FUNDAMENTALS OF PHYSICAL GEOGRAPHY

TEXTBOOK FOR CLASS XI

विद्यया ऽमृतमश्नुते

एन सी ई आर टी
NCERT

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OFFICES OF THE PUBLICATION DIVISION, NCERT

NCERT Campus
Sri Aurobindo Marg
New Delhi 110 016 **Phone : 011-26562708**

108, 100 Feet Road
Hosdakere Halli Extension
Banashankari III Stage
Bengaluru 560 085 **Phone : 080-26725740**

Navjivan Trust Building
P.O.Navjivan
Ahmedabad 380 014 **Phone : 079-27541446**

CWC Campus
Opp. Dhankal Bus Stop
Panihati
Kolkata 700 114 **Phone : 033-25530454**

CWC Complex
Maligaon
Guwahati 781 021 **Phone : 0361-2674869**

Publication Team

Head, Publication Division	:	*Ashok Srivastava*
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Chief Business Manager	:	*Gautam Ganguly*
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Cover
Shweta Rao

Illustrations
K.N. Prudhvi Raju
Nidhi Wadhwa
Dilip Kumar

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FOREWORD

The National Curriculum Framework (NCF), 2005, recommends that children's life at school must be linked to their life outside the school. This principle marks a departure from the legacy of bookish learning which continues to shape our system and causes a gap between the school, home and community. The syllabi and textbooks developed on the basis of NCF signify an attempt to implement this basic idea. They also attempt to discourage rote learning and the maintenance of sharp boundaries between different subject areas. We hope these measures will take us significantly further in the direction of a child-centred system of education outlined in the National Policy on Education (1986).

The success of this effort depends on the steps that school principals and teachers will take to encourage children to reflect on their own learning and to pursue imaginative activities and questions. We must recognise that, given space, time and freedom, children generate new knowledge by engaging with the information passed on to them by adults. Treating the prescribed textbook as the sole basis of examination is one of the key reasons why other resources and sites of learning are ignored. Inculcating creativity and initiative is possible if we perceive and treat children as participants in learning, not as receivers of a fixed body of knowledge.

These aims imply considerable change in school routines and mode of functioning. Flexibility in the daily time-table is as necessary as rigour in implementing the annual calendar so that the required number of teaching days are actually devoted to teaching. The methods used for teaching and evaluation will also determine how effective this textbook proves for making children's life at school a happy experience, rather than a source of stress or boredom. Syllabus designers have tried to address the problem of curricular burden by restructuring and reorienting knowledge at different stages with greater consideration for child psychology and the time available for teaching. The textbook attempts to enhance this endeavour by giving higher priority and space to opportunities for contemplation and wondering, discussion in small groups, and activities requiring hands-on experience.

The National Council of Educational Research and Training (NCERT) appreciates the hard work done by the textbook development committee responsible for this book. We wish to thank the Chairperson of the advisory committee for textbooks in Social Sciences, at the higher secondary level, Professor Hari Vasudevan and the Chief Advisor for this book, Professor M.H. Qureshi for guiding the work of this committee. Several teachers contributed to the development of this textbook; we are grateful to their principals for making this possible. We are indebted to the institutions and organisations which have generously permitted us to draw upon their resources, material and personnel. We are especially grateful to the members of the National Monitoring Committee, appointed by the Department of Secondary and Higher Education, Ministry of Human Resource Development under the Chairpersonship of Professor Mrinal Miri and Professor G.P. Deshpande, for their valuable time and contribution. As an organisation committed to systemic reform and continuous improvement in the quality of its products, NCERT welcomes comments and suggestions which will enable us to undertake further revision and refinement.

Director
National Council of Educational
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New Delhi
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Textbook Development Committee

Chairperson, Advisory Committee for Textbooks in Social Sciences at the Higher Secondary Level

Hari Vasudevan, *Professor,* Department of History, University of Calcutta, Kolkata

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S. R. Jog, *Professor (Retd.),* Department of Geography, University of Pune, Pune

Member-Coordinator

Aparna Pandey, *Lecturer*, Geography, DESSH, NCERT, New Delhi

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CONTENTS

CONSTITUTION OF INDIA

Part III (Articles 12 – 35)

(Subject to certain conditions, some exceptions and reasonable restrictions)

guarantees these

Fundamental Rights

Right to Equality

- before law and equal protection of laws;
- irrespective of religion, race, caste, sex or place of birth;
- of opportunity in public employment;
- by abolition of untouchability and titles.

Right to Freedom

- of expression, assembly, association, movement, residence and profession;
- of certain protections in respect of conviction for offences;
- of protection of life and personal liberty;
- of free and compulsory education for children between the age of six and fourteen years;
- of protection against arrest and detention in certain cases.

Right against Exploitation

- for prohibition of traffic in human beings and forced labour;
- for prohibition of employment of children in hazardous jobs.

Right to Freedom of Religion

- freedom of conscience and free profession, practice and propagation of religion;
- freedom to manage religious affairs;
- freedom as to payment of taxes for promotion of any particular religion;
- freedom as to attendance at religious instruction or religious worship in educational institutions wholly maintained by the State.

Cultural and Educational Rights

- for protection of interests of minorities to conserve their language, script and culture;
- for minorities to establish and administer educational institutions of their choice.

Right to Constitutional Remedies

- by issuance of directions or orders or writs by the Supreme Court and High Courts for enforcement of these Fundamental Rights.

UNIT I

GEOGRAPHY AS A DISCIPLINE

This unit deals with

- *Geography as an integrating discipline; as a science of spatial attributes*
- *Branches of geography; importance of physical geography*

CHAPTER

1

Geography as a Discipline

You have studied geography as one of the components of your Social Science course upto the secondary stage. You are already aware of some of the phenomena of geographical nature in the world and its different parts. Now, you will study 'Geography' as an independent subject and learn about the physical environment of the earth, human activities and their interactive relationships. Therefore, a pertinent question you can ask at this stage is — Why should we study geography? We live on the surface of the earth. Our lives are affected by our surroundings in many ways. We depend on the resources to sustain ourselves in the surrounding areas. Primitive societies subsisted on 'natural means of subsistence', i.e. edible plants and animals. With the passage of time, we developed technologies and started producing our food using natural resources such as land, soil and water. We adjusted our food habits and clothing according to the prevailing weather conditions. There are variations in the natural resource base, technological development, adaptation with and modification of physical environment, social organisations and cultural development. As a student of geography, you should be curious to know about all the phenomena which vary over space. You learn about the diverse lands and people. You should also be interested in understanding the changes which have taken place over time. Geography equips you to appreciate diversity and investigate into the causes responsible for creating such variations over time and space. You will develop skills to understand the globe converted into maps and have a visual sense of the earth's surface. The understanding and the skills obtained in modern scientific techniques such as GIS and *computer cartography* equip you to meaningfully contribute to the national endeavour for development.

Now the next question which you may like to ask is — What is geography? You know that earth is our home. It is also the home of many other creatures, big and small, which live on the earth and sustain. The earth's surface is not uniform. It has variations in its physical features. There are mountains, hills, valleys, plains, plateaus, oceans, lakes, deserts and wilderness. There are variations in its social and cultural features too. There are villages, cities, roads, railways, ports, markets and many other elements created by human beings across the entire period of their cultural development.

This variation provides a clue to the understanding of the relationship between the physical environment and social/cultural features. The physical environment has provided the stage, on which human societies enacted the drama of their creative skills with the tools and techniques which they invented and evolved in the process of their cultural development. Now, you should be able to attempt the answer of the question posed earlier as to "What is geography"? In very simple words, it can be said that geography is the description of the earth. The term *geography* was first coined by *Eratosthenese*, a Greek scholar (276-194 BC.). The word has been derived from two roots from Greek language *geo* (earth) and *graphos* (description).

Put together, they mean description of the earth. The earth has always been seen as the abode of human beings and thus, scholars defined geography as, “the description of the earth as the abode of human beings”. You are aware of the fact that reality is always multifaceted and the ‘earth’ is also multi-dimensional, that is why many disciplines from natural sciences such as geology, pedology, oceanography, botany, zoology and meteorology and a number of sister disciplines in social sciences such as economics, history, sociology, political science, anthropology, etc. study different aspects of the earth’s surface. Geography is different from other sciences in its subject matter and methodology but at the same time, it is closely related to other disciplines. Geography derives its data base from all the natural and social sciences and attempts their synthesis.

We have noted that there exist variations over the surface of the earth in its physical as well as cultural environment. A number of phenomena are similar and many are dissimilar. It was, therefore, logical to perceive geography as the study of *areal differentiation*. Thus, geography was perceived to study all those phenomena which vary over space. Geographers do not study only the variations in the phenomena over the earth’s surface (space) but also study the associations with the other factors which cause these variations. For example, cropping patterns differ from region to region but this variation in cropping pattern, as a phenomenon, is related to variations in soils, climates, demands in the market, capacity of the farmer to invest and technological inputs available to her/him. Thus, the concern of geography is to find out the causal relationship between any two phenomena or between more than one phenomenon.

A geographer explains the phenomena in a frame of cause and effect relationship, as it does not only help in interpretation but also foresees the phenomena in future.

The geographical phenomena, both the physical and human, are not static but highly dynamic. They change over time as a result of the interactive processes between *ever changing earth and untiring and ever-active human beings*. Primitive human societies were directly dependent on their immediate environment. Geography, thus, is concerned with the study of *Nature* and *Human* interactions as an integrated whole. ‘Human’ is an integral part of ‘nature’ and ‘nature’ has the imprints of ‘human’. ‘Nature’ has influenced different aspects of human life. Its imprints can be noticed on food, clothing, shelter and occupation. Human beings have come to terms with nature through adaptation and modification. As you already know, the present society has passed the stage of primitive societies, which were directly dependent on their immediate physical environment for sustenance. Present societies have modified their natural environment by inventing and using technology and thus, have expanded the horizon of their operation by appropriating and utilising the resources provided by nature. With the gradual development of technology, human beings were able to loosen the shackles of their physical environment. Technology helped in reducing the harshness of labour, increased labour efficiency and provided leisure to human beings to attend to the higher needs of life. It also increased the scale of production and the mobility of labour.

The interaction between the physical environment and human beings has been very succinctly described by a poet in the following dialogue between ‘human’ and ‘nature’ (God). *You created the soil, I created the cup, you created night, I created the lamp. You created wilderness, hilly terrains and deserts; I created flower beds and gardens.* Human beings have claimed their contribution using natural resources. With the help of technology, human beings moved from the stage of necessity to a stage of freedom. They have put their imprints everywhere and created new possibilities in collaboration with nature. Thus, we now find *humanised nature* and *naturalised human beings* and geography studies this interactive relationship. The space got organised with the help of the means of transportation and communication network. The links (routes) and nodes (settlements of all types and hierarchies) integrated the space and gradually, it got organised. As a social science discipline, geography studies the 'spatial organisation' and 'spatial integration'.

Geography as a discipline is concerned with three sets of questions:

(i) Some questions are related to the identification of the patterns of natural and cultural features as found over the surface of the earth. These are the questions about *what?*

(ii) Some questions are related to the distribution of the natural and human/cultural features over the surface of the earth. These are the questions about *where?*

Taken together, both these questions take care of distributional and locational aspects of the natural and cultural features. These questions provided inventorised information of what features and where located. It was a very popular approach during the colonial period. These two questions did not make geography a scientific discipline till the third question was added.

(iii) The third question is related to the explanation or the causal relationships between features and the processes and phenomena. This aspect of geography is related to the question, *why?*

Geography as a discipline is related to space and takes note of spatial characteristics and attributes. It studies the patterns of distribution, location and concentration of phenomena over space and interprets them providing explanations for these patterns. It takes note of the associations and inter-relationships between the phenomena over space and interprets them providing explanations for these patterns. It also takes note of the associations and inter-relationships between the phenomena resulting from the dynamic interaction between human beings and their physical environment.

Geography as an Integrating Discipline

Geography is a discipline of synthesis. It attempts *spatial synthesis*, and history attempts *temporal synthesis*. Its approach is holistic in nature. It recognises the fact that the world is a system of interdependencies. The present world is being perceived as a global village. The distances have been reduced by better means of transportation increasing accessibility. The audio-visual media and information technology have enriched the data base. Technology has provided better chances of monitoring natural phenomena as well as the economic and social parameters. Geography as an integrating discipline has interface with numerous natural and social sciences. All the sciences, whether natural or social, have one basic objective, of *understanding the reality*. Geography attempts to comprehend the associations of phenomena as related in sections of reality. Figure 1.1 shows the relationship of geography with other sciences. Every discipline, concerned with scientific knowledge is linked with geography as many of their elements vary over space. Geography helps in understanding the reality in totality in its spatial perspective. Geography, thus, not only takes note of the differences in the phenomena from place to place but integrates them holistically which may be different at other places. A geographer is required to have a broad understanding of all the related fields, to be able to logically integrate them. This integration can be understood with some examples. Geography influences historical events. Spatial distance itself has been a very potent factor to alter the course of history of the world. Spatial depth provided defence to many countries, particularly in the last century. In traditional warfare, countries with large size in area, gain time at the cost of space. The defence provided by oceanic expanse around the countries of the new world has protected them from wars being imposed on their soil. If we look at the historical events world over, each one of them can be interpreted geographically.

In India, Himalayas have acted as great barriers and provided protection but the passes provided routes to the migrants and invaders from Central Asia. The sea coast has encouraged contact with people from East and Southeast Asia, Europe and Africa. Navigation technology helped European countries to colonise a number of countries of Asia and Africa, including India as they got accessibility through oceans. The geographical factors have modified the course of history in different parts of the world.

Every geographical phenomenon undergoes change through time and can be explained temporally. The changes in landforms, climate, vegetation, economic activities occupations and cultural developments have followed a definite historical course. Many geographical features result from the decision making process by different institutions at a particular point of time. It is possible to convert time in terms of space and space in terms of time. For example, it can be said that place A is 1,500 km from place B or alternately, it can also be said that place A is two hours away (if one travels by plane) or seventeen hours away (if one travels by a fast moving train). It is for this reason, time is an integral part of geographical studies as the fourth dimension. Please mention other three dimensions?

Figure1.1 amply depicts the linkages of geography with different natural and social sciences. This linkage can be put under two segments.

Physical Geography and Natural Sciences

All the branches of physical geography, as shown in Figure 1.1, have interface with natural sciences. The traditional physical geography is linked with geology, meteorology, hydrology and pedology, and thus, geomorphology, climatology, oceanography and soil geography respectively have very close link with the natural sciences as these derive their data from these sciences. Bio-Geography is closely related to botany, zoology as well as ecology as human beings are located in different locational niche.

A geographer should have some proficiency in mathematics and art, particularly in drawing maps. Geography is very much linked with the study of astronomical locations and deals with latitudes and longitudes. The shape of the earth is *Geoid* but the basic tool of a geographer is a map which is two dimensional representation of the earth. The problem of converting geoids into two dimensions can be tackled by projections constructed graphically or mathematically. The cartographic and quantitative techniques require sufficient proficiency in mathematics, statistics and econometrics. Maps are prepared through artistic imagination. Making sketches, mental maps and cartographic work require proficiency in arts.

Geography and Social Sciences

Each social science sketched in Figure 1.1 has interface with one branch of geography. The relationships between geography and history have already been outlined in detail. Every discipline has a philosophy which is the *raison d'etre* for that discipline. Philosophy provides roots to a discipline and in the process of its evolution, it also experiences distinct historical processes. Thus, the history of geographical thought as mother branch of geography is included universally in its curricula. All the social science disciplines, viz. sociology, political science, economics and demography study different aspects of social reality. The branches of geography, viz. social, political, economic and population and settlements are closely linked with these disciplines as each one of them has spatial attributes. The core concern of political science is territory, people and sovereignty while political geography is also interested in the study of the state as a spatial unit as well as people and their political behaviour. Economics deals with basic attributes of the economy such as production, distribution, exchange and consumption. Each of these attributes also has spatial aspects and here comes the role of economic geography to study the spatial aspects of production, distribution, exchange and consumption. Likewise, *population geography* is closely linked with the discipline of *demography*.

The above discussion shows that geography has strong interface with natural and social sciences. It follows its own methodology of study which makes it distinct from others. It has osmotic relationship with other disciplines. While all the disciplines have their own individual scope, this individuality does not obstruct the flow of information as in case of all cells in the body that have individual identity separated by membranes but the flow of blood is not obstructed. Geographers use data obtained from sister disciplines and

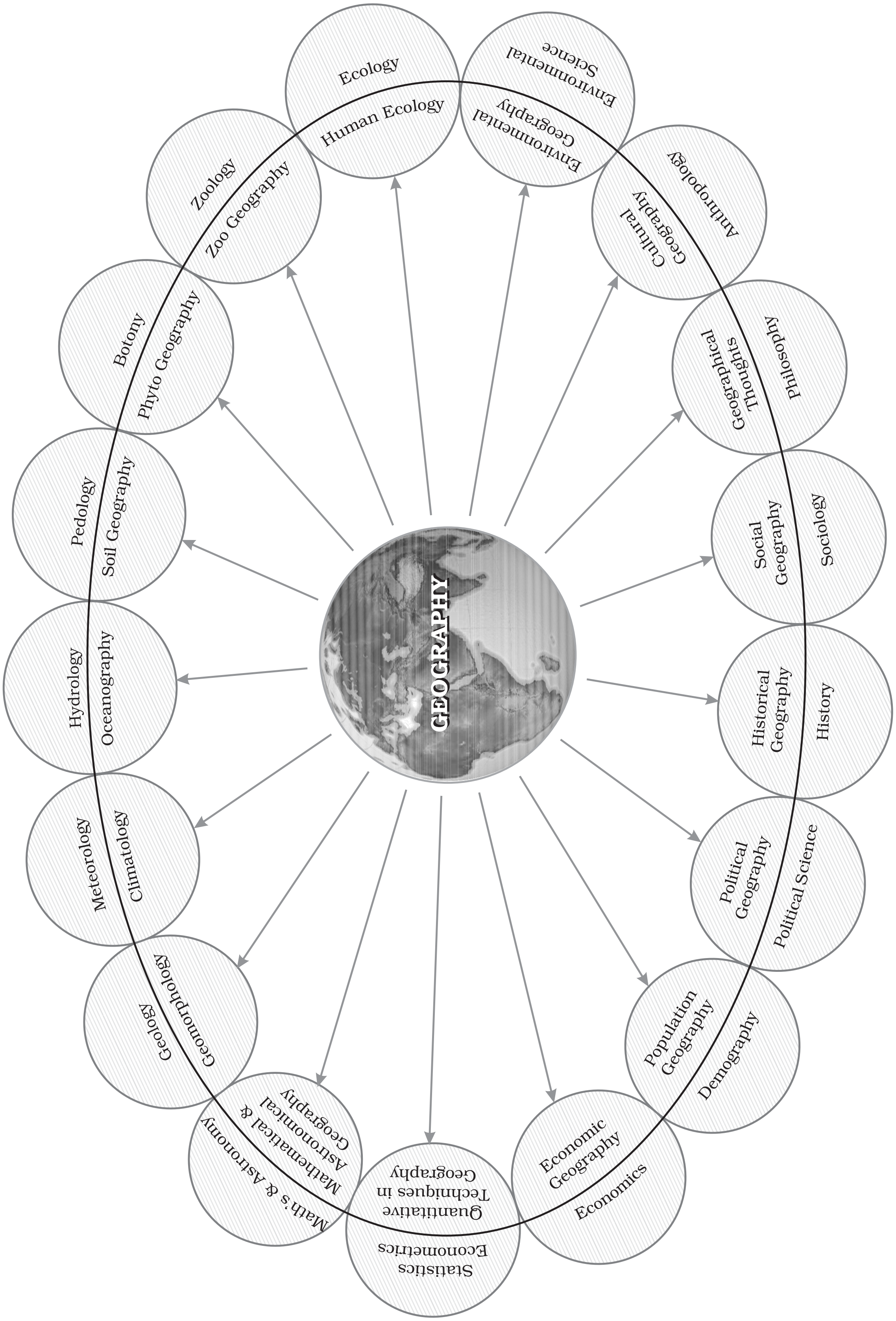


Figure 1.1 : Geography and its relation with other subjects

attempt synthesis over space. Maps are very effective tools of geographers in which the tabular data is converted into visual form to bring out the spatial pattern.

BRANCHES OF GEOGRAPHY

Please study Figure 1.1 for recapitulation. It has very clearly brought out that geography is an interdisciplinary subject of study. The study of every subject is done according to some approach. The major approaches to study geography have been (i) Systematic and (ii) Regional. The systematic geography approach is the same as that of general geography. This approach was introduced by *Alexander Von Humboldt*, a German geographer (1769-1859) while regional geography approach was developed by another German geographer and a contemporary of Humboldt, *Karl Ritter* (1779-1859).

In systematic approach (Figure 1.2), a phenomenon is studied world over as a whole, and then the identification of typologies or spatial patterns is done. For example, if one is interested in studying natural vegetation, the study will be done at the world level as a first step. The typologies such as equatorial rain forests or softwood conical forests or monsoon forests, etc. will be identified, discussed and delimited. In the regional approach, the world is divided into regions at different hierarchical levels and then all the geographical phenomena in a particular region are studied. These regions may be natural, political or designated region. The phenomena in a region are studied in a holistic manner searching for unity in diversity.

Dualism is one of the main characteristics of geography which got introduced from the very beginning. This dualism depended on the aspect emphasised in the study. Earlier scholars laid emphasis on physical geography. But human beings are an integral part of the earth's surface. They are part and parcel of nature. They also have contributed through their cultural development. Thus developed human geography with emphasis on human activities.

BRANCHES OF GEOGRAPHY (BASED ON SYSTEMATIC APPROACH)

1. Physical Geography

(i) *Geomorphology* is devoted to the study of landforms, their evolution and related processes.

(ii) *Climatology* encompasses the study of structure of atmosphere and elements of weather and climates and climatic types and regions.

(iii) *Hydrology* studies the realm of water over the surface of the earth including oceans, lakes, rivers and other water bodies and its effect on different life forms including human life and their activities.

(iv) *Soil Geography* is devoted to study the processes of soil formation, soil types, their fertility status, distribution and use.

2. Human Geography

(i) *Social/Cultural Geography* encompasses the study of society and its spatial dynamics as well as the cultural elements contributed by the society.

(ii) *Population and Settlement Geography* (Rural and Urban). It studies population growth, distribution, density, sex ratio, migration and occupational structure etc. Settlement geography studies the characteristics of rural and urban settlements.

(iii) *Economic Geography* studies economic activities of the people including agriculture, industry, tourism, trade, and transport, infrastructure and services, etc.

(iv) *Historical Geography* studies the historical processes through which the space gets organised. Every region has undergone some historical experiences before attaining the present day status. The geographical features also experience temporal changes and these form the concerns of historical geography.

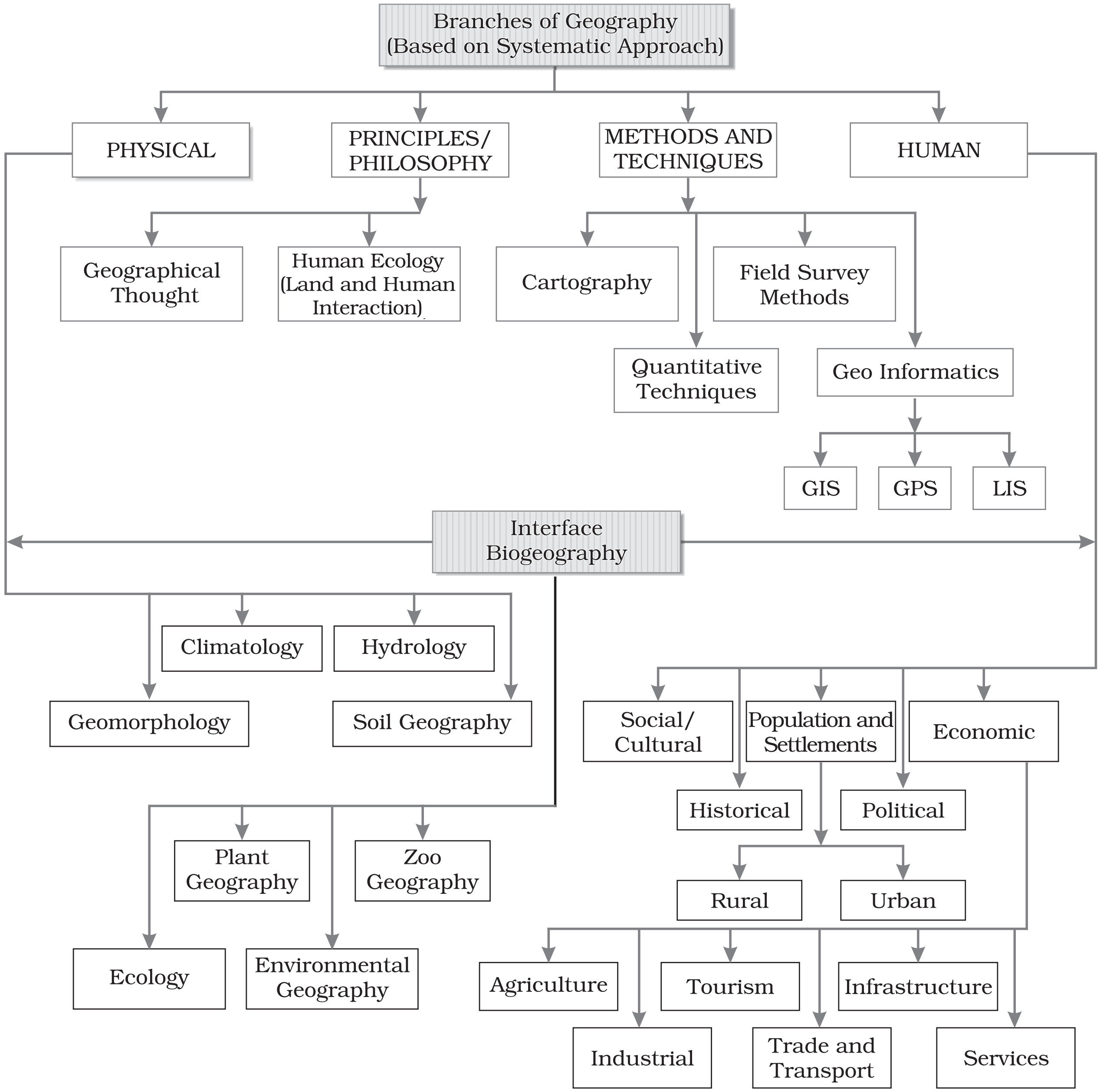


Figure 1.2 : Branches of geography based on systematic approach

(v) *Political Geography* looks at the space from the angle of political events and studies boundaries, space relations between neighbouring political units, delimitation of constituencies, election scenario and develops theoretical *framework* to understand the political behaviour of the population.

3. Biogeography

The interface between physical geography and human geography has lead to the development of Biogeography which includes:

(i) *Plant Geography* which studies the spatial pattern of natural vegetation in their habitats.

(ii) *Zoo Geography* which studies the spatial patterns and geographic characteristics of animals and their habitats.
(iii) *Ecology /Ecosystem* deals with the scientific study of the habitats characteristic of species.
(iv) *Environmental Geography* concerns world over leading to the realisation of environmental problems such as land gradation, pollution and concerns for conservation has resulted in the introduction of this new branch in geography.

Branches of Geography based on Regional Approach (Figure 1.3)

1. **Regional Studies/Area Studies**
   Comprising *Macro*, *Meso* and *Micro* Regional Studies
2. **Regional Planning**
   Comprising Country/Rural and Town/ Urban Planning
3. **Regional Development**
4. **Regional Analysis**
   There are two aspects which are common to every discipline, these are:
   (i) Philosophy
      (a) Geographical Thought
      (b) Land and Human Interaction/ Human Ecology
   (ii) Methods and Techniques
      (a) Cartography including Computer Cartography
      (b) Quantitative Techniques/Statistical Techniques
      (c) Field Survey Methods
      (d) Geo-informatics comprising techniques such as Remote Sensing, GIS, GPS, etc.

The above classification gives a comprehensive format of the branches of geography. Generally geography curricula is taught and learnt in this format but this format is not static. Any discipline is bound to grow with new ideas, problems, methods and techniques. For example, what was once manual cartography has now been transformed into computer cartography. Technology has enabled scholars to handle large quantum of data. The internet provides extensive information. Thus, the capacity to attempt analysis has increased tremendously. GIS has further opened vistas of knowledge. GPS has become a handy tool to find out exact locations. Technologies have enhanced the capacity of attempting synthesis with sound theoretical understanding.

You will learn some preliminary aspects of these techniques in your book, *Practical work in Geography – Part I* (NCERT, 2006). You will continue to improve upon your skills and learn about their application.

Physical Geography and its Importance

This chapter appears in the book entitled *Fundamentals of Physical Geography*. The contents of the book clearly reflect its scope. It is therefore, appropriate to know the importance of this branch of geography.

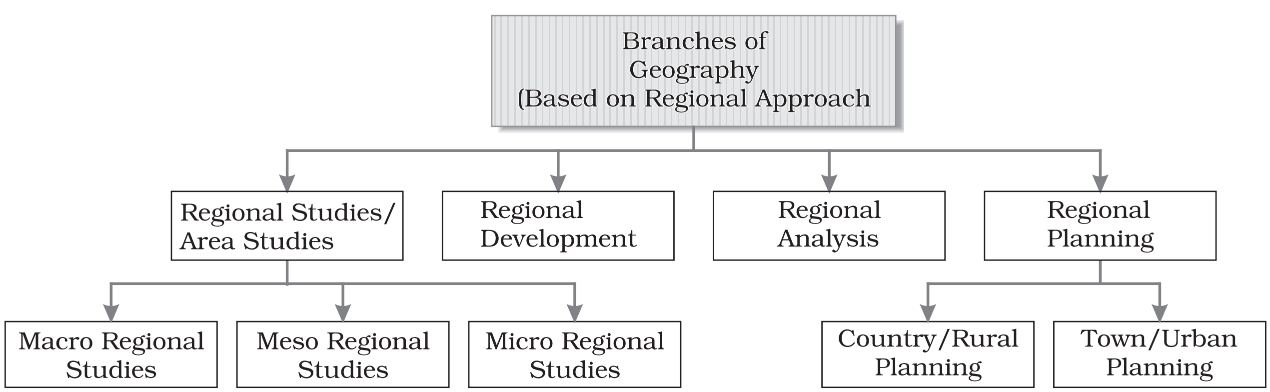


Figure 1.3 : Branches of geography based on regional approach

Physical geography includes the study of lithosphere (landforms, drainage, relief and physiography), atmosphere (its composition, structure, elements and controls of weather and climate; temperature, pressure, winds, precipitation, climatic types, etc.), hydrosphere (oceans, seas, lakes and associated features with water realm) and biosphere (life forms including human being and macro-organism and their sustaining mechanism, viz. food chain, ecological parameters and ecological balance). Soils are formed through the process of *pedogenesis* and depend upon the parent rocks, climate, biological activity and time. Time provides maturity to soils and helps in the development of soil profiles. Each element is important for human beings. Landforms provide the base on which human activities are located. The plains are utilised for agriculture. Plateaus provide forests and minerals. Mountains provide pastures, forests, tourist spots and are sources of rivers providing water to lowlands. Climate influences our house types, clothing and food habits. The climate has a profound effect on vegetation, cropping pattern, livestock farming and some industries, etc. Human beings have developed technologies which modify climatic elements in a restricted space such as air conditioners and coolers. Temperature and precipitation ensure the density of forests and quality of grassland. In India, monsoonal rainfall sets the agriculture rhythm in motion. Precipitation recharges the *ground water aquifers* which later provides water for agriculture and domestic use. We study oceans which are the store house of resources. Besides fish and other sea-food, oceans are rich in mineral resources. India has developed the technology for collecting manganese nodules from oceanic bed. Soils are renewable resources, which influence a number of economic activities such as agriculture. The fertility of the soil is both naturally determined and culturally induced. Soils also provide the basis for the biosphere accommodating plants, animals and micro organisms.

What is Geography?

Geography is concerned with the description and explanation of the areal differentiation of the earth's surface.

Richard Hartshorne

Geography studies the differences of phenomena usually related in different parts of the earth's surface.

Hettner

The study of physical geography is emerging as a discipline of evaluating and managing natural resources. In order to achieve this objective, it is essential to understand the intricate relationship between physical environment and human beings. Physical environment provides resources, and human beings utilise these resources and ensure their economic and cultural development. Accelerated pace of resource utilisation with the help of modern technology has created ecological imbalance in the world. Hence, a better understanding of physical environment is absolutely essential for sustainable development.

EXERCISES

1. Multiple choice questions.

(i) Which one of the following scholars coined the term 'Geography'?

(a) Herodotus
(c) Galileo
(b) Erathosthenese
(d) Aristotle

(ii) Which one of the following features can be termed as 'physical feature'?

(a) Port
(c) Plain
(b) Road
(d) Water park

(iii) Make correct pairs from the following two columns and mark the correct option.

1. Meteorology	A. Population Geography
2. Demography	B. Soil Geography
3. Sociology	C. Climatology
4. Pedology	D. Social Geography

(a) 1B,2C,3A,4D
(b) 1A,2D,3B,4C
(c) 1D,2B,3C,4A
(d) 1C,2A,3D,4B

(iv) Which one of the following questions is related to cause-effect relationship?

(a) Why
(b) Where
(c) What
(d) When

(v) Which one of the following disciplines attempts temporal synthesis?

(a) Sociology
(b) Geography
(c) Anthropology
(d) History

2. Answer the following questions in about 30 words.

(i) What important cultural features do you observe while going to school? Are they similar or dissimilar? Should they be included in the study of geography or not? If yes, why?

(ii) You have seen a tennis ball, a cricket ball, an orange and a pumpkin. Which one amongst these resembles the shape of the earth? Why have you chosen this particular item to describe the shape of the earth?

(iii) Do you celebrate *Van Mahotsava* in your school? Why do we plant so many trees? How do the trees maintain ecological balance?

(iv) You have seen elephants, deer, earthworms, trees and grasses. Where do they live or grow? What is the name given to this sphere? Can you describe some of the important features of this sphere?

(v) How much time do you take to reach your school from your house? Had the school been located across the road from your house, how much time would you have taken to reach school? What is the effect of the distance between your residence and the school on the time taken in commuting? Can you convert time into space and vice versa?

3. Answer the following questions in about 150 words.

(i) You observe every day in your surroundings that there is variation in natural as well as cultural phenomena. All the trees are not of the same variety. All the birds and animals you see, are different. All these different elements are found on the earth. Can you now argue that geography is the study of "areal differentiation"?

(ii) You have already studied geography, history, civics and economics as parts of social studies. Attempt an integration of these disciplines highlighting their interface.

Project Work

Select forest as a natural resource.

(i) Prepare a map of India showing the distribution of different types of forests.

(ii) Write about the economic importance of forests for the country.

(iii) Prepare a historical account of conservation of forests in India with focus on Chipko movements in Rajasthan and Uttaranchal.

UNIT II

THE EARTH

This unit deals with

- *Origin and evolution of the earth; Interior of the earth; Wegener's continental drift theory and plate tectonics; earthquakes and volcanoes*

CHAPTER

2

The Origin and Evolution of the Earth

Do you remember the nursery rhyme "…Twinkle, twinkle little star…"?

Starry nights have always attracted us since the childhood. You may also have thought of these stars and had numerous questions in your mind. Questions such as how many stars are there in the sky? How did they come into existence? Can one reach the end of the sky? May be many more such questions are still there in your mind. In this chapter, you will learn how these "twinkling little stars" were formed. With that you will eventually also read the story of origin and evolution of the earth.

Early Theories

Origin of the Earth

A large number of hypotheses were put forth by different philosophers and scientists regarding the origin of the earth. One of the earlier and popular arguments was by German philosopher Immanuel Kant. Mathematician Laplace revised it in 1796. It is known as *Nebular Hypothesis*. The hypothesis considered that the planets were formed out of a cloud of material associated with a youthful sun, which was slowly rotating. Later in 1900, Chamberlain and Moulton considered that a wandering star approached the sun. As a result, a cigar-shaped extension of material was separated from the solar surface. As the passing star moved away, the material separated from the solar surface continued to revolve around the sun and it slowly condensed into planets. Sir James Jeans and later Sir Harold Jeffrey supported this argument. At a later date, the arguments considered of a companion to the sun to have been coexisting. These arguments are called *binary theories*. In 1950, Otto Schmidt in Russia and Carl Weizascar in Germany somewhat revised the 'nebular hypothesis', though differing in details. They considered that the sun was surrounded by solar nebula containing mostly the hydrogen and helium along with what may be termed as dust. The friction and collision of particles led to formation of a disk-shaped cloud and the planets were formed through the process of accretion.

However, scientists in later period took up the problems of origin of universe rather than that of just the earth or the planets.

Modern Theories

Origin of the Universe

The most popular argument regarding the origin of the universe is the *Big Bang Theory*. It is also called *expanding universe hypothesis*. Edwin Hubble, in 1920, provided evidence that the universe is expanding. As time passes, galaxies move further and further apart. You can experiment and find what does the expanding universe mean. Take a balloon and mark some points on it to represent the galaxies. Now, if you start inflating the balloon, the points marked on the balloon will appear to be moving away from each other as the balloon expands. Similarly, the distance between the galaxies is also found to be increasing and thereby, the universe is considered to be expanding. However, you will find that besides the increase in the distances between the points on the balloon, the points themselves are expanding. This is not in accordance with the fact. Scientists believe that though the space between the galaxies is increasing, observations do not support the expansion of galaxies. So, the balloon example is only partially correct.

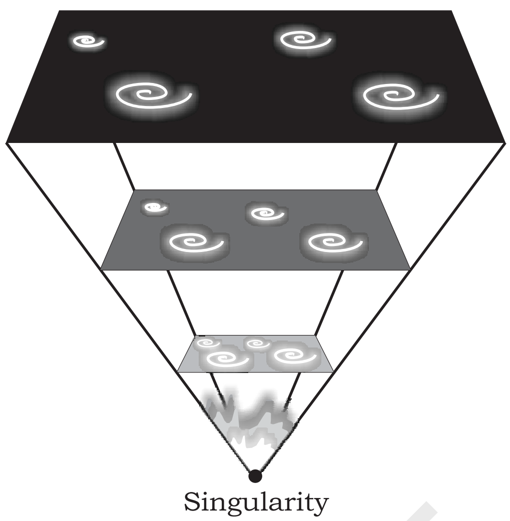


Figure 2.1 : The Big Bang

The Big Bang Theory considers the following stages in the development of the universe.

(i) In the beginning, all matter forming the universe existed in one place in the form of a "tiny ball" (singular atom) with an unimaginably small volume, infinite temperature and infinite density.

(ii) At the Big Bang the "tiny ball" exploded violently. This led to a huge expansion. It is now generally accepted that the event of big bang took place 13.7 billion years before the present. The expansion continues even to the present day. As it grew, some energy was converted into matter. There was particularly rapid expansion within fractions of a second after the bang. Thereafter, the expansion has slowed down. Within first three minutes from the Big Bang event, the first atom began to form.

(iii) Within 300,000 years from the Big Bang, temperature dropped to 4,500 K (Kelvin) and gave rise to atomic matter. The universe became transparent.

The expansion of universe means increase in space between the galaxies. An alternative to this was Hoyle's concept of *steady state*. It considered the universe to be roughly the same at any point of time. However, with greater evidence becoming available about the expanding universe, scientific community at present favours argument of expanding universe.

The Star Formation

The distribution of matter and energy was not even in the early universe. These initial density differences gave rise to differences in gravitational forces and it caused the matter to get drawn together. These formed the bases for development of galaxies. A *galaxy* contains a large number of stars. Galaxies spread over vast distances that are measured in thousands of *light-year*s. The diameters of individual galaxies range from 80,000-150,000 light years. A galaxy starts to form by accumulation of hydrogen gas in the form of a very large cloud called *nebula*. Eventually, growing nebula develops localised clumps of gas. These clumps continue to grow into even denser gaseous bodies, giving rise to formation of stars. The formation of stars is believed to have taken place some 5-6 billion years ago.

> A light year is a measure of distance and not of time. Light travels at a speed of 300,000 km/second. Considering this, the distances the light will travel in one year is taken to be one light year. This equals to $9.461 10^{12}$ km. The mean distance between the sun and the earth is 149,598,000 km. In terms of light years, it is 8.311minutes.

Formation of Planets

The following are considered to be the stages in the development of planets :

(i) The stars are localised lumps of gas within a nebula. The gravitational force within the lumps leads to the formation of a core to the gas cloud and a huge rotating disc of gas and dust develops around the gas core.

(ii) In the next stage, the gas cloud starts getting condensed and the matter around the core develops into small-rounded objects. These small-rounded objects by the process of cohesion develop into what is called *planetesimals*. Larger bodies start forming by collision, and gravitational attraction causes the material to stick together. Planetesimals are a large number of smaller bodies.

(iii) In the final stage, these large number of small planetesimals accrete to form a fewer large bodies in the form of planets.

Our Solar System

Our Solar system consists of eight planets. The nebula from which our Solar system is supposed to have been formed, started its collapse and core formation some time 5-5.6 billion years ago and the planets were formed about 4.6 billion years ago. Our solar system consists of the sun (the star), 8 planets, 63 moons, millions of smaller bodies like *asteroids* and *comets* and huge quantity of dust-grains and gases.

Out of the eight planets, mercury, venus, earth and mars are called as the *inner planets* as they lie between the sun and the belt of asteroids the other four planets are called the *outer planets*. Alternatively, the first four are called *Terrestrial*, meaning earth-like as they are made up of rock and metals, and have relatively high densities. The rest four are called *Jovian* or Gas Giant planets. Jovian means jupiter-like. Most of them are much larger than the terrestrial planets and have thick atmosphere, mostly of helium and hydrogen. All the planets were formed in the same period sometime about 4.6 billion years ago. Till recently (August 2006), Pluto was also considered a planet. However, in a meeting of the International Astronomical Union, a decision was taken that Pluto like other celestial objects (2003 UB_{313})discovered in recent past may be called 'dwarf planet'. Some data regarding our solar system are given in the box below.

Why are the inner planets rocky while others are mostly in gaseous form?

The difference between terrestrial and jovian planets can be attributed to the following conditions:

(i) The terrestrial planets were formed in the close vicinity of the parent star where it was too warm for gases to condense to solid particles. Jovian planets were formed at quite a distant location.

(ii) The solar wind was most intense nearer the sun; so, it blew off lots of gas and dust from the terrestrial planets. The solar winds were not all that intense to cause similar removal of gases from the Jovian planets.

(iii) The terrestrial planets are smaller and their lower gravity could not hold the escaping gases.

The Moon

The moon is the only natural satellite of the earth. Like the origin of the earth, there have been attempts to explain how the moon was formed. In 1838, Sir George Darwin suggested that initially, the earth and the moon formed a single rapidly rotating body. The whole mass

The Solar System

	Mercury	*Venus*	*Earth*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
Distance*	0.387	0.723	1.000	1.524	5.203	9.539	19.182	30.058
Density@	5.44	5.245	5.517	3.945	1.33	0.70	1.17	1.66
Radius#	0.383	0.949	1.000	0.533	11.19	9.460	4.11	3.88
Satellites	0	0	1	2	16	about 18	about 17	8

* Distance from the sun in astronomical unit i.e. average mean distance of the earth is 149,598,000 km = 1 @ Density in gm/cm^3

Radius: Equatorial radius 6378.137 km = 1

became a dumb-bell-shaped body and eventually it broke. It was also suggested that the material forming the moon was separated from what we have at present the depression occupied by the Pacific Ocean.

However, the present scientists do not accept either of the explanations. It is now generally believed that the formation of moon, as a satellite of the earth, is an outcome of 'giant impact' or what is described as "the big splat". A body of the size of one to three times that of mars collided into the earth sometime shortly after the earth was formed. It blasted a large part of the earth into space. This portion of blasted material then continued to orbit the earth and eventually formed into the present moon about 4.44 billion years ago.

EVOLUTION OF THE EARTH

Do you know that the planet earth initially was a barren, rocky and hot object with a thin atmosphere of hydrogen and helium. This is far from the present day picture of the earth. Hence, there must have been some events–processes, which may have caused this change from rocky, barren and hot earth to a beautiful planet with ample amount of water and conducive atmosphere favouring the existence of life. In the following section, you will find out how the period, between the 4,600 million years and the present, led to the evolution of life on the surface of the planet.

The earth has a layered structure. From the outermost end of the atmosphere to the centre of the earth, the material that exists is not uniform. The atmospheric matter has the least density. From the surface to deeper depths, the earth's interior has different zones and each of these contains materials with different characteristics.

> How was the layered structure of the earth developed?

Evolution of Lithosphere

The earth was mostly in a volatile state during its primordial stage. Due to gradual increase in density the temperature inside has increased. As a result the material inside started getting separated depending on their densities. This allowed heavier materials (like iron) to sink towards the centre of the earth and the lighter ones to move towards the surface. With passage of time it cooled further and solidified and condensed into a smaller size. This later led to the development of the outer surface in the form of a crust. During the formation of the moon, due to the giant impact, the earth was further heated up. It is through the process of differentiation that the earth forming material got separated into different layers. Starting from the surface to the central parts, we have layers like the crust, mantle, outer core and inner core. From the crust to the core, the density of the material increases. We shall discuss in detail the properties of each of this layer in the next chapter.

Evolution of Atmosphere and Hydrosphere

The present composition of earth's atmosphere is chiefly contributed by nitrogen and oxygen. You will be dealing with the composition and structure of the earth's atmosphere in Chapter 8.

There are three stages in the evolution of the present atmosphere. The first stage is marked by the loss of primordial atmosphere. In the second stage, the hot interior of the earth contributed to the evolution of the atmosphere. Finally, the composition of the atmosphere was modified by the living world through the process of *photosynthesis*.

The early atmosphere, with hydrogen and helium, is supposed to have been stripped off as a result of the solar winds. This happened not only in case of the earth, but also in all the terrestrial planets, which were supposed to have lost their primordial atmosphere through the impact of solar winds.

During the cooling of the earth, gases and water vapour were released from the interior solid earth. This started the evolution of the present atmosphere. The early atmosphere largely contained water vapour, nitrogen, carbon dioxide, methane, ammonia and very little of free oxygen. The process through which the gases were outpoured from the interior is called *degassing*. Continuous volcanic eruptions contributed water vapour and gases

Geological Time Scale

Eons	*Era*	*Period*	*Epoch*	*Age/ Years Before Present*	*Life/ Major Events*
	Cainozoic (From 65 million years to the present times)	Quaternary	Holocene	0 - 10,000	Modern Man
			Pleistocene	10,000 - 2 million	Homo Sapiens
		Tertiary	Pliocene	2 - 5 million	Early Human Ancestor
			Miocene	5 - 24 million	Ape: Flowering Plants and Trees
			Oligocene	24 - 37 million	Anthropoid Ape
			Eocene	37 - 58 Million	Rabbits and Hare
			Palaeocene	57 - 65 Million	Small Mammals : Rats – Mice
	Mesozoic 65 - 245 Million Mammals	Cretaceous		65 - 144 Million	Extinction of Dinosaurs
		Jurassic		144 - 208 Million	Age of Dinosaurs
		Triassic		208 - 245 Million	Frogs and turtles
	Palaeozoic 245 - 570 Million	Permian		245 - 286 Million	Reptile dominate-replace amphibians
		Carboniferous		286 - 360 Million	First Reptiles: Vertebrates: Coal beds
		Devonian		360 - 408 Million	Amphibians
		Silurian		408 - 438 Million	First trace of life on land: Plants
		Ordovician		438 - 505 Million	First Fish
		Cambrian		505 - 570 Million	No terrestrial Life : Marine Invertebrate
Proterozoic	Pre-Cambrian 570 Million - 4,800 Million			570 - 2,500 Million	Soft-bodied arthropods
Archean				2,500 - 3,800 Million	Blue green Algae: Unicellular bacteria
Hadean				3,800 - 4,800 Million	Oceans and Continents form – Ocean and Atmosphere are rich in Carbon dioxide
Origin of Stars	5,000 - 13,700 Million			5,000 Million	Origin of the sun
Supernova				12,000 Million	Origin of the universe
Big Bang				13,700 Million	

to the atmosphere. As the earth cooled, the water vapour released started getting condensed. The carbon dioxide in the atmosphere got dissolved in rainwater and the temperature further decreased causing more condensation and more rains. The rainwater falling onto the surface got collected in the depressions to give rise to oceans. The earth's oceans were formed within 500 million years from the formation of the earth. This tells us that the oceans are as old as 4,000 million years. Sometime around 3,800 million years ago, life began to evolve. However, around 2,500-3,000 million years before the present, the process of photosynthesis got evolved. Life was confined to the oceans for a long time. Oceans began to have the contribution of oxygen through the process of *photosynthesis*. Eventually, oceans were saturated with oxygen, and 2,000 million years ago, oxygen began to flood the atmosphere.

Origin of Life

The last phase in the evolution of the earth relates to the origin and evolution of life. It is undoubtedly clear that initially the earth or even the atmosphere of the earth was not conducive for the development of life. Modern scientists refer to the origin of life as a kind of chemical reaction, which first generated complex organic molecules and assembled them. This assemblage was such that they could duplicate themselves converting inanimate matter into living substance. The record of life that existed on this planet in different periods is found in rocks in the form of fossils. The microscopic structures closely related to the present form of blue algae have been found in geological formations much older than some 3,000 million years. It can be assumed that life began to evolve sometime 3,800 million years ago. The summary of evolution of life from unicellular bacteria to the modern man is given in the Geological Time Scale on page 18.

EXERCISES

1. Multiple choice questions.

   (i) Which one of the following figures represents the age of the earth?

   (a) 4.6 million years (c) 4.6 billion years

   (b) 13.7 billion years (d) 13.7 trillion years

   (ii) Which one of the following has the longest duration?

   (a) Eons (c) Era

   (b) Period (d) Epoch

   (iii) Which one of the following is not related to the formation or modification of the present atmosphere?

   (a) Solar winds (c) Degassing

   (b) Differentiation (d) Photosynthesis

   (iv) Which one of the following represents the inner planets?

   (a) Planets between the sun and the earth

   (b) Planets between the sun and the belt of asteroids

   (c) Planets in gaseous state

   (d) Planets without satellite(s)

   (v) Life on the earth appeared around how many years before the present?

   (a) 13.7 billion (c) 4.6 billion

   (b) 3.8 million (d) 3.8 billion

2. Answer the following questions in about 30 words.

   (i) Why are the terrestrial planets rocky?

   (ii) What is the basic difference in the arguments related to the origin of the earth given by :

   (a) Kant and Laplace

   (b) Chamberlain and Moulton

(iii) What is meant by the process of differentiation?

(iv) What was the nature of the earth surface initially?

(v) What were the gases which initially formed the earth's atmosphere?

3. Answer the following questions in about 150 words.

(i) Write an explanatory note on the 'Big Bang Theory'.

(ii) List the stages in the evolution of the earth and explain each stage in brief.

Project Work

Collect information about the project "Stardust" (website: *www.sci.edu/public.html* and *www.nasm.edu*) along the following lines.

(i) Which is the agency that has launched this project?

(ii) Why are scientists interested in collecting Stardust?

(iii) Where from the Stardust is being collected?

CHAPTER

3

Interior of the Earth

What do you imagine about the nature of the earth? Do you imagine it to be a solid ball like cricket ball or a hollow ball with a thick cover of rocks i.e. lithosphere? Have you ever seen photographs or images of a volcanic eruption on the television screen? Can you recollect the emergence of hot molten lava, dust, smoke, fire and magma flowing out of the volcanic crater? The interior of the earth can be understood only by indirect evidences as neither any one has nor any one can reach the interior of the earth.

The configuration of the surface of the earth is largely a product of the processes operating in the interior of the earth. Exogenic as well as endogenic processes are constantly shaping the landscape. A proper understanding of the physiographic character of a region remains incomplete if the effects of endogenic processes are ignored. Human life is largely influenced by the physiography of the region. Therefore, it is necessary that one gets acquainted with the forces that influence landscape development. To understand why the earth shakes or how a tsunami wave is generated, it is necessary that we know certain details of the interior of the earth. In the previous chapter, you have noted that the earth-forming materials have been distributed in the form of layers from the crust to the core. It is interesting to know how scientists have gathered information about these layers and what are the characteristics of each of these layers. This is exactly what this chapter deals with.

Sources of Information about the Interior

The earth's radius is 6,370 km. No one can reach the centre of the earth and make observations or collect samples of the material. Under such conditions, you may wonder how scientists tell us about the earth's interior and the type of materials that exist at such depths. Most of our knowledge about the interior of the earth is largely based on estimates and inferences. Yet, a part of the information is obtained through direct observations and analysis of materials.

Direct Sources

The most easily available solid earth material is surface rock or the rocks we get from mining areas. Gold mines in South Africa are as deep as 3 - 4 km. Going beyond this depth is not possible as it is very hot at this depth. Besides mining, scientists have taken up a number of projects to penetrate deeper depths to explore the conditions in the crustal portions. Scientists world over are working on two major projects such as "Deep Ocean Drilling Project" and "Integrated Ocean Drilling Project". The deepest drill at Kola, in Arctic Ocean, has so far reached a depth of 12 km. This and many deep drilling projects have provided large volume of information through the analysis of materials collected at different depths.

Volcanic eruption forms another source of obtaining direct information. As and when the molten material (magma) is thrown onto the surface of the earth, during volcanic eruption it becomes available for laboratory analysis. However, it is difficult to ascertain the depth of the source of such magma.

Indirect Sources

Analysis of properties of matter indirectly provides information about the interior. We know through the mining activity that temperature and pressure increase with the increasing distance from the surface towards the interior in deeper depths. Moreover, it is also known that the density of the material also increases with depth. It is possible to find the rate of change of these characteristics. Knowing the total thickness of the earth, scientists have estimated the values of temperature, pressure and the density of materials at different depths. The details of these characteristics with reference to each layer of the interior are discussed later in this chapter.

Another source of information are the meteors that at times reach the earth. However, it may be noted that the material that becomes available for analysis from meteors, is not from the interior of the earth. The material and the structure observed in the meteors are similar to that of the earth. They are solid bodies developed out of materials same as, or similar to, our planet. Hence, this becomes yet another source of information about the interior of the earth.

The other indirect sources include gravitation, magnetic field, and seismic activity. The gravitation force (g) is not the same at different latitudes on the surface. It is greater near the poles and less at the equator. This is because of the distance from the centre at the equator being greater than that at the poles. The gravity values also differ according to the mass of material. The uneven distribution of mass of material within the earth influences this value. The reading of the gravity at different places is influenced by many other factors. These readings differ from the expected values. Such a difference is called *gravity anomaly*. Gravity anomalies give us information about the distribution of mass of the material in the crust of the earth. Magnetic surveys also provide information about the distribution of magnetic materials in the crustal portion, and thus, provide information about the distribution of materials in this part. Seismic activity is one of the most important sources of information about the interior of the earth. Hence, we shall discuss it in some detail.

Earthquake

The study of seismic waves provides a complete picture of the layered interior. An earthquake in simple words is shaking of the earth. It is a natural event. It is caused due to release of energy, which generates waves that travel in all directions.

Why does the earth shake?

The release of energy occurs along a fault. A fault is a sharp break in the crustal rocks. Rocks along a fault tend to move in opposite directions. As the overlying rock strata press them, the friction locks them together. However, their tendency to move apart at some point of time overcomes the friction. As a result, the blocks get deformed and eventually, they slide past one another abruptly. This causes a release of energy, and the energy waves travel in all directions. The point where the energy is released is called the *focus* of an earthquake, alternatively, it is called the *hypocentre*. The energy waves travelling in different directions reach the surface. The point on the surface, nearest to the focus, is called *epicentre*. It is the first one to experience the waves. It is a point directly above the focus.

Earthquake Waves

All natural earthquakes take place in the lithosphere. You will learn about different layers of the earth later in this chapter. It is sufficient to note here that the lithosphere refers to the portion of depth up to 200 km from the surface of the earth. An instrument called 'seismograph' records the waves reaching the surface. A curve of earthquake waves recorded on the seismograph is given in Figure 3.1. Note that the curve shows three distinct sections each representing different types of wave patterns. Earthquake waves are basically of two types — *body waves* and *surface waves*. Body waves are generated due to the release of energy at the focus and move in all directions travelling through the body of the earth. Hence, the name body waves. The body waves interact with the surface rocks and generate new set of waves called surface waves. These waves move along the surface. The velocity of waves changes as they travel through materials with different densities. The denser the material, the higher is the velocity. Their direction also changes as they reflect or refract when coming across materials with different densities.

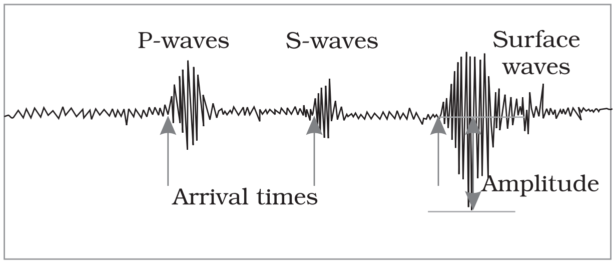


Figure 3.1 : Earthquake Waves

There are two types of body waves. They are called P and S-waves. P-waves move faster and are the first to arrive at the surface. These are also called 'primary waves'. The P-waves are similar to sound waves. They travel through gaseous, liquid and solid materials. S-waves arrive at the surface with some time lag. These are called secondary waves. An important fact about S-waves is that they can travel only through solid materials. This characteristic of the S-waves is quite important. It has helped scientists to understand the structure of the interior of the earth. Reflection causes waves to rebound whereas refraction makes waves move in different directions. The variations in the direction of waves are inferred with the help of their record on seismograph. The surface waves are the last to report on seismograph. These waves are more destructive. They cause displacement of rocks, and hence, the collapse of structures occurs.

Propagation of Earthquake Waves

Different types of earthquake waves travel in different manners. As they move or propagate, they cause vibration in the body of the rocks through which they pass. P-waves vibrate parallel to the direction of the wave. This exerts pressure on the material in the direction of the propagation. As a result, it creates density differences in the material leading to stretching and squeezing of the material. Other three waves vibrate perpendicular to the direction of propagation. The direction of vibrations of S-waves is perpendicular to the wave direction in the vertical plane. Hence, they create troughs and crests in the material through which they pass. Surface waves are considered to be the most damaging waves.

Emergence of Shadow Zone

Earthquake waves get recorded in seismographs located at far off locations. However, there exist some specific areas where the waves are not reported. Such a zone is called the 'shadow zone'. The study of different events reveals that for each earthquake, there exists an altogether different shadow zone. Figure 3.2 (a) and (b) show the shadow zones of P and S-waves. It was observed that seismographs located at any distance within 105° from the epicentre, recorded the arrival of both P and S-waves. However, the seismographs located beyond 145° from epicentre, record the arrival of P-waves, but not that of S-waves. Thus, a zone between 105° and 145° from epicentre was identified as the shadow zone for both the types of waves. The entire zone beyond 105° does not receive S-waves. The shadow zone of S-wave is much larger than that of the P-waves. The shadow zone of P-waves appears as a band around the earth between 105° and 145° away from the epicentre. The shadow zone of S-waves is not only larger in extent but it is also a little over 40 per cent of the earth surface. You can draw the shadow zone for any earthquake provided you know the location of the epicentre. (See the activity box on page 28 to know how to locate the epicentre of a quake event).

Types of Earthquakes

(i) The most common ones are the *tectonic* earthquakes. These are generated due to sliding of rocks along a fault plane.

(ii) A special class of tectonic earthquake is sometimes recognised as *volcanic* earthquake. However, these are confined to areas of active volcanoes.

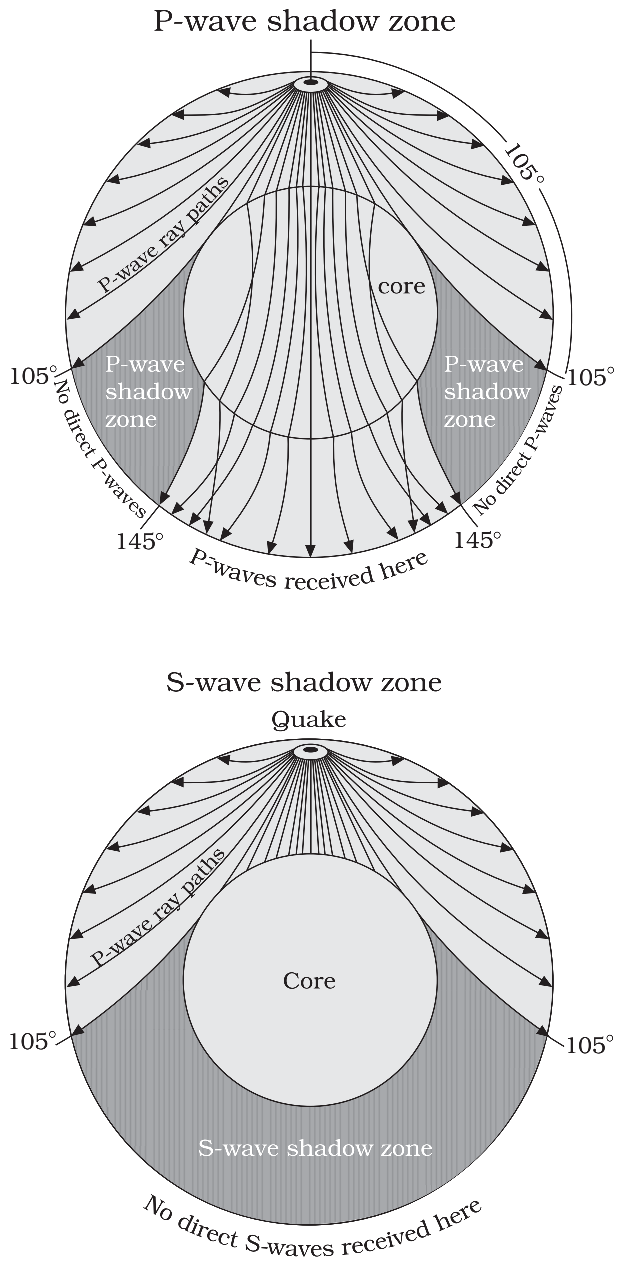


Figure 3.2 (a) and (b) : Earthquake Shadow Zones

(iii) In the areas of intense mining activity, sometimes the roofs of underground mines collapse causing minor tremors. These are called *collapse* earthquakes.

(iv) Ground shaking may also occur due to the explosion of chemical or nuclear devices. Such tremors are called *explosion* earthquakes.

(v) The earthquakes that occur in the areas of large reservoirs are referred to as *reservoir induced* earthquakes.

Measuring Earthquakes

The earthquake events are scaled either according to the magnitude or intensity of the shock. The magnitude scale is known as the *Richter scale*. The magnitude relates to the energy released during the quake. The magnitude is expressed in absolute numbers, 0-10. The intensity scale is named after *Mercalli*, an Italian seismologist. The intensity scale takes into account the visible damage caused by the event. The range of intensity scale is from 1-12.

Effects of Earthquake

Earthquake is a natural hazard. The following are the immediate hazardous effects of earthquake:

(i) Ground Shaking
(ii) Differential ground settlement
(iii) Land and mud slides
(iv) Soil liquefaction
(v) Ground lurching
(vi) Avalanches
(vii) Ground displacement
(viii) Floods from dam and levee failures
(ix) Fires
(x) Structural collapse
(xi) Falling objects
(xii) Tsunami

The first six listed above have some bearings upon landforms, while others may be considered the effects causing immediate concern to the life and properties of people in the region. The effect of tsunami would occur only if the epicentre of the tremor is below oceanic waters and the magnitude is sufficiently high. *Tsunamis* are waves generated by the tremors and not an earthquake in itself. Though the actual quake activity lasts for a few seconds, its effects are devastating provided the magnitude of the quake is more than 5 on the Richter scale.

A view of the destruction caused by tidal waves in Marina Beach, India

A view of the destruction caused by tidal waves in Thailand

People walk through debris of their houses destroyed by tidal waves on the coastal area in Colombo, Sri Lanka

A view of the destruction caused by tidal waves in Indonesia

Frequency of Earthquake Occurrences

The earthquake is a natural hazard. If a tremor of high magnitude takes place, it can cause heavy damage to the life and property of people. However, not all the parts of the globe necessarily experience major shocks. We shall be discussing the distribution of earthquakes and volcanoes with some details in the next

A view of the damaged Aman Setu at the LOC in Uri, due to an earthquake

chapter. Note that the quakes of high magnitude, i.e. 8+ are quite rare; they occur once in 1-2 years whereas those of 'tiny' types occur almost every minute.

STRUCTURE OF THE EARTH

The Crust

It is the outermost solid part of the earth. It is brittle in nature. The thickness of the crust varies under the oceanic and continental areas. Oceanic crust is thinner as compared to the continental crust. The mean thickness of oceanic crust is 5 km whereas that of the continental is around 30 km. The continental crust is thicker in the areas of major mountain systems. It is as much as 70 km thick in the Himalayan region.

It is made up of heavier rocks having density of 3 g/cm^3. This type of rock found in the oceanic crust is basalt. The mean density of material in oceanic crust is 2.7 g/cm^3.

The Mantle

The portion of the interior beyond the crust is called the mantle. The mantle extends from Moho's discontinuity to a depth of 2,900 km. The upper portion of the mantle is called *asthenosphere*. The word *astheno* means weak. It is considered to be extending upto 400 km. It is the main source of magma that finds

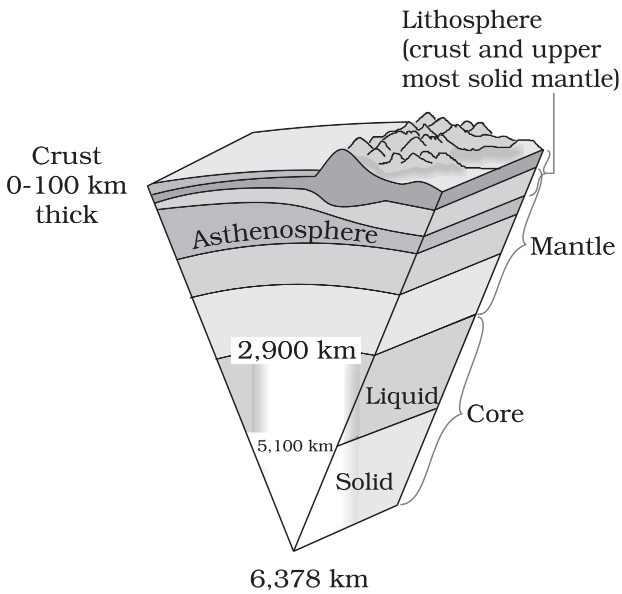


Figure 3.4 : The interior of the earth

its way to the surface during volcanic eruptions. It has a density higher than the crust's (3.4 g/cm^3). The crust and the uppermost part of the mantle are called lithosphere. Its thickness ranges from 10-200 km. The lower mantle extends beyond the asthenosphere. It is in solid state.

The Core

As indicated earlier, the earthquake wave velocities helped in understanding the existence of the core of the earth. The core-mantle boundary is located at the depth of 2,900 km. The outer core is in liquid state while the inner core is in solid state. The density of material at the mantle core boundary is around 5 g/cm^3 and at the centre of the earth at 6,300 km, the density value is around 13g/cm^3. The core is made up of very heavy material mostly constituted by nickel and iron. It is sometimes referred to as the *nife* layer.

Volcanoes and Volcanic Landforms

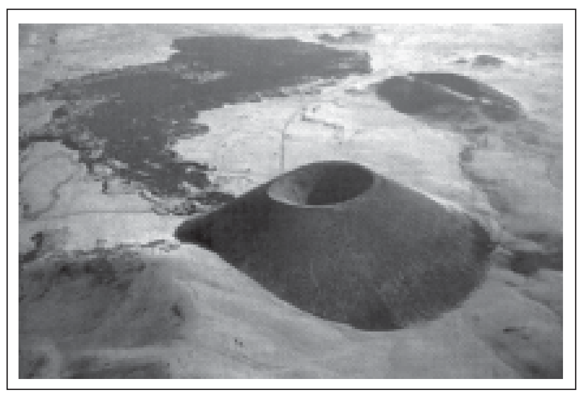
You may have seen photographs or pictures of volcanoes on a number of occasions. A volcano is a place where gases, ashes and/or molten rock material – lava – escape to the ground. A volcano is called an active volcano if the materials mentioned are being released or have been released out in the recent past. The layer below the solid crust is mantle. It has higher density than that of the crust. The mantle contains a weaker zone called *asthenosphere*. It is from this that the molten rock materials find their way to the surface. The material in the upper mantle portion is called *magma*. Once it starts moving towards the crust or it reaches the surface, it is referred to as *lava*. The material that reaches the ground includes lava flows, pyroclastic debris, volcanic bombs, ash and dust and gases such as nitrogen compounds, sulphur compounds and minor amounts of chlorene, hydrogen and argon.

Volcanoes

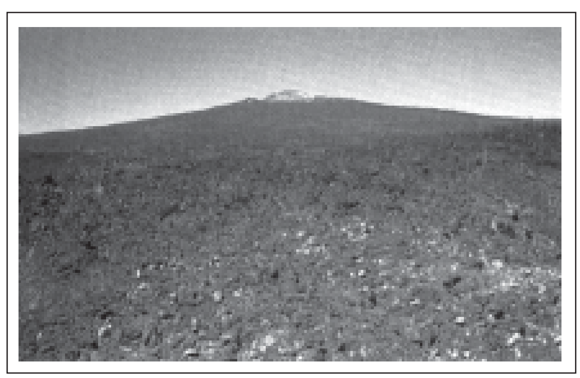
Volcanoes are classified on the basis of nature of eruption and the form developed at the surface. Major types of volcanoes are as follows:

Shield Volcanoes

Barring the basalt flows, the shield volcanoes are the largest of all the volcanoes on the earth. The Hawaiian volcanoes are the most famous



Shield Volcano



Cinder Cone

examples. These volcanoes are mostly made up of basalt, a type of lava that is very fluid when erupted. For this reason, these volcanoes are not steep. They become explosive if somehow water gets into the vent; otherwise, they are characterised by low-explosivity. The upcoming lava moves in the form of a fountain and throws out the cone at the top of the vent and develops into cinder cone.

Composite Volcanoes

These volcanoes are characterised by eruptions of cooler and more viscous lavas than basalt. These volcanoes often result in explosive eruptions. Along with lava, large quantities of pyroclastic material and ashes find their way to the ground. This material accumulates in the vicinity of the vent openings leading to formation of layers, and this makes the mounts appear as composite volcanoes.

Composite Volcano

Caldera

These are the most explosive of the earth's volcanoes. They are usually so explosive that when they erupt they tend to collapse on themselves rather than building any tall structure. The collapsed depressions are called *calderas*. Their explosiveness indicates that the magma chamber supplying the lava is not only huge but is also in close vicinity.

Flood Basalt Provinces

These volcanoes outpour highly fluid lava that flows for long distances. Some parts of the world are covered by thousands of sq. km of thick basalt lava flows. There can be a series of flows with some flows attaining thickness of more than 50 m. Individual flows may extend for hundreds of km. The *Deccan Traps* from India, presently covering most of the Maharashtra plateau, are a much larger flood basalt province. It is believed that initially the trap formations covered a much larger area than the present.

Mid-Ocean Ridge Volcanoes

These volcanoes occur in the oceanic areas. There is a system of mid-ocean ridges more than 70,000 km long that stretches through all the ocean basins. The central portion of this ridge experiences frequent eruptions. We shall be discussing this in detail in the next chapter.

VOLCANIC LANDFORMS

Intrusive Forms

The lava that is released during volcanic eruptions on cooling develops into igneous rocks. The cooling may take place either on reaching the surface or also while the lava is still in the crustal portion. Depending on the location of the cooling of the lava, igneous rocks are classified as *volcanic rocks* (cooling at the surface) and *plutonic rocks* (cooling in the crust). The lava that cools within the crustal portions assumes different forms. These forms are called *intrusive forms*. Some of the forms are shown in Figure 3.5.

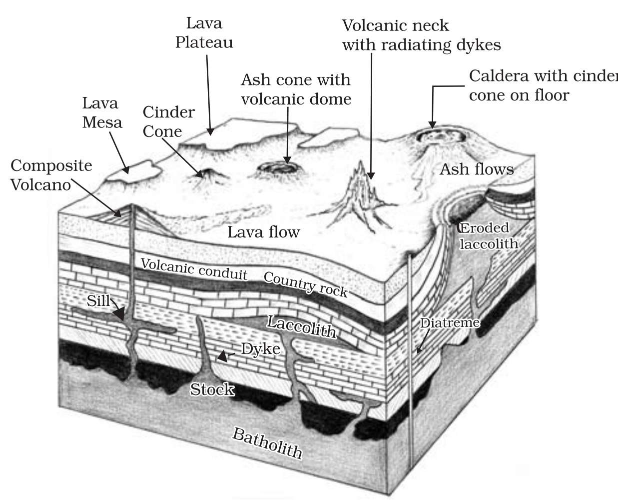


Figure 3.5 : Volcanic Landforms

Batholiths

A large body of magmatic material that cools in the deeper depth of the crust develops in the form of large domes. They appear on the surface only after the denudational processes remove the overlying materials. They cover large areas, and at times, assume depth that may be several km. These are granitic bodies. Batholiths are the cooled portion of magma chambers.

Lacoliths

These are large dome-shaped intrusive bodies with a level base and connected by a pipe-like conduit from below. It resembles the surface volcanic domes of composite volcano, only these are located at deeper depths. It can be regarded as the localised source of lava that finds its way to the surface. The Karnataka plateau is spotted with domal hills of granite rocks. Most of these, now exfoliated, are examples of lacoliths or batholiths.

Lapolith, Phacolith and Sills

As and when the lava moves upwards, a portion of the same may tend to move in a horizontal direction wherever it finds a weak

Activity : Locating an Epicentre

For this you will need

Data from 3 seismograph stations about the time of arrival of P-waves, S-waves.

Procedure

1. Find the time of arrival of P and S-waves of the given quake for the three stations for which you have the data.
2. Compute the time lag between the arrival of P and S-waves for each station; it is called time lag. (Note that it is directly related to the distance of the seismograph from the focus.)

A. *Basic rule : For every second of time lag, the earthquake is roughly 8 km away from you.*

3. Using the rule quoted above, convert the time lag into distance (# seconds of time lag * 8) for each station.
4. On a map locate the seismograph stations.
5. Draw circles, taking the seismograph stations as the centre, with the radius equal to the distance you have calculated in the previous step. (Do not forget to convert distance as per the map scale.)
6. These circles will intersect each other in a point. This point is the location of the epicentre.

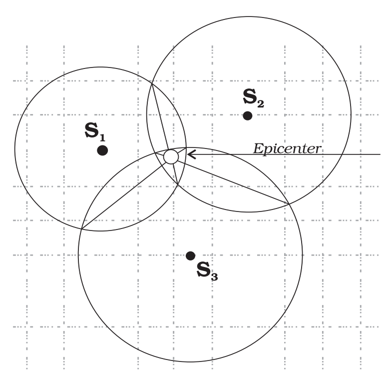
In normal practice, the epicentres are located using computer models. They take into account the structure of the earth's crust. The locations with accuracy within a few hundred metres can be achieved. The procedure outlined here is a much simplified version of what is normally done, although the principle is the same.

In the following diagram, the epicentre is located using this procedure. It also contains a table giving necessary data. Why don't you try for yourself?

Data

Station	Arrival time of					
	P-waves			S-waves		
	Hour	Min.	Sec.	Hour	Min.	Sec.
S1	03	23	20	03	24	45
S2	03	22	17	03	23	57
S3	03	22	00	03	23	55

Scale of the map 1cm = 40km



plane. It may get rested in different forms. In case it develops into a saucer shape, concave to the sky body, it is called *lapolith*. A wavy mass of intrusive rocks, at times, is found at the base of synclines or at the top of anticline in folded igneous country. Such wavy materials have a definite conduit to source beneath in the form of magma chambers (subsequently developed as batholiths). These are called the phacoliths.

The near horizontal bodies of the intrusive igneous rocks are called *sill* or *sheet*, depending on the thickness of the material. The thinner ones are called sheets while the thick horizontal deposits are called sills.

Dykes

When the lava makes its way through cracks and the fissures developed in the land, it solidifies almost perpendicular to the ground. It gets cooled in the same position to develop a wall-like structure. Such structures are called dykes. These are the most commonly found intrusive forms in the western Maharashtra area. These are considered the feeders for the eruptions that led to the development of the Deccan traps.

EXERCISES

1. Multiple choice questions.

   (i) Which one of the following earthquake waves is more destructive?

   (a) P-waves (c) Surface waves

   (b) S-waves (d) None of the above

   (ii) Which one of the following is a direct source of information about the interior of the earth?

   (a) Earthquake waves (c) Gravitational force

   (b) Volcanoes (d) Earth magnetism

   (iii) Which type of volcanic eruptions have caused Deccan Trap formations?

   (a) Shield (c) Composite

   (b) Flood (d) Caldera

   (iv) Which one of the following describes the lithosphere:

   (a) upper and lower mantle (c) crust and core

   (b) crust and upper mantle (d) mantle and core

2. Answer the following questions in about 30 words.

   (i) What are body waves?

   (ii) Name the direct sources of information about the interior of the earth.

   (iii) Why do earthquake waves develop shadow zone?

   (iv) Briefly explain the indirect sources of information of the interior of the earth other than those of seismic activity.

3. Answer the following questions in about 150 words.

   (i) What are the effects of propagation of earthquake waves on the rock mass through which they travel?

   (ii) What do you understand by intrusive forms? Briefly describe various intrusive forms.

CHAPTER

4

Distribution of Oceans and Continents

In the previous chapter, you have studied the interior of the earth. You are already familiar with the world map. You know that continents cover 29 per cent of the surface of the earth and the remainder is under oceanic waters. The positions of the continents and the ocean bodies, as we see them in the map, have not been the same in the past. Moreover, it is now a well-accepted fact that oceans and continents will not continue to enjoy their present positions in times to come. If this is so, the question arises what were their positions in the past? Why and how do they change their positions? Even if it is true that the continents and oceans have changed and are changing their positions, you may wonder as to how scientists know this. How have they determined their earlier positions? You will find the answers to some of these and related questions in this chapter.

Continental Drift

Observe the shape of the coastline of the Atlantic Ocean. You will be surprised by the symmetry of the coastlines on either side of the ocean. No wonder, many scientists thought of this similarity and considered the possibility of the two Americas, Europe and Africa, to be once joined together. From the known records of the history of science, it was *Abraham Ortelius*, a Dutch map maker, who first proposed such a possibility as early as 1596. *Antonio Pellegrini* drew a map showing the three continents together. However, it was *Alfred Wegener*—a German meteorologist who put forth a comprehensive argument in the form of "the continental drift theory" in 1912. This was regarding the distribution of the oceans and the continents.

According to Wegener, all the continents formed a single continental mass and mega ocean surrounded the same. The super continent was named PANGAEA, which meant all earth. The mega-ocean was called PANTHALASSA, meaning all water. He argued that, around 200 million years ago, the super continent, Pangaea, began to split. Pangaea first broke into two large continental masses as Laurasia and Gondwanaland forming the northern and southern components respectively. Subse-quently, Laurasia and Gondwanaland continued to break into various smaller continents that exist today. A variety of evidence was offered in support of the continental drift. Some of these are given below.

Evidence in Support of the Continental Drift

The Matching of Continents (Jig-Saw-Fit)

The shorelines of Africa and South America facing each other have a remarkable and unmistakable match. It may be noted that a map produced using a computer programme to find the best fit of the Atlantic margin was presented by Bullard in 1964. It proved to be quite perfect. The match was tried at 1,000-fathom line instead of the present shoreline.

Rocks of Same Age Across the Oceans

The radiometric dating methods developed in the recent period have facilitated correlating the rock formation from different continents across the vast ocean. The belt of ancient rocks of 2,000 million years from Brazil coast matches with those from western Africa. The earliest marine deposits along the coastline of South America and Africa are of the Jurassic age. This suggests that the ocean did not exist prior to that time.

Tillite

It is the sedimentary rock formed out of deposits of glaciers. The Gondawana system of sediments from India is known to have its counter parts in six different landmasses of the Southern Hemisphere. At the base the system has thick tillite indicating extensive and prolonged glaciation. Counter parts of this succession are found in Africa, Falkland Island, Madagascar, Antarctica and Australia besides India. Overall resemblance of the Gondawana type sediments clearly demonstrates that these landmasses had remarkably similar histories. The glacial tillite provides unambiguous evidence of palaeoclimates and also of drifting of continents.

Placer Deposits

The occurrence of rich placer deposits of gold in the Ghana coast and the absolute absence of source rock in the region is an amazing fact. The gold bearing veins are in Brazil and it is obvious that the gold deposits of the Ghana are derived from the Brazil plateau when the two continents lay side by side.

Distribution of Fossils

When identical species of plants and animals adapted to living on land or in fresh water are found on either side of the marine barriers, a problem arises regarding accounting for such distribution. The observations that Lemurs occur in India, Madagascar and Africa led some to consider a contiguous landmass "Lemuria" linking these three landmasses. Mesosaurus was a small reptile adapted to shallow brackish water. The skeletons of these are found only in two localities : the Southern Cape province of South Africa and Iraver formations of Brazil. The two localities presently are 4,800 km apart with an ocean in between them.

Force for Drifting

Wegener suggested that the movement responsible for the drifting of the continents was caused by pole-fleeing force and tidal force. The polar-fleeing force relates to the rotation of the earth. You are aware of the fact that the earth is not a perfect sphere; it has a bulge at the equator. This bulge is due to the rotation of the earth. The second force that was suggested by Wegener—the tidal force—is due to the attraction of the moon and the sun that develops tides in oceanic waters. Wegener believed that these forces would become effective when applied over many million years. However, most of scholars considered these forces to be totally inadequate.

Post-Drift Studies

It is interesting to note that for continental drift, most of the evidence was collected from the continental areas in the form of distribution of flora and fauna or deposits like tillite. A number of discoveries during the post-war period added new information to geological literature. Particularly, the information collected from the ocean floor mapping provided new dimensions for the study of distribution of oceans and continents.

Convectional Current Theory

Arthur Holmes in 1930s discussed the possibility of convection currents operating in the mantle portion. These currents are generated due to radioactive elements causing thermal differences in the mantle portion. Holmes argued that there exists a system of such currents in the entire mantle portion. This was an attempt to provide an explanation to the issue of force, on the basis of which contemporary scientists discarded the continental drift theory.

Mapping of the Ocean Floor

Detailed research of the ocean configuration revealed that the ocean floor is not just a vast plain but it is full of relief. Expeditions to map the oceanic floor in the post-war period provided a detailed picture of the ocean relief and indicated the existence of submerged mountain ranges as well as deep trenches, mostly located closer to the continent margins. The mid-oceanic ridges were found to be most active in terms of volcanic eruptions. The dating of the rocks from the oceanic crust revealed the fact that they are much younger than the continental areas. Rocks on either side of the crest of oceanic ridges and having equi-distant locations from the crest were found to have remarkable similarities both in terms of their constituents and their age.

Ocean Floor Configuration

In this section we shall note a few things related to the ocean floor configuration that help us in the understanding of the distribution of continents and oceans. You will be studying the details of ocean floor relief in Chapter 13. The ocean floor may be segmented into three major divisions based on the depth as well as the forms of relief. These divisions are continental margins, deep-sea basins and mid-ocean ridges.

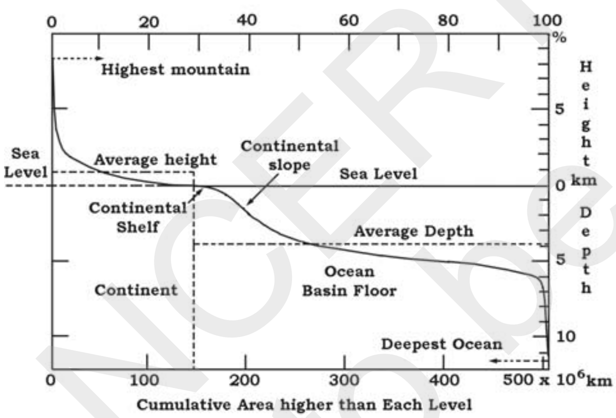


Figure 4.1 : Ocean Floor

Continental Margins

These form the transition between continental shores and deep-sea basins. They include continental shelf, continental slope, continental rise and deep-oceanic trenches. Of these, the deep-oceanic trenches are the areas which are of considerable interest in so far as the distribution of oceans and continents is concerned.

Abyssal Plains

These are extensive plains that lie between the continental margins and mid-oceanic ridges. The abyssal plains are the areas where the continental sediments that move beyond the margins get deposited.

Mid-Oceanic Ridges

This forms an interconnected chain of mountain system within the ocean. It is the longest mountain-chain on the surface of the earth though submerged under the oceanic waters. It is characterised by a central rift system at the crest, a fractionated plateau and flank zone all along its length. The rift system at the crest is the zone of intense volcanic activity. In the previous chapter, you have been introduced to this type of volcanoes as mid-oceanic volcanoes.

Distribution of Earthquakes and Volcanoes

Study the maps showing the distribution of seismic activity and volcanoes given in Figure 4.2. You will notice a line of dots in the central parts of the Atlantic Ocean almost parallel to the coastlines. It further extends into the Indian Ocean. It bifurcates a little south of the Indian subcontinent with one branch moving into East Africa and the other meeting a similar line from Myanmar to New Guiana. You will notice that this line of dots coincides with the mid-oceanic ridges. The shaded belt showing another area of concentration coincides with the Alpine-Himalayan system and the rim of the Pacific Ocean. In general, the foci of the earthquake in the areas of mid-oceanic ridges are at shallow depths whereas along the Alpine-Himalayan belt as well as the rim of the Pacific, the earthquakes are deep-seated ones. The map of volcanoes also shows a similar pattern. The rim of the Pacific is also called rim of fire due to the existence of active volcanoes in this area.

CONCEPT OF SEA FLOOR SPREADING

As mentioned above, the post-drift studies provided considerable information that was not

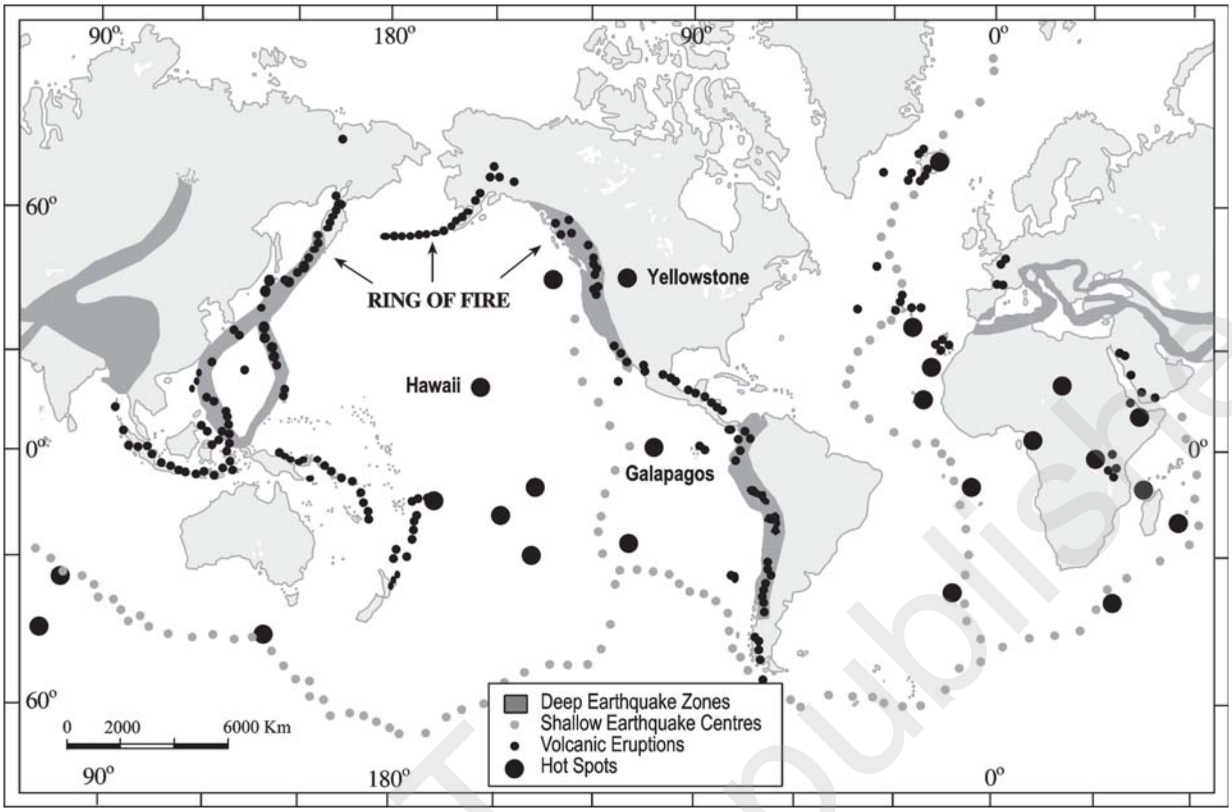


Figure 4. 2 : Distribution of earthquakes and volcanoes

available at the time Wegener put forth his concept of continental drift. Particularly, the mapping of the ocean floor and palaeomagnetic studies of rocks from oceanic regions revealed the following facts :

(i) It was realised that all along the mid-oceanic ridges, volcanic eruptions are common and they bring huge amounts of lava to the surface in this area.

(ii) The rocks equidistant on either sides of the crest of mid-oceanic ridges show remarkable similarities in terms of period of formation, chemical compositions and magnetic properties. Rocks closer to the mid-oceanic ridges have normal polarity and are the youngest. The age of the rocks increases as one moves away from the crest.

(iii) The ocean crust rocks are much younger than the continental rocks. The age of rocks in the oceanic crust is nowhere more than 200 million years old. Some of the continental rock formations are as old as 3,200 million years.

(iv) The sediments on the ocean floor are unexpectedly very thin. Scientists were expecting, if the ocean floors were as old as the continent, to have a complete sequence of sediments for a period of much longer duration. However, nowhere was the sediment column found to be older than 200 million years.

(v) The deep trenches have deep-seated earthquake occurrences while in the mid-oceanic ridge areas, the quake foci have shallow depths.

These facts and a detailed analysis of magnetic properties of the rocks on either sides of the mid-oceanic ridge led Hess (1961) to propose his hypothesis, known as the "sea floor spreading". Hess argued that constant eruptions at the crest of oceanic ridges cause the rupture of the oceanic crust and the new lava wedges into it, pushing the oceanic crust on either side. The ocean floor, thus spreads. The younger age of the oceanic crust as well as the fact that the spreading of one ocean does not cause the shrinking of the other, made Hess

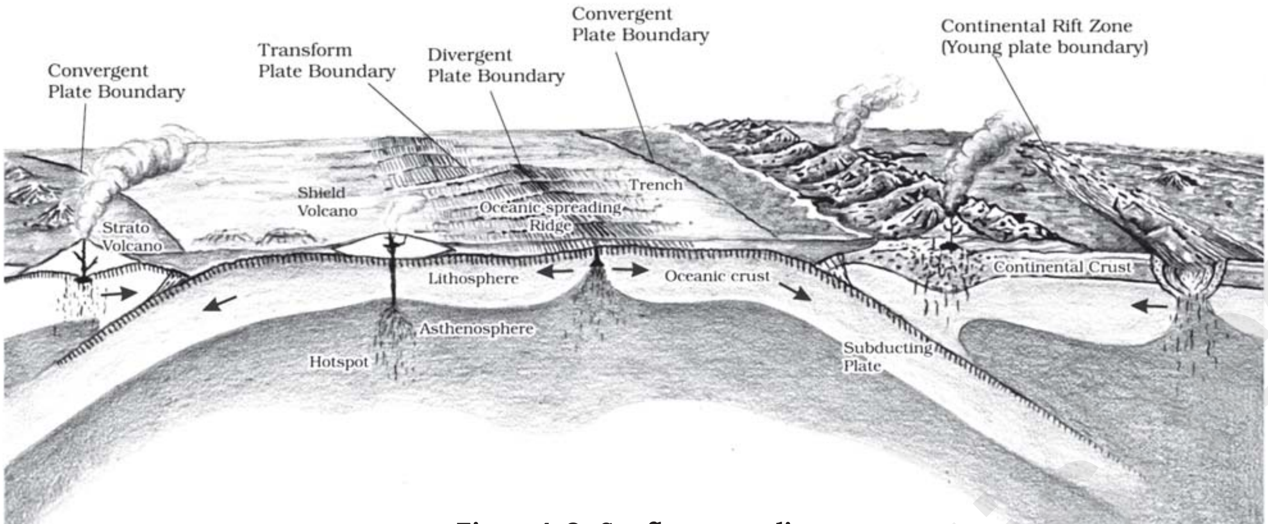


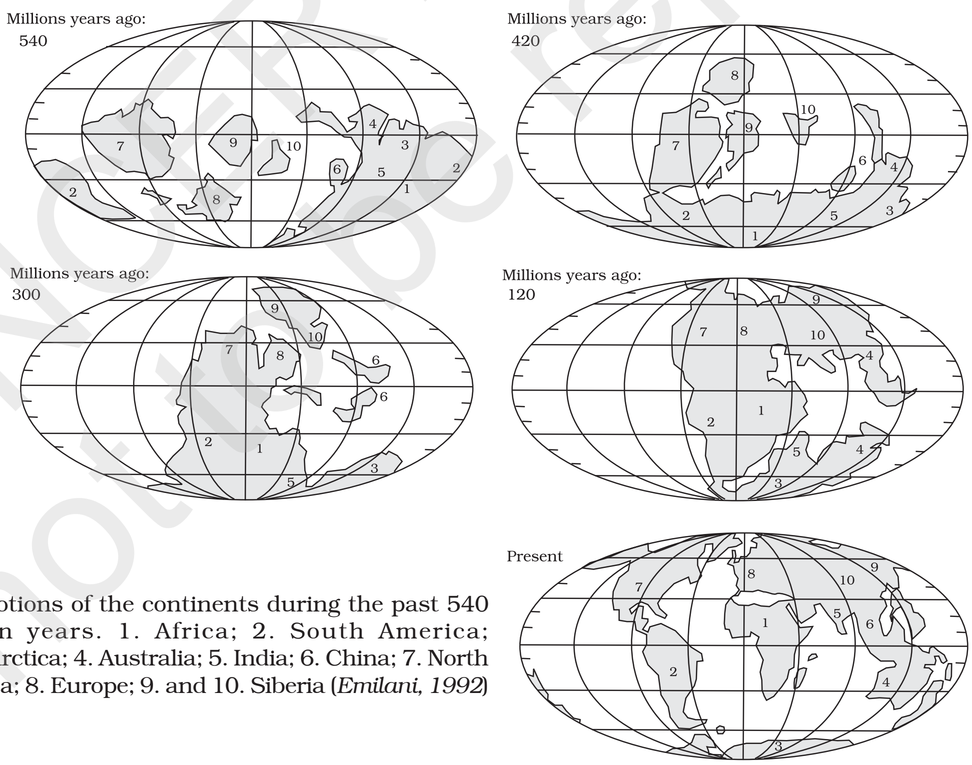
Figure 4. 3 : Sea floor spreading

think about the consumption of the oceanic crust. He further maintained that the ocean floor that gets pushed due to volcanic eruptions at the crest, sinks down at the oceanic trenches and gets consumed.

The basic concept of sea floor spreading has been depicted in Figure 4.3.

Plate Tectonics

Since the advent of the concept of sea floor spreading, the interest in the problem of distribution of oceans and continents was revived. It was in 1967, McKenzie and Parker and also Morgan, independently collected the available ideas and came out with another



The motions of the continents during the past 540 million years. 1. Africa; 2. South America; 3. Antarctica; 4. Australia; 5. India; 6. China; 7. North America; 8. Europe; 9. and 10. Siberia (*Emilani, 1992*)

Figure 4.4 : Position of continents through geological past

concept termed *Plate Tectonics*. A tectonic plate (also called lithospheric plate) is a massive, irregularly-shaped slab of solid rock, generally composed of both continental and oceanic lithosphere. Plates move horizontally over the asthenosphere as rigid units. The lithosphere includes the crust and top mantle with its thickness range varying between 5-100 km in oceanic parts and about 200 km in the continental areas. A plate may be referred to as the continental plate or oceanic plate depending on which of the two occupy a larger portion of the plate. Pacific plate is largely an oceanic plate whereas the Eurasian plate may be called a continental plate. The theory of plate tectonics proposes that the earth's lithosphere is divided into seven major and some minor plates. Young Fold Mountain ridges, trenches, and/or faults surround these major plates (Figure 4.5). The major plates are as follows :

(i) Antarctica and the surrounding oceanic plate
(ii) North American (with western Atlantic floor separated from the South American plate along the Caribbean islands) plate
(iii) South American (with western Atlantic floor separated from the North American plate along the Caribbean islands) plate
(iv) Pacific plate
(v) India-Australia-New Zealand plate
(vi) Africa with the eastern Atlantic floor plate
(vii) Eurasia and the adjacent oceanic plate.

Some important minor plates are listed below:

(i) *Cocos plate* : Between Central America and Pacific plate
(ii) *Nazca plate* : Between South America and Pacific plate
(iii) *Arabian plate* : Mostly the Saudi Arabian landmass
(iv) *Philippine plate* : Between the Asiatic and Pacific plate

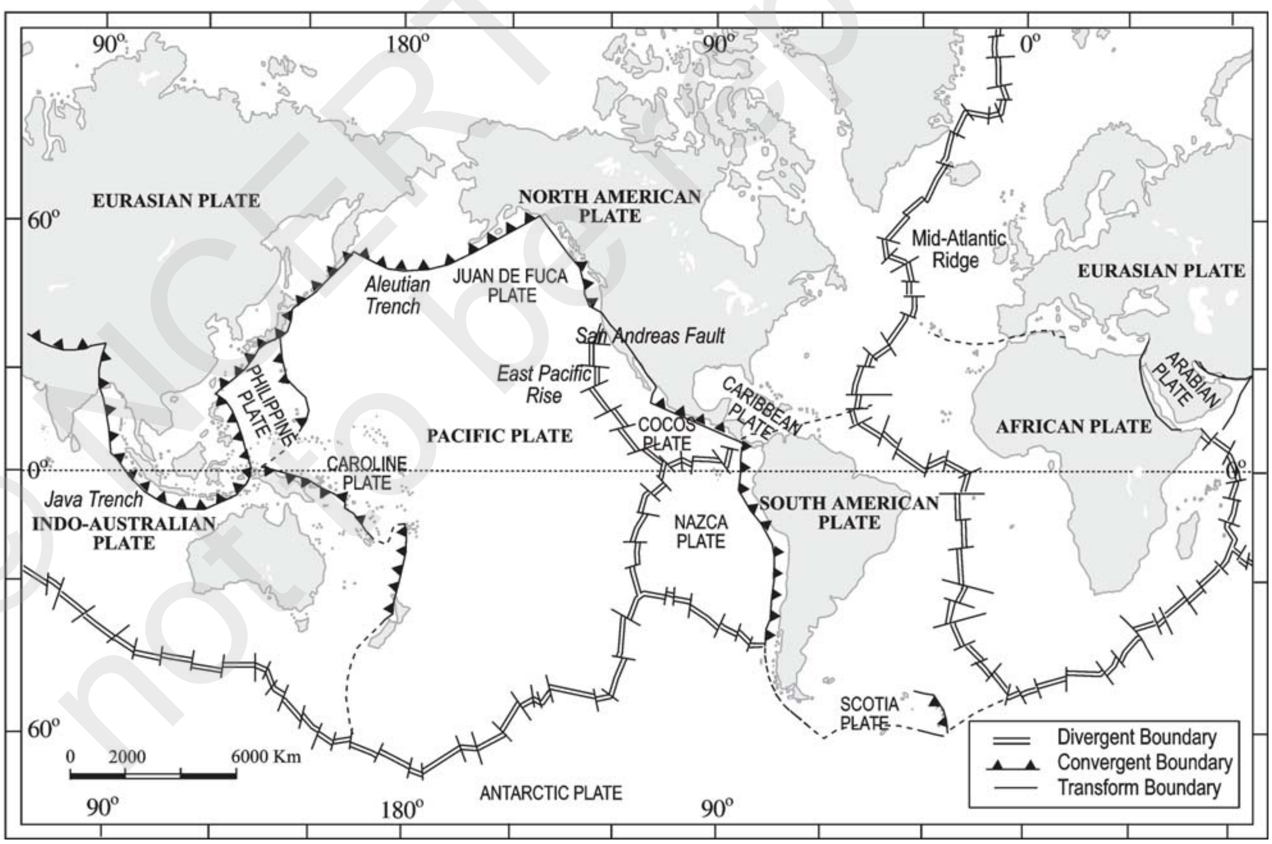


Figure 4.5 : Major and minor plates of the world

(v) *Caroline plate* : Between the Philippine and Indian plate (North of New Guinea)
(vi) *Fuji plate* : North-east of Australia.

These plates have been constantly moving over the globe throughout the history of the earth. It is not the continent that moves as believed by Wegener. Continents are part of a plate and what moves is the plate. Moreover, it may be noted that all the plates, without exception, have moved in the geological past, and shall continue to move in the future as well. Wegener had thought of all the continents to have initially existed as a super continent in the form of Pangaea. However, later discoveries reveal that the continental masses, resting on the plates, have been wandering all through the geological period, and Pangaea was a result of converging of different continental masses that were parts of one or the other plates. Scientists using the palaeomagnetic data have determined the positions held by each of the present continental landmass in different geological periods (Fig 4.4). Position of the Indian sub-continent (mostly Peninsular India) is traced with the help of the rocks analysed from the Nagpur area.

There are three types of plate boundaries:

Divergent Boundaries

Where new crust is generated as the plates pull away from each other. The sites where the plates move away from each other are called *spreading sites*. The best-known example of divergent boundaries is the Mid-Atlantic Ridge. At this, the American Plate(s) is/are separated from the Eurasian and African Plates.

Convergent Boundaries

Where the crust is destroyed as one plate dived under another. The location where sinking of a plate occurs is called a *subduction zone*. There are three ways in which convergence can occur. These are: (i) between an oceanic and continental plate; (ii) between two oceanic plates; and (iii) between two continental plates.

Transform Boundaries

Where the crust is neither produced nor destroyed as the plates slide horizontally past each other. Transform faults are the planes of separation generally perpendicular to the mid-oceanic ridges. As the eruptions do not take all along the entire crest at the same time, there is a differential movement of a portion of the plate away from the axis of the earth. Also, the rotation of the earth has its effect on the separated blocks of the plate portions.

How do you think the rate of plate movement is determined?

Rates of Plate Movement

The strips of normal and reverse magnetic field that parallel the mid-oceanic ridges help scientists determine the rates of plate movement. These rates vary considerably. The Arctic Ridge has the slowest rate (less than 2.5 cm/yr), and the East Pacific Rise near Easter Island, in the South Pacific about 3,400 km west of Chile, has the fastest rate (more than 15 cm/yr).

Force for the Plate Movement

At the time that Wegener proposed his theory of continental drift, most scientists believed that the earth was a solid, motionless body. However, concepts of sea floor spreading and the unified theory of plate tectonics have emphasised that both the surface of the earth and the interior are not static and motionless but are dynamic. The fact that the plates move is now a well-accepted fact. The mobile rock beneath the rigid plates is believed to be moving in a circular manner. The heated material rises to the surface, spreads and begins to cool, and then sinks back into deeper depths. This cycle is repeated over and over to generate what scientists call a convection cell or convective flow. Heat within the earth comes from two main sources: radioactive decay and residual heat. Arthur Holmes first considered this idea in the 1930s, which later influenced Harry Hess' thinking about seafloor spreading. The slow movement of hot, softened mantle that lies below the rigid plates is the driving force behind the plate movement.

Movement of the Indian Plate

The Indian plate includes Peninsular India and the Australian continental portions. The subduction zone along the Himalayas forms the northern plate boundary in the form of continent— *continent convergence*. In the east, it extends through Rakinyoma Mountains of Myanmar towards the island arc along the Java Trench. The eastern margin is a *spreading site* lying to the east of Australia in the form of an oceanic ridge in SW Pacific. The Western margin follows Kirthar Mountain of Pakistan. It further extends along the Makrana coast and joins the *spreading site* from the Red Sea rift southeastward along the Chagos Archipelago. The boundary between India and the Antarctic plate is also marked by oceanic ridge *(divergent boundary)* running in roughly W-E direction and merging into the *spreading site*, a little south of New Zealand.

India was a large island situated off the Australian coast, in a vast ocean. The Tethys Sea separated it from the Asian continent till about 225 million years ago. India is supposed to have started her northward journey about 200 million years ago at the time when Pangaea broke. India collided with Asia about 40-50 million years ago causing rapid uplift of the Himalayas. The positions of India since about 71 million years till the present are shown in the Figure 4.6. It also shows the position of the Indian subcontinent and the Eurasian plate. About 140 million years before the present, the subcontinent was located as south as 50^{o}S. latitude. The two major plates were separated by the Tethys Sea and the Tibetan block was closer to the Asiatic landmass. During the movement of the Indian

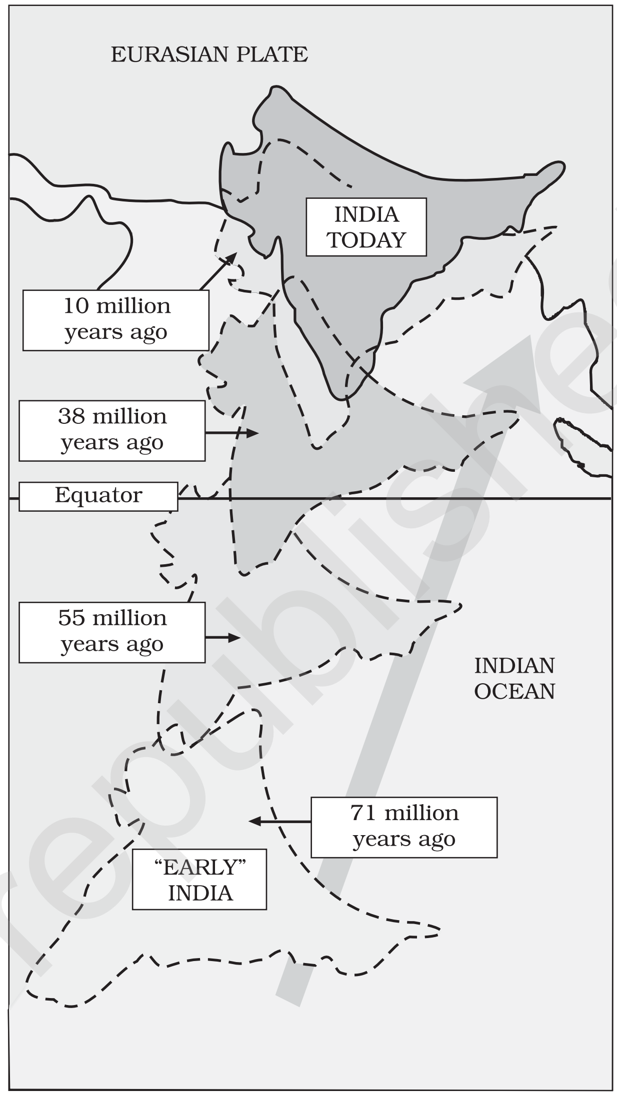


Figure 4.6 : Movement of the Indian plate

plate towards the Asiatic plate, a major event that occurred was the outpouring of lava and formation of the Deccan Traps. This started somewhere around 60 million years ago and continued for a long period of time. Note that the subcontinent was still close to the equator. From 40 million years ago and thereafter, the event of formation of the Himalayas took place. Scientists believe that the process is still continuing and the height of the Himalayas is rising even to this date.

EXERCISES

1. Multiple choice questions.

(i) Who amongst the following was the first to consider the possibility of Europe, Africa and America having been located side by side.

(a) Alfred Wegener (c) Abraham Ortelius

(b) Antonio Pellegrini (d) Edmond Hess

(ii) Polar fleeing force relates to:

(a) Revolution of the Earth (c) Rotation of the earth

(b) Gravitation (d) Tides

(iii) Which one of the following is not a minor plate?

(a) Nazca (c) Philippines

(b) Arabia (d) Antarctica

(iv) Which one of the following facts was not considered by those while discussing the concept of sea floor spreading?

(a) Volcanic activity along the mid-oceanic ridges.

(b) Stripes of normal and reverse magnetic field observed in rocks of ocean floor.

(c) Distribution of fossils in different continents.

(d) Age of rocks from the ocean floor.

(v) Which one of the following is the type of plate boundary of the Indian plate along the Himalayan mountains?

(a) Ocean-continent convergence

(b) Divergent boundary

(c) Transform boundary

(d) Continent-continent convergence

2. Answer the following questions in about 30 words.

(i) What were the forces suggested by Wegener for the movement of the continents?

(ii) How are the convectional currents in the mantle initiated and maintained?

(iii) What is the major difference between the transform boundary and the convergent or divergent boundaries of plates?

(iv) What was the location of the Indian landmass during the formation of the Deccan Traps?

3. Answer the following questions in about 150 words.

(i) What are the evidences in support of the continental drift theory?

(ii) Bring about the basic difference between the drift theory and Plate tectonics.

(iii) What were the major post-drift discoveries that rejuvenated the interest of scientists in the study of distribution of oceans and continents?

Project Work

Prepare a collage related to damages caused by an earthquake.

UNIT III

LANDFORMS

This unit deals with

- *Rocks and minerals — major types of rocks and their characteristics*
- *Landforms and their evolution*
- *Geomorphic processes — weathering, mass wasting, erosion and deposition; soils — formation*

CHAPTER

5

Minerals and Rocks

The earth is composed of various kinds of elements. These elements are in solid form in the outer layer of the earth and in hot and molten form in the interior.

About 98 per cent of the total crust of the earth is composed of eight elements like oxygen, silicon, aluminium, iron, calcium, sodium, potassium and magnesium (Table 5.1), and the rest is constituted by titanium, hydrogen, phosphorous, manganese, sulphur, carbon, nickel and other elements.

Table 5.1 : The Major Elements of the Earth's Crust

Sl. No.	Elements	By Weight(%)
1.	Oxygen	46.60
2.	Silicon	27.72
3.	Aluminium	8.13
4.	Iron	5.00
5.	Calcium	3.63
6.	Sodium	2.83
7.	Potassium	2.59
8.	Magnesium	2.09
9.	Others	1.41

The elements in the earth's crust are rarely found exclusively but are usually combined with other elements to make various substances. These substances are recognised as minerals.

Thus, a mineral is a naturally occurring organic and inorganic substance, having an orderly atomic structure and a definite chemical composition and physical properties. A mineral is composed of two or more elements. But, sometimes single element minerals like sulphur, copper, silver, gold, graphite etc. are found.

Though the number of elements making up the lithosphere are limited they are combined in many different ways to make up many varieties of minerals. There are at least 2,000 minerals that have been named and identified in the earth crust; but almost all the commonly occurring ones are related to six major mineral groups that are known as major rock forming minerals.

The basic source of all minerals is the hot magma in the interior of the earth. When magma cools, crystals of minerals appear and a systematic series of minerals are formed in sequence to solidify so as to form rocks. Minerals such as coal, petroleum and natural gas are organic substances found in solid, liquid and gaseous forms respectively.

A brief information about some important minerals in terms of their nature and physical characteristics is given below :

Physical Characteristics

(i) External crystal form — determined by internal arrangement of the molecules — cubes, octahedrons, hexagonal prisms, etc.

(ii) Cleavage — tendency to break in given directions producing relatively plane surfaces — result of internal arrangement of the molecules — may cleave in one or more directions and at any angle to each other.

(iii) Fracture — internal molecular arrangement so complex there are no planes of molecules; the crystal will break in an irregular manner, not along planes of cleavage.

(iv) Lustre — appearance of a material without regard to colour; each mineral has a distinctive lustre like metallic, silky, glossy etc.

(v) Colour — some minerals have characteristic colour determined by their molecular structure — malachite, azurite, chalcopyrite etc., and some minerals are coloured by impurities. For example, because of impurities quartz may be white, green, red, yellow etc.

(vi) Streak — colour of the ground powder of any mineral. It may be of the same colour as the mineral or may differ — malachite is green and gives green streak, fluorite is purple or green but gives a white streak.

(vii) Transparency — transparent: light rays pass through so that objects can be seen plainly; translucent — light rays pass through but will get diffused so that objects cannot be seen; opaque — light will not pass at all.

(viii) Structure — particular arrangement of the individual crystals; fine, medium or coarse grained; fibrous — separable, divergent, radiating.

(ix) Hardness — relative resistance being scratched; ten minerals are selected to measure the degree of hardness from 1-10. They are: 1. talc; 2. gypsum; 3. calcite; 4. fluorite; 5. apatite; 6. feldspar; 7. quartz; 8. topaz; 9. corundum; 10. diamond. Compared to this for example, a fingernail is 2.5 and glass or knife blade is 5.5.

(x) Specific gravity — the ratio between the weight of a given object and the weight of an equal volume of water; object weighed in air and then weighed in water and divide weight in air by the difference of the two weights.

Some Major Minerals and their Characteristics

Feldspar

Silicon and oxygen are common elements in all types of feldspar and sodium, potassium, calcium, aluminium etc. are found in specific feldspar variety. Half of the earth's crust is composed of feldspar. It has light cream to salmon pink colour. It is used in ceramics and glass making.

Quartz

It is one of the most important components of sand and granite. It consists of silica. It is a hard mineral virtually insoluble in water. It is white or colourless and used in radio and radar. It is one of the most important components of granite.

Pyroxene

Pyroxene consists of calcium, aluminum, magnesium, iron and silica. Pyroxene forms 10 per cent of the earth's crust. It is commonly found in meteorites. It is in green or black colour.

Amphibole

Aluminium, calcium, silica, iron, magnesium are the major elements of amphiboles. They form 7 per cent of the earth's crust. It is in green or black colour and is used in asbestos industry. Hornblende is another form of amphiboles.

Mica

It comprises of potassium, aluminium, magnesium, iron, silica etc. It forms 4 per cent of the earth's crust. It is commonly found in igneous and metamorphic rocks. It is used in electrical instruments.

Olivine

Magnesium, iron and silica are major elements of olivine. It is used in jewellery. It is usually a greenish crystal, often found in basaltic rocks.

Besides these main minerals, other minerals like chlorite, calcite, magnetite, haematite, bauxite and barite are also present in some quantities in the rocks.

Metallic Minerals

These minerals contain metal content and can be sub-divided into three types:

(i) *Precious metals* : gold, silver, platinum etc.
(ii) *Ferrous metals* : iron and other metals often mixed with iron to form various kinds of steel.
(iii) *Non-ferrous metals* : include metals like copper, lead, zinc, tin, aluminium etc.

Non-Metallic Minerals

These minerals do not contain metal content. Sulphur, phosphates and nitrates are examples of non-metallic minerals. Cement is a mixture of non-metallic minerals.

Rocks

The earth's crust is composed of rocks. A rock is an aggregate of one or more minerals. Rock may be hard or soft and in varied colours. For example, granite is hard, soapstone is soft. Gabbro is black and quartzite can be milky white. Rocks do not have definite composition of mineral constituents. Feldspar and quartz are the most common minerals found in rocks.

> Petrology is science of rocks. A petrologist studies rocks in all their aspects viz., mineral composition, texture, structure, origin, occurrence, alteration and relationship with other rocks.

As there is a close relation between rocks and landforms, rocks and soils, a geographer requires basic knowledge of rocks. There are many different kinds of rocks which are grouped under three families on the basis of their mode of formation. They are: (i) Igneous Rocks — solidified from magma and lava; (ii) Sedimentary Rocks — the result of deposition of fragments of rocks by exogenous processes; (iii) Metamorphic Rocks — formed out of existing rocks undergoing recrystallisation.

Igneous Rocks

As igneous rocks form out of magma and lava from the interior of the earth, they are known as primary rocks. The igneous rocks (Ignis – in Latin means 'Fire') are formed when magma cools and solidifies. You already know what magma is. When magma in its upward movement cools and turns into solid form it is called igneous rock. The process of cooling and solidification can happen in the earth's crust or on the surface of the earth.

Igneous rocks are classified based on texture. Texture depends upon size and arrangement of grains or other physical conditions of the materials. If molten material is cooled slowly at great depths, mineral grains may be very large. Sudden cooling (at the surface) results in small and smooth grains. Intermediate conditions of cooling would result in intermediate sizes of grains making up igneous rocks. Granite, gabbro, pegmatite, basalt, volcanic breccia and tuff are some of the examples of igneous rocks.

Sedimentary Rocks

The word 'sedimentary' is derived from the Latin word sedimentum, which means settling. Rocks (igneous, sedimentary and metamorphic) of the earth's surface are exposed to denudational agents, and are broken up into various sizes of fragments. Such fragments are transported by different exogenous agencies and deposited. These deposits through compaction turn into rocks. This process is called *lithification*. In many sedimentary rocks, the layers of deposits retain their characteristics even after lithification. Hence, we see a number of layers of varying thickness in sedimentary rocks like sandstone, shale etc.

Depending upon the mode of formation, sedimentary rocks are classified into three major groups: (i) mechanically formed — sandstone, conglomerate, limestone, shale, loess etc. are examples; (ii) organically formed — geyserite, chalk, limestone, coal etc. are some examples; (iii) chemically formed — chert, limestone, halite, potash etc. are some examples.

Metamorphic Rocks

The word metamorphic means 'change of form'. These rocks form under the action of pressure, volume and temperature (PVT) changes. Metamorphism occurs when rocks are forced down to lower levels by tectonic processes or when molten magma rising through the crust comes in contact with the crustal rocks or the underlying rocks are subjected to great amounts of pressure by overlying rocks. Metamorphism is a process by which already consolidated rocks undergo recrystallisation and reorganisation of materials within original rocks.

Mechanical disruption and reorganisation of the original minerals within rocks due to breaking and crushing without any appreciable chemical changes is called dynamic metamorphism. The materials of rocks chemically alter and recrystallise due to thermal metamorphism. There are two types of thermal metamorphism — contact metamorphism and regional metamorphism. In contact metamorphism the rocks come in contact with hot intruding magma and lava and the rock materials recrystallise under high temperatures. Quite often new materials form out of magma or lava are added to the rocks. In regional metamorphism, rocks undergo recrystallisation due to deformation caused by tectonic shearing together with high temperature or pressure or both. In the process of metamorphism in some rocks grains or minerals get arranged in layers or lines. Such an arrangement of minerals or grains in metamorphic rocks is called *foliation* or *lineation*. Sometimes minerals or materials of different groups are arranged into alternating thin to thick layers appearing in light and dark shades. Such a structure in metamorphic rocks is called *banding* and rocks displaying banding are called *banded rocks*. Types of metamorphic rocks depend upon original rocks that were subjected to metamorphism. Metamorphic rocks are classified into two major groups — foliated rocks and non-foliated rocks. Gneissoid, granite, syenite, slate, schist, marble, quartzite etc. are some examples of metamorphic rocks.

Rock Cycle

Rocks do not remain in their original form for long but may undergo transformation. Rock cycle is a continuous process through which old rocks are transformed into new ones.

Igneous rocks are primary rocks and other rocks (sedimentary and metamorphic) form from these primary rocks. Igneous rocks can be changed into metamorphic rocks. The fragments derived out of igneous and metamorphic rocks form into sedimentary

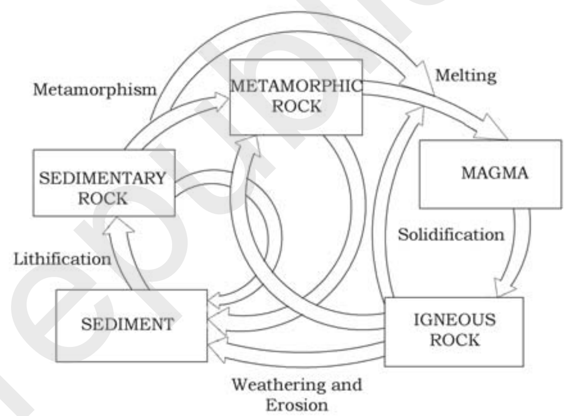


Fig 5.1 : Rock Cycle

rocks. Sedimentary rocks themselves can turn into fragments and the fragments can be a source for formation of sedimentary rocks. The crustal rocks (igneous, metamorphic and sedimentary) once formed may be carried down into the mantle (interior of the earth) through subduction process (parts or whole of crustal plates going down under another plate in zones of plate convergence) and the same melt down due to increase in temperature in the interior and turn into molten magma, the original source for igneous rocks (Figure 5.1).

EXERCISES

1. Multiple choice questions.

   (i) Which one of the following are the two main constituents of granite?
   (a) Iron and nickel (c) Silica and aluminium
   (b) Iron and silver (d) Iron Oxide and potassium

   (ii) Which one of the following is the salient feature of metamorphic rocks?
   (a) Changeable (c) Crystalline
   (b) Quite (d) Foliation

   (iii) Which one of the following is not a single element mineral?
   (a) Gold (c) Mica
   (b) Silver (d) Graphite

   (iv) Which one of the following is the hardest mineral?
   (a) Topaz (c) Quartz
   (b) Diamond (d) Feldspar

   (v) Which one of the following is not a sedimentary rock?
   (a) Tillite (c) Breccia
   (b) Borax (d) Marble

2. Answer the following questions in about 30 words.

   (i) What do you mean by rocks? Name the three major classes of rocks.

   (ii) What is an igneous rock? Describe the method of formation and characteristics of igneous rock.

   (iii) What is meant by sedimentary rock? Describe the mode of formation of sedimentary rock.

   (iv) What relationship explained by rock cycle between the major type of rock?

3. Answer the following questions in about 150 words.

   (i) Define the term 'mineral' and name the major classes of minerals with their physical characteristics.

   (ii) Describe the nature and mode of origin of the chief types of rock at the earth's crust. How will you distinguish them?

   (iii) What are metamorphic rocks? Describe the types of metamorphic rock and how are they formed?

Project Work

Collect different rock samples and try to recognise them from their physical characteristics and identify their family.

CHAPTER

6

Geomorphic Processes

After learning about how the earth was born, how it evolved its crust and other inner layers, how its crustal plates moved and are moving, and other information on earthquakes, the forms of volcanism and about the rocks and minerals the crust is composed of, it is time to know in detail about the surface of the earth on which we live. Let us start with this question.

Why is the surface of the earth uneven?

The earth's crust is dynamic. You are well aware that it has moved and moves vertically and horizontally. Of course, it moved a bit faster in the past than the rate at which it is moving now. The differences in the internal forces operating from within the earth which built up the crust have been responsible for the variations in the outer surface of the crust. The earth's surface is being continuously subjected to external forces induced basically by energy (sunlight). Of course, the internal forces are still active though with different intensities. That means, the earth's surface is being continuously subjected to by external forces originating within the earth's atmosphere and by internal forces from within the earth. The external forces are known as *exogenic forces* and the internal forces are known as *endogenic forces*. The actions of exogenic forces result in wearing down (degradation) of relief/elevations and filling up (aggradation) of basins/depressions, on the earth's surface. The phenomenon of wearing down of relief variations of the surface of the earth through erosion is known as *gradation*. The endogenic forces continuously elevate or build up parts of the earth's surface and hence the exogenic processes fail to even out the relief variations of the surface of the earth. So, variations remain as long as the opposing actions of exogenic and endogenic forces continue. In general terms, the endogenic forces are mainly land building forces and the exogenic processes are mainly land wearing forces. The surface of the earth is sensitive. Humans depend on it for their sustenance and have been using it extensively and intensively. So, it is essential to understand its nature in order to use it effectively without disturbing its balance and diminishing its potential for the future. Almost all organisms contribute to sustain the earth's environment. However, humans have caused extensive damage to the environment through over use of resources. Use we must, but must also leave it potential enough to sustain life through the future. Most of the surface of the earth had and has been shaped over very long periods of time (hundreds and thousands of years) and because of its use and misuse by humans its potential is being diminished at a fast rate. If the processes which shaped and are shaping the surface of the earth into varieties of forms (shapes) and the nature of materials of which it is composed of, are understood, precautions can be taken to minimise the detrimental effects of human use and to preserve it for posterity.

Geomorphic Processes

You would like to know the meaning of geomorphic processes. The endogenic and exogenic forces causing physical stresses and chemical actions on earth materials and bringing about changes in the configuration of the surface of the earth are known as *geomorphic processes*. Diastrophism and volcanism are endogenic geomorphic processes. These have already been discussed in brief in the preceding unit. Weathering, mass wasting, erosion and deposition are exogenic geomorphic processes. These exogenic processes are dealt with in detail in this chapter.

Any exogenic element of nature (like water, ice, wind, etc.,) capable of acquiring and transporting earth materials can be called a geomorphic agent. When these elements of nature become mobile due to gradients, they remove the materials and transport them over slopes and deposit them at lower level. Geomorphic processes and geomorphic agents especially exogenic, unless stated separately, are one and the same.

A process is a force applied on earth materials affecting the same. An agent is a mobile medium (like running water, moving ice masses, wind, waves and currents etc.) which removes, transports and deposits earth materials. Running water, groundwater, glaciers, wind, waves and currents, etc., can be called *geomorphic agents*.

> Do you think it is essential to distinguish geomorphic agents and geomorphic processes?

Gravity besides being a directional force activating all downslope movements of matter also causes stresses on the earth's materials. Indirect gravitational stresses activate wave and tide induced currents and winds. Without gravity and gradients there would be no mobility and hence no erosion, transportation and deposition are possible. So, gravitational stresses are as important as the other geomorphic processes. Gravity is the force that is keeping us in contact with the surface and it is the force that switches on the movement of all surface material on earth. All the movements either within the earth or on the surface of the earth occur due to gradients — from higher levels to lower levels, from high pressure to low pressure areas etc.

Endogenic Processes

The energy emanating from within the earth is the main force behind endogenic geomorphic processes. This energy is mostly generated by radioactivity, rotational and tidal friction and primordial heat from the origin of the earth. This energy due to geothermal gradients and heat flow from within induces diastrophism and volcanism in the lithosphere. Due to variations in geothermal gradients and heat flow from within, crustal thickness and strength, the action of endogenic forces are not uniform and hence the tectonically controlled original crustal surface is uneven.

Diastrophism

All processes that move, elevate or build up portions of the earth's crust come under *diastrophism*. They include: (i) *orogenic* processes involving mountain building through severe folding and affecting long and narrow belts of the earth's crust; (ii) *epeirogenic* processes involving uplift or warping of large parts of the earth's crust; (iii) earthquakes involving local relatively minor movements; (iv) plate tectonics involving horizontal movements of crustal plates.

In the process of orogeny, the crust is severely deformed into folds. Due to epeirogeny, there may be simple deformation. Orogeny is a mountain building process whereas epeirogeny is continental building process. Through the processes of orogeny, epeirogeny, earthquakes and plate tectonics, there can be faulting and fracturing of the crust. All these processes cause pressure, volume and temperature (PVT) changes which in turn induce metamorphism of rocks.

> Epeirogeny and orogeny, cite the differences.

Volcanism

Volcanism includes the movement of molten rock (magma) onto or toward the earth's surface and also formation of many intrusive and extrusive volcanic forms. Many aspects of volcanism have already been dealt in detail under volcanoes in the Unit II and under igneous rocks in the preceding chapter in this unit.

What do the words volcanism and volcanoes indicate?

Exogenic Processes

The exogenic processes derive their energy from atmosphere determined by the ultimate energy from the sun and also the gradients created by tectonic factors.

Why do you think that the slopes or gradients are created by tectonic factors?

Gravitational force acts upon all earth materials having a sloping surface and tend to produce movement of matter in down slope direction. Force applied per unit area is called *stress*. Stress is produced in a solid by pushing or pulling. This induces deformation. Forces acting along the faces of earth materials are shear stresses (separating forces). It is this stress that breaks rocks and other earth materials. The shear stresses result in angular displacement or slippage. Besides the gravitational stress earth materials become subjected to molecular stresses that may be caused by a number of factors amongst which temperature changes, crystallisation and melting are the most common. Chemical processes normally lead to loosening of bonds between grains, dissolving of soluble minerals or cementing materials. Thus, the basic reason that leads to weathering, mass movements, and erosion is development of stresses in the body of the earth materials.

As there are different climatic regions on the earth's surface the exogenic geomorphic processes vary from region to region. Temperature and precipitation are the two important climatic elements that control various processes.

All the exogenic geomorphic processes are covered under a general term, *denudation*. The word 'denude' means to strip off or to uncover. Weathering, mass wasting/movements, erosion and transportation are included in denudation. The flow chart (Figure 6.1) gives the denudation processes and their respective driving forces. It should become clear from this chart that for each process there exists a distinct driving force or energy.

As there are different climatic regions on the earth's surface owing to thermal gradients created by latitudinal, seasonal and land and water spread variations, the exogenic geomorphic processes vary from region to region. The density, type and distribution of vegetation which largely depend upon precipitation and temperature exert influence indirectly on exogenic geomorphic processes. Within different climatic regions there may be local variations of the effects of different climatic elements due to altitudinal differences, aspect variations and the variation in the amount of insolation received by north and south facing slopes as compared to east and west facing slopes. Further, due to differences in wind velocities and directions, amount and kind of precipitation, its intensity, the relation between precipitation and evaporation, daily range of temperature, freezing and thawing frequency, depth of frost penetration, the geomorphic processes vary within any climatic region.

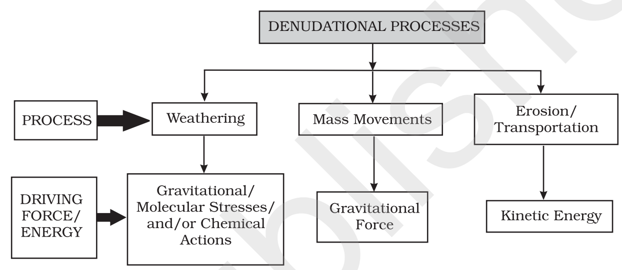


Figure 6.1 : Denudational processes and their driving forces

What is the sole driving force behind all the exogenic processes?

Climatic factors being equal, the intensity of action of exogenic geomorphic processes depends upon type and structure of rocks. The term structure includes such aspects of rocks as folds, faults, orientation and inclination of beds, presence or absence of joints, bedding planes, hardness or softness of constituent minerals, chemical susceptibility of mineral constituents; the permeability or impermeability etc. Different types of rocks with differences in their structure offer varying resistances to various geomorphic processes. A particular rock may be resistant to one process and non-resistant to another. And, under varying climatic conditions, particular rocks may exhibit different degrees of resistance to geomorphic processes and hence they operate at differential rates and give rise to differences in topography. The effects of most of the exogenic geomorphic processes are small and slow and may be imperceptible in a short time span, but will in the long run affect the rocks severely due to continued fatigue.

Finally, it boils down to one fact that the differences on the surface of the earth though originally related to the crustal evolution continue to exist in some form or the other due to differences in the type and structure of earth materials, differences in geomorphic processes and in their rates of operation.

Some of the exogenic geomorphic processes have been dealt in detail here.

Weathering

Weathering is action of elements of weather and climate over earth materials. There are a number of processes within weathering which act either individually or together to affect the earth materials in order to reduce them to fragmental state.

> Weathering is defined as mechanical disintegration and chemical decomposition of rocks through the actions of various elements of weather and climate.

As very little or no motion of materials takes place in weathering, it is an *in-situ* or on-site process.

> Is this little motion which can occur sometimes due to weathering synonymous with transportation? If not, why?

Weathering processes are conditioned by many complex geological, climatic, topographic and vegetative factors. Climate is of particular importance. Not only weathering processes differ from climate to climate, but also the depth of the weathering mantle (Figure 6.2).

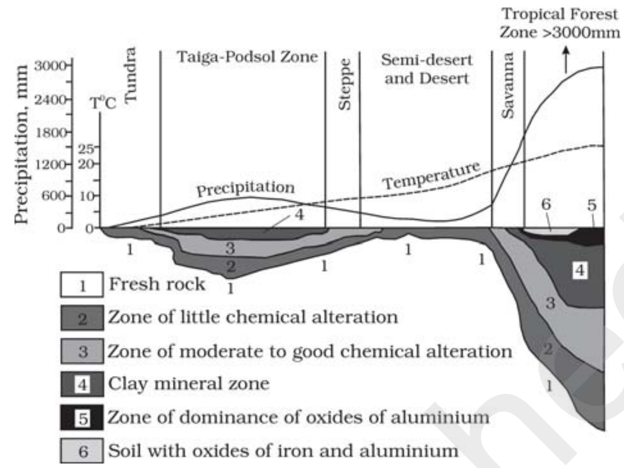


Figure 6.2 : Climatic regimes and depth of weathering mantles (adapted and modified from Strakhov, 1967)

> **Activity**
>
> Mark the latitude values of different climatic regimes in Figure 6.2 and compare the details.

There are three major groups of weathering processes : (i) chemical; (ii) physical or mechanical; (iii) biological weathering processes. Very rarely does any one of these processes ever operate completely by itself, but quite often a dominance of one process can be seen.

Chemical Weathering Processes

A group of weathering processes viz; solution, carbonation, hydration, oxidation and reduction act on the rocks to decompose, dissolve or reduce them to a fine clastic state through chemical reactions by oxygen, surface and/or soil water and other acids. Water and air (oxygen and carbon dioxide) along with heat must be present to speed up all chemical reactions. Over and above the carbon dioxide present in the air, decomposition of plants and animals increases the quantity of carbon dioxide underground. These chemical reactions on various minerals are very much similar to the chemical reactions in a laboratory.

Solution

When something is dissolved in water or acids, the water or acid with dissolved contents is called *solution*. This process involves removal of solids in solution and depends upon solubility of a mineral in water or weak acids. On coming in contact with water many solids disintegrate and mix up as suspension in water. Soluble rock forming minerals like nitrates, sulphates, and potassium etc. are affected by this process. So, these minerals are easily leached out without leaving any residue in rainy climates and accumulate in dry regions. Minerals like calcium carbonate and calcium magnesium bicarbonate present in limestones are soluble in water containing carbonic acid (formed with the addition of carbon dioxide in water), and are carried away in water as solution. Carbon dioxide produced by decaying organic matter along with soil water greatly aids in this reaction. Common salt (sodium chloride) is also a rock forming mineral and is susceptible to this process of solution.

Carbonation

Carbonation is the reaction of carbonate and bicarbonate with minerals and is a common process helping the breaking down of feldspars and carbonate minerals. Carbon dioxide from the atmosphere and soil air is absorbed by water, to form carbonic acid that acts as a weak acid. Calcium carbonates and magnesium carbonates are dissolved in carbonic acid and are removed in a solution without leaving any residue resulting in cave formation.

Hydration

Hydration is the chemical addition of water. Minerals take up water and expand; this expansion causes an increase in the volume of the material itself or rock. Calcium sulphate takes in water and turns to gypsum, which is more unstable than calcium sulphate. This process is reversible and long, continued repetition of this process causes fatigue in the rocks and may lead to their disintegration. Many clay minerals swell and contract during wetting and drying and a repetition of this process results in cracking of overlying materials. Salts in pore spaces undergo rapid and repeated hydration and help in rock fracturing. The volume changes in minerals due to hydration will also help in physical weathering through exfoliation and granular disintegration.

Oxidation and Reduction

In weathering, oxidation means a combination of a mineral with oxygen to form oxides or hydroxides. Oxidation occurs where there is ready access to the atmosphere and oxygenated waters. The minerals most commonly involved in this process are iron, manganese, sulphur etc. In the process of oxidation rock breakdown occurs due to the disturbance caused by addition of oxygen. Red colour of iron upon oxidation turns to brown or yellow. When oxidised minerals are placed in an environment where oxygen is absent, reduction takes place. Such conditions exist usually below the water table, in areas of stagnant water and waterlogged ground. Red colour of iron upon reduction turns to greenish or bluish grey.

These weathering processes are inter-related. Hydration, carbonation and oxidation go hand in hand and hasten the weathering process.

> Can we give iron rusting as an example of oxidation? How essential is water in chemical weathering processes? Can chemical weathering processes dominate in water scarce hot deserts?

Physical Weathering Processes

Physical or mechanical weathering processes depend on some applied forces. The applied forces could be: (i) gravitational forces such as overburden pressure, load and shearing stress; (ii) expansion forces due to temperature changes, crystal growth or animal activity; (iii) water pressures controlled by wetting and drying cycles. Many of these forces are applied both at the surface and within different earth materials leading to rock fracture. Most of the physical weathering processes are caused by thermal expansion and pressure release. These processes are small and slow but can cause great damage to the rocks because of continued fatigue the rocks suffer due to repetition of contraction and expansion.

Unloading and Expansion

Removal of overlying rock load because of continued erosion causes vertical pressure release with the result that the upper layers of the rock expand producing disintegration of rock masses. Fractures will develop roughly parallel to the ground surface. In areas of curved ground surface, arched fractures tend to produce massive sheets or exfoliation slabs of rock. Exfoliation sheets resulting from expansion due to unloading and pressure release may measure hundreds or even thousands of metres in horizontal extent. Large, smooth rounded domes called *exfoliation domes* (Figure 6.3) result due to this process.

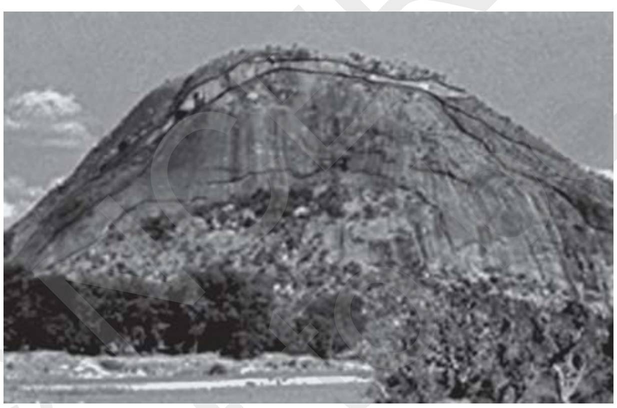


Figure 6.3 : A large exfoliation dome in granite rock near bhongir (Bhuvanagiri) town in Andhra Pradesh

Temperature Changes and Expansion

Various minerals in rocks possess their own limits of expansion and contraction. With rise in temperature, every mineral expands and pushes against its neighbour and as temperature falls, a corresponding contraction takes place. Because of diurnal changes in the temperatures, this internal movement among the mineral grains of the superficial layers of rocks takes place regularly. This process is most effective in dry climates and high elevations where diurnal temperature changes are drastic. As has been mentioned earlier though these movements are very small they make the rocks weak due to continued fatigue. The surface layers of the rocks tend to expand more than the rock at depth and this leads to the formation of stress within the rock resulting in heaving and fracturing parallel to the surface. Due to differential heating and resulting expansion and contraction of surface layers and their subsequent exfoliation from the surface results in smooth rounded surfaces in rocks. In rocks like granites, smooth surfaced and rounded small to big boulders called *tors* form due to such exfoliation.

What is the difference between exfoliation domes and exfoliated tors?

Freezing, Thawing and Frost Wedging

Frost weathering occurs due to growth of ice within pores and cracks of rocks during repeated cycles of freezing and melting. This process is most effective at high elevations in mid-latitudes where freezing and melting is often repeated. Glacial areas are subject to frost wedging daily. In this process, the rate of freezing is important. Rapid freezing of water causes its sudden expansion and high pressure. The resulting expansion affects joints, cracks and small inter granular fractures to become wider and wider till the rock breaks apart.

Salt Weathering

Salts in rocks expand due to thermal action, hydration and crystallisation. Many salts like calcium, sodium, magnesium, potassium and barium have a tendency to expand. Expansion of these salts depends on temperature and their thermal properties. High temperature ranges between 30 and 50°C of surface temperatures in deserts favour such salt expansion. Salt crystals in near-surface pores cause splitting of individual grains within rocks, which eventually fall off. This process of falling off of individual grains may result in granular disintegration or granular foliation.

Salt crystallisation is most effective of all salt-weathering processes. In areas with alternating wetting and drying conditions salt crystal growth is favoured and the neighbouring grains are pushed aside. Sodium chloride and gypsum crystals in desert areas heave up overlying layers of materials and with the result polygonal cracks develop all over the heaved surface. With salt crystal growth, chalk breaks down most readily, followed by limestone, sandstone, shale, gneiss and granite etc.

Biological Activity and Weathering

Biological weathering is contribution to or removal of minerals and ions from the weathering environment and physical changes due to growth or movement of organisms. Burrowing and wedging by organisms like earthworms, termites, rodents etc., help in exposing the new surfaces to chemical attack and assists in the penetration of moisture and air. Human beings by disturbing vegetation, ploughing and cultivating soils, also help in mixing and creating new contacts between air, water and minerals in the earth materials. Decaying plant and animal matter help in the production of humic, carbonic and other acids which enhance decay and solubility of some elements. Plant roots exert a tremendous pressure on the earth materials mechanically breaking them apart.

Special Effects of Weathering

Exfoliation

This has already been explained under physical weathering processes of unloading, thermal contraction and expansion and salt weathering. Exfoliation is a result but not a process. Flaking off of more or less curved sheets of shells from over rocks or bedrock results in smooth and rounded surfaces (Figures 6.3; 6.4). Exfoliation can occur due to expansion and contraction induced by temperature changes. Exfoliation domes and tors result due to unloading and thermal expansion respectively.

Fig.6.4 : Exfoliation (Flacking) and granular disintegration

Significance of Weathering

Weathering processes are responsible for breaking down the rocks into smaller fragments and preparing the way for formation of not only regolith and soils, but also erosion and mass movements. Biomes and bio-diversity is basically a result of forests (vegetation) and forests depend upon the depth of weathering mantles. Erosion cannot be significant if the rocks are not weathered. That means, weathering aids mass wasting, erosion and reduction of relief and changes in landforms are a consequence of erosion. Weathering of rocks and deposits helps in the enrichment and concentrations of certain valuable ores of iron, manganese, aluminium, copper etc., which are of great importance for the national economy. Weathering is an important process in the formation of soils.

> When rocks undergo weathering, some materials are removed through chemical or physical leaching by groundwater and thereby the concentration of remaining (valuable) materials increases. Without such a weathering taking place, the concentration of the same valuable material may not be sufficient and economically viable to exploit, process and refine. This is what is called enrichment.

Mass Movements

These movements transfer the mass of rock debris down the slopes under the direct influence of gravity. That means, air, water or ice do not carry debris with them from place to place but on the other hand the debris may carry with it air, water or ice. The movements of mass may range from slow to rapid, affecting shallow to deep columns of materials and include creep, flow, slide and fall. Gravity exerts its force on all matter, both bedrock and the products of weathering. So, weathering is not a pre-requisite for mass movement though it aids mass movements. Mass movements are very active over weathered slopes rather than over unweathered materials.

Mass movements are aided by gravity and no geomorphic agent like running water, glaciers, wind, waves and currents participate in the process of mass movements. That means mass movements do not come under erosion though there is a shift (aided by gravity) of materials from one place to another. Materials over the slopes have their own resistance to disturbing forces and will yield only when force is greater than the shearing resistance of the materials. Weak unconsolidated materials, thinly bedded rocks, faults, steeply dipping beds, vertical cliffs or steep slopes, abundant precipitation and torrential rains and scarcity of vegetation etc., favour mass movements.

Several activating causes precede mass movements. They are : (i) removal of support from below to materials above through natural or artificial means; (ii) increase in gradient and height of slopes; (iii) overloading through addition of materials naturally or by artificial filling; (iv) overloading due to heavy rainfall, saturation and lubrication of slope materials; (v) removal of material or load from over the original slope surfaces; (vi) occurrence of earthquakes, explosions or machinery; (vii) excessive natural seepage; (viii) heavy drawdown of water from lakes, reservoirs and rivers leading to slow outflow of water from under the slopes or river banks; (ix) indiscriminate removal of natural vegetation.

Heave (heaving up of soils due to frost growth and other causes), *flow* and *slide* are the three forms of movements. Figure 6.5 shows the relationships among different types of mass movements, their relative rates of movement and moisture limits.

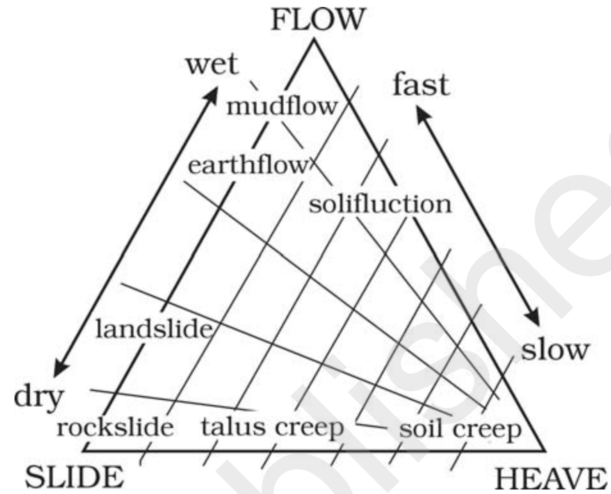


Figure 6.5 : Relationships among different types of mass movements, their relative rates of movement and moisture limits (after Whitehead, 2001)

Mass movements can be grouped under two major classes: (i) slow movements; (ii) rapid movements.

Slow Movements

Creep is one type under this category which can occur on moderately steep, soil covered slopes. Movement of materials is extremely slow and imperceptible except through extended observation. Materials involved can be soil or rock debris. Have you ever seen fence posts, telephone poles lean downslope from their vertical position and in their linear alignment? If you have, that is due to the creep effect. Depending upon the type of material involved, several types of creep viz., soil creep, talus creep, rock creep, rock-glacier creep etc., can be identified. Also included in this group is *solifluction* which involves slow downslope flowing soil mass or fine grained rock debris saturated or lubricated with water. This process is quite common in moist temperate areas where surface melting of deeply frozen ground and long continued rain respectively, occur frequently. When the upper portions get saturated and when the lower parts are impervious to water percolation, flowing occurs in the upper parts.

Rapid Movements

These movements are mostly prevalent in humid climatic regions and occur over gentle to steep slopes. Movement of water-saturated clayey or silty earth materials down low-angle terraces or hillsides is known as *earthflow*. Quite often, the materials slump making step-like terraces and leaving arcuate scarps at their heads and an accumulation bulge at the toe. When slopes are steeper, even the bedrock especially of soft sedimentary rocks like shale or deeply weathered igneous rock may slide downslope.

Another type in this category is *mudflow*. In the absence of vegetation cover and with heavy rainfall, thick layers of weathered materials get saturated with water and either slowly or rapidly flow down along definite channels. It looks like a stream of mud within a valley. When the mudflows emerge out of channels onto the piedmont or plains, they can be very destructive engulfing roads, bridges and houses. Mudflows occur frequently on the slopes of erupting or recently erupted volcanoes. Volcanic ash, dust and other fragments turn into mud due to heavy rains and flow down as tongues or streams of mud causing great destruction to human habitations.

A third type is the debris *avalanche*, which is more characteristic of humid regions with or without vegetation cover and occurs in narrow tracks on steep slopes. This debris avalanche can be much faster than the mudflow. Debris avalanche is similar to snow avalanche.

> In Andes mountains of South America and the Rockies mountains of North America, there are a few volcanoes which erupted during the last decade and very devastating mudflows occurred down their slopes during eruption as well as after eruption.

Landslides

These are relatively rapid and perceptible movements. The materials involved are relatively dry. The size and shape of the detached mass depends on the nature of discontinuities in the rock, the degree of weathering and the steepness of the slope. Depending upon the type of movement of materials several types are identified in this category.

Slump is slipping of one or several units of rock debris with a backward rotation with respect to the slope over which the movement takes place (Figure 6.6). Rapid rolling or sliding

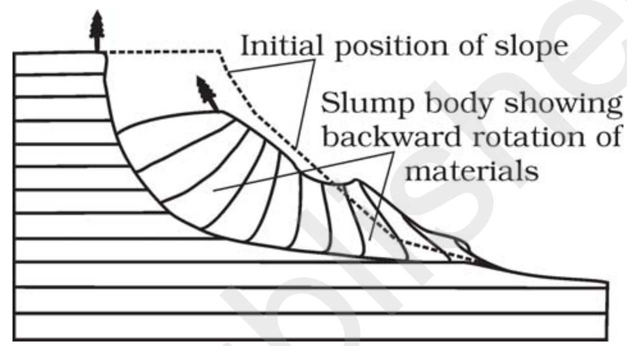


Figure 6.6 : Slumping of debris with backward rotation

of earth debris without backward rotation of mass is known as *debris slide*. Debris fall is nearly a free fall of earth debris from a vertical or overhanging face. Sliding of individual rock masses down bedding, joint or fault surfaces is *rockslide*. Over steep slopes, rock sliding is very fast and destructive. Figure 6.7 shows landslide scars over steep slopes. Slides occur as planar failures along discontinuities like bedding planes that dip steeply. Rock fall is free falling of rock blocks over any steep slope keeping itself away from the slope. Rock falls occur from the superficial layers of the rock

Figure 6.7 : Landslide scars in Shiwalik Himalayan ranges near river Sarada at India-Nepal border, Uttar Pradesh

face, an occurrence that distinguishes it from rockslide which affects materials up to a substantial depth.

Between mass wasting and mass movements, which term do you feel is most appropriate? Why? Can solifluction be included under rapid flow movements? Why it can be and can't be?

In our country, debris avalanches and landslides occur very frequently in the Himalayas. There are many reasons for this. One, the Himalayas are tectonically active. They are mostly made up of sedimentary rocks and unconsolidated and semi-consolidated deposits. The slopes are very steep. Compared to the Himalayas, the Nilgiris bordering Tamilnadu, Karnataka, Kerala and the Western Ghats along the west coast are relatively tectonically stable and are mostly made up of very hard rocks; but, still, debris avalanches and landslides occur though not as frequently as in the Himalayas, in these hills. Why? Many slopes are steeper with almost vertical cliffs and escarpments in the Western Ghats and Nilgiris. Mechanical weathering due to temperature changes and ranges is pronounced. They receive heavy amounts of rainfall over short periods. So, there is almost direct rock fall quite frequently in these places along with landslides and debris avalanches.

Erosion and Deposition

Erosion involves acquisition and transportation of rock debris. When massive rocks break into smaller fragments through weathering and any other process, erosional geomorphic agents like running water, groundwater, glaciers, wind and waves remove and transport it to other places depending upon the dynamics of each of these agents. Abrasion by rock debris carried by these geomorphic agents also aids greatly in erosion. By erosion, relief degrades, i.e., the landscape is worn down. That means, though weathering aids erosion it is not a pre-condition for erosion to take place. Weathering, mass-wasting and erosion are degradational processes. It is erosion that is largely responsible for continuous changes that the earth's surface is undergoing. As indicated in Figure 6.1, denudational processes like erosion and transportation are controlled by kinetic energy. The erosion and transportation of earth materials is brought about by wind, running water, glaciers, waves and ground water. Of these the first three agents are controlled by climatic conditions. They represent three states of matter —gaseous (wind), liquid (running water) and solid (glacier) respectively.

Can you compare the three climatically controlled agents?

The erosion can be defined as "application of the kinetic energy associated with the agent to the surface of the land along which it moves". Kinetic energy is computed as $KE = {}^{1}/_{2}\, mv^2$ where 'm' is the mass and 'v' is the velocity. Hence the energy available to perform work will depend on the mass of the material and the velocity with which it is moving. Obviously then you will find that though the glaciers move at very low velocities due to tremendous mass are more effective as the agents of erosion and wind, being in gaseous state, is less effective.

The work of the other two agents of erosion-waves and ground water is not controlled by climate. In case of waves it is the location along the interface of litho and hydro sphere — coastal region — that will determine the work of waves, whereas the work of ground water is determined more by the lithological character of the region. If the rocks are permeable and soluble and water is available only then karst topography develops. In the next chapter we shall be dealing with the landforms produced by each of these agents of erosion.

Deposition is a consequence of erosion. The erosional agents loose their velocity and hence energy on gentler slopes and the materials carried by them start to settle themselves. In other words, deposition is not actually the work of any agent. The coarser materials get deposited first and finer ones later. By deposition depressions get filled up. The same erosional agents viz., running water, glaciers, wind, waves and groundwater act as aggradational or depositional agents also.

What happens to the surface of the earth due to erosion and deposition is elaborated in the next chapter on landforms and their evolution.

> There is a shift of materials in mass movements as well as in erosion from one place to the other. So, why can't both be treated as one and the same? Can there be appreciable erosion without rocks undergoing weathering?

Soil Formation

Soil and Soil Contents

You see plants growing in soils. You play in the ground and come into contact with soil. You touch and feel soil and soil your clothes while playing. Can you describe it?

A pedologist who studies soils defines soil as a collection of natural bodies on the earth's surface containing living and/or dead matter and supporting or capable of supporting plants.

Soil is a dynamic medium in which many chemical, physical and biological activities go on constantly. Soil is a result of decay, it is also the medium for growth. It is a changing and developing body. It has many characteristics that fluctuate with the seasons. It may be alternatively cold and warm or dry and moist. Biological activity is slowed or stopped if the soil becomes too cold or too dry. Organic matter increases when leaves fall or grasses die. The soil chemistry, the amount of organic matter, the soil flora and fauna, the temperature and the moisture, all change with the seasons as well as with more extended periods of time. That means, soil becomes adjusted to conditions of climate, landform and vegetation and will change internally when these controlling conditions change.

Process of Soil Formation

Soil formation or pedogenesis depends first on weathering. It is this weathering mantle (depth of the weathered material) which is the basic input for soil to form. First, the weathered material or transported deposits are colonised by bacteria and other inferior plant bodies like mosses and lichens. Also, several minor organisms may take shelter within the mantle and deposits. The dead remains of organisms and plants help in humus accumulation. Minor grasses and ferns may grow; later, bushes and trees will start growing through seeds brought in by birds and wind. Plant roots penetrate down, burrowing animals bring up particles, mass of material becomes porous and sponge-like with a capacity to retain water and to permit the passage of air and finally a mature soil, a complex mixture of mineral and organic products forms.

> Is weathering solely responsible for soil formation? If not, why?

> Pedology is soil science. A pedologist is a soil-scientist.

Soil-forming Factors

Five basic factors control the formation of soils: (i) parent material; (ii) topography; (iii) climate; (iv) biological activity; (v) time. In fact soil forming factors act in union and affect the action of one another.

Parent Material

Parent material is a passive control factor in soil formation. Parent materials can be any *in-situ* or on-site weathered rock debris (residual soils) or transported deposits (transported soils). Soil formation depends upon the texture (sizes of debris) and structure (disposition of individual grains/particles of debris) as well as the mineral and chemical composition of the rock debris/deposits.

Nature and rate of weathering and depth of weathering mantle are important considerations under parent materials. There may be differences in soil over similar bedrock and dissimilar bedrocks may have similar soils above them. But when soils are very young and have not matured these show strong links with the type of parent rock. Also, in case of some limestone areas, where the weathering processes are specific and peculiar, soils will show clear relation with the parent rock.

Topography

Topography like parent materials is another passive control factor. The influence of topography is felt through the amount of exposure of a surface covered by parent materials to sunlight and the amount of surface and sub-surface drainage over and through the parent materials. Soils will be thin on steep slopes and thick over flat upland areas. Over gentle slopes where erosion is slow and percolation of water is good, soil formation is very favourable. Soils over flat areas may develop a thick layer of clay with good accumulation of organic matter giving the soil dark colour. In middle latitudes, the south facing slopes exposed to sunlight have different conditions of vegetation and soils and the north facing slopes with cool, moist conditions have some other soils and vegetation.

Climate

Climate is an important active factor in soil formation. The climatic elements involved in soil development are : (i) moisture in terms of its intensity, frequency and duration of precipitation - evaporation and humidity; (ii) temperature in terms of seasonal and diurnal variations.

Precipitation gives soil its moisture content which makes the chemical and biological activities possible. Excess of water helps in the downward transportation of soil components through the soil (eluviation) and deposits the same down below (illuviation). In climates like wet equatorial rainy areas with high rainfall, not only calcium, sodium, magnesium, potassium etc. but also a major part of silica is removed from the soil. Removal of silica from the soil is known as *desilication.* In dry climates, because of high temperature, evaporation exceeds precipitation and hence ground water is brought up to the surface by capillary action and in the process the water evaporates leaving behind salts in the soil. Such salts form into a crust in the soil known as hardpans. In tropical climates and in areas with intermediate precipitation conditions, calcium carbonate nodules (*kanker*) are formed.

Temperature acts in two ways — increasing or reducing chemical and biological activity. Chemical activity is increased in higher temperatures, reduced in cooler temperatures (with an exception of carbonation) and stops in freezing conditions. That is why, tropical soils with higher temperatures show deeper profiles and in the frozen tundra regions soils contain largely mechanically broken materials.

Biological Activity

The vegetative cover and organisms that occupy the parent materials from the beginning and also at later stages help in adding organic matter, moisture retention, nitrogen etc. Dead plants provide humus, the finely divided organic matter of the soil. Some organic acids which form during humification aid in decomposing the minerals of the soil parent materials.

Intensity of bacterial activity shows up differences between soils of cold and warm climates. Humus accumulates in cold climates as bacterial growth is slow. With undecomposed organic matter because of low bacterial activity, layers of peat develop in sub-arctic and tundra climates. In humid tropical and equatorial climates, bacterial growth and action is intense and dead vegetation is rapidly oxidised leaving very low humus content in the soil. Further, bacteria and other soil organisms take gaseous nitrogen from the air and convert it into a chemical form that can be used by plants. This process is known as nitrogen fixation. Rhizobium, a type of bacteria, lives in the root nodules of leguminous plants and fixes nitrogen beneficial to the host plant. The influence of large animals like ants, termites, earthworms, rodents etc., is mechanical, but, it is nevertheless important in soil formation as they rework the soil up and down. In case of earthworms, as they feed on soil, the texture and chemistry of the soil that comes out of their body changes.

Time

Time is the third important controlling factor in soil formation. The length of time the soil forming processes operate, determines

Is it necessary to separate the process of soil formation and the soil forming control factors?

Why are time, topography and parent material considered as passive control factors in soil formation?

maturation of soils and profile development. A soil becomes mature when all soil-forming processes act for a sufficiently long time developing a profile. Soils developing from recently deposited alluvium or glacial till are considered young and they exhibit no horizons or only poorly developed horizons. No specific length of time in absolute terms can be fixed for soils to develop and mature.

EXERCISES

1. Multiple choice questions.

   (i) Which one of the following processes is a gradational process?

   (a) Deposition (c) Volcanism

   (b) Diastrophism (d) Erosion

   (ii) Which one of the following materials is affected by hydration process?

   (a) Granite (c) Quartz

   (b) Clay (d) Salts

   (iii) Debris avalanche can be included in the category of:

   (a) Landslides (c) Rapid flow mass movements

   (b) Slow flow mass movements (d) Subsidence

2. Answer the following questions in about 30 words.

   (i) It is weathering that is responsible for bio-diversity on the earth. How?

   (ii) What are mass movements that are real rapid and perceptible? List.

   (iii) What are the various mobile and mighty exogenic geomorphic agents and what is the prime job they perform?

   (iv) Is weathering essential as a pre-requisite in the formation of soils? Why?

3. Answer the following questions in about 150 words.

   (i) "Our earth is a playfield for two opposing groups of geomorphic processes." Discuss.

   (ii) Exogenic geomorphic processes derive their ultimate energy from the sun's heat. Explain.

   (iii) Are physical and chemical weathering processes independent of each other? If not, why? Explain with examples.

   (iv) How do you distinguish between the process of soil formation and soil-forming factors? What is the role of climate and biological activity as two important control factors in the formation of soils?

Project Work

Depending upon the topography and materials around you, observe and record climate, possible weathering process and soil contents and characteristics.

CHAPTER

7

LANDFORMS AND THEIR EVOLUTION

After weathering processes have had their actions on the earth materials making up the surface of the earth, the geomorphic agents like running water, ground water, wind, glaciers, waves perform erosion. It is already known to you that erosion causes changes on the surface of the earth. Deposition follows erosion and because of deposition too, changes occur on the surface of the earth.

As this chapter deals with landforms and their evolution 'first' start with the question, what is a landform? In simple words, small to medium tracts or parcels of the earth's surface are called landforms.

> If landform is a small to medium sized part of the surface of the earth, what is a landscape?

Several related landforms together make up landscapes, (large tracts of earth's surface). Each landform has its own physical shape, size, materials and is a result of the action of certain geomorphic processes and agent(s). Actions of most of the geomorphic processes and agents are slow, and hence the results take a long time to take shape. Every landform has a beginning. Landforms once formed may change in their shape, size and nature slowly or fast due to continued action of geomorphic processes and agents.

Due to changes in climatic conditions and vertical or horizontal movements of landmasses, either the intensity of processes or the processes themselves might change leading to new modifications in the landforms. Evolution here implies stages of transformation of either a part of the earth's surface from one landform into another or transformation of individual landforms after they are once formed. That means, each and every landform has a history of development and changes through time. A landmass passes through stages of development somewhat comparable to the stages of life — youth, mature and old age.

> What are the two important aspects of the evolution of landforms?

The evolutionary history of the continually changing surface of the earth is essential to be understood in order to use it effectively without disturbing its balance and diminishing its potential for the future. Geomorphology deals with the reconstruction of the history of the surface of the earth through a study of its forms, the materials of which it is made up of and the processes that shape it.

Changes on the surface of the earth owe mostly to erosion by various geomorphic agents. Of course, the process of deposition too, by covering the land surfaces and filling the basins, valleys or depressions, brings changes in the surface of the land. Deposition follows erosion and the depositional surfaces too are ultimately subjected to erosion. Running water, ground-water, glaciers, wind and waves are powerful erosional and depositional agents shaping and changing the surface of the earth aided by weathering and mass wasting processes. These geomorphic agents acting over long periods of time produce systematic changes leading to sequential development of landforms. Each geomorphic agent produces its own assemblage of landforms. Not only this, each geomorphic process and agent leave their distinct imprints on the landforms they produce. You know that most of the geomorphic processes are imperceptible functions and can only be seen and measured through their results. What are the results? These results are nothing but landforms and their characteristics. Hence, a study of landforms, will reveal to us the process and agent which has made or has been making those landforms.

> Most of the geomorphic processes are imperceptible. Cite a few processes which can be seen and a few which can't be seen.

As the geomorphic agents are capable of erosion and deposition, two sets — erosional or destructional and depositional or constructional — of landforms are produced by them. Many varieties of landforms develop by the action of each of the geomorphic agents depending upon especially the type and structure i.e. folds, faults, joints, fractures, hardness and softness, permeability and impermeability, etc. There are some other independent controls like (i) stability of sea level; (ii) tectonic stability of landmasses; (iii) climate, which influence the evolution of landforms. Any disturbance in any of these three controlling factors can upset the systematic and sequential stages in the development and evolution of landforms.

In the following pages, under each of the geomorphic regimes i.e. running water, groundwater, glaciers, waves, and winds, first a brief discussion is presented as to how landmasses are reduced in their relief through erosion and then, development of some of the erosional and depositional landforms is dealt with.

RUNNING WATER

In humid regions, which receive heavy rainfall running water is considered the most important of the geomorphic agents in bringing about the degradation of the land surface. There are two components of running water. One is overland flow on general land surface as a sheet. Another is linear flow as streams and rivers in valleys. Most of the erosional landforms made by running water are associated with vigorous and youthful rivers flowing over steep gradients. With time, stream channels over steep gradients turn gentler due to continued erosion, and as a consequence, lose their velocity, facilitating active deposition. There may be depositional forms associated with streams flowing over steep slopes. But these phenomena will be on a small scale compared to those associated with rivers flowing over medium to gentle slopes. The gentler the river channels in gradient or slope, the greater is the deposition. When the stream beds turn gentler due to continued erosion, downward cutting becomes less dominant and lateral erosion of banks increases and as a consequence the hills and valleys are reduced to plains.

> Is complete reduction of relief of a high land mass possible?

Overland flow causes sheet erosion. Depending upon irregularities of the land surface, the overland flow may concentrate into narrow to wide paths. Because of the sheer friction of the column of flowing water, minor or major quantities of materials from the surface of the land are removed in the direction of flow and gradually small and narrow rills will form. These rills will gradually develop into long and wide gullies; the gullies will further deepen, widen, lengthen and unite to give rise to a network of valleys. In the early stages, down-cutting dominates during which irregularities such as waterfalls and cascades will be removed. In the middle stages, streams cut their beds slower, and lateral erosion of valley sides becomes severe. Gradually, the valley sides are reduced to lower and lower slopes. The divides between drainage basins are likewise lowered until they are almost completely flattened leaving finally, a lowland of faint relief with some low resistant remnants called *monadnocks* standing out here and there. This type of plain forming as a result of stream erosion is called a *peneplain* (an almost plain). The characteristics of each of the stages of landscapes developing in running water regimes may be summarised as follows:

Youth

Streams are few during this stage with poor integration and flow over original slopes showing shallow V-shaped valleys with no floodplains or with very narrow floodplains along trunk streams. Streams divides are broad and flat with marshes, swamp and lakes. Meanders if present develop over these broad upland surfaces. These meanders may eventually entrench themselves into the uplands. Waterfalls and rapids may exist where local hard rock bodies are exposed.

Mature

During this stage streams are plenty with good integration. The valleys are still V-shaped but deep; trunk streams are broad enough to have wider floodplains within which streams may flow in meanders confined within the valley. The flat and broad inter stream areas and swamps and marshes of youth disappear and the stream divides turn sharp. Waterfalls and rapids disappear.

Old

Smaller tributaries during old age are few with gentle gradients. Streams meander freely over vast floodplains showing natural levees, oxbow lakes, etc. Divides are broad and flat with lakes, swamps and marshes. Most of the landscape is at or slightly above sea level.

Erosional Landforms

Valleys

Valleys start as small and narrow rills; the rills will gradually develop into long and wide gullies; the gullies will further deepen, widen and lengthen to give rise to valleys. Depending upon dimensions and shape, many types of valleys like *V-shaped valley, gorge, canyon*, etc. can be recognised. A gorge is a deep valley with very steep to straight sides (Figure 7.1) and a canyon is characterised by steep step-like side slopes (Figure 7.2) and may be as deep as a gorge. A gorge is almost equal in width at its top as well as its bottom. In contrast, a canyon is wider at its top than at its bottom. In fact, a canyon is a variant of gorge. Valley types depend upon the type and structure of rocks in which they form. For example, canyons commonly form in horizontal bedded sedimentary rocks and gorges form in hard rocks.

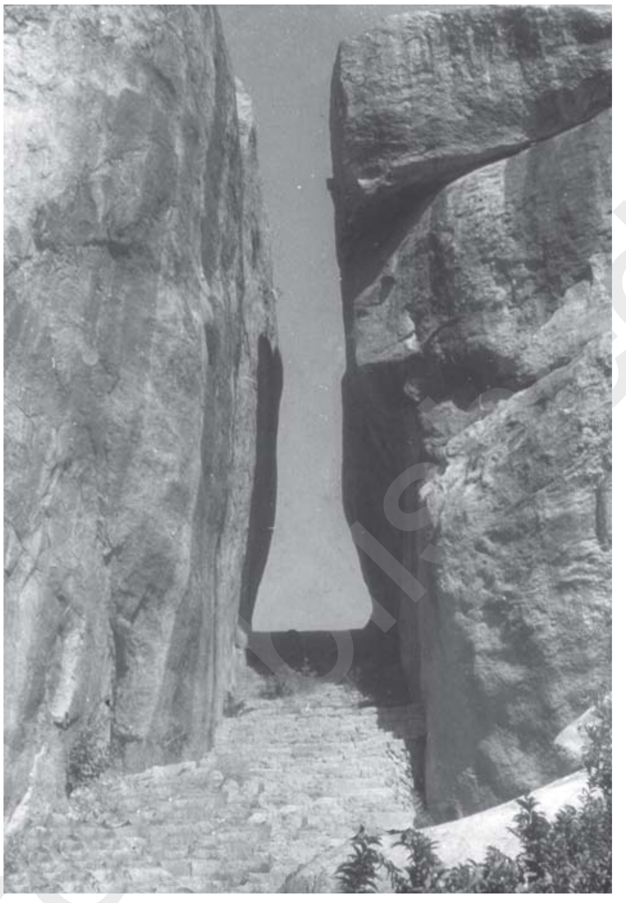


Figure 7.1 : The Valley of Kaveri river near Hogenekal, Dharmapuri district, Tamilnadu in the form of gorge

Figure 7.2 : An entrenched meander loop of river Colorado in USA showing step-like side slopes of its valley typical of a canyon

Potholes and Plunge Pools

Over the rocky beds of hill-streams more or less circular depressions called *potholes* form because of stream erosion aided by the abrasion of rock fragments. Once a small and shallow depression forms, pebbles and boulders get collected in those depressions and get rotated by flowing water and consequently the depressions grow in dimensions. A series of such depressions eventually join and the stream valley gets deepened. At the foot of waterfalls also, large potholes, quite deep and wide, form because of the sheer impact of water and rotation of boulders. Such large and deep holes at the base of waterfalls are called *plunge pools*. These pools also help in the deepening of valleys. Waterfalls are also transitory like any other landform and will recede gradually and bring the floor of the valley above waterfalls to the level below.

Incised or Entrenched Meanders

In streams that flow rapidly over steep gradients, normally erosion is concentrated on the bottom of the stream channel. Also, in the case of steep gradient streams, lateral erosion on the sides of the valleys is not much when compared to the streams flowing on low and gentle slopes. Because of active lateral erosion, streams flowing over gentle slopes, develop sinuous or meandering courses. It is common to find meandering courses over floodplains and delta plains where stream gradients are very gentle. But very deep and wide meanders can also be found cut in hard rocks. Such meanders are called *incised or entrenched meanders* (Figure 7.2). Meander loops develop over original gentle surfaces in the initial stages of development of streams and the same loops get entrenched into the rocks normally due to erosion or slow, continued uplift of the land over which they start. They widen and deepen over time and can be found as deep gorges and canyons in hard rock areas. They give an indication on the status of original land surfaces over which streams have developed.

What are the differences between incised meanders and meanders over flood and delta plains?

River Terraces

River terraces are surfaces marking old valley floor or floodplain levels. They may be bedrock surfaces without any alluvial cover or alluvial terraces consisting of stream deposits. River terraces are basically products of erosion as they result due to vertical erosion by the stream into its own depositional floodplain. There can be a number of such terraces at different heights indicating former river bed levels. The river terraces may occur at the same elevation on either side of the rivers in which case they are called *paired terraces* (Figure 7.3).

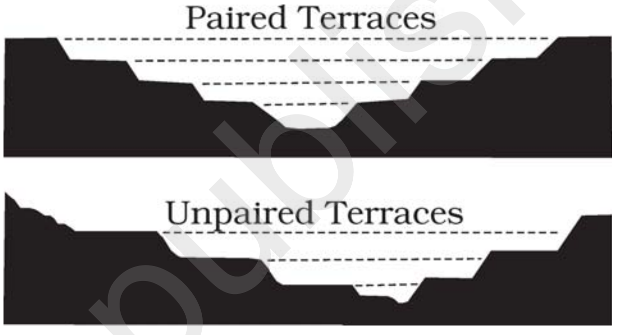


Figure 7.3 : Paired and unpaired river terraces

When a terrace is present only on one side of the stream and with none on the other side or one at quite a different elevation on the other side, the terraces are called *unpaired terraces*. Unpaired terraces are typical in areas of slow uplift of land or where the water column changes are not uniform along both the banks. The terraces may result due to (i) receding water after a peak flow; (ii) change in hydrological regime due to climatic changes; (iii) tectonic uplift of land; (iv) sea level changes in case of rivers closer to the sea.

Depositional Landforms

Alluvial Fans

Alluvial fans (Figure 7.4) are formed when streams flowing from higher levels break into foot slope plains of low gradient. Normally very coarse load is carried by streams flowing over mountain slopes. This load becomes too heavy for the streams to be carried over gentler gradients and gets dumped and spread as a broad low to high cone shaped deposit called *alluvial fan*. Usually, the streams which flow over fans are not confined to their original channels for long and shift their position across the fan forming many channels called *distributaries*. Alluvial fans in humid areas show normally low cones with gentle slope from

Figure 7.4 : An alluvial fan deposited by a hill stream on the way to Amarnath, Jammu and Kashmir

head to toe and they appear as high cones with steep slope in arid and semi-arid climates.

Deltas

Deltas are like alluvial fans but develop at a different location. The load carried by the rivers is dumped and spread into the sea. If this load is not carried away far into the sea or distributed along the coast, it spreads and accumulates

Figure 7.5 : A satellite view of part of Krishna river delta, Andhra Pradesh

as a low cone. Unlike in alluvial fans, the deposits making up deltas are very well sorted with clear stratification. The coarsest materials settle out first and the finer fractions like silts and clays are carried out into the sea. As the delta grows, the river distributaries continue to increase in length (Figure 7.5) and delta continues to build up into the sea.

Floodplains, Natural Levees and Point Bars

Deposition develops a floodplain just as erosion makes valleys. Floodplain is a major landform of river deposition. Large sized materials are deposited first when stream channel breaks into a gentle slope. Thus, normally, fine sized materials like sand, silt and clay are carried by relatively slow moving waters in gentler channels usually found in the plains and deposited over the bed and when the waters spill over the banks during flooding above the bed. A river bed made of river deposits is the active floodplain. The floodplain above the bank is inactive floodplain. Inactive floodplain above the banks basically contain two types of deposits — flood deposits and channel deposits. In plains, channels shift laterally and change their courses occasionally leaving cut-off courses which get filled up gradually. Such areas over flood plains built up by abandoned or cut-off channels contain coarse deposits. The flood deposits of spilled waters carry relatively finer materials like silt and clay. The flood plains in a delta are called *delta plains*.

Natural levees and point bars (Figure 7.6) are some of the important landforms found associated with floodplains. *Natural levees* are found along the banks of large rivers. They are low, linear and parallel ridges of coarse deposits along the banks of rivers, quite often cut into individual mounds. During flooding as the water spills over the bank, the velocity of the water comes down and large sized and high specific gravity materials get dumped in the immediate vicinity of the bank as ridges. They are high nearer the banks and slope gently away from the river. The levee deposits are coarser than the deposits spread by flood waters away from the river. When rivers shift laterally, a series of natural levees can form.

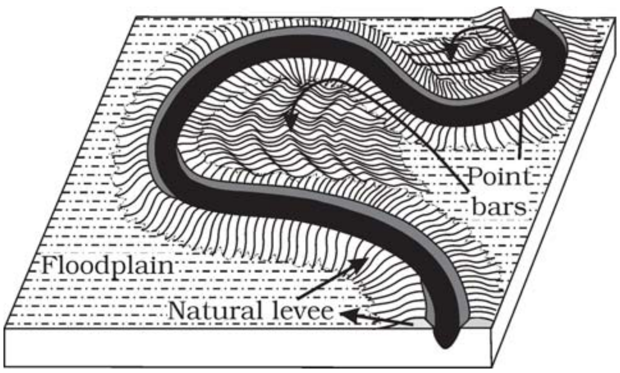


Figure 7.6 : Natural levee and point bars

Point bars are also known as *meander bars*. They are found on the convex side of meanders of large rivers and are sediments deposited in a linear fashion by flowing waters along the bank. They are almost uniform in profile and in width and contain mixed sizes of sediments. If there more than one ridge, narrow and elongated depressions are found in between the point bars. Rivers build a series of them depending upon the water flow and supply of sediment. As the rivers build the point bars on the convex side, the bank on the concave side will erode actively.

> In what way do natural levees differ from point bars?

Meanders

In large flood and delta plains, rivers rarely flow in straight courses. Loop-like channel patterns called *meanders* develop over flood and delta plains (Figure 7.7).

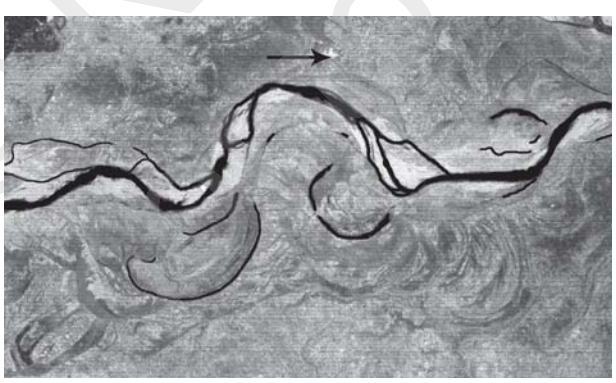


Figure 7.7 : A satellite scene showing meandering Burhi Gandak river near Muzaffarpur, Bihar, showing a number of oxbow lakes and cut-offs

Meander is not a landform but is only a type of channel pattern. This is because of (i) propensity of water flowing over very gentle gradients to work laterally on the banks; (ii) unconsolidated nature of alluvial deposits making up the banks with many irregularities which can be used by water exerting pressure laterally; (iii) coriolis force acting on the fluid water deflecting it like it deflects the wind. When the gradient of the channel becomes extremely low, water flows leisurely and starts working laterally. Slight irregularities along the banks slowly get transformed into a small curvature in the banks; the curvature deepens due to deposition on the inside of the curve and erosion along the bank on the outside. If there is no deposition and no erosion or undercutting, the tendency to meander is reduced. Normally, in meanders of large rivers, there is active deposition along the convex bank and undercutting along the concave bank.

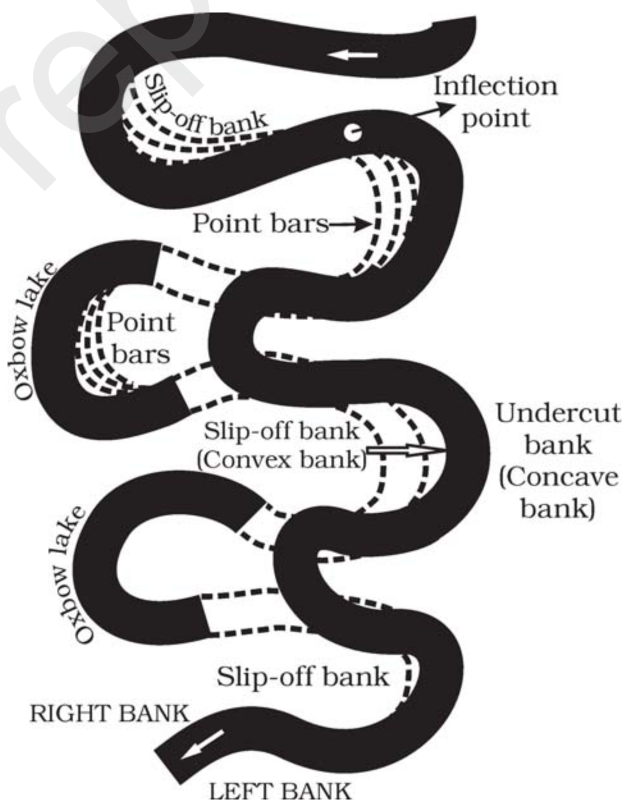


Figure 7.8 : Meander growth and cut-off loops and slip-off and undercut banks

The concave bank is known as cut-off bank which shows up as a steep scarp and the convex bank presents a long, gentle profile and is known as slip-off bank (Figure 7.8). As meanders grow into deep loops, the same may get cut-off due to erosion at the inflection points and are left as *ox-bow lakes*.

Braided Channels

When rivers carry coarse material, there can be selective deposition of coarser materials causing formation of a central bar which diverts the flow towards the banks; and this flow increases lateral erosion on the banks. As the valley widens, the water column is reduced and more and more materials get deposited as islands and lateral bars developing a number of separate channels of water flow. Deposition and lateral erosion of banks are essential for the formation of braided pattern. Or, alternatively, when discharge is less and load is more in the valley, channel bars and islands of sand, gravel and pebbles develop on the floor of the channel and the water flow is divided into multiple threads. These thread-like streams of water rejoin and subdivide repeatedly to give a typical braided pattern (Figure 7.9).

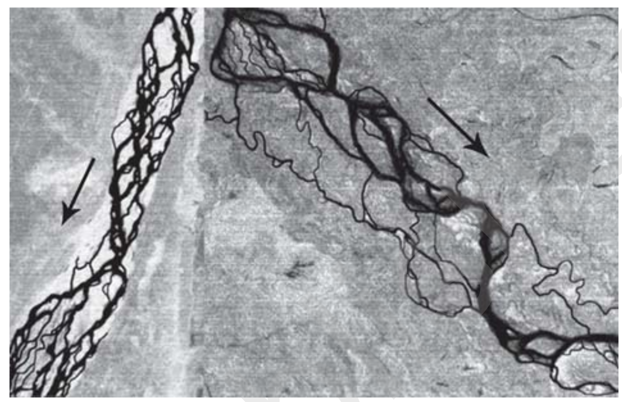


Figure 7.9 : Satellite scenes showing braided channel segments of Gandak (right) and Son (left) rivers Arrows show the direction of flow

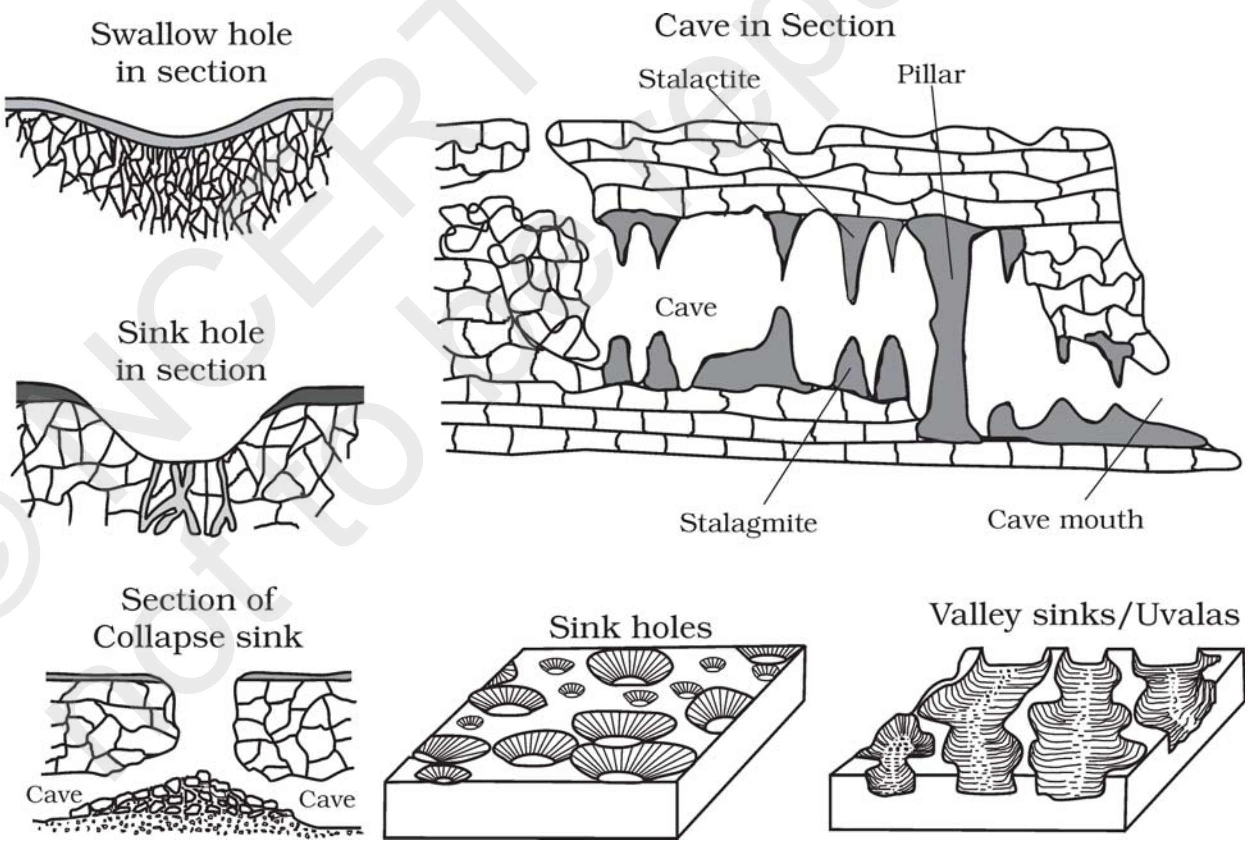


Figure 7.10 : Various karst features

GROUNDWATER

Here the interest is not on groundwater as a resource. Our focus is on the work of groundwater in the erosion of landmasses and evolution of landforms. The surface water percolates well when the rocks are permeable, thinly bedded and highly jointed and cracked. After vertically going down to some depth, the water under the ground flows horizontally through the bedding planes, joints or through the materials themselves. It is this downward and horizontal movement of water which causes the rocks to erode. Physical or mechanical removal of materials by moving groundwater is insignificant in developing landforms. That is why, the results of the work of groundwater cannot be seen in all types of rocks. But in rocks like limestones or dolomites rich in calcium carbonate, the surface water as well as groundwater through the chemical process of solution and precipitation deposition develop varieties of landforms. These two processes of solution and precipitation are active in limestones or dolomites occurring either exclusively or interbedded with other rocks. Any limestone or dolomitic region showing typical landforms produced by the action of groundwater through the processes of solution and deposition is called *Karst topography* after the typical topography developed in limestone rocks of Karst region in the Balkans adjacent to Adriatic sea.

The karst topography is also characterised by erosional and depositional landforms.

EROSIONAL LANDFORMS

Pools, Sinkholes, Lapies and Limestone Pavements

Small to medium sized round to sub-rounded shallow depressions called *swallow holes* form on the surface of limestones through solution. Sinkholes are very common in limestone/karst areas. *A sinkhole* is an opening more or less circular at the top and funnel-shapped towards the bottom with sizes varying in area from a few sq. m to a hectare and with depth from a less than half a metre to thirty metres or more. Some of these form solely through solution action (solution sinks) and others might start as solution forms first and if the bottom of a sinkhole forms the roof of a void or cave underground, it might collapse leaving a large hole opening into a cave or a void below (collapse sinks). Quite often, sinkholes are covered up with soil mantle and appear as shallow water pools. Anybody stepping over such pools would go down like it happens in quicksands in deserts. The term *doline* is sometimes used to refer the collapse sinks. Solution sinks are more common than collapse sinks. Quite often the surface run-off simply goes down swallow and sink holes and flow as underground streams and re-emerge at a distance downstream through a cave opening. When sink holes and dolines join together because of slumping of materials along their margins or due to roof collapse of caves, long, narrow to wide trenches called *valley sinks* or *Uvalas* form. Gradually, most of the surface of the limestone is eaten away by these pits and trenches, leaving it extremely irregular with a maze of points, grooves and *ridges* or *lapies*. Especially, these ridges or lapies form due to differential solution activity along parallel to sub-parallel joints. The lapie field may eventually turn into somewhat smooth *limestone pavements*.

Caves

In areas where there are alternating beds of rocks (shales, sandstones, quartzites) with limestones or dolomites in between or in areas where limestones are dense, massive and occurring as thick beds, cave formation is prominent. Water percolates down either through the materials or through cracks and joints and moves horizontally along bedding planes. It is along these bedding planes that the limestone dissolves and long and narrow to wide gaps called *caves* result. There can be a maze of caves at different elevations depending upon the limestone beds and intervening rocks. Caves normally have an opening through which cave streams are discharged. Caves having openings at both the ends are called tunnels.

Depositional Landforms

Many depositional forms develop within the limestone caves. The chief chemical in limestone is calcium carbonate which is easily soluble in carbonated water (carbon dioxide absorbed rainwater). This calcium carbonate is deposited when the water carrying it in solution evaporates or loses its carbon dioxide as it trickles over rough rock surfaces.

Stalactites, Stalagmites and Pillars

Stalactites hang as icicles of different diameters. Normally they are broad at their bases and taper towards the free ends showing up in a variety of forms. *Stalagmites* rise up from the floor of the caves. In fact, stalagmites form due to dripping water from the surface or through the thin pipe, of the stalactite, immediately below it (Figure 7.11).

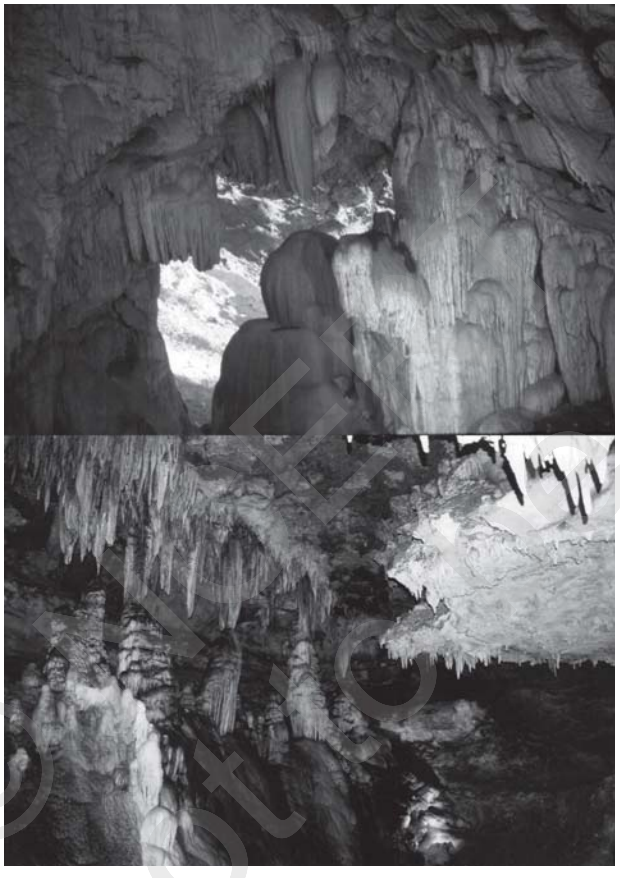


Figure 7.11 : Stalactites and stalagmites in limestone caves

Stalagmites may take the shape of a column, a disc, with either a smooth, rounded bulging end or a miniature crater like depression. The stalagmite and stalactites eventually fuse to give rise to *columns and pillars* of different diameters.

GLACIERS

Masses of ice moving as sheets over the land (continental glacier or piedmont glacier if a vast sheet of ice is spread over the plains at the foot of mountains) or as linear flows down the slopes of mountains in broad trough-like valleys (mountain and valley glaciers) are called *glaciers* (Figure 7.12). The movement of glaciers

Figure 7.12 : A glacier in its valley

is slow unlike water flow. The movement could be a few centimetres to a few metres a day or even less or more. Glaciers move basically because of the force of gravity.

> We have many glaciers in our country moving down the slopes and valleys in Himalayas. Higher reaches of Uttaranchal, Himachal Pradesh and Jammu and Kashmir, are places to see some of them. Do you know where one can see river Bhagirathi is basically fed by meltwaters from under the snout (Gaumukh) of the Gangotri glacier. In fact, Alkapuri glacier feeds waters to Alakananda river. Rivers Alkananda and Bhagirathi join to make river Ganga near Deoprayag.

Erosion by glaciers is tremendous because of friction caused by sheer weight of the ice. The material plucked from the land by glaciers (usually large-sized angular blocks and fragments) get dragged along the floors or sides of the valleys and cause great damage through abrasion and plucking. Glaciers can cause significant damage to even un-weathered rocks and can reduce high mountains into low hills and plains.

As glaciers continue to move, debris gets removed, divides get lowered and eventually the slope is reduced to such an extent that glaciers will stop moving leaving only a mass of low hills and vast outwash plains along with other depositional features. Figures 7.13 and 7.14 show various glacial erosional and depositional forms described in the text.

EROSIONAL LANDFORMS

Cirque

Cirques are the most common of landforms in glaciated mountains. The cirques quite often are found at the heads of glacial valleys. The accumulated ice cuts these cirques while moving down the mountain tops. They are deep, long and wide troughs or basins with very steep concave to vertically dropping high walls at its head as well as sides. A lake of water can be seen quite often within the cirques after the glacier disappears. Such lakes are called *cirque or tarn lakes*. There can be two or more cirques one leading into another down below in a stepped sequence.

Horns and Serrated Ridges

Horns form through head ward erosion of the cirque walls. If three or more radiating glaciers cut headward until their cirques meet, high, sharp pointed and steep sided peaks called *horns* form. The divides between cirque side walls or head walls get narrow because of progressive erosion and turn into serrated or saw-toothed ridges sometimes referred to as *arêtes* with very sharp crest and a zig-zag outline.

> The highest peak in the Alps, Matterhorn and the highest peak in the Himalayas, Everest are in fact horns formed through headward erosion of radiating cirques.

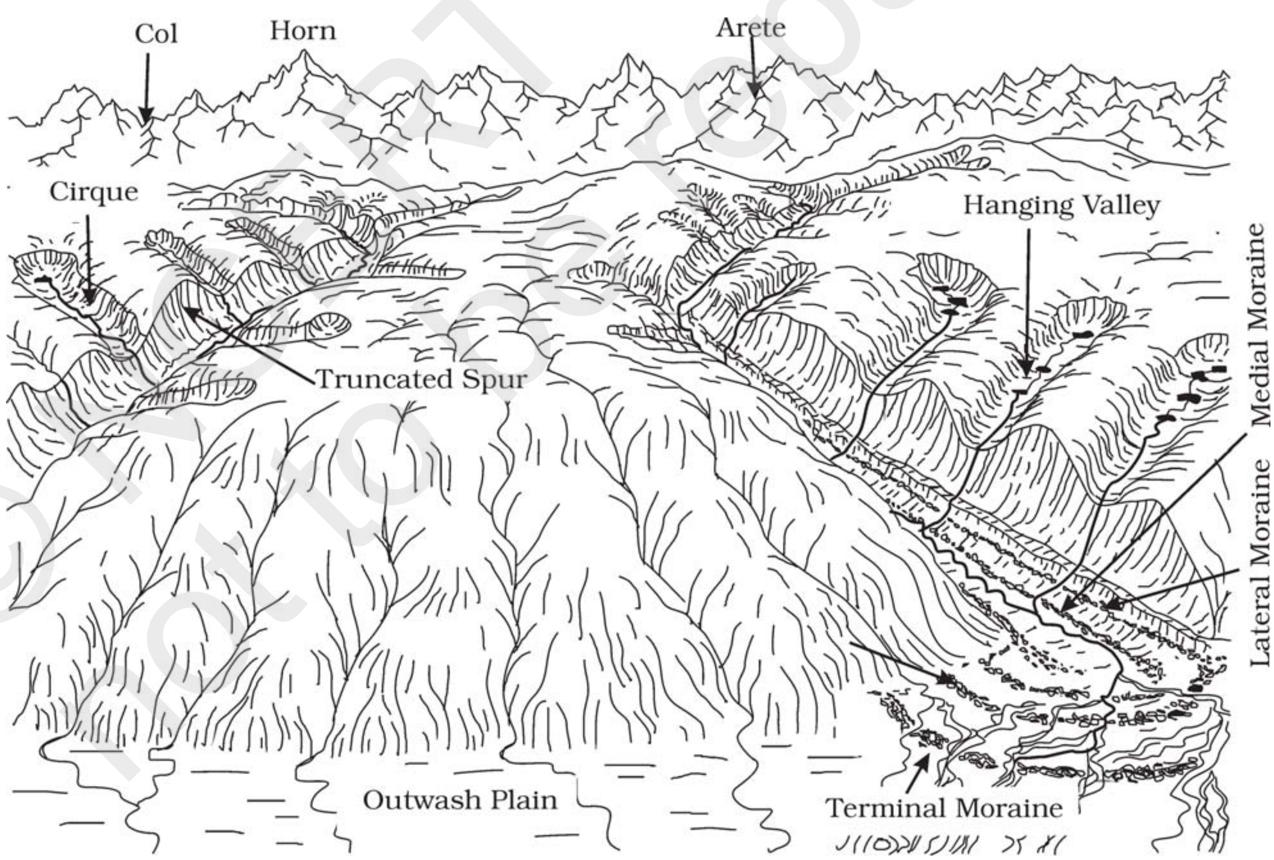


Figure 7.13 : Some glacial erosional and depositional forms (adapted and modified from Spencer, 1962)

Glacial Valleys/Troughs

Glaciated valleys are trough-like and *U-shaped* with broad floors and relatively smooth, and steep sides. The valleys may contain littered debris or debris shaped as *moraines* with swampy appearance. There may be lakes gouged out of rocky floor or formed by debris within the valleys. There can be hanging valleys at an elevation on one or both sides of the main glacial valley. The faces of divides or spurs of such hanging valleys opening into main glacial valleys are quite often truncated to give them an appearance like triangular facets. Very deep glacial troughs filled with sea water and making up shorelines (in high latitudes) are called *fjords/fiords*.

> What are the basic differences between glacial valleys and river valleys?

Depositional Landforms

The unassorted coarse and fine debris dropped by the melting glaciers is called *glacial till*. Most of the rock fragments in till are angular to sub-angular in form. Streams form by melting ice at the bottom, sides or lower ends of glaciers. Some amount of rock debris small enough to be carried by such melt-water streams is washed down and deposited. Such glacio-fluvial deposits are called *outwash deposits*. Unlike till deposits, the outwash deposits are roughly stratified and assorted. The rock fragments in outwash deposits are somewhat rounded at their edges. Figure 7.14 shows a few depositional landforms commonly found in glaciated areas.

Moraines

They are long ridges of deposits of glacial till. Terminal moraines are long ridges of debris deposited at the end (toe) of the glaciers. *Lateral moraines* form along the sides parallel to the glacial valleys. The lateral moraines may join a terminal moraine forming a horse-shoe shaped ridge (Fig. 7.13). There can be many lateral moraines on either side in a glacial valley. These moraines partly or fully owe their origin to glacio-fluvial waters pushing up materials to the sides of glaciers. Many valley glaciers retreating rapidly leave an irregular sheet of till over their valley floors. Such deposits varying greatly in thickness and in surface topography are called *ground moraines*. The moraine in the centre of the

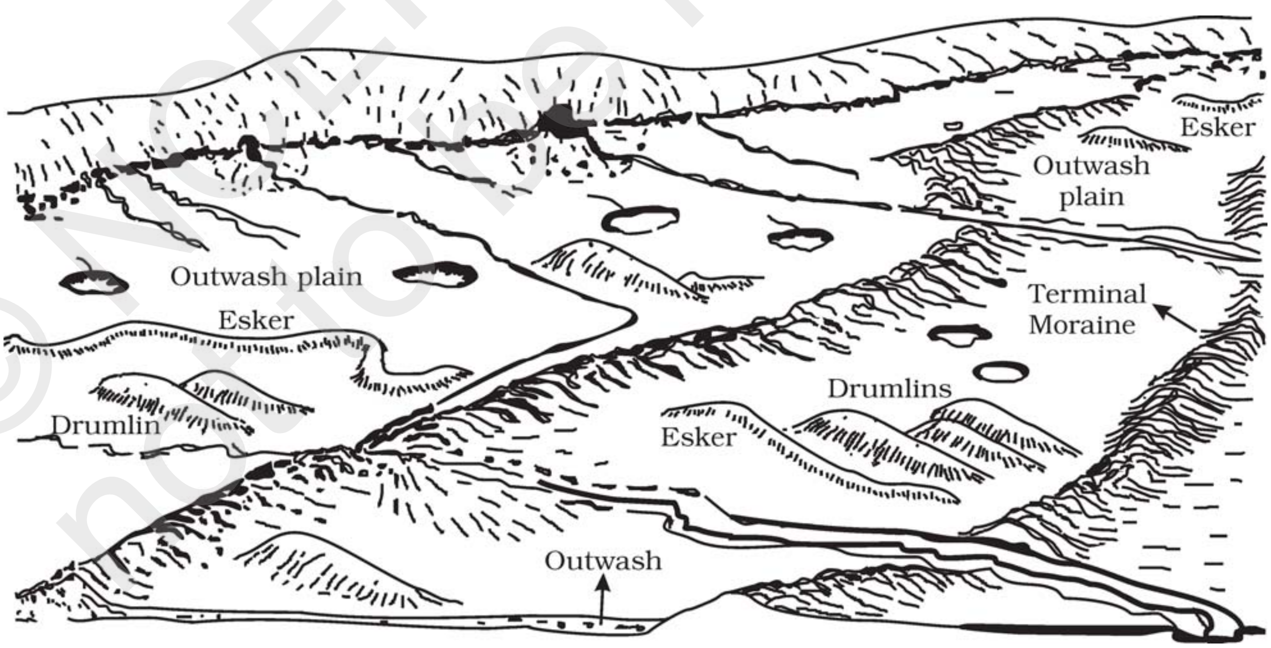


Figure 7.14 : A panoramic diagram of glacial landscape with various depositional landforms (adapted and modified from Spencer, 1962)

glacial valley flanked by lateral moraines is called *medial moraine*. They are imperfectly formed as compared to lateral moraines. Sometimes medial moraines are indistinguishable from ground moraines.

Eskers

When glaciers melt in summer, the water flows on the surface of the ice or seeps down along the margins or even moves through holes in the ice. These waters accumulate beneath the glacier and flow like streams in a channel beneath the ice. Such streams flow over the ground (not in a valley cut in the ground) with ice forming its banks. Very coarse materials like boulders and blocks along with some minor fractions of rock debris carried into this stream settle in the valley of ice beneath the glacier and after the ice melts can be found as a sinuous ridge called *esker*.

Outwash Plains

The plains at the foot of the glacial mountains or beyond the limits of continental ice sheets are covered with glacio-fluvial deposits in the form of broad flat alluvial fans which may join to form outwash plains of gravel, silt, sand and clay.

> Distinguish between river alluvial plains and glacial outwash plains.

Drumlins

Drumlins are smooth oval shaped ridge-like features composed mainly of glacial till with some masses of gravel and sand. The long axes of drumlins are parallel to the direction of ice movement. They may measure up to 1 km in length and 30 m or so in height. One end of the drumlins facing the glacier called the *stoss* end is blunter and steeper than the other end called *tail*. The drumlins form due to dumping of rock debris beneath heavily loaded ice through fissures in the glacier. The stoss end gets blunted due to pushing by moving ice. Drumlins give an indication of direction of glacier movement.

> What is the difference between till and alluvium?

Waves and Currents

Coastal processes are the most dynamic and hence most destructive. So, don't you think it is important to know about the coastal processes and forms?

Some of the changes along the coasts take place very fast. At one place, there can be erosion in one season and deposition in another. Most of the changes along the coasts are accomplished by waves. When waves break, the water is thrown with great force onto the shore, and simultaneously, there is a great churning of sediments on the sea bottom. Constant impact of breaking waves drastically affects the coasts. Storm waves and tsunami waves can cause far-reaching changes in a short period of time than normal breaking waves. As wave environment changes, the intensity of the force of breaking waves changes.

> Do you know about the generating forces behind waves and currents? If not, refer to the chapter on movements in ocean waters.

Other than the action of waves, the coastal landforms depend upon (i) the configuration of land and sea floor; (ii) whether the coast is advancing (emerging) seaward or retreating (submerging) landward. Assuming sea level to be constant, two types of coasts are considered to explain the concept of evolution of coastal landforms: (i) high, rocky coasts (submerged coasts); (ii) low, smooth and gently sloping sedimentary coasts (emerged coasts).

High Rocky Coasts

Along the high rocky coasts, the rivers appear to have been drowned with highly irregular coastline. The coastline appears highly indented with extension of water into the land where glacial valleys *(fjords)* are present. The hill sides drop off sharply into the water. Shores do not show any depositional landforms initially. Erosion features dominate.

Along high rocky coasts, waves break with great force against the land shaping the hill sides into cliffs. With constant pounding by waves, the cliffs recede leaving a *wave-cut platform* in front of the sea cliff. Waves gradually minimise the irregularities along the shore.

The materials which fall off, and removed from the sea cliffs, gradually break into smaller fragments and roll to roundness, will get deposited in the offshore. After a considerable period of cliff development and retreat when coastline turns somewhat smooth, with the addition of some more material to this deposit in the offshore, a wave-built terrace would develop in front of wave-cut terrace. As the erosion along the coast takes place a good supply material becomes available to longshore currents and waves to deposit them as beaches along the shore and as bars (long ridges of sand and/or shingle parallel to the coast) in the nearshore zone. Bars are submerged features and when bars show up above water, they are called *barrier bars*. Barrier bar which get keyed up to the headland of a bay is called a *spit*. When barrier bars and spits form at the mouth of a bay and block it, a *lagoon* forms. The lagoons would gradually get filled up by sediments from the land giving rise to a coastal plain.

Low Sedimentary Coasts

Along low sedimentary coasts the rivers appear to extend their length by building coastal plains and deltas. The coastline appears smooth with occasional incursions of water in the form of *lagoons and tidal creeks*. The land slopes gently into the water. Marshes and swamps may abound along the coasts. Depositional features dominate.

When waves break over a gently sloping sedimentary coast, the bottom sediments get churned and move readily building *bars, barrier bars, spits and lagoons*. Lagoons would eventually turn into a swamp which would subsequently turn into a coastal plain. The maintenance of these depositional features depends upon the steady supply of materials. Storm and tsunami waves cause drastic changes irrespective of supply of sediments. Large rivers which bring lots of sediments build deltas along low sedimentary coasts.

The west coast of our country is a high rocky retreating coast. Erosional forms dominate in the west coast. The east coast of India is a low sedimentary coast. Depositional forms dominate in the east coast.

What are the various differences between a high rocky coast and a low sedimentary coast in terms of processes and landforms?

Erosional Landforms

Cliffs, Terraces, Caves and Stacks

Wave-cut cliffs and terraces are two forms usually found where erosion is the dominant shore process. Almost all sea cliffs are steep and may range from a few m to 30 m or even more. At the foot of such cliffs there may be a flat or gently sloping platform covered by rock debris derived from the sea cliff behind. Such platforms occurring at elevations above the average height of waves is called a *wave-cut terrace*. The lashing of waves against the base of the cliff and the rock debris that gets smashed against the cliff along with lashing waves create hollows and these hollows get widened and deepened to form *sea caves*. The roofs of caves collapse and the sea cliffs recede further inland. Retreat of the cliff may leave some remnants of rock standing isolated as small islands just off the shore. Such resistant masses of rock, originally parts of a cliff or hill are called *sea stacks*. Like all other features, sea stacks are also temporary and eventually coastal hills and cliffs will disappear because of wave erosion giving rise to narrow coastal plains, and with onrush of deposits from over the land behind may get covered up by alluvium or may get covered up by shingle or sand to form a wide beach.

Depositional Landforms

Beaches and Dunes

Beaches are characteristic of shorelines that are dominated by deposition, but may occur as patches along even the rugged shores. Most of the sediment making up the beaches comes from land carried by the streams and rivers or from wave erosion. Beaches are temporary features. The sandy beach which appears so permanent may be reduced to a very narrow strip of coarse pebbles in some other season. Most of the beaches are made up of sand sized materials. Beaches called shingle beaches contain excessively small pebbles and even cobbles.

Just behind the beach, the sands lifted and winnowed from over the beach surfaces will be deposited as sand dunes. Sand dunes forming long ridges parallel to the coastline are very common along low sedimentary coasts.

Bars, Barriers and Spits

A ridge of sand and shingle formed in the sea in the off-shore zone (from the position of low tide waterline to seaward) lying approximately parallel to the coast is called an *off-shore bar*. An off-shore bar which is exposed due to further addition of sand is termed a *barrier bar*. The off-shore bars and barriers commonly form across the mouth of a river or at the entrance of a bay. Sometimes such barrier bars get keyed up to one end of the bay when they are called *spits* (Figure 7.15). Spits may also develop attached to headlands/hills. The barriers, bars and spits at the mouth of the bay gradually extend leaving only a small opening of the bay into the sea and the bay will eventually develop into a lagoon. The lagoons get filled up gradually by sediment coming from the land or from the beach itself (aided by wind) and a broad and wide coastal plain may develop replacing a lagoon.

Figure 7.15 : A satellite picture of a part of Godavari river delta showing a spit

> Do you know, the coastal off-shore bars offer the first buffer or defence against storm or tsunami by absorbing most of their destructive force. Then come the barriers, beaches, beach dunes and mangroves, if any, to absorb the destructive force of storm and tsunami waves. So, if we do anything which disturbs the 'sediment budget' and the mangroves along the coast, these coastal forms will get eroded away leaving human habitations to bear first strike of storm and tsunami waves.

Winds

Wind is one of the two dominant agents in hot deserts. The desert floors get heated up too much and too quickly because of being dry and barren. The heated floors heat up the air directly above them and result in upward movements in the hot lighter air with turbulence, and any obstructions in its path sets up eddies, whirlwinds, updrafts and downdrafts. Winds also move along the desert floors with great speed and the obstructions in their path create turbulence. Of course, there are storm winds which are very destructive. Winds cause deflation, abrasion and impact. Deflation includes lifting and removal of dust and smaller particles from the surface of rocks. In the transportation process sand and silt act as effective tools to abrade the land surface. The impact is simply sheer force of momentum which occurs when sand is blown into or against a rock surface. It is similar to sand-blasting operation. The wind action creates a number of interesting erosional and depositional features in the deserts.

In fact, many features of deserts owe their formation to mass wasting and running water as sheet floods. Though rain is scarce in deserts, it comes down torrentially in a short period of time. The desert rocks devoid of vegetation, exposed to mechanical and chemical weathering processes due to drastic diurnal temperature changes, decay faster and the torrential rains help in removing the weathered materials easily. That means, the weathered debris in deserts is moved by not only wind but also by rain/sheet wash. The wind moves fine materials and general mass erosion is accomplished mainly through sheet floods or sheet wash. Stream channels in desert areas are broad, smooth and indefinite and flow for a brief time after rains.

Erosional Landforms

Pediments and Pediplains

Landscape evolution in deserts is primarily concerned with the formation and extension of pediments. Gently inclined rocky floors close to the mountains at their foot with or without a thin cover of debris, are called *pediments*. Such rocky floors form through the erosion of mountain front through a combination of lateral erosion by streams and sheet flooding.

Erosion starts along the steep margins of the landmass or the steep sides of the tectonically controlled steep incision features over the landmass. Once, pediments are formed with a steep wash slope followed by cliff or free face above it, the steep wash slope and free face retreat backwards. This method of erosion is termed as parallel retreat of slopes through backwasting. So, through parallel retreat of slopes, the pediments extend backwards at the expense of mountain front, and gradually, the mountain gets reduced leaving an *inselberg* which is a remnant of the mountain. That's how the high relief in desert areas is reduced to low featureless plains called *pediplains*.

Playas

Plains are by far the most prominent landforms in the deserts. In basins with mountains and hills around and along, the drainage is towards the centre of the basin and due to gradual deposition of sediment from basin margins, a nearly level plain forms at the centre of the basin. In times of sufficient water, this plain is covered up by a shallow water body. Such types of shallow lakes are called as *playas* where water is retained only for short duration due to evaporation and quite often the playas contain good deposition of salts. The playa plain covered up by salts is called *alkali flats*.

Deflation Hollows and Caves

Weathered mantle from over the rocks or bare soil, gets blown out by persistent movement of wind currents in one direction. This process may create shallow depressions called *deflation hollows*. Deflation also creates numerous small pits or cavities over rock surfaces. The rock faces suffer impact and abrasion of wind-borne sand and first shallow depressions called blow outs are created, and some of the *blow outs* become deeper and wider fit to be called *caves*.

Mushroom, Table and Pedestal Rocks

Many rock-outcrops in the deserts easily susceptible to wind deflation and abrasion are worn out quickly leaving some remnants of resistant rocks polished beautifully in the shape of mushroom with a slender stalk and a broad and rounded pear shaped cap above. Sometimes, the top surface is broad like a table top and quite often, the remnants stand out like pedestals.

> List the erosional features carved out by wind action and action of sheet floods.

Depositional Landforms

Wind is a good sorting agent. Depending upon the velocity of wind, different sizes of grains are moved along the floors by rolling or saltation and carried in suspension and in this process of transportation itself, the materials get sorted. When the wind slows or begins to die down, depending upon sizes of grains and their critical velocities, the grains will begin to settle. So, in depositional landforms made by wind, good sorting of grains can be found. Since wind is there everywhere and wherever there is good source of sand and with constant wind directions, depositional features in arid regions can develop anywhere.

Sand Dunes

Dry hot deserts are good places for sand dune formation. Obstacles to initiate dune formation are equally important. There can be a great variety of dune forms (Figure 7.16).

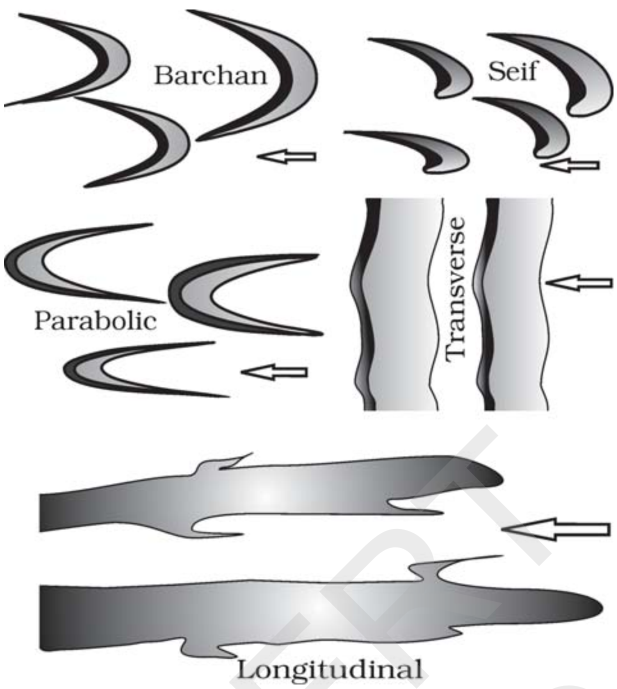


Figure 7.16 : Various types of sand dunes Arrows indicate wind direction

Crescent shaped dunes called *barchans* with the points or wings directed away from wind direction i.e., downwind, form where the wind direction is constant and moderate and where the original surface over which sand is moving is almost uniform. *Parabolic dunes* form when sandy surfaces are partially covered with vegetation. That means parabolic dunes are reversed barchans with wind direction being the same. *Seif* is similar to barchan with a small difference. Seif has only one wing or point. This happens when there is shift in wind conditions. The lone wings of seifs can grow very long and high. Longitudinal dunes form when supply of sand is poor and wind direction is constant. They appear as long ridges of considerable length but low in height. *Transverse dunes* are aligned perpendicular to wind direction. These dunes form when the wind direction is constant and the source of sand is an elongated feature at right angles to the wind direction. They may be very long and low in height. When sand is plenty, quite often, the regular shaped dunes coalesce and lose their individual characteristics. Most of the dunes in the deserts shift and a few of them will get stabilised especially near human habitations.

EXERCISES

1. Multiple choice questions.

   (i) In which of the following stages of landform development, downward cutting is dominated?

   (a) Youth stage (c) Early mature stage

   (b) Late mature stage (d) Old stage

   (ii) A deep valley characterised by steep step-like side slopes is known as

   (a) U-shaped valley (c) Blind valley

   (b) Gorge (d) Canyon

   (iii) In which one of the following regions the chemical weathering process is more dominant than the mechanical process?

   (a) Humid region (c) Arid region

   (b) Limestone region (d) Glacier region

(iv) Which one of the following sentences best defines the term 'Lapies'?

(a) A small to medium sized shallow depression

(b) A landform whose opening is more or less circular at the top and funnel shaped towards bottom

(c) A landform formed due to dripping water from surface

(d) An irregular surface with sharp pinnacles, grooves and ridges

(v) A deep, long and wide trough or basin with very steep concave high walls at its head as well as in sides is known as:

(a) Cirque (c) Lateral Moraine

(b) Glacial valley (d) Esker

2. Answer the following questions in about 30 words.

(i) What do incised meanders in rocks and meanders in plains of alluvium indicate?

(ii) Explain the evolution of valley sinks or uvalas.

(iii) Underground flow of water is more common than surface run-off in limestone areas. Why?

(iv) Glacial valleys show up many linear depositional forms. Give their locations and names.

(v) How does wind perform its task in desert areas? Is it the only agent responsible for the erosional features in the deserts?

3. Answer the following questions in about 150 words.

(i) Running water is by far the most dominating geomorphic agent in shaping the earth's surface in humid as well as in arid climates. Explain.

(ii) Limestones behave differently in humid and arid climates. Why? What is the dominant and almost exclusive geomorphic process in limestone areas and what are its results?

(iii) How do glaciers accomplish the work of reducing high mountains into low hills and plains?

Project Work

Identify the landforms, materials and processes around your area.

UNIT IV

CLIMATE

This unit deals with

- *Atmosphere — compositions and structure; elements of weather and climate*
- *Insolation — angle of incidence and distribution; heat budget of the earth — heating and cooling of atmosphere (conduction, convection, terrestrial radiation, advection); temperature — factors controlling temperature; distribution of temperature — horizontal and vertical; inversion of temperature*
- *Pressure — pressure belts; winds-planetary seasonal and local, air masses and fronts; tropical and extra tropical cyclones*
- *Precipitation — evaporation; condensation — dew, frost, fog, mist and cloud; rainfall — types and world distributon*
- *World climates — classification (Koeppen), greenhouse effect, global warming and climatic changes*

CHAPTER

8

Composition and Structure of Atmosphere

Can a person live without air? We eat food two - three times a day and drink water more frequently but breathe every few seconds. Air is essential to the survival of all organisms. Some organisms like humans may survive for some time without food and water but can't survive even a few minutes without breathing air. That shows the reason why we should understand the atmosphere in greater detail. Atmosphere is a mixture of different gases and it envelopes the earth all round. It contains life-giving gases like oxygen for humans and animals and carbon dioxide for plants. The air is an integral part of the earth's mass and 99 per cent of the total mass of the atmosphere is confined to the height of 32 km from the earth's surface. The air is colourless and odourless and can be felt only when it blows as wind.

> Can you imagine what will happen to us in the absence of ozone in the atmosphere?

Composition of the Atmosphere

The atmosphere is composed of gases, water vapour and dust particles. Table 8.1 shows details of various gases in the air, particularly in the lower atmosphere. The proportion of gases changes in the higher layers of the atmosphere in such a way that oxygen will be almost in negligible quantity at the height of 120 km. Similarly, carbon dioxide and water vapour are found only up to 90 km from the surface of the earth.

Table 8.1 : Permanent Gases of the Atmosphere

Constituent	*Formula*	*Percentage by Volume*
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Carbon dioxide	CO_2	0.036
Neon	Ne	0.002
Helium	He	0.0005
Krypto	Kr	0.001
Xenon	Xe	0.00009
Hydrogen	H_2	0.00005

Gases

Carbon dioxide is meteorologically a very important gas as it is transparent to the incoming solar radiation but opaque to the outgoing terrestrial radiation. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth's surface. It is largely responsible for the *green house effect*. The volume of other gases is constant but the volume of carbon dioxide has been rising in the past few decades mainly because of the burning of fossil fuels. This has also increased the temperature of the air. Ozone is another important component of the atmosphere found between 10 and 50 km above the earth's surface and acts as a filter and absorbs the *ultra-violet rays* radiating from the sun and prevents them from reaching the surface of the earth.

Water Vapour

Water vapour is also a variable gas in the atmosphere, which decreases with altitude. In the warm and wet tropics, it may account for four per cent of the air by volume, while in the dry and cold areas of desert and polar regions, it may be less than one per cent of the air. Water vapour also decreases from the equator towards the poles. It also absorbs parts of the insolation from the sun and preserves the earth's radiated heat. It thus, acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour also contributes to the stability and instability in the air.

Dust Particles

Atmosphere has a sufficient capacity to keep small solid particles, which may originate from different sources and include sea salts, fine soil, smoke-soot, ash, pollen, dust and disintegrated particles of meteors. Dust particles are generally concentrated in the lower layers of the atmosphere; yet, convectional air currents may transport them to great heights. The higher concentration of dust particles is found in subtropical and temperate regions due to dry winds in comparison to equatorial and polar regions. Dust and salt particles act as hygroscopic nuclei around which water vapour condenses to produce clouds.

Structure of the Atmosphere

The atmosphere consists of different layers with varying density and temperature. Density is highest near the surface of the earth and decreases with increasing altitude. The column of atmosphere is divided into five different layers depending upon the temperature condition. They are: troposphere, stratosphere, mesosphere, thermosphere and exosphere.

The troposphere is the lowermost layer of the atmosphere. Its average height is 13 km and extends roughly to a height of 8 km near the poles and about 18 km at the equator. Thickness of the troposphere is greatest at the equator because heat is transported to great heights by strong convectional currents. This layer contains dust particles and water vapour. All changes in climate and weather take place in this layer. The temperature in this layer decreases at the rate of 1°C for every 165m of height. This is the most important layer for all biological activity.

The zone separating the tropsophere from stratosphere is known as the *tropopause*. The air temperature at the tropopause is about minus 80^0C over the equator and about minus 45^oC over the poles. The temperature here is nearly constant, and hence, it is called the tropopause. *The stratosphere* is found above the tropopause and extends up to a height of 50 km. One important feature of the stratosphere is that it contains the *ozone layer*. This layer absorbs ultra-violet radiation and shields life on the earth from intense, harmful form of energy.

The mesosphere lies above the stratosphere, which extends up to a height of 80 km. In this layer, once again, temperature starts decreasing with the increase in altitude and reaches up to minus 100°C at the height of 80 km. The upper limit of mesosphere is known as the *mesopause*. *The ionosphere* is located between 80 and 400 km above the mesopause. It contains electrically charged particles known as ions, and hence, it is known as ionosphere. Radio waves transmitted from the earth are reflected back to the earth by this layer. Temperature here starts increasing with height. The uppermost layer of the atmosphere above

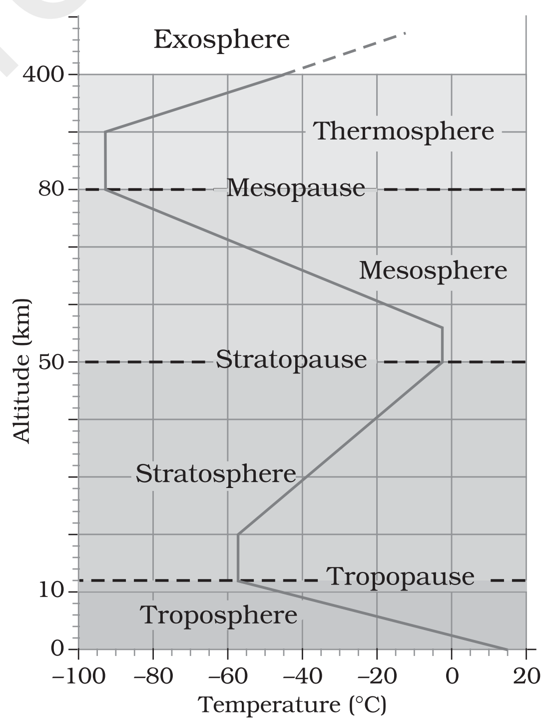


Figure 8.1 : Structure of atmosphere

the thermosphere is known as the *exosphere*. This is the highest layer but very little is known about it. Whatever contents are there, these are extremely rarefied in this layer, and it gradually merges with the outer space. Although all layers of the atmosphere must be exercising influence on us, geographers are concerned with the first two layers of the atmosphere.

Elements of Weather and Climate

The main elements of atmosphere which are subject to change and which influence human life on earth are temperature, pressure, winds, humidity, clouds and precipitation. These elements have been dealt in detail in Chapters 9, 10 and 11.

EXERCISES

1. Multiple choice questions.

(i) Which one of the following gases constitutes the major portion of the atmosphere?

(a) Oxygen (c) Argon
(b) Nitrogen (d) Carbon dioxide

(ii) Atmospheric layer important for human beings is:

(a) Stratosphere (c) Troposphere
(b) Mesosphere (d) Ionosphere

(iii) Sea salt, pollen, ash, smoke soot, fine soil — these are associated with:

(a) Gases (c) Water vapour
(b) Dust particles (d) Meteors

(iv) Oxygen gas is in negligible quantity at the height of atmosphere:

(a) 90 km (c) 100 km
(b) 120 km (d) 150 km

(v) Which one of the following gases is transparent to incoming solar radiation and opaque to outgoing terrestrial radiation?

(a) Oxygen (c) Helium
(b) Nitrogen (d) Carbon dioxide

2. Answer the following questions in about 30 words.

(i) What do you understand by atmosphere?

(ii) What are the elements of weather and climate?

(iii) Describe the composition of atmosphere.

(iv) Why is troposphere the most important of all the layers of the atmosphere?

3. Answer the following questions in about 150 words.

(i) Describe the composition of the atmosphere.

(ii) Draw a suitable diagram for the structure of the atmosphere and label it and describe it.

CHAPTER

9

Solar Radiation, Heat Balance and Temperature

Do you feel air around you? Do you know that we live at the bottom of a huge pile of air? We inhale and exhale but we feel the air when it is in motion. It means air in motion is wind. You have already learnt about the fact that earth is surrounded by air all around. This envelop of air is atmosphere which is composed of numerous gases. These gases support life over the earth's surface.

The earth receives almost all of its energy from the sun. The earth in turn radiates back to space the energy received from the sun. As a result, the earth neither warms up nor does it get cooled over a period of time. Thus, the amount of heat received by different parts of the earth is not the same. This variation causes pressure differences in the atmosphere. This leads to transfer of heat from one region to the other by winds. This chapter explains the process of heating and cooling of the atmosphere and the resultant temperature distribution over the earth's surface.

Solar Radiation

The earth's surface receives most of its energy in short wavelengths. The energy received by the earth is known as incoming solar radiation which in short is termed as *insolation*.

As the earth is a geoid resembling a sphere, the sun's rays fall obliquely at the top of the atmosphere and the earth intercepts a very small portion of the sun's energy. On an average the earth receives 1.94 calories per sq. cm per minute at the top of its atmosphere. The solar output received at the top of the atmosphere varies slightly in a year due to the variations in the distance between the earth and the sun. During its revolution around the sun, the earth is farthest from the sun (152 million km) on 4th July. This position of the earth is called *aphelion*. On 3rd January, the earth is the nearest to the sun (147 million km). This position is called *perihelion*. Therefore, the annual insolation received by the earth on 3rd January is slightly more than the amount received on 4th July. However, the effect of this variation in the solar output is masked by other factors like the distribution of land and sea and the atmospheric circulation. Hence, this variation in the solar output does not have great effect on daily weather changes on the surface of the earth.

Variability of Insolation at the Surface of the Earth

The amount and the intensity of insolation vary during a day, in a season and in a year. The factors that cause these variations in insolation are : (i) the rotation of earth on its axis; (ii) the angle of inclination of the sun's rays; (iii) the length of the day; (iv) the transparency of the atmosphere; (v) the configuration of land in terms of its aspect. The last two however, have less influence.

The fact that the earth's axis makes an angle of 66□ with the plane of its orbit round the sun has a greater influence on the amount of insolation received at different latitudes. Note the variations in the duration of the day at different latitudes on solstices given in Table 9.1.

The second factor that determines the amount of insolation received is the angle of inclination of the rays. This depends on the latitude of a place. The higher the latitude the less is the angle they make with the surface of the earth resulting in slant sun rays. The area covered by vertical rays is always less than the slant rays. If more area is covered, the energy gets distributed and the net energy received per unit area decreases. Moreover, the slant rays are required to pass through greater depth of the atmosphere resulting in more absorption, scattering and diffusion.

Table 9.1 : Length of the Day in Hours and Minutes on Winter and Summer Solstices in the Northern Hemisphere

Latitude	0°	20°	40°	60°	90°
December 22	12h 00m	10h 48m	9h 8m	5h 33m	0
June 21	12 h	13h 12m	14h 52m	18h 27m	6 months

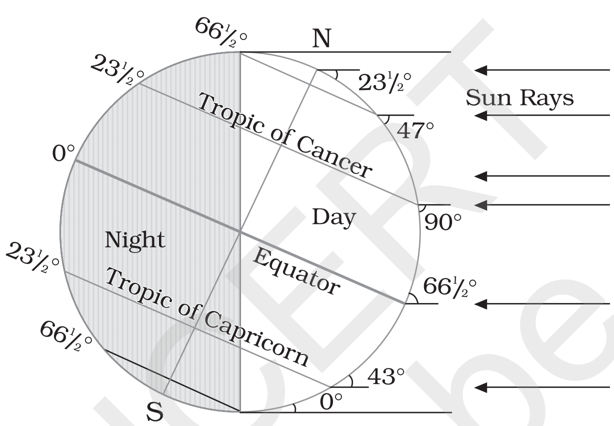


Figure 9.1 : Summer Solstice

The Passage of Solar Radiation through the Atmosphere

The atmosphere is largely transparent to short wave solar radiation. The incoming solar radiation passes through the atmosphere before striking the earth's surface. Within the troposphere water vapour, ozone and other gases absorb much of the near infrared radiation.

Very small-suspended particles in the troposphere scatter visible spectrum both to the space and towards the earth surface. This process adds colour to the sky. The red colour of the rising and the setting sun and the blue colour of the sky are the result of scattering of light within the atmosphere.

Spatial Distribution of Insolation at the Earth's Surface

The insolation received at the surface varies from about 320 Watt/m^2 in the tropics to about 70 Watt/m^2 in the poles. Maximum insolation is received over the subtropical deserts, where the cloudiness is the least. Equator receives comparatively less insolation than the tropics. Generally, at the same latitude the insolation is more over the continent than over the oceans. In winter, the middle and higher latitudes receive less radiation than in summer.

Heating and Cooling of Atmosphere

There are different ways of heating and cooling of the atmosphere.

The earth after being heated by insolation transmits the heat to the atmospheric layers near to the earth in long wave form. The air in contact with the land gets heated slowly and the upper layers in contact with the lower layers also get heated. This process is called *conduction*. Conduction takes place when two bodies of unequal temperature are in contact with one another, there is a flow of energy from the warmer to cooler body. The transfer of heat continues until both the bodies attain the same temperature or the contact is broken. Conduction is important in heating the lower layers of the atmosphere.

The air in contact with the earth rises vertically on heating in the form of currents and further transmits the heat of the atmsphere. This process of vertical heating of the atmosphere is known as *convection*. The convective transfer of energy is confined only to the troposphere.

The transfer of heat through horizontal movement of air is called *advection*. Horizontal movement of the air is relatively more important than the vertical movement. In middle latitudes, most of dirunal (day and night) variation in daily weather are caused by advection alone. In tropical regions particularly in northern India during summer season local winds called 'loo' is the outcome of advection process.

Terrestrial Radiation

The insolation received by the earth is in short waves forms and heats up its surface. The earth after being heated itself becomes a radiating body and it radiates energy to the atmosphere in long wave form. This energy heats up the atmosphere from below. This process is known as terrestrial radiation.

The long wave radiation is absorbed by the atmospheric gases particularly by carbon dioxide and the other green house gases. Thus, the atmosphere is indirectly heated by the earth's radiation.

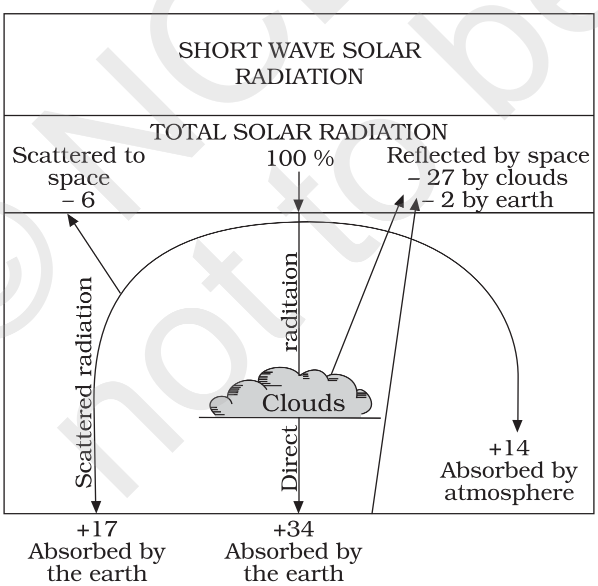
The atmosphere in turn radiates and transmits heat to the space. Finally the amount of heat received from the sun is returned to space, thereby maintaining constant temperature at the earth's surface and in the atmosphere.

Heat Budget of the Planet Earth

Figure 9.2 depicts the heat budget of the planet earth. The earth as a whole does not accumulate or loose heat. It maintains its temperature. This can happen only if the amount of heat received in the form of insolation equals the amount lost by the earth through terrestrial radiation.

Consider that the insolation received at the top of the atmosphere is 100 per cent. While passing through the atmosphere some amount of energy is reflected, scattered and absorbed. Only the remaining part reaches the earth surface. Roughly 35 units are reflected back to space even before reaching the earth's surface. Of these, 27 units are reflected back from the top of the clouds and 2 units from the snow and ice-covered areas of the earth. The reflected amount of radiation is called the *albedo of the earth*.

The remaining 65 units are absorbed, 14 units within the atmosphere and 51 units by the earth's surface. The earth radiates back 51 units in the form of terrestrial radiation. Of these, 17 units are radiated to space directly and the remaining 34 units are absorbed by the atmosphere (6 units absorbed directly by the atmosphere, 9 units through convection and turbulence and 19 units through latent heat of condensation). 48 units absorbed by the atmosphere (14 units from insolation +34 units from



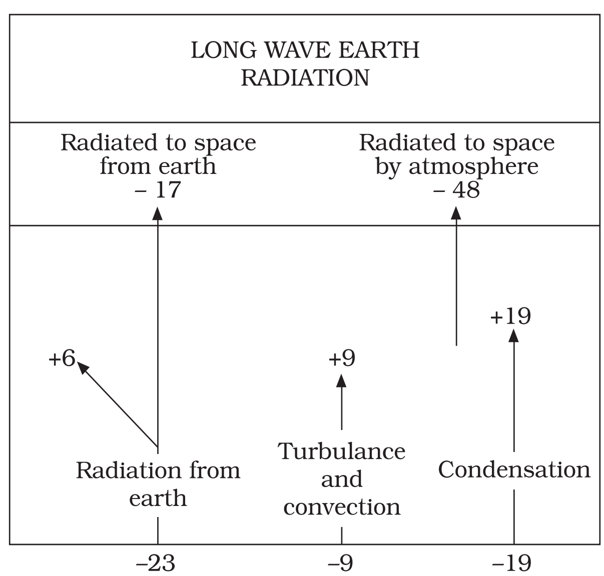


Figure 9.2 : Heat budget of the earth

terrestrial radiation) are also radiated back into space. Thus, the total radiation returning from the earth and the atmosphere respectively is 17+48=65 units which balance the total of 65 units received from the sun. This is termed the heat budget or heat balance of the earth.

This explains, why the earth neither warms up nor cools down despite the huge transfer of heat that takes place.

Variation in the Net Heat Budget at the Earth's Surface

As explained earlier, there are variations in the amount of radiation received at the earth's surface. Some part of the earth has surplus radiation balance while the other part has deficit.

Figure 9.3 depicts the latitudinal variation in the net radiation balance of the earth — the atmosphere system. The figure shows that there is a surplus of net radiation balance between 40 degrees north and south and the regions near the poles have a deficit. The surplus heat energy from the tropics is redistributed pole wards and as a result the tropics do not get progressively heated up due to the accumulation of excess heat or the high latitudes get permanently frozen due to excess deficit.

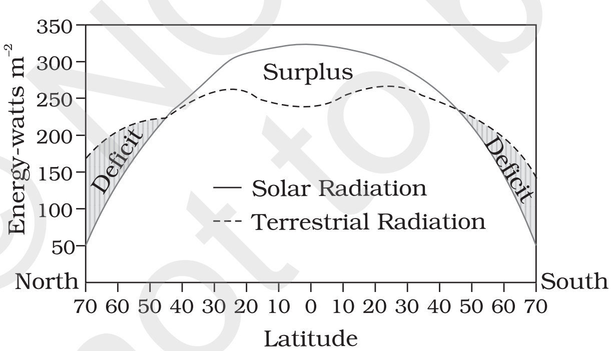


Figure 9.3 : Latitudinal variation in net radiation balance

Temperature

The interaction of insolation with the atmosphere and the earth's surface creates heat which is measured in terms of temperature. While heat represents the molecular movement of particles comprising a substance, the temperature is the measurement in degrees of how hot (or cold) a thing (or a place) is.

Factors Controlling Temperature Distribution

The temperature of air at any place is influenced by (i) the latitude of the place; (ii) the altitude of the place; (iii) distance from the sea, the air-mass circulation; (iv) the presence of warm and cold ocean currents; (v) local aspects.

The latitude : The temperature of a place depends on the insolation received. It has been explained earlier that the insolation varies according to the latitude hence the temperature also varies accordingly.

The altitude : The atmosphere is indirectly heated by terrestrial radiation from below. Therefore, the places near the sea-level record higher temperature than the places situated at higher elevations. In other words, the temperature generally decreases with increasing height. The rate of decrease of temperature with height is termed as the normal lapse rate. It is 6.5°C per 1,000 m.

Distance from the sea : Another factor that influences the temperature is the location of a place with respect to the sea. Compared to land, the sea gets heated slowly and loses heat slowly. Land heats up and cools down quickly. Therefore, the variation in temperature over the sea is less compared to land. The places situated near the sea come under the moderating influence of the sea and land breezes which moderate the temperature.

Air-mass and Ocean currents : Like the land and sea breezes, the passage of air masses also affects the temperature. The places, which come under the influence of warm air-masses experience higher temperature and the places that come under the influence of cold air-masses experience low temperature. Similarly, the places located on the coast where the warm ocean currents flow record higher temperature than the places located on the coast where the cold currents flow.

Distribution of Temperature

The global distribution of temperature can well be understood by studying the temperature distribution in January and July. The temperature distribution is generally shown on the map with the help of isotherms. The *Isotherms* are lines joining places having equal temperature. Figure 9.4 (a) and (b) show the distribution of surface air temperature in the month of January and July.

In general the effect of the latitude on temperature is well pronounced on the map, as the isotherms are generally parallel to the latitude. The deviation from this general trend is more pronounced in January than in July, especially in the northern hemisphere. In the northern hemisphere the land surface area is much larger than in the southern hemisphere. Hence, the effects of land mass and the ocean currents are well pronounced. In January the isotherms deviate to the north over the ocean and to the south over the continent. This can be seen on the North Atlantic Ocean. The presence of warm ocean currents, Gulf Stream and North Atlantic drift, make the Northern Atlantic Ocean warmer and the isotherms bend towards the north. Over the land the temperature decreases sharply and the isotherms bend towards south in Europe.

It is much pronounced in the Siberian plain. The mean January temperature along 60° E longitude is minus 20° C both at 80° N and 50° N latitudes. The mean monthly temperature for January is over 27° C, in equatorial oceans over 24° C in the tropics and 2° C - 0° C in the middle latitudes and –18° C to –48° C in the Eurasian continental interior.

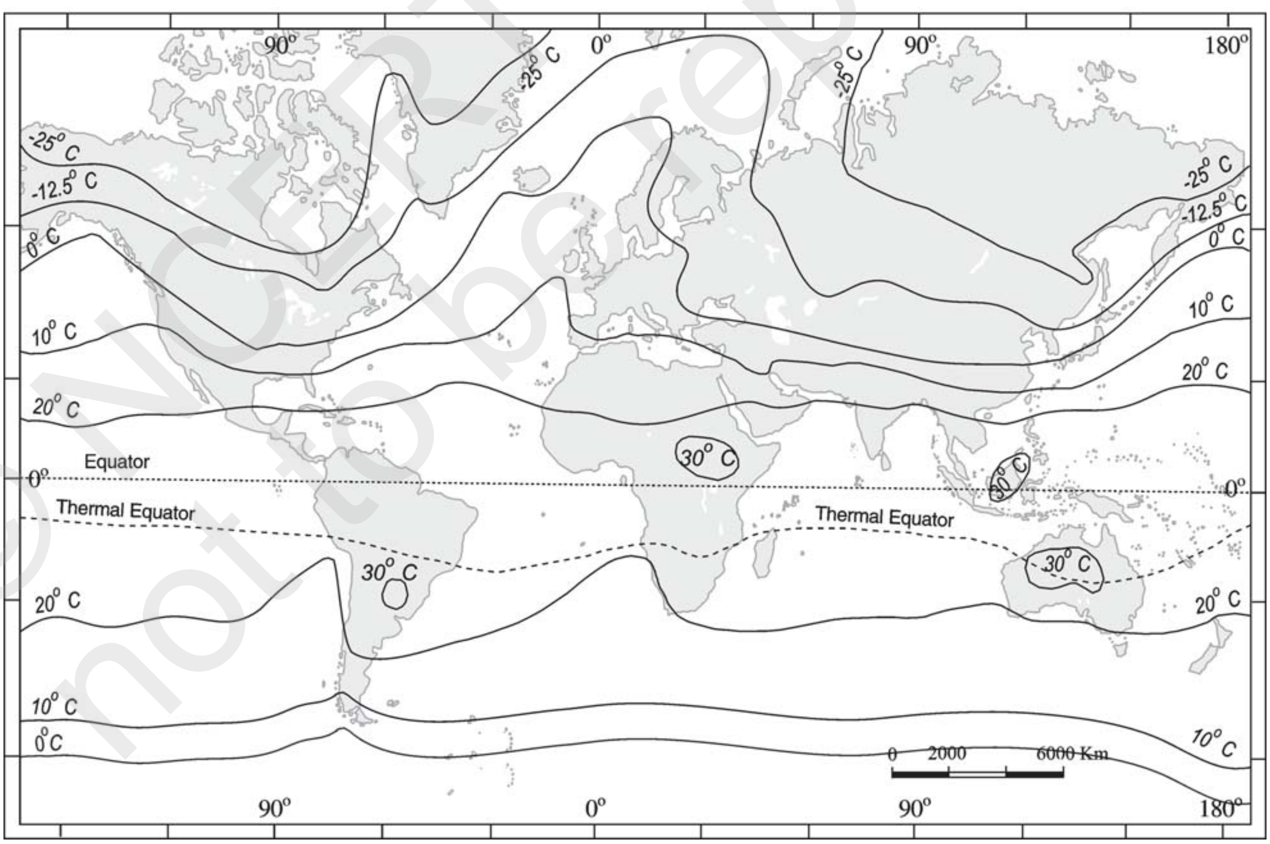


Figure 9.4 (a) : The distribution of surface air temperature in the month of January

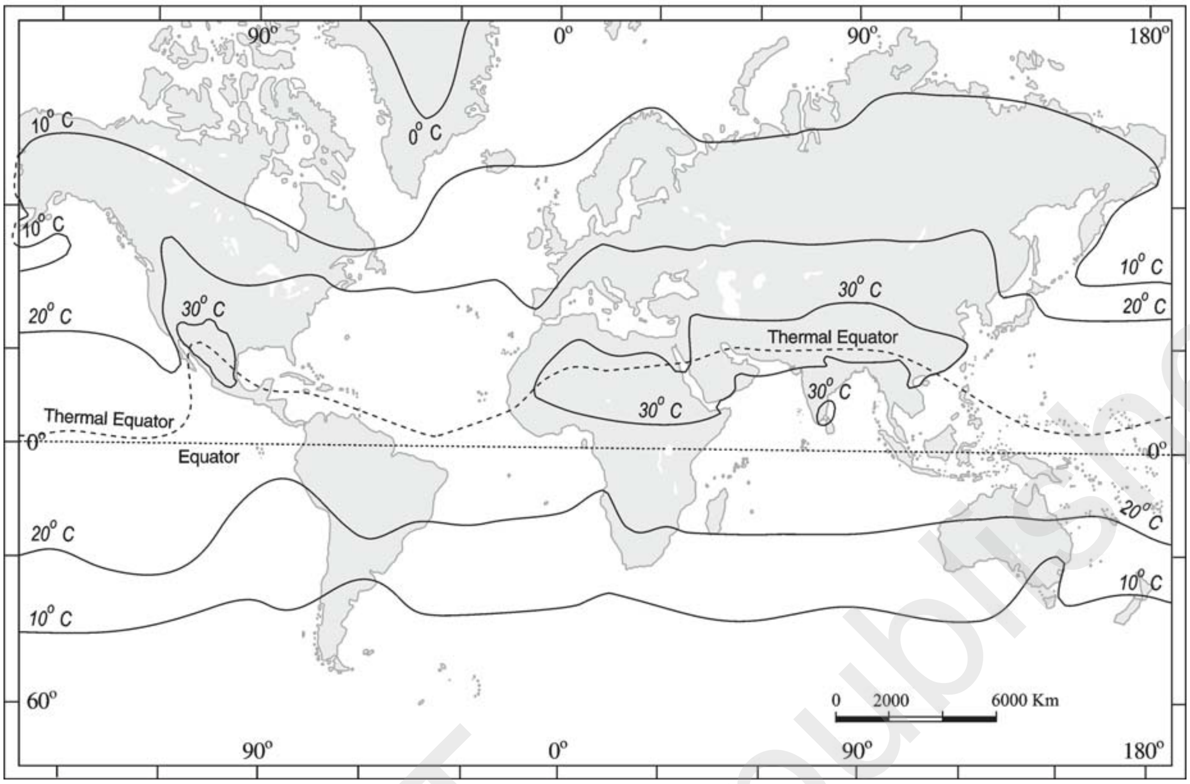


Figure 9.4 (b) : The distribution of surface air temperature in the month of July

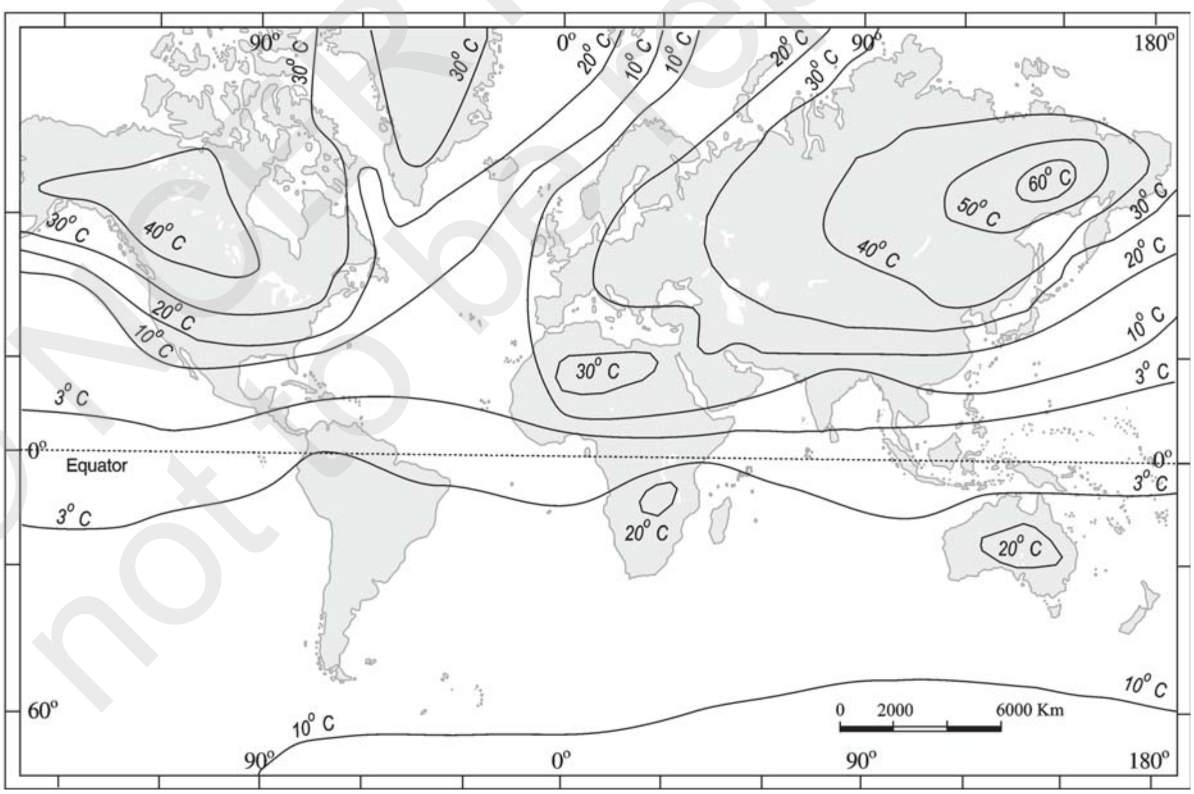


Figure 9.5 : The range of temperature between January and July

The effect of the ocean is well pronounced in the southern hemisphere. Here the isotherms are more or less parallel to the latitudes and the variation in temperature is more gradual than in the northern hemisphere. The isotherm of 20° C, 10° C, and 0° C runs parallel to 35° S, 45° S and 60° S latitudes respectively.

In July the isotherms generally run parallel to the latitude. The equatorial oceans record warmer temperature, more than 27°C. Over the land more than 30°C is noticed in the subtropical continental region of Asia, along the 30° N latitude. Along the 40° N runs the isotherm of 10° C and along the 40° S the temperature is 10° C.

Figure 9.5 shows the range of temperature between January and July. The highest range of temperature is more than 60° C over the north-eastern part of Eurasian continent. This is due to continentality. The least range of temperature, 3°C, is found between 20° S and 15° N.

Inversion of Temperature

Normally, temperature decreases with increase in elevation. It is called normal lapse rate. At times, the situations is reversed and the normal lapse rate is inverted. It is called Inversion of temperature. Inversion is usually of short duration but quite common nonetheless. A long winter night with clear skies and still air is ideal situation for inversion. The heat of the day is radiated off during the night, and by early morning hours, the earth is cooler than the air above. Over polar areas, temperature inversion is normal throughout the year.

Surface inversion promotes stability in the lower layers of the atmosphere. Smoke and dust particles get collected beneath the inversion layer and spread horizontally to fill the lower strata of the atmosphere. Dense fogs in mornings are common occurrences especially during winter season. This inversion commonly lasts for few hours until the sun comes up and beings to warm the earth.

The inversion takes place in hills and mountains due to air drainage. Cold air at the hills and mountains, produced during night, flows under the influence of gravity. Being heavy and dense, the cold air acts almost like water and moves down the slope to pile up deeply in pockets and valley bottoms with warm air above. This is called *air drainage.* It protects plants from frost damages.

- Plank's law states that hotter a body, the more energy it will radiate and shorter the wavelength of that radiation.
- Specific heat is the energy needed to raise the temperature of one gram of substance by one Celsius.

EXERCISES

1. Multiple choice questions.

(i) The sun is directly overhead at noon on 21st June at:

(a) The equator (c) 23.5° N

(b) 23.5° S (d) 66.5° N

(ii) In which one of the following cities, are the days the longest?

(a) Tiruvanantpuram (c) Hyderabad

(b) Chandigarh (d) Nagpur

(iii) The atmosphere is mainly heated by the:

(a) Short wave solar radiation (c) Long wave terrestrial radiation

(b) Reflected solar radiation (d) Scattered solar radiation

(iv) Make correct pairs from the following two columns.

(i) Insolation	(a) The difference between the mean temperature of the warmest and the coldest months
(ii) Albedo	(b) The lines joining the places of equal temperature
(iii) Isotherm	(c) The incoming solar radiation
(iv) Annual range	(d) The percentage of visible light reflected by an object

(v) The main reason that the earth experiences highest temperatures in the subtropics in the northern hemisphere rather than at the equator is :

(a) Subtropical areas tend to have less cloud cover than equatorial areas.

(b) Subtropical areas have longer day hours in the summer than the equatorial.

(c) Subtropical areas have an enhanced "green house effect" compared to equatorial areas.

(d) Subtropical areas are nearer to the oceanic areas than the equatorial locations.

2. Answer the following questions in about 30 words.

(i) How does the unequal distribution of heat over the planet earth in space and time cause variations in weather and climate?

(ii) What are the factors that control temperature distribution on the surface of the earth?

(iii) In India, why is the day temperature maximum in May and why not after the summer solstice?

(iv) Why is the annual range of temperature high in the Siberian plains?

3. Answer the following questions in about 150 words.

(i) How do the latitude and the tilt in the axis of rotation of the earth affect the amount of radiation received at the earth's surface?

(ii) Discuss the processes through which the earth-atmosphere system maintains heat balance.

(iii) Compare the global distribution of temperature in January over the northern and the southern hemisphere of the earth.

Project Work

Select a meteorological observatory located in your city or near your town. Tabulate the temperature data as given in the climatological table of observatories :

(i) Note the altitude, latitude of the observatory and the period for which the mean is calculated.

(ii) Define the terms related to temperature as given in the table.

(iii) Calculate the daily mean monthly temperature.

(iv) Draw a graph to show the daily mean maximum, the daily mean minimum and the mean temperature.

(v) Calculate the annual range of temperature.

(vi) Find out in which months the daily range of temperature is the highest and the lowest.

(vii) List out the factors that determine the temperature of the place and explain the possible causes for temperature variation in the months of January, May, July and October.

Example

Observatory : New Delhi (Safdarjung)

Latitude : 28°35°' N

Based on observations : 1951 - 1980

Altitude above mean sea level : 216 m

Month	*Mean of Daily Max.(°C)*	*Mean of Daily Min.(°C)*	*Highest Recorded (°C)*	*Lowest Recorded (°C)*
January	21.1	7.3	29.3	0.6
May	39.6	25.9	47.2	17.5

Daily mean monthly temperature

January $\frac{21.1+7.3}{2} = 14.2^{o}C$

May $\frac{39.6+25.9}{2} = 32.75^{o}C$

Annual range of temperature

Mean Max. Temperature in May - Mean Temperature in January

Annual range of temperature = 32.75°C – 14.2°C = 18.55°C

CHAPTER

10

Atmospheric Circulation and Weather Systems

Earlier Chapter 9 described the uneven distribution of temperature over the surface of the earth. Air expands when heated and gets compressed when cooled. This results in variations in the atmospheric pressure. The result is that it causes the movement of air from high pressure to low pressure, setting the air in motion. You already know that air in horizontal motion is wind. Atmospheric pressure also determines when the air will rise or sink. The wind redistributes the heat and moisture across the planet, thereby, maintaining a constant temperature for the planet as a whole. The vertical rising of moist air cools it down to form the clouds and bring precipitation. This chapter has been devoted to explain the causes of pressure differences, the forces that control the atmospheric circulation, the turbulent pattern of wind, the formation of air masses, the disturbed weather when air masses interact with each other and the phenomenon of violent tropical storms.

Atmospheric Pressure

Do you realise that our body is subjected to a lot of air pressure. As one moves up the air gets varified and one feels breathless.

The weight of a column of air contained in a unit area from the mean sea level to the top of the atmosphere is called the *atmospheric pressure*. The atmospheric pressure is expressed in units of milibar. At sea level the average atmospheric pressure is 1,013.2 milibar. Due to gravity the air at the surface is denser and hence has higher pressure. Air pressure is measured with the help of a mercury barometer or the aneroid barometer. Consult your book, *Practical Work in Geography — Part I* (NCERT, 2006) and learn about these instruments. The pressure decreases with height. At any elevation it varies from place to place and its variation is the primary cause of air motion, i.e. wind which moves from high pressure areas to low pressure areas.

Vertical Variation of Pressure

In the lower atmosphere the pressure decreases rapidly with height. The decrease amounts to about 1 mb for each 10 m increase in elevation. It does not always decrease at the same rate. Table 10.1 gives the average pressure and temperature at selected levels of elevation for a standard atmosphere.

Table 10.1 : Standard Pressure and Temperature at Selected Levels

Level	*Pressure in mb*	*Temperature °C*
Sea Level	1,013.25	15.2
1 km	898.76	8.7
5 km	540.48	–17. 3
10 km	265.00	– 49.7

The vertical pressure gradient force is much larger than that of the horizontal pressure gradient. But, it is generally balanced by a nearly equal but opposite gravitational force. Hence, we do not experience strong upward winds.

Horizontal Distribution of Pressure

Small differences in pressure are highly significant in terms of the wind direction and

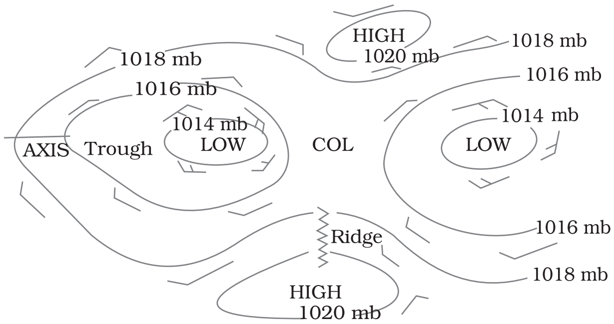


Figure 10.1 : Isobars, pressure and wind systems in Northern Hemisphere

velocity. Horizontal distribution of pressure is studied by drawing isobars at constant levels. Isobars are lines connecting places having equal pressure. In order to eliminate the effect of altitude on pressure, it is measured at any station after being reduced to sea level for purposes of comparison. The sea level pressure distribution is shown on weather maps.

Figure 10.1 shows the patterns of isobars corresponding to pressure systems. Low-pressure system is enclosed by one or more isobars with the lowest pressure in the centre. High-pressure system is also enclosed by one or more isobars with the highest pressure in the centre.

World Distribution of Sea Level Pressure

The world distribution of sea level pressure in January and July has been shown in Figures 10.2 and 10.3. Near the equator the sea level pressure is low and the area is known as *equatorial low*. Along 30° N and 30° S are found the high-pressure areas known as the subtropical highs. Further pole wards along 60° N and 60° S, the low-pressure belts are termed as the sub polar lows. Near the poles the pressure is high and it is known as the *polar high*. These pressure belts are not permanent

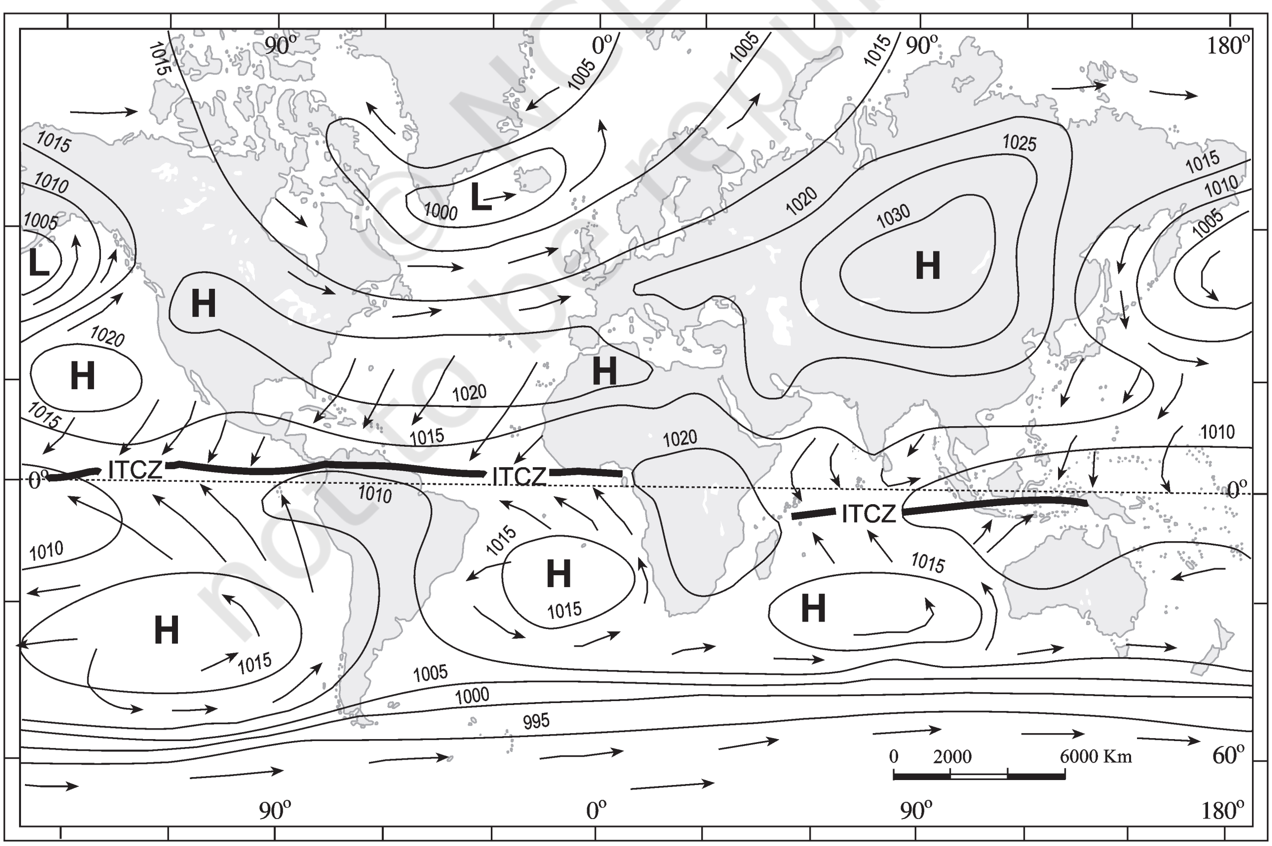


Figure 10.2 : Distribution of pressure (in millibars) — January

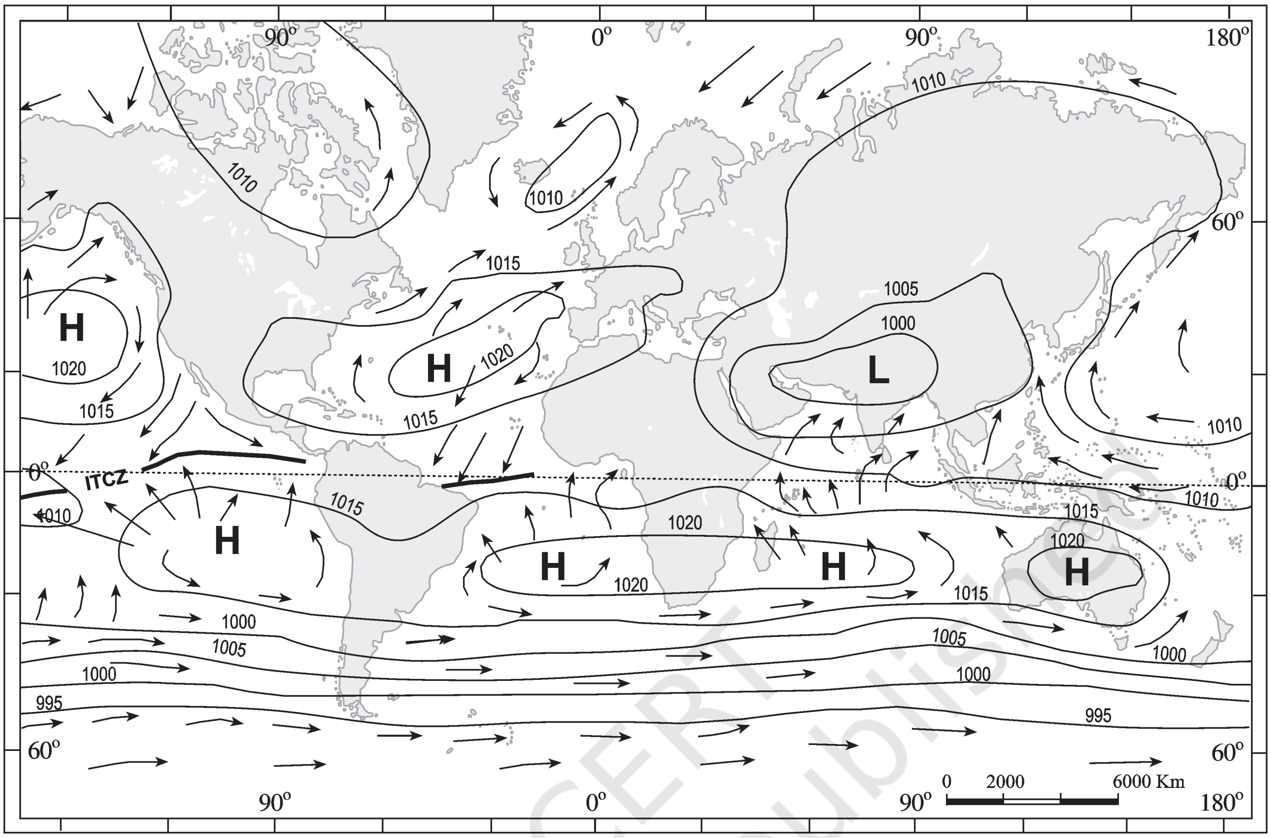


Figure 10.3 : Distribution of pressure (in millibars) — July

in nature. They oscillate with the apparent movement of the sun. In the northern hemisphere in winter they move southwards and in the summer northwards.

Forces Affecting the Velocity and Direction of Wind

You already know that the air is set in motion due to the differences in atmospheric pressure. The air in motion is called wind. The wind blows from high pressure to low pressure. The wind at the surface experiences friction. In addition, rotation of the earth also affects the wind movement. The force exerted by the rotation of the earth is known as the Coriolis force. Thus, the horizontal winds near the earth surface respond to the combined effect of three forces – the pressure gradient force, the frictional force and the Coriolis force. In addition, the gravitational force acts downward.

Pressure Gradient Force

The differences in atmospheric pressure produces a force. The rate of change of pressure with respect to distance is the pressure gradient. The pressure gradient is strong where the isobars are close to each other and is weak where the isobars are apart.

Frictional Force

It affects the speed of the wind. It is greatest at the surface and its influence generally extends upto an elevation of 1 - 3 km. Over the sea surface the friction is minimal.

Coriolis Force

The rotation of the earth about its axis affects the direction of the wind. This force is called the Coriolis force after the French physicist who described it in 1844. It deflects the wind to the right direction in the northern hemisphere and to the left in the southern hemisphere. The deflection is more when the wind velocity is high. The Coriolis force is directly proportional to the angle of latitude. It is maximum at the poles and is absent at the equator.

The Coriolis force acts perpendicular to the pressure gradient force. The pressure gradient force is perpendicular to an isobar. The higher the pressure gradient force, the more is the velocity of the wind and the larger is the deflection in the direction of wind. As a result of these two forces operating perpendicular to each other, in the low-pressure areas the wind blows around it. At the equator, the Coriolis force is zero and the wind blows perpendicular to the isobars. The low pressure gets filled instead of getting intensified. That is the reason why tropical cyclones are not formed near the equator.

Pressure and Wind

The velocity and direction of the wind are the net result of the wind generating forces. The winds in the upper atmosphere, 2 - 3 km above the surface, are free from frictional effect of the surface and are controlled mainly by the pressure gradient and the Coriolis force. When isobars are straight and when there is no friction, the pressure gradient force is balanced by the Coriolis force and the resultant wind blows parallel to the isobar. This wind is known as the geostrophic wind (Figure 10.4).

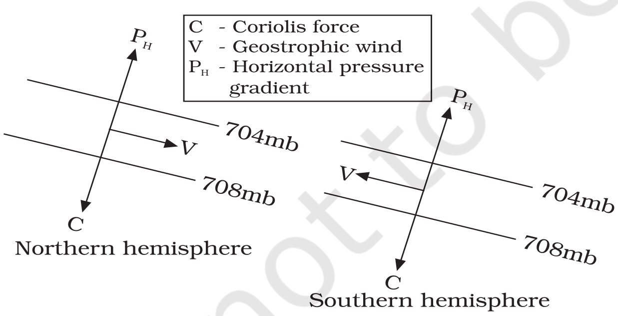


Figure 10.4 : Geostropic Wind

The wind circulation around a low is called *cyclonic circulation*. Around a high it is called *anti cyclonic circulation*. The direction of winds around such systems changes according to their location in different hemispheres (Table 10.2).

The wind circulation at the earth's surface around low and high on many occasions is closely related to the wind circulation at higher level. Generally, over low pressure area the air will converge and rise. Over high pressure area the air will subside from above and diverge at the surface (Figure10.5). Apart from convergence, some eddies, convection currents, orographic uplift and uplift along fronts cause the rising of air, which is essential for the formation of clouds and precipitation.

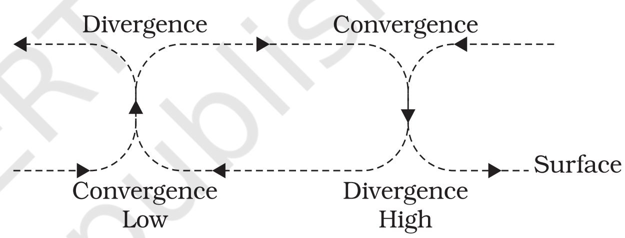


Figure 10.5 : Convergence and divergence of winds

General circulation of the atmosphere

The pattern of planetary winds largely depends on : (i) latitudinal variation of atmospheric heating; (ii) emergence of pressure belts; (iii) the migration of belts following apparent path of the sun; (iv) the distribution of continents and oceans; (v) the rotation of earth. The pattern of the movement of the planetary winds is called the general circulation of the atmosphere. The general circulation of the atmosphere also sets in motion the ocean water circulation which influences the earth's

Table 10.2 : Pattern of Wind Direction in Cyclones and Anticyclones

Pressure System	*Pressure Condition at the Centre*	*Pattern of Wind Direction*	
		Northern Hemisphere	*Southern Hemisphere*
Cyclone	Low	Anticlockwise	Clockwise
Anticyclone	High	Clockwise	Anticlockwise

climate. A schematic description of the general circulation is shown in Figure 10.6.

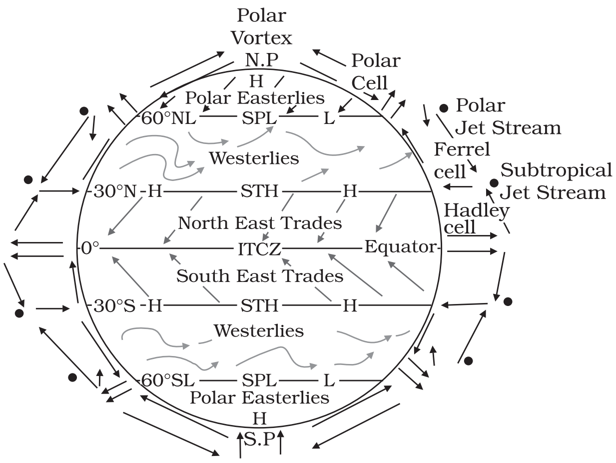


Figure 10. 6 : Simplified general circulation of the atmosphere

The air at the Inter Tropical Convergence Zone (ITCZ) rises because of convection caused by high insolation and a low pressure is created. The winds from the tropics converge at this low pressure zone. The converged air rises along with the convective cell. It reaches the top of the troposphere up to an altitude of 14 km. and moves towards the poles. This causes accumulation of air at about 30° N and S. Part of the accumulated air sinks to the ground and forms a subtropical high. Another reason for sinking is the cooling of air when it reaches 30° N and S latitudes. Down below near the land surface the air flows towards the equator as the easterlies. The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). Such circulations from the surface upwards and *vice-versa* are called cells. Such a cell in the tropics is called *Hadley Cell*. In the middle latitudes the circulation is that of sinking cold air that comes from the poles and the rising warm air that blows from the subtropical high. At the surface these winds are called westerlies and the cell is known as the *Ferrel cell*. At polar latitudes the cold dense air subsides near the poles and blows towards middle latitudes as the polar easterlies. This cell is called the polar cell. These three cells set the pattern for the general circulation of the atmosphere. The transfer of heat energy from lower latitudes to higher latitudes maintains the general circulation.

The general circulation of the atmosphere also affects the oceans. The large-scale winds of the atmosphere initiate large and slow moving currents of the ocean. Oceans in turn provide input of energy and water vapour into the air. These interactions take place rather slowly over a large part of the ocean.

General Atmospheric Circulation and its Effects on Oceans

Warming and cooling of the Pacific Ocean is most important in terms of general atmospheric circulation. The warm water of the central Pacific Ocean slowly drifts towards South American coast and replaces the cool Peruvian current. Such appearance of warm water off the coast of Peru is known as the El Nino. The El Nino event is closely associated with the pressure changes in the Central Pacific and Australia. This change in pressure condition over Pacific is known as the southern oscillation. The combined phenomenon of southern oscillation and El Nino is known as ENSO. In the years when the ENSO is strong, large-scale variations in weather occur over the world. The arid west coast of South America receives heavy rainfall, drought occurs in Australia and sometimes in India and floods in China. This phenomenon is closely monitored and is used for long range forecasting in major parts of the world.

Seasonal Wind

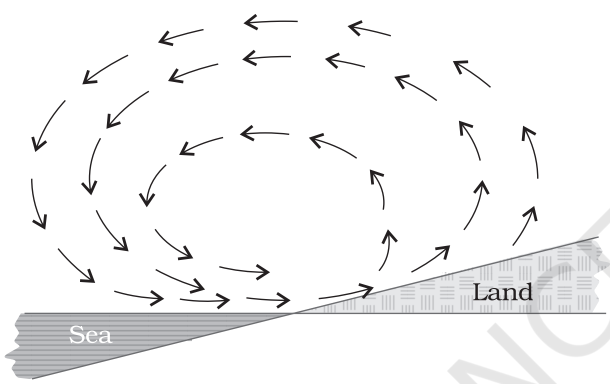
The pattern of wind circulation is modified in different seasons due to the shifting of regions of maximum heating, pressure and wind belts. The most pronounced effect of such a shift is noticed in the monsoons, especially over southeast Asia. You would be studying the details of monsoon in the book *India : Physical Environment* (NCERT, 2006). The other local deviations from the general circulation system are as follows.

Local Winds

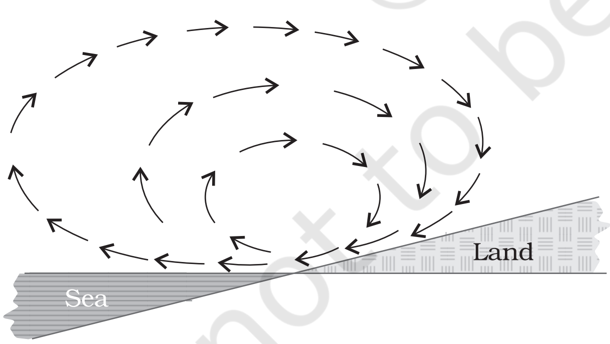
Differences in the heating and cooling of earth surfaces and the cycles those develop daily or annually can create several common, local or regional winds.

Land and Sea Breezes

As explained earlier, the land and sea absorb and transfer heat differently. During the day the land heats up faster and becomes warmer than the sea. Therefore, over the land the air rises giving rise to a low pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high. Thus, pressure gradient from sea to land is created and the wind blows from the sea to the land as the sea breeze. In the night the reversal of condition takes place. The land loses heat faster and is cooler than the sea. The pressure gradient is from the land to the sea and hence land breeze results (Figure 10.7).



Sea Breeze



Land Breeze

Figure 10.7 : Land and sea breezes

Mountain and Valley Winds

In mountainous regions, during the day the slopes get heated up and air moves upslope and to fill the resulting gap the air from the valley blows up the valley. This wind is known as the valley breeze. During the night the slopes get cooled and the dense air descends into the valley as the mountain wind. The cool air, of the high plateaus and ice fields draining into the valley is called katabatic wind. Another type of warm wind occurs on the leeward side of the mountain ranges. The moisture in these winds, while crossing the mountain ranges condense and precipitate. When it descends down the leeward side of the slope the dry air gets warmed up by adiabatic process. This dry air may melt the snow in a short time.

Air Masses

When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. The homogenous regions can be the vast ocean surface or vast plains. The air with distinctive characteristics in terms of temperature and humidity is called an airmass. It is defined as a large body of air having little horizontal variation in temperature and moisture. The homogenous surfaces, over which air masses form, are called the source regions.

The air masses are classified according to the source regions. There are five major source regions. These are: (i) Warm tropical and subtropical oceans; (ii) The subtropical hot deserts; (iii) The relatively cold high latitude oceans; (iv) The very cold snow covered continents in high latitudes; (v) Permanently ice covered continents in the Arctic and Antarctica. Accordingly, following types of air-masses are recognised: (i) Maritime tropical (mT); (ii) Continental tropical (cT); (iii) Maritime polar (mP); (iv) Continental polar (cP); (v) Continental arctic (cA). Tropical air masses are warm and polar air masses are cold.

Fronts

When two different air masses meet, the boundary zone between them is called a *front*. The process of formation of the fronts is known as *frontogenesis*. There are four types of fronts: (a) Cold; (b) Warm; (c) Stationary; (d) Occluded. When the front remains stationary, it is called a *stationary front*. When the cold air moves

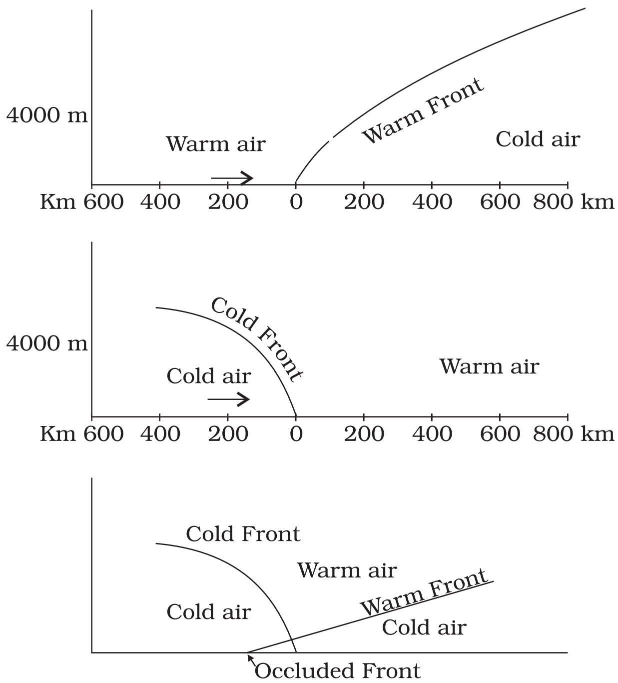


Figure 10.8 : Vertical Sections of : (a) Warm Front; (b) Cold Front; (c) Occluded Front

towards the warm air mass, its contact zone is called the *cold front*, whereas if the warm air mass moves towards the cold air mass, the contact zone is a warm front. If an air mass is fully lifted above the land surface, it is called the *occluded front*. The fronts occur in middle latitudes and are characterised by steep gradient in temperature and pressure. They bring abrupt changes in temperature and cause the air to rise to form clouds and cause precipitation.

Extra Tropical Cyclones

The systems developing in the mid and high latitude, beyond the tropics are called the *middle latitude or extra tropical cyclones*. The passage of front causes abrupt changes in the weather conditions over the area in the middle and high latitudes.

Extra tropical cyclones form along the polar front. Initially, the front is stationary. In the northern hemisphere, warm air blows from the south and cold air from the north of the front. When the pressure drops along the front, the warm air moves northwards and the cold air move towards, south setting in motion an anticlockwise cyclonic circulation. The cyclonic circulation leads to a well developed extra tropical cyclone, with a warm front and a cold front. The plan and cross section of a well developed cyclone is given in Figure 10.9. There are pockets of warm air or warm sector wedged between the forward and the rear cold air or cold sector. The warm air glides over the cold air and a sequence of clouds appear over the sky ahead of the warm front and cause precipitation. The cold front approaches the warm air from behind and pushes the warm air up. As a result, cumulus clouds develop along the cold front. The cold front moves faster than the warm front ultimately overtaking the warm front. The warm air is completely lifted up and the front is occluded and the cyclone dissipates.

The processes of wind circulation both at the surface and aloft are closely interlinked. The extra tropical cyclone differs from the tropical cyclone in number of ways. The extra tropical cyclones have a clear frontal system

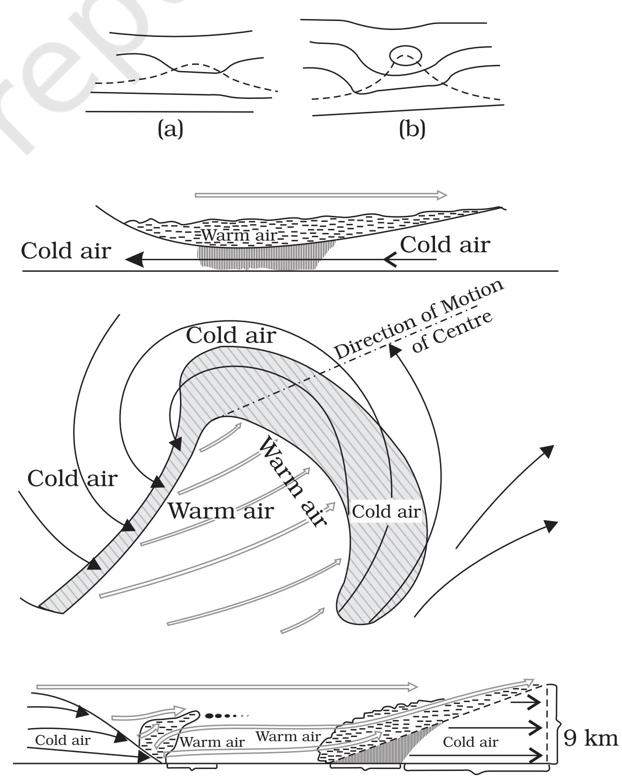


Figure 10. 9 : Extra tropical cyclones

which is not present in the tropical cyclones. They cover a larger area and can originate over the land and sea. Whereas the tropical cyclones originate only over the seas and on reaching the land they dissipate. The extra tropical cyclone affects a much larger area as compared to the tropical cyclone. The wind velocity in a tropical cyclone is much higher and it is more destructive. The extra tropical cyclones move from west to east but tropical cyclones, move from east to west.

Tropical Cyclones

Tropical cyclones are violent storms that originate over oceans in tropical areas and move over to the coastal areas bringing about large scale destruction caused by violent winds, very heavy rainfall and storm surges. This is one of the most devastating natural calamities. They are known as *Cyclones* in the Indian Ocean, *Hurricanes* in the Atlantic, *Typhoons* in the Western Pacific and South China Sea, and *Willy-willies* in the Western Australia.

Tropical cyclones originate and intensify over warm tropical oceans. The conditions favourable for the formation and intensification of tropical storms are: (i) Large sea surface with temperature higher than 27° C; (ii) Presence of the Coriolis force; (iii) Small variations in the vertical wind speed; (iv) A pre-existing weak-low-pressure area or low-level-cyclonic circulation; (v) Upper divergence above the sea level system.

The energy that intensifies the storm, comes from the condensation process in the towering cumulonimbus clouds, surrounding the centre of the storm. With continuous supply of moisture from the sea, the storm is further strengthened. On reaching the land the moisture supply is cut off and the storm dissipates. The place where a tropical cyclone crosses the coast is called the landfall of the cyclone. The cyclones, which cross 20° N latitude generally, recurve and they are more destructive.

A schematic representation of the vertical structure of a mature tropical cyclonic storm is shown in Figure 10.10.

A mature tropical cyclone is characterised by the strong spirally circulating wind around the centre, called the eye. The diameter of the circulating system can vary between 150 and 250 km.

The eye is a region of calm with subsiding air. Around the eye is the eye wall, where there is a strong spiralling ascent of air to greater height reaching the tropopause. The wind reaches maximum velocity in this region, reaching as high as 250 km per hour. Torrential rain occurs here. From the eye wall rain bands may radiate and trains of cumulus and cumulonimbus clouds may drift into the outer region. The diameter of the storm over the Bay of Bengal, Arabian sea and Indian ocean is between 600 - 1200 km. The system moves slowly about 300 - 500 km per day. The cyclone creates storm surges and they inundate the coastal low lands. The storm peters out on the land.

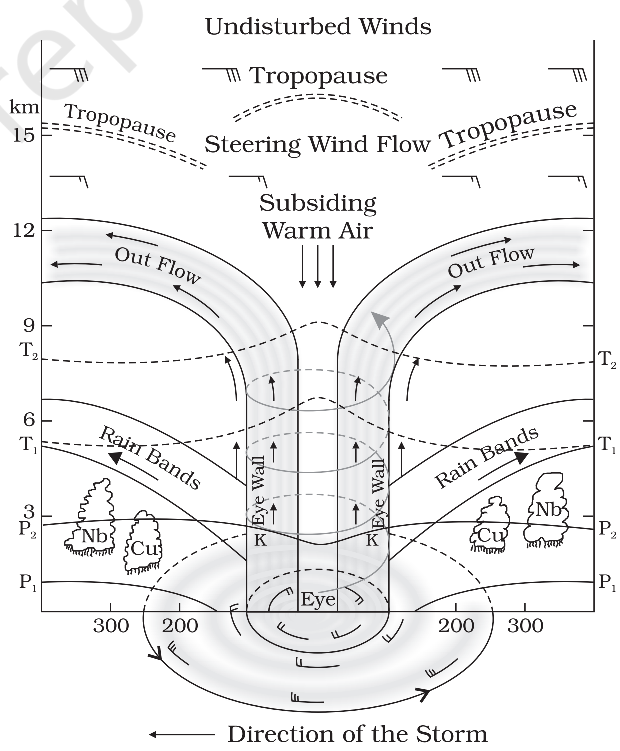


Figure 10.10 : Vertical section of the tropical cyclone (after Rama Sastry)

Thunderstorms and Tornadoes

Other severe local storms are thunderstorms and tornadoes. They are of short duration, occurring over a small area but are violent. *Thunderstorms* are caused by intense convection on moist hot days. A thunderstorm is a well-grown cumulonimbus cloud producing thunder and lightening. When the clouds extend to heights where sub-zero temperature prevails, hails are formed and they come down as hailstorm. If there is insufficient moisture, a thunderstorm can generate dust-storms. A thunderstorm is characterised by intense updraft of rising warm air, which causes the clouds to grow bigger and rise to greater height. This causes precipitation. Later, downdraft brings down to earth the cool air and the rain. From severe thunderstorms sometimes spiralling wind descends like a trunk of an elephant with great force, with very low pressure at the centre, causing massive destruction on its way. Such a phenomenon is called a *tornado*. Tornadoes generally occur in middle latitudes. The tornado over the sea is called *water spouts*.

These violent storms are the manifestation of the atmosphere's adjustments to varying energy distribution. The potential and heat energies are converted into kinetic energy in these storms and the restless atmosphere again returns to its stable state.

EXERCISES

1. Multiple choice questions.

   (i) If the surface air pressure is 1,000 mb, the air pressure at 1 km above the surface will be:

   (a) 700 mb (c) 900 mb
   (b) 1,100 mb (d) 1,300 mb

   (ii) The Inter Tropical Convergence Zone normally occurs:

   (a) near the Equator (b) near the Tropic of Cancer
   (c) near the Tropic of Capricorn (d) near the Arctic Circle

   (iii) The direction of wind around a low pressure in northern hemisphere is:

   (a) clockwise (c) anti-clock wise
   (b) perpendicular to isobars (d) parallel to isobars

   (iv) Which one of the following is the source region for the formation of air masses?

   (a) the Equatorial forest (c) the Siberian Plain
   (b) the Himalayas (d) the Deccan Plateau

2. Answer the following questions in about 30 words.

   (i) What is the unit used in measuring pressure? Why is the pressure measured at station level reduced to the sea level in preparation of weather maps?

   (ii) While the pressure gradient force is from north to south, i.e. from the subtropical high pressure to the equator in the northern hemisphere, why are the winds north easterlies in the tropics.

   (iii) What are the geotrophic winds?

   (iv) Explain the land and sea breezes.

3. Answer the following questions in about 150 words.

    (i) Discuss the factors affecting the speed and direction of wind.

    (ii) Draw a simplified diagram to show the general circulation of the atmosphere over the globe. What are the possible reasons for the formation of subtropical high pressure over 30^{o} N and S latitudes?

    (iii) Why does tropical cyclone originate over the seas? In which part of the tropical cyclone do torrential rains and high velocity winds blow and why?

Project Work

(i) Collect weather information over media such as newspaper, TV and radio for understanding the weather systems.

(ii) Read the section on weather in any newspaper, preferably, one having a map showing a satellite picture. Mark the area of cloudiness. Attempt to infer the atmospheric circulation from the distribution of clouds. Compare the forecast given in the newspaper with the TV coverage, if you have access to TV. Estimate, how many days in a week was the forecast were accurate.

CHAPTER

11

WATER IN THE ATMOSPHERE

You have already learnt that the air contains water vapour. It varies from zero to four per cent by volume of the atmosphere and plays an important role in the weather phenomena. Water is present in the atmosphere in three forms namely – gaseous, liquid and solid. The moisture in the atmosphere is derived from water bodies through evaporation and from plants through transpiration. Thus, there is a continuous exchange of water between the atmosphere, the oceans and the continents through the processes of evaporation, transpiration, condensation and precipitation.

Water vapour present in the air is known as humidity. It is expressed quantitatively in different ways. The actual amount of the water vapour present in the atmosphere is known as the *absolute humidity*. It is the weight of water vapour per unit volume of air and is expressed in terms of grams per cubic metre. The ability of the air to hold water vapour depends entirely on its temperature. The absolute humidity differs from place to place on the surface of the earth. The percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature is known as the *relative humidity*. With the change of air temperature, the capacity to retain moisture increases or decreases and the relative humidity is also affected. It is greater over the oceans and least over the continents.

The air containing moisture to its full capacity at a given temperature is said to be *saturated*. It means that the air at the given temperature is incapable of holding any additional amount of moisture at that stage. The temperature at which saturation occurs in a given sample of air is known as *dew point*.

EVAPORATION AND CONDENSATION

The amount of water vapour in the atmosphere is added or withdrawn due to evaporation and condensation respectively. Evaporation is a process by which water is transformed from liquid to gaseous state. Heat is the main cause for evaporation. The temperature at which the water starts evaporating is referred to as the *latent heat of vapourisation*.

Increase in temperature increases water absorption and retention capacity of the given parcel of air. Similarly, if the moisture content is low, air has a potentiality of absorbing and retaining moisture. Movement of air replaces the saturated layer with the unsaturated layer. Hence, the greater the movement of air, the greater is the evaporation.

The transformation of water vapour into water is called *condensation*. Condensation is caused by the loss of heat. When moist air is cooled, it may reach a level when its capacity to hold water vapour ceases. Then, the excess water vapour condenses into liquid form. If it directly condenses into solid form, it is known as *sublimation*. In free air, condensation results from cooling around very small particles termed as hygroscopic condensation nuclei. Particles of dust, smoke and salt from the ocean are particularly good nuclei because they absorb water. Condensation also takes place when the moist air comes in contact with some colder object and it may also take place when the temperature is close to the dew point. Condensation, therefore, depends upon the amount of cooling and the relative humidity of the air. Condensation is influenced by the volume of air, temperature, pressure and humidity. Condensation takes place: (i) when the temperature of the air is reduced to dew point with its volume remaining constant; (ii) when both the volume and the temperature are reduced; (iv) when moisture is added to the air through evaporation. However, the most favourable condition for condensation is the decrease in air temperature.

After condensation the water vapour or the moisture in the atmosphere takes one of the following forms — dew, frost, fog and clouds. Forms of condensation can be classified on the basis of temperature and location. Condensation takes place when the dew point is lower than the freezing point as well as higher than the freezing point.

Dew

When the moisture is deposited in the form of water droplets on cooler surfaces of solid objects (rather than nuclei in air above the surface) such as stones, grass blades and plant leaves, it is known as *dew*. The ideal conditions for its formation are clear sky, calm air, high relative humidity, and cold and long nights. For the formation of dew, it is necessary that the dew point is above the freezing point.

Frost

Frost forms on cold surfaces when condensation takes place below freezing point (0^0C), i.e. the dew point is at or below the freezing point. The excess moisture is deposited in the form of minute ice crystals instead of water droplets. The ideal conditions for the formation of white frost are the same as those for the formation of dew, except that the air temperature must be at or below the freezing point.

Fog and Mist

When the temperature of an air mass containing a large quantity of water vapour falls all of a sudden, condensation takes place within itself on fine dust particles. So, the *fog* is a cloud with its base at or very near to the ground. Because of the fog and mist, the visibility becomes poor to zero. In urban and industrial centres smoke provides plenty of nuclei which help the formation of fog and mist. Such a condition when fog is mixed with smoke, is described as *smog*. The only difference between the mist and fog is that mist contains more moisture than the fog. In mist each nuceli contains a thicker layer of moisture. Mists are frequent over mountains as the rising warm air up the slopes meets a cold surface. Fogs are drier than mist and they are prevalent where warm currents of air come in contact with cold currents. Fogs are mini clouds in which condensation takes place around nuclei provided by the dust, smoke, and the salt particles.

Clouds

Cloud is a mass of minute water droplets or tiny crystals of ice formed by the condensation of the water vapour in free air at considerable elevations. As the clouds are formed at some height over the surface of the earth, they take various shapes. According to their height, expanse, density and transparency or opaqueness clouds are grouped under four types : (i) cirrus; (ii) cumulus; (iii) stratus; (iv) nimbus.

Cirrus

Cirrus clouds are formed at high altitudes (8,000 - 12,000m). They are thin and detatched clouds having a feathery appearance. They are always white in colour.

Cumulus

Cumulus clouds look like cotton wool. They are generally formed at a height of 4,000 - 7,000 m. They exist in patches and can be seen scattered here and there. They have a flat base.

Stratus

As their name implies, these are layered clouds covering large portions of the sky. These clouds are generally formed either due to loss of heat or the mixing of air masses with different temperatures.

Nimbus

Nimbus clouds are black or dark gray. They form at middle levels or very near to the surface of the earth. These are extremely dense and opaque to the rays of the sun. Sometimes, the clouds are so low that they seem to touch the ground. Nimbus clouds are shapeless masses of thick vapour.

Figure 11.1

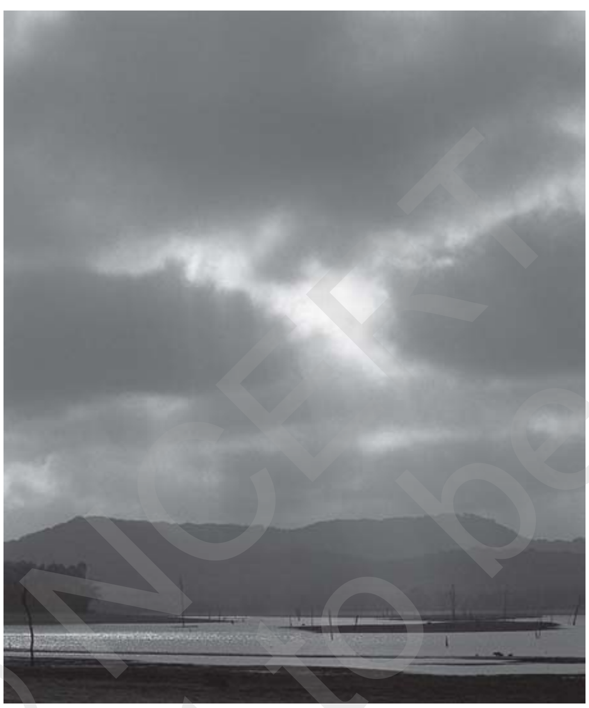


Figure 11.2

Identify these cloud types which are shown in Figure 11.1 and 11.2.

A combination of these four basic types can give rise to the following types of clouds: *high clouds* – cirrus, cirrostratus, cirrocumulus; *middle clouds* – altostratus and altocumulus; *low clouds* – stratocumulus and nimbostratus and *clouds with extensive vertical development* – cumulus and cumulonimbus.

Precipitation

The process of continuous condensation in free air helps the condensed particles to grow in size. When the resistance of the air fails to hold them against the force of gravity, they fall on to the earth's surface. So after the condensation of water vapour, the release of moisture is known as *precipitation*. This may take place in liquid or solid form. The precipitation in the form of water is called *rainfall*, when the temperature is lower than the 0^0C, precipitation takes place in the form of fine flakes of snow and is called *snowfall*. Moisture is released in the form of hexagonal crystals. These crystals form flakes of snow. Besides rain and snow, other forms of precipitation are *sleet* and *hail*, though the latter are limited in occurrence and are sporadic in both time and space.

Sleet is frozen raindrops and refrozen melted snow-water. When a layer of air with the temperature above freezing point overlies a subfreezing layer near the ground, precipitation takes place in the form of sleet. Raindrops, which leave the warmer air, encounter the colder air below. As a result, they solidify and reach the ground as small pellets of ice not bigger than the raindrops from which they are formed.

Sometimes, drops of rain after being released by the clouds become solidified into small rounded solid pieces of ice and which reach the surface of the earth are called *hailstones*. These are formed by the rainwater passing through the colder layers. Hailstones have several concentric layers of ice one over the other.

Types of Rainfall

On the basis of origin, rainfall may be classified into three main types – the convectional, orographic or relief and the cyclonic or frontal.

Convectional Rain

The, air on being heated, becomes light and rises up in convection currents. As it rises, it expands and loses heat and consequently, condensation takes place and cumulous clouds are formed. With thunder and lightening, heavy rainfall takes place but this does not last long. Such rain is common in the summer or in the hotter part of the day. It is very common in the equatorial regions and interior parts of the continents, particularly in the northern hemisphere.

Orographic Rain

When the saturated air mass comes across a mountain, it is forced to ascend and as it rises, it expands; the temperature falls, and the moisture is condensed. The chief characteristic of this sort of rain is that the windward slopes receive greater rainfall. After giving rain on the windward side, when these winds reach the other slope, they descend, and their temperature rises. Then their capacity to take in moisture increases and hence, these leeward slopes remain rainless and dry. The area situated on the leeward side, which gets less rainfall is known as the *rain-shadow area*. It is also known as the *relief rain*.

Cyclonic Rain

You have already read about extra tropical cyclones and cyclonic rain in Chapter 10. Please consult Chapter 10 to understand cyclonic rainfall.

World Distribution of Rainfall

Different places on the earth's surface receive different amounts of rainfall in a year and that too in different seasons.

In general, as we proceed from the equator towards the poles, rainfall goes on decreasing steadily. The coastal areas of the world receive greater amounts of rainfall than the interior of the continents. The rainfall is more over the oceans than on the landmasses of the world because of being great sources of water. Between the latitudes 35^0 and 40^0 N and S of the equator, the rain is heavier on the eastern coasts and goes on decreasing towards the west. But, between 45^0 and 65^0 N and S of equator, due to the westerlies, the rainfall is first received on the western margins of the continents and it goes on decreasing towards the east. Wherever mountains run parallel to the coast, the rain is greater on the coastal plain, on the windward side and it decreases towards the leeward side.

On the basis of the total amount of annual precipitation, major precipitation regimes of the world are identified as follows.

The equatorial belt, the windward slopes of the mountains along the western coasts in the cool temperate zone and the coastal areas of the monsoon land receive heavy rainfall of over 200 cm per annum. Interior continental areas receive moderate rainfall varying from 100 - 200 cm per annum. The coastal areas of the continents receive moderate amount of rainfall. The central parts of the tropical land and the eastern and interior parts of the temperate lands receive rainfall varying between 50 - 100 cm per annum. Areas lying in the rain shadow zone of the interior of the continents and high latitudes receive very low rainfall-less than 50 cm per annum. Seasonal distribution of rainfall provides an important aspect to judge its effectiveness. In some regions rainfall is distributed evenly throughout the year such as in the equatorial belt and in the western parts of cool temperate regions.

EXERCISES

1. Multiple choice questions.

(i) Which one of the following is the most important constituent of the atmosphere for human beings?

(a) Water vapour (c) Dust particle

(b) Nitrogen (d) Oxygen

(ii) Which one of the following process is responsible for transforming liquid into vapour?

(a) Condensation
(b) Transpiration
(c) Evaporation
(d) Precipitation

(iii) The air that contains moisture to its full capacity :

(a) Relative humidity
(b) Specific humidity
(c) Absolute humidity
(d) Saturated air

(iv) Which one of the following is the highest cloud in the sky?

(a) Cirrus
(b) Stratus
(c) Nimbus
(d) Cumulus

2. Answer the following questions in about 30 words.

(i) Name the three types of precipitation.

(ii) Explain relative humidity.

(iii) Why does the amount of water vapour decreases rapidly with altitude?

(iv) How are clouds formed? Classify them.

3. Answer the following questions in about 150 words.

(i) Discuss the salient features of the world distribution of precipitation.

(ii) What are forms of condensation? Describe the process of dew and frost formation.

Project Work

Browse through the newspaper from 1st June to 31st December and note the news about extreme rainfall in different parts of the country.

CHAPTER

12

World Climate and Climate Change

The world climate can be studied by organising information and data on climate and synthesising them in smaller units for easy understanding, description and analysis. Three broad approaches have been adopted for classifying climate. They are empirical, genetic and applied. Empirical classification is based on observed data, particularly on temperature and precipitation. Genetic classification attempts to organise climates according to their causes. Applied classification is for specific purpose.

Koeppen's Scheme of Classification of Climate

The most widely used classification of climate is the empirical climate classification scheme developed by V. Koeppen. Koeppen identified a close relationship between the distribution of vegetation and climate. He selected certain values of temperature and precipitation and related them to the distribution of vegetation and used these values for classifying the climates. It is an empirical classification based on mean annual and mean monthly temperature and precipitation data. He introduced the use of capital and small letters to designate climatic groups and types. Although developed in 1918 and modified over a period of time, Koeppen's scheme is still popular and in use.

Koeppen recognised five major climatic groups, four of them are based on temperature and one on precipitation. Table 12.1 lists the climatic groups and their characteristics according to Koeppen. The capital letters : A,C, D and E delineate humid climates and B dry climates.

The climatic groups are subdivided into types, designated by small letters, based on seasonality of precipitation and temperature characteristics. The seasons of dryness are indicated by the small letters : f, m, w and s, where f corresponds to no dry season,

Table 12.1 : Climatic Groups According to Koeppen

Group	*Characteristics*
A - Tropical	Average temperature of the coldest month is 18° C or higher
B - Dry Climates	Potential evaporation exceeds precipitation
C - Warm Temperate	The average temperature of the coldest month of the (Mid-latitude) climates years is higher than minus 3°C but below 18°C
D - Cold Snow Forest Climates	The average temperature of the coldest month is minus 3° C or below
E - Cold Climates	Average temperature for all months is below 10° C
H - High Land	Cold due to elevation

m - monsoon climate, w- winter dry season and s - summer dry season. The small letters a, b, c and d refer to the degree of severity of temperature. The B- Dry Climates are subdivided using the capital letters S for steppe or semi-arid and W for deserts. The climatic types are listed in Table 12.2. The distribution of climatic groups and types is shown in Table 12.1.

Table 12.2 : Climatic Types According to Koeppen

Group	*Type*	*Letter Code*	*Characteristics*
A-Tropical Humid Climate	Tropical wet	Af	No dry season
	Tropical monsoon	Am	Monsoonal, short dry season
	Tropical wet and dry	Aw	Winter dry season
B-Dry Climate	Subtropical steppe	BSh	Low-latitude semi arid or dry
	Subtropical desert	BWh	Low-latitude arid or dry
	Mid-latitude steppe	BSk	Mid-latitude semi arid or dry
	Mid-latitude desert	BWk	Mid-latitude arid or dry
C-Warm temperate (Mid-latitude) Climates	Humid subtropical	Cfa	No dry season, warm summer
	Mediterranean	Cs	Dry hot summer
	Marine west coast	Cfb	No dry season, warm and cool summer
D-Cold Snow-forest Climates	Humid continental	Df	No dry season, severe winter
	Subarctic	Dw	Winter dry and very severe
E-Cold Climates	Tundra	ET	No true summer
	Polar ice cap	EF	Perennial ice
H-Highland	Highland	H	Highland with snow cover

Group A : Tropical Humid Climates

Tropical humid climates exist between Tropic of Cancer and Tropic of Capricorn. The sun being overhead throughout the year and the presence of Inter Tropical Convergence Zone (ITCZ) make the climate hot and humid. Annual range of temperature is very low and annual rainfall is high. The tropical group is divided into three types, namely (i) Af- Tropical wet climate; (ii) Am - Tropical monsoon climate; (iii) Aw- Tropical wet and dry climate.

Tropical Wet Climate (Af)

Tropical wet climate is found near the equator. The major areas are the Amazon Basin in South America, western equatorial Africa and the islands of East Indies. Significant amount of rainfall occurs in every month of the year as thunder showers in the afternoon. The temperature is uniformly high and the annual range of temperature is negligible. The maximum temperature on any day is around 30°C while the minimum temperature is around 20°C. Tropical evergreen forests with dense canopy cover and large biodiversity are found in this climate.

Tropical Monsoon Climate (Am)

Tropical monsoon climate (Am) is found over the Indian sub-continent, North Eastern part of South America and Northern Australia. Heavy rainfall occurs mostly in summer. Winter is dry. The detailed climatic account of this climatic type is given in the book on *India: Physical Environment.*

Tropical Wet and Dry Climate (Aw)

Tropical wet and dry climate occurs north and south of Af type climate regions. It borders with dry climate on the western part of the continent and Cf or Cw on the eastern part. Extensive Aw climate is found to the north and south of the Amazon forest in Brazil and adjoining parts of Bolivia and Paraguay in South America, Sudan and south of Central Africa. The annual rainfall in this climate is considerably less than that in Af and Am climate types and is variable also. The wet season is shorter and the dry season is longer with the drought being more severe. Temperature is high throughout the year and diurnal ranges of temperature are the greatest in the dry season. Deciduous forest and tree-shredded grasslands occur in this climate.

Dry Climates : B

Dry climates are characterised by very low rainfall that is not adequate for the growth of plants. These climates cover a very large area of the planet extending over large latitudes from 15° - 60° north and south of the equator. At low latitudes, from 15° - 30°, they occur in the area of subtropical high where subsidence and inversion of temperature do not produce rainfall. On the western margin of the continents, adjoining the cold current, particularly over the west coast of South America, they extend more equatorwards and occur on the coast land. In middle latitudes, from 35° - 60° north and south of equator, they are confined to the interior of continents where maritime-humid winds do not reach and to areas often surrounded by mountains.

Dry climates are divided into steppe or semi-arid climate (BS) and desert climate (BW). They are further subdivided as subtropical steppe (BSh) and subtropical desert (BWh) at latitudes from 15° - 35° and mid-latitude steppe (BSk) and mid-latitude desert (BWk) at latitudes between 35° - 60°.

Subtropical Steppe (BSh) and Subtropical Desert (BWh) Climates

Subtropical steppe (BSh) and subtropical desert (BWh) have common precipitation and temperature characteristics. Located in the transition zone between humid and dry climates, subtropical steppe receives slightly more rainfall than the desert, adequate enough for the growth of sparse grasslands. The rainfall in both the climates is highly variable. The variability in the rainfall affects the life in the steppe much more than in the desert, more often causing famine. Rain occurs in short intense thundershowers in deserts and is ineffective in building soil moisture. *Fog* is common in coastal deserts bordering cold currents. Maximum temperature in the summer is very high. The highest shade temperature of 58° C was recorded at *Al Aziziyah*, Libya on 13 September 1922. The annual and diurnal ranges of temperature are also high.

Warm Temperate (Mid-Latitude) Climates-C

Warm temperate (mid-latitude) climates extend from 30° - 50° of latitude mainly on the eastern and western margins of continents. These climates generally have warm summers with mild winters. They are grouped into four types: (i) Humid subtropical, i.e. dry in winter and hot in summer (Cwa); (ii) Mediterranean (Cs); (iii) Humid subtropical, i.e. no dry season and mild winter (Cfa); (iv) Marine west coast climate (Cfb).

Humid Subtropical Climate (Cwa)

Humid subtropical climate occurs poleward of Tropic of Cancer and Capricorn, mainly in North Indian plains and South China interior plains. The climate is similar to Aw climate except that the temperature in winter is warm.

Mediterranean Climate (Cs)

As the name suggests, Mediterranean climate occurs around Mediterranean sea, along the west coast of continents in subtropical latitudes between 30° - 40° latitudes e.g. — Central California, Central Chile, along the coast in south eastern and south western Australia. These areas come under the influence of sub tropical high in summer and westerly wind in winter. Hence, the climate is characterised by hot, dry summer and mild, rainy winter. Monthly average temperature in summer is around 25° C and in winter below 10°C. The annual precipitation ranges between 35 - 90 cm.

Humid Subtropical (Cfa) Climate

Humid subtropical climate lies on the eastern parts of the continent in subtropical latitudes. In this region the air masses are generally unstable and cause rainfall throughout the year. They occur in eastern United States of America, southern and eastern China, southern Japan, northeastern Argentina, coastal south Africa and eastern coast of Australia. The annual averages of precipitation vary from 75-150 cm. Thunderstorms in summer and frontal precipitation in winter are common. Mean monthly temperature in summer is around 27°C, and in winter it varies from 5°-12° C. The daily range of temperature is small.

Marine West Coast Climate (Cfb)

Marine west coast climate is located poleward from the Mediterranean climate on the west coast of the continents. The main areas are: Northwestern Europe, west coast of North America, north of California, southern Chile, southeastern Australia and New Zealand. Due to marine influence, the temperature is moderate and in winter, it is warmer than for its latitude. The mean temperature in summer months ranges from 15°-20°C and in winter 4°-10°C. The annual and daily ranges of temperature are small. Precipitation occurs throughout the year. Precipitation varies greatly from 50-250cm.

Cold Snow Forest Climates (D)

Cold snow forest climates occur in the large continental area in the northern hemisphere between 40°-70° north latitudes in Europe, Asia and North America. Cold snow forest climates are divided into two types: (i) Df- cold climate with humid winter; (ii) Dw- cold climate with dry winter. The severity of winter is more pronounced in higher latitudes.

Cold Climate with Humid Winters (Df)

Cold climate with humid winter occurs poleward of marine west coast climate and mid latitude steppe. The winters are cold and snowy. The frost free season is short. The annual ranges of temperature are large. The weather changes are abrupt and short. Poleward, the winters are more severe.

Cold Climate with Dry Winters (Dw)

Cold climate with dry winter occurs mainly over Northeastern Asia. The development of pronounced winter anti cyclone and its weakening in summer sets in monsoon like reversal of wind in this region. Poleward summer temperatures are lower and winter temperatures are extremely low with many locations experiencing below freezing point temperatures for up to seven months in a year. Precipitation occurs in summer. The annual precipitation is low from 12-15 cm.

Polar Climates (E)

Polar climates exist poleward beyond 70° latitude. Polar climates consist of two types: (i) Tundra (ET); (ii) Ice Cap (EF).

Tundra Climate (ET)

The tundra climate (ET) is so called after the types of vegetation, like low growing mosses, lichens and flowering plants. This is the region of permafrost where the sub soil is permanently frozen. The short growing season and water logging support only low growing plants. During summer, the tundra regions have very long duration of day light.

Ice Cap Climate (EF)

The ice cap climate (EF) occurs over interior Greenland and Antartica. Even in summer, the temperature is below freezing point. This area receives very little precipitation. The snow and ice get accumulated and the mounting pressure causes the deformation of the ice sheets and they break. They move as icebergs that float in the Arctic and Antarctic waters. Plateau Station , Antarctica ,79°S, portray this climate.

Highland Climates (H)

Highland climates are governed by topography. In high mountains, large changes in mean temperature occur over short distances. Precipitation types and intensity also vary spatially across high lands. There is vertical zonation of layering of climatic types with elevation in the mountain environment.

CLIMATE CHANGE

The earlier chapters on climate summarised our understanding of climate as it prevails now. The type of climate we experience now might be prevailing over the last 10,000 years with minor and occasionally wide fluctuations. The planet earth has witnessed many variations in climate since the beginning. Geological records show alteration of glacial and inter-glacial periods. The geomorphological features, especially in high altitudes and high latitudes, exhibit traces of advances and retreats of glaciers. The sediment deposits in glacial lakes also reveal the occurrence of warm and cold periods. The rings in the trees provide clues about wet and dry periods. Historical records describe the vagaries in climate. All these evidences indicate that change in climate is a natural and continuous process.

India also witnessed alternate wet and dry periods. Archaeological findings show that the Rajasthan desert experienced wet and cool climate around 8,000 B.C. The period 3,000-1,700 B.C. had higher rainfall. From about 2,000-1,700 B.C., this region was the centre of the Harappan civilisation. Dry conditions accentuated since then.

In the geological past, the earth was warm some 500-300 million years ago, through the Cambrian, Ordovician and Silurian periods. During the Pleistocene epoch, glacial and inter-glacial periods occurred, the last major peak glacial period was about 18,000 years ago. The present inter-glacial period started 10,000 years ago.

Climate in the recent past

Variability in climate occurs all the time. The nineties decade of the last century witnessed extreme weather events. The 1990s recorded the warmest temperature of the century and some of the worst floods around the world. The worst devastating drought in the Sahel region, south of the Sahara desert, from 1967-1977 is one such variability. During the 1930s, severe drought occurred in southwestern Great Plains of the United States, described as the *dust bowl*. Historical records of crop yield or crop failures, of floods and migration of people tell about the effects of changing climate. A number of times Europe witnessed warm, wet, cold and dry periods, the significant episodes were the warm and dry conditions in the tenth and eleventh centuries, when the Vikings settled in Greenland. Europe witnessed "Little Ice Age" from 1550 to about 1850. From about 1885-1940 world temperature showed an upward trend. After 1940, the rate of increase in temperature slowed down.

Causes of Climate Change

The causes for climate change are many. They can be grouped into astronomical and terrestrial causes. The astronomical causes are the changes in solar output associated with sunspot activities. Sunspots are dark and cooler patches on the sun which increase and decrease in a cyclical manner. According to some meteorologists, when the number of sunspots increase, cooler and wetter weather and greater storminess occur. A decrease in sunspot numbers is associated with warm and drier conditions. Yet, these findings are not statistically significant.

An another astronomical theory is Millankovitch oscillations, which infer cycles in the variations in the earth's orbital characteristics around the sun, the wobbling of the earth and the changes in the earth's axial tilt. All these alter the amount of insolation received from the sun, which in turn, might have a bearing on the climate.

Volcanism is considered as another cause for climate change. Volcanic eruption throws up lots of aerosols into the atmosphere. These aerosols remain in the atmosphere for a considerable period of time reducing the sun's radiation reaching the Earth's surface. After the recent Pinatoba and El Cion volcanic eruptions, the average temperature of the earth fell to some extent for some years.

The most important anthropogenic effect on the climate is the increasing trend in the concentration of greenhouse gases in the atmosphere which is likely to cause global warming.

Global Warming

Due to the presence of greenhouse gases, the atmosphere is behaving like a *greenhouse*. The atmosphere also transmits the incoming solar radiation but absorbs the vast majority of long wave radiation emitted upwards by the earth's surface. The gases that absorb long wave radiation are called greenhouse gases. The processes that warm the atmosphere are often collectively referred to as the *greenhouse effect*.

> The term *greenhouse* is derived from the analogy to a greenhouse used in cold areas for preserving heat. *A greenhouse* is made up of glass. The glass which is transparent to incoming short wave solar radiation is opaque to outgoing long wave radiation. The glass, therefore, allows in more radiation and prevents the long wave radiation going outside the glass house, causing the temperature inside the glasshouse structure warmer than outside. When you enter a car or a bus, during summers, where windows are closed, you feel more heat than outside. Likewise during winter the vehicles with closed doors and windows remain warmer than the temperature outside. This is another example of the greenhouse effect.

Greenhouse Gases(GHGs)

The primary GHGs of concern today are carbon dioxide (CO_2), Chlorofluorocarbons (CFCs), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Some other gases such as nitric oxide (NO) and carbon monoxide (CO) easily react with GHGs and affect their concentration in the atmosphere.

The effectiveness of any given GHG molecule will depend on the magnitude of the increase in its concentration, its life time in the atmosphere and the wavelength of radiation that it absorbs. The chlorofluorocarbons (CFCs) are highly effective. *Ozone* which absorbs ultra violet radiation in the stratosphere is very effective in absorbing terrestrial radiation when it is present in the lower troposphere. Another important point to be noted is that the more time the GHG molecule remains in the atmosphere, the longer it will take for earth's atmospheric system to recover from any change brought about by the latter.

The *largest concentration* of GHGs in the atmosphere is *carbon dioxide*. The emission of CO_2 comes mainly from fossil fuel combustion (oil, gas and coal). Forests and oceans are the sinks for the carbon dioxide. Forests use CO_2 in their growth. So, deforestation due to changes in land use, also increases the concentration of Co_2. The time taken for atmospheric CO_2 to adjust to changes in sources to sinks is 20-50 years. It is rising at about 0.5 per cent annually. Doubling of concentration of CO_2 over pre-industrial level is used as an index for estimating the changes in climate in climatic models.

Chlorofluorocarbons (CFCs) are products of human activity. *Ozone* occurs in the stratosphere where ultra-violet rays convert oxygen into ozone. Thus, ultra violet rays do not reach the earth's surface. The CFCs which drift into the stratosphere destroy the ozone. Large depletion of ozone occurs over Antarctica. *The* depletion *of ozone concentration in the* stratosphere is called the *ozone hole*. This allows the ultra violet rays to pass through the troposphere.

International efforts have been initiated for reducing the emission of GHGs into the atmosphere. The most important one is the *Kyoto protocol* proclaimed in 1997. This protocol went into effect in 2005, ratified by 141 nations. Kyoto protocol bounds the 35 industrialised countries to reduce their emissions by the year 2012 to 5 per cent less than the levels prevalent in the year 1990.

The increasing trend in the concentration of GHGs in the atmosphere may, in the long run, warm up the earth. Once the global warming sets in, it will be difficult to reverse it. The effect of global warming may not be uniform everywhere. Nevertheless, the adverse effect due to global warming will adversely affect the life supporting system. Rise in the sea level due to melting of glaciers and ice-caps and thermal expansion of the sea may inundate large parts of the coastal area and islands, leading to social problems. This is another cause for serious concern for the world community. Efforts have already been initiated to control the emission of GHGs and to arrest the trend towards global warming. Let us hope the world community responds to this challenge and adopts a lifestyle that leaves behind a livable world for the generations to come.

One of the major concerns of the world today is global warming. Let us look at how much the planet has warmed up from the temperature records.

Temperature data are available from the middle of the 19th century mostly for western Europe. The reference period for this study is 1961-90. The temperature anomalies for the earlier and later periods are estimated from the average temperature for the period 1961-90. The annual average near-surface air temperature of the world is approximately 14°C. The time series show anomalies of annual near surface temperature over land from 1856-2000, relative to the period 1961-90 as normal for the globe.

An increasing trend in temperature was discernible in the 20th century. The greatest warming of the 20th century was during the two periods, 1901-44 and 1977-99. Over each of these two periods, global temperatures rose by about 0.4°C. In between, there was a slight cooling, which was more marked in the Northern Hemisphere.

The globally averaged annual mean temperature at the end of the 20th century was about 0.6°C above that recorded at the end of the 19th century. The seven warmest years during the 1856-2000 were recorded in the last decade. The year 1998 was the warmest year, probably not only for the 20th century but also for the whole millennium.

Write an explanatory note on "global warming".

EXERCISES

1. Multiple choice questions.

   (i) Which one of the following is suitable for Koeppen's "A" type of climate?

   (a) High rainfall in all the months

   (b) Mean monthly temperature of the coldest month more than freezing point

   (c) Mean monthly temperature of all the months more than 18° C

   (d) Average temperature for all the months below 10° C

   (ii) Koeppen's system of classification of climates can be termed as :

   (a) Applied (b) Systematic (c) Genetic (d) Empirical

   (iii) Most of the Indian Peninsula will be grouped according to Koeppen's system under:

   (a) "Af" (b) "BSh" (c) "Cfb" (d) "Am"

   (iv) Which one of the following years is supposed to have recorded the warmest temperature the world over?

   (a) 1990 (b) 1998 (c) 1885 (d) 1950

   (v) Which one of the following groups of four climates represents humid conditions?

   (a) A—B—C—E

   (b) A—C—D—E

   (c) B—C—D—E

   (d) A—C—D—F

2. Answer the following questions in about 30 words.

   (i) Which two climatic variables are used by Koeppen for classification of the climate?

   (ii) How is the "genetic" system of classification different from the "empirical one"?

   (iii) Which types of climates have very low range of temperature?

   (iv) What type of climatic conditions would prevail if the sun spots increase?

3. Answer the following questions in about 150 words.

   (i) Make a comparison of the climatic conditions between the "A" and "B" types of climate.

   (ii) What type of vegetation would you find in the "C" and "A" type(s) of climate?

   (iii) What do you understand by the term "Greenhouse Gases"? Make a list of greenhouse gases.

Project Work

Collect information about Kyoto declaration related to global climate changes.

UNIT V

WATER (OCEANS)

This unit deals with

- *Hydrological Cycle*
- *Oceans — submarine relief; distribution of temperature and salinity; movements of ocean water-waves, tides and currents*

CHAPTER

13

WATER (OCEANS)

Can we think of life without water? It is said that the water is life. Water is an essential component of all life forms that exist over the surface of the earth. The creatures on the earth are lucky that it is a water planet, otherwise we all would have no existence. Water is a rare commodity in our solar system. There is no water on the sun or anywhere else in the solar system. The earth, fortunately has an abundant supply of water on its surface. Hence, our planet is called the *'Blue Planet'*.

HYDROLOGICAL CYCLE

Water is a cyclic resource. It can be used and re-used. Water also undergoes a cycle from the ocean to land and land to ocean. The hydrological cycle describes the movement of water on, in, and above the earth. The water cycle has been working for billions of years and all the life on earth depends on it. Next to air, water is the most important element required for the existence of life on earth. The distribution of water on earth is quite uneven. Many locations have plenty of water while others have very limited quantity. The *hydrological cycle*, is the circulation of water within the earth's hydrosphere in different forms i.e. the liquid, solid and the gaseous phases. It also refers to the continuous exchange of water between the oceans,

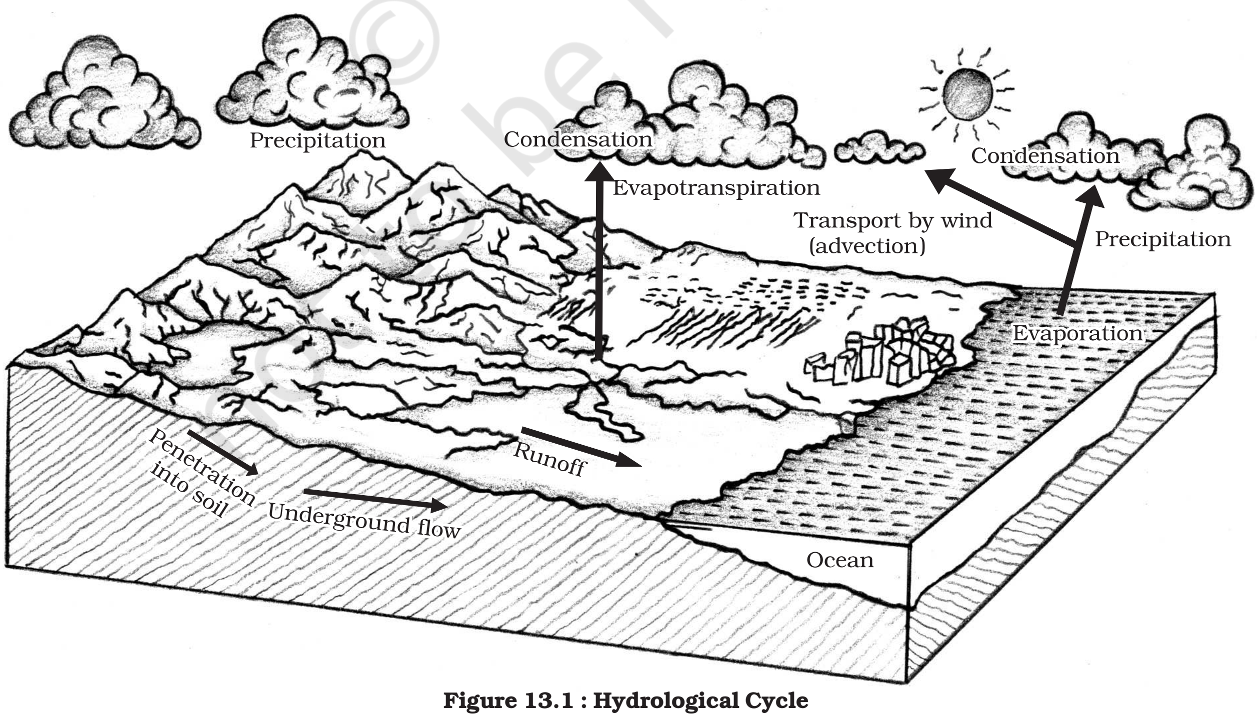


Figure 13.1 : Hydrological Cycle

Table 13.1 : Water on the Earth's surface

Reservoir	Volume (Million Cubic km)	Percentage of the Total
Oceans	1,370	97.25
Ice Caps and Glaciers	29	2.05
Groundwater	9.5	0.68
Lakes	0.125	0.01
Soil Moisture	0.065	0.005
Atmosphere	0.013	0.001
Streams and Rivers	0.0017	0.0001
Biosphere	0.0006	0.00004

Table 13.2 : Components and Processes of the Water Cycle

Components	Processes
Water storage in oceans	Evaporation Evapotranspiration Sublimation
Water in the atmosphere	Condensation Precipitation
Water storage in ice and snow	Snowmelt runoff to streams
Surface runoff	Stream flow freshwater storage infiltration
Groundwater storage	Groundwater discharge springs

atmosphere, landsurface and subsurface and the organisms.

Table 13.1 shows distribution of water on the surface of the earth. About 71 per cent of the planetary water is found in the oceans. The remaining is held as freshwater in glaciers and icecaps, groundwater sources, lakes, soil moisture, atmosphere, streams and within life. Nearly 59 per cent of the water that falls on land returns to the atmosphere through evaporation from over the oceans as well as from other places. The remainder runs-off on the surface, infiltrates into the ground or a part of it becomes glacier (Figure 13.1).

It is to be noted that the renewable water on the earth is constant while the demand is increasing tremendously. This leads to water crisis in different parts of the world — spatially and temporally. The pollution of river waters has further aggravated the crisis. How can you intervene in improving the water quality and augmenting the available quantity of water?

Relief of the Ocean Floor

The oceans are confined to the great depressions of the earth's outer layer. In this section, we shall see the nature of the ocean basins of the earth and their topography. The oceans, unlike the continents, merge so naturally into one another that it is hard to demarcate them. The geographers have divided the oceanic part of the earth into five oceans, namely the Pacific, the Atlantic, the Indian, Southern ocean and the Arctic. The various seas, bays, gulfs and other inlets are parts of these four large oceans.

A major portion of the ocean floor is found between 3-6 km below the sea level. The 'land' under the waters of the oceans, that is, the ocean floor exhibits complex and varied features as those observed over the land (Figure 13.2). The floors of the oceans are rugged with the world's largest mountain ranges, deepest trenches and the largest plains. These features are formed, like those of the continents, by the factors of tectonic, volcanic and depositional processes.

Divisions of the Ocean Floors

The ocean floors can be divided into four major divisions: (i) the Continental Shelf; (ii) the Continental Slope; (iii) the Deep Sea Plain; (iv) the Oceanic Deeps. Besides, these divisions there are also major and minor relief features in the ocean floors like ridges, hills, sea mounts, guyots, trenches, canyons, etc.

Continental Shelf

The continental shelf is the extended margin of each continent occupied by relatively shallow seas and gulfs. It is the shallowest part of the ocean showing an average gradient of 1° or even less. The shelf typically ends at a very steep slope, called the shelf break.

The width of the continental shelves vary from one ocean to another. The average width of continental shelves is about 80 km. The shelves are almost absent or very narrow along some of the margins like the coasts of Chile, the west coast of Sumatra, etc. On the contrary, the Siberian shelf in the Arctic Ocean, the largest in the world, stretches to 1,500 km in width. The depth of the shelves also varies. It may be as shallow as 30 m in some areas while in some areas it is as deep as 600 m.

The continental shelves are covered with variable thicknesses of sediments brought down by rivers, glaciers, wind, from the land and distributed by waves and currents. Massive sedimentary deposits received over a long time by the continental shelves, become the source of fossil fuels.

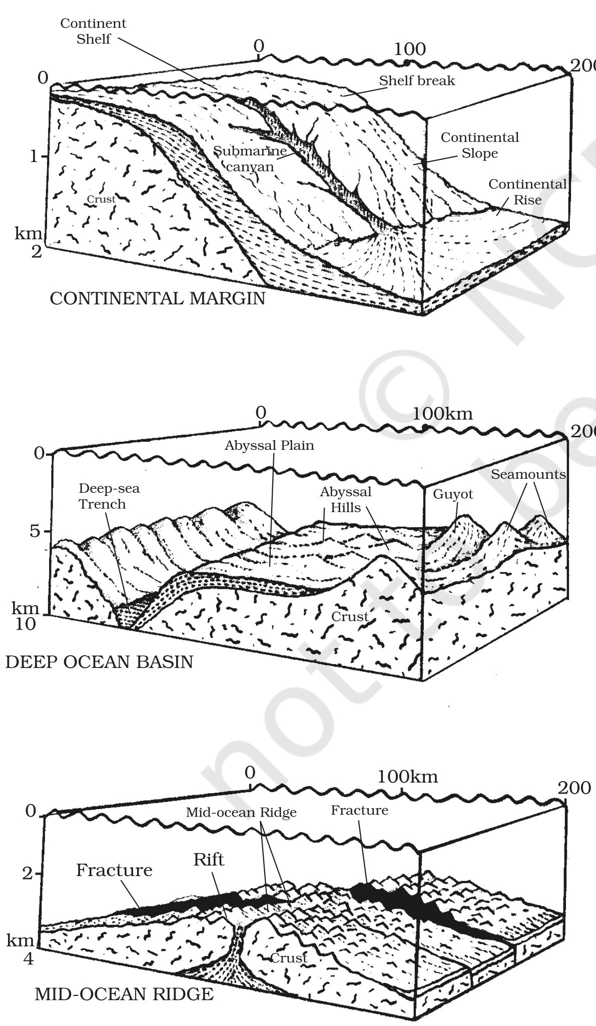


Figure 13.2 : Relief features of ocean floors

Continental Slope

The continental slope connects the continental shelf and the ocean basins. It begins where the bottom of the continental shelf sharply drops off into a steep slope. The gradient of the slope region varies between 2-5°. The depth of the slope region varies between 200 and 3,000 m. The slope boundary indicates the end of the continents. Canyons and trenches are observed in this region.

Deep Sea Plain

Deep sea plains are gently sloping areas of the ocean basins. These are the flattest and smoothest regions of the world. The depths vary between 3,000 and 6,000m. These plains are covered with fine-grained sediments like clay and silt.

Oceanic Deeps or Trenches

These areas are the deepest parts of the oceans. The trenches are relatively steep sided, narrow basins. They are some 3-5 km deeper than the surrounding ocean floor. They occur at the bases of continental slopes and along island arcs and are associated with active volcanoes and strong earthquakes. That is why they are very significant in the study of plate movements. As many as 57 deeps have been explored so far; of which 32 are in the Pacific Ocean; 19 in the Atlantic Ocean and 6 in the Indian Ocean.

Minor Relief Features

Apart from the above mentioned major relief features of the ocean floor, some minor but significant features predominate in different parts of the oceans.

Mid-Oceanic Ridges

A mid-oceanic ridge is composed of two chains of mountains separated by a large depression. The mountain ranges can have peaks as high as 2,500 m and some even reach above the ocean's surface. Iceland, a part of the mid-Atlantic Ridge, is an example.

Seamount

It is a mountain with pointed summits, rising from the seafloor that does not reach the surface of the ocean. Seamounts are volcanic in origin. These can be 3,000-4,500 m tall. The Emperor seamount, an extension of the Hawaiian Islands in the Pacific Ocean, is a good example.

Submarine Canyons

These are deep valleys, some comparable to the Grand Canyon of the Colorado river. They are sometimes found cutting across the continental shelves and slopes, often extending from the mouths of large rivers. The Hudson Canyon is the best known submarine canyon in the world.

Guyots

It is a flat topped seamount. They show evidences of gradual subsidence through stages to become flat topped submerged mountains. It is estimated that more than 10,000 seamounts and guyots exist in the Pacific Ocean alone.

Atoll

These are low islands found in the tropical oceans consisting of coral reefs surrounding a central depression. It may be a part of the sea (lagoon), or sometimes form enclosing a body of fresh, brackish, or highly saline water.

Temperature of Ocean Waters

This section deals with the spatial and vertical variations of temperature in various oceans. Ocean waters get heated up by the solar energy just as land. The process of heating and cooling of the oceanic water is slower than land.

Factors Affecting Temperature Distribution

The factors which affect the distribution of temperature of ocean water are :

(i) *Latitude* : the temperature of surface water decreases from the equator towards the poles because the amount of insolation decreases poleward.

(ii) *Unequal distribution of land and water* : the oceans in the northern hemisphere receive more heat due to their contact with larger extent of land than the oceans in the southern hemisphere.

(iii) *Prevailing wind* : the winds blowing from the land towards the oceans drive warm surface water away form the coast resulting in the upwelling of cold water from below. It results into the longitudinal variation in the temperature. Contrary to this, the onshore winds pile up warm water near the coast and this raises the temperature.

(iv) *Ocean currents* : warm ocean currents raise the temperature in cold areas while the cold currents decrease the temperature in warm ocean areas. Gulf stream (warm current) raises the temperature near the eastern coast of North America and the West Coast of Europe while the Labrador current (cold current) lowers the temperature near the north-east coast of North America.

All these factors influence the temperature of the ocean currents locally. The enclosed seas in the low latitudes record relatively higher temperature than the open seas; whereas the enclosed seas in the high latitudes have lower temperature than the open seas.

Horizontal and Vertical Distribution of Temperature

The temperature-depth profile for the ocean water shows how the temperature decreases with the increasing depth. The profile shows a boundary region between the surface waters of the ocean and the deeper layers. The boundary usually begins around 100 - 400 m below the sea surface and extends several hundred of metres downward (Figure 13.3). This boundary region, from where there is a rapid decrease of temperature, is called the *thermocline*. About 90 per cent of the total volume of water is found below the thermocline in the deep ocean. In this zone, temperatures approach 0° C.

The temperature structure of oceans over middle and low latitudes can be described as a three-layer system from surface to the bottom.

The *first layer* represents the top layer of warm oceanic water and it is about 500m thick with temperatures ranging between 20° and 25° C. This layer, within the tropical region, is present throughout the year but in mid latitudes it develops only during summer.

The *second layer* called the thermocline layer lies below the first layer and is characterised by rapid decrease in temperature with increasing depth. The thermocline is 500 -1,000 m thick.

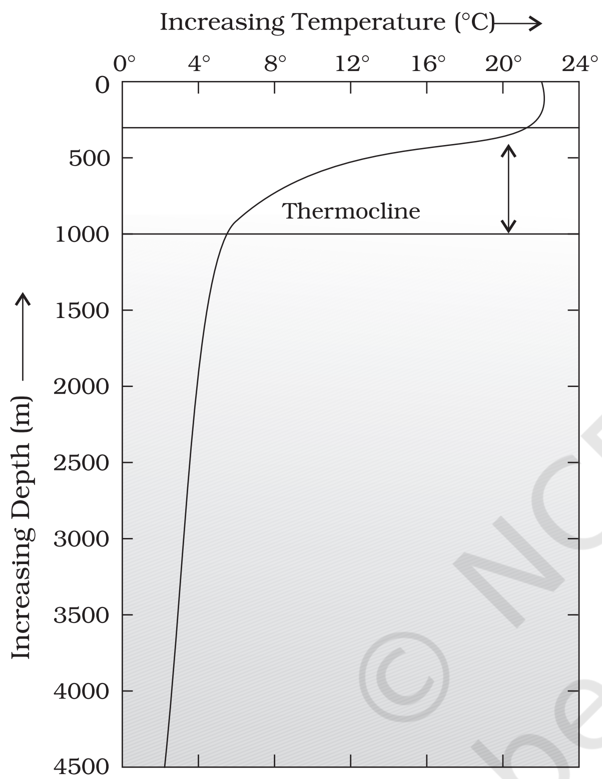


Figure 13.3 : Thermocline

The *third layer* is very cold and extends upto the deep ocean floor. In the Arctic and Antartic circles, the surface water temperatures are close to 0° C and so the temperature change with the depth is very slight. Here, only one layer of cold water exists, which extends from surface to deep ocean floor.

The average temperature of surface water of the oceans is about 27°C and it gradually decreases from the equator towards the poles. The rate of decrease of temperature with increasing latitude is generally 0.5°C per latitude. The average temperature is around 22°C at 20° latitudes, 14° C at 40° latitudes and 0° C near poles. The oceans in the northern hemisphere record relatively higher temperature than in the southern hemisphere. The highest temperature is not recorded at the equator but slightly towards north of it. The average annual temperatures for the northern and southern hemisphere are around 19° C and 16° C respectively. This variation is due to the unequal distribution of land and water in the northern and southern hemispheres. Figure 13.4 shows the spatial pattern of surface temperature of the oceans.

It is a well known fact that the maximum temperature of the oceans is always at their surfaces because they directly receive the heat from the sun and the heat is transmitted to the lower sections of the oceans through the process of convection. It results into decrease of temperature with the increasing depth, but the rate of decrease is not uniform throughout. The temperature falls very rapidly up to the depth of 200 m and thereafter, the rate of decrease of temperature is slowed down.

Salinity of Ocean Waters

All waters in nature, whether rain water or ocean water, contain dissolved mineral salts. Salinity is the term used to define the total content of dissolved salts in sea water (Table 13.4). It is calculated as the amount of salt (in gm) dissolved in 1,000 gm (1 kg) of seawater. It is usually expressed as parts per thousand ($^{o}/_{oo}$) or ppt. Salinity is an important property of sea water. Salinity of 24.7 $^{o}/_{oo}$ has been considered as the upper limit to demarcate 'brackish water'.

Factors affecting ocean salinity are mentioned below:

(i) The salinity of water in the surface layer of oceans depend mainly on evaporation and precipitation.

(ii) Surface salinity is greatly influenced in coastal regions by the fresh water flow from rivers, and in polar regions by the processes of freezing and thawing of ice.

(iii) Wind, also influences salinity of an area by transferring water to other areas.

(iv) The ocean currents contribute to the salinity variations. Salinity, temperature and density of water are interrelated. Hence, any change in the temperature or density influences the salinity of water in an area.

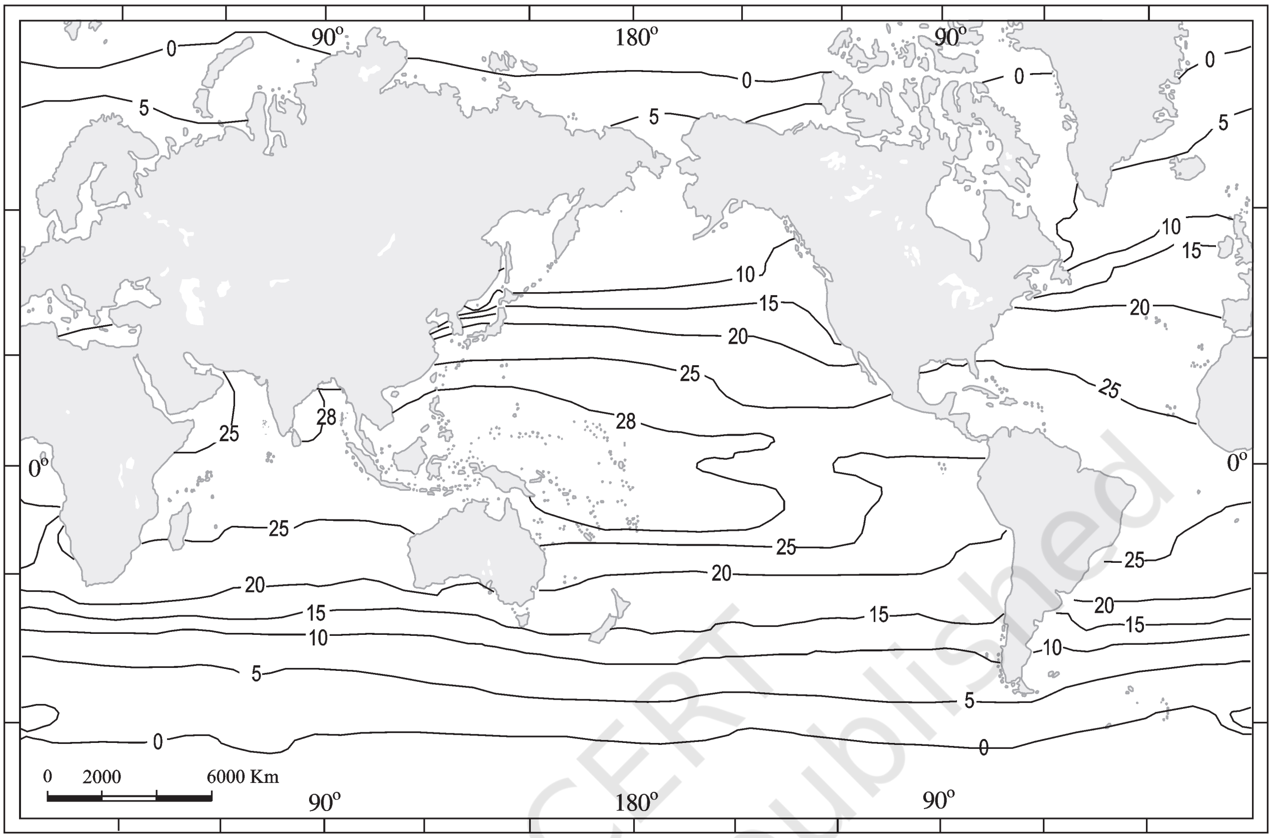


Figure 13.4 : Spatial pattern of surface temperature (°C) of the oceans

> Highest salinity in water bodies
> Lake Van in Turkey ($330 ^{o}/_{oo}$),
> Dead Sea ($238 ^{o}/_{oo}$),
> Great Salt Lake ($220 ^{o}/_{oo}$)

Table 13.4 : Dissolved Salts in Sea Water (gm of Salt per kg of Water)

Chlorine	18.97
Sodium	10.47
Sulphate	2.65
Magnesium	1.28
Calcium	0.41
Potassium	0.38
Bicarbonate	0.14
Bromine	0.06
Borate	0.02
Strontium	0.01

HORIZONTAL DISTRIBUTION OF SALINITY

The salinity for normal open ocean ranges between $33 ^{o}/_{oo}$ and $37 ^{o}/_{oo}$. In the land locked Red Sea, it is as high as $41 ^{o}/_{oo}$, while in the estuaries and the Arctic, the salinity fluctuates from 0 - 35 $^{o}/_{oo}$, seasonally. In hot and dry regions, where evaporation is high, the salinity sometimes reaches to $70 ^{o}/_{oo}$.

The salinity variation in the Pacific Ocean is mainly due to its shape and larger areal extent. Salinity decreases from $35 ^{o}/_{oo}$ - $31 ^{o}/_{oo}$ on the western parts of the northern hemisphere because of the influx of melted water from the Arctic region. In the same way, after 15° - 20° south, it decreases to $33 ^{o}/_{oo}$.

The average salinity of the Atlantic Ocean is around $36 ^{o}/_{oo}$. The highest salinity is recorded between 15° and 20° latitudes. Maximum salinity ($37 ^{o}/_{oo}$) is observed between 20° N and 30° N and 20° W - 60° W. It gradually decreases towards the north. The North Sea, in spite of its location in higher latitudes, records higher salinity due to more saline water brought by the North Atlantic Drift. Baltic Sea records low salinity due to influx of river waters in large quantity. The Mediterranean Sea

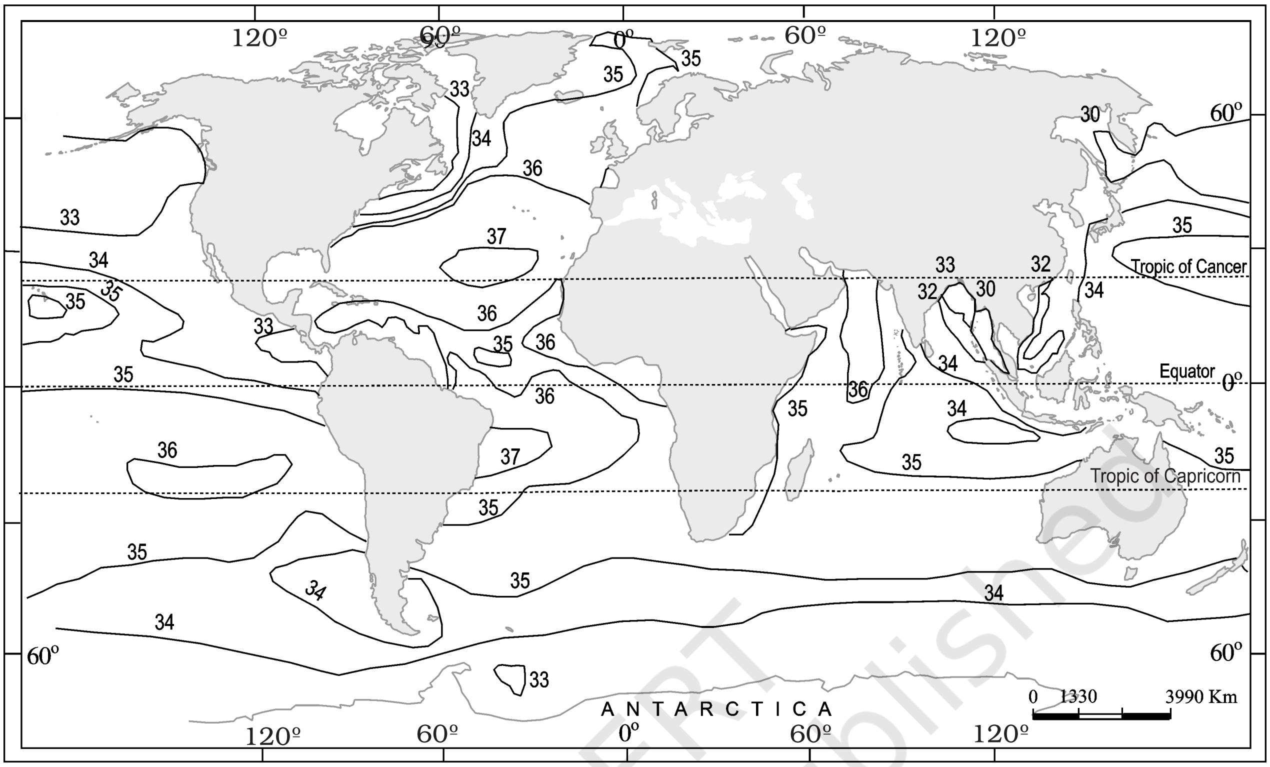


Figure13.5 : Surface salinity of the World's Oceans

records higher salinity due to high evaporation. Salinity is, however, very low in Black Sea due to enormous fresh water influx by rivers. See the atlas to find out the rivers joining Black Sea.

The average salinity of the Indian Ocean is 35 $^o/_{oo.}$ The low salinity trend is observed in the Bay of Bengal due to influx of river water. On the contrary, the Arabian Sea shows higher salinity due to high evaporation and low influx of fresh water. Figure 13.5 shows the salinity of the World's oceans.

Vertical Distribution of Salinity

Salinity changes with depth, but the way it changes depends upon the location of the sea. Salinity at the surface increases by the loss of water to ice or evaporation, or decreased by the input of fresh waters, such as from the rivers. Salinity at depth is very much fixed, because there is no way that water is 'lost', or the salt is 'added.' There is a marked difference in the salinity between the surface zones and the deep zones of the oceans. The lower salinity water rests above the higher salinity dense water. Salinity, generally, increases with depth and there is a distinct zone called the *halocline*, where salinity increases sharply. Other factors being constant, increasing salinity of seawater causes its density to increase. High salinity seawater, generally, sinks below the lower salinity water. This leads to stratification by salinity.

EXERCISES

1. Multiple choice questions.

   (i) Identify the element which is not a part of the hydrological cycle

   (a) Evaporation (c) Precipitation

   (b) Hydration (d) Condensation

(ii) The average depth of continental slope varies between

(a) 2-20m (c) 20-200m

(b) 200-2,000m (d) 2,000-20,000m

(iii) Which one of the following is not a minor relief feature in the oceans:

(a) Seamount (c) Oceanic Deep

(b) Atoll (d) Guyot

(iv) Salinity is expressed as the amount of salt in grams dissolved in sea water per

(a) 10 gm (c) 100 gm

(b) 1,000 gm (d) 10,000 gm

(v) Which one of the following is the smallest ocean:

(a) Indian Ocean (c) Atlantic Ocean

(b) Arctic Ocean (d) Pacific Ocean

2. Answer the following questions in about 30 words.

(i) Why do we call the earth a Blue Planet?

(ii) What is a continental margin?

(iii) List out the deepest trenches of various oceans.

(iv) What is a thermocline?

(v) When you move into the ocean what thermal layers would you encounter? Why the temperature varies with depth?

(vi) What is salinity of sea water?

3. Answer the following questions in about 150 words.

(i) How are various elements of the hydrological cycle interrelated?

(ii) Examine the factors that influence the temperature distribution of the oceans.

Project Work

(i) Consult the atlas and show ocean floor relief on the outline of the world map.

(ii) Identify the areas of mid oceanic ridges from the Indian Ocean.

CHAPTER

14

Movements of Ocean Water

The ocean water is dynamic. Its physical characteristics like temperature, salinity, density and the external forces like of the sun, moon and the winds influence the movement of ocean water. The horizontal and vertical motions are common in ocean water bodies. The horizontal motion refers to the ocean currents and waves. The vertical motion refers to tides. Ocean currents are the continuous flow of huge amount of water in a definite direction while the waves are the horizontal motion of water. Water moves ahead from one place to another through ocean currents while the water in the waves does not move, but the wave trains move ahead. The vertical motion refers to the rise and fall of water in the oceans and seas. Due to attraction of the sun and the moon, the ocean water is raised up and falls down twice a day. The upwelling of cold water from subsurface and the sinking of surface water are also forms of vertical motion of ocean water.

Waves

Waves are actually the energy, not the water as such, which moves across the ocean surface. Water particles only travel in a small circle as a wave passes. Wind provides energy to the waves. Wind causes waves to travel in the ocean and the energy is released on shorelines. The motion of the surface water seldom affects the stagnant deep bottom water of the oceans. As a wave approaches the beach, it slows down. This is due to the friction occurring between the dynamic water and the sea floor. And, when the depth of water is less than half the wavelength of the wave, the wave breaks. The largest waves are found in the open oceans. Waves continue to grow larger as they move and absorb energy from the wind.

Most of the waves are caused by the wind driving against water. When a breeze of two knots or less blows over calm water, small ripples form and grow as the wind speed increases until white caps appear in the breaking waves. Waves may travel thousands of km before rolling ashore, breaking and dissolving as surf.

A wave's size and shape reveal its origin. Steep waves are fairly young ones and are probably formed by local wind. Slow and steady waves originate from far away places, possibly from another hemisphere. The maximum wave height is determined by the strength of the wind, i.e. how long it blows and the area over which it blows in a single direction.

Waves travel because wind pushes the water body in its course while gravity pulls the crests of the waves downward. The falling water pushes the former troughs upward, and the

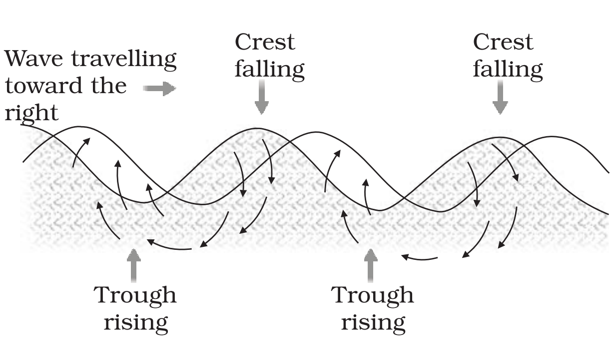


Figure 14.1 : Motion of waves and water molecules

wave moves to a new position (Figure 14.1). The actual motion of the water beneath the waves is circular. It indicates that things are carried up and forward as the wave approaches, and down and back as it passes.

Characteristics of Waves

Wave crest and trough : The highest and lowest points of a wave are called the crest and trough respectively.

Wave height : It is the vertical distance from the bottom of a trough to the top of a crest of a wave.

Wave amplitude : It is one-half of the wave height.

Wave period : It is merely the time interval between two successive wave crests or troughs as they pass a fixed point.

Wavelength : It is the horizontal distance between two successive crests.

Wave speed : It is the rate at which the wave moves through the water, and is measured in knots.

Wave frequency : It is the number of waves passing a given point during a one-second time interval.

TIDES

The periodical rise and fall of the sea level, once or twice a day, mainly due to the attraction of the sun and the moon, is called a *tide*. Movement of water caused by meteorological effects (winds and atmospheric pressure changes) are called *surges*. Surges are not regular like tides. The study of tides is very complex, spatially and temporally, as it has great variations in frequency, magnitude and height.

The moon's gravitational pull to a great extent and to a lesser extent the sun's gravitational pull, are the major causes for the occurrence of tides. Another factor is centrifugal force, which is the force that acts to counter balance the gravity. Together, the gravitational pull and the centrifugal force are responsible for creating the two major tidal bulges on the earth. On the side of the earth facing the moon, a tidal bulge occurs while on the opposite side though the gravitational attraction of the moon is less as it is farther away, the centrifugal force causes tidal bulge on the other side (Figure 14.2).

The 'tide-generating' force is the difference between these two forces; i.e. the gravitational attraction of the moon and the centrifugal force. On the surface of the earth, nearest the moon, pull or the attractive force of the moon is greater than the centrifugal force, and so there is a net force causing a bulge towards the moon. On the opposite side of the earth, the attractive force is less, as it is farther away from the moon, the centrifugal force is dominant. Hence, there is a net force away from the moon. It creates the second bulge away from the moon. On the surface of the earth, the horizontal tide generating forces are more important than the vertical forces in generating the tidal bulges.

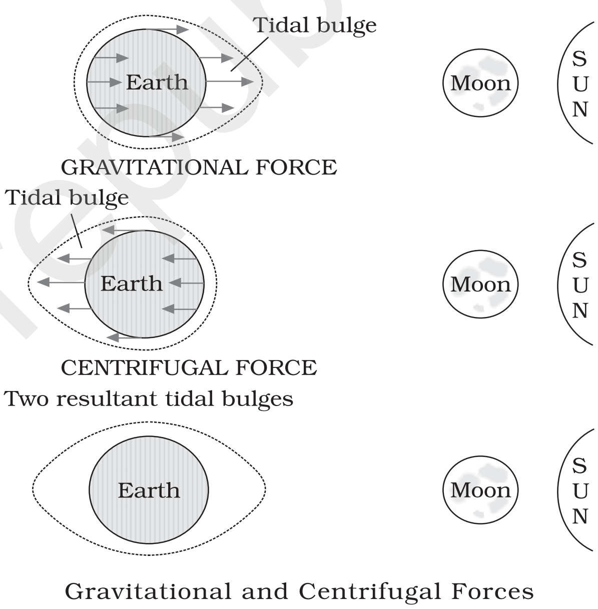


Figure14.2 : Relation between gravitational forces and tides

The tidal bulges on wide continental shelves, have greater height. When tidal bulges hit the mid-oceanic islands they become low. The shape of bays and estuaries along a coastline can also magnify the intensity of tides. Funnel-shaped bays greatly change tidal magnitudes. When the tide is channelled between islands or into bays and estuaries they are called *tidal currents*.

Tides of Bay of Fundy, Canada

The highest tides in the world occur in the Bay of Fundy in Nova Scotia, Canada. The tidal bulge is 15 - 16 m. Because there are two high tides and two low tides every day (roughly a 24 hour period); then a tide must come in within about a six hour period. As a rough estimate, the tide rises about 240 cm an hour (1,440 cm divided by 6 hours). If you have walked down a beach with a steep cliff alongside (which is common there), make sure you watch the tides. If you walk for about an hour and then notice that the tide is coming in, the water will be over your head before you get back to where you started!

Types of Tides

Tides vary in their frequency, direction and movement from place to place and also from time to time. Tides may be grouped into various types based on their frequency of occurrence in one day or 24 hours or based on their height.

Tides based on Frequency

Semi-diurnal tide : The most common tidal pattern, featuring two high tides and two low tides each day. The successive high or low tides are approximately of the same height.

Diurnal tide : There is only one high tide and one low tide during each day. The successive high and low tides are approximately of the same height.

Mixed tide : Tides having variations in height are known as mixed tides. These tides generally occur along the west coast of North America and on many islands of the Pacific Ocean.

Tides based on the Sun, Moon and the Earth Positions

The height of rising water (high tide) varies appreciably depending upon the position of sun and moon with respect to the earth. Spring tides and neap tides come under this category.

Spring tides : The position of both the sun and the moon in relation to the earth has direct bearing on tide height. When the sun, the moon and the earth are in a straight line, the height of the tide will be higher. These are called spring tides and they occur twice a month, one on full moon period and another during new moon period.

Neap tides : Normally, there is a seven day interval between the spring tides and neap tides. At this time the sun and moon are at right angles to each other and the forces of the sun and moon tend to counteract one another. The Moon's attraction, though more than twice as strong as the sun's, is diminished by the counteracting force of the sun's gravitational pull.

Once in a month, when the moon's orbit is closest to the earth *(perigee)*, unusually high and low tides occur. During this time the tidal range is greater than normal. Two weeks later, when the moon is farthest from earth *(apogee)*, the moon's gravitational force is limited and the tidal ranges are less than their average heights.

When the earth is closest to the sun *(perihelion)*, around 3rd January each year, tidal ranges are also much greater, with unusually high and unusually low tides. When the earth is farthest from the sun *(aphelion)*, around 4th July each year, tidal ranges are much less than average.

The time between the high tide and low tide, when the water level is falling, is called the *ebb*. The time between the low tide and high tide, when the tide is rising, is called the *flow* or *flood*.

Importance of Tides

Since tides are caused by the earth-moon-sun positions which are known accurately, the tides can be predicted well in advance. This helps the navigators and fishermen plan their activities. Tidal flows are of great importance in navigation. Tidal heights are very important, especially harbours near rivers and within estuaries having shallow 'bars' at the entrance, which prevent ships and boats from entering into the harbour. Tides are also helpful in desilting the sediments and in removing polluted water from river estuaries. Tides are used to generate electrical power (in Canada, France, Russia, and China). A 3 MW tidal power project at Durgaduani in Sunderbans of West Bengal is under way.

Ocean Currents

Ocean currents are like river flow in oceans. They represent a regular volume of water in a definite path and direction. Ocean currents are influenced by two types of forces namely : (i) primary forces that initiate the movement of water; (ii) secondary forces that influence the currents to flow.

The primary forces that influence the currents are: (i) heating by solar energy; (ii) wind; (iii) gravity; (iv) coriolis force. Heating by solar energy causes the water to expand. That is why, near the equator the ocean water is about 8 cm higher in level than in the middle latitudes. This causes a very slight gradient and water tends to flow down the slope. Wind blowing on the surface of the ocean pushes the water to move. Friction between the wind and the water surface affects the movement of the water body in its course. Gravity tends to pull the water down the pile and create gradient variation. The Coriolis force intervenes and causes the water to move to the right in the northern hemisphere and to the left in the southern hemisphere. These large accumulations of water and the flow around them are called *Gyres*. These produce large circular currents in all the ocean basins.

Characteristics of Ocean Currents

Currents are referred to by their "drift". Usually, the currents are strongest near the surface and may attain speeds over five knots. At depths, currents are generally slow with speeds less than 0.5 knots. We refer to the speed of a current as its "drift." Drift is measured in terms of knots. The strength of a current refers to the speed of the current. A fast current is considered strong. A current is usually strongest at the surface and decreases in strength (speed) with depth. Most currents have speeds less than or equal to 5 knots.

Differences in water density affect vertical mobility of ocean currents. Water with high salinity is denser than water with low salinity and in the same way cold water is denser than warm water. Denser water tends to sink, while relatively lighter water tends to rise. Cold-water ocean currents occur when the cold water at the poles sinks and slowly moves towards the equator. Warm-water currents travel out from the equator along the surface, flowing towards the poles to replace the sinking cold water.

Types of Ocean Currents

The ocean currents may be classified based on their depth as surface currents and deep water currents : (i) *surface currents* constitute about 10 per cent of all the water in the ocean, these waters are the upper 400 m of the ocean; (ii) *deep water currents* make up the other 90 per cent of the ocean water. These waters move around the ocean basins due to variations in the density and gravity. Deep waters sink into the deep ocean basins at high latitudes, where the temperatures are cold enough to cause the density to increase.

Ocean currents can also be classified based on temperature : as cold currents and warm currents: (i) *cold currents* bring cold water into warm water areas. These currents are usually found on the west coast of the continents in the low and middle latitudes (true in both hemispheres) and on the east coast in the higher latitudes in the Northern Hemisphere; (ii) *warm currents* bring warm water into cold water areas and are usually observed on the east coast of continents in the low and middle latitudes (true in both hemispheres). In the northern hemisphere they are found on the west coasts of continents in high latitudes.

Major Ocean Currents

Major ocean currents are greatly influenced by the stresses exerted by the prevailing winds and coriolis force. The oceanic circulation pattern roughly corresponds to the earth's atmospheric circulation pattern. The air circulation over the oceans in the middle latitudes is mainly anticyclonic (more pronounced in the southern hemisphere than in the northern hemisphere). The oceanic circulation pattern also corresponds with the same. At higher latitudes,

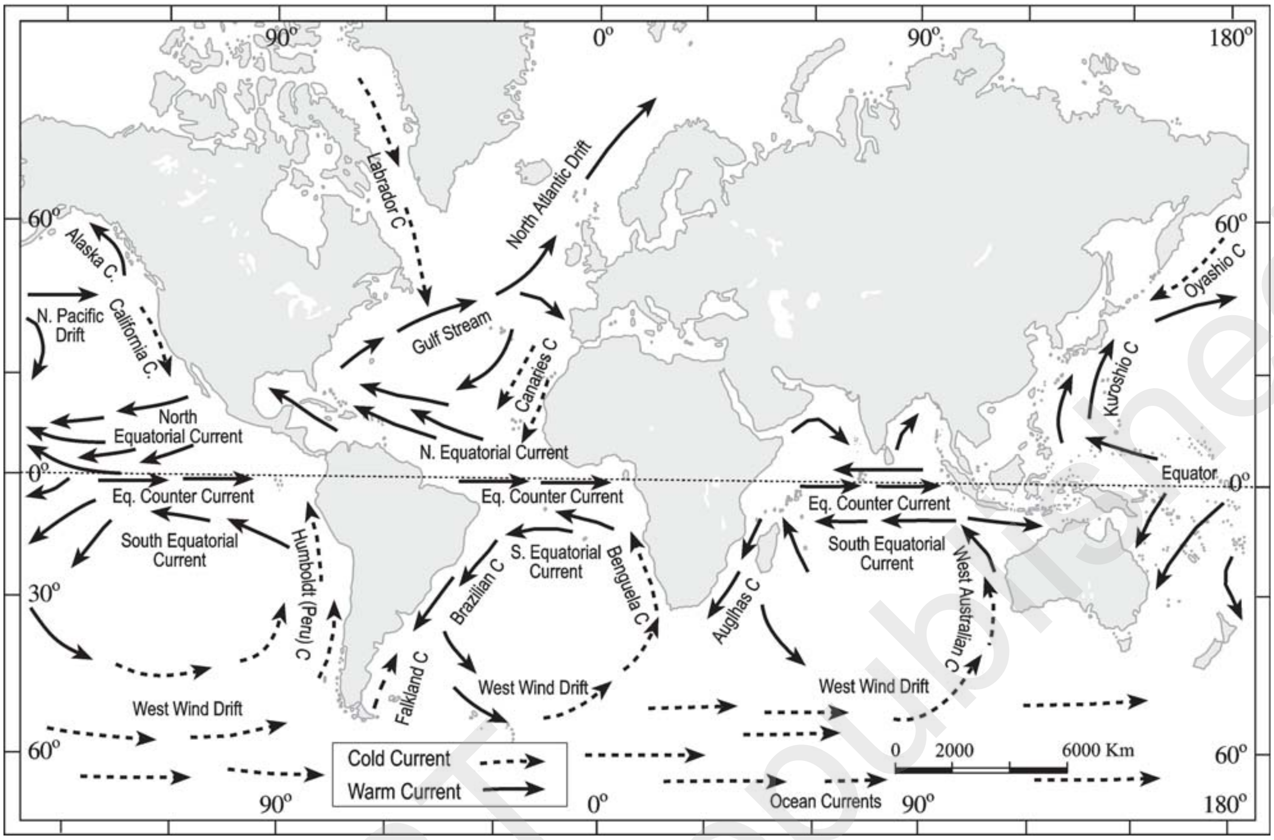


Fig.14.3 : Major currents in the Pacific, Atlantic and Indian oceans

where the wind flow is mostly cyclonic, the oceanic circulation follows this pattern. In regions of pronounced monsoonal flow, the monsoon winds influence the current movements. Due to the coriolis force, the warm currents from low latitudes tend to move to the right in the northern hemisphere and to their left in the southern hemisphere.

The oceanic circulation transports heat from one latitude belt to another in a manner similar to the heat transported by the general circulation of the atmosphere. The cold waters of the Arctic and Antarctic circles move towards warmer water in tropical and equatorial regions, while the warm waters of the lower latitudes move polewards. The major currents in the different oceans are shown in Figure14.3.

> Prepare a list of currents which are found in Pacific, Atlantic and Indian Oceans.
>
> How is the movement of currents influenced by prevailing winds? Give some examples from Figure14.3.

Effects of Ocean Currents

Ocean currents have a number of direct and indirect influences on human activities. West coasts of the continents in tropical and subtropical latitudes (except close to the equator) are bordered by cool waters. Their average temperatures are relatively low with a narrow diurnal and annual ranges. There is fog, but generally the areas are arid. West coasts of the continents in the middle and higher latitudes are bordered by warm waters which cause a distinct marine climate. They are characterised by cool summers and relatively mild winters with a narrow annual range of temperatures. Warm currents flow parallel to the east coasts of the continents in tropical and subtropical latitudes. This results in warm and rainy climates. These areas lie in the western margins of the subtropical anti-cyclones. The mixing of warm and cold currents help to replenish the oxygen and favour the growth of planktons, the primary food for fish population. The best fishing grounds of the world exist mainly in these mixing zones.

EXERCISES

1. Multiple choice questions.

   (i) Upward and downward movement of ocean water is known as the :

   (a) tide (c) wave

   (b) current (d) none of the above

   (ii) Spring tides are caused :

   (a) As result of the moon and the sun pulling the earth gravitationally in the same direction.

   (b) As result of the moon and the sun pulling the earth gravitationally in the opposite direction.

   (c) Indention in the coast line.

   (d) None of the above.

   (iii) The distance between the earth and the moon is minimum when the moon is in :

   (a) Aphelion (c) Perihelion

   (b) Perigee (d) Apogee

   (iv) The earth reaches its perihelion in:

   (a) October (c) July

   (b) September (d) January

2. Answer the following questions in about 30 words.

   (i) What are waves?

   (ii) Where do waves in the ocean get their energy from?

   (iii) What are tides?

   (iv) How are tides caused?

   (v) How are tides related to navigation?

3. Answer the following questions in about 150 words.

   (i) How do currents affect the temperature? How does it affect the temperature of coastal areas in the N. W. Europe?

   (ii) What are the causes of currents?

Project Work

(i) Visit a lake or a pond and observe the movement of waves. Throw a stone and notice how waves are generated.

(ii) Take a globe and a map showing the currents of the oceans. Discuss why certain currents are warm or cold and why they deflect in certain places and examine the reasons.

UNIT VI

LIFE ON THE EARTH

This unit deals with

- *Biosphere — importance of plants and other organisms; ecosystems, bio-geo chemical cycle and ecological balance; biodiversity and conservation*

CHAPTER

15

LIFE ON THE EARTH

By now you might have realised that all units of this book have acquainted you with the three major realms of the environment, that is, the lithosphere, the atmosphere and the hydrosphere. You know that living organisms of the earth, constituting the *biosphere,* interact with other environmental realms. The biosphere includes all the living components of the earth. It consists of all plants and animals, including all the micro-organisms that live on the planet earth and their interactions with the surrounding environment. Most of the organisms exist on the lithosphere and/or the hydrosphere as well as in the atmosphere. There are also many organisms that move freely from one realm to the other.

> Life on the earth is found almost everywhere. Living organisms are found from the poles to the equator, from the bottom of the sea to several km in the air, from freezing waters to dry valleys, from under the sea to underground water lying below the earth's surface.

The biosphere and its components are very significant elements of the environment. These elements interact with other components of the natural landscape such as land, water and soil. They are also influenced by the atmospheric elements such as the temperature, rainfall, moisture and sunlight. The interactions of biosphere with land, air and water are important to the growth, development and evolution of the organism.

ECOLOGY

You have been reading about ecological and environmental problems in newspapers and magazines. Have you ever thought what ecology is? The environment as you know, is made up of abiotic and biotic components. It would be interesting to understand how the diversity of life-forms is maintained to bring a kind of balance. This balance is maintained in a particular proportion so that a healthy interaction between the biotic and the abiotic components goes on.

The interactions of a particular group of organisms with abiotic factors within a particular habitat resulting in clearly defined energy flows and material cycles on land, water and air, are called *ecological systems*.

> The term *ecology* is derived from the Greek word *'oikos'* meaning 'house', combined with the word *'logy'* meaning the 'science of' or 'the study of'. Literally, ecology is the study of the earth as a 'household', of plants, human beings, animals and micro-organisms. They all live together as interdependent components. A German zoologist *Ernst Haeckel*, who used the term as '*oekologie*' in 1869, became the first person to use the term 'ecology'. The study of interactions between life forms (biotic) and the physical environment (abiotic) is the science of ecology. Hence, *ecology can be defined as a scientific study of the interactions of organisms with their physical environment and with each other.*

A *habitat* in the ecological sense is the totality of the physical and chemical factors that constitute the general environment. A system consisting of biotic and abiotic components is known as ecosystem. All these components in ecosystem are inter related and interact with each other. Different types of ecosystems exist with varying ranges of environmental conditions where various plants and animal species have got adapted through evolution. This phenomenon is known as *ecological adaptation*.

Types of Ecosystems

Ecosystems are of two major types: *terrestrial* and *aquatic*. Terrestrial ecosystem can be further be classified into *'biomes'*. *A biome* is a plant and animal community that covers a large geographical area. The boundaries of different biomes on land are determined mainly by climate. Therefore, a biome can be defined as the total assemblage of plant and animal species interacting within specific conditions. These include rainfall, temperature, humidity and soil conditions. Some of the major biomes of the world are: *forest, grassland, desert and tundra biomes*. Aquatic ecosystems can be classed as marine and freshwater ecosystems. Marine ecosystem includes the oceans, estuaries and coral reefs. Freshwater ecosystem includes lakes, ponds, streams, marshes and bogs.

Structure and Functions of Ecosystems

The structure of an ecosystem involves a description of the available plant and animal species. From a structural point of view, all ecosystems consist of abiotic and biotic factors. *Abiotic factors* include rainfall, temperature, sunlight, atmospheric humidity, soil conditions, inorganic substances (carbon dioxide, water, nitrogen, calcium, phosphorus, potassium, etc.). *Biotic factors* include the producers, the consumers (primary, secondary, tertiary) and the decomposers. The *producers* include all the green plants, which manufacture their own food through photosynthesis. The *primary consumers* include herbivorous animals like deer, goats, mice and all plant-eating animals. The *carnivores* include all the flesh-eating animals like snakes, tigers and lions. Certain carnivores that feed also on carnivores are known as top carnivores like hawks and mongooses. *Decomposers* are those that feed on dead organisms (for example, scavengers like vultures and crows), and further breaking down of the dead matter by other decomposing agents like bacteria and various micro-organisms.

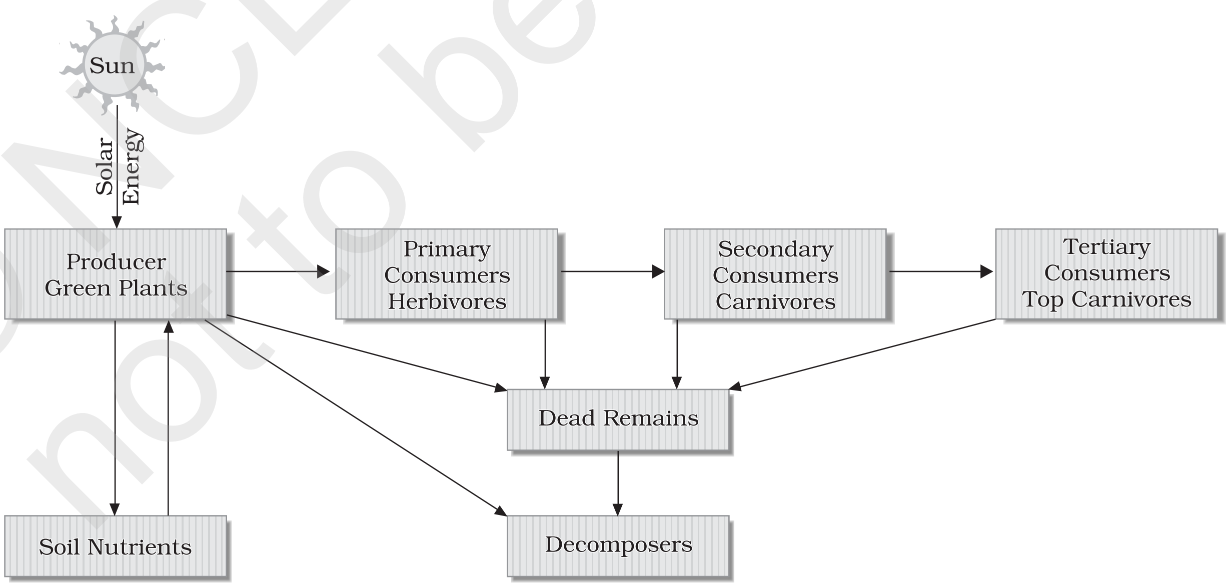


Figure 15.1 : Structure and functions of ecosystems

The producers are consumed by the primary consumers whereas the primary consumers are, in turn, being eaten by the secondary consumers. Further, the secondary consumers are consumed by the tertiary consumers. The decomposers feed on the dead at each and every level. They change them into various substances such as nutrients, organic and inorganic salts essential for soil fertility. Organisms of an ecosystem are linked together through a foodchain (Figure 15.1). For example, a plant eating beetle feeding on a paddy stalk is eaten by a frog, which is, in turn, eaten by a snake, which is then consumed by a hawk. This sequence of eating and being eaten and the resultant transfer of energy from one level to another is known as the *food-chain*. Transfer of energy that occurs during the process of a foodchain from one level to another is known as *flow of energy*. However, food-chains are not isolated from one another. For example, a mouse feeding on grain may be eaten by different secondary consumers (carnivores) and these carnivores may be eaten by other different tertiary consumers (top carnivores). In such situations, each of the carnivores may consume more than one type of prey. As a result, the food- chains get interlocked with one another. This inter-connecting network of species is known as *food web*. Generally, two types of food-chains are recognised: *grazing food-chain* and *detritus food-chain*. In a grazing food-chain, the first level starts with plants as producers and ends with carnivores as consumers at the last level, with the herbivores being at the intermediate level. There is a loss of energy at each level which may be through respiration, excretion or decomposition. The levels involved in a food-chain range between three to five and energy is lost at each level. A detritus food-chain is based on autotrophs energy capture initiated by grazing animals and involves the decomposition or breaking down of organic wastes and dead matter derived from the grazing food-chain.

Types of Biomes

In the earlier paragraphs, you have learnt the meaning of the term 'biome'. Let us now try to identify the major biomes of the world. There are five major biomes — forest, desert, grassland, aquatic and altitudinal biomes. Some features of these biomes are given in Table 15.1.

Biogeochemical Cycles

The sun is the basic source of energy on which all life depends. This energy initiates life processes in the biosphere through photosynthesis, the main source of food and energy for green plants. During photosynthesis, carbon dioxide is converted into organic compounds and oxygen. Out of the total solar insolation that reaches the earth's surface, only a very small fraction (0.1 per cent) is fixed in photosynthesis. More than half is used for plant respiration and the remaining part is temporarily stored or is shifted to other portions of the plant.

Life on earth consists of a great variety of living organisms. These living organisms exist and survive in a diversity of associations. Such survival involves the presence of systemic flows such as flows of energy, water and nutrients. These flows show variations in different parts of the world, in different seasons of the year and under varying local circumstances. Studies have shown that for the last one billion years, the atmosphere and hydrosphere have been composed of approximately the same balance of chemical components. This balance of the chemical elements is maintained by a cyclic passage through the tissues of plants and animals. The cycle starts by absorbing the chemical elements by the organism and is returned to the air, water and soil through decomposition. These cycles are largely energised by solar insolation. These cyclic movements of chemical elements of the biosphere between the organism and the environment are referred to as *biogeochemical cycles*. *Bio* refers to living organisms and *geo* to rocks, soil, air and water of the earth.

There are two types of biogeochemical cycles : the *gaseous* and the *sedimentary* cycle. In the gaseous cycle, the main reservoir of nutrients is the atmosphere and the ocean. In the sedimentary cycle, the main reservoir is the soil and the sedimentary and other rocks of the earth's crust.

The Water Cycle

All living organisms, the atmosphere and the lithosphere maintain between them a

Table 15.1 : World Biomes

Biomes	*Subtypes*	*Regions*	*Climatic Characteristics*	*Soil*	*Flora and Fauna*
Forest	A. Tropical 1. Equatorial 2. Deciduous B. Temperate C. Boreal	A1. 10° N-S A2. 10° - 25° N-S B. Eastern North America, N.E. Asia, Western and Central Europe C. Broad belt of Eurasia and North America (parts of Siberia, Alaska, Canada and Scandinavia)	A1. Temp. 20-25°C, evenly distributed A2. Temp. 25-30°C, Rainfall, ave. ann. 1,000mm, seasonal B. Temp. 20-30° C, Rainfall evenly distributed 750-1,500mm, Well-defined seasons and distinct winter. C. Short moist moderately warm summers and long cold dry winter; very low temperatures. Precipitation mostly snowfall 400 -1,000mm	A1. Acidic, poor in nutrients A2. Rich in nutrients B. Fertile, en-riched with decaying litter C. Acidic and poor in nutrients, thin soil cover	A1. Multi-layered canopy tall and large trees A2. Less dense, trees of medium height; many varieties co-exist. Insects, bats, birds and mammals are common species in both B. Moderately dense broad leaved trees. With less diversity of plant species. Oak, Beach, Maple etc. are some common species. Squirrels, rabbits, skunks, birds, black bears, mountain lions etc. C. Evergreen conifers like pine, fur and spruce etc. Wood peckers, hawks, bears, wolves, deer, hares and bats are common animals
Desert	A. Hot and Dry desert B. Semi arid desert C. Coastal desert D. Cold desert	A. Sahara, Kalahari, Marusthali, Rub-el-Khali B. Marginal areas of hot deserts C. Atacama D. Tundra climatic regions	A. Temp. 20 - 45°C. B. 21 - 38°C. C. 15 - 35°C. D. 2 - 25°C A-D Rainfall is less than 50 mm	Rich in nutrients with little or no organic matter	A-C. Scanty vegetation; few large mammals, insects, reptiles and birds D. Rabbits, rats, antelopes and ground squirrels
Grassland	A. Tropical Savannah B. Temperate Steppe	A. Large areas of Africa, Australia, South America and India B. Parts of Eurasia and North America	A. Warm hot climates, Rainfall 500-1,250 mm B. Hot summers and cold winter. Rainfall 500 - 900 mm	A. Porous with thin layer of humus. B. Thin flocculated soil, rich in bases	A. Grasses; trees and large shrubs absent; giraffes zebras, buffalos, leopards, hyenas, elephants, mice, moles, snakes and worms etc., are common animals B. Grasses; occasional trees such as cotton-woods, oaks and willows; gazelles, zebras, rhin-

					oceros, wild horses, lions, varieties of birds, worms, snakes etc., are common animals
Aquatic	A. Freshwater B. Marine	A. Lakes, streams, rivers and wetlands B. Oceans, coral reefs, lagoons and estuaries	A-B Temperatures vary widely with cooler air temperatures and high humidity	A. Water, swamps and marshes B. Water, tidal swamps and marshes	Algal and other aquatic and marine plant communities with varieties of water dwelling animals
Altitudinal	———	Slopes of high mountain ranges like the Himalayas, the Andes and the Rockies	Temperature and precipitation vary depending upon latitudinal zone	Regolith over slopes	Deciduous to tundra vegetation varying according to altitude

circulation of water in solid, liquid or gaseous form referred to as the water or hydrologic cycle (Chapter 13 of this book).

The Carbon Cycle

Carbon is one of the basic elements of all living organisms. It forms the basic constituent of all the organic compounds. The biosphere contains over half a million carbon compounds in them. The carbon cycle is mainly the conversion of carbon dioxide. This conversion is initiated by the fixation of carbon dioxide from the atmosphere through *photosynthesis*. Such conversion results in the production of carbohydrate, glucose that may be converted to other organic compounds such as sucrose, starch, cellulose, etc. Here, some of the carbohydrates are utilised directly by the plant itself. During this process, more carbon dioxide is generated and is released through its leaves or roots during the day. The remaining carbohydrates not being utilised by the plant become part of the plant tissue. Plant tissues are either being eaten by the herbivorous animals or get decomposed by the micro-organisms. The herbivores convert some of the consumed carbohydrates into carbon dioxide for release into the air through respiration. The micro-organisms decompose the remaining carbohydrates after the animal dies. The carbohydrates that are decomposed by the micro-organisms then get oxidised into carbon dioxide and are returned to the atmosphere (Figure 15.2).

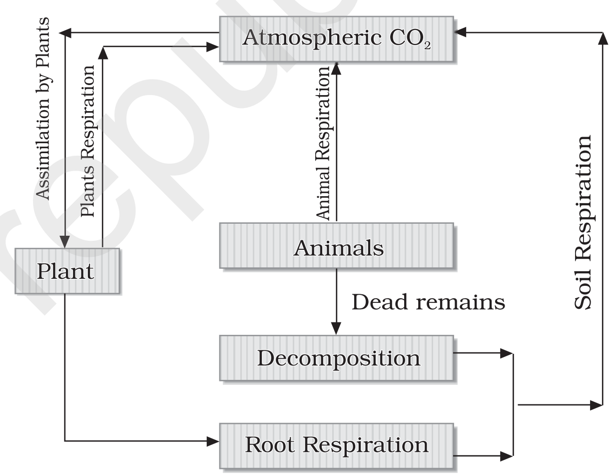


Figure 15.2 : Carbon Cycle

The Oxygen Cycle

Oxygen is the main by-product of photosynthesis. It is involved in the oxidation of carbohydrates with the release of energy, carbon dioxide and water. The cycling of oxygen is a highly complex process. Oxygen occurs in a number of chemical forms and combinations. It combines with nitrogen to form nitrates and with many other minerals and elements to form various oxides such as the iron oxide, aluminium oxide and others. Much of oxygen is produced from the decomposition of water molecules by sunlight during photosynthesis and is released in the atmosphere through transpiration and respiration processes of plants.

The Nitrogen Cycle

Nitrogen is a major constituent of the atmosphere comprising about seventy-nine per cent of the atmospheric gases. It is also an essential constituent of different organic compounds such as the amino acids, nucleic acids, proteins, vitamins and pigments. Only a few types of organisms like certain species of soil bacteria and blue green algae are capable of utilising it directly in its gaseous form. Generally, nitrogen is usable only after it is fixed. Ninety per cent of fixed nitrogen is biological. The principal source of free nitrogen is the action of soil micro-organisms and associated plant roots on atmospheric nitrogen found in pore spaces of the soil. Nitrogen can also be fixed in the atmosphere by lightning and cosmic radiation. In the oceans, some marine animals can fix it. After atmospheric nitrogen has been fixed into an available form, green plants can assimilate it. Herbivorous animals feeding on plants, in turn, consume some of it. Dead plants and animals, excretion of nitrogenous wastes are converted into nitrites by the action of bacteria present in the soil. Some bacteria can even convert nitrites into nitrates that can be used again by green plants. There are still other types of bacteria capable of converting nitrates into free nitrogen, a process known as *denitrification* (Figure 15.3).

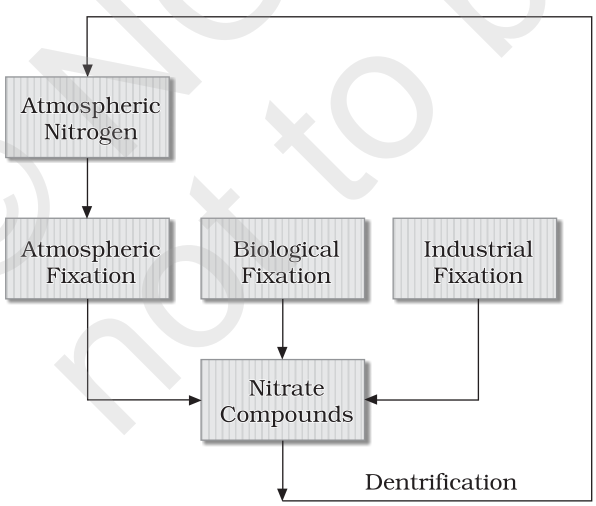


Figure 15.3 : Nitrogen Cycle

Other Mineral Cycles

Other than carbon, oxygen, nitrogen and hydrogen being the principal geochemical components of the biosphere, many other minerals also occur as critical nutrients for plant and animal life. These mineral elements required by living organisms are obtained initially from inorganic sources such as phosphorus, sulphur, calcium and potassium. They usually occur as salts dissolved in soil water or lakes, streams and seas. Mineral salts come directly from the earth's crust by weathering where the soluble salts enter the water cycle, eventually reaching the sea. Other salts are returned to the earth's surface through sedimentation, and after weathering, they again enter the cycle. All living organisms fulfill their mineral requirements from mineral solutions in their environments. Other animals receive their mineral needs from the plants and animals they consume. After the death of living organisms, the minerals are returned to the soil and water through decomposition and flow.

Ecological Balance

Ecological balance is a state of dynamic equilibrium within a community of organisms in a habitat or ecosystem. It can happen when the diversity of the living organisms remains relatively stable. Gradual changes do take place but that happens only through natural succession. It can also be explained as a stable balance in the numbers of each species in an ecosystem. This occurs through competition and cooperation between different organisms where population remains stable. This balance is brought about by the fact that certain species compete with one another determined by the environment in which they grow. This balance is also attained by the fact that some species depend on others for their food and sustenance. Such accounts are encountered in vast grasslands where the herbivorous animals (deer, zebras, buffaloes, etc.) are found in plenty. On the other hand, the carnivorous animals (tigers, lions, etc.) that are not usually in large numbers, hunt and feed on the herbivores, thereby controlling their population. In the plants, any disturbance in the native forests such as clearing the forest for shifting cultivation usually brings about a change in the species distribution. This change is due to competition where the secondary forest species such as grasses, bamboos or pines overtakes the native species changing the original forest structure. This is called *succession*.

Ecological balance may be disturbed due to the introduction of new species, natural hazards or human causes. Human interference has affected the balance of plant communities leading to disturbances in the ecosystems. Such disturbances bring about numerous secondary successions. Human pressure on the earth's resources has put a heavy toll on the ecosystem. This has destroyed its originality and has caused adverse effects to the general environment. Ecological imbalances have brought many natural calamities like floods, landslides, diseases, erratic climatic occurrences, etc.

There is a very close relationship between the plant and animal communities within particular habitats. Diversity of life in a particular area can be employed as an indicator of the habitat factor. Proper knowledge and understanding of such factors provide a strong base for protecting and conserving the ecosystems.

EXERCISES

1. Multiple choice questions.

   (i) Which one of the following is included in biosphere?

   (a) only plants (c) only animals

   (b) all living and non-living organisms (d) all living organisms

   (ii) Tropical grasslands are also known as :

   (a) the prairies (c) the steppes

   (b) the savannas (d) none of the above

   (iii) Oxygen combines with iron found in the rocks to form :

   (a) iron carbonate (c) iron oxides

   (b) iron nitrites (d) iron sulphate

   (iv) During photosynthesis, carbon dioxide combines with water in the presence of sunlight to form :

   (a) proteins (c) carbohydrates

   (b) amino acids (d) vitamins

2. Answer the following questions in about 30 words.

   (i) What do you understand by the term 'ecology'?

   (ii) What is an ecological system? Identify the major types of ecosystems in the world.

   (iii) What is a food-chain? Give one example of a grazing food-chain identifying the various levels.

   (iv) What do you understand by the term 'food web'? Give examples.

   (v) What is a biome?

3. Answer the following questions in about 150 words.
   (i) What are bio-geochemical cycles? Explain how nitrogen is fixed in the atmosphere.
   (ii) What is an ecological balance? Discuss the important measures needed to prevent ecological imbalances.

Project Work

(i) Show the distribution of the different biomes on the outline map of the world with a note highlighting the important characteristics of each biome.

(ii) Make a note of trees, shrubs and perennial plants in your school campus and devote half a day to observe the types of birds which come to the garden. Can you describe the diversity of birds?

CHAPTER

16

BIODIVERSITY AND CONSERVATION

You have already learnt about the geomorphic processes particularly weathering and depth of weathering mantle in different climatic zones. See the Figure 6.2 in Chapter 6 in order to recapitulate. You should know that this weathering mantle is the basis for the diversity of vegetation and hence, the biodiversity. The basic cause for such weathering variations and resultant biodiversity is the input of solar energy and water. No wonder that the areas that are rich in these inputs are the areas of wide spectrum of biodiversity.

> Biodiversity as we have today is the result of 2.5-3.5 billion years of evolution. Before the advent of humans, our earth supported more biodiversity than in any other period. Since, the emergence of humans, however, biodiversity has begun a rapid decline, with one species after another bearing the brunt of extinction due to overuse. The number of species globally vary from 2 million to 100 million, with 10 million being the best estimate. New species are regularly discovered most of which are yet to be classified (an estimate states that about 40 per cent of fresh water fishes from South America are not classified yet). Tropical forests are very rich in bio-diversity.

Biodiversity is a system in constant evolution, from a view point of species, as well as from view point of an individual organism. The average half-life of a species is estimated at between one and four million years, and 99 per cent of the species that have ever lived on the earth are today extinct. Biodiversity is not found evenly on the earth. It is consistently richer in the tropics. As one approaches the polar regions, one finds larger and larger populations of fewer and fewer species.

Biodiversity itself is a combination of two words, *Bio* (life) and *diversity* (variety). In simple terms, biodiversity is the number and variety of organisms found within a specified geographic region. It refers to the varieties of plants, animals and micro-organisms, the genes they contain and the ecosystems they form. It relates to the variability among living organisms on the earth, including the variability within and between the species and that within and between the ecosystems. Biodiversity is our living wealth. It is a result of hundreds of millions of years of evolutionary history.

Biodiversity can be discussed at three levels : (i) Genetic diversity; (ii) Species diversity; (iii) Ecosystem diversity.

Genetic Diversity

Genes are the basic building blocks of various life forms. Genetic biodiversity refers to the variation of genes within species. Groups of individual organisms having certain similarities in their physical characteristics are called *species*. Human beings genetically belong to the *homo sapiens* group and also differ in their characteristics such as height, colour, physical appearance, etc., considerably. This is due to genetic diversity. This genetic diversity is essential for a healthy breeding of population of species.

Species Diversity

This refers to the variety of species. It relates to the number of species in a defined area. The diversity of species can be measured through its richness, abundance and types. Some areas are more rich in species than others. Areas rich in species diversity are called *hotspots* of diversity (Figure 16.5).

Ecosystem Diversity

You have studied about the ecosystem in the earlier chapter. The broad differences between ecosystem types and the diversity of habitats and ecological processes occurring within each ecosystem type constitute the ecosystem diversity. The 'boundaries' of communities (associations of species) and ecosystems are not very rigidly defined. Thus, the demarcation of ecosystem boundaries is difficult and complex.

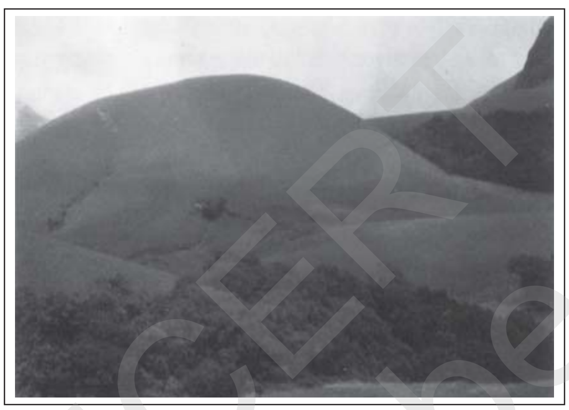


Figure 16.1 : Grasslands and sholas in Indira Gandhi National Park, Annamalai, Western Ghats — an example of ecosystem diversity

Importance of Biodiversity

Biodiversity has contributed in many ways to the development of human culture and, in turn, human communities have played a major role in shaping the diversity of nature at the genetic, species and ecological levels. Biodiversity plays the following roles: ecological, economic and scientific.

Ecological Role of Biodiversity

Species of many kinds perform some function or the other in an ecosystem. Nothing in an ecosystem evolves and sustains without any reason. That means, every organism, besides extracting its needs, also contributes something of useful to other organisms. Can you think of the way we, humans contribute to the sustenance of ecosystems. Species capture and store energy, produce and decompose organic materials, help to cycle water and nutrients throughout the ecosystem, fix atmospheric gases and help regulate the climate. These functions are important for ecosystem function and human survival. The more diverse an ecosystem, better are the chances for the species to survive through adversities and attacks, and consequently, is more productive. Hence, the loss of species would decrease the ability of the system to maintain itself. Just like a species with a high genetic diversity, an ecosystem with high biodiversity may have a greater chance of adapting to environmental change. In other words, the more the variety of species in an ecosystem, the more stable the ecosystem is likely to be.

Economic Role of Biodiversity

For all humans, biodiversity is an important resource in their day-to-day life. One important part of biodiversity is 'crop diversity', which is also called agro-biodiversity. Biodiversity is seen as a reservoir of resources to be drawn upon for the manufacture of food, pharmaceutical, and cosmetic products. This concept of biological resources is responsible for the deterioration of biodiversity. At the same time, it is also the origin of new conflicts dealing with rules of division and appropriation of natural resources. Some of the important economic commodities that biodiversity supplies to humankind are: food crops, livestock, forests, fish, medicinal resources, etc.

Scientific Role of Biodiversity

Biodiversity is important because each species can give us some clue as to how life evolved and will continue to evolve. Biodiversity also helps in understanding how life functions and the role of each species in sustaining ecosystems of which we are also a species. This fact must be drawn upon every one of us so that we live and let other species also live their lives.

It is our ethical responsibility to consider that each and every species along with us have an intrinsic right to exist. Hence, it is morally wrong to voluntarily cause the extinction of any species. The level of biodiversity is a good indicator of the state of our relationships with other living species. In fact, the concept of biodiversity is an integral part of many human cultures.

Loss of Biodiversity

Since the last few decades, growth in human population has increased the rate of consumption of natural resources. It has accelerated the loss of species and habitation in different parts of the world. Tropical regions which occupy only about one-fourth of the total area of the world, contain about three-fourth of the world human population. Over-exploitation of resources and deforestation have become rampant to fulfil the needs of large population. As these tropical rain forests contain 50 per cent of the species on the earth, destruction of natural habitats have proved disastrous for the entire biosphere.

Natural calamities such as earthquakes, floods, volcanic eruptions, forest fires, droughts, etc. cause damage to the flora and fauna of the earth, bringing change the biodiversity of respective affected regions. Pesticides and other pollutants such as hydrocarbons and toxic heavy metals destroy the weak and sensitive species. Species which are not the natural inhabitants of the local habitat but are introduced into the system, are called *exotic species*. There are many examples when a natural biotic community of the ecosystem suffered extensive damage because of the introduction of exotic species. During the last few decades, some animals like tigers, elephants, rhinoceros, crocodiles, minks and birds were hunted mercilessly by poachers for their horn, tusks, hides, etc. It has resulted in the rendering of certain types of organisms as endangered category.

The International Union of Conservation of Nature and Natural Resources (IUCN) has classified the threatened species of plants and animals into three categories for the purpose of their conservation.

Endangered Species

It includes those species which are in danger of extinction. The IUCN publishes information about endangered species world-wide as the *Red List* of threatened species.

Figure 16.2 : Red Panda — an endangered species

Figure 16.3 : Zenkeria Sebastinei — a critically endangered grass in Agasthiyamalai peak (India)

Vulnerable Species

This includes the species which are likely to be in danger of extinction in near future if the factors threatening to their extinction continue. Survival of these species is not assured as their population has reduced greatly.

Rare Species

Population of these species is very small in the world; they are confined to limited areas or thinly scattered over a wider area.

Figure 16.4 : Humbodtia decurrens Bedd — highly rare endemic tree of Southern Western Ghats (India)

Conservation of Biodiversity

Biodiversity is important for human existence. All forms of life are so closely interlinked that disturbance in one gives rise to imbalance in the others. If species of plants and animals become endangered, they cause degradation in the environment, which may threaten human being's own existence.

There is an urgent need to educate people to adopt environment-friendly practices and reorient their activities in such a way that our development is harmonious with other life forms and is sustainable. There is an increasing consciousness of the fact that such conservation with sustainable use is possible only with the involvement and cooperation of local communities and individuals. For this, the development of institutional structures at local levels is necessary. The critical problem is not merely the conservation of species nor the habitat but the continuation of process of conservation.

The Government of India along with 155 other nations have signed the Convention of Biodiversity at the Earth Summit held at Rio de Janeiro, Brazil in June 1992. The world conservation strategy has suggested the following steps for biodiversity conservation:

(i) Efforts should be made to preserve the species that are endangered.
(ii) Prevention of extinction requires proper planning and management.
(iii) Varieties of food crops, forage plants, timber trees, livestock, animals and their wild relatives should be preserved;
(iv) Each country should identify habitats of wild relatives and ensure their protection.
(v) Habitats where species feed, breed, rest and nurse their young should be safeguarded and protected.
(vi) International trade in wild plants and animals be regulated.

To protect, preserve and propagate the variety of species within natural boundaries, the Government of India passed the *Wild Life (Protection) Act, 1972*, under which national parks and sanctuaries were established and biosphere reserves declared. Details of these biosphere reserves are given in the book *India: Physical Environment* (NCERT, 2006).

There are some countries which are situated in the tropical region; they possess a large number of the world's species diversity. They are called *mega diversity centres*. There are 12 such countries, namely Mexico, Columbia, Ecuador, Peru, Brazil, Democratic Republic of Congo, Madagascar, China, India, Malaysia, Indonesia and Australia in which these centres are located. In order to concentrate resources on those areas that are most vulnerable, the International Union for the Conservation of Nature and Natural Resources (IUCN) has identified certain areas as biodiversity hotspots (Figure 16.5). Hotspots are defined according to their vegetation. Plants are important because these determine the primary productivity of an ecosystem. Most, but not all, of the hotspots rely on species-rich ecosystems for food, firewood, cropland, and income from timber. In Madagascar, for example, about 85 per cent of the plants and animals are found nowhere else in the world, Other hotspots in wealthy countries are facing

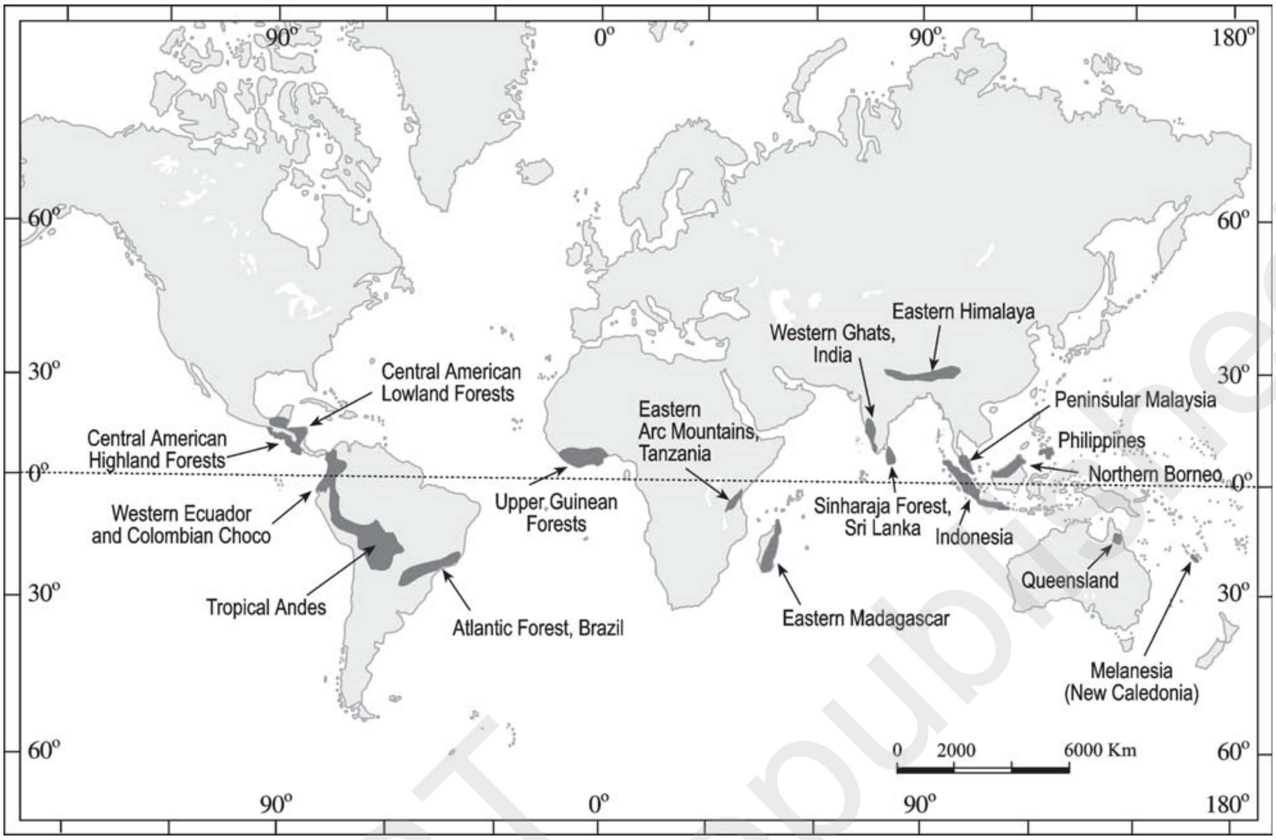


Figure 16.5 : Ecological 'hotspots' in the world

different types of pressures. The islands of Hawaii have many unique plants and animals that are threatened by introduced species and land development.

EXERCISES

1. Multiple choice questions.

(i) Conservation of biodiversity is important for :

(a) Animals (c) Plants

(b) Animals and plants (d) All organisms

(ii) Threatened species are those which :

(a) threaten others

(b) Lion and tiger

(c) are abundant in number

(d) are suffering from the danger of extinction

(iii) National parks and sanctuaries are established for the purpose of :

(a) Recreation (c) Pets

(b) Hunting (d) Conservation

(iv) Biodiversity is richer in :

(a) Tropical Regions (c) Temperate Regions

(b) Polar Regions (d) Oceans

(v) In which one of the following countries, the 'Earth Summit' was held?

(a) the UK (c) Brazil

(b) Mexico (d) China

2. Answer the following questions in about 30 words.

(i) What is biodiversity?

(ii) What are the different levels of biodiversity?

(iii) What do you understand by 'hotspots'?

(iv) Discuss briefly the importance of animals to human kind.

(v) What do you understand by 'exotic species'?

3. Answer the following questions in about 150 words.

(i) What are the roles played by biodiversity in the shaping of nature?

(ii) What are the major factors that are responsible for the loss of biodiversity? What steps are needed to prevent them?

Project Work

Collect the names of national parks, sanctuaries and biosphere reserves of the state where your school is located and show their location on the map of India.