeared around 145 million years ago. Today, angiosperms comprise about 90% of the plant kingdom. Although a number of flowering plants live in aquatic habitats and have adapted to the saline conditions of dry lake beds and salt marshes, no species live in the oceans.

The first flowering plants – also called angiosperms – appeared around 145 million years ago.

Besides being a source of oxygen and food, plants also play an important role in the shaping of the environment. Think of a place without plants. The only such places on Earth are the arctic wastelands, beyond the tree line on high mountains, really arid deserts, and the deep ocean. Everywhere else, from the tundra to the rainforest to the desert, to the continental shelves, you will find plants. In fact, when we think of a particular landscape, it is the plants which first come to mind. Try to picture a forest without trees, or a prairie without grasses. It is the plants which produce and maintain the terrestrial environment as we know it.

Rooted in soil

The plants that grow on land would not exist without the thin layer we call the soil. It not only provides plants with mechanical support or anchorage, it also provides mineral nutrients for plant growth. Water and air, trapped within the soil are used by the roots.

The soil is made up of weathered rock particles and decayed products of organic matter. Soil is not an inert, unchanging body. It is constantly being transformed by chemical and physical processes and by the activities of living organisms. When plants die, their decomposed remains are added to the soil. This helps to make the soil rich with nutrients.

Even as the soil provides support to land plants, plants, in turn, hold the soil together preventing erosion by wind and air and help in soil conservation. So if the vegetation cover is removed, as happens when forests are indiscriminately cut down and pastures overgrazed, soil is lost rapidly by blowing wind and flowing water, causing rapid silting of rivers, lakes, and reservoirs. When vegetation is removed adjoining desert areas the desert takes over the denuded areas, often turning arable and habitable land to desert. Soil erosion and desertification are major ecological problems today threatening agriculture in many parts of the world.

Plants are the primary habitat for thousands of other organisms. Animals live in, on, or under plants. Plants provide shelter and safety for animals. Plants also provide a place for animals to find other food. As a habitat, plants alter the climate. On a small scale, plants provide shade, help moderate the temperature, and protect animals from the wind. On a larger scale, such as in tropical rainforests, plants actually change the rainfall patterns over large areas of the Earth's surface by moderating atmospheric humidity.

Plants in our life

Plants are so interwoven into our lives that we often take them for granted. And not just for food and drink! Many plants are important sources of products that we use, including food, fibres, and medicines. Plants also help provide some of our energy needs. In many parts of the world, including India, wood is the primary fuel used by poor people to cook their meals and heat their homes. Many of the other types of fuel we use today, such as coal, natural gas, and gasoline, are also products of plants that lived millions of years ago. Try to imagine your life without plants or plant products. Even if we could discover alternative sources of food and other products, if all the plants on Earth were gone, we would suffocate within 11 years without oxygen.

The rapid deforestation in many parts of the world today is a serious threat to our environment. This is not only because they produce oxygen. Since green plants use up large volumes of carbon dioxide for photosynthesis, they act as an important sink for the gas. Cutting down forests not only takes away this sink, but burning wood also adds to the carbon dioxide load of the atmosphere. The rapid pace of industrialisation around the globe has already resulted in alarming rise in the carbon dioxide level in the atmosphere. Indiscriminate cutting of forests is aggravating the situation further.

A single tree can absorb up to 1,000 kilograms of carbon dioxide over its lifetime. So planting trees could be a cheap and viable way of reducing the level of carbon dioxide in the atmosphere. In India, fortunately, we have a long tradition of planting trees as part of the *vanomahotsavs* (forest festivals) during the rainy season. However, in the past several decades hundreds of thousands of hectares of forestland have been denuded for various reasons. Now it is time to undo the damage. The recent initiative of the Government of India to take up a countrywide afforestation drive under the "Green India" programme is a welcome step.

8

The Human Invasion

There have been several reports of the discovery of fossils claimed to be of modern human's 'true ancestors' from time to time. They include two, named Proconsul and *Kenyapithecus*, from Kenya; two, named *Ramapithecus* and *Sivapithecus*, from locations in India, Pakistan, and China; and two, named *Dryopithecus* and *Rudapithecus*, from Europe. These ape-like creatures lived at various times between about 8 and 20 million years ago. Of these the one that created a sensation and which was once regarded as modern human's oldest direct ancestor was the *Ramapithecus* (named after Lord Rama, the exiled prince in the epic Ramayana), fossils of the upper jaw of which were first found in the Siwalik Hills in India. But in the mid 1970s the

The Ramapithecus *was once regarded as modern human's oldest direct ancestor.*

support for *Ramapithecus* began to wane, when the discovery of fossils of *Australopithecus afarensis* showed that the hominid family most likely arose in Africa, not in Asia. Soon it became clear that most, if not all, of the hominid characteristics of *Ramapithecus* were actually the result of 'reconstructive wishful thinking' rather than hard fossil evidence. *Ramapithecus* was, after all, just another ape, a member of a group related to the orangutan.

As we know today, the ape-like creature of which we can claim to be direct descendants came much later – about 3 million years ago. This creature appeared after spells of climatic upheavals that swept through the world around that time and made the tree-dwellers come out in the open. It was indeed a question of life and death and those among the apes that could adapt to the changing environment came out winners. It was one of the successors of these plains-dwellers who would ultimately become our forefathers.

Between 5 and 6 million years ago, a catastrophic environmental change – a sharp fall in temperature – occurred that ended the peaceful life of many forest-dwellers including the early apes. They were confronted with a different kind of adversary – a sharp climatic change that led to rapid disappearance of the forests that were their only abode. It was this challenge that ultimately decided the fate of the tree-dwelling apes, forcing some of them to adapt to a life on ground and walk on two feet that would finally lead them towards humanhood.

Evidence of the profound global cooling that brought about large-scale disappearance of forests came from the analysis of deep-sea cores and terrestrial deposits of fossil pollens, and other geological records. According to one scenario, the drastic plunge in temperature – some believe by as much as 11°C – produced a rapid build-up of ice in Antarctica. This led to the locking up of so much water in the polar ice sheets that sea levels worldwide dropped by 50 to 60 metres. At the same time, the climate became so dry that rainfall was severely affected and in many places, especially in tropical Africa, lush forests gave way to open grasslands. As the forests disappeared the habitats of the early apes shrank alarmingly, threatening their very survival.

It is quite possible that the emergence of humanlike features, such as a flatter face, more level teeth and larger brain size also came about during the period the early apes were trying to come to terms with a more demanding and hostile life on the ground. They learned to walk upright, were forced to eat almost anything that came to hand, and learned the value of sharing their food with others – typical human traits.


Scientifically reconstructed face of an Australopithecus afarensis, *the earliest human ancestor to walk on two legs.*

Ape that walked

For scientists trying to probe the origins of the human race, discovery of the fossil remains of an adult female – who came to be known as 'Lucy' (scientific name *Australopithecus afarensis*) was a remarkable find on several counts. She was the most complete and the oldest ancestor of modern humans known up to that time. Moreover, the discovery of a part of the pelvis and the thigh bone helped establish beyond doubt that Lucy walked upright. Another notable feature was the alignment of the big toe on Lucy's foot with the other fingers – a characteristic of the human foot. Several more fossil remains of *A. Afarensis* have since been found.

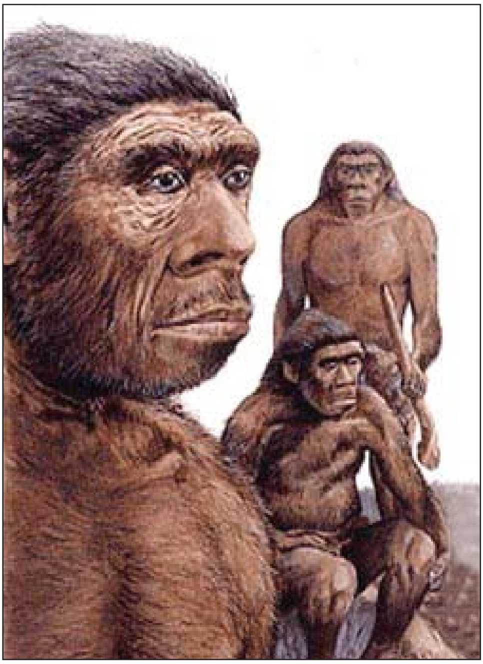
Being able to walk on two feet, *A. afarensis* had literally taken the 'first step' to humanhood, for it is now believed that the increase in brain size that ultimately led to the appearance of our species around 100,000 years ago, came later. It was only after the 'hands' became free for complex tasks such as tool making, that the need for a better, more capable brain arose.

The ability to stand and walk on two feet offers many advantages for a life on the plains. For example, it enables the individual to have a much better view of the surroundings and to get advance warning of predators. It also makes it easier to find food. Besides, the now freed 'hands' made it possible to collect the food and carry it to another place – to the family group to share, perhaps. It also made possible the use of 'tools' and 'weapons, which would turn out to be a tremendous advantage. So it was around 4 million years ago, that the earliest human ancestors broke away from a life on the branches of forest trees, compelled by environmental upheavals, and started on a different kind of life on the plains.

The fossil record for the interval between 2.4 million years ago and the present includes the skeletal remains of several species assigned to the genus *Homo*. Remains of *Homo habilis* (meaning 'handy man'), considered to be the first true member of the human family, were discovered in 1963 at a place in Africa called the Olduvai Gorge in Kenya. The 1.8-million-year-old fragments belonged a new genus, which had features resembling humans more than apes. It was the first tool-making ancestor of modern humans. By the time *Homo habilis* died out some 1.5 million years ago a new, more advanced human ancestor had appeared on the scene. Named *Homo erectus*, or the 'upright man', this large-brained ancestor of ours was a true wanderer. It became the first early human to leave the cradle of the African continent and spread around the world.

The Neanderthal man

Now it appears that between 400,000 and 200,000 years ago, there began a remarkable change in *Homo erectus*. There was the beginning of a much bigger increase in brain size and thinning of the skull bone, till by about 250,000 ago, when the earliest Homo sapiens appeared. They looked like modern



Neanderthal man looked like modern humans in all except minor anatomical humans in all except minor anatomical details and were named *Homo sapiens neanderthaenslis*, or Neanderthal man. By 120,000 years ago, *Homo sapiens sapiens* or modern humans had appeared. Thus by 100,000 years ago, two subspecies existed, although not necessarily side by side. Neanderthals moved out of Africa first, around 250,000 years ago. Modern humans followed more than 200,000 years later.

The Neanderthal man was the closest kin of modern humans. When the first fossil skeleton of a Neanderthal was discovered in a limestone cave near Dusseldorf in the Neander Valley in Germany in 1856, no one had any idea of human evolution. The knowledge that modern humans have evolved from some ape-like creature had still not taken root. So, when limestone miners found pieces of what looked like a human skeleton, no one really understood its real importance. From fossil records, we know that Neanderthals roamed as far north as Britain and as far south as Spain in Europe and later extended east into Central Asia and West Asia. But their population was never very large – at anyone time, probably never exceeding some tens of thousands.

It is now widely accepted that that both modern humans and the Neanderthal man have evolved from the same stock – *Homo erectus* – in Africa. In fact, from the analysis of the genetic material called DNA found in the mitochondria of cells, scientists have concluded that the ancestry of every living person on this Earth can be traced back to a female who lived in Africa some 200,000 years ago. Such a deduction is possible because mitochondrial DNA is passed on from mother to offspring unchanged; unlike the DNA found in cell nucleus half of which is inherited from each parent. But mitochondrial DNA does change with time due to natural mutations, and the rate at which these changes are brought about is more or less constant. By comparing the amount of variation in mitochondrial DNA in different populations, therefore, it is possible to work out the length of time that has elapsed since that population originated. So it is; we are all descendants of a common mother, the African 'Eve' who lived some 200,000 years ago.

Cro-Magnon man was the first true human species to settle in Europe around 35,000 years ago. These ancestors of ours were far advanced than the Neanderthals in tool-making and hunting skills and had extraordinary artistic ability. But his origins possibly go back to around 100,000 years ago, in Africa, as has been revealed by the discovery of a human skull, some 110,000 years old, in a cave in South Africa.

After spreading through Europe and Southeast Asia, populations of modern humans moved into new continents – North America in the north and Australia in the south. From stone tools recovered from sites in the two continents it appears that our ancestors first arrived in Australia and New Guinea (then joined by a land bridge) some 50,000 years ago, crossing at least 100 kilometres of open sea from southeast Asia.

Migration to North America took place much later – around 15,000 years ago – and it may have been over a land route. From past records of glaciations and consequent falls in sea levels, we know that between 25,000 and 12,000 years ago, the continents of Asia and North America were joined by a landmass, now called Beringia, where Bering Strait is located today. Small groups of Asian hunters and their families may have crossed over to North America while following the mammoth herds during their seasonal migrations. When the sea level rose again some 12,000 years ago some migrants may have remained back in Alaska, later moving south to colonise rest of North America and South America.

The first harvest

It is difficult to pin down the moment of birth of truly modern humans. By convention, the 40,000-year-old skeletons of Cro-Magnon are considered the first examples of modern humans. But not everyone agrees. It is argued that it was only when agriculture was becoming well established that modern man truly arrived on the scene. It may well be so, for it was only after humans gave up the nomadic life of foraging and hunting and began a settled life that cultures flourished. They developed skills to become artists, scientists, poets, novelists, explorers and what not. It was only after our ancestors learned to live a settled life that great civilisations evolved, which changed the face of the Earth forever.

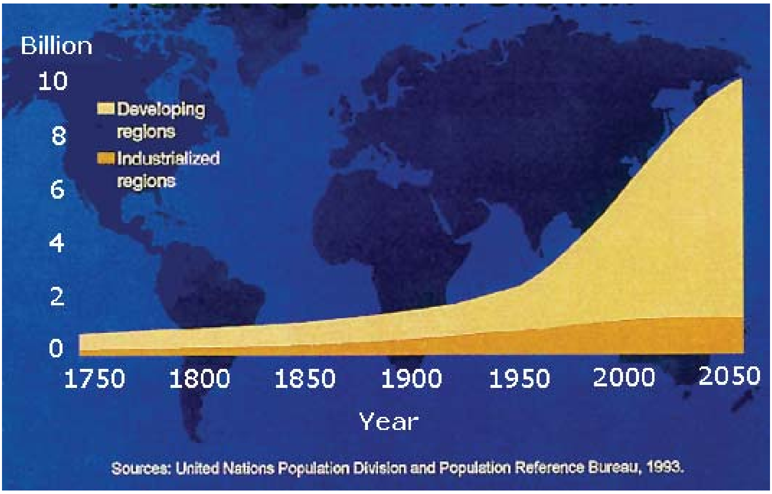
Twenty thousand years ago, our ancestors, who had by then reached almost all corners of the globe, were mostly foragers and hunters, depending mainly on wild animals and wild fruits and tubers for food. As millennia passed by, our wits got a little sharper and, most important of all, our social and cultural fabric grew more elaborate and richly patterned, until, about 10,000 years ago, when we stood at the threshold of a revolution that was to transform the world.

Around 12,000 years ago the last Ice Age was losing its grip over the continent. The vast ice sheet that covered much of northern Europe was receding. The climate was turning more salubrious. It was around this time that our ancestors discovered a new capability. They discovered that they could grow crops for food without having to forage and gather it from the wild. It marked the beginning of agriculture that had profound impact on the future of humankind.

Burgeoning population

With the coming of agriculture it was possible to produce more food, which also meant ability to feed more people. No wonder, with the availability of assured food supply the world population started rising sharply. From just one million in 10000 BCE it shot up to 27 million by 2000 BCE. By AD 1000 it was 254 million. By AD 2000 the world population had crossed the 6,000 million mark and is expected to nearly double by 2050.

To meet the growing demand of food, shelter and energy for the burgeoning population large tracts of forest land are being denuded. Forests were also cut to clear land for growing crops. Overgrazing by cattle has turned vast tracts of land into wasteland. Earth's environment was being degraded without check. The Industrial Revolution of the late 18th century added another threat – rising levels of the greenhouse gas carbon dioxide in the atmosphere. Since the beginning of the Industrial Revolution the carbon dioxide level in the atmosphere has already increased by more than 100 parts per million (ppm), to over 382 ppm, and it is still increasing. One effect of this increase has been the steady rise in Earth's average temperature, leading to severe



Sources: United Nations Population Division and Population Reference Bureau, 1993.

The world population is likely to cross the 12 billion mark by 2050.

disruption of weather systems around the world.

Impact on Earth's biosphere

During the past hundred years or so, human population growth and associated activities have had tremendous impact on the Earth System, especially a strong negative impact on the Earth's biosphere. This is despite the fact that humans constitute only one of 4,500 species of mammals that exist on Earth and the human species is only one species in the estimated 30 to 100 million species that form the Earth's complex biosphere. Further, humans are totally dependent on the biosphere for food, oxygen, and other necessities of life.

Among all the species that inhabit our planet, the human species is unique in that it is the only one capable of logical thinking and speech and written communication. This capability has enabled humans to become so successful at modifying their environment that many of the natural limitations on the expansion of populations of our fellow animals have been overcome by technological and cultural innovations. As a consequence, the overwhelming and expanding human presence leaves less and less room in the environment for other forms of life. It is said that the 21st century will be a pivotal time in the fate of Earth's biosphere. The damage that humans have wrought to the lithosphere will slowly recover over time, but the damage inflicted by humans to the biosphere may not recover so easily and may even spell doom for many a species, some of which are already on verge of extinction. Will humans effectively use the new knowledge of natural and human history to stop further degradation of Earth's ecosystems and extinction of its biota? Only time will tell.

Timeline of Life on Earth

Pre-Cambrian Period (4,500-570 million years ago)

Continents, atmosphere, oceans formed. First single-celled organisms known as prokaryotes – the ancestors of present-day bacteria and cyanobacteria arise. Atmospheric oxygen increases. Organisms known as eukaryotes, possessing cellular nucleus and nuclear membrane appear. Simple plants and invertebrate animals – algae, bacteria, jellyfish, flagellates, amoebas, worms, and sponges appear.

Palaeozoic Era (570-250 million years ago)

Cambrian Period (570-500 million years ago)

Multicellular life proliferates. First trilobites, brachiopods, nautiloids (mollusks with spiral shells), clams, snails, crustaceans, gastropods, corals, protozoans appear.

Ordovician Period (500-438 million years ago)

Primitive life appears on land. Vertebrates appear in the ocean. First starfish, sea urchins, blastoids, bryozoa, jawless fish, echinoids appear.

Silurian Period (438-408 million years ago)

The first plants and insects appear on land. Ferns, sharks, bony fish, and scorpions appear.

Devonian Period (408-360 million years ago)

Spiders, mites, and amphibians appear.

Carboniferous Period (360-286 million years ago)

First true reptiles appear. Synapsids (extinct mammal-like reptile with strong jaw muscles and large jaws) appear. Coal begins to form.

Permian Period (286-250 million years ago)

Abundant life wiped out by mass extinction. 90 percent of all organisms die out. Reptiles with large sail-like fins appear.

Mesozoic Era (250-65 million years ago)

Triassic Period (250-205 million years ago)

Cycads (tropical trees resembling palm trees) appear. Small dinosaurs, icthyosaurs, plesiosaurs appear. First turtles, lizards, and mammals appear.

Jurassic Period (205-138 million years ago)

Huge dinosaurs, flying pterosaurs (oldest known birds), first squids, frogs, and salamanders appear.

Cretaceous Period (138-65 million years ago)

Dinosaurs dominate the Earth. First flowering plants, snakes, and modern fish appear. Dinosaurs wiped out by asteroid impact and consequent fallout of debris.

Cenozoic Era (65 million years ago to the present)

Tertiary Period (65-1.8 million years ago)

Paleocene Epoch (65-55.5 million years ago)

Mammals inherit the Earth. Chief among the early mammals are marsupials, insectivores, lemuroids, creodonts (the carnivorous stock ancestral to all cats and dogs), and primitive hoofed animals.

Eocene Epoch (55.5-33.7 million years ago)

Ancestral forms of the horse, rhinoceros, camel and other modern groups such as bats, primates, and squirrel-like rodents appear simultaneously in Europe and North America. Mammals adapt to marine life.

Oligocene Epoch (33.7-23.8 million years ago)

Rhinoceros rank as the largest land mammals of any age. Elephants, cats, dogs, monkeys and great apes make their debut on the stage of life. First grasses appear.

Miocene Epoch (23.8-5.3 million years ago)

Global climate cools, fostering the establishment of the Antarctic ice sheet. Raccoons and weasels make their first appearance. Large apes roam Africa and southern Europe. First hominids (erect bipedal primates whose only living descendant is *Homo sapiens*) appear.

Pleiocene Epoch (5.3-1.8 million years ago)

Climate becomes cooler and drier. Mammals are well-established as the dominant terrestrial life form, and the rapid evolution of one group, the primates, produces species considered direct ancestors of modern humans. First Australopithecines (early hominids that lived in southern and eastern Africa and showed similarities to both apes and humans) appear.

Quaternary Period (1.8 million years ago - present)

Pleistocene Epoch (1.8 million years ago - 8,000 years ago)

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