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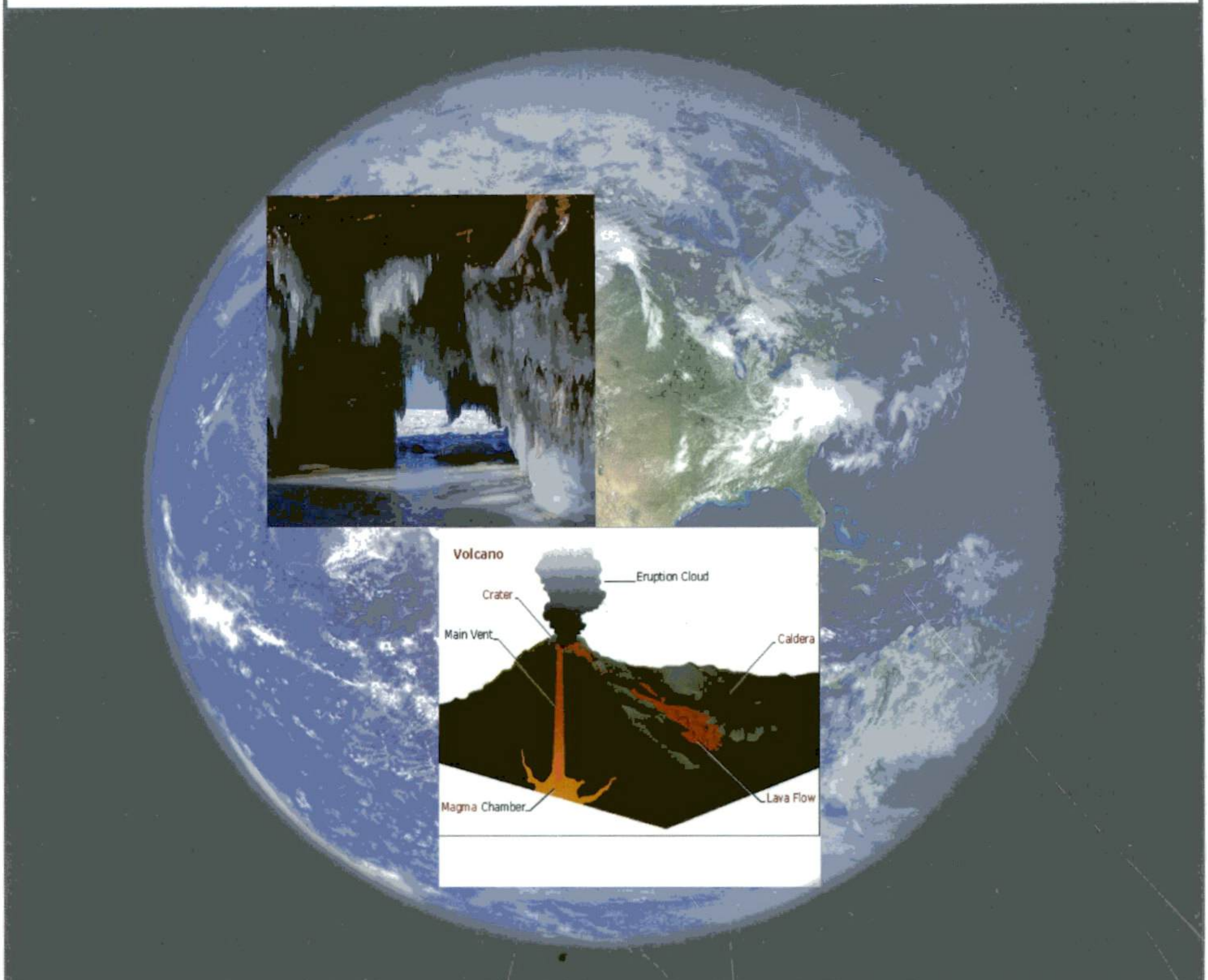
Karnataka State Open University

Manasagangotri, Mysore – 570 006

M.Sc., GEOGRAPHY

First Semester



GEOMORPHOLOGY

COURSE – 101 **BLOCK – 1, 2, 3 and 4**

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ಮುಕ್ತ ವಿಶ್ವವಿದ್ಯಾನಿಲಯವು ದೂರಶಿಕ್ಷಣ ಪದ್ಧತಿಯಲ್ಲಿ ಬಹುಮಾಧ್ಯಮಗಳನ್ನು ಉಪಯೋಗಿಸುತ್ತದೆ. .... ವಿದ್ಯಾಕಾಂಕ್ಷಿಗಳನ್ನು ಜ್ಞಾನ ಸಂಪಾದನೆಗಾಗಿ ಕಲಿಕಾ ಕೇಂದ್ರಕ್ಕೆ ಕೊಂಡೊಯ್ಯುವ ಬದಲು, ಜ್ಞಾನ ಸಂಪತ್ತನ್ನು ವಿದ್ಯೆ ಕಲಿಯುವವರ ಬಳಿ ಕೊಂಡೊಯ್ಯುವ ವಾಹಕವಾಗಿದೆ.

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M.Sc.
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BLOCK 1

Course Design and Editorial Committee

Prof. K.S. Rangappa
Vice-Chancellor
Karanataka State Open University
Manasagangotri, Mysore – 570 006

Prof. Jagadeesha
Dean (Academic) & Convenor
Karnataka State Open University
Manasagangotri, Mysore – 570 006

Course Co-Ordinator

Dr. Y.P. Chandrashekara
Dept of Studies in Geography
Karnataka State Open University
Mysore

Subject Co-ordinator

Dr. B.N. Shivalingappa
Associate professor
Department of studies in Geography
University of Mysore.
Manasagangothri , Mysore.

Lesson Writers **Block 1**

Prof. B. Eshwarappa. **U 1-4**
Department of Studies in Geography
Bangalore University
Gnynabharathi, Bangalore

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Manasagangotri, Mysore - 6.

Developed by Academic Section, KSOU, Mysore

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BLOCK I

GEOMORPHOLOGY

INTRODUCTION

Geomorphology is defined as the science of land forms with an emphasis on their origin, evolution, form, and distribution across the physical landscape. An understanding of geomorphology and its process is therefore essential to the understanding of physical geography.

Although the study of geomorphology has been around since ancient times, the first official geomorphologic model was proposed between 1884 and 118919 by the American geographer, William Davis Morris.

You will observe this in the manner in which the various blocks of this course have been organized. Block 1 light on the field and scope of geomorphology, with evolution of geomorphology. We then proceed to basic concepts of geomorphology to the geomorphic concepts. Later we discuss on applied geomorphology and geological time.

Block 2 attempts to deal the earths interior and Isostacy theory which is related to earths balance continental theory and theory of plate tectonics are also help you to understand the distribution of land and water. Endogenetic, movements which is deals about earthquakes and volcanoes. This block is also deals about orogenic and Epirogenic movement and their resultant land forms.

Block 3 gives more information about Folds formation and their types with illustrations. Exogenetic forces, mainly weathering, land forms by Fluvial glacial agent, Eolian and Karst agents are discuss. Their erosional and depositional features are also discussed with related illustrations.

Block 4 attempts to deal the coast agent as an exogenetic movement. This block which concludes the course deals with cycle concepts by William Davis Morris and W.Penk, and also focuses on recent trends in geomorphology.

UNIT : 1 FIELD AND SCOPE OF GEOMORPHOLOGY, EVOLUTION OF GEOMORPHOLOGY

Structure

1.0 OBJECTIVES

This very first unit of Geomorphology provides information on the definition, Field, Scope and Evolution of subject geomorphology.

After studying this unit, you will be able to

- Explain the recent branch off from geology and geography as a vital branch of science.
- Evaluate how important to study geomorphology for the scientific understanding of surface features of earth's crust.
- Compare the interlinkages of this applied subject with geology and geography.
- Examines the applied nature of Geomorphology in this scientific world in studying the outer crust of the earth.
- Be familiar with the very evolution of the subject Geomorphology with the major contributors to its field.

1.1 INTRODUCTION

Geomorphology is a science of landforms. It is studied both by Geologists as well as Geographers. According to W. Thornbury it is more a geology than geography. However across the world it is studied and applied for various human engineering and mining activities. As a major branch of physical geography it deals with the study of land forms from their origin, sculpturing agents and their distribution. In its evolution four to five phases can be historically seen and they are (a) Historic period of Greeco- Romans; (b) Modern era of pre Hutton times; (c) Modern period of Hutton and others; (d) Its scientific development in Europe in 19th and early 20th centuries and (e) Its phenomenal growth in North America in 19th and 20th centuries. At present it is studied as an applied branch of geology and also as major branch of physical geography. It is also aided with empirical and quantitative techniques in describing the land forms and dynamism associated with earth's crust leading to formation of certain landforms.

1.2 DEFINITION OF GEOMORPHOLOGY

According to W.D. Thornbury, "Subject geomorphology has its roots in Greek words referring to 'a discourse on earth forms." More clear and accepted version of its definition is 'Geomorphology is the science of land forms'. Compared to other branches of human knowledge it has developed into an individual branch of both geology and geography since a few decades. It is stated that, the term Geomorphology was coined by Keith in 1894.

For a considerable period it was known as physiography a branch of physical geography. With the growth of scientific understand of earth's crust and its dynamism it emerged more a branch of both geology and Geography emphasizing the scientific study of land forms and its application for the benefit of man in his modern construction activities.

1.3 FIELD OF GEOMORPHOLOGY

Being a science of landforms, geomorphology encompasses the study of geomorphic process which are engaged in carrying out land forms. Some of them operate from below the surface of the earth. Endogenetic forces viz., Earthquakes, volcanoes and the like. There are exogenetic forces operating on the surface of the earth and they are weathering, mass wasting which also have their own set of land forms. But wonderful landforms are sculptured by the external forces like stream, glacier, wind, underground water and by sea-waves. Emphasis is given more to the end products e.g. the land form and their distribution by these processes in various stages.

While studying such landforms of the earth crust /surface and even ocean floor geomorphology lays stress on the role of the structure, rocks, lithology like geological aspects. Distribution of land form through dealt with process wise, regional geographical aspects are considered. In the scientific analysis of land forms it employs not only quantitative techniques but also uses well known theories like cycle concept by Davis and Penck. Off late emphasis is laid on Paleo- Geomorphology, Glacio-Geomorphology which deals with recent landforms of Holocene period and pleistoscene period of earth history. In fact they have helped in the discovery of fossil fuels and there by placing, Geomorphology as an applied branch of human knowledge under Geography and Geology.

1.4 SCOPE OF GEOMORPHOLOGY

Geomorphology the science of landforms or the relief of the earth's surface is being equally developed by both the geologists and geographers and can be considered as an intermediate science.

Geology and geomorphology are closely bound to the soil science, which is concerned with the study of soil, the formation of which, to a great extent, depends on the geological structure and composition of parental rock, the dept of under ground waters and their chemical composition, the relief of the landscape and the like.

Applied Geomorphology studies the relief with the aim of solving a number of problems that have practical significance. Thus the elaboration of various theoretical problems in geology and Geomorphology goes hand in hand with the solution of the highly important problems of national economy. Discovery of mineral deposits, construction of hydro/irrigational projects, new cities, railway lines, canals etc., in these days involve profound preliminary study of the engineering and geological conditions of the regions. Successful drilling of tube wells for irrigation and drinking water schemes make use of Geomorphological knowledge.

In the study of the earth, even with continuing differentiation of sciences of present, there is a growing tendency toward their integration. The synchronic use of various methods and the synthesis of data provided by related sciences. This tendency has already found its expression in the emergence of geo-chemistry, geophysics, bio-geo-chemistry, geomorphology, paleo-geography and other bordering sciences. This interaction of related sciences, make it possible to have a better understanding of the development of the whole material process in the progress of out planet.

1.5 EVOLUTION OF GEOMORPHOLOGY

Elements of Geomorphology can be seen even in historical times. Subsequent modern developments, scientific observation of earth's relief features have laid the foundation for the evolution of Geomorphology. For a considerable period of its evolution it was nothing but physiography. The course of evolution of Geomorphology has seen about four to five phases of evolution and they are:

(i) Historic period consisting Greeco-Romans contributions.

(ii) Modern era covering Pre-Hutton.

(iii) Modern era of Hutton and Playfair and others.

(iv) Period of phenomenal growth in Europe (19^{th} and 20^{th} centuries) and

(v) Scientific evolution of geomorphology in North America 19^{th} and 20^{th} centuries.

Now let us come to some detailed discussion of these periods of evolution of Geomorphology one by one.

(i) Historic period consisting Greeco-Romans contributions :

Seeds of Geomorphology were sown by early philosophers who have observed the changing features of earth and made statements in the form of basic ideas. As early as 485-425 BC **Herodatus** observed the deposition of silt and clay by the river Nile. He also noted the presence of Shells like Marine organisms in the hills of Egypt and came to conclusion that, sea at some time must have extended to over lower Egypt. It shows his knowledge of Geomorphology about changing levels of sea and sedimentary rocks.

Subsequently in this period **Aristotle** (384-322 BC) had observed the origin of springs to rain water, ground water coming from rains on mountains. He believed that, earthquakes and volcanoes are related and they are caused due to accumulation of hot moisture in the earth's crust. He also made observation on the accumulation of silt along Black sea affecting the movements of boats.

Another notable contribution to Geomorphology of this period was by **Strabo** (54 BC – 45 BC) who said that volcanoes like Mt. Vesuvius are caused due to hot winds within earth's crust. He noted the erosion and deposition of silt in weak rocky areas leading to formation of deltas. Similar views on volcanoes were expressed by **Seneca** (65 AD) and also observed the variation in rainfall lead to different size and depth of river valleys.

(ii) Modern era- Pre Hutton Period :

Like others areas of human knowledge, even Geomorphology saw decline during darkage inspite of early remarkable contribution by Greeks and Roman scholars. By the end it is Arab Scholars like **Iban Sinha** (980 AD- 1037) has made significant contributions. He said that, origin of mountains is due to uplifting of ground and also erosion of soft rocks by streams and winds. Thus the concept of differential erosion came into existence. There are some unknown Arab scholars who have made significant contributions to weathering, stream and wind erosion. They have made four volume of work viz., The Discourses of brother of Purity' consisting of basic ideas geomorphology including vague reference to even paneplanation.

During 15^{th}, 16^{th} and 17^{th} centuries particularly in Europe the philosophy of 'Catastrophim' prevailed under which scholars explain rat the features of earth were created or formed due to violent cataclysms.

In this pre Hutton modern period of Geomorphology notable contribution came from European scholars like.

Leonardo da Vince (1452-1519) recognized that the valleys were cut by streams and the streams transported materials and deposited elsewhere. A French scholar **Buffon** (1707-1788) tried to measure the age of the earth which was against to Biblical six days creation of Earth. An Italian scholar **T. Tozetti** (1782-1784) recognized the varying geological materials structure leading to irregular courses of streams. Another French Geologist **Gultthard** (1715-1786) has contributed towards formation of flood plains. By observing strong sea erosion of chalk cliffs of N.W. France he came to the conclusion that sea waves also equally powerful agents of erosion. A French scholar Desmarest recognized the successive stages of erosion and formation of stream cut valleys in central France. Swiss **De Sassure** while coining the word Geology made significant contribution towards land form by stream and also Glaceiers. It is said that, these French scholars have made worth mentioning land form related studies which subsequently helped Hutton.

(iii) Modern era of Hutton and Playfair and others :

James Hutton (1726-1797) a Scotish by birth has made significant contribution in the form of a famous concept of Geomorphology ' Present is key to the past'. He established the doctrine of 'Uniformitarianism' in opposition to 'Catastrophism'. His books and research papers which were presented in Royal society of Edinburg between 1785 and 1795 have laid strong foundation to Geomorphology. Some of them are- 'The theory of the Earth with proofs and Illustrations'; Transactions contained his seminal papers. Hutton views on earth's crust and its modification were further projected by Playfair and Charles Lyell and these two were strong supporters of concepts of unifiormitaniarism. In later years further elaborated field work in geomorphology by America geologist and also European scholars got benefited by the Hutton's concept of uniformitarim.

(iv) Period of phenomenal growth of Geomorphology in Europe :

Followed by J. Hutton's concept of 'uniformitarianism' has admirer Playfair published 'Principles of Geology' in 1872. Most important development in Europe was recognition of work of Glaciers and discovering Pleistocene ice age continental ice sheets covering Europe. Swiss engineer **Venetz and Esmark** from Norway have studied Alpine and Scandivevian glaciations. In Germany **Bernhardi** (1832) published a paper on the continental glaciations in Europe. Worth mentioning scholars who have contributed to continental glaciations are **Agassiz** and **Charpentier** from Germany. All their works lead to acknowledgement of great ice age and its multiple advancements and retreats. **A. Ramsey** and **Lyell** have made prominent contribution to marine erosion and sea floor topographical features. Around 1862 **Jukes** from Ireland explained the classification and the evolution of transverse steams and longitudinal streams and even stream piracy due to weak geological structure and head ward erosion of streams. By the last quarter of 19th century text books started appearing in geomorphology in Europe. Seminal contributions came from **Peschel, Richthofen** and **A. Penek** who published his famous book 'Morphologie der Erdoberflache'. The latter is considered as genetic treatment of land forms.

(v) Scientific Evolution of Geomorphology in North America :

Period between 1875 and 1900 as the heroic age in American geomorphology, famous geologists of that period like J.W. Powell, G.K. Gilbert, C.E. Dutton conducted surveys in the western USA. In fact they laid the foundation for W.M. Davis to develop his well known 'Cycle concept'.

J.W. Powell explored the treacherous rapids of the Colorado Canyon. By studying geological structure and giving the concept of 'Base level' of erosion he laid the foundation for American school of geomorphology. Along with recognition of base level erosion, he contributed to different types of erosion Scraps.

G.K. Gilbert is considered as an important geomorphologist of American school of geomorphology. His areas of contribution belong to subareal erosion and its modifications which concerned the lateral plantation by streams and development of valleys. He made first quantitative assessment and mining debris relating to their role in river load/ volume, velocity and gradient. He made important contribution on origin of salt lake, Henry Mountains of Utah and origin of fault block of Great Basin region.

C.E. Dutton was equally famous geomorphologist of USA. He worked on erosional surfaces of Colorado plateau "The Great Denudation".

W.M. Davis (1850-1934) is considered as 'the great definer and analyst' of landforms. In fact, the Davisian school of geomorphology and the American school are practically synonymous. It is said that, W.M. Davis breathed new life into geomorphology through introduction of his genetic method of land form description. His famous geomorphic cycle he has stated that 'evolution of landscapes there is a systematic sequence of land forms which makes possible the recognition of stages of development, a sequence that he recognized as 'youth maturity and old age'.

Though **Walther Penck** provided an alternate view of evolution of landforms, there is no satisfying theory which totally refute Davis. But, off late in 1960's **'Hack'** developed what he called the 'Theory of dynamic equilibrium' which supports Davis view on the evolution of Geomorphology.

In the later half of 20th century geomorphology armed with quantitative techniques, remotely sensed data, more refined methods determining age of earth materials have made it to emerge as an applied branch of geology and geography. Both in Europe and North America there is a remarkable development of geomorphology both as an academic and applied discipline.

Note: Since 1950 Indian scholars, geographers, geologists have initiated geomorphological studies in the university of Pune (K.R. Dixit and Kale et. al.); University of Waltair (Dr. Vaidyanathan et. al); Universities of Rajastan (Sharma et. al); CAZRI Jodhpur (Bimal Ghrsh etc.) and in their universities (Ranchi, etc.) of Northern India (see Geomorphology by Savindran Singh for Indian contribution to Geomorphology).

1.6 LET US SUM UP

In this very first unit of Geomorphology we discussed the definition, field, scope and evolution of Geomorphology. Geomorphology is the science of land forms. It encompasses as a branch of geology and physical geography the basic concepts, drainage patterns, weathering and mass wasting and resultant landforms. It also contains endogenetic forces (earthquakes and volcanoes) and exogenetic forces or processes of erosion like streams, glaciers, wind underground water and sea waves and their stage wise evolution of land forms.

In this section emphasis was laid on the evolution of subject Geomorphology through Historic period, premodern period (Pre Hutton); Modern period i.e., Hutton and Playfair times; its scientific development in Europe and phenomenal development in North America. Under each of these period of evolution of geomorphology, respective ideas and concepts and scholars, geologists who have made significant contribution were discussed. For example under the period of phenomenal growth in north America Powell- Base level of erosion, Davis-Geomorphic cycle like concepts and contributors have been discussed with some details.

1.7 KEY WORDS

Land forms- Phases of evolution – Historic period – Pre modern – Hutton & Playfair times – European geomorphic contributors – North American contributors – Quantitative and Applied Geomorphology – Endogenetic and Exogenetic forces / Processes – Geomorphic cycle – Uniformitarianism- Base level- Paleo Geomorphology – Glacial Geomorphology-Pleistocene glaciations – theory of Dynamic Equilibrium.

1.8 QUESTIONS FOR SELF STUDY

1. Define Geomorphology and explain its field.
2. Explain the scope of Geomorphology
3. Discuss the evolution of Geomorphology in Historical Greeco- Roman period.
4. Bring out the Arabs contribution to Geomorphology under Modern period (pre Hutton).
5. Examine the salient features of evolution of Geomorphology under Modern era of Hutton and Playfair.
6. Trace the evolution of Geomorphology during 18^{th}, 19^{th} and 20^{th} century in Europe.
7. Discuss the evolution of Geomorphology in North America.
8. 'There is a noticeable contribution by Indian scholars to Geomorphology since 1950's'. Discuss.

1.9 FURTHER READING

1.	Thornbury W.D. (1984)	:	'Principles of Geomorphology', 2^{nd} Edn., Wiley Eastern Ltd., New Delhi, Pp.1-15.
2.	Yakushoun A.F. (1986)	:	'Geology with the Elements of Geomorphology', Mir Publishers, Moscow.
3.	Savindra Singh (1998)	:	'Geomorphology', Prayag Pustak Bhavan, Allahabad, Pp.1-11 (for Indian contribution to Geomorphology).

UNIT : 2 BASIC CONCEPTS OF GEOMORPHOLOGY – PART- I

Structure

2.0 OBJECTIVES

In this sub unit of Geomorphology in its early part emphasis is laid to provide information on basic concepts of Geomorphology. Though there are ten basic concepts, some first five are discussed in this Unit.

After studying this unit, you will able to

- Identify the first list out all the ten basic concepts in order to have a birds eye view of them.
- Define the meaning and nature of Geomorphic process and the nature of operation.
- Relate the what is geologic structure and its role in the evolution of landforms.
- Explain how the landform features on earth's surface is also due to operational variations in the geomorphic process.
- Discuss how each geomorphic process has its own set of land forms and leaves its imprint on the landforms.
- Explain how land forms are produced by each geomorphic process have sequential development.

2.1 INTRODUCTION

Before going into the detailed study of different geomorphic processes operating both within and outside the earth's curst, there is a need to understand the basic concepts of geomorphology. There are about ten basic Geomorphic concepts in the famous text book of Geomorphology (Thornbury). Each one of them dwelve on unique concept of Geomorphic processes which are delt in detail later in the subject of Geomorphology. A brief study of them helps to get an over view of not only those process but their allied factors like role of structure, sequential development of land form, differential rate of their operation in the geologic past and the like. In fact, these basic concepts of Geomorphology form foundation for the further study of Geomorphology. However, in this unit first five are taken up for their detailed discussion and in the next sub unit the other five will be discussed.

2.2 LIST OF BASIC CONCEPTS OF GEOMORPHOLOGY

Ten Concepts :

1. The physical processes and laws that operate today operated through out geologic time although not necessarily always with the same intensity as now.

2. Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them.
3. To a large degree the earth's surface possesses relief because the geomorphic processes operate at differential rates.
4. Geomorphic processes leave their distinctive imprint upon landforms, and each geomorphic process develop its own characteristic assemblage of landforms.
5. As the different erosional agents act upon the earth's surface there is produced an orderly sequence of landforms.
6. Complexicity of geomorphic evolution is more common than simplicity.
7. Little of the earth's topography is older than Tertiary and most of it no older than Pleistocene.
8. Proper interpretation of present day landscapes is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene.
9. An appreciation of world climates is necessary to a proper understanding of the varying importance of the different geomorphic processes.
10. Geomorphology, although concerned primarily with present day landscapes, attain its maximum usefulness by historical extension.

Let us take first five concepts of geomorphology for their detailed study in this lesson.

2.3 THE SAME PHYSICAL PROCESSES AND LAWS THAT OPERATE TODAY, OPERATED THROUGH OUT GEOLOGIC TIME, ALTHOUGH NOT NECESSARILY ALWAYS WITH THE SAME INTENSITY AS NOW':

'The same physical processes and laws that operate today, operated through out geologic time, although not necessarily always with the same intensity as now':

This concept represents the basic principle of modern geology viz., 'The principle of uniformitarianism' which was basically put-forth by Hutton. He also enumerated the related concept 'Present is key to the Past' where he applied the aforesaid concept rigidly and said that the geologic process operated in the past and present with same intensity but it is not so. For example, glaciers as geomorphic process of sculpting the earth's crust in certain areas were very vigorous during Pleistocene ice ages. Now, their intensity is not so widespread and confines to high mountains and polar regions only. But during ice ages there were extensive continental glaciers covering half of northern hemisphere and even lower reaches of mountains. There are evidences that, Himalayan Valley glaciers were stretched to lower areas beyond Siwaliks. Present desert areas like Thar of India and even mighty deserts like Sahara had different climate and were humid with lush vegetation. Heavy rains and stream erosion was active on those days compared to present wind erosion in those areas. Even volcanoes were much more extensive and intense in the later Cretaceous period which leads to formation extensive lava plateaus across the world. This concept stresses the principle of uniformitarianism i.e., 'Present is key to the past' but this must be remembered that though the processes operating were same but operated with different intensity.

2.4 FUNDAMENTAL CONCEPT NO.2

'GEOLOGIC STRUCTURE IS A DOMINANT CONTROL FACTOR IN THE EVOLUTION OF LANDFORMS AND IS REFLECTED IN THEM' :

Geologic structure was clearly stated by W.M. Davis in his famous 'Geomorphic cycle concept where he explains the three major factors which, determine the evolution of land forms and they are 'Structure, Process and Stage'. There are geologists who doubt the role of stage in the evolution of land forms but no geologist doubt the role of structure. The term structure not only includes rock features like folds, faults and unconformities but it includes all those ways in which the earth materials out of which land forms are carved. They differ from one another in their physical and chemical properties. Other aspects of rocks like the presence or absence of joints, bedding planes, faults and folds, the physical hardness of rocks, rock massiveness and the susceptibility of the mineral constraints to chemical alteration, the permeability on impermeability of rocks and in many other ways rocks of earth's crust differ from one another.

Some example will illustrate the role of structure in the evolution of land forms. Lime stones are weak structure in a humid region but they are strong resistant structure in dry climatic desert regions.

Some structural features of rocks are older than the geomorphic forms developed upon them. The folds, faults, synclines and anticlines of Himalayas are older than the 'U' shaped valleys or subsequent 'V' shaped valleys and moraines. Rising granitic domes and volcanic cones have often lead to radial drainage with 'Tauls' and 'Fans' in their foothills. With the advent of aerial photo interpretation it is possible to bring pictorial presentation of role of structure and its influence on the evolution of land forms.

2.5 FUNDAMENTAL CONCEPT NO.3

'TO A LARGE DEGREE THE EARTH'S SURFACE POSSESSES RELIEF BECAUSE THE GEOMORPHIC PROCESSES OPERATE AT DIFFERENTIAL RATES' :

There is no doubt that underlying rocks, lithology having varying resistance and result in differential erosion and also different landforms. But they are by no means the only reasons why geomorphic processes may change notably in response to differences in such factors as temperature, moisture. Altitude, exposure, topographic configuration and even type of vegetation cover. The micro climatic conditions may vary markedly between a valley floor and hill top, between northern and southern exposure and between bare ground and that with a heavy vegetation cover. Slopes of Western Ghats and Himalayas have such topographical and stratified vegetation and variations in climate. These aspects certainly bring in differential rates of operation of prevailing exogenetic processes. On a bare rocky slope winter snow slips faster than relating low gradient region Himalayas. Valleys deep cutting is high in these hilly and treacherous mountain slopes forming gorges, water falls. Sunny moisture ridden section have better vegetation cover protecting areas from on slaught of rains and weathering than bare slopes.

So, it is stated that, complex are the many factors influencing the local rates of geomorphic processes that it is probably not much of an exaggeration to state that the rate of all weathering, all mass-wasting, all erosion and all deposition varies appreciably within rather narrow limits in relation to the influence of local conditioning factors.

2.6 FUNDAMENTAL CONCEPT NO.4

'GEOMORPHIC PROCESSES LEAVE THEIR DISTINCTIVE IMPRINT UPON LANDFORMS AND EACH GEOMORPHIC PROCESSES DEVELOP ITS OWN CHARACTERISTIC ASSESSMBLAGE OF LANDFORMS' :

The term process refers to all many physical and chemical ways by which earth's surface undergoes modification. Look at hills in our surroundings, one can see evidences of mechanical and chemical weathering of rocks. Simple glance at them reveal how some rocks precariously balance, sit one over other or weathered boulders have rolled down to foot hills where the former indicates absence of earthquakes for a longer period whereas the later denotes an earthquake in the region in the recent past.

Some processes such as diastrophism and volcanism, originate from forces within the earth's crust and they are known as 'Endogenetic' (Penck) and others like weathering, mass wasting and erosion have been term as 'Exogenetic'. In general endogenetic processes tend to build up or restore areas which have been worn down by the exogenetic processes; otherwise the earth's surface would eventually become largely featureless. Operation of these processes was known to our elders but they leaving their own imprint on landforms in rather new.

Landforms have their own individual distinguishing features dependent upon the geomorphic processes responsible for their development. Streams build flood plains, alluvial fans and deltas with their host of other erosional features in their upper courses. Similarly, fascinatingly both erosional and depositional features are there by work of under ground water like Sink holes and Caverns to name a few. 'U' shaped valleys, end moraines and Drumlins can be seen with a host of other features in a region where once glaciers were active and has left its own imprint on the landforms. As W.M. Davis said their genetic classification is possible under each geomorphic process.

2.7 FUNDAMENTAL CONCEPT NO.5

'AS THE DIFFERENT EROSIONAL AGENTS ACT UPON THE EARTH'S SURFACE THERE IS PRODUCED AN ORDERLY SEQUENCE OF LANDFORMS' :

W.M. Davis in his famous 'Geomorphic Cycle' has said that, the cycle contains in any geomorphic process the influence of structure, process and stage, but also in each stage e.g., youth, maturity and old stages. In each stage of an individual geomorphic process has carved out or deposited its own set of landforms. Though all geomorphologists do not completely agree with Davisian concept of geomorphic cycle and orderly development of land forms, after Davis there is no convincing similar concept to explain the stages and sequential landforms. Hence, though landform evolution and their assemblage in detail appears complex, but, it is not only safe but quite convincing to accept geomorphic cycle and each geomorphic process has developed landforms which are orderly and sequential. For example a glacial process in its youth stage it has Arêtes, saw tooth ridges, matterhorns, hanging valleys etc. In its maturity stage vast continental glaciers have a variety of moraines. In its old /deposition stage thawing of glacier has built drumlins, Eskers Kames and Erratic blocks and the like. This kind of assemblage of landforms is possible for each geomorphic processes often with complexity in their formation and distribution in a given region.

In reality there will be partial cycles than fully completed ones with total reduction of landscape to the level of peneplain. There are evidences of such partial cycles and also regions which stood stable for considerable length of geological time which lead to quite reduction of topography to the base level or even paneplain level. It is said that in areas of active diastrophic movements like California or our Himalayan region of continuous uplift or intermittent uplift completion geomorphic cycle may not be seen.

2.8 LET US SUM UP

In this part of Unit-I we discussed the first five geomorphic concepts. The first concept was about how geomorphic process acting today in shaping the land forms were also acting in the geologic past but not with the same intensity. In the second concept we critically evaluated the dominant control of structure in the evolution of land forms. Then the third concept explained that, much of the earth's surface has land forms which are the result of differential rates of erosion by each process. The fourth geomorphic concept we saw the elucidation of how each geomorphic process leave their distinct imprint on landforms but also have their own set of landforms. In the end, the fifth concept brought to us that how with the progression of each geomorphic process led to formation of orderly and sequential development of land forms.

2.9 KEY WORDS

Ten Basic concepts – Physical processes- Intensity – geologic structure – Dominant control – Evolution of land forms – Differential rates – Distinctive imprint – Orderly sequential development – Complexity of land forms – Tertiary – Pleistocene- Present day landscapes- Manifold influences – World climates – Present is key to the past – Concept of Uniformitarianism – Structure- Process & Stage – Endogenetic forces – Exogenetic forces.

2.10 QUESTIONS FOR SELF STUDY

1. Give a list of fundamental concepts of geomorphology from concept 1 to 5 and explain any one of your choice in detail.
2. Examine the concept no.1, 'The same physical processes and laws that operate today operated through out Geologic time, although not necessarily always with the same intensity as now'.
3. 'Geologic structure is a dominant control factor in the evolution of land forms and is reflected in them'. Discuss.

4. Write a critical essay on concept no.3 'to a large degree the earth's surface possess relief because the geomorphic processes operate at differential rates'.

5. Explain how the 'geomorphic processes leave their distinctive imprint upon land forms, and each geomorphic process develops its own characteristic assemblage of land forms'.

6. Bring out the concept no. 5 'As the different erosional agents act upon the earth's surface there is produced an orderly sequence of landforms.

2.11 FURTHER READINGS

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2.	Savindna Singh (1998)	:	"Geomorphology', Prayag Pustak Bhavan, Allahabad, Pp.25-49.
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UNIT : 3 BASIC CONCEPTS OF GEOMORPHOLOGY- PART- II

Structure

3.0 Objectives

3.1 Introduction

3.2 List of fundamental concepts (no.1–10) here no.5 to 10

3.3 Fundamental concept no. 6

3.4 Concept no. 7

3.5 Fundamental concept no. 8

3.6 Fundamental concept no. 9

3.7 Fundamental concept no. 10

3.8 Let us sum up

3.9 Key words

3.10 Questions for self Study

3.11 Further readings

3.0 OBJECTIVES

In this third sub section of first unit we will discuss remaining five fundamental concepts of geomorphology. In all, there are ten fundamental concepts and in the previous section concept No. 1 to 5 were discussed. Now, if we come to remaining five serially they have the following objectives :

After studying this unit, you will be able to

- Memorize the detailed study of any region of the earth's surface in general we see complexity in land forms than simplicity. Concept No. 6 has this theme and associated details.
- Realize the concept No.7 reveals that more or less upper most crustal topography of the earth has relatively younger land forms which either belong to tertiary or pleistence times.
- Recognize concept No.8 has the objective of explaining how it is important to understand present day land forms there is a need for understanding influences of underlying structure and climatic changes which happened in Pleistocene period.
- Demonstrate the another objective of this sub section is to explain the importance of understanding of the role of world climates which have significant influence on various geomorphic processes.
- Interpret the last objective of this subsection is to describe how geomorphology being a subject of land forms, to explain them in their present status, it is to a great extent necessary to go back to geological history.

3.1 INTRODUCTION

After understanding some first five fundamental concepts like the meaning, nature and functioning of geomorphic processes which have varying intensity, land forms evolution has significant control of underlying structure; earth's surface has present topography due to the operation of both endogenetic and various exogenetic processes, these geomorphic processes have dinctinet imprint on land forms at the same time they develop their own set of land forms; also as they work on landforms they have sequential development like youth, maturity and old age land forms in each geomorphic processes.

At the same time in studying land forms across the world one will observe there is complexity than simplicity in their very evolution. Most of the topography is not older than Pleistocene ice age and little of it is older than tertiary indicating the dynamism of land for evolution on the earth's crust. Proper analysis and detailed study of land forms demands appreciation of both the underlying structure and Pleistocene climatic conditions of the earth. There is also a strong influence of world climate on the working of different geomorphic processes. In the study of land form of present day there is a need to look into their geologic past i.e., how endogenetic forces influenced in their building and later geomorphic sculptured than depending on structure.

3.2 LIST OF FUNDAMENTAL CONCEPTS NO.6 TO 10 (as in Thornbury book) :

Concept No.6 : 'Complexity of Geomorphic evolution is more common than simplicity.'

Concept No.7 : 'Little of the earth's topography is older than tertiary and most of ok is no older than Pleistocene'.

Concept No.8 : 'Proper interpretation of present day landscapes is impossible with out a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene'.

Concept No.9 : 'An appreciation of world climates is necessary to a proper understanding of the varying importance of the different geomorphic processes'.

Concept No.10 : 'Geomorphology, although concerned primarily with present day landscapes, attains its maximum usefulness by historical extensions.'

3.3 FUNDAMENTAL CONCEPT NO.6

COMPLEXITY OF GEOMORPHIC EVOLUTION IS MORE COMMON THAN SIMPLICITY :

A detailed study of land forms across the world reveals that, little of the earth's topography can be explained as the result of the operation of a single geomorphic process or a single geomorphic cycle of development. Usually most of the topographic details have been produced during the current cycle of erosion, that there may exist within an area remnants of features produced during prior cycles. At the same time there are many individual land forms which can be said to be the product of some single geomorphic process. It is a rare thing to find landscape assemblages which can be attributed solely to one geomorphic process, even though commonly we are able to recognize the dominance of the for Ex: in Karnataka along river Cauvery there are Talakad Sand Dunes it appears, they have been formed by river erosion and deposition, but they are the result of strong premonsoon winds carrying sands from dry river bed where there is lean water supply in April, May etc. Between Ramanagara and Bangalore, South to North running younger granitic hills standing amidst of champion Gneisses are another example for hills formed by plutonic volcanoes into non-fossilized Archean rocks.

This concept of existing complexity in land forms than their simplicity can be better understood by their classification into –

(a) Simple landscapes - are the product of a single dominant geomorphic process ex: coastal features by sea waves and Thar desert sand dunes and the like.

(b) Compound landscapes - are those in which two or more geomorphic processes have played major roles in the development of existing topography. Ex: Himalayas have been formed by plate tectonics at the same time they have river erosion features like Giligit Gorge on river Indus, foot hill alluvial fans and the like. Prominently they have a host of glacial features belong to later Pleistocene and even recent (Holocene) landforms like glacio-flucial landforms on Tertiary beds.

Hence, often it is said that, nearly all landscapes are compound in nature, it is hard to find an extensive area in which the land forms can be attributed solely to the action of one process. However, it is convenient to group and study landforms based on dominant process at work in a given region. Like land form by work of river, by wind, by glacier, by underground water and landforms by the work of sea waves. But closer examination reveals that presence of compound landscapes in most part of the earth's surface.

For further clarification of landforms, analysis and their evolution in a geomorphic cycle concept, they have been grouped as-

(i) Mono cyclic landscapes: are those which bear the imprint of only one cycle of erosion. (ii) Multi cycle landscapes: have been produced during more than one cycle of erosion. Again this later multi cycle landscapes are more common than the former monotype. Mono cyclic landscapes confine to newly created land surfaces as a recently uplifted portion of the ocean floor, the surface of volcanic cone, lava plain or plateau on areas buried beneath a cover of pleistseene glacial deposits. These can be seen in half of northern side of n. hemisphere in temperate lands. Much, if not most, of the world's topography bears the imprint of more than one period of erosion. The older erosional topography may be represented only by limited upland remnants like our southern peninsular India. This kind of landscapes of multi cyclic can be seen in all continents except Antarctica. It is also important to remember that both mono and multi cyclic landscape may be either simple or compound in nature.

Recent studies in Geomorphology have added new terminology to landscape classification and they are:

a) *Poly climatic landscapes*– which have evolved under more than one set of climatic conditions with accompanying variation in the dominant geomorphic process.

b) *Exhumed on Resurrected landscapes* – are those which formed during some past period of geologic time, then buried beneath a cover of igneous or sedimentary origin. Then later exposed through removal of the cover. Topographic features now being exhumed may date back as far as pre Cambrian or they may be as recent as the Pleistocene. In the present times, stream erosion in North hemisphere is exhuming landscapes buried under the Pleistocene deposits (See P.25, Thornbury- Geomorphology for details).

3.4 CONCEPT NO.7

'LITTLE OF THE EARTH'S TOPOGRAPHY IS OLDER THAN TERTIARY AND MOST OF IT NO OLDER THAN PLEISTOCENE' :

Another concept in which content appears same but these trees is on the time of land forms development is concept No.7 in geomorphology. Though some geologists refer certain landscapes origin to Createrious or even pre Cambrian times but off-late, there is a strong opinion towards that topographic features so ancient are rare and if they exist are more likely exhumed forms. Most of the details of present topography probably do not date back of the Pleistocene. Certainly little of it existed as surface topography back of the tertiary. Geologists like Ashley has said that, at least 90% of our present land surface has been developed in post tertiary period time and perhaps 99% is post middle Miocene age.

It is of course, true that many geologic structure are very old ex: Peninsular India which has Precambrian rocks. It has been previously stated that geologic structures are in general much older than the topographic features developed upon them. Example of our Himalayas proves these aspects of this concept. Himalayas were probably first folded in the Cretaceous and later in the Eocene and Miocene but their present elevation was not attained until the Pliocene and most of the topographic details is Pleistocene on later in age. Even Rocky Mountains of North America present same temporal scenario of landscape development.

3.5 FUNDAMENTAL CONCEPT NO. 8 :

'Proper interpretation of present day landscapes is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene.'

The geologic and climatic changes during the Pleistocene have had far reaching effects upon present day topography. Glaciations directly affected nearly 6.25 million sq. km. But its effects extended far beyond the areas actually glaciated. Ex: In Himalayan region during Pleistocene times valley glaciers extended beyond Siwaliks which has come to light by the presence of erratic blocks. Glacial outwash and wind blown materials of glacial origin extended into areas not glaciated, and the climatic effects were probably world wide in extent. Certainly in the middle latitudes the climatic effects were profound. It is quite clear that, many regions that are today arid or semi arid had humid climates during the geological ages. Ex: Thar Desert of India, studies in CAZRI- Jodhpur have proved that it had humid climate with continuous natural drainage across the present desert. In other deserts of today, then existed fresh water lakes which today have interior drainage. Western United States had at least one hundred closed basins and Pleistocene lakes in them. Similar evidence of pluvial conditions in regions now arid or semiarid has been found in Asia, Africa, South America and Australia. This proves profound effect of glaciations upon climates.

Present temperate regions of North America and Eurasia have experienced almost polar temperature conditions and there existed permafrost conditions. Stream erosion regions were affected by the climatic changes and we find evidence of alternation of periods of aggradations and down cutting of valleys. Many streams courses were profoundly affected and altered as a result of ice invasions. River valleys show evidences of such fluctuation resulted features. World sea levels were also affected. Withdrawal of large quantities of water from the oceans to form great ice sheets produced a lowering of sea level of at least 100 to 150 meters. Return of this water to oceans during the interglacial ages caused a return of high sea levels which is the feature of present geologic time. The discharge of cold melt glacial waters to the oceans may have had significant effects upon certain marine organisms such as the reef building corals. Winds blowing across glacial outwash plains or fresh glacial deposits in many areas built up dunal accumulations of sand or deposited silt and clay called 'Loess'. Glaciation has been responsible for the formation of more lakes than all other causes combined Ex: Lakes of Canada and Scandenivan countries. The great lakes of USA and Canada, world's greatest internal waterway system are the result of glacial modifications of preglacial low lands and valleys.

3.6 FUNDAMENTAL CONCEPT NO. 9

'An appreciation of world climates is necessary to a proper understanding of the varying importance of the different geomorphic processes'.

This is a rather brief concept among ten concepts of geomorphology. This is partly due to both geologists and geographers for one reason or the other have not given importance to the operation of elements of weather and climate their exact influence on the landscape. However, the climatic factors, particularly those of temperature and precipitation have positive influence on the very operation of geomorphic processes.

Climatic variations may affect the operation of geomorphic processes either indirectly or directly. The indirect influences are largely related to how climate affects the amount, kind and distribution of the vegetation cover. Ex: Western of Western Ghats and Siwalik Himalayas have thick forests certainly this vegetation covers slows down stream process of erosion compared to bare slopes. The direct controls are the amount and kind of precipitation, its intensity, the relation between precipitation and evaporation, daily range of temperature, whether and how frequently the temperature falls below freezing, depth of frost penetration and wind velocities and directions. There are however, other climatic factors whose effects are less clear, such as how long the ground is frozen, exceptionally heavy rainfalls and their frequency (arid region- wind action with streams), seasons of maximum rainfall, frequency of freeze and thaw days, differences in climatic conditions as related to slopes facing the sun and those not exposed, the differences between conditions on the windward and iceward sides of topographic features transverse to the moisture bearing winds, and the rapid changes in climatic conditions with increase in altitude (stratified climate – vegetation cover in Himalayas…).

Most of the geomorphology literature in the processes has evolved under trumid temperate climatic generalizations, off-late there is a considerable development about theorization of taking into account of climatic conditions of lower latitudes towards understanding their influences on the process and landscape evolution. High altitudes within any climate realm impose modifications which should also be considered.

3.7 FUNDAMENTAL CONCEPT NO. 10

'Geomorphology, although concerned primarily with present day landscapes, attains its maximum usefulness by historical extension'.

In this last concept of geomorphology we will discuss about to analyze present day landscapes one must look into the geologic past of that region and process. In fact this concept systematic application, of concept of uniformaitarianism or 'present is key to the past'. In true sense geomorphology is concerned with the origin of present day landscapes. But in most landscapes there are present forms that date back to previous geologic epochs or periods. For ex: the north western lava plateau region of India (Maharastra etc.) has present landscape with Mesha, Butte, erosion lava surfaces / terraces like topography. Their complete understanding of leads to cretaceous period when lava plateau formed and subsequent periods too. Present glacio-flucial deposits and Erratic blocks takes us to whole of Pleistocene period.

However, some geologists who deal with such past geological periods from the point of view of analyzing very evolution of land forms call this as 'Paleogeomorphology'. Famous geologists have drawn the attention of geomorphists, this distinction of general geomorphology (science of present day landforms) with 'Paleogeomorphology' or historical geology. Off late there is an opinion that geomorphology must adopt this historical geological approach in the study of landforms which will enable it to become an applied discipline for practical applications.

3.8 LET US SUM UP

In this section we discussed second half of five fundamental concepts of Geomorphology. Starting from concept No. 6 which went into details of how landscapes across the world are complex/ compound in nature of their evolution than simple features. In the next, concept No. 7 we discussed about how outermost earth's surface landforms are geologically younger that too most of them belong to post

Pleistocene period and a few of them just older than tertiary. Under concept No. 8 we had lengthy account of climatic changes particularly Pleistocene ice age which is necessary for the proper interpretation of landscapes across the world. This is particularly true in the case of mid-latitude temperate zones landforms of north hemisphere. Under concept No.9, we went into details of how all the geomorphic process and their creation of landforms need an appreciation of world climates. Elements of weather and climatic factors affect in a region that too with elevation differently on geomorphic processes. In the end briefly we discussed on how, though geomorphology is a science of present day landforms, yet when it takes into consideration older geological aspects of land forms i.e., 'Paleo-geomorphology' only then there will be full understanding of land forms. This approach makes geomorphology as an applied subject.

3.9 KEY WORDS

Cycles of erosion- Simple – Compound- Mono- Cyclic Multi-Cyclic- Exhumed - Resurrected landscapes- Poly- Cylic landscapes- Tertiary- Precambrian- Createaecous- Pleistoncene- Post Micocene- Eocene geologic times- Pleistocene climate changes- Glaciations- Fresh water lakes- Permafrost conditions- world sea levels- Release of cold glacial waters- Marine organis- Coral reefs - building- Climate minded geographers- Unclimatic mind of geologists- Climatic variations- Direct- Indirect variations- Humid temperate regions- High altitude- Placeo- geomorphology- Practical applications.

3.10 QUESTIONS FOR SELF STUDY

1. Explain the concept 'complexity of geomorphic evolution is more common than simplicity'.
2. Define terms (with suitable examples of land forms): (i) simple landscapes; (ii) Complex / Compound landscapes; (iii) Mono cyclic; (iv) Multi cyclic / polly cyclic landscapes; (v) Exhumed or Resurrected landscapes.
3. Bring out the salient aspects of concepts 'little of the earth's topography is older than Tertiary and most of it no older than Pleistocene'.
4. With suitable example examine the climate changes of Pleistocene ice age and its influence of world's land forms.
5. Examine the influence of 'Climatic variations' and their influence on the performance of various geomorphic processes.
6. What are the 'Direct' and 'Indirect' controls of climate on landforms and performance of geomorphic processes.

7. Describe the concept Geomorphology- although concerned primarily with present day landscapes, attains its maximum usefulness by historical extension.

8. Define and add a detailed note on 'Paleo-Geomorphology and Historical Geology

3.11 FURTHER READINGS

1.	Thombury, W.D. (1984)	-	"Principles of Geomorphology", 2nd Edn., Wiley Eastern Ltd., New Delhi, Pp.23-33.
2.	Savindra Singh (2005)	-	"Geomorphology", Praying Pustak Bhavan, Allahabad, Pp.24-56.
3.	White, J.F. (1972)	-	"Study of the Earth Readings in Geological Science", Prentice Hall of India Pvt. Ltd., New Delhi, Pp.203-271.

UNIT : 4 APPLIED GEOMORPHOLOGY AND GEOLOGICAL TIME SCALE

Structure

4.0 OBJECTIVES

In this unit of block I, we will be discussing broadly two themes viz., applied aspects of geomorphology followed by Geological time scale. These two consist the following objectives

After studying of this unit, you will be able to

- Recognise the Application of concepts of geomorphology to the field of hydrology i.e., behaviour of limestone topography in yielding water for human consumption.
- Explain the Behaviour of glacial land seapes particularly the depositional surfaces in containing water; reservoir and road building.
- Describe how surface expression of topography and related land forms indicate mineral depositions? i.e., utilization of geomorphology for the exploration of mineral resources.
- Discuss the Application of geomorphology in the petroleum oil exploration through studying surface drainage patterns.
- Interpret the importance of geological time scale in the study of geomorphology. In fact we will have a table showing geological time scale with Eras, Epoches and periods with some major events of macro land formations on the earth's surface.

4.1 INTRODUCTION

In the last less than a century this common area of study 'Geomorphology' between geography and geology has emerged as an applied subject. This is particularly true in its application in understanding the behaviour of karst landscapes regarding hydrology. Compared to geography which examines the distributional aspects scientifically geology has made use of geomorphology for mineral exploration, reserviour and road building like engineering constructional activities. At least in U.S.A. there are ample studies under geomorphology in the scientific analysis of topographical and geological expression of drainage and land forms as an indication of underlying mineral resources particularly salt domes indicating oil serviors. Now it is evident that, knowledge of geomorphology helps in effective municipal water supply, high way or road building and they will be long losting if proper geomorphology is applied. Even the study of soil erosion and beach engineering are benefited by the application of geomorphology.

4.2 APPLICATION OF GEOMORPHOLOGY TO HYDROLOGY

By applying geomorphology to limestone areas their aspects like primary permeability and secondary permeability can be better understood. Aspects of present limestone layer capping with erosional surfaces, solutional cavities level of water table and movement of groundwater in the karst terrain etc., their study with geomorphology helps in location and utilization of ground water. There are good numbers of such studies in USA (Thornbury, Pp.539-542). Ex: Solutional cavities are common at considerable depth in the tertiary limestones of Florida. In orange country, some 76 cavities were reported at depth's down to as much as 558 feet below sea level. The distribution of these cavities along with their decrease in size and number with distance from recharge and discharge areas seems to suggest that they formed during times of pleistocene low sea levels, as there presently appears to be very little circulation in the deeper parts of acquifers. It is said that, the ability to recognize ancient Karst topographies, now buried becomes important in the evolution of the water yielding possibilities of some regions, for such regions lowered water table under hydrostatic head may yield water in great quantities. There are instances where, swallow holes and sink holes feed water to the underground drainage systems which emerge as springs. Knowledge of structural geology of the region is important here, for understanding ground water movement which moves more readity down than up the regional dip.

Glaciated regions and hydrology :

Over much of North America ground water for domestic and industrial purposes is obtained from glacio-fluvial deposits. Recognition of the possibilities of large quantities of ground water from glaciated areas largely depends upon familiarity with the types of deposits from which large yields can be obtained, along with an understanding of the geomorphic history of the area during both pre-glacial and glacial times. Outwash plains, valley terrains and interfile gravels are buried outwash are particularly likely to yield large volumes of water. Most tills are poor aquifers because of the clay in them. But they contains local lenses of sand and gravel which may supply enough water to meet domestic needs. Surface topography rarely gives a clue to the existence of such water bearing lenses. But they are likely to be more abundant in adjacent areas to lines of glacial drainage and they commonly are elongated in the direction of glacial movement.

There are glacial deposional buried valleys and they are destined to play an increasingly important role in water supply. In sub Himalayan /Siwaliks of North West India as the region receives relatively poor rainfall compared to other parts, identification such buried valley and helps in augmenting domestic water supply. Elsewhere, their full utilization awaits a determination of their distribution by geologists versed in the preglacial and glacial history of the regions in which they may be found. Water from such valleys is in particular demand (North America) for use in air-conditioning because its temperature is notably lower than summer time temperatures.

Now, geologists are contemplating that, buried valleys can be made use of ground water reserviours like how some exhausted oil and gas fields used for storage of gas for later use in times of heavy demand.

4.3 APPLICATION OF GEOMORPHOLOGY AS A TOOL IN ECONOMIC GEOLOGY

Understanding geomorphic features and their history in a region helps in the exploration of minerals. There are three broad ways in which exploration of minerals based on knowledge of geomorphology helps and they are :

(i) Some mineral deposits have a direct topographic expression :

It has been noticed that, outcrops of ore, gossan or residual minerals or such structural features as fractures, faults and zones of breccia have been formed as a result of mineral content and differential erosion. Numerous examples of positive topographic features which mark the sites of lodes exist. Ex: The Lead-Zinc of broken-hill, Australia is marked by a conspicuous ridges. Santa Barbra (USA) and Mexico Massive Quartz Veins stand out conspicuously because they are much more resistant to weathering and erosion and stand out as hills and ridges.

Some Veins and mineralized areas may lack conscpicuous expression or be reflected by depressions or subsidence features. Ex: Calcite Veins represent such features in USA (Arizona). Shrinkage of ore bodies during oxidation give rise to what is known as 'mineralization slump' has been observed in several localities. Ex: Sierra Mojada, Mexico and Bisbee-Arizona. At Bisbee the effect was much the same as that produced by stope mining. Recognition of this type of mineral ore body, helped Bisbee copper mining development by USA. Identification of 'Oxidation Subsidence' surface manifestation in USA helped in mapping of the areas and existence of ore bodies. The iron ore bodies of like superior region are so commonly associated with hills and ridges that the term iron range has been implanted in the literature.

In Karnataka Dharwar Schist belt – Belligudda near Chitradurga and Kunduremnk peak appears to be of this kind but need further geomorphological analysis, right now discovery of copper and iron ore respectively but need more geological investigation. It is worth noting that, when the higher grade ores of the middle latitudes have been exhausted, the lateritic deposits of tropical and sub tropical regions may become important economic ores and search for them will entail application of some knowledge of ancient geomorphology and climates. Bog iron ore deposits are usually local and limited extent but they are found under definite topographic conditions that are easily recognizable. Bauxite is a weathering residue. The aluminous laterites of the West Indies apparently are examples of first class, for they seem to represent concentrations through weathering of small amounts of alumina in limestones and dolomites. Weathering surface which has sink holes provide favourable sites for accumulation of aluminous laterite.

In temperate climates the residual products from the weathering of igneous rocks have clay minerals. This type of weathering has been termed as 'Kaolinization', but it should be recognized that numerous minerals other than Kaolin may form. On the other hand under tropical climates final weathering products are hydrous oxides of such metals as aluminum, iron and manganese. This type of weathering has been called 'Laterization'. Weathering residues are definitely to be associated with old 'weathering Surfaces' at or near peneplane stage of a geomorphic cycle. Probably iron, manganese, Bauxite like minerals of peninsular India can be cited here.

Placer deposits and principles of Geomorphology :

Geomorphic principles have been applied to the location of placer deposits more than to any other phase of economic geology. Placer concentrations of minerals result from any definite geomorphic processes are found in specific topographic positions, and may have distinctive topographic expression. As many as nine type of placer deposits have been recognized. They are- residual, colluvial, Eolian, bajada, beach, glacial including end moraines and valley trains buried and ancient placers. Alluvial placers are most important. At least one type with its example is desired here- In India Travencore- Kerala coast has beach placers have monazite and it is obtained. California (USA) Gold; Namaqua land of South Africa Diamonds; Zircon is available in placers in India, Brazil and Australia.

4.4 APPLICATION OF BEOMORPHY IN ENGINEERING PROJECTS

While constructing highways understanding the prevailing terrain and topography is important. For ex: if a highway is to be built in a Karst plain it requires repeated cut and fill, otherwise road will be flooded after heavy rains as sinkholes fill with surface runoff. Bridge abutments in a Karst region should be so designed that they will not be weakened by enlarged solutional cavities which are likely to be present.

Glacial terrains present many types of engineering problems. A flat till plain is topographically ideal for road construction. But in areas where end moraines, Eskers, Kames or Drumlins exist there is need for cut and fill to avoid circuitious routes.

Areas with considerable relief which characterizes late youth and early maturity will necessitate much bridge construction and many cuts and fills. In such areas landslides, earth flows and slumping become serious problems. Landslides and other types of mass wasting present problems not only in highway construction but in various other phases of engineering. Highway construction designed to carry heavy traffic the nature of the soil beneath a road surface on what is called the sub grade has become increasingly significant because of its control over the highway. The appreciation of the relationships of soils to varying topographic conditions and type of parent material becomes essential in modern highway construction. Knowledge of soil profiles which to a large degree reflect the influence of geomorphic conditions and history is basic.

Let us look into another important area engineering where knowledge of geomorphology is applied and useful and it is dam site solution. It involves synthesis of knowledge of geomorphology, lithology and geologic structure of terrains. Five requirements of a good reserviour site which depend on geologic conditions are

(1) a watertight basin of adequate size, (2) a narrow outlet of the basin with foundation that will permit economical construction of a dam; (3) opportunity to build an adequate and safe spill way to carry surplus waters; (4) availability of materials needed for dam construction and (5) assurance that the life of the reservoir will not be too short as a result of exercise deposition mud and silt.

4.6 OIL EXPLORATION AND KNOWLEDGE OF GEOMORPHOLOGY:

Several studies have indicated that, there is a correspondence between topography, structure and oil fields. Domes and anticlines have striking topographic expression also have oil reserves. Even 'drainage analysis' of a region particularly sedimentary basins which have experienced some diastrophic movements in geologic past and resulting burying of oil bearing rocks now show not only different cap rocky strata but also have drainage anomalies. Geomorphological investigation of drainage patterns provide valuable clues of oil reservoirs. According to 'Howard' 95% of oil yields from limestone reservoirs was associated with erosion surfaces on limestones beneath which there had been solutional enlargement of joints and bedding planes. Limestone formations several hundred feet thick may yield oil in quantity only from upper 25 to 50 feet, in which solutional openings are present. For details of buried ancient karst land seapes and oil fields see p. 570-571 in Geomorphology by W. Thornbury.

Another notable geomorphical features which have oil reservoirs are 'shoe string sands' which are elongate buried sand bodies. These may be buried coastal delta distributary's channel fillings, coastal beaches and bars, barrier islands, river channel fillings or tidal channel fillings oil drilling programmes must have the prior knowledge of these buried features during oil exploration.

In USA the east Texas oil field has produced more oil than any other oil field. It is but one of many examples of a stratigraphic trap produced by the sealing of an 'old erosion surface'.

4.7 GEOLOGIC TIME SCALE AND GEOMORPHOLOGY

Earth scientists know the significance of geologic time scale which shows the both geologic, geomorpghic and evolution of life forms. In fact in nut shell it diagrammatically and scientifically denotes these events under its sub divisions like eras, epochoes and periods within about 4600 million years of earth's history. Geographers particularly physical geographers and geomorphologists basically must know the geological time scale. One of the fundamental concepts of geomorphology explains that, most of the land forms belong to Pleistocene tertiary periods of Cainozoic era in which earth is at present. There are epoes in earth's geological history which have significant diastrophic movements and formation of fossil fuels, which necessitates its knowledge.

From the following table we can get these aspects of geologic time scale:

GEOLOGICAL TIME CHART

Era	Period	Epoch	Year /Age (Million)	Major Life Form	Major –Select Landforms
CAINO-ZOIC	Quaternary	Recent (Holocene)	0.01	Homosapiens	Most of present tertiary land forms
		Pleistocene	2	Ice ages	-
	Tertiary	Pliocene	7	Firstnmen	-
		Miacene	26	First Monkeys & Apes	-
		Oilgocene	38	Ancestors of most	-
		Eocene	53	Modern	Himalayan Orogeny & other young fold mountains
		Palaeocere	65	animals	
MESOZOIC		Cretaceous	136	Birds, flowering plants, mammals extinction of Dimsaurs	Deccan lava plateau
		Jurrasic	195	Dinosaurs & other gaint reptiles	-
		Triassic	225	First dinosaurs, marine & Flying reptiles first mammals	-
PALAEOZOIC		Permain	280	Trees	-
		Carboniferous	345	First reptiles, winged insects	Coal, oil & N.gas reserves formation
		Devonian	395	Fish, first Dmphibians, winged insects	Major crustal disturbances
		Silurian	440	First plants	-
		Ordovician	500	First fish	-
		Cambrian	600	Harine Invertebrates Corals, Molluscs	Deccan Crystalline Gneissic rocks
PRE-CAMBRIAN		Proterozoic	1000	Marine algae, sponges	-
		Archaeozoic	3000	Earliest known life algae & fungi	-
		Azoic	About 4600	Formation of earth's crust	-

4.8 LET US SUM UP

In this subsection of last part of unit one, we discussed about the applied aspects of Geomorphology. Being a science of land forms, they have significance in the life modern man. Man has build huge cities, industries and economic activities like modern agriculture. These have great demand for domestic, industrial and agricultural water needs. It necessitates the help of geology and also geomorphology. Understanding behavior of different terrain conditions particularly Karst, glacial and others becomes imperative for the utilization of surface and ground water resources.

Modern man consumes huge quantities of a variety of mineral resources. Discovery of mineral occurrences has made use of the knowledge of geomorphology extensively. Differential erosions and old erosion surfaces, very appearances of some landscapes indicate the presence of minerals. Iron ore, copper, bauxite, lead-zinc like valuable metallic minerals have definite association with erosion surfaces and distortions of natural drainage pattern. A keen eye trained in geomorphology and geology identifies the landforms and associated minerals. Location of placer deposits across the terrain has the use of geomorphic knowledge study. Salt domes, fractured structures and their geomorphic studies have benefited oil and gas explorations.

We see the use of geomorphological analysis and information in high way and multipurpose irrigation dams construction. Terrain analysis study of vulnerable areas of earth movements and land slides have been immensely benefited from geomorphology. Even soil studies particularly erosion and its conservation have been benefited by geomorphology. Off late coastal zone management is benefited by geomorphology. Geomorpholigists while studying land forms need the information of geologic time scale. It has sub divisions like Eras, Epoches and periods which clearly divide earth history. One can get an over view of evolution earth's land forms, life form and respective ages under the geologic time scale.

4.9 KEY WORDS

Hydrology- Karst landscapes- Primary permeability- Secondary permeability- Solution cavities–Glaciated areas–Glacial land forms- Buried valleys- Pre and post glaciated areas–Surface expression of one bodies with landscapes – Mineralization slump- Oxidation subsidence-Hills and Ridges and ore bodies- Weathering Residues-Laterization- Paleopedology-Unconformities in Karst areas–Channel fillings–Placer deposits-Beach placers- Highway construction- Surface runoff- Grade construction- Landslides–Dam site- Salt dome /plug – Drainage Analysis- Topographic Maps- Soil erosion- Soil profiles.

4.10 QUESTIONS FOR SELF STUDY

1. Explain the application of geomorphology in hydrology of limestone and glacial terrains.
2. Discuss the application of principles of geomorphology in the exploration of minerals.
3. With adequate examples bring out the use of geomorphology in the field of oil exploration.
4. Examine the areas of application of geomorphology in Highway and Dam's like engineering projects.
5. Write short notes on the following :
   a) Placer deposits
   b) Landslides
   c) Glacial terrain
   d) Erosion surfaces
   e) Terrain analysis
   f) Drainage analysis
   g) Shoestring sands
   h) Pleistocene period
   i) Cretacious period
   j) Recent / Holcene period
   k) Tertiary epoch
6. Describe the importance of geological time scale in the study of geomorphology.

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Course Design and Editorial Committee

Prof. K.S. Rangappa
Vice-Chancellor
Karanataka State Open University
Manasagangotri, Mysore – 570 006

Prof. Jagadeesha
Dean (Academic) & Convenor
Karnataka State Open University
Manasagangotri, Mysore – 570 006

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Dept of Studies Geography
Karnataka State Open University
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UNIT : 5 INTERIOR OF THE EARTH , THEORY OF ISOSTASY

Structure

5.0 OBJECTIVES

The main purpose of this unit is to provide information related to the invisible interior structure of the earth.

By the end of completing the study of this unit, you will be able to

- Explain the earth's interior development
- Identify the structure of the earth's interior, the composition, the density, temperature, thickness of each layer
- Recognize the Evidences the earth's interior composition and structure can be proved.
- Explain the density of the crust is determining the balance between the continental and oceanic crust.
- Identify the relationship between the density and the gravitational force of the earth.

5.1 INTRODUCTION

Being the student of geography and geomorphology, Information about interior earth is most required and expected knowledge. Firstly, we our-self should ascertain, whether the planet earth on which we are living is stable or unstable. Without understanding the earth's interior we are not in a position to explain the other process of geomorphology and the plate tectonics. In simple terms we can say that, the entire earth's physical mechanism is based on the earth's interior.

5.2 HISTORY OF THE EARTH

Estimating the age of the earth was one of the challenging tasks for the scientist during 18 and 19^{th} century. Henri Becquerel (1852-1908) first developed the technique of radio metric dating.

According to the radio metric dating the oldest rocks on Earth was ***Acasta Gniess*** of Northern Canada. It was dated 4030 Million years old. The Crab Nebula of a meteorite dates back to 4550 Million years old. This proves the formation of the solar system and the earth planet. From these evidences it is also clear that, the earth took origin somewhere earlier to this period of geological time.

5.3 SCIENTIFIC EVIDENCES TO PROVE THE EARTH'S INTERIOR

One of the striking questions everyone gets in their mind as soon the term earth's interior is referred is how scholars know about the interior of the earth when man has not travelled more than 5 Kms deep inside the earth.

Based on the available information regarding the origin of the earth, it is believed that, the earth took origin from the thrown out material of the SUN. When the material was thrown out, those materials were in the form of liquid molten lava and gases. In the process of cooling, earth started taking spherical shape and also the material inside took position as per its density. Thus, it formed into Lithosphere, Hydrosphere and Atmosphere. But we are interested in understanding only the Lithosphere and its interior position with proof of evidence. There are few proofs which can be discussed to believe the contents of the interior earth.

5.3.1 Seismological Evidences

The study of the earthquake waves refers as seismology. To record the vibration, tremor, jolting impacts produced during earthquakes an instrument called seismograph is used. This instrument records the seismic waves. Based on the characteristic features of the waves it has been classified into three types, such as,

i. 'P' Waves

ii. 'S' Waves

iii. 'L' Waves.

The 'P' Waves is also called as longitudinal waves can travelled through solid and liquid material and slower in the liquid material.

The 'S'waves are also called as secondary waves. This waves cannot pass through liquid material but it develops repels in the solid material which are more destructive in nature.

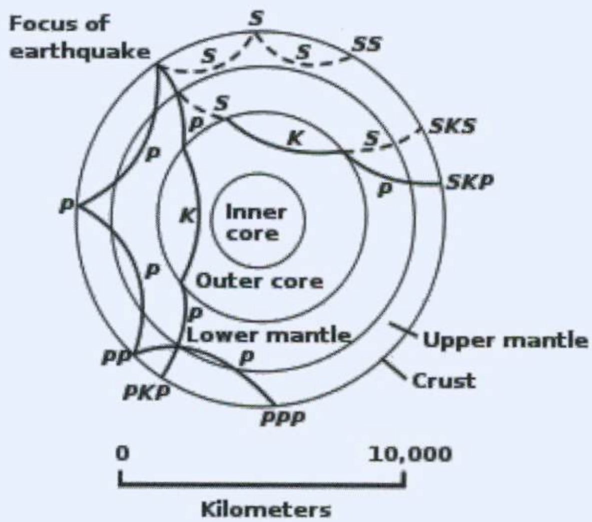


Fig.1. showing the complexity of paths of earthquake waves in interior of Earth.

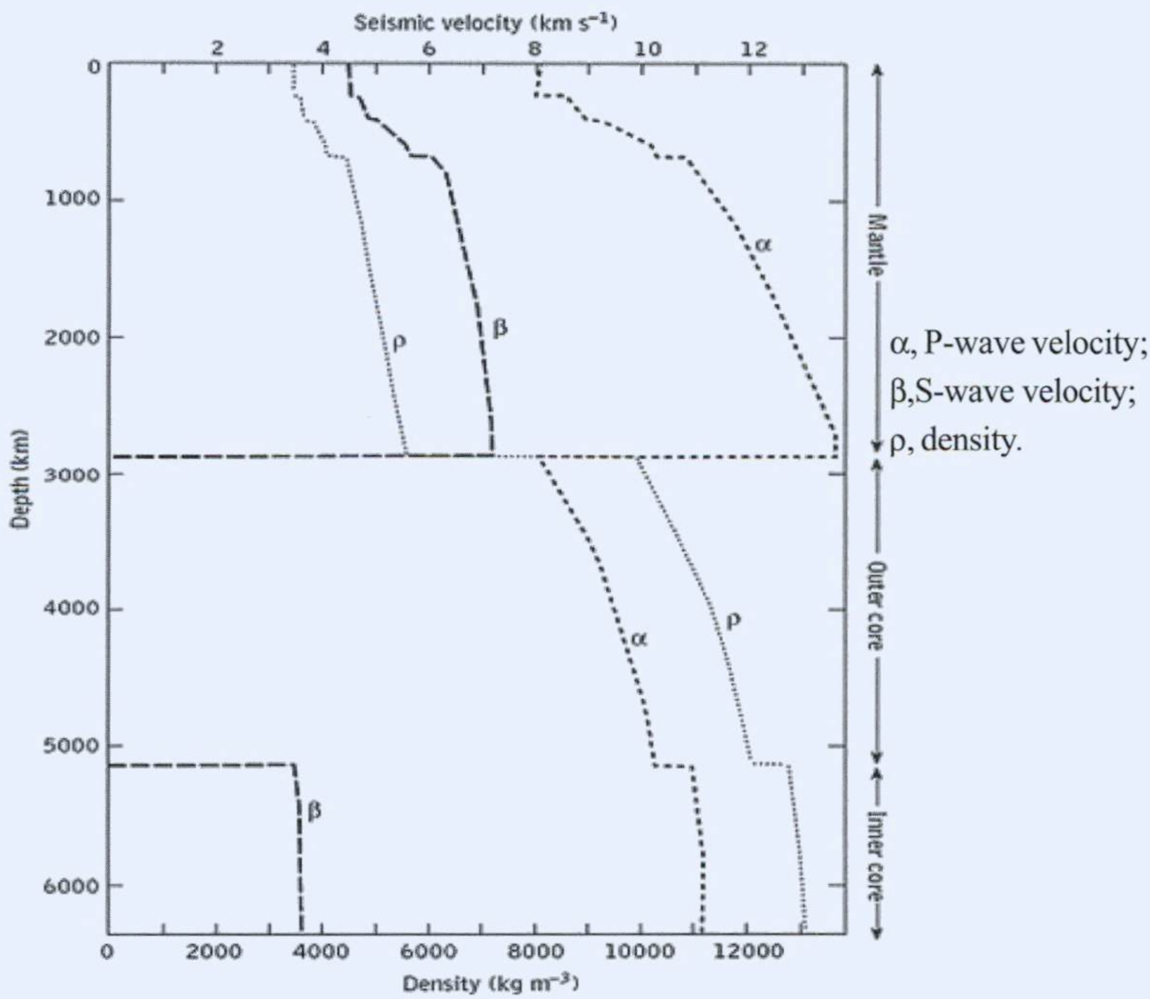


Fig.2. seismic velocity and density model for the Earth.

The 'L' waves are long waves and it passes through solid material and become slower as soon it enters into the liquid material.

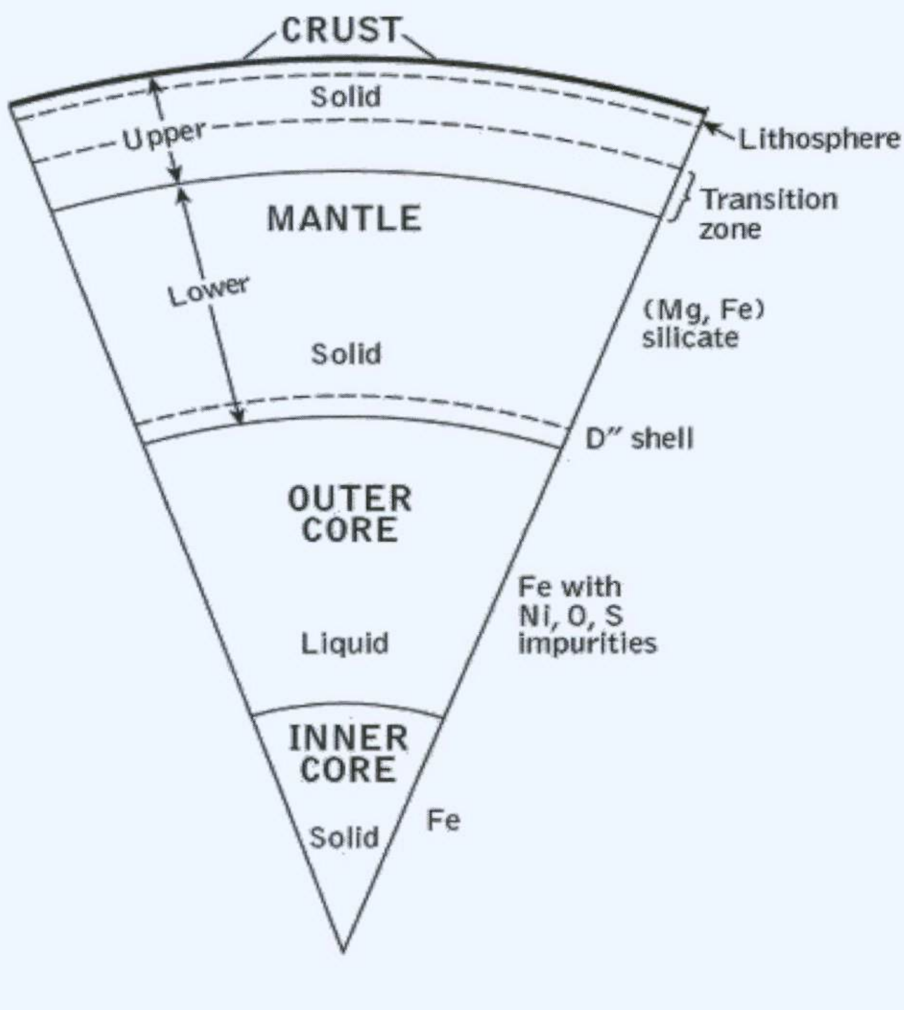
Based on the traveling nature of the waves it is evident that the interior earth possesses the liquid and solid material.

5.3.2 The volcanic evidence :

Volcanoes eruptions are the direct evidence for all, where the interior material of the earth is ejected out from the lava chamber due to the inbuilt thermal pressure.

5.3.3 Thermal status :

The temperature of the ejected volcanic lava has been studied by the scientists. Based on those evidence, it is has been proved that no substance can remain solid, if the temperature goes beyond 1150 °c. The hardest substance found on the earth is Basalt. Basalt get's melted at 1150 °c temperature. Hence there is no doubt about the material present in the interior of the earth is in which condition and form.



Other important data on the Earth's interior come from geological observation of surface rocks and studies of the Earth's motions in the Solar System, its gravity and magnetic fields, and the flow of heat from inside the Earth.

5.4 LAYERS OF THE INTERIOR OF THE EARTH

During the condensation process the various substances as per its density settled down in the form of layers. The lighter material took upper position and dense material got settled in the bottom or at the core part of the earth. As per the density and composition of the earth, the earth's interior has been broadly classified into

1. Crust,
2. Mantle,
3. Core.

5.4.1 Crust

Crust is upper most layer of the earth's interior. The formation of the earth is believed to be taken place 3500 million years back. The slow cooling processes has resulted in to the formation of the solid rock structure. There are many theories regarding the origin of the earth crust. The crust can be broadly classified to in two.

i. Oceanic crust and

ii. Continental crust.

Oceanic crust is formed by the dense material like Silicon and Magnesium (Sima) and it is thinner than continental crust. The continental crust is made out of the silicon and aluminum (Sial), which are less dense in nature. The thicknesses of the continental crust various between few feet to 5 kms. The average density of Sial is 2.9 g/cm^3.

Crust is the only layer accessible to us. Its geology has been extensively studied, and therefore more information is known about its structure and composition than about the structure and composition of the mantle and core. Within the crust, intricate patterns are created when rocks are redistributed and deposited in layers through the geologic processes of eruption and intrusion of lava, erosion, and consolidation of rock particles, and solidification and re crystallization of porous rock.

The boundary between the crust and mantle is called the Mohorovicic discontinuity (or Mohor); it is named in honor of the man who discovered it, the Croatian scientist Andrija

Mohorovicic. No one has ever seen this boundary, but it can be detected by a sharp increase downward in the speed of earthquake waves there. The explanation for the increase at the Mohor is presumed to be a change in rock types. Drill holes to penetrate the Mohor have been proposed, and a Soviet hole on the Kola Peninsula has been drilled to a depth of 12 kilometers, but drilling expense increases enormously with depth, and Mohor penetration is not likely very soon.

5.4.2 Mantle

The semi liquid substance found beneath the crust and at the top of the outer core liquid layer is called Mantle. The viscosity of the mantle gets decreasing towards the core of the earth. The top most layer of the mantle is Asthenosphere over which Mohor zone is situated. The Mohor layer separates the solid curst and the semi liquid Asthenosphere.

Asthenosphere is a semi liquid layer mainly composed of silicon and magnesium. The density of asthenosphere in its upper most zone is $3g/cm^3$ and in the bottom position it is varying between 4 to 5 gm/cm^3. The total thickness of mantle is about 2900 kms and temperature in this layer varies between 1500 to 2500 °c

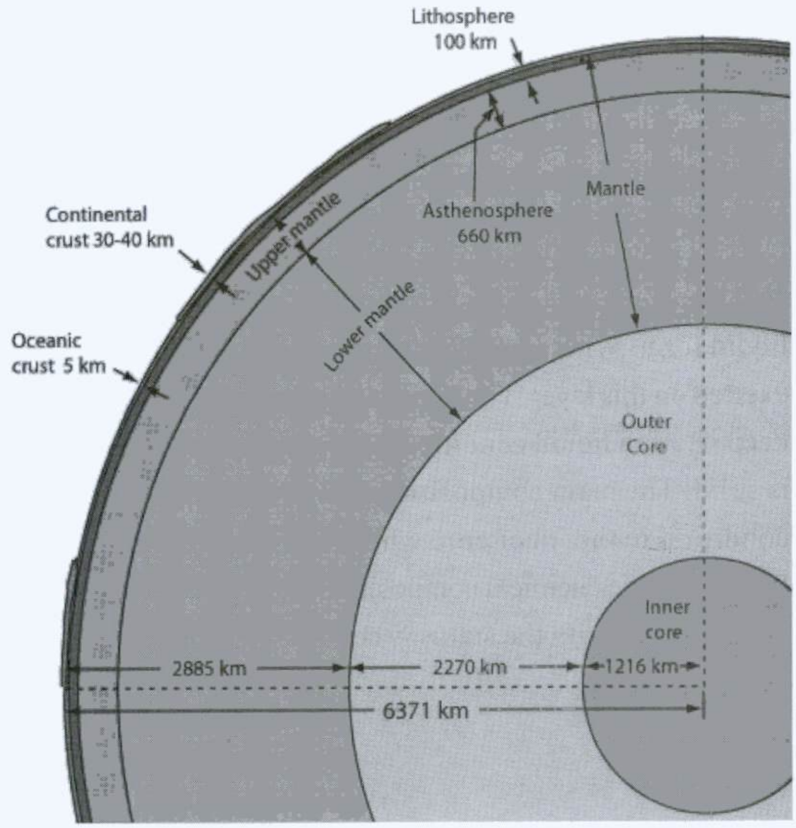


Fig.4. Cross section of Earth's Interior

The mantle is divided into two such as,

i. Upper mantle and

ii. Lower mantle

The upper mantle contains two discontinuities caused by changes from less dense to more dense minerals. The chemical composition and crystal forms of these minerals have been identified by laboratory experiments at high pressure and temperature.

The lower mantle, below the transition zone, is made up of relatively simple iron and magnesium silicate minerals, which change gradually with depth to very dense forms. Going from mantle to core, there is a marked decrease (about 30 percent) in earthquake wave velocity and a marked increase (about 30 percent) in density.

5.4.3 Core

Data from earthquake waves, rotations and inertia of the whole Earth, magnetic-field dynamo theory, and laboratory experiments on melting and alloying of iron all contribute to the identification of the composition of the inner and outer core. The core is presumed to be composed principally of iron, with about 10 percent alloy of oxygen or sulfur or nickel, or perhaps some combination of these three elements.

The core of the earth has been classified into two, namely,

i. Inner core and

ii. Outer core

The total thickness of the core layer is 3500 kms. Out of 3500 kilometers the outer core stretches 2300kms. Remaining 1200kms is occupied by inner core. The outer Core is in liquid form. Where has, the inner core is solid in condition, because of the excess of pressure exerted on this layer. The material in this layer is although having very high temperature cannot keep itself in liquid condition. Hence the outer core is composed by liquid and the inner core is solid. The main composition of minerals is Iron and Nickel alloy. The alloy exist in solid condition in the inner core where has the same alloy exist in liquid form in the outer core. Regarding the chemical composition is concerned both the layers are having same composition only it varies with the status is concerned.

Data on the Earth's Interior

	Thickness (km)	Density (g/cm³) Top	Density (g/cm³) Bottom	Types of rock found
Crust	30	2.2	—	Silicic rocks.
		—	2.9	Andesite, basalt at base.
Upper mantle	720	3.4	—	Peridotite, eclogite, olivine, spinel, garnet, pyroxene.
		—	4.4	Perovskite, oxides.
Lower mantle	2,171	4.4	—	Magnesium and
		—	5.6	silicon oxides.
Outer core	2,259	9.9	—	Iron+oxygen, sulfur,
		—	12.2	nickel alloy.
Inner core	1,221	12.8	—	Iron+oxygen, sulfur,
		—	13.1	nickel alloy.
Total thickness	6,401			

Based on the information derived from various sources explained in this unit it is sufficient enough to have a good understanding about the structure and configuration of earth's interior. Still there are many research works are carried out in laboratories to know how the rock reacts to various composition, temperature and pressure condition. It is only in the recent years the experiments proved that the inner core of the earth in solid condition. Therefore in coming years much more accurate information will be available to prove the interior structure of the earth.

ISOSTASY

5.6 INTRODUCTION

The basic fundamental concept for an earth science student need to understand is the principle of earth equi -balance. The term Isostacy was derived from Greek language 'Iso' and 'Stasy'. Iso meaning 'equal' and 'stasy' denotes 'balance'. The term Isostasy was first used by Dutton in 1880. Dutton was an American geologist. He brought into light the balancing act of continental crust and sea floor crust.

5.7 NEED OF A STUDY

Why we need to understand the balance of earth crust means in order to understand the entire mechanism of endo-genetic and exo-genetic activities .Without knowledge of Isostacy getting to know how volcanoes and earthquake, Continental drift and plate tectonic activity will be a half sided knowledge. After understanding the principle of Isostacy, when you study the continental drift theory you can realize the relevance of Isostacy. Similarly continental drift theory will be a stepping stone of understanding plate tectonics theory. The study of Isostasy, Continental drift theory, plate tectonics, sea floor spreading and other topics is related with one another. Decoupling any one this will not be a complete study. Hence it is most appropriate for the student of earth science to know how the Isostacitc balance is maintained by the earth crust, the effect gravitation force, the formation of new continents and also submergence and emergence process of the crust.

5.8 THE PRINCIPLE OF FLOTATION

To make it simple to understand the principle of Isostacy, let us try to envisage by taking an example of a small fishing boat. The boat floats over water due to the variation between the density of the wood and the water. The density of water is greater than the density of wooden boat. When we see a boat floating over the water surface, we know for sure it is not static; it keeps moving sidewise or too and fro. The boat also sinks into the water by few inches if a person sits over the boat. Suppose one more person is added into the boat, the sinking level will be increases by one or two inches. Up to certain weight the water can keep the boat and its load in a floating condition. In case of excess load the boat may sink totally. The vice versa effect takes place suppose we release the load from boat; the boat will rise inch by inch from water. What we understand from this example is, the boat is floating on a liquid substance (that is water). Secondly since it floating it cannot remain static. When a floating object cannot be static it is sure that it will be moving horizontally and vertically.

Similarly the earth crust is also floating on a semi liquid substance called Asthenosphere found beneath the crust. Therefore it is for sure that the earth crust is not static, secondly it is also maintaining balance between less denser crust verses high density crust.

The earth crust can be broadly classified into two forms

a. Continental crust

b. Oceanic crust.

The continental crusts are formed out of a less denser material and it is compensated by high density ocean crust. The less density material occupies greater volume and high density material occupies less volume. We can notice that, continental crust is compensated by its raised topography and the oceanic crust is compensated by down thrust topography.

5.10 DEVELOPMENT OF ISOSTASY THEORY

Although Dutton was the first person to profound the concept of Isostasy in 1858 most of the scholars did not accept this principle. Isostasy did not come into limelight until 1870. Accidently this principle was emerged as a fact by non geologist and also unconcerned scholars about the balance of the crust. The East India Company Surveyor General when encountered with a problem during his course of land surveying the balance of the crust was realized.

There are many theories regarding Isostasy, the most relevant and debated theories are

1. Sir George Everest theory
2. Pratt's Theory of Isostasy
3. Airys's Theory of Isostasy
4. Hay ford and Bowie Gravitational Anomaly and Isostasy Theory
5. Venning Meinesz theory of Isostasy

1. Sir George Everest theory

Sir George Everest was a Surveyor General in British East India Company. He was assigned to survey the northern part of India. Everest adopted three methods of surveying like triangulation, trignometrical and astronomical methods to find out the correct longitude values of each station. To maintain accuracy Sir George Everest conducted surveying by all the three methods. After ascertaining the results obtained by all the three methods are same up to the extent of mille seconds, then he could designate the value to the that particular station and shift to next station. When Sir George Everest was given the task of surveying the Himalayan Mountain, he took three points for triangulation 'Kalyani in foot hills of Himalayan Mountain and Kalyanpur in Gangetic plains. When he completed the surveying by astronomical and triangulation the result obtained by triangulation method were not same as compared with the reading obtained in astronomical method. The readings are as follows,

Triangulation Method	=	5^0 23' 42.294"
Astronomical Method	=	5^0 23' 37.058"
Difference	=	5.236"

After many more investigation, George Everest concluded his work by saying that, the lofty Himalayan Mountains which are comprised of denser material must have attracted the plumb bob, hence the error has occurred.

2. Pratt's Theory of Isostasy

The East India Company assigns the resurvey work to J.H. Pratt, who was a surveyor in Britain. Part accepts the flotation principle of the crust. He also agrees that, the crust possess SIAL and SIMA layers. The density of SIAL is lesser than the density of the SIMA. With this understanding Pratt takes up the job of resurvey in the Himalayan region.

Pratt believing the cause of error according to Everest, he reoriented the instrument by the difference in value i.e. 5.236" mille second, hoping that the reading will be reduced to zero and it should be the same value as that of the Astronomical Method. But, after completion of surveying, Pratt was surprised to see the error multiplied by three times instead of zero the value was 15.885"milli seconds.

Seeing the error gets increased by three times, He came to an understanding that, the plum bob of the surveying instrument has not attracted by the Mighty Himalayas instead, it is the Plains which has caused the error. Form this error Pratt review his understanding about Himalaya. He states that, the Himalaya Mountain is not composed of high density material, instead it is composed with low density, where as the Plains is composed of much denser material than the Himalayas.

Pratt makes two hypotheses; firstly, he states that the Himalaya Mountain might be having hallow area at the center covered by solid surface around. Secondly, the deep stretching base of the Himalayan Mountain might have displaced the substratum to greater depth, which might have resulted in to less gravitational pull with less density. Where as Kalyanpur is having high density with grater gravitational pull.

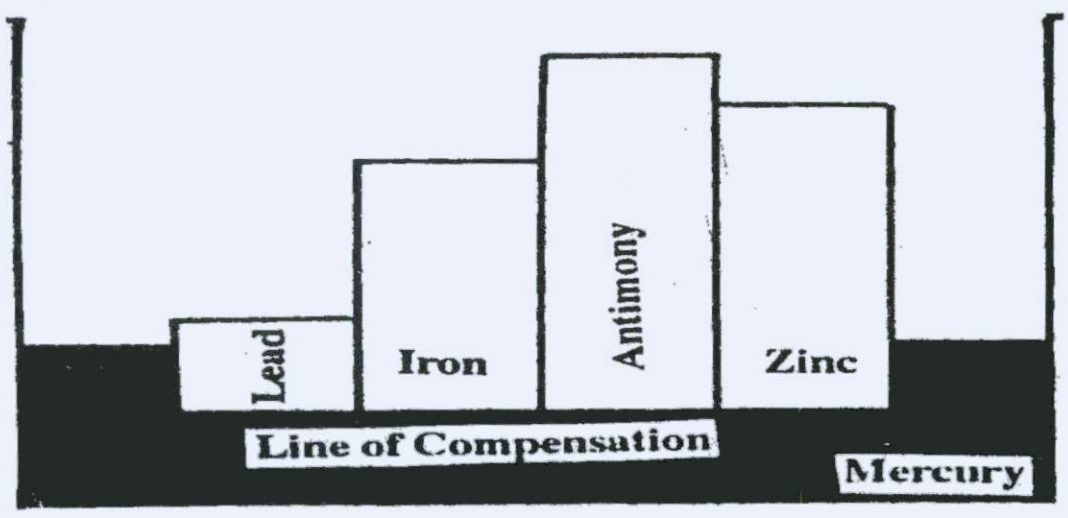


Fig.1. Illustration of concept of Pratt's on Isostasy

Pratt's Theory

To prove his hypothesis Pratt took different density materials of same weight such as Zink, iron lead and Platinum. He immersed them in a container containing mercury. All the metallic blocks sink at equal depth and float in uneven exposure over the Mercury. Because, the density of mercury is greater than the different metallic blocks. The density of mercury is 3.0 per gram. The metallic blocks were having varying density but, less than 3.0. Through this experiment Pratt derive the following concluding remarks.

a. Earth crust are composed with varying density and are sinking at equal depth in the substratum but, with uneven exposure on earth surface as per its density.

b. Pratt also maintains that, there is a Line of Compensation which is a final limit up to which the crustal blocks can sink; beyond this depth the sinking is not possible.

c. The relative density of mountain plateaus and plains are not same because a denser block occupies lesser volume and less denser blocks occupies greater volume.

d. Pratt, finally concludes that, the raised relief features like mountains and plateaus are compensated or balanced by the down set relief features like plains and sea floor.

Pratt's theory of Isostasy has been severely criticized on the grounds that, the earth crust is a sub material of the interior lava and it is the only source for its creation, when it is the situation, how there can be the existence of different density material on the earth surface. Secondly the whole idea of line of compensation and the balance between the down set features and the raised features are mere illusion developed by Pratt rather of the actual facts. In fact, there were many favorable arguments regarding the Part's theory of Isostasy.

3. Aireys's Principle of Isostasy

Aireys an American surveyor develop interest in the discrepancies arising in surveying. Airy employs his own methods of surveying to know the exact cause of error. He totally disagree both such Sir George and Pratt's hypothesis.

Airy adapted Archimedes principle to find the solution to problem of error. According to Archimedes principles any floating body will displaces liquid equal to the volume of submerged part of the floating body. Keeping the Archimedes principle as base, Airy profound his theory of Isostasy.

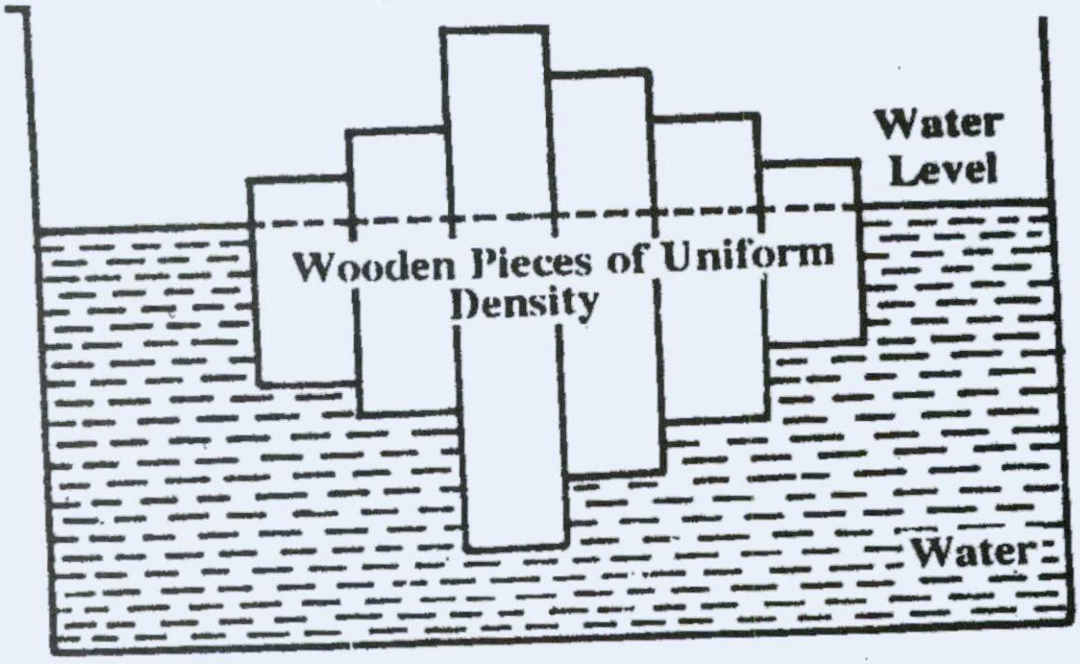


Fig.2. Illustration of concept of Airey on Isostacy

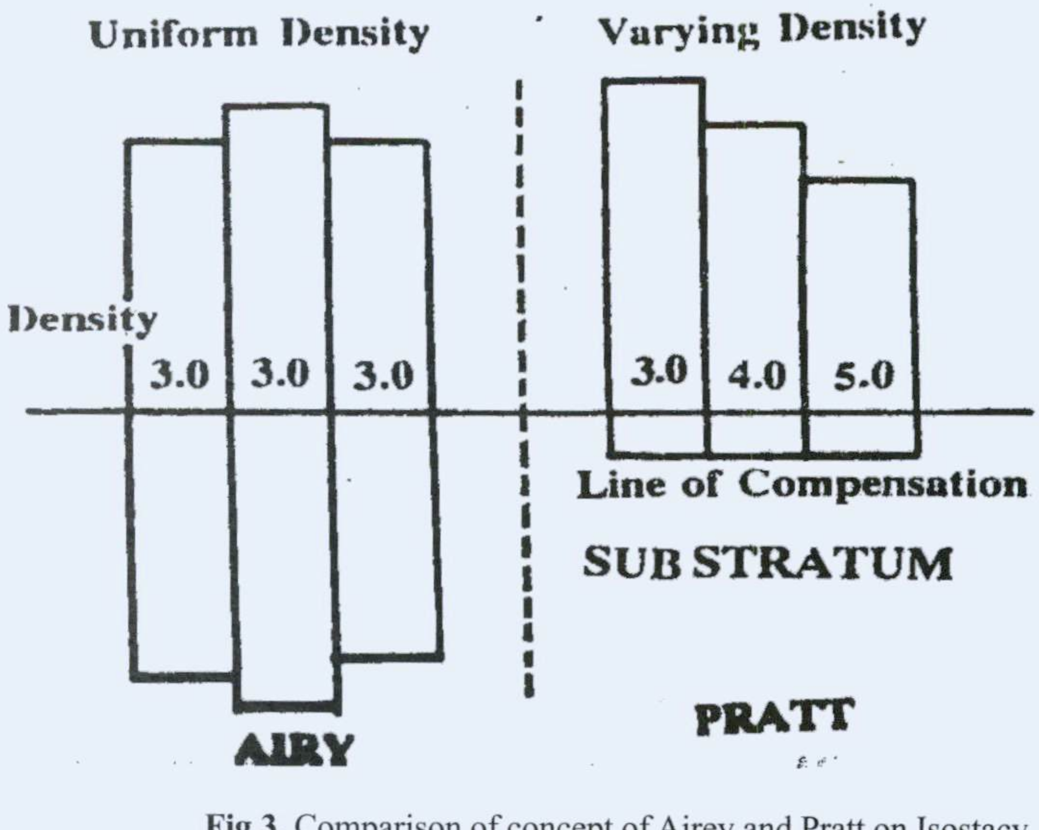


Fig.3. Comparison of concept of Airey and Pratt on Isostacy

Airy's Assumptions

Airy disagree uneven density of crust as believed by Partt. His emphasis on equal density material with uneven depth of submergence below the sea level.

To prove his hypothesis Airy conduct two experiments. He takes the ice cubes and immense in the glass container filled with water. The ice cubes in different size float unevenly but sink nine times of the exposed part at varying depth. In his second experiment he takes wooden blocks of varying size which is of equal density and floats them in container of water. All the wooden blocks of different size float at an equal exposure but sink at an uneven depth.

Through this experiment Airy advocates that the earth crust is composed with same density material but of different size like mountain, plateaus and plains, which displaces the substratum as per its size.

Airys View about Error

Based on the experiments Airy concludes saying that,

- The cause of error is due to the displacement of substratum developed by the nine times of the exposed size of the Himalaya, which are extending below the sea level to greater depth in the substratum, and this has displaced the substratum.
- The displacement has caused low gravitation pull in the Himalayan region and low attraction of plum bob towards the Himalaya Mountain has created error.
- The density of the crust is uniform.
- different relief has developed into different relief features.
- And he strongly believes that, all the relief features of the earth are in a state of balance between the raised topography and the down set topography.

Criticisms

The cause of error and his views regarding the balance of the earth crust was criticized on the following grounds.

- If the crust is made of uniform density then the material found in the earth crust should be of mono litho. But, the earth curst is filled by various types of rocks which are against his findings.
- The sinking pattern of the crust as per the Arcemeies principle is questioned. If the elevated land bodies are stretching deep inside in the substratum there should be

evidences of all features having a proportional thickness of nine times of its exposed part. But in reality there is no such cases found. The investigation has revealed that there is no such match between the exposed crust thickness and the displacement of the substratum. There are many features which do not have even half of the size of the exposed part compared with its sinked thickness.

4. Hay ford and Bowie Principles

Hay ford and Bowie are two American surveyors; they were engaged in recording the gravitational force of the earth. These two scholars accept Aireys findings and rejects Pratt's theory thinking that if the density is different in the earth curst the gravitational pull should be different. But, as per their knowledge the gravitational pull of the earth is uniform. Hence they reject Pratt's view and accept Airy's finding. With these assumptions Hayford and Bowie conducts gravitational pull experiment to put an end to the problem of Isostasy. They take up investigation at Alps Mountains and the shore land of Atlantic Ocean.

According to their common understanding the density between the plains and mountain are equal. Keeping this view in mind they conduct gravitation investigation at the Atlantic shore. As per their gravitational recording instrument the value recorded at shore of Atlantic Ocean was 600. Now hoping to clarify the error they does a small manipulation in the instrument. By means calculating the elevation of the Alps from the Atlantic shore, they readjust the instrument to zero and check the gravitational value on top of the Alps having a prediction of getting 600,but the instrument recorded minus 600 and when they rechecked at the Atlantic shore with the same adjustment the value increased by plus 600.

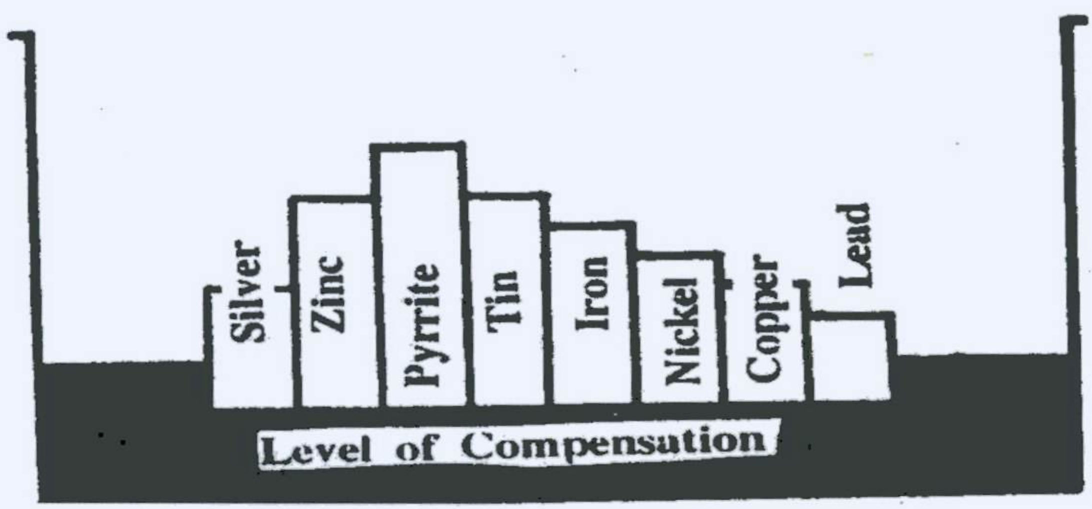


Fig.4. Illustration of concept of Bowie on Isostacy

Hayford and Bowies Findings

The gravitational anomaly made them to accept Pratt's hypnotizes and reject Airy's hypothesis. They conclude their experiment by the following remarks.

Earth crust is composed of varying density material.

The densities of the raised relief are lesser than the down set relief features. Lesser the density greater the size and greater the density lesser the size.

The raised relief is balanced by the high denser material and earth curst is compensated by its size.

5. Vening Meinesz Theory of Isostasy

Vening Meinesz proposed an Isostatic model taking due care of the deficiencies in the earlier models. After making detailed studies on the relationship between topography and gravity anomalies over prominent topographic features, such as the deep sea trenches and island arcs in south East Asia. He concluded that the Isostatic compensation is not always a local phenomenon.

The model of Isostasy by Vening Meinesz is based on the idea of regional Isostatic compensation assumed and upper elastic layer overlaying a weak layer. The strength of the overlaying layer is such that the load of any surface feature is distributed over a wider horizontal distance than the feature itself. The topographic layer bends the upper layer downwards into the fluid substratum, which is pushed aside. The buoyancy of the displaced fluid forces it upward, giving support to the bent layer at distances well away from the central depression.

5.10 DENUDATION PROCESS AND ISOSTATIC ADJUSTMENT

The two main function of denudation process does is, Erosion and Deposition. The raised reliefs are the target of attack by the denudation agents. While performing the erosion process, the mountains are reduced to the sea level. But as per the Isostatic adjustments, when the mountain is eroded and the material is transported and deposited at the plains or in the coastal plains, the elastic nature of the curst allow them to bend and the impact is uplifting or rising of the eroded mountain to attain the Isostatic equilibrium. This kind of relationship is found to exist and it has been proved through GPS.

5.11 LET US SUM UP

Obviously, it is clear that the mountains are less dense than plains and plains are less dense than sea crust. In other wards the raised features like mountain, plains and plateaus are balanced by the down set features like plains and sea floor crust.

From the above hypothesis and the theory it is simply easer to come to understanding that the crust is floating and they are not static, they keep moving vertically and horizontally just like boat. Secondly, the earth curst is in a state of balance.

The Isostatic theory is an important geologic concept which explains the vertical movement of the earth's curst. The dynamism induced by the Isostasy keeps the earth surface changing. The deformation and tectonic activity are present as a natural phenomenon due to the flotation concept.

5.12 KEYWORDS

Sial, Sima, Nife: Silicon and Aluminum, Silicon and Magnesium, Nickel and Ferrium.

Asthenosphere: Asthenosphere is a semi liquid layer mainly composed of silicon and magnesium .the density of asthenosphere in it upper most zones is 3g/cm^3 and in the bottom position it is varying between 4 to 5 g/cm^3.

Crust: Crust is upper most la yer of the earth interior .the formation of the earth is believed to be taken place 3500 million years back. The slow cooling processes as resulted in to the formation of the solid rock structure. This portion called as Crust.

Mantle: The semi liquid substance found beneath the crust and at the top of outer core liquid layer is Mantle. The viscosity of the mantle gets decreasing towards the core of the earth. This portion called as Crust.

Core: The core of the earth has been classified into namely inner core and outer core, the total thickness of the core is 3500 kms. Out of 3500 kilometers the outer core structured 2300kms.another 1200 kms by inner core. Core is liquid in form is where as the inner core solid because of the variation in chemical composition and temperature ,the outer core is composed by liquid and the inner core is solid due inner nickel alloy.

***Isostacy*:** The term Isostacy is derived from Greek language 'Iso' and 'Stay', Iso mean equal and stay denotes the balance. The term Isostacy first used by Dutton in 1880, he is American geologist.

Survey Methods: triangulation, trignometrical and astronomical methods are used for survey.

Isostacy theories: 1) Sir George Everest theory, 2) Pratt's Principles, 3) Aireys's Principle, 4) Hay ford and Bowie Principles

5.13 QUESTIONS FOR SELF STUDY

1 Discuss the evidences to prove the structure of the interior earth?

2 Explain the compositional characteristics of Curst?

3 Explain the composition and structure of the Mantle?

4 Explain the composition and structure of the Core?

5 Explain the development of the Isostasy as a concept in the field of Earth Science?with

6 Explain how George Everest ended with wrong results in his surveying ?.

7 Discuss the Pratt's view of Isostasy and on what basis he arrives into the conclusion.

8 Explain Airy's view of Isostasy and what are his bases of explanation?

9 How Hayford and Bowies Gravitational anomaly gave a striking revelation in the field of Isostasy?

10. Discuss the relationships that exist between the Earth's Equilibrium and the denudation process?

5.14 FURTHER READING

Strahler, A.N and A.H. Strahler, 1976 : Geography and Man's Environment, Jhon Wiley, New York.

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UNIT : 6 THEORY OF CONTINENTAL DRIFT AND THEORY OF PLATE TECTONICS

Structure

6.13 Causes of plate movements

6.13.1 Radioactive convection current

6.13.2 Outer core convection currents

6.13.3 Horizontal thermal plumes

6.13.4 Evidence of the plate movement

6.13.5 Earthquake and Volcanic Incidences as Evidences

6.14 Evaluation of plate tectonics

6.15 Let us sum up.

6.16 Keywords

6.17 Questions for self study

6.18 Further readings

6.0 OBJECTIVES

The study of continental drift theory is a continuation of Isostasy. Since the entire theory brought in to light by Wegner is emphasized on flotation principle. Continental drift theory sheds light on the plate tectonics which is discussed in detail in the next unit.

After the studying this unit, you will be able to

- Be familiar with the earlier scholars idea about the origin of continents and oceans
- Identify the position and shape of the continents in the Permian period
- Make out the continents started splitting and later drifting occurred.
- Categorize major and minor plates of the world
- Construct out the Classification of plate boundaries
- Make out the Evaluation of Plate Tectonic Theory

6.1 INTRODUCTION

The origin of the continents and the oceans remained as a mystery until the evolution of tetrahedral hypotheses by Lothian green, the horizontal displacement theory by Taylor and finally the continental drift theory propounded by Alfred Wegener. Among all the theories regarding the origin of continents and oceans, Wegners continental drift theory was widely discussed and it became more popular theory after the Plate Tectonic Theory came into light.

6.2 TETRAHEDRAL HYPOTHESIS

Lothian Green's Tetrahedron hypotheses, although not connected with continental drift theory, it is better to understand the mind of the earlier scholar in their approach in evaluating the origin of the continents and oceans are concerned.

Lothian green in (1875) assumed the earth is in a tetrahedral shape and it's covered by spherical water in all the side except the apex of the triangle .the apex and the tip projected out of the water, he believed as continents and rest of the surface covered by water referred as ocean.

6.3 DISPLACEMENT THEORY

Taylor postulated the horizontal displacement theory in (1910), according to him there were two land mass existed during cretaceous period called Lauratia and Gondwana and they were located near north and South Pole respectively.

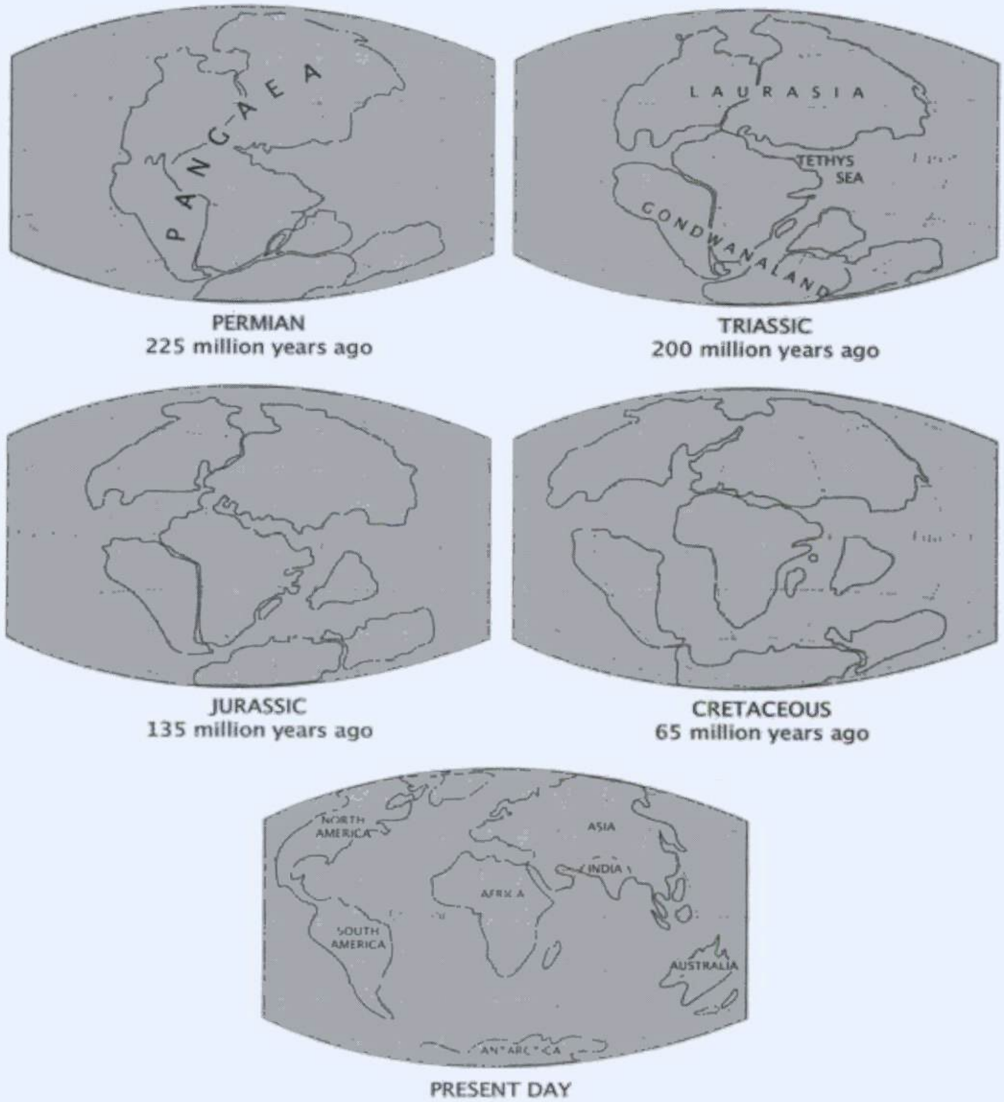
According to Taylor the tidal force started to push the Lauratia away from the North Pole. The tensional force built upon Lauratia land body was caused by the tidal force. This lead to stretching and split of these two lands mass such as, the North America and Eurasian continents. In the case of Gondwanaland, the tensional force developed by the tide stretched and splited Gondwanaland into two. Thus, emerged the new continents such as Africa, South America from one part. India and Australia from another part. These two landmasses separated the water body into Atlantic and Indian oceans.

6.4 ALFRED WAGNER CONTINENTAL THEORY

Alfred Wegener in 1930 postulated continental drift theory. Wegner by profession was a meteorologist in a German university. He was interested in understanding the changing climate of world. Accidentally while collecting the evidence regarding the climatic change he encountered with contradicting facts and mismatch in evidence either it is least expected when compared with the location and existing climate condition. This made him re oriented himself to think and work more towards the understand about such striking evidence is possible to exist. Alfred Wegener takes a world tour to collect the evidence about climate change. During his course of visit to various continents, Alfred Wegener matches with the existing climate and the remnants of Paleo climate. Similar type of evidences were found in the adjoin continents, where the existing climatic condition is totally varying. For example, the Kalahari Desert having temperate climate signatures which should be least expected to be seen if the continents set in the same position to be static and stationed from the time of its origin.

This contradicting evidence ignited greater interest in Wegener to understand the actual causes for such type of evidence to be seen in different part of the world.

Fig.1. Continental Drift



Alfred Wegener not only find or collect the metrological evidence, but also he cross check with the fossils, geological evidence and botanical evidence to his surprise he could see all the three type of evidences matches and similar evidences are also located in the adjoining continents. This evidence makes him to believe that the continents has drifted from one single landmass has been splited into number of continents. Based on the evidences Wegner postulates Continental Drift hypothesis.

According to Wegener during the Carboniferous period, there existed a single land mass called "Pangaea" this land was (Fig.1) surrounded by water called "Panthalasa". at the center of the "Pangaea" a sea called "Tethys" was located. Alfred Wegener named the northern part of the Tethys Sea as Angwara land and southern part he named as Gondwanaland. According to Wegener, the Pangaea was floating over the semi liquid surface and it was composed of silicon and aluminum (SIAL).

The Angara land comprised of the present day continents such as America and Eurasia and Northern India. The Gondwanaland comprised of South America, Africa, Deccan plateau of India and Australia.

6.5 SPLITTING OF PANGAEA

During Permian period (225 years ago) the Pangaea started drifting in two directions. In Triassic period (200 years ago) the Angara land (Fig.1) started moving towards the north and Gondwana land towards west equator direction. During the Jurassic period, Gondwana and Angara land split further into two major blocks such as North America and Eurasian continents. The Gondwanaland splited into Africa, Australia and Antarctica. These continents further drifted northerly and westerly direction by developing huge gaps between each landmass surrounded by water during Cretaceous period (65years ago). The present day continents and ocean were developed during tertiary period according to Alfred Wegner.

6.6 CAUSES FOR THE MOVEMENT OF CONTINENTS

According to Alfred Wegener the continents have drifted due to two forces; the law of buoyancy (gravitational) and tidal force. The buoyancy force is developed due to the gravitational pull of the earth. Wegener believed the gravitational pull at the equator resulted into drift. He is also of the opinion that, the pull of moon resulted into high tidal force might have caused drift.

6.7 EVIDENCE OF CONTINENTAL DRIFT

As stated in the earlier paragraph, Alfred Wegener developed curiosity in studying the continental drift hypothesis only by his evidences he collected from different part of the world. His evidence can be categorized into geological, zoological and botanical.

6.7.1 Geological evidence

The Juxta fit position (Fig.3) of the continental margin with the adjoining continental margin neatly fit with one and another. Example, the bulge of Brazil fits exactly with Genea. The Madagascar Island of Africa fit with the west coast of India, Similarly, the west coast of Australia fits with the east coast of India.

The mountains of the adjoining continents matches (Fig.2) the geological structure, configuration and properties with one and another although they located apart from one another and divided by sea, such as the Caledonia and Arsinain mountain of Britain and North America. The cape mountain of Africa and Tendil mountain of South America, the Western Ghats of India and mountain of Madagascar have same geological structures.

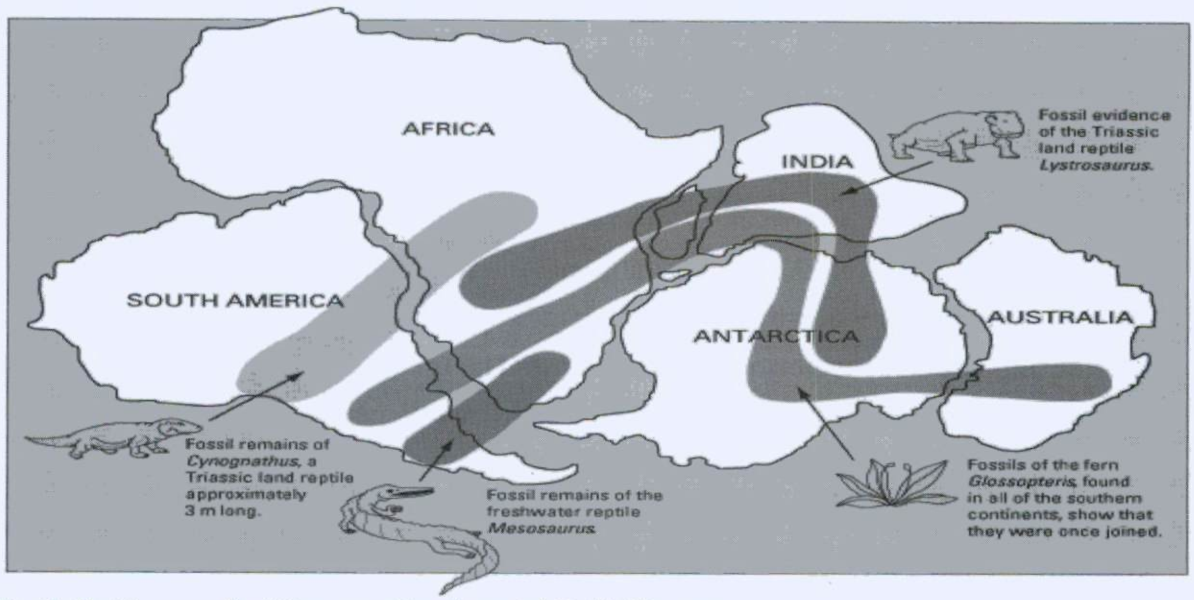


Fig.2. Evidences for Wegener Continental Drift Theory

6.7.2 Zoological evidence

Good accounts of animal fossil have been substantiated by Wegener to support his claim of drift theory. A few zoological evidence quoted by him are Misossrous (Type of animal live in South America and Australia) which clearly indicate (Fig.2) this two land mass were together. The Ellies, Pomatia a type of snail is found in Western Europe and Northern America. The Lemoore Monkey of India, Sri Lanka, and South East Asia is a good evidence of a single landmass.

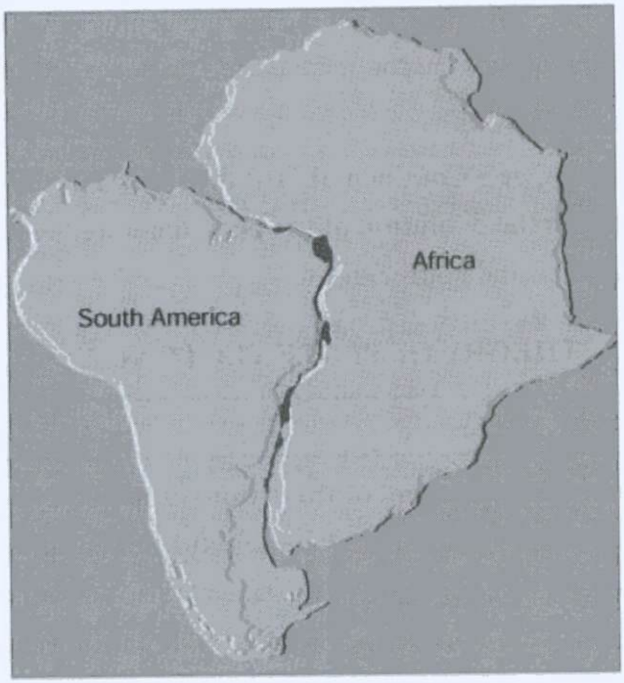


Fig.3. Juxta Fit

6.7.3 Botanical evidence

The fossil of fern plant, Glossopteris is (Fig.2) found in the whole of southern continents is a very good evidence of continental drift, the Sal tree of Western India , Sri lanka and Madagascar island are few botanical evidences furnished by Wegener.

6.8 CRITICISM

- Alfred Wegener continental drift theory was criticized for its insufficient information regarding the evidence he substantiated.
- The tidal force considered by Wegener for the movement of the continents was strongly criticized saying that the moon should have come closer to the earth to create such a vast tidal effect. Even if such tidal force is believed to have taken place, it is out of belief to accept that the vast continental crust can be pushed by this force.
- Suppose if we imagine that the moon would have come closer to the earth, in such instance, the gravitational movement of the moon can halt the rotational movement of the earth. When it is the case how to believe the Tidal force pushing the continent from one end to another end was the main question of debate.
- Many of his geological evidence were criticized, since the geological composition is not same when compared with other adjoining continental mountain.

- The Juxta fit position of the continent as per the marine geologist will match only visually. The submarine contours indicates the continental shelf do not exactly fit with the submarine relief.

With these criticisms Wegener's Continental drift theory was discarded for long time in the geological world. But with the evolution of the plate tectonic theory, the Wegners drift theory gained broad acceptance and appreciation.

THEORY OF PLATE TECTONICS

6.9 INTRODUCTION

Having been understood the concept of floatation discussed in the theory of Isostacy and continental drift theory, Study about plate tectonic further enlighten the knowledge to understand how the endogenetic force are active. This theory also answers most of the question which were not able to be answered properly. Especially, regarding the causes of volcano, earthquake, faulting and folding, seafloor spreading, submergence and emergence of continents and the evolution of new continent can be clearly answered through the study of plate tectonics.

6.10 DEFINITION

The term plate tectonic means the structural adjustment and the transformation. Tectonic is Greek term which means "Carpenter "or builder" the term plate refers to the fractured and dislocated floating crust pieces.

6.11 DEVELOPMENT OF PLATE TECTONICS.

During 1930 When Alfred Wagener propounded theory of continental drift, there was a lot of criticism and nobody took much interest in ascertaining the fact of plate or continental drift theory. But Pichon Le advocated plate tectonic theory based on Wagner's concept of drifting continents. As per the plate tectonic school of thought, there was a single land mass called "Pangaea" as stated by Wagener and "Panthalasa" was surrounded by water body around " Pangaea". The single landmass was broken into seven major pieces and started moving north and westerly direction. The figure shown in the continental drift theory provides you a good conceptual base about the shape and position of continents during the different geological time period.

6.11.1 Major plates of the world.

The theory of plate tectonics maintain that, the surface of the earth, which we call as crust is classified in to six larger plates and nine minor plates. According to Le Pichon the six plates are 1) American Plate, 2) Australian Plate, 3) African Plate, 4) Eurasian Plate, 5) Pacific Plate, 6) Antarctic Plate as shown in the figure (Fig.1) below.

6.11.2 Minor plates of the world

According to be the Le Pichon there are nine minor plates such as 1) Indian plate 2) Philippine Sea Plate, 3) Arabian plate, 4) Caribbean Plate, 5) Juan de Fuca Plate 6) Cocos Plate, 7) Nazca Plate, 8) Somali Plate, 9) Scotia Plate. All these major and minor plates are floating over the semi liquid substance found underneath called as "Asthenosphere."

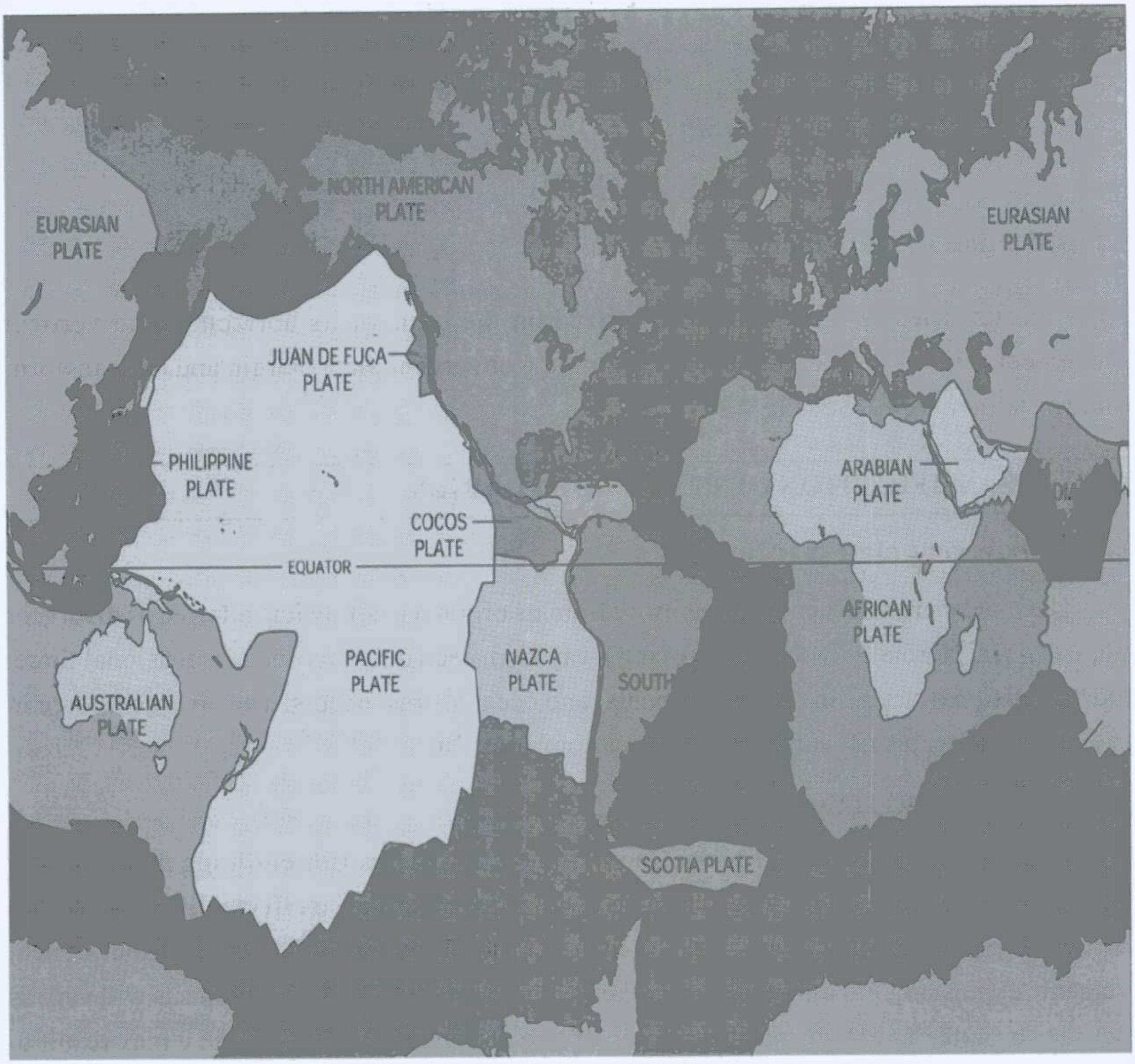
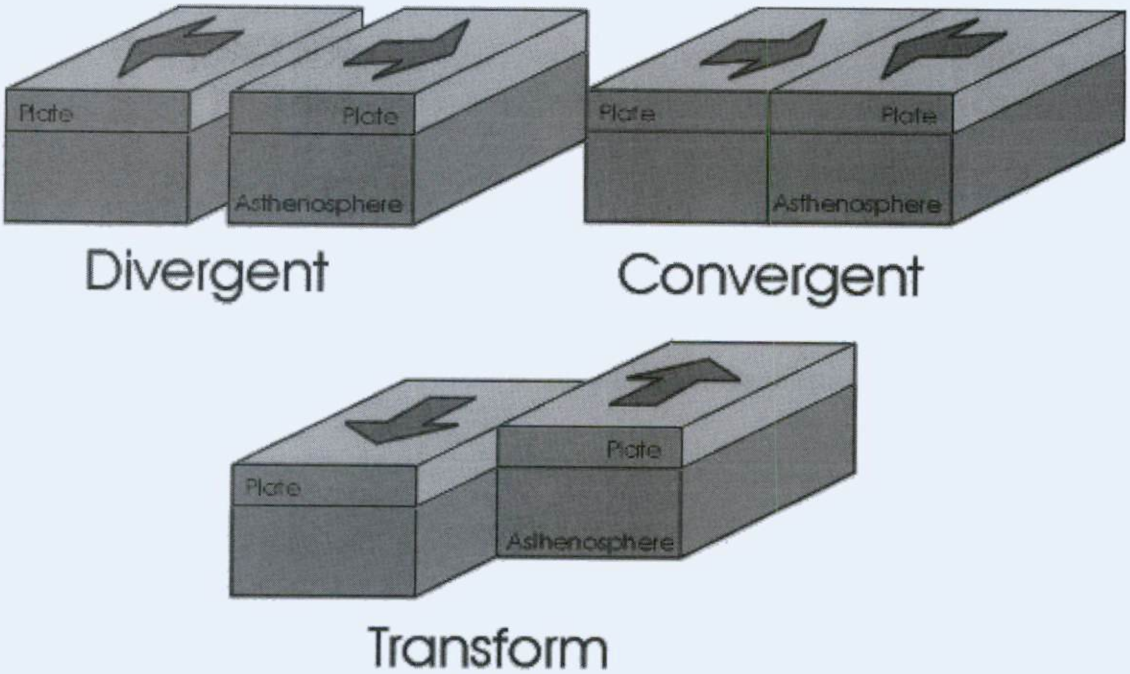


Fig.1. World Major and Minor plates



Classification of plate boundaries

Boundaries of a plate are categorized on the basis of its horizontal and vertical movement, such as i. divergent plate margin, ii. Convergent plate margin and iii. transform plate or fault margin. (See Fig.2).

6.12 CLASSIFICATION OF PLATE BOUNDARIES

6.12.1 Divergent plate margin

The plate margins when it moves away from its original position it is referred as divergent plate margin. Normally two plates moving away from each other, it produces tensional force. Due to tension, fracture in the in continental and oceanic crust occurs. The divergent force in the sea floor creates rift valley and also seafloor spreading.

6.12.2 Convergent plate margin

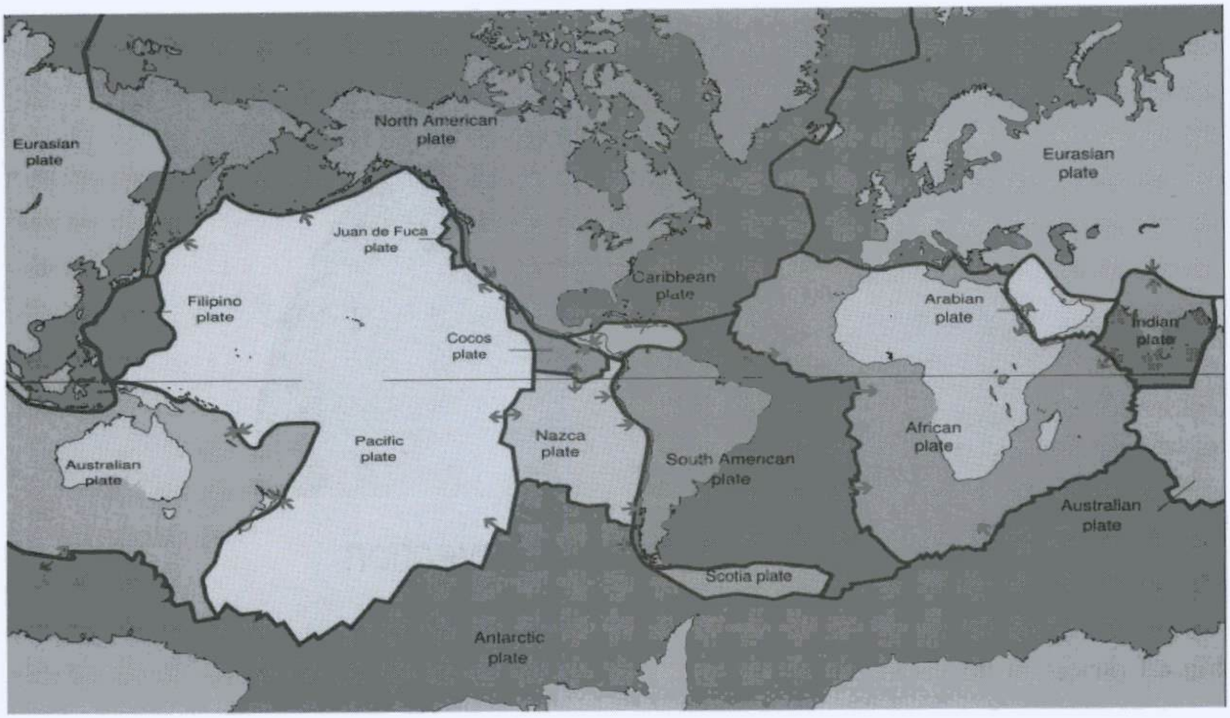
When a plate move towards one another to collide or towards colliding like situation such plate are called convergence plate margins. The convergence effect will be having the serious impact on the landscape. The convergent force produces earthquake, seafloor trench, volcanic explosion, fold mountains and other tectonic activities. All these impacts will vary as per the strength of the two colliding plates. If two continental plates collide it may result to fold mountain, similarly oceanic plate with continental plate collision produces volcanic eruption, sea floor trench formation. Suppose if it is a collision between oceanic and oceanic plates this leads to the development of seafloor trenches and earthquakes.

6.12.3 Transform fault margin

Transform fault margins occurs when a plate move latterly as well, if it move vertically either upward or downward it is called as transform fault margin. The major impact of transform fault margin plates are development of huge faults and valley ridges.

6.13 CAUSES OF PLATE MOVEMENTS

Alfred Wegener failed to give proper evidence about the force for the movement of the continents. As we have discussed in the earlier units that, the plates are like boat floating over the Asthenosphere. Obviously, it is subjected to the horizontal and vertical movement. But the main question here is, what is the force that causes the movement. For example, in the case of a boat the wind is the force which pushes the water due to this effect, the boat swing up and down or too and fro, as it is floating over water. Similarly the major and minor plates are also floating over semi liquid substance (asthenosphere), which by itself is unstable. Because, the material on which the plates are floating is hot molten lava having temperature more than 1000^0 centigrade. The temperature at the interior core of the earth is 6000^0 centigrade. Hence any object floating over a boiling state of a liquid, it cannot remain static. Secondly, two different thermal conditions existing in the interior of earth could easily produce three forms of currents. Such as 1)convection current, 2) Outer core convection current, 3) Horizontal thermal plumes.



6.13.1 Radioactive convection current

The radioactive substances which are present in the lithosphere produces heat. Due to the heat generated both form bottom and within the crust the rocks get heated and subjected to melting. Since the asthenosphere is in contact with the bottom of the crust there exit a conventional current produced by the radioactive minerals. The currents in its movement pushes the plates vertically, at the zone, where the current is rising upwards. At the place of descending zone, the convection current pushes the plates towards the bottom at a minor scale this type of radioactive convection currents are formed at regional and local level in the interior earth. (See the fig.4)

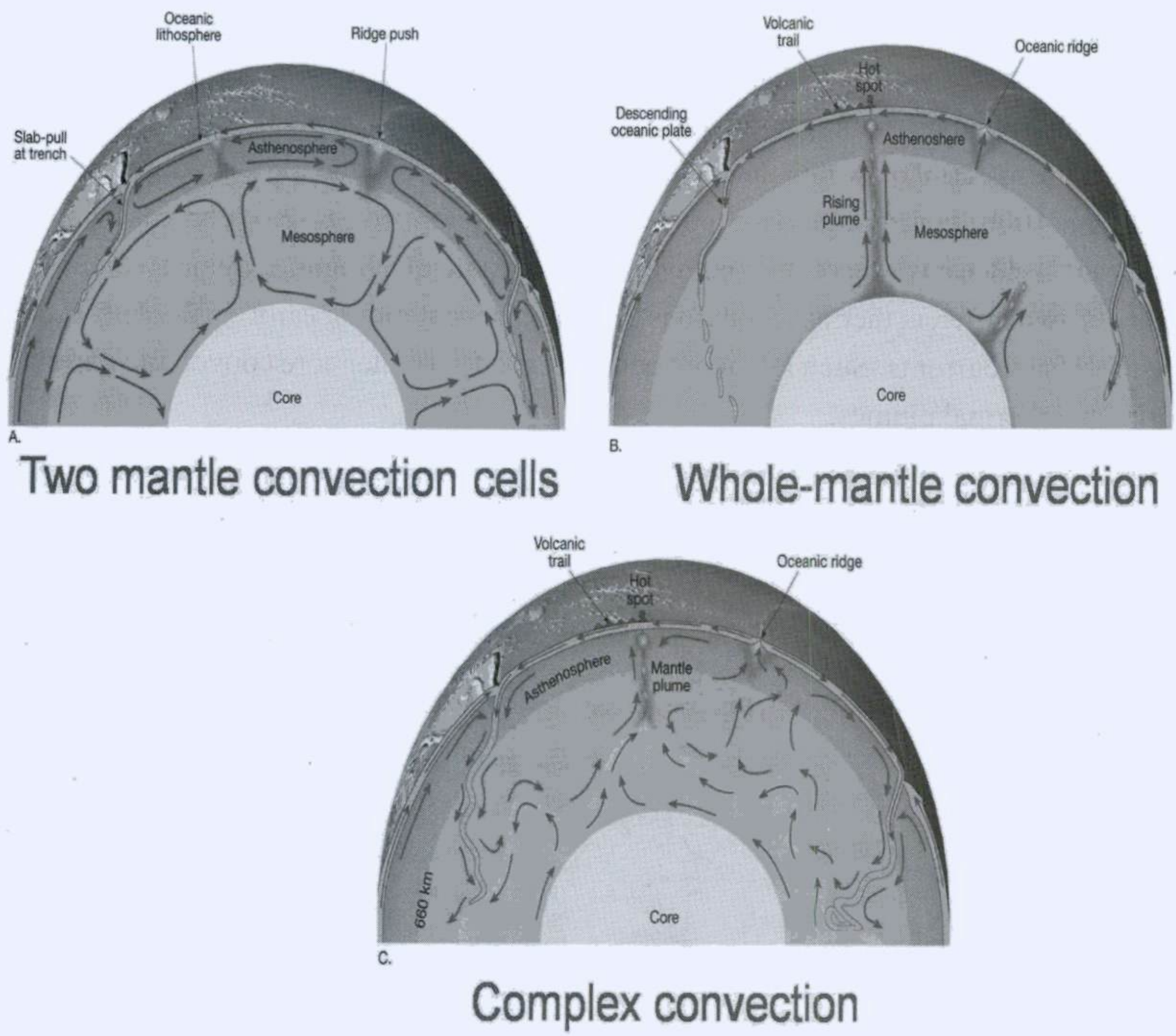


Fig.4. Convection models and Plumes

6.13.2 Outer core convection currents

The outer core convection currents are produce from interior earth just above from the solid inner core, as the temperature at the outer core is high, that sets the convection current rising from interior towards the Asthenosphere. The rising current from the bottom towards the earth crust produces fracture in the early stages. The constant hit by the rising currents at one particular zone leads to widening of fracture. Ultimately the plate is getting pushed by the currents at a rate of 0.5 cms to 12 cms per annum. It means each day the plates are pushed by milli meters. Millions of years effect leads to pushing of plates to several kilometers. Refer the figure to get a better understanding about the plate margins and the currents.

6.13.3 Horizontal thermal plumes

Scientist also believes that, the hot substance of high temperature can produce thermal plumes which move vertically from the inner core towards the asthenosphere. When this plumes hits the bottom of the crust it further enhances the temperature and accelerates the convectional current. The thermal plumes which are produced from the interior earth functions with the convectional force as an ancillary agent.

6.13.4 Evidence of the plate movement

Many evidences about the movement of plates are available to substantiate the evidence of the plate movement. Scientist have measured the rate of movement the plates with the help of DGPS (Differential global positioning system) instrument. DGPS are highly sophisticated instrument used to record the direction of the movement of plates and the rate of movement of different plates. The minor plates are moving lesser than the major plates. The lowest rate of movement varies between 0.5 to 1 cms per annum and high rate of movement recorded goes up to 16 cm per annum.

6.13.5 Earthquake and Volcanic Incidences as Evidences

To prove the occurrence of plate theory, if we look at the past incidences of the epicenter of the earthquakes and volcanoes it exactly falls over the plate margins. Through this evidence, it is beyond doubt that, the curst is in the form of plates and it is moving. The plate margins are the most vulnerable zone for most of the endogenetic calamities such as Earthquakes, Volcanoes, Faulting, Sea Floor

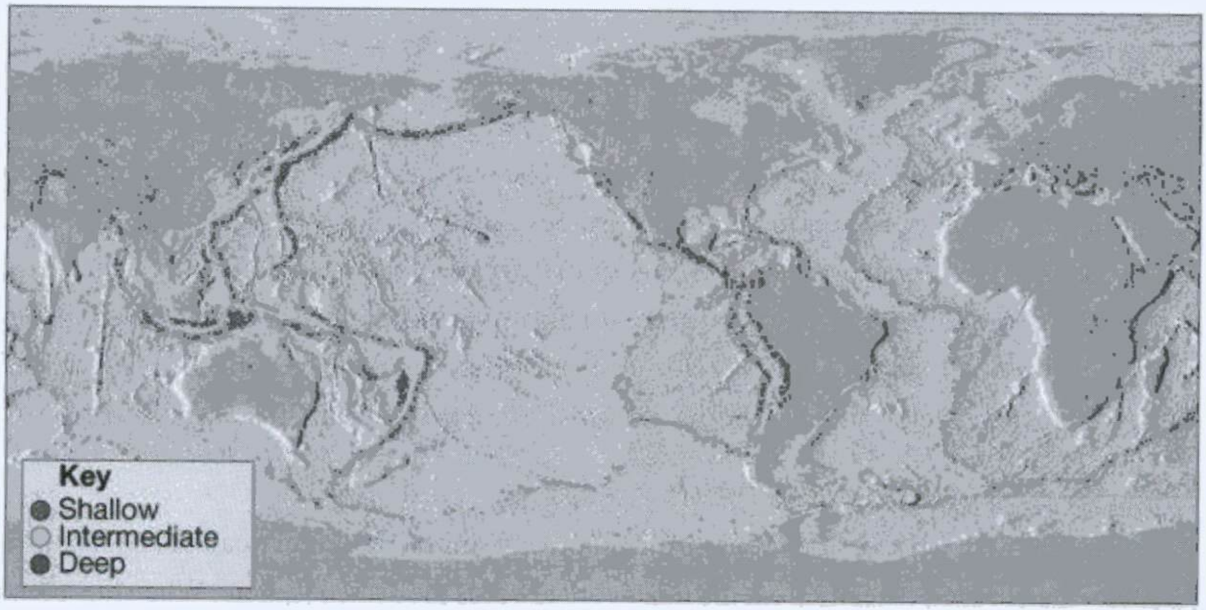


Fig.5. World Earthquake zones

spreading, marine trenches and rift valleys. The figure 5 represents three types of earthquake incidences that have occurred past 150 years. The earthquake wave generated from the lower depth of the interior earth is referred as shallow earthquake. The blue dots in the map show the earthquake occurred places which also neatly depicts the plate margins. Hence it is clear from the forces discussed in the above paragraph are the cause for the movement of plates. As per the measurement recorded Nasca (Minor) plate is moving at the rate of 16 cms per annum, the African plate at the rate of _10 cms per annum. The Philippines plate is moving towards Indian plate at the rate of 2cms per annum and the Arabian plate is moving towards the northwestern India exerting substantial pressure on the North frontier boundary thrust fault (NFBT) (see Fig.6).

6.14 EVALUATION OF PLATE TECTONICS

Despite of a good acceptance and appreciation plate tectonics theory is not devoid of criticisms. Many scholars have raised serious question about its validity, which need to be tested.

1. The transfer of heat from lower mantle to upper mantle is questioned.
2. The movement of vast gigantic plates is subjected to questioned.
3. The closely Juxta fit position of plates and its movement are contradictory.
4. The mismatching thickness of the plates and depth of the rift is questioned

6.15 LET US SUM UP

Although Alfred Wegener continental drift theory was criticized, it holds substance and approach of evaluating the origin of the continents and ocean. From his theory, the earth scientists are benefited to unravel further to explore the facts about the drift concept

Plate tectonic theory which is based on the continental drift theory by Wagener shed light on the endogenetic activities and closes the curtains about the various unanswered exogenetic and endogenetic process which were not able to be proved scientifically, was possible to prove with the help of plate tectonic theory. Even today we consider the plate margins are most susceptible for natural calamities.

6.16 KEYWORDS

Pangaea: During the Carboniferous period, there existed a single land mass called "Pangaea".

Panthalasa: "Pangaea" was surrounded by huge water body called "Panthalasa". ***Gondwanaland:*** During Permian period (225 years ago) the Pangaea splited into two landmasses, one is Lauratia another one is Gondwanaland.

Lauratia: During Permian period (225 years ago) the Pangaea splited into two landmasses, one is Lauratia another one is Gondwanaland.

Tethys: at the center of the "Pangaea" a sea was located that is called "Tethys".

Major plates: 1) American Plate, 2) Australian Plate, 3) African Plate, 4) Eurasian Plate, 5) Pacific Plate, 6) Antarctic Plate.

Minor plates: 1) Indian plate 2) Philippine Sea Plate, 3) Arabian plate, 4) Caribbean Plate, 5) Juan de Fuca Plate 6) Cocos Plate, 7) Nazca Plate, 8) Somali Plate, 9) Scotia Plate.

Divergent plate margin: The plate margins which have the tendency of moving away its original passion is referred as divergent plate margin.

Convergent plate margin: When a plate move towards to other plate the colliding like situation such plate are called convergence plate margins.

Transform fault margin: Transform fault margins occurs when a plate without moving latterly if it move vertically either upward or downward it is called ad transform fault margin.

6.17 QUESTIONS FOR SELF STUDY

1) Explain the development of Continental Drift Theory by Wegener?
2) Explain the validity of the evidences furnished by Wegener to support his claim about continental drift theory?
3) Discuss the criticisms about Drift theory?
4) Discuss about world major and minor plates,
5) Describe about plate margins
6) Define Plate tectonic theory in detail.
7) What are the Causes of plate movements?
8) Discuss the validity of plate tectonic theory?

6.18 FURTHER READINGS

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UNIT : 7 ENDOGENETIC MOVEMENTS – EARTH QUAKES & VOLCANOES

Structure

7.0 OBJECTIVES

This unit provides you the basic information about the forces affecting the landforms. Earthquakes and Volcanoes are the most important sudden forces operating, modifying and creating various types of landforms.

After studying this unit, you will able to

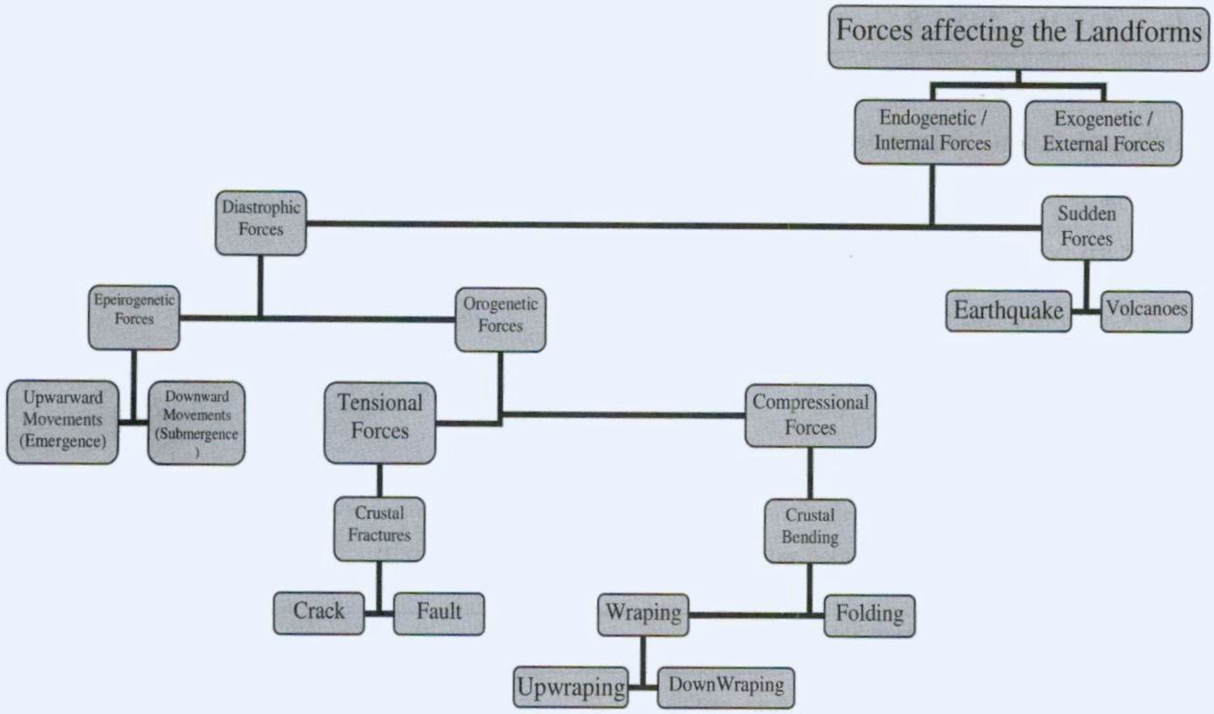
- Compare the forces affecting the landforms
- Connect about the causes, consequences and distribution of Earthquakes and Volcanic activities.
- Analyse the Landforms created by Earthquake and Volcanic activities.
- Identify the Earthquake and Volcanic zones in the world.

7.1 INTRODUCTION

We can observe many types of landform over the surface. Small and medium tracts of the earth's surface are called **Landforms**. Several other related landforms together forms **Landscapes**. Landforms are not constant. They always change with time and process. The first principle of Geomorphology states that **'The same physical processes and laws that operate today operated throughout Geological time, although not necessarily always with the same intensity as now'.** In this unit we are going to discuss endogenic forces affecting the landforms.

7.2 FORCES CHANGING THE LANDFORMS - ENDOGENIC MOVEMENTS

There are certain forces and movements which are always active in shaping the earth's crust. We can list out the forces as following.



'Geomorphic processes leave their distinctive imprint upon landforms and each geomorphic process develops its own characteristic assemblage of landforms' (Concept.4). The landforms over the surface of the earth are the products of the interaction of two types of forces. They are-

I. Endogenetic or Endogenic or Internal Forces

II. Exogenetic or Exogenic or External Forces

Endogenic forces originate in the core of the earth. According to scientists, these forces are caused by contraction of earth on cooling, action of radio active elements, change in the rotation of the Earth etc., Internal forces of the earth are responsible for irregularities over the surface of the earth in the form of various type of landforms. Hence these are also called as **Constructive Forces**.

Exogenic or External forces are acting over the surface of the earth. The action of these forces are visible in the form of the work of agents of gradation. Ex: River, Glaciers, Sea waves, Winds etc. These forces remove the irregularities created by internal forces. Hence these forces are also known as **Destructive Forces**.

ENDOGENIC FORCES OR MOVEMENTS:

The term 'Earth Movement' is confined to movements caused by the internal forces within the crust. Differential movements of the earth's crust caused by Diastrophic forces are called the **'Earth Movements'.** The internal forces can be classified into two groups. They are-

1. Sudden Forces.
2. Diastrophic Forces

7.2.1. Sudden Forces: These forces break the crust of the earth suddenly and makes the opening through which various type of materials like molten magma, gases, solid particles, ash etc., are ejected to the surface. Earthquakes and Volcanoes are the examples for these.

7.2.2. Diastrophic Forces: These are very slow forces, but causes large scale deformation of the crust of the earth. It leads to the formation of mountain ranges, ocean basins etc., The slow changes caused by the forces operating within the earth are known as **Tectonic Movements**. The diastrophic forces are further classified into two. They are –

a. Epierogenetic or Epierogenic Forces

b. Orogenetic or Orogenic Forces

a. Epierogenetic or Epierogenic Forces: The word **Epeiros** mean Continent. Certain internal forces are acting radially from the centre of the earth and results in vertical movements. It can raise or depress parts of the earth's crust. These movements are called as **Epierogenetic or Continetal building movements**. During upliftment or depressing a large area as a whole, rock layers are not disturbed.

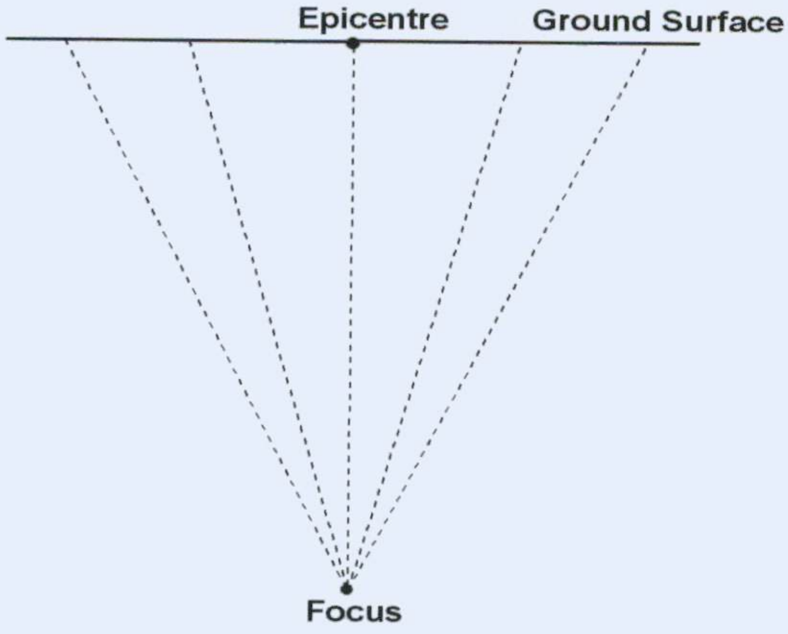
b. Orogenetic or Orogenic Forces: The internal forces which acts horizontally or tangentially to the earth's surface, disturbs the horizontal layers of the earth's crust. These movements are called **Orogenic or Mountain building movements.** The horizontal force may act as Tensional and Compression forces. Tensional forces are operate in opposite directions (⇦ ⇨) from a common centre. Due to this crustal rocks are stretched, the rocks get fractured. This process is known as Faulting. Compressional force may operate from opposite directions to a common centre (⇦ ⇨) and leads to folding of crustal rocks.

You will study in detail of these two forces in the next unit. In the present unit we will discuss the sudden forces like Earthquakes and Volcanoes in detail.

7.3 EARTHQUAKES

An Earthquake is a vibration or oscillation of the surface of the earth caused by a transient disturbance of the elastic or gravitational equilibrium rocks at or beneath the surface (Macelwane J.B. 1933). In other words ***'Tremors and vibrations in the crust of the earth are called Earthquakes'.*** Any sudden disturbance below the earth's surface may produce vibrations or shakings in the crust. It is the movement of one rock mass against another that causes vibrations. Some of these vibrations reach the surface and are known as Earthquakes.

Fig.7.1 Focus and Epicentre of the earthquake



The Earthquake originates usually some kilometers below the surface. The place of origin of the Earthquake below the ground is called **Focus or Seismic Focus.** Earthquake tremors move from the Focus in all directions. The point on the earth's surface vertically above the focus is called **Epicentre or Epicentral Line.**

The vibration first reaches the Epicentre, because it is the shortest distance between the focus and the surface of the earth. The intensity of the earthquake is also maximum at the Epicentre. Here the vibration is experienced in the form of up and down. Due to this, damage is comparatively small at the Epicentre. But the maximum damage will occur where the earthquake waves reach the surface in slanting. Far away from the Epicentre the intensity of the Earthquake decreases and maximum damage occurs in the areas close to the Epicentre.

7.3.1.Earthquake Waves:

When rocks suddenly break within the earth, vibrations are set up which are called as **Earthquake or Seismic Waves**. Three types of earthquake waves are produced from the focus of an earthquake. They are-

a. Primary or Longitudinal or Waves of Condensation or 'P' Waves

b. Secondary or Transverse or 'S' Waves

c. Tertiary or 'L' Waves.

a. **Primary or Longitudinal or Waves of Condensation or Push or 'P' Waves:** These waves travel outward in straight lines in all directions from the focus of the shock. These are the fastest of all the earthquake waves having an average velocity of 5.4 to 13.8 km per second.

b. **Secondary or Transverse or 'S' Waves:** They vibrate at right angles to the direction of the propagation closely follow the 'P' waves. These waves cause a shaking of the earth's surface, hence these are also known as **Shaking-waves.** The average velocity of these waves is about one-half that of the 'P' waves. It travels at a speed of 3.2 to 7.2 km per second. It is more destructive than primary waves.

   'P' and 'S' waves travel through the earth's interior and spread outward from the focus in all directions, these are also known as **Body waves.**

c. **Tertiary or 'L' Waves:** After the 'P' and 'S' waves reach the surface of the earth, a surface wave 'L' travels at a low velocity than other two waves. Their speed is 4 to 4.3 km per second. It is very destructive in nature. These are also known as **Love or Long waves**. These waves are confined to surface only. Hence these are also known as **Surface waves.**

7.3.2. Earthquake Intensity and Magnitude:

Several earthquake occur every day. Based on the number of recorded shocks during a year, on an average at least one earthquake will occur at every two hours. The intensity of an earthquake is measured with the help of a self recording instrument called **Seismograph**. It records a zigzag line that shows varying magnitude of the ground oscillations below the surface. The scientific study of earthquake is known as **Seismology**. It is a special branch of Geology. It is derived from the Greek word **Seismos** meaning the earthquake.

Seismogram is a graph out put by a Seismograph. It is a record of the ground motion at a measuring station. **Seismometer** is an instrument which records the movement of the rocks in a particular direction. An imaginary line which connects the area of having equal earthquake intensity is known as **Isoseismal Line.** In a particular earthquake-record the lines joining the places where the shock arrives at the same time are called **Homoseismals or Coseismals or Homoseists.**

Magnitude is a measure of the energy released during an earthquake. The magnitude of the tremors caused by an earthquake measured on **Richter Scale**. It is the name of the Seismologist **Charles F.Richter** (1935) of the California Institute of Technology of U.S.A. Most of the earthquakes measure between 'o'(zero) and '9' on this scale. The earthquakes measuring 7 or above on this scale are considered as highly destructive.

Intensity of an earthquake is now expressed by reference to a scale devised by **Mercalli**. According to this scale if the magnitude of the earthquake is 6.9 it is known as Ruinous, 7 to 7.3 is Disastrous, 7.4 to 8.1 is Very Disastrous and more than 8.1 is considered as Catastrophic.

When there is release of pressure, vibrations will occur. There are certain minor disturbances after the main shocks are known as **After Shocks.**

There are more than 600 stations in the world which measures and records the intensity of the earthquakes. In India there are five stations, where the intensity of earthquakes are recorded. They are Kodaikanal (Tamilnadu), Poona, Kolba (Maharastra), Kolkatta (WestBengal) and Gowrdibidanur (Karnataka).

7.4 CAUSES OF EARTHQUAKES

As stated in the previous paragraphs, a large number of earthquakes occur in every year. However we do not feel all of them due to a number of reasons like less magnitude, occurs in far off places, night time etc., Some of the major causes for occurrence of earthquake are-

a. **Crustal Instability:** About 95% of all the earthquakes occur due to sudden earth movements along existing or new faults. The term Tectonic is derived from the Greek word ***'Tekton'*** means builder. It refers to any structural change in rocks brought about by their deformation or displacement. These forces lead to sudden movements of the crustal blocks. Lines of fault in the crust are the areas, where major earthquakes occur.

Ex: San Andreas Fault in California in U.S.A., etc., These earthquakes are also known as **Tectonic Earthquakes.**

b. **Volcanic Activity:** Due to volcanic explosion, surrounding areas of volcano are disturbed. Hence tremours occur in these regions. The intensity of earthquake is high near the volcano.

c. **Disturbance of the Crustal Balance:** The isostatic balance between the depressed and elevated blocks are maintained. If there is any disturbance trigger the earthquake. Large accumulations of sediments in depressed areas also disturb the crustal balance. These types of earthquakes are known as **Isostatic Origin.**

d. **Elasticity of Rocks:** The elastic rebound hypothesis is propounded by Reid H.F. and his associates. Elasticity of rocks, are also responsible for the occurrence of earthquakes.

e. **Local Causes:** Land slides in mountainous areas, sudden collapse of the roof of the caves in Karst region, sudden subsidence or break of continental slopes also trigger minor earthquakes.

According to the **Plate Tectonic theory**, the crust of the earth consist a number of rigid blocks called Plates. These plates are believed to be move horizontally. The margins or the edges of the plates along which two neighbouring plates are displaced are the regions of most of the Tectonic Earthquakes.

Prof.Reid H.F has postulated the **Elastic Rebound Theory** to explain the origin of Tectonic Earthquakes. The materials of the earth, being elastic can sustain a certain amount of stress without a permanent deformation. When the stress exceeds the elastic limit, a crack or fracture is developed. With increasing of stress on either sides of the fracture, the rocks can not hold more straining. At this point, there is a sudden slip off the fractured blocks to position of no strain. The energy stored from decades is released instantly causing underground dislocation of rocks and waves of energy are emitted through the earth. The crack or fracture along which the displacements of rocks occur is known as a Fault. So according to this theory, earthquakes are most commonly associated with movement along a fault.

7.5 TYPES OF EARTHQUAKES

Earthquakes are generally classified on the basis of their cause of origin, depth of focus, Intensity and Magnitude of Earthquake. They are-

7.5.1. Tectonic Earthquakes:

These are caused by sudden movements of the earth's crust. These are usually found at a depth of three to fifteen miles below the surface. Their intensity varies from one to another. Some are very severe. Gutenberg and Richter classified the earthquakes based on the depth of their origin into three types. They are-

a. **Shallow or Normal:** These earthquakes origin at a depth of less than 60km.

b. **Intermediate Earthquakes:** They occur at a depth of 60 to 300 km from the surface.

c. **Deep Earthquakes:** They origin at a depth between 300 to 720 km from the surface.

7.5.2. Plutonic Earthquakes:

They occur less frequently and originate at a depth of 150 to 420 miles from the surface. Recrystallization of minerals, molecular changes in the minerals, chemical explosions and others are possible causes of these earthquakes.

7.5.3. Volcanic Earthquakes:

They occur due to volcanic activities. They are caused by sudden violent displacement of lava in or beneath the surface. They occur frequently in volcanic regions.

7.6 EFFECTS OF EARTHQUAKES

Earthquake also effects over the surface. Some of the disadvantages of earthquakes are-

- Vibrations in the crust may lead to development of cracks or fissures in the rocks. Ex.Koyna Earthquake (1967) has caused a fissure in the ground about 25 km long and 10 to 15 cm in width.
- Changes in the crust of the earth leads to a number of indirect effects like – landslides, blocking the course of the river, bursting of dams, flooding etc., Ex: Loess highlands of China two lakh people were killed in 1920 and one lakh in 1927 due to landslides caused by earthquakes.
- Means of transport like roads, railways and bridges are all destroyed.
- It may damage large dams, power stations and nuclear power plants. Ex: Fukushima Nuclear power plant in Japan has been affected by March-2011 earthquake.
- They also damage the underground pipelines, water systems etc.,
- Telecommunication is also disturbed by these.

- Strong earthquakes which occur in the bottom of the sea causes very strong sea waves which are known as **Tsunamis ('tsu' means harbor, 'nami' means waves)**. It rushes toward coastal area like a wall of water submerging large areas and causes immense damage to life and property. Ex: Tsunami in Indian Ocean (2004) has killed more than two lakh people, Tsunami in Japan (23 feet wave) in March 2011, killed more than 30,000 people. This earthquake occurred at Pacific coast of Tohoku with a magnitude of 9.0 has been termed officially by the Japan Meteorological Agency as 4^{th} largest in the world since 1900.
- Buildings will collapse due to earthquakes. Severe earthquakes kill thousands of people and make more people as homeless. Fires often accompany with collapse of buildings. Ex: San Francisco earthquake of 1906 caused more damage by fires, than by the earthquake itself. In 1923 fire had broken out by the earthquake devasted the cities of Tokyo and Yokohama.
- The earthquake in Japan (March-2011) shifts the Honshu Island by 2.4 meters.
- Underground water is also affected. Lakes and swamps are created in many places.

7.6.1. Advantages of Earthquakes:

Sometimes the earthquakes may produce some benefits also. It will create new waterfalls, streams etc., shallow sea areas may be uplifted providing more land. Due to the subsidence of the sea bottoms, deep gulfs are formed, which are the best sites for sea ports. Sometimes the dry lakes get water from these earthquakes. They also lead to the formation of springs and sometimes rocks rich in valuable minerals may be brought to the surface. By studying earthquake waves, it is possible to know about the interior of the earth.

7.7 DISTRIBUTION OF EARTHQUAKES

No region in the world is completely free from earthquakes. Even the stable landmass like Deccan plateau of India has experienced earthquakes (Latur Earthquake). But all the regions of the world are not equally experience the same intensity of earthquakes. In some regions earthquakes are frequent and more intensity. In other regions low intensity and less frequent earthquakes will occur. Regions of young fold mountains and active volcanic regions are experiencing more earthquakes. The movement of plates is the fundamental cause of earthquakes. Most of the earthquakes occur in the boundaries between lithospheric plates and between the plates. There are three well defined Seismic Zones in the world. They are-

1. Circum-Pacific Zone
2. Mediterranean and Trans-Asiatic Zone
3. Mid-Oceanic ridges and East African Rift Valley system.

7.7.1. Circum-Pacific Zone:

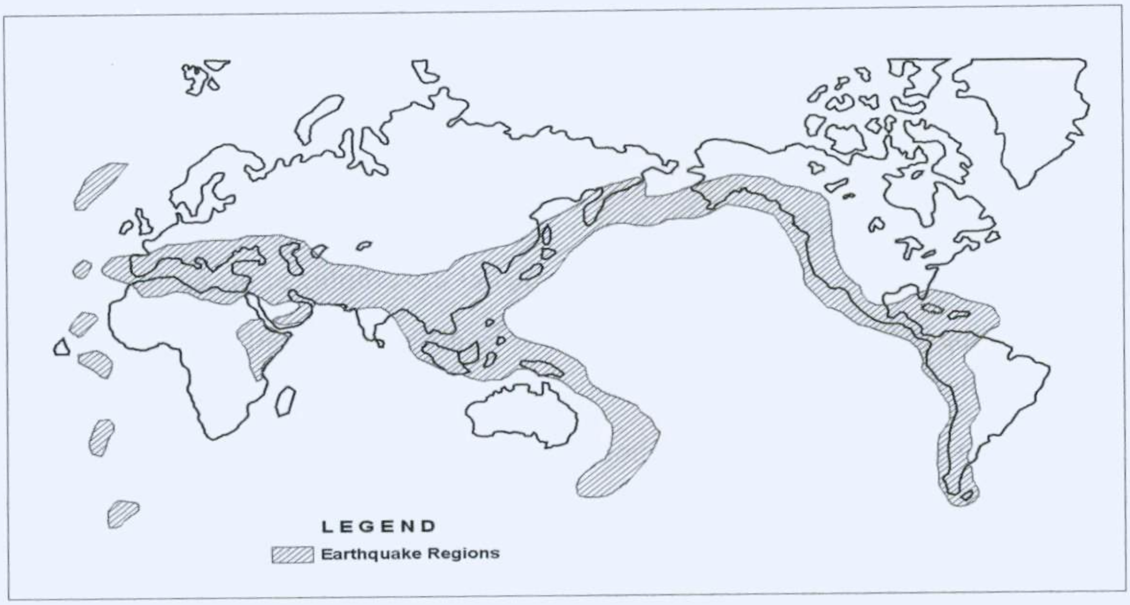
It has oceanic trenches and associated island areas where plates converge and the oceanic lithosphere is depressed into Asthenosphere. The epicenter of the earthquake is located on the continental sides of the trenches. From the west it begins from Alaska, Japan and Philippine trenches. It is divided into two branches. One branch extends towards Indonesian trench and the other towards Newzeland. On the eastern side of pacific, it consist the west coast of North America, particularly California. It continues towards south parallel to the middle American trench, Peru and Chile trench on the west coast of South America. Earthquakes not only occur in the plate boundary, but occur over a broad zone. These are called plate boundary related earthquakes. These are caused by Stress at the plate margins. These earthquakes are common in Japan.

7.7.2. Mediterranean and Trans-Asiatic Zone:

It extends along the Alpine mountain system of Europe and North Africa, Asia Minor and Caucasus, Iran, Pakistan, Himalayan Mountain including Tibet, Pamirs and China. In this region earthquakes are shallow intermediate origin. It does not consist any oceanic trenches, but continental plates.

7.7.3. Mid-Oceanic ridges and East African Rift Valley system:

It is found along the mid-oceanic ridges and transform faults. Here the earthquakes are shallow variety in this region. This region is located on major fracture zones where the plates diverge and the new oceanic crust is being formed by the rising magma. It is also extend along the Red Sea and the rift valley of East Africa.



The earthquake regions in the world can be observed in the figure 7.2

VOLCANOES

7.8 INTRODUCTION TO VOLCANO

In the previous topic, we have discussed the various forces operating in the earth. Volcanic activity is another result of the sudden operation of internal forces of the earth. Volcanic landforms may form in any region or climate. In course of time, they are modified by the agents of gradation. In recent years, due to development of new techniques the studies of volcanoes have gained Geomorphic interest. Because it is possible to know the exact dating of eruptive rocks. By measuring the amount of rocks eroded from a dated volcanic landscape, it is now possible to measure the absolute rate of landscape modification and to reconstruct the original volcanic features. Volcanic activity is greatly responsible of the creation of atmosphere and hydrosphere in our planet.

7.8.1. Meaning of Volcano:

The word volcano is derived from a small island near Sicisily. It is a name of God of ancient Romans. ***'A volcano is an opening in the crust of the earth through which materials from the interior of the earth is ejected on to the surface'.***

Some definitions of Volcano are –

'A deep vent in the earth's crust through which molten rocks or hot lava, ash and hot gases are ejected from the earth's interior to the surface of the earth' (Dayal P- 1995).

'A Volcano is a conical or dome shaped initial landform built by the emission of lava and its contained gases from a vent in the earth's surface' (Alan Strahler and Arthur Strahler–2007).

According to A. Holmes and D.L.Homes (1978) ' A volcano is essentially a fissure or vent, communicating with the interior from which flows of lava, fountains of incandescent spray or explosive bursts of gases and volcanic ashes are erupted at the surface'.

According to Philip G.Worcester (1965) "Volcanism includes all phenomena connected with the movement of heated material from the interior to or toward the surface of the earth".

The term Vulcanicity is very comprehensive and broad. It includes all the processes by which solid, liquid or gaseous materials which are present under the surface are ejected to the surface. Sometimes the volcanic activities are also termed as Vulcanicity. It includes the process under the surface and above the crust.

All these definitions show that it is a natural phenomenon from which different kind of landforms are created as well as modified. In forth coming pages, you will study about volcanoes, different types of eruptions, their results and their distribution. The scientific study of Volcano is known as **Volcanology.**

7.8.2 Structure of Volcano:

A volcano is a vent or a group of closely spaced vents through which different materials are ejected from the beneath to the surface. The important parts of a volcano are-

a. **Vent or Pipe:** The hot magma, gases and other materials were ejected through a narrow opening of a volcano is called Vent.

b. **Cone:** The ejected magma rushing out of the vent creates a cone like formation in the upper part of the vent. Sometimes the cone looks like a Mountain.

c. **Crater:** The upper part of a vent is often a cup or saucer shaped depression called Crater.

Large sized craters are called **Caldera.** The base of the crater is connected with the vent through which the lava rises to the top. Figure 7.3 shows different structure of a volcano.

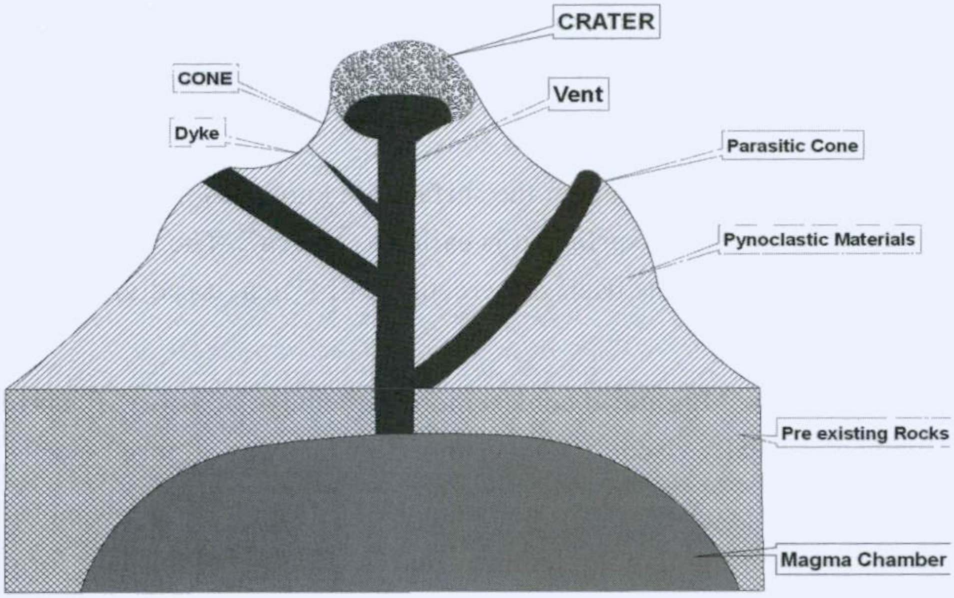


Figure 7.3 Structure of a Volcano.

7.9 MATERIALS OF VOLCANO

Ejection of the material from the interior of the earth is known as **Volcanic Eruption.** The ejected materials may be solid or liquid or gaseous. Steam is the most important gaseous material released by a volcano. It accounts 60 to 90% of the total gases released by a volcano. Other volcanic gases are Carbon dioxide, Nitrogen, Sulphur dioxide, Hydrogen, Carbon monoxide, Sulphur, Chlorine etc.,

The solid rock fragments of different sizes are erupted by a volcano are known as **'Pyroclasts'**. These are sometimes called as **'Tephra'**. It consists of fragments of different sizes and shapes from fine dust to gravel. According to their size, they are called in different names. The largest angular fragments are called **'Blocks'** or **'Brecia'**. When molten lava is thrown out into the atmosphere, before reaching the surface, it cools down, solidify to round, oval or pear-shaped forms. These solid rounded materials are called as **'Volcanic Bombs'**. If they are small like peas they are known as **'Lapilli'**. If they are in the form of solid rocks, they are known as **'Cinders'** or **'Pumice'** or **'Scoriae'**. When the volcanic materials are in sand size and finer tephra, it is called as **'Volcanic Ash'**. If they are further thinner, they are known as **'Volcanic Dust'**. The rock which are composed of a mixture of ash, dust, lapilli and cinder is called **'Tuffs'.**

The bigger solid particles like Lapilli, Cinders, Bombs and blocks falls down close to volcano. But thinner particles like ash and dust may cover several kilometers before settling down.

The molten rock materials under the surface are known as **'Magma'.** When it come outside from the volcano to the surface it is called as **'Lava'.** The temperature is usually between 900^0 to 1200^0 C. On the basis of percentage of Silica, it is divided into two types. They are-

a. **Acidic Lava or Magma:** It consist more percentage of Silica. It has high melting point and usually viscous. So it cannot flow far away. It forms steep sided cones.

b. **Basic Lava:** It consist of low percentage of Silica. It has a low melting point. It is more liquid and flows to far away places. Cooling of this lava forms Basalt. It also produces a flatter cone of a big diameter.

On the basis of contrasting surface textures may develop, which are know by Hawaiian names. They are-

a. **aa Lava:** Consist little gas and flows slowly. While flowing, bubbles are formed due to escape of gases.

b. **Pahoehoe or Ropy Lava:** It is more fluid, smooth and flows quickly. It develops a thin, glassy crust. Sometimes these are tightly packed round masses which are called as **'Pillow Lava'.** It is commonly found on the ocean floor.

7.10 CAUSES OF VOLCANISM

There are several causes of volcanic activities. The most important are-

1. **High Temperature and Pressure:** As depth increases from the surface, the temperature also increases. For every 32 meter depth, 1^0C of temperature increases. Roughly at 68 km depth, all most all the solid particles are melted and they are in liquid state (magma). It is pasty in nature and has more pressure. It is lighter (viscosity) than the surrounding rocks, hence it rises. Due to very high temperature, it melts the surrounding rocks and expanding its zone. So the solid crust will become thinner and at some time the magma comes out from this thin layer.

2. **Radio activity:** In the unit 8, you will study about Radio Active theory of Joly. Radio active particles are present in magma. Under the Sima layer, the temperature is about 1150^0C. Nearly at 60 km depth all kinds of rocks are in liquid state. Due to this it

expands. It has low density than Sial layer. So Sial layer slowly subsides and fissures will occur. From these fissures the magma comes outside. We can observe volcanic islands in the edges of Pacific Ocean are formed by this.

3. **Water:** The water on the surface of the earth percolates into the interior of the earth through cracks and fissures. When the water gets contact with molten magma it is dissolved. When it cools (crystallizes), water is freed. Due to high temperature it is converted into steam. It escapes out from the holes, magma also comes out side.

4. **Crustal Deformation:** When folds, faults occur, fissures will be formed. Through these magma comes out side.

5. **Sea Floor Spreading:** Wherever two plates moves in opposite directions, fissures will occur and from these magma comes out side. Similarly when two plates like oceanic plate and continental plate converges, high density of oceanic plate subsides under continental plate of low density. Trenches will be formed due to this. From these magma comes outside and it forms **Island Arc.**

7.11 TYPES OF VOLCANO

Volcanoes are classified into different types on the basis of mode of eruption and periodicity of eruptions. They are-

I. Based on mode of eruption:

1. **Central or Explosive Eruption:**
    a. Hawaiian Type
    b. Strambolian Type
    c. Vulcanian Type
    d. Vesuvian Type
    e. Pelean Type
    f. Plinian Type.
2. **Fissure or Quiet Eruption:**
    a. Lava flood or Lava flow
    b. Mud flow
    c. Fumaroles

II. On the basis of periodicity of Eruption:

1. Active Volcanoes
2. Dormant Volcanoes
3. Extinct Volcanoes

Now you will learn various type of volcanoes in detail.

7.11.1 I. Based on mode of eruption:

1. Central or Explosive Eruption:

In this type, eruption will take place through a Central vent or mouth. Through the vent or opening which is circular or nearly circular in form, heated materials consisting of gases, water, liquid magma and pieces of rocks are ejected from the hot interior to the surface. This type of eruption is confined to a pipe like vent and after the eruption, Cone and Crater will develop. Ex: Cotopaxi volcano in Ecuador. Sometimes, there may be presence of other subsidiary holes, along the slope of the hill, through which magma and other materials are also released at lower elevations. Ex: Etna Volcano.

In this type, the nature and intensity of eruption varies according to amount, pressure of gases and viscosity of the lava. When magma is basic (basalt) which is less viscous, the eruption is peaceful. If the magma is acid, which is more viscous, the eruption is explosive. But the amount of gases, magma, their pressure and action determines whether the eruption is peaceful or explosive.

Based on the nature, intensity of eruption and differences in ejected materials, Central eruption volcanoes are further classified into six types. They are-

7.11.1.a. Hawaiian Type: In this type, violent eruptions are rare. The magma is very fluid (basalt) and are rarely expelled without explosion with liberation of gases or fragmented materials. The lava flows like a

river along the slopes of mountain. There is little or no Tephra. It is the characteristic of the Hawaiian Islands of Pacific Ocean. Hence, these are known as Hawaiian type. Ex: Basalt plateau of Columbia.

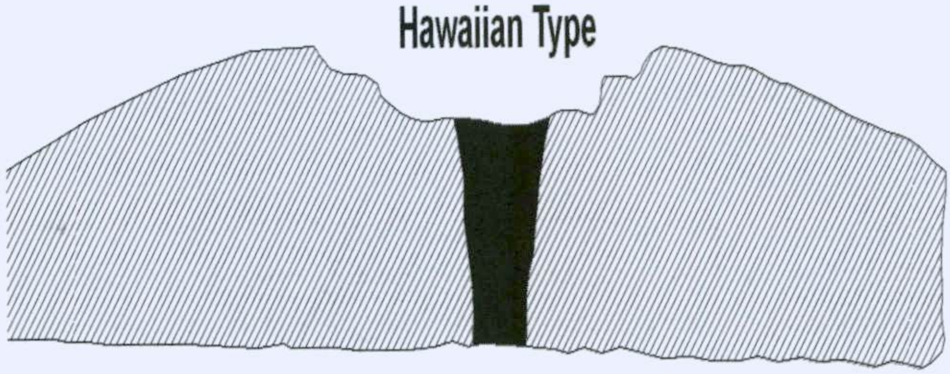


Figure. 7.4. Hawaiian Type volcano.

7.11.1.b. Strambolian Type: This type of volcanoes are named after the famous volcano **Stramboli,** situated in Lipri Island North of Sicily in the Mediterranean Sea. The eruption of this volcano in night looks like red glow fountain releasing steam plume has caused the volcano to be called as **"Light House of the Mediterranean".** The lava is basaltic, less fluid than the Hawaiian type. Some times violent explosions occur due to resistance in the release of gases, fragmented materials like Dust, Pumice, Scoria, Bombs etc. Eruption is not continuous, but it is intermittent and fountains of lava are erupted at regular intervals varying from a few minutes to about an hour. Ex: Volcano at Helka, Iceland which erupted during 1947-48.

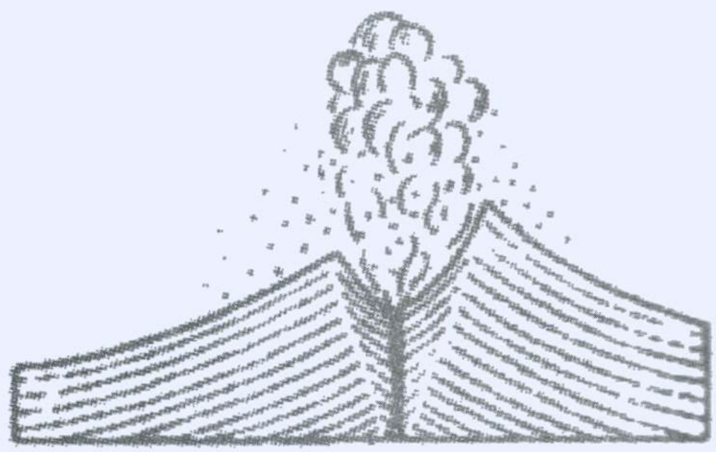


Figure 7.5 Strambolian type Volcano

7.11.1.c Vesuvian Type : These are named after the Vulcano near Stramboli in the Lipari Islands in Mediterranean Sea. In this type, lava is so thick and viscous. When magma comes out contact with atmosphere, it solidifies very quickly and closes the mouth of the crater in between two eruptions. Gases and other materials accumulate inside the volcano, when pressure increases, the vent is exploded. Different of materials, ash and dust are thrown out. Dark dust filled clouds of steam and other gases hang over the volcano which looks like a large Cauliflower during an eruption. Showers of bombs, blocks and Lapilli will occur in the surrounding area and the ashes covers a large area in the Sky. The magma is from acidic to basic are found in these volcanoes. Ex: Vulcano in the Lipari Islands which erupted during 1888-90.

Figure 7.6 Vulcanian Type

7.11.1.d. Vesuvian Type: These are more or less similar to Vulcanian and Strambolian type. In this type, there is violent explosion due to the intensity of the gases and the magma comes out with great force. The gases will form Cauliflower like clouds. This type of eruption was recorded by **Pliny** in A.D.79, which occurred at Vesuvius. Some scholar states that Vulcanian and Vesuvian type of volcanoes are similar to each other.

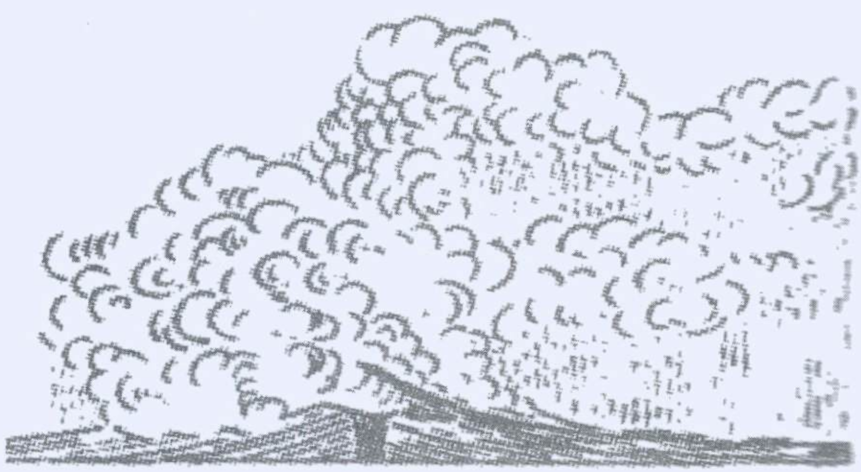


Figure 7.7 Vesuvian type volcano

7.11.1.e. Pelean Type: This is the most violent explosive of all the types. The lava is extremely viscous. At the time of eruption the dense magma solidifies and closes the mouth of the crater and a dome. After some time, due to excessive pressure inside, gas explosion will takes place at a greater scale. It is followed by dense mass of hot lava, fragmented materials and ash flows down the slope like an avalanche. It has been called as **'Nuees Ardentes'** or **'Glowing Clouds'.** The clouds may be illuminated by the burning gases. In this type hot gas and lava mixture is not thrown upwards, but spreads along the slope. Every thing in its path was burnt and destroyed. Nuee Ardente is the most fearful form of explosive volcanic activity. In 1902 in Martinque Island of the West Indies, there was a terrific explosion of Mount Pelee, the tremendous black, dust filled cloud of gases role down and devasted every thing in its path. Hovey states that in this eruption many enormous blocks of lava of more than 100 tons in weight were thrown far from the crater. In 1883 Krakatoa (Java-Indonesia) eruption, more than 1/3 of a cubic mile of the old cone was blown away. In 1911, Mt.Taal in Philippine Islands violently erupted. The old crater walls were partly blown away and a new inner crater was formed.

In Strambolian and Vesuvian type of eruptions, the gases come out from the crater through the Central Vent, where as in Pelean type thick lava comes out from the crater and blocks the mouth of the volcano. After this, gas and magma comes out from the subsidiary vents and cracks along the slope.

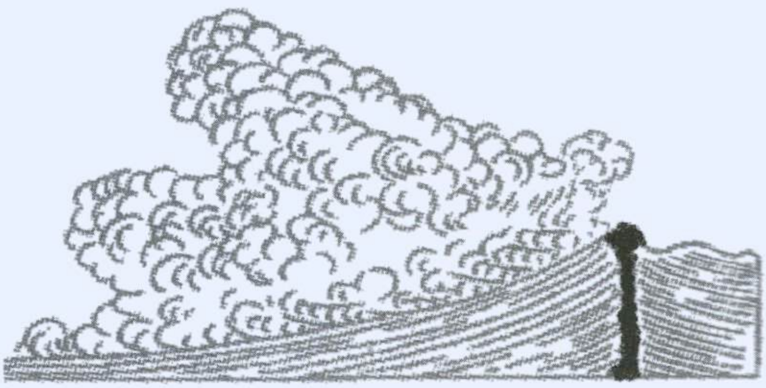


Figure 7.8 Pelean Type

7.11.1. f. Plinian Type : It is more violent form of Vesuvian eruption. In the last phase there is uprush of gas that carries cloud rapidly upward in vertical column for kilometers. It is narrow at base but expands outward at upper elevations. Tephra are less in the clouds.

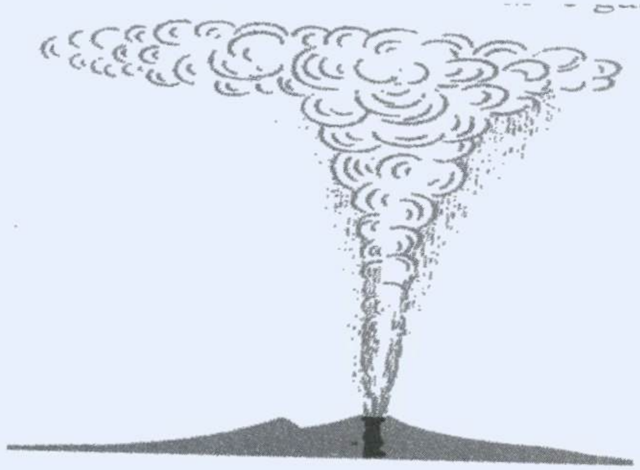


Figure 7.9 Plinian Type

2. Fissure or Quiet Eruption: This type of volcanic eruption takes place along the fracture, fault and fissures. There is a slow upwelling of magma from the interior and the lava spread over the ground surface. In this there is an absence of explosion and the lava is usually thin basalt. Ex: In 1783, Laki eruption in Iceland, In 1886 the Travera eruption in Newzeland.

Fissure - Icelandic Type

Figure. 7.10 Fissure Type

Fumaroles are the openings in the earth through which gases and water vapour through the vent is known as Fumaroles. These are linked with volcanic activities. These are the last signs of the active volcanoes. Several Fumaroles are found in groups near Katmai Volcano of Alaska. It is found in an extensive valley, which is known as **' A Valley of Ten Thousand Smokes'**. These are found along a linear fracture. Carbon dioxide, Hydrochloric acid, Hydrogen sulphide, Nitrogen, Ammonia are released by these. If it mostly releases Sulphur, these are known as **'Solfatara'**. Some volcanoes releases Carbon dioxide, these are called **'Mhofettas'**.

Mudflow occurs in the early stages of eruption. The dust ejected from the vent mixes with condensed steam and water. It carries these fragmented materials to far away places.

7.11.2. On the basis of periodicity of Eruption:

Volcanoes are classified into three types based on periodicity of eruption. They are-

1. Active Volcanoes
2. Dormant Volcanoes
3. Extinct Volcanoes.

7.11.2.a. Active Volcanoes: These are periodically erupt. Ex: Mt.Vesuvius in Italy, Etna in Sicily, Mona Loa in Hawaii Islands, Cotopaxi of Andes Mountain in South America etc., Barren Island of Andaman and Nicobar Islands in India is also an active volcano. It is estimated that there are about 500 active volcanoes in the world.

7.11.2.b. Dormant Volcanoes: These have erupted in a long back. But remained inactive for a long time. In any time they may become active. These are also considered as **Sleeping Volcanoes**. Ex: Vesuvius Volcano, Mt.Kilimanjaro, Fujiyama of Japan, Krakatoa of Indonesia etc.,

7.11.2.c. Extinct Volcanoes: These have not erupted since a long period. They have been inactive for so long that they are not likely to erupt in future. Ex: Volcanoes of the Eiffel district of Western parts of Germany, Auvergne in Central France, Popa Mountains in Myanmar etc., Several extinct volcanoes are also found in Mauritius, Malagassy and several islands in Indian Ocean. These volcanoes are also known as **Dead Volcanoes.**

We should also remember that, it is extremely difficult to classify the volcanoes as Active, Dormant and Extinct. Because at any time Dormant volcano may become active.

7.12 LANDFORMS PRODUCED BY VOLCANOES

In these paragraphs we will discuss about the landforms produced by vulcancity. Various kinds of topographical features were formed by volcanic activities over the surface and also below the surface, due to cooling and solidifying of lava or magma, dust, ash, fragmented materials etc. Topography of volcanoes is likely to change with each eruption especially of explosive volcanoes (Vulcanian and Pelean type). Most of the volcanic mountains of the earth were formed long back. The agents of denudation are eroding these landforms continuously. In Ecuador, there are 22 great volcanic mountains of which 15 of these have more than 15000 feet height. Cotopaxi is the highest (19613 feet) active volcano in the world.

Volcanism is the process through which the molten materials are ejected to the surface of the earth. As we already discussed about central and fissure eruptions, through which several landforms are formed.

The major elevated topographical features produced by the **volcanoes of Central Eruption are-**

a. Composite Cones

b. Cinder or Ash Cones

c. Spatter Cones

d. Shield Volcano (Exogenous/Shield domes)

e. Acid Lava Cones

f. Lava domes or Mounds

g. Lava Cinder and Ash Plains

h. Parasite Cones

i. Mud flows

j. Lava Plugs, Spines

k. Cliffs and Crags etc.,

7.12.a. Composite Cones: It is formed by lava, ash and other volcanic materials, which are deposited one after the other in almost parallel layers. The sheets of solidified lava give strength to this, which rock fragments that are thrown away from the crater built these cones. Dust and the fragmented materials deposits along the slopes, which is about 35^0 (angle of the rest of material). At higher angles the materials role down the slopes. The cone consist of basaltic lava, breccias, sheets of obsidian etc., These are the higher volcanic cones compared to others. These are also known as **'Strato Cones'**. Most of the largest, highest and symmetrical volcanic mountains of the world are of this type. Ex: Shasta, Hood, Rainier in western parts of USA, Mayon in Philippine Islands, Fujiyama in Japan, Vesuvius of Italy, Cotopaxy of Ecuador etc.,

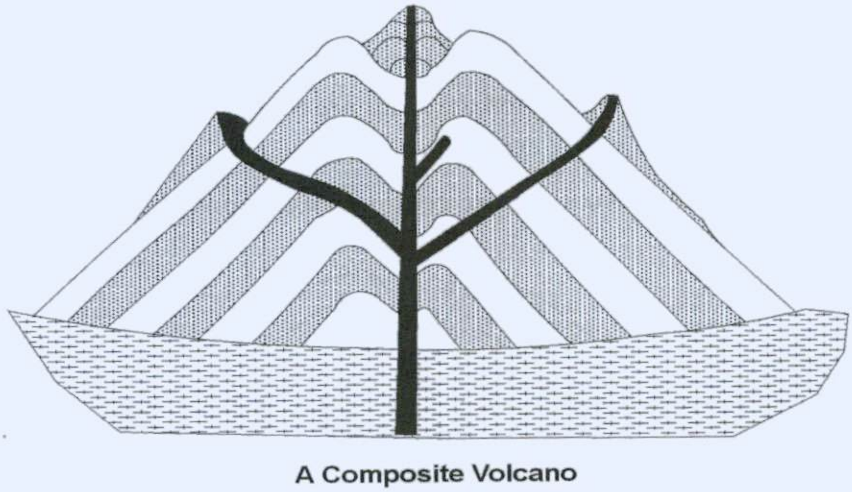


Figure 7.11 Composite Volcano

7.12.b. Cinder or Ash Cones: These are normally of low height and are formed of volcanic dusts, ashes and fragmented materials. These cones grow around a crater. Several cones develop large craters which are cleared and enlarged by successive eruptions. In humid regions, the fine materials are washed away from these cones forming fans at the foot of the slopes. Due to the resistance in of coarse materials, bombs etc., the original form of the cone is preserved.

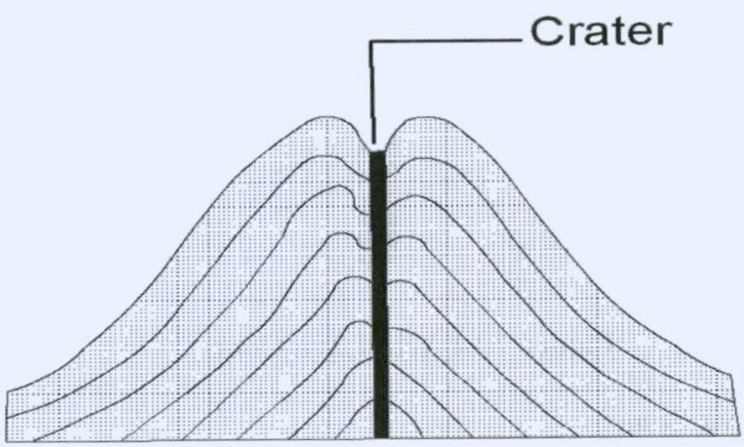


Figure 7.12. Cinder Cone

7.12. c. Spatter Cones: These are formed by lava flow from central and fissure eruptions. These are small cones which are only few meters high are also known as **Driblet Cones**. They are formed by gas bubbles which accumulate and burst through the raising lava.

7.12. d. ***Shield Volcano (Exogenous Domes / Shield domes) :*** If lava is fluid, it flows to a greater distance. When volcanoes erupt lava through their craters or cracks in their side, these domes are formed. Fragmented material are relatively less, but the major thing is the flow of lava to a greater distance. The flow of lava may extend to the base of the mountains. The slopes of these domes usually more gentle than composite cones or endogenous domes.

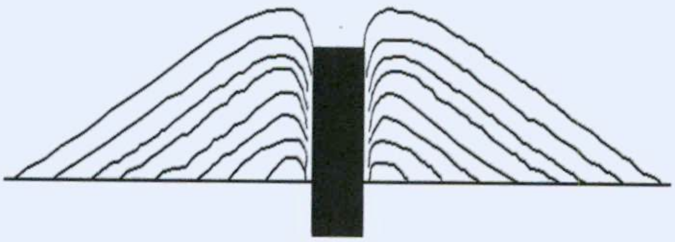


Figure 7.13 Shield Volcano

7.12. e. ***Acid Lava Cone:*** These are formed by highly viscous lava which is rich in silica. They are light coloured with low density. They flow slowly and solidify quickly. This type of lava forms high cones with steep slopes. This form of cone is also known as '**Strambolian type of Cone**'.

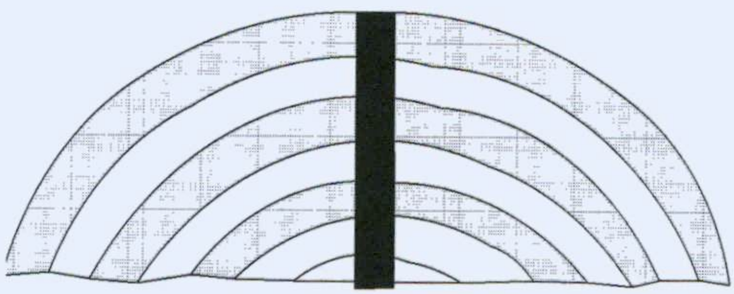


Figure 7.14 Acid Lava Cone

Figure 7.14 Acid Lava Cone

7.12. f. Lava domes or Mounds: These are steep sided dome formed by more viscous lava or fluid basic lava which has rich in iron and magnesium. These lava domes are also known as '**Cumulo domes**'. ***Howel Williams*** has divided these domes into three types. They are-

i. **Plug domes:** It represent upwelling conduit fillings.

ii. **Endogenous domes:** It is developed by expansion within it. Ex: Mt.Pele. After its eruption on 8th May 1902, the rounded crest had attained a height of 400 feet above its base on May 21. There was a deep moat between the sides of the rising dome and the crater walls. In July 1902, a great Monolith (Spine) was formed and destroyed by continuous explosions. When dome continued to grow, a new greater Spine appeared in July 1903, which was 1000 feet above the surface of the dome.

In Endogenous type domes are much fractured and consist many Spines. Through the cracks, gases and fragmented materials may be ejected, spines may be pushed up. These type of domes are found in France, Japan, South America, Greece, Mexico, Alaska, California and in many other regions.

iii. Exogenous Domes or Shield Domes: These are found over the surface. We are already discussed this type of dome in the previous paragraphs.

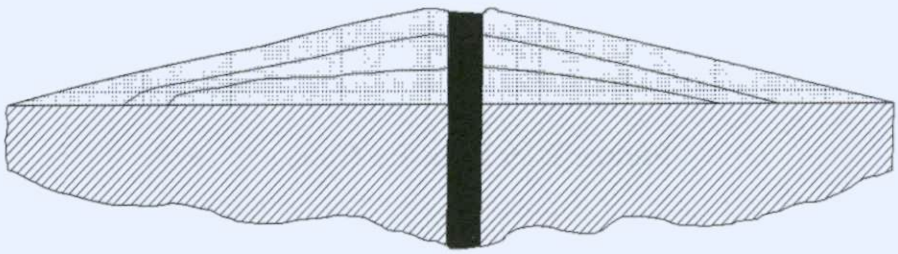


Figure 7.15 Lava Dome or Shield Volcano.

7.12. g. Lava Cinder and Ash Plains: The explosive volcanoes releases the dust and other fragmented materials over the large areas. The fine dust (ash) and small fragments may be deposited by the wind. By this extensive plains are created. It also consist Pumice, Scoria and Breccias of different types. Successive eruptions and partial consolidation due to the weight of the overlying load, cementation of the fragments by minerals from ground water forms a rough stratified structure. By the same way lava plains are also formed.

Depending on the composition, viscosity and constituent gases of the lava, many type of surface are formed. Some surface like sponge like texture, many are ropy, corded surfaces which are called as **'Pahoehoe Lavas'**. Some irregular surfaces are also formed which are **'aa' type** (refer aa lava).

7.12. h. Parasite Cones: These are associated with the composite cones. Due to explosion of volcano, blows the top of the main composite cone and forms a larger crater. Within this enlarged crater, a secondary cone may develop. These secondary cones are known as **Parasite Cones**. They develop along the flanks of the main cone. Ex: Etna in Sicily. Some volcanoes have several major cones which are called as **Multiple Volcanoes.** Along the slopes of Etna, there are nearly 200 parasite cones.

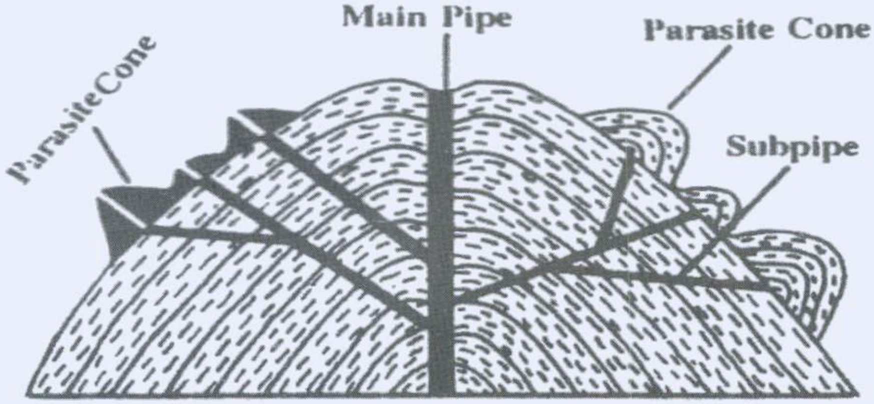


Figure 7.16 Parasite Cone

7.12 .i. Mud flows: It occurs in the early stage of violent explosions and continues until eruptions are over. The dust which was ejected by the volcano joins with condensed steam and with rain water which occurs during an eruption. The rain water also carries the fragmented material from the previous eruptions. Alluvial fans and plains are formed at the foot of the volcanoes. Due to this stream courses are blocked, large boulders are carried by the mud, cities are flooded. When lava flows over snow fields or glaciers, large quantity of water has been released. It rushes down the sides of the mountains depositingfragmental materials of all types and causing devastating mud flows. Avalanches and land slides may also occur due to melting of Ice.

7.12. j. Lava Plugs and Spines: When the composite type of volcano become extinct, their vents are filled with solidified lava. As the cones are worn away by gradational forces, the more resistant rock is finally exposed. The lava which solidified in vents or pipes or necks are known as **Volcanic / Lava Plug or Volcanic Neck.** Ex: The Devil's tower or Mato Tepee of Wyoming in the black hill district.

The great gaseous explosions of the main and subsequent eruptions came out horizontally from beneath, an older lava plug which had filled the core of upper part of the cone to a considerable depth. The old plug slowly rises by the volcanic forces. It is known as **Volcanic Spine.** Ex: Spine in Mount Pele (1902), due to two great horizontal explosions in Lassen Peak in California (1915) and old plug which was lifted upto 300 feet .

7.12. k. Cliffs and Crags: In Strambolian, Vulcanian or Pelean type great explosions and intense eruptions will occur. The mountain tops are blown away with the sides of the cones, old crater are destroyed. Due to accumulation of gases, great amount of masses of lava will blown away leaving caves, cliffs and other irregular forms after erosion.

There are different forms of **depressed landscapes formed by Central Eruptions.** The most important are-

i. Craters

ii. Nested Craters.

iii. Adventive craters

iv. Calderas

v. Volcanic Rents.

i. Craters: It is a pit at the top of a volcanic vent. These are usually in rounded bowl or funnel-shape. Its diameter is normally within a mile. It is formed by the blowing up of the rocks from the violent explosions or collapse of the rocks near the mouth or vent after the extrusion of magma. Some times the materials which are ejected from the volcano are deposited around its mouth and form a circular ring with a depression in the middle. These craters are called **'Ring Craters' or 'Crater Rings'.** Ex: Eiffel volcanic region of Germany, Western parts of the Rift Valley of Africa. In these craters, small lakes are found and are known as **'Maars' or 'Maare'.**

The size of the craters differs from small to several miles in diameter. Ex: Crater of Aniakchak an extinct volcano in Alaska is about six miles in diameter and has walls of 1200 to 3000 feet in height.

ii. Nested Craters: Several volcanoes have craters within craters. Ex: Three craters are found in Mt.Taal in Philippine Island, Vesuvius etc., These are called as **Nested Craters or Cone-in-Cone.**

iii. Adventive Craters: These are small craters found on the sides of old volcanic cones. They are formed by the fracturing of the older rocks. From these fractures gases and lava comes out to the surface with explosion.

iv. Caldera: It is an extensive rounded volcanic depression whose diameter is many times greater than that of a crater. It is formed due to the blowing off the top of the volcanic cone through violent explosion or the collapse of the overlying rocks. Ex: Krakatoa explosion (1883) created a huge caldera with four miles diameter, Mt.Katmai in Alaska (1912), the crater lake of Oregon, Lonar lake in Berar, Madhya Pradesh etc., The floor of the Calderas is much larger than of the volcanic vent. Nested calderas which are similar to nested craters have been found in many places.

v. Volcanic Rents: Some cones or mounds exhibit large irregular depressions in their sides due to explosions. These depressions are called volcanic Rents.

7.13 LANDFORMS PRODUCED BY FISSURE ERUPTIONS

Topographical features formed by central eruptions do not represent the magnitude of volcanic forces compared to fissure flows. The major landscape created by fissure eruptions are-

a. Lava Plateau

b. Lava Plains

c. Lava capped Mesas and Buttes

d. Rim Rocks

e. Volcanic Rifts.

7.13. a. Lava Plateau: Through fissures the magma comes out and flows to surrounding regions. Frequent eruptions leads to the hundreds of feet thickness of lava, which solidifies forming plateau. Ancient basalt plateau are found in different parts of the world. Ex: Decan plateau of India, Columbia Plateau of Western USA etc., The thickness of the lava in these plateau varies from 5000 to 2000 feet. In this plateau, the fissure eruption started in Eocene Epoch and continued frequently till Pliocene. During this period 50,000 to 60,000 cubic miles of lava was released from the magma chamber. The other important lava plateau are-Iceland plateau, Ivesti mountains in East Africa, Ahaggar in the Central region of Sahara etc.,

7.13. b. Lava Plains: It is thinner and less extensive piles of lava sheets. It consist of single layers or at the most few superposed layers of lava which solidified on gentle slopes or after running down on the valley floors. Small rounded Knolls (hills) are formed. Due to escape of gas bubbles, caves, scoriaceous or glassy nature of the upper and lower surfaces of the individual flows are almost present.

7.13. c. Lava capped Mesas and Buttes: In several places, thin lava flows over older rocks. When streams have cut valleys, the land between the valley is protected from erosion by the resistant layers of lava. It leads to the formation of Mesa or Butte or a group of Meas and Buttes are separated by river valleys of varying depth. Ex: Southern Wyoming of Colorado and New Mexico. Large Mesas are also called as Plateau. Ex: Grand Mesa in Western Central Colorado.

7.13. d. Rim Rocks: The sides of the vertical cliffs of Mesas are covered by solidified of lava are known as ***Rim Rocks.*** The steep cliffs are maintained by the columnar jointing of the lava, which permit blocks to drop down when the underlying, less resistant materials are eroded by water and wind.

7.13. e. Volcanic Rifts: When fissure eruption is explosive, it forms volcanic rifts. Ex: In Iceland, the rift is about 18 miles long and 600 feet in depth. Tarawera in Newzeland (1886) a continuous trench of 9 miles long, nearly 500 feet wide at the top and the depth of this varies from 300 to 1400 feet below the surface was opened by an explosive eruption. But no lava was released, only fragmented materials are ejected.

7.13.1 Inversion of Relief : These are common relief features. Frequent fissure eruption build great plateau by lava floods and it will also fill the rifts and valleys and bring out changes in drainage courses. Streams are blocked so that lakes form in the valley above the lava dam. Their flow is diverted to new channels along the borders of the lava sheet. Successive lava flow form layered structure. Ex: Western slopes of Sierra Nevada in California, Auvergne region of France and Hessen in Germany.

7.13.2. Intrusive Topography: When magma solidifies under the surface it forms intrusive igneous rocks like Batholiths, Laccoliths, Phacoliths, Lopoliths, Sills and Dykes.

a. Batholiths: These are very large intrusions of irregular shape and their base is at great depth. They form the cores of old mountains. These are usually dome-shaped, steep side walls and it is almost vertical. When agents of denudation removes the top portion, these are exposed to the surface. Many batholithic domes are exposed to the surface. Ex: Many Batholiths are found in parts of Chotanagpur Plateau of India. Smaller Batholiths are called **Stocks or Bosses.** Several low hills to the south of Chennai in India are considered as parts of a big Batholith.

b. Laccoliths: Some times the magma intrusions push the sedimentary rocks upwards from below and form dome (mushroom) shape with a convex summit. Their extent and thickness vary from place to place. When it is exposed to the surface, they form low hills of dome shape.

c. Phacoliths: These are crescent in shape, found in the bottoms of the Synclines and top of the Anticlines in folded secondary rocks. Their thickness varies from hundred to thousands of feet. In Sedimentary rock strata, they are arranged one above the other between various layers of rocks.

d. Lopoliths: The term **Lopas** is derived from German language means a ***Shallow Basin***. These are saucer-shaped intrusions of large size which are concave upwards. Some of them are very large in size. Ex: Duluth Gabbro in Canada , Bush veld complex in South America.

e. Sills: Intrusion of magma in the horizontal bedding planes and fissures leads to the formation of horizontal sheet like the deposits of lava are known as Sills. If such intrusions are present in mountains, they get exposed on the slopes due to denudation and such exposed parts of the sills form terraces and bench on the hill slopes.

f. Dyke: These are formed by intrusion of magma into a fracture, joints and fissures in the rocks. It solidifies there only forming Dyke. They are narrow, vertical wall like features. When these are exposed through agents of gradation, they looks like ridges. These may be small. The great Dyke of Zimbabwe is the largest Dyke in the world, which is 600 km long and 10 km wide.

Figure 7.17 shows some intrusive topographical features created by volcanoes.

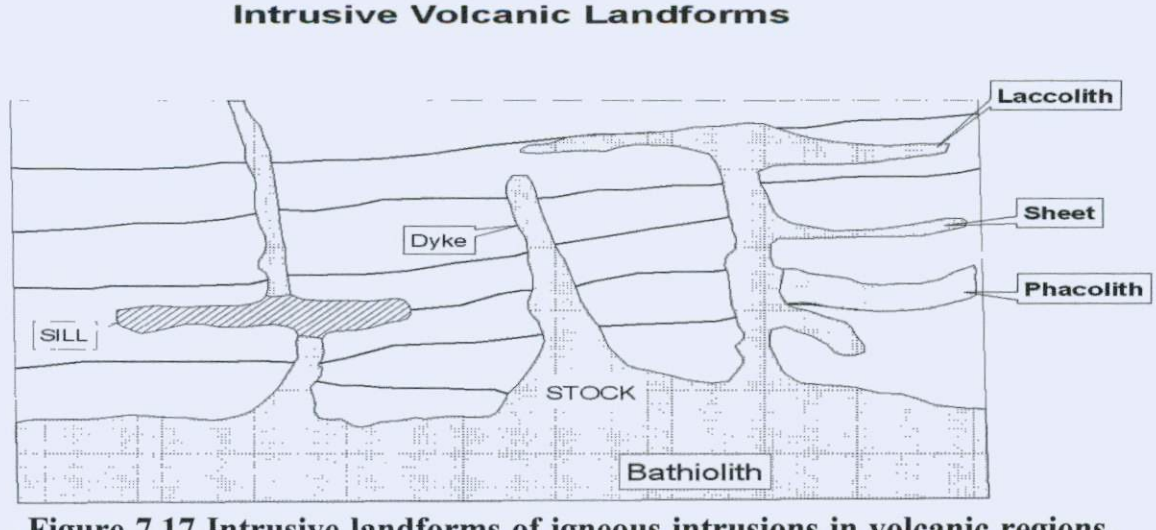


Figure 7.17 Intrusive landforms of igneous intrusions in volcanic regions.

GEYSERS AND HOT SPRINGS: The underground water when it is contact with molten magma or hot substance, it is also heated. The hot water flows continuously from a spring. These springs are known as Hot Springs. These are common in the volcanic regions. In Iceland, Yellowstone Park of USA and North Island of Newzeland are known for hot springs. These are also found in India. Ex: Anantnag, Ladakh of Kashmir, Badrinath of Uttarkhand, Rajgir hills etc.,

When hot water and steam are thrown at regular interval from a fountain is known as a Geyser. Some times hot water and steam rises to a height of 30 to 60 meters. The mouth of the Geyser is connected with hot interior by a pipe. At the bottom of the pipe in the interior, water is heated and it is converted into steam at a high temperature. The steam forces the hot water to ascend along the pipe and comes out side the surface like a fountain. When the pressure reduced in the pipe, ejection of steam and hot water stops. After some time when the pressure increases again steam and hot water thrown out. Ex: Old faithful Geyser in Yellow Stone National Park of USA where the hot water and steam is released for every 66 minutes. Geysers are also common in Iceland and Newzeland.

You will study about Geysers and Hot springs in the forthcoming units in detail.

7.14 WORLD DISTRIBUTION OF VOLCANOES

There is an estimate that active volcanoes including that have been in eruption in historical times would not exceed 800. But there are innumerable extinct volcanoes. Volcanoes are found in definite belts. These belts are associated with Plate boundaries. There are three major Volcanic Belts. They are-

a. Circum-Pacific Belt

b. The Mid-Continental Belt

c. The Mid-Atlantic Belt.

7.14.a. Circum-Pacific Belt :

It is the most prominent zone of volcanic activity. It is found in the coast of Pacific ocean. This region is called **'The Pacific Girdle' or 'Ring of Fire'.** The belt extends from Andes of South America, Central America, Mexico, Western USA, Canada, Alaska, Aleutian Islands, Eastern coast of Asia and passes through Kamchatka, Kurile Islands, Japan, Philippines, New Guinea, Solomon Islands, Newzeland and Antarctica. This belt has 80% of active volcanoes of the world. The major volcanoes of this region are – Cotapaxi, Fuziyama, Shasta, Rainer and Hood, a Valley of Ten Thousand Smokes in Alaska, Mt.St.Helens, Kilavea, Mt.Taal, Mayon etc., In this belt volcanic eruptions occur due to subduction of Pacific plate below the Asiatic plate.

7.14. b. The Mid-Continental Belt: It consist of Alpine-Himalayan orogenic belt. Ex: Vesuvius, Etna, Stromboli etc., There are volcanoes in the Caucasus, Elburz mountain, Iran and Baluchistan. But the main Alps and Himalayas are free from volcanoes.

These are also found along the Rift valley. The rift valley of Africa have volcanoes like Kilimanjaro, Elgon, Birunga, Rungwe etc. In this region the lava is rich in alkalis, potash and sodium. Here it is called Alkali Basalts.

7.14. c. The Mid-Atlantic Belt: It is found along the Mid-Atlantic ridge. In this region two plates diverge in opposite directions (American plate towards west, Eurasian plate towards east) from the mid-oceanic ridge. In this splitting zone fissure eruption is common. Ex: Lesser Antilles, Azores, St.Helens etc.,

Apart from these volcanoes are also found in the inner parts of the continents. These are known as **Intraplate Volcanoes.**

Volcanoes are limited in India. Andaman-Nicobar group of islands are formed by volcanic activities. Barren and Narkodomn islands of this group consist active volcanoes. Figure 7.18 shows the distribution of Active and Extinct volcanoes in the world.

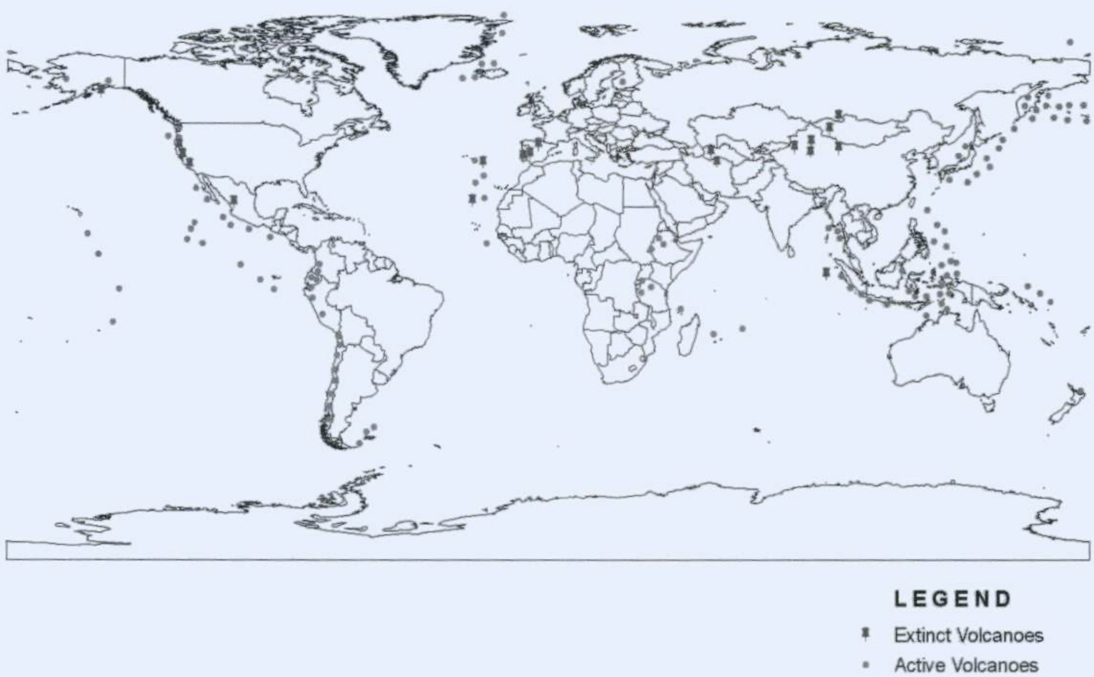


Figure 7.18 Distribution of Active and Extinct Volcanoes.

7.15 EFFECTS OF VOLCANIC ACTIVITY

There are several disadvantages and advantages from the volcanic activities. Now we will point out the main disadvantages of volcanism.

- It destroy the life and property. Several towns were completely destroyed by this. Ex: Ancient Pompeii and Herculianeous towns were destroyed by Vesuvius volcano. When lava flows from volcanic eruptions, it spreads over settlements, roads, cultivated areas and destroy the houses.
- Steam from volcanic eruptions may cause heavy rainfall, which is responsible for landslides, mudflows and floods
- In coastal regions, it causes high sea waves which causes large scale flooding.
- Many poisonous gases were released at the time of volcanic eruption and cause environmental pollution.
- When it releases huge quantum of dust and ash, it disrupts road, railway and air traffic.

There are several advantages from volcanoes also. The significant are-

- Due to weathering of igneous rocks, fertile soils are formed. Ex: Black soil. It is known for the cultivation of cotton, banana, grapes, sugarcane etc.,
- Volcanic rocks consists a number of minerals. Volcanic activity is also responsible for metamorphism of rocks and minerals. Ex: conversion of Carbon into Diamond. The diamond mines of Kimberley in South Africa and Sudbury in Canada are associated with volcanic rocks.
- Springs and Geysers eject mineral salts in solution. These have some medicinal value.
- The energy of the hot springs can be used to generate geothermal energy. Ex: Italy, Mexico, Newzeland, USA, Iceland etc.,
- Many volcanic landforms attract tourists. Ex: Old faithful in Yellowstone National Park in USA etc.,

7.16 LET US SUM UP

In this unit you have studied about the sudden forces operating under the surface. In different parts of the world we are experiencing both Earthquake and Volcanic activities. These forces are caused due to several factors. These are creating and modifying various types of landforms over the surface. These are inter relating to each other. These forces are sudden in nature; they have both advantages and disadvantages to human beings.

7.17 KEY WORDS

Exogenic, Endogenic, Diastrophic, Epeirogenic, Orogenic, Faults, Focus, Epicentre, Seismology, Seismograph, Richter Scale, Isoseismal Line, Tsunami, Volcanology, Vulcanism, Vent, Cone, Crater, Caldera, Pyroclasts, Tephra, Volcanic Bombs, Pumice, Volcanic Ash, Magma, aaLava, pahoehoe lava, Ring of Fire.

7.18 QUESTIONS FOR SELF STUDY

1. What is an Earthquake? Explain the causes and effects of Earthquakes.
2. Give an account of the major earthquake belts of the world.
3. Define the following:
   a. Epicentre
   b. Seismic Focus
   c. Tsunami
   d. Earthquake waves
4. Give reasons for the following:
   a. Himalayan region experiences more earthquakes than peninsular plateau.
   b. Earthquakes are common in the regions of young fold mountains.
5. What are volcanoes? Describe different types of volcanoes and their characteristics.
6. Explain the causes of Volcanism.
7. Give an account of the major landforms formed by Central type of eruption.
8. Explain the landforms produced by fissure eruption.
9. Explain the distribution of volcanoes in the world.
10. Write short notes on-

Caldera, Materials of volcano, Composite Volcanoes, Geysers, Hotsprings, Cinder cones, Shield Volcanoes, Lava plugs, Batholiths, Dyke, Sills and Laccolith.

7.19 FURTHER READING

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UNIT : 8 OROGENIC AND EPIROGENIC MOVEMENTS - MOUNTAIN BUILDING.

Structure

8.7 Phases of Mountain Building or Stages of Geosynclines.

8.7.1 Period of Lithogenesis

8.7.2 Period of Orogensis

8.7.3 Period of Glyptogenesis

8.8. Theories of Mountain Building – Kober, Jeffreys, Daly, Joly and Holmes.

8.8.1 Geosynclinal-Orogen Theory of Kober

8.8.2 Thermal Contraction Theory of Jeffreys

8.8.3 RADIO-ACTIVE THEORY OF JOLY

8.8.4. DALY'S HYPOTHESIS OF SLIDING CONTINENTS

8.8.5. Convection Current Theory Of Arthur Holmes:

8.9. Plate Tectonics and Mountain Building.

8.10 Significance of Mountains.

8.11 Let us Sum Up

8.12 Key words

8.13 Questions

8.14 Further Reading

8.0 OBJECTIVES

This unit provides knowledge to you that the forces operating under the surface.

By studying this unit you will able to –

- Apply the types of Diastrophic forces.
- Be familiar with the Epierogenic forces and its affects
- Produce the formation of Mountains
- Interpret the several scholars about mountain formation.
- Identify the Kinds of Mountains.

8.1 INTRODUCTION

We have already discussed that the two forces endogenic and exogenic are operating and modifying the features of the earth. One of the forces affecting the earth is Endogenic force. This force is operating under the surface. This force has been classified into two types namely – Sudden and Diastrophic forces. The Diastrophic force has been further classified into two types – Epierogenetic and Orogenetic. This unit will give you the details about these forces in detail.

8.2 DIASTROPHIC FORCE

In the 7[th] unit we have learnt about endogenetic movements. There are two types of endogenetic force, namely – Diastrophic and Sudden forces. Any kind of crustal movements, gentle or severe, continuous or periodic, which cause the rocks to shift vertically, horizontally or in any other direction is known as **'Diastrophism'.**

The term **'Diastropos'** is a Greek term, which means **'turned, twisted or distorted'.** These movements result directly or indirectly in relative or absolute change in rock's position, level or altitude.

The earth's crust is unstable. It is clearly known from the occurrence of earthquakes and volcanic activities. They may produce new landform or remove the landforms. But these activities are related to the internal movements of the earth. So the earth movements of all kinds and ranges from fracturing, rise of mountains, rise of continents, depressed oceans and sea. These earth movements as a whole are known as **'Diastrophism'.** According to **P.G.Worcester** (1965) "The term diastrophism includes all crustal movements of the earth".

The diastrophic forces operate very slowly and their affects are observed after thousands of years. These forces are also known as **'Constructive forces'.** Because they affect larger parts of the earth and produce meso level relief features like Mountains, Plateaux, Plains,Lakes, Faults etc.,

The diastrophic processes are broadly classified into two types. They are –

1. Epierogenic Movement
2. Orogenic Movement

8.3.1.i. Epierogenic Movement : The term **'Epierogenic'** is derived from two **Greek** words **'Epiros'** means **'Continent'** and **'Genesis'** means **'Origin'.** This movement causes upliftment and subsidence of continental masses through vertical (Upward and Downward) movements. It affects larger parts of the earth's crust without much deformation.

This type of tectonic movement is called **'Continental Building'** and **'Oscillatory Movements'.** Because, the elevation or upliftment is replaced by subsidence in its course. It had been taking place in the past geological periods and it continues even today. In coastal line or nearer to it, we can see the evidences of upliftment and subsidence.

According to the direction of Epierogenic movement, it may be classified into two types. They are-

a. **Upward Movement:** It includes the upliftment of landmasses. There are two types of this movement over the continent. They are –

    i. **Uplift:** When a part of the continental block rises above the near by surface it is known as uplift. Ex: The Atlantic coastal plain of south-east USA, has a broad regional uplift. Uplifted parts have been noticed in some parts of Northern Sweden and Finland that adjoining Gulf of Bothnia, Raised beaches in Northern England and Scotland, raised Coral Reefs of Peru and Cuba, Evidences in coastal lines of Gujarath of India etc.,

    ii. **Emergence:** The earlier submerged part of the coastal area rises above the sea level, it is called Emergence.

b. **Downward Movement:** When the landmasses move downwards or subsides due to vertical movements. It causes two types of movements. They are –

i. **Subsidence:** When a land mass subsides below the surrounding area is known as Subsidence. Ex: Some parts of Holland is at present below the sea level, much of the north coast of the Gulf of Mexico has been subsiding slowly from many centuries.

ii. **Submergence :** The land area near the sea coast is moved downward or subsided below the sea level, the area under the water is called submerged area. Ex: Evidences are found in Gangetic delta, Pondichery in India, several islands of the coast of British Columbia, Fiords of Norway. The eastern part of Island Crete, ancient buildings now is submerged.

All these shows that all the continents are relatively unstable and the movements of great variety and extent have occurred through out the earth's history. Diastrophic changes have revived and rejuvenated in all continents and have allowed new relief features to be developed.

8.3.2 Features of Epierogenic Movements:

- In this movement there is no breaking of rock beds. The beds remain nearly horizontal.
- It affects a large area.
- The periods of Epierogenic movements are quite large.
- These movements are reversible in nature. The same area may be disrupted followed by subsidence and vice-versa.
- It affect the thickness of sedimentary beds being formed in the time of their operation.

8.3.3 Causes of Epierogenic Movement:

The upliftment may be caused due to Isostasy. It is the state of hydrostatic balance of crustal segments of different thickness and density. Due to the work of agents of denudation, the landforms above the sea level are eroded and the sediments of these are deposited to other area. It disturbs the Isostatic balance. The load is shifted from higher area to lower area. In order to maintain the Isostatic balance which is disturbed by shifting of load, the rocks in the mantle which has plastic behavior move towards the area from which load is removed, at the bottom of the crust, it tends to uplift it. Isostatic movements are always vertical. Advancement and retreating of glaciers will also affect their balance. Its balance has been maintained by uplifting the area.

The Epierogenic process is very slow, but continuous in nature. It affects a larger portion of the earth. Sea level is mostly used as a base to observe and measure the elevation or subsidence caused by this movement.

8.4 ORGENIC MOVEMENT

The word **'Orogeny'** is derived from the Greek word **'Oros'** mean Mountain and **'Genesis'** mean Origin. The term orogeny was first introduced by the American Geologist **G.K.Gilbert** in 1890 to explain the mountain building process. This movement is caused due to the horizontal forces operating in the earth's crust which are tangential to the surface. These movements are periodic in nature and severe in their effects. It causes compression and tension in the crust, creating Strain and Stress.

The Orogenic or horizontal force work in two ways. One is in opposite directions which are known as Tensional or Divergent forces. This force causes rupture, cracks, fracture and faults in the crustal parts of the earth. The other is that they act towards each other. It is known as Compression force or Convergent force. This force causes crustal bending, which results in folding or crustal wrapping.

Convergent forces make crustal rocks bending in two ways. One is wrapping and another is folding. Crustal wrapping affects larger areas. The wrapping may be upward (unwrapping) and downward (down wrapping). In the process of unwrapping or down wrapping of crustal rocks, affects larger areas and it is known as **Broad Wrapping.**

8.4.1 Orogenic Forces : In the unit No.7 we have discussed the forces affecting the earth. Among Endogenic forces, Diastrophic forces are also modify or causes the various types of landforms. As stated in 7.3, Epierogenetic forces form continents, whereas Orogenetic causes Mountains. These two forces are slow compared to sudden forces. Due to Compression, folds are formed, while Tensional forces cause Faults and Joints.

8.4.2 Mountain Building- Meaning : Mountain is an important relief feature of the second order landform. It is an uplifted part of the earth which is clearly higher than the surrounding areas. According to **Prof.Flinch** 'A mountain is a landblock whose height is atleast 900 meters above the sea level and with a slope of 25^0 to $35^0$to the horizontal plane'. If the height of this elevated block is less than 900 meter, it is known as a hill or mound.

Mountains have several forms. The most important are-

a. **Mountain Ridge:** It is a long, narrow and high hills. Generally one side of the ridge is steep, while the other is moderate. But there are many ridges with symmetrical slopes.

b. **Mountain Range:** It consist of mountains and hills having several ridges, peaks, summits and valleys.

c. **Mountain Chain:** It consist of several parallel long and narrow mountains of different periods.

d. **Mountain System:** It comprises different mountain ranges of the same period. Different mountain ranges are separated by valleys.

e. **Mountain Group:** It consist of several patterns of different mountain systems. Ex: Appalachian.

f. **Cordillera:** It is a Spanish term which means several mountain groups and systems. Ex:Western Cordillera of USA.

8.4.3 Classification of Mountains: Mountains are classified into different types, based on their height, location, Orogenesis and mode of Origin.

I. **Based on Height of Mountains:** It is classified into four types. They are-

1. **Low Mountains:** 700 to 1000 meters height.
2. **Rough Mountains:** 1000 to 1500 meters height.
3. **Rugged Mountain:** 1500 to 2000 meters height.
4. **High Mountains:** are more than 2000 meters height.

8.4.4 Based on Location : There are two types of mountains. They are-

1. **Continental Mountains:** It is further classified into two types.

   a. **Coastal Mountains:** Located in the coastal area. Ex: Rockies, Andes Western Ghats of India etc.,

   b. **Inland Mountains:** These are located in the interior of the continents. Ex: Ural mountains of Russia, Block forest Mountain of Europe, Himalayas etc.,

2. **Oceanic Mountains:** These are submerged under the sea water. But some of these are above the sea level.

8.4.5 Based on Orogenesis: Orogrenesis referes to the geologic periods during which these mountains were formed. These are further classified into four types. They are-

1. **PreCambrian Mountain (4 billion years ago):** The mountains which were formed during this period are almost reduced to plain. Ex: Canadian shield and Eastern Scandinavia.

2. **Caledonian Movement (435 million years ago):** These mountains are situated in Ireland, Britain, Norway, North-west of New Southwales in Australia, Southern part of Sahara etc., These mountains have been eroded into plateaus.

3. **Hercynian or Variscon Movements (230 million years ago):** This movement started in Precarboniferous period. It began from the end of Caledonian movement and ended in the beginning of the Alpine movement. The major mountains formed during this period are – Meseta in Morocco, Altai etc., These mountains are found in Spain, Britain, France, Russia, China, Malaya, Australia, Morocco etc.,

4. **Alpine Mountain:** It started by the end of Mesozoic era and continued in tertiary period. During this period highest mountains of the world were formed. Ex: Himalayas in Asia, Alps in Europe, Rockies in North America, Andes in South America.

8.4.6. Based on the mode of origin: Mountains are classified into four types. They are-

1. Volcanic Mountains
2. Fault Mountains
3. Residual or Relic Mountains
4. Fold Mountains.

8.4.6.1 Volcanic Mountains: These are formed by the accumulation of volcanic materials like lava and pyroclastic materials around a volcanic vent. These are also known as **'Mountains of Accumulation'.** If the lava is thin and basic in its composition, it spreads a long distance forming a flat cone with a gentle slope and low elevation. If lava is thick and acidic in nature, a cone with a steep slope and pointing at the peak is formed. These are also formed on the sea floor and are submarine volcanic mountains. Some of the these mountains appear over the sea level. Ex: Aleutian Islands. The major volcanic mountains in the world are Mt.Kilimanjaro in Africa, Cotopaxi and Chimborazo in Ecuador, Fujiyama in Japan, Vesuvius in Italy, Aconcagua in Chile etc., Aconcagua is the highest (7021 meter) volcanic mountain in the world.

8.4.6.2 Fault Mountain: These mountains were formed due to faulting. The land between the two parallel faults either raises forming Block Mountains or Horsts, or subsides into a depression called as a Rift Valley or Graben. An old fold mountain may also be left as Block Mountains due to continuous denudation. These mountains have flat tops, steep fault scraps and subsided portions between parallel fault and flat bottom.

Vosges of France, Black forest mountains in Germany, Salt Range in Pakistan are examples for Block Mountains. Great Rift Valley of Africa runs from East Africa to Syria. River Rhine in Europe flows through a rift valley, River Narmada in India also flows through rift valley (Between Vindhya and Satpura Ranges) etc.,

Block mountains or Horsts and Rift valley or Graben are explained in detail in the next unit.

8.4.6.3 Residual or Relic or Dissected Mountains: These mountains are formed due to erosion by different agents. These mountains are also called as ***Mountains of Circum denudation.*** They have been worn down from previously existing elevated regions. Ex: Nilgiris, Parasnath, Girnar, Aravallis and Rajmahal of India, Mt.Manodnock in USA etc., The residual mountains stand alone in the surrounding area reduced in height.

8.4.6.4 Fold Mountains: These are formed due to folding of crustal rocks by compressional force (Endogenetic). The major mountains of the present day including Alps in Europe, Rockies of North America, Andes of South America and the Himalayas of Asia are the structural fold mountains. These are most extensive mountains of the world. When we observe the distribution of these, it shows that they are generally located along the margins of the continents. The phenomenon of folding and faulting is most complex in the central areas of these mountains.

Fold mountains are classified into different types, based on several factors. They are-

1. **On the basis of nature of folds:**

   a. **Simple Folded Mountains with open folds:** These mountains are found in wave-like pattern. There is a well development of anticline and syncline.

   b. **Complex Fold Mountains:** These are formed due to great compressive forces. Ex: Nappe.

2. **On the basis of affectness of denudational forces:**

   a. **Young fold mountains:** Which are least affected by denudational agents.

b. Mature fold mountains: It consist of monoclonal ridges and valleys.

3. On the basis of period of origin:

a. Old Fold Mountains: These are formed during Caledonian and Hercynian periods. These have been eroded and now these are residual mountains. Ex: Aravallis of India.

b. New Folded Mountains: These are formed in tertiary period (60 to 75 million years). These are also known as **Young fold mountains**. Ex: Himalayas, Rockies, Andes, Alps etc.,

8.4.7 Characteristic features of Folded Mountains :

1. All the young folded mountains have been formed from sedimentary rocks. Shallow-water marine sediments are commonly found. Sedimentary rocks are thousands of feet thick.
2. They are formed by intense lateral compression. The rock strata are folded and consist low angle thrust faults.
3. They have been formed in long, narrow and shallow sea called Geosynclines.
4. They are extending in greater length and shorter width. Ex: Himalayas are 2400 km in length and only 400 km in width.
5. They are in arch shape having one side concave slope and the other side convex slope.
6. There are also massive granite intrusions (Batholiths) along the trend of the fold mountain ranges.
7. The folding is less near the margins and more intense towards the central part of the belt.
8. Due to tectonic forces, intensive heat and pressure, the rocks were metamorphosed on a large scale.
9. Valuable minerals are found in fault regions. Ex: Gold, Silver, Tungsten etc.,
10. Generally the Fold Mountains are situated along the margins of the continents. Ex: Rockies of North America, Andes of South America etc.,
11. Highest peaks are found in Young fold mountains. Ex: Mt.Everest (8848 meter).
12. The fold mountain belts are irregular and are usually curved.

8.5 STAGES OF MOUNTAIN BUILDING

Formation of folded mountains took a long time. We may identify three important stages of Mountain building. They are-

I. Geosynclinal Stage

II. Orogenic Stage

III. Epeirogenic Stage

8.5.1. Geosynclinal Stage: Geosynclines are long and subsiding seas from which mountains have been originated. According to **Steers J.A.**(1932), 'These are long and relatively narrow depressions which seem to have subsided during the accumulation of sediments in them.'

In the narrow ocean basin, deposition of sediments has continued for a long time and during this period, subsidence was common. These sediments which have been uplifted and folded to form folded mountains. So these have been borned out of Geosynclines. But it has taken a long geological period.

8.5.2. Characteristics of Geosynclines:

a. These are long, narrow and shallow depressions of water.

b. Continuous sedimentation and subsidence are common.

c. Due to earth movement and geological process the location, extent, shape of geosynclines have been altered.

d. These are the store house of water.

e. They are surrounded by two rigid masses which are known as Forelands.

8.6 CONCEPT OF GEOSYNCLINE AND ITS DEVELOPMENT

The concept of Geosyncline was propounded by ***J.Hall and J.D.Dana in 1859.*** According to J.Hall 'Appalachian mountains of eastern USA were formed by the upliftment of sedimentary deposits in a subsiding trough. In 1873 J.D.Dana called these troughs as **'Geosynclinals troughs'.** The views of **J.Hall and J.D.Dana** were based on their studies of Appalachian Geosynclines. According to them, Geosyncline was an area of shallow sea situated on continental margins.

E.Hang presented an analysis of Geosynclines in 1900 based on his studies of the Alpine Mountains. According to him 'Sedimentation has not been a continuous and uninterrupted process'. The periods of sedimentation have been interrupted with period of uplift and the erosion of this uplifted part has resulted in deposition of fresh sediments and subsidence. Most probably, Geosyncline lies in between two continental masses rather than on the coastal margin of one continent. The erosion of the mountains has also supplied debris to the sinking troughs. These barriers of rock which ascend from within a geosynclinals system are known as **'Genticlines'.**

H.Stille classified Geosynclines into different types during 1935-50.

J.W. Evans states that the shape and location of Geosynclines varies according to environmental conditions. Sedimentation subsidences are common in all Geosynclines irrespective of their form, shape and location.

Schuchert has classified the geosynclines into three types based on their size, location and evolution. They are-

8.6.1. Mono Geosynclines : These are long, narrow and shallow water tracts indentified by Hall and Dana. It is located either within a continent or along its borders. As they passes through only one sedimentation cycle, they are called as Mono Geosyncline. Ex: Appalachian Geosyncline.

8.6.2. Poly Geosynclines : These are broader than Mono Geosynclines. They are long and wide and older than Mono Geosynclines. These have complex evolutionary process, undergone more than one phase of orogenesis and Geanticlines. Ex:Rocky and Ural Geosynclines.

8.6.3. Meso Geosynclines : These are most complex in nature and have passed several Geosynclinals phases like sedimentation, subsidence and folding. They are very long, narrow and mobile in nature surrounded by continents from all sides. Ex: Tethys Geosyncline, Alpine, Himalayan Mountains etc.,

Arthur Holmes has also explained about the causes of origin of different Geosynclines. He states that sedimentation leads to subsidence. But this process has greatly affected by earth movements. He identified four major types of Geosynclines on the basis of their origin. They are-

a. Geosynclines due to migration of magma.
b. Metamorphism also cause formation of Geosyncline.
c. Due to compression Geosynclines are formed.
d. Due to thinning of sialic layer, Geosynclines are formed.

Dustar has classified the Geosynclines into three types based on structure of Mountain ranges. They are-

i. Inter-Continental Geosynclines

ii. Circum-Continental Geosynclines

iii. Circum-Oceanic Geosynclines.

In relation to **Plate Tectonics**, three types of Geosynclines are identified. They are-

a. **Pacific type:** These are found on converging plate boundaries. It is further classified into two.

   i. **Oceanic Type:** Oceanic trench lies close to continent.

   ii. **Island-Arc type:** Shallow sea behind the arc. Here trenches run parallel to arc.

b. **Atlantic type:** Sedimentation takes place on the edge of the continents.

c. **Mediterranean type:** Sedimentation occurs in the sea located between two continents. There is a convergence of continental plate boundaries.

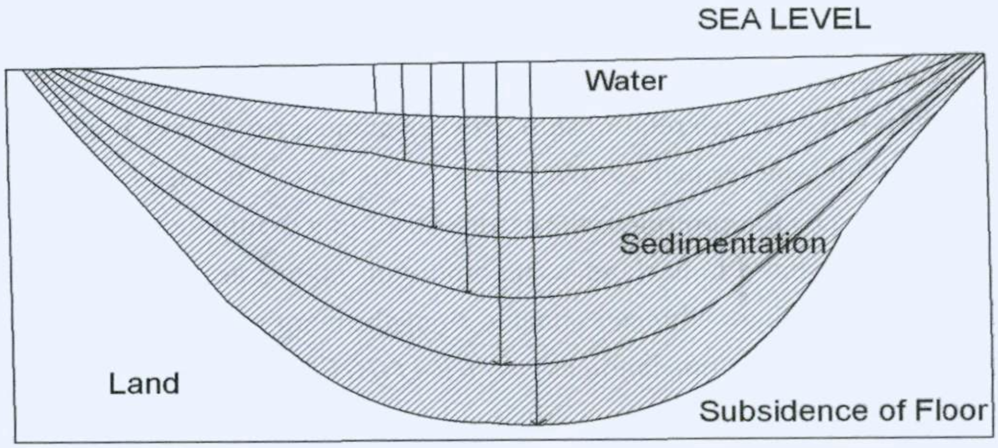
8.7 PHASES OF MOUNTAIN BUILDING OR STAGES OF GEOSYNCLINES

Change of Geosynclines into folded mountain system requires geologically a long time. We may identify three stages or phases of the mountain building process. They are-

8.7.1. Period of Lithogenesis: It is the initial stage of the mountain building. In this stage Geosynclines were created. Sedimentation and subsidence process has been common. In the same period compression-subsidence is also takes place.

8.7.2. Period of Orogensis: In this stage, there is an increase of pressure and folding of geosynclinals sediments. The process of thrust fault and recumbent folding further increases the thickness of the sediments. Here vertical uplift of mountain begins only after horizontal compression has been ceased.

8.7.3. Period of Glyptogenesis: During this period, there is a gradual rise of mountains and the work of agents of denudation starts to reduce the height of these mountains. In this stage there is a disappearance of the Geosynclines.



8.1 Shrinking beds of Geosynclines due to sedimentation and subsidence.

8.7.a.Hinterland and Foreland: In Mesozoic era (nearly 240 to 63 million years ago), there was an extensive Geosyncline called the Tethys Sea in the present Alpine and Himalayan mountain system. Continental block situated towards north of this sea was known as Laurasia and towards south, the continental block was called Gondwana. During Cretaceous period (138 million years back) the above two stable continental blocks came closer to each other due to earth movements. According to ***Suess***, the southern block (Africa) was pushing towards north. The continental block which was moving towards north has been called **'Backland' (Hinterland)** by Suess. Laurasian land block which was (pushed) by southern land block was known as **'Foreland'.** ***Argand*** has also supported the views of Suess.

8.8 OROGENIC STAGE

The term Orogeny means 'Mountain Building'. Geosynclines are not constant. In a long period of time, sedimentation-subsidence and compression-subsidence process occurred. Suess, Hang, J.W.Ewans and Argund states that folds are formed due to compression of Geosynclines. There are several thoughts of scholars regarding the origin of folded mountains. The most important theories of mountain building are-

1. Geosynclinal-Orogen Theory of Kober.
2. Thermal Contraction Theory of Jeffreys.
3. Radio-Activity Theory of Joly.
4. Daly's Hypothesis of Sliding Continents.
5. Convection current Theory of Arthur
6. Plate Tectonic Theory.

8.8.1 Geosynclinal-Orogen Theory of Kober: The famous ***German Geologist Kober***, after studying the mountains in the different parts of the world has postulated this theory. His main objective was to establish relationship between ancient rigid mass and Geosynclines (mobile zones), which he termed as ***'OREGON'.*** His theory is based on the forces of contraction produced by the cooling of the earth. According to him there are two forelands instead of a foreland and a hinterland. The mountain ranges are formed as a result of compression of Geosynclinal sediments situated along the margins of the foreland of ancient rigid land masses. He called this landmass as ***'KRATOGEN'.*** He named the border areas of this as ***'RANDKATTEN'.*** The area situated between the two border ranges remains unaffected by folding. This area is known as **Median Mass** (between mountains – **ZWISCHENGEBIRGE**) by him. Ex: Alpid in the north and Dinarid in the south in the Alps, Hungarian Plain between Carpathians and Dinaric ranges, Anatolian Plateau in Turkey located between Elburz and Italian range, Tibet plateau between Himalayas and Kunlun etc.,

The shape and size of the Median mass is depending on the magnitude of the two under thrusts. Wherever the earth movements and compression are high, the two forelands have been pushed to close each other forming a complex mountain system called **'Narbe'.** In this median mass is completely absent. Ex: Alps in Switzerland.

He also tried to explain the evolution of continents and ocean basins. According to him the ancient rigid masses form the foundations of the present continents. The area of these rigid masses has been increased due to sedimentation in Geosynclines and formation of mountains.

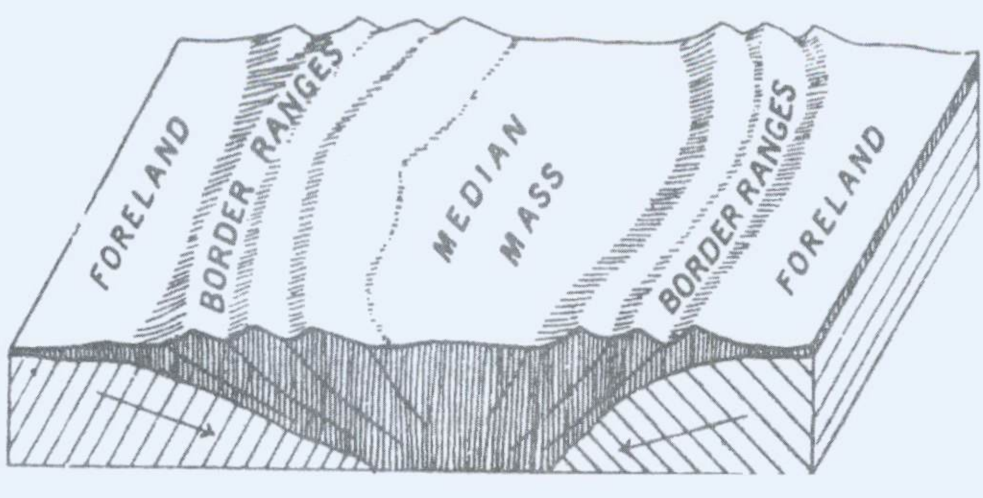


Figure 8.2 Formation of an Orogen resulting from the mutual approach of two rigid masses (Steers J.A)

He was a propounder of **Contraction (Shrinking) hypothesis**. He identified six major mountain building periods from the origin of the earth. Three periods have occurred in Pre-Cambrian period (4 billion years) and another three occurred in post Cambrian period. When mountains were uplifted, denudation agents starts to work and they reduced them depositing the sediments in Geosynclines. So there is a long gap between one Orogeny to another.

He also mentioned another type of movement in the rigid landmasses or ***KRATOGEN*** and called it as ***KRATOGENIC*** movement. This movement is responsible for the formation of rifts and fractures in the landmasses. According to him the direction and location of mountains have controlled to a great extent by the location of the rigid land masses. In different continents the area has been expanded by the addition of folded zones in several geological periods. This view is first proposed by Suess and it is supported by H.Stille.

According to Kober, Contraction (Shrinking) is the basic force for the compressive stress. In the same time he also accepts the theory of Isostacy. There is a constant conflict between the vertical and horizontal forces. Due to this sinking and uplift are taking place alternatively in the same zone in different geological periods.

CRITICS: There are few comments regarding his theory. The most important are-

1. As postulated by Kober, the force of contraction is not sufficient in the formation of mountains like Alps, Himalayas, Rockies and Andes.
2. He assumed that two forelands move towards each other and compressive stress produced by this is responsible for folding. This assumption has not been accepted by several scholars. Suess states that only one side of the Geosyncline moves, the other side remains constant. The moving side has been called as Backland and stable side has been termed as Foreland. When plate tectonic theory has been postulated, these two views are not accepted.
3. He explained about west-east extending of mountains. But he failed to explain the origin of north-south mountain chains like Rockies and Andes.

   Inspite of few comments, his theory throws light on the formation of mountains from Geosyncline sediments. It provided a base for all other theories.

8.8.2 Thermal Contraction Theory of Jeffreys : H.Jeffrey has postulated this theory in his book **"The Earth: Its origin, history and physical constitution (1929)".** He is a great supporter of contraction theory. According to him, ***"Cooling of the earth due to loss of heat and decrease of the speed of rotation are responsible for contraction".***

He calculated that in the interior of the earth (below 700 km from the surface) there has been no change of temperature. The upper layer which is about 700 km thickness has cooled, layer by layer. The uppermost layer cools quickly than the next layer. So the upper layer undergoes crustal bending, where the contraction of lower crustal layer becomes smaller than the hot interior and does not fit with the upper layer. It causes tension, which results in the formation of fissures and cracks. These are filled by the hot magma from the interior. According to him between the upper layers (zone of compression) and lower layer (zone of tension), there should be an intermediate layer which is able to adjust to the lower contracting layer. This intermediate layer is known as **'Level of No Strain'.** As the earth goes on cooling, the level of no strain starts to slide downwards. Due to this, horizontal compressive force in the upper layer forms the folds and there is the origin of folded mountains.

In this theory, he explained that the compressive stress goes on accumulating and the earth movement starts only when this stress exceeds the strength of the rocks. During this time the mountain building begins and ends when there is less pressure. Again the compression stress starts to pile up. So there is a time gap between mountain building and accumulation of stress. He calculated that there have been five periods when the compressive stress exceeds the strength of the rocks. During these periods mountains were formed. He believed that the possibility of mountain building is greater in the areas where the rocks are soft and flexible, where as hard and less flexible rocks are liable to break and crack.

He assumed that the degree of cooling was more under the oceans than under continental masses. The rocks which lie under bottom of the ocean floor are heavy basic rocks which are stronger than the continental rocks. Due to these reasons, the horizontal compressive force generated in the oceans move toward the continental land blocks. Through this process he explained the formation of mountains along the coastal area.

In his theory, he also explained that the upper layer when it collapse over thinner lower layer and when there is an increase of compression, the pressure over lower layer further increases, which results in the melting of lower layer which uplifts the mountains. He has not accepted the views of Wegner (Continental Drift Theory).

He also stated that contraction of the earth is not from the loss of heat, but also from crystallization of rocks. According to him, in the upper 400 km thick layer there is a decrease of 500^0 C of temperature. This will reduce 130 km of circumference of the earth. If crystallization, contraction and loss of gases were also included nearly 200 km of circumference of the earth will be reduced.

CRITICS: He tried to explain the origin of several surface features with certain evidences and calculations. But his theory has been criticized on several backgrounds. They are-

1. A.Holmes criticized that the force of contraction resulting from the cooling of the earth is not sufficient for the origin of major relief features of the earth.
2. The concept of cooling of the earth in the form of concentric layers is not accepted.
3. J.A.Steers questioned the impact of decrease in the speed of the rotation of the earth over mountain building.
4. There is a possibility of miner folds and wrinkles due to thermal contraction, but not at extent of gigantic mountains of tertiary period like Alps, Rockies, Andes, Himalayas etc.,
5. He fails to explain the formation of mountains like Alps and the Himalayas which extend in a different direction.
6. If the earth was contracted from all the sides, there should equal distribution of continents and oceans. But at present there is an uneven distribution of these.
7. According to this theory, mountains may be formed every where, due to all parts of the earth's crust experienced contraction. But we can observe that mountains are found along the margins of the continents either north-south or west-east.

8.8.3 RADIO-ACTIVE THEORY OF JOLY : J.Joly has postulated this theory based on radioactivity of certain radioactive minerals. His theory is stated in his book **'The Surface History of the Earth' (1925).** His main aim is to study the history of the earth's surface and in the same time he also tries to explain the formation of mountains. His theory is also known as **'Thermal Cycle Theory'** or **'Theory of the Surface of the Earth'.** He accepted the concept of Isostasy and calculated the thickness of Sial which is about 30 km, but wherever the mountains have been formed, the thickness of the Sial penetration into Sima increases proportionately.

His theory is based on the presence of Radio active elements in the rocks, which are unevenly distributed. The rocks in Sial layer are rich in Radio active minerals compared to the rocks of Sima layer. He believed that the amount of heat lost by the earth's surface by radiation is more compared to the heat received from the radio-activity of Sialic rocks. The heat derived by radio activity in Sima is accumulated and finally the temperature becomes very high, that basalt rocks (Sima) start to melt. The condition under the floor of the ocean is so different. Here there is no sialic layer and the heat generated in the upper layers of sima is lost in the oceanic water through conductivity. There is no loss of heat in the lower layer of sima.

He calculated the thickness of sial which is about 30 km. At this depth the temperature should be about 1050^0 C . The melting point of basalt is 1150^0 C. The sima or sub-stratum may melt with an increase of another 100^0 C. He tried to explain through mathematical calculations that another 33 to 56 million years, the accumulated heat will further increases and melt the basaltic rocks.

Due to increase of temperature in Sima or Substratum, it becomes liquid partially or as a whole. So density decreases in Sima and the flotability of continents (Sial) has been reduced. So they sink further down into Sima. Due to this oceanic cover over the surface increases. This is known as **'Trangressional Sea'.** Expansion of ocean over the surface submerges the low-lying land bodies. By this way Geosynclines were formed according to him. In course of time the sediments in Geosyncline are folded and uplifted to form the mountains.

When the continents are floating over this liquid, due to tidal effect, sialic blocks starts moving towards west. Through this process, the heat is released from the beneath of the continents. Now sub-stratum begins to solidify as a result of loss of heat. Solidification increases the density and the continental blocks (Sial) are pushed up. Due to this, there is a fall of sea level. This is known as **'Regressional Sea'.** So the submerged parts of continental margin emerges.

The expansion of Sima is maximum in the oceanic parts. When it starts to solidify, the maximum contraction will also takes place below the ocean floor. The shrinking ocean floor exerts pressure on the continental margins. The margins of continent situated between two contracting oceans are subjected to lateral compression, the soft sediments are folded. It is the first stage of mountain building. When the entire Sima has solidified, the continental blocks located above them starts to rise. In this way he explained the second stage of mountain formation.

He also tried to explain the periods of Orogeny and the periods of Quiet intervals between them. Melting of Sima and again resolidification has been termed as a **Revolution.** According to him, the melting of Sima takes nearly 33 to 56 million years. Mountain building is a cyclic in nature.

CRITICS: Several scholars have criticized his theory. The most important are-

a. Jeffrey has severely criticized this theory. Joly assumed that the thickness of Sial is about 30 km. According to Jeffrey, it is around 16 km on the basis of Seismological evidences. If it is 16 km, the heat below this layer is not sufficient to melt the basalt rocks.

b. J.A.Steers pointed out that the mountain building periods are some extent is acceptable, but the time interval stated by Joly is doubtful.

c. Jeffrey has shown with mathematical laws that, once the Sima has melted under the influence of radio-activity, it cannot resolidify.

d. This theory is depending on the radio active elements in the interior rocks. But till today, we have only little information about the interior of the earth.

e. In this theory, he states that the margins of the continent must have mountains of the same period and both the margins should be regular. This view has not been accepted by several scholars.

f. Joly has a wrong concept regarding Geosynclines. According to him, Geosynclines should always located around the continents. But it has been already accepted that Geosynclines are long, narrow and shallow water bodies which have sedimentation and subsidence process.

From all these reasons, it is difficult to accept the process of mountain formation postulated by Joly.

But this theory throws light on several aspects regarding the mountain building.

8.8.4 DALY'S HYPOTHESIS OF SLIDING CONTINENTS: Daly postulated his hypothesis of ***'Sliding Continents'*** in his book ***'Our Mobile Earth' in 1926.*** His main aim is to explain the causes and processes of mountain building. His theory is based on Gravity.

He made certain assumptions to develop his hypothesis. According to him, the distribution of land and water was determined in the early days. The land masses lay near equator and the poles. Between the rigid land masses low lying areas are occupied by sea. He called them as **'Mid-Latitude Furrows'.** Tethys Sea was a Mid-Latitude Furrow in the northern hemisphere, but there is a speculation about similar depression in southern hemisphere. There is an extensive primitive pacific ocean. In the prehistoric time the earth's surface has been classified as land and water bodies. Land blocks are higher than the sea, and they sloped towards Pacific Ocean and the Mid-Latitude Furrows. In these sediments were deposited by the agents of gradation. It may be considered as first Geosyncline. Due to increase of pressure of the sediments and the ocean water, the sea floor started to subside.

In course of time, the downward pressure has been constantly increased and caused lateral pressure on the continental masses. Due to this lateral pressure, the extent and height of continental masses have been increased. In the same time the pressure on Geosyncline has been increased and due to excess strain, the Geosyncline will rupture. When it happens the support of continental block weakens and strong tensional movement will happen. So large continental blocks start to slide slowly toward Geosyncline and it results in compression squeezing and folding of the sediments in Geosyncline caused the first stage in the evolution of mountain.

According to Daly, the substratum consists of hot glassy basalt which is slippery in nature on which the crust is easily slide. In his opinion, the density of the sub-stratum is lower than the crust, the broken part of the crust sinks into sub-stratum. Due to pressure from the sliding continental masses, the Geosynclinals sediments are not only folded, but also pushed into sub-stratum. The lowest portion of this is heated, melts and expands. Due to this the folded sediments are raised up (vertical upliftment) and the second phase of mountain building has been completed.

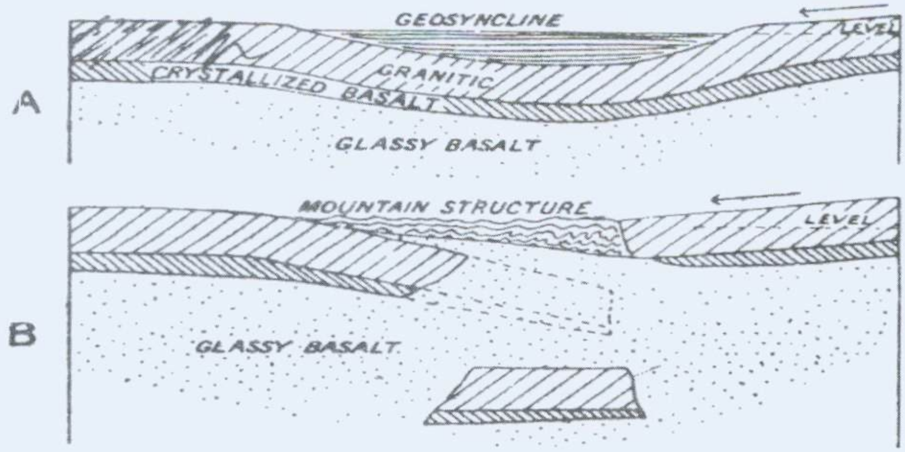


Figure 8.3 (a) & (b) Crumpling of Geosynclinal prisms of layered rocks by the sliding of a large block of the earth's crust (Steers J.A.)

According to him, mountains have been formed by the folding of Geosynclinals sediments and lateral pressure exerted by sliding of continents towards Geosynclinal sea. On this basis, the Alps-Himalayan (west-east) mountains are resulted due to the sliding of continents towards Mid-Latitude Furrow. The sliding continental blocks toward Pacific Ocean has resulted in the formation of Rocky and Andes from the North to South. Sliding of Asiatic landmass toward Pacific Ocean resulted in the formation of Island Arcs and Islands in East Asia.

The earliest ocean is Pacific. Indian, Arctic and Atlantic oceans were formed later as a result of tensional forces.

CRITICS:

a. His theory is based on a number of assumptions, which are mostly guesses.

b. He assumed that the original land mass Pangaea divided into three parts due to sliding and two depressions were formed between them. How all these become possible? He has not answered for this.

c. It is difficult to accept his assumption that the substratum is less dense than the upper crust.

d. The crustal structure is different from the Jeffrey's which is based on Seismic evidences.

e. His concept regarding Geosynclines is confusing.

f. Wooldrige and Morgan have stated that 'the cause of the primary bulges which start the slipping has not been satisfactorily indicated'.

8.8.5. Convection Current Theory Of Arthur Holmes: Arthur Holmes propounded this theory in 1928-29. The main objective of this theory is to explain the formation of mountain. But it also explains volcanicity and continental drift.

He made a distinction between the solid crust and the liquid substratum. The earth's crust (the upper layer Sial), the intermediate layer (upper part of the Sima) and lower layer which consist crystalline rocks. Below this is the substratum which is in liquid condition. This theory is based on the convection current in the substratum. The presence of radio active substances in the substratum is responsible for the origin of convection currents. Due to this it is in fluid condition. Where as the radio active minerals are more in the upper layers of the crust, the heat from these layers is lost by radiation and conduction, temperature does not rises. There is no accumulation of heat in the upper and the middle layers of the crust. Even though, the radio active substances are less in the substratum, the heat released by them and the original heat of the substratum combines together and they are able to generate convection currents, which rises upward. It is influenced by two factors. They are-

a. The thickness of the crust near equator is more than in polar areas. Due to this temperature gradient is more in the equatorial regions compared to polar region. So convection current ascends near the equator flow horizontally and descends near the poles. Due to this there is greater movement in the lower layer than in upper layer resulting in tension. The original equatorial landmass was broken into two; one is drifted toward north and another toward south. Between these Tethys Sea originated.

b. The temperature is high under the continental block and convection currents are more active and powerful. Below the continental block, the convection currents carry the molten material upwards and turn towards ocean. But below the ocean, convection currents are weak. These two currents meet under the continental margins in the area of continental shelves and then go downwards. We should remember that convection currents do not originate at one place. It may restart from other place.

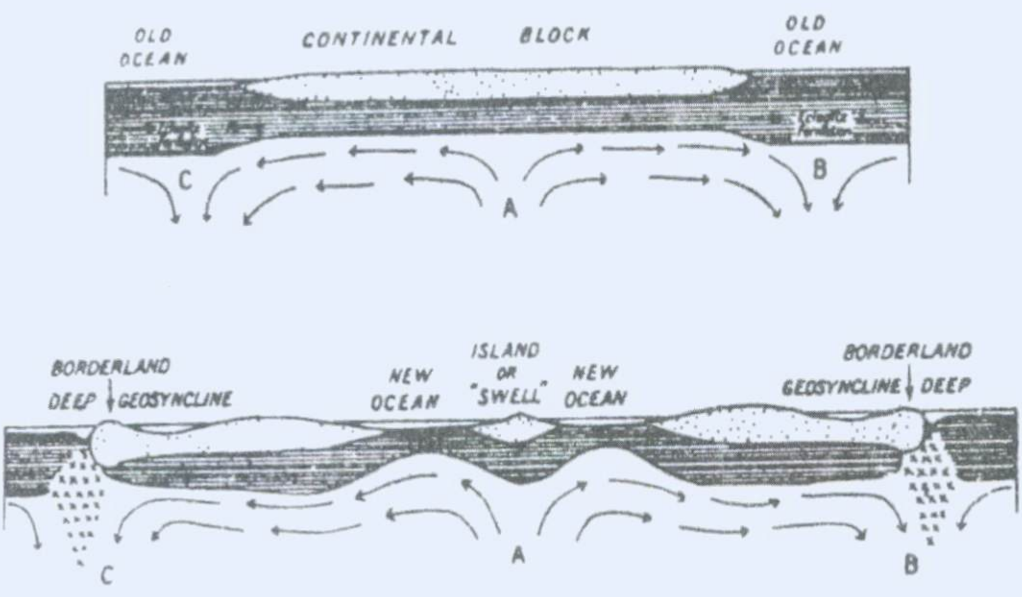


Figure 8.4 Convectional currents (Steers J.A)

When two convectional currents (one under the continental block and another under the ocean bottom) converges and compression takes place. Here the current descend downwards and Geosynclines are formed. It create conditions for mountain building.

According to Holmes, if the substratum is weaker than the Sialic blocks floating on it, there will be no folding. Folding of the sediments takes place with deposition of sediments and subsidence of the Geosyncline.

He identified three stages in which formation of Geosyncline, folding and upliftment of mountain takes place.

In the first stage, convection currents converge and descend near the continental shelves forming Geosynclines. Sediments are deposited in Geosyncline and there is subsidence of this. In the zone of descending currents the roots of mountains are formed by subsidence of Geosynclines. It is the preparatory stage of mountain building. This stage has a long duration of time.

The second stage is short and the speed of the convection currents is faster. They descend with maximum force and great scale of compression occurs in the Geosynclinal sediments causing folds. By this stage mountain building begins.

In the last stage, the convection currents become weak. Due to this the downward pressure also reduces resulting in the beginning of upliftment of folded sediments. Upliftment continues still Isostatic balance occurs.

In 1939 Griggs confirmed the cyclic arrangement of the convection currents through an experiment. Based on the results of his experiment he postulated Tactogene or Root Theory of Mountains.

Holmes also explained the drifting of continents and formation of oceans (see drift theories). In the same time he pointed out the origin of Alps-Himalayan range, North American Cordillera, Island groups East Asia. On the margins of Lauratia Andes mountains are formed on the margins of Gondawana land.

CRITICS or LIMITATIONS:

- Our knowledge about the existence of convection currents, their behavior is extremely limited. We do not know whether they are so powerful to break up and drifting of continents.
- Rising and falling of blocks are doubtful.
- Some scientists questioned about the high temperature in substratum generated by radio active elements.
- In this theory, he stated that convectional currents originate at few places. Why they are not originated at all places?

In these years, the theory received support and confirmation from the study of Plate Tectonics.

studied the theory of Plate Tectonics in previous chapter. Here we will concentrate on mountain building with relation to Plate Tectonic theory

As you know that we have three plate boundaries like – Divergent boundaries (mid oceanic ridge or rifts), Shear boundaries (two plates pass across each other) and Convergent boundaries (two plates collide each other). On the divergent boundaries ocean ridges and rift valleys are formed. Folded mountains are built on convergent plate boundaries. Ex: Alps, Himalayas, Circum Pacific belt of mountains etc.,

Convergence of plate boundaries occur in three situations. They are-

a. Continent – Ocean plate collision

b. Continent – Continent collision

c. Ocean – Ocean plates collision

a. **Continent – Ocean plate collision:** It is the most common type of collision. The collision of continental and Oceanic convergent plates results in the formation of Cordillera type of folded mountains. Ex: Rockies and Andes Mountain. The oceanic plate is heavier due to dense materials. It moves down under the continental plate in the trenches. Due to this intense pressure, the sediments in the continental margin are compressed and folded.

b. **Continent – Continent collision:** When the Gondwana land started to break after Mesozoic era, Indian plate started to move towards north and joined Asiatic landmass about 30 to 60 million years ago. Due to this the Tethys Sea became narrow and finally closed. The marine sediments and the crust located between these two plates were folded and thrusted to form Himalayan Mountain. In the same period, Africa started to move towards north. It collided with European plate. The sediments along the continental margins have been folded and thrusted to form Alps in Southern Europe, Atlas Mountain in North-west Africa.

c. **Ocean – Ocean plates collision:** When two oceanic plate collides, one plate will move under the other plate in the trenches. Due to this, compression takes place and it forms 'Island of Festoons and Island Arcs'. Ex: West coast of Pacific and north-east coast of Indian Ocean. Japan has been formed by the union of two island arcs of different periods. At present there are two island arcs – Philippine arc and Mariana arc which is south to Japan.

Some times due to collision of continent and Island Arc, mountains may be formed. Ex: Mountains of New Guinea.

Converging movements cause geological effects. The most important are-

- It may result in down-wrapping of the crust, Geosynclines or Linear basins may be formed.
- The deformation of the crust resulting from the compression.
- The heat produced by metamorphic and magmatic activity.
- Upliftment of Mountains.

All these will help us to form a geological history of mountain belt.

Continental Drift theory of Wegner has also thrown light over the origin of Mountains (See Drift theories in previous chapters).

EPIEROGENIC STAGE: There is a relationship between continental building and formation of mountains. Due to compression on either side, unwraps and down wrapping takes place. Some times due to huge compressive force, the entire block may be uplifted forming mountains. The surrounding low lying area, sediments will be deposited by agents of gradation. So there is a continuous upliftment and sedimentation takes place. Due to this new mountains will be formed. The height of the existing mountains will also increase.

8.10 SIGNIFACANCE OF MOUNTAINS

There are several uses of mountains to man. They provide direct and indirect benefits. It checks the cold winds and gives security from the foreign invasion. They are the sources of river. They have ideal location for the establishment of hydro power stations. They are known for flora and fauna. So it is useful to lumbering. Certain places are hill stations in the mountains, which are attracting tourists. They have plenty of mineral and power resources. The vast river plains are the gift of these mountains. Ex: Indo-Gangetic plains etc.,

But development of transport, agriculture is difficult in these places. In several mountainous regions the climate is not favourable for human habitation. The population is sparse in these regions.

8.11 LET US SUM UP

In this unit you have studied about Diastrophic force and its type. The causes of Epierogenic force and its effects, Orogenic force and its effects are studied. We observe that there are several views regarding Mountain Building or formation. Each and every hypothesis has its own merits and demerits. In recent years Plate Tectonic theory is one of the most important which throw light on the movements of continents and the formation of mountains and ocean trenches.

8.12 KEY WORDS

Mountain Ridge, Range, Chain, Cordillera, Residual Mountain, Geosyncline, Genticlines, Mono Geosynclines, Poly Geosynclines, Meso Geosynclines, Lithogenesis, Orogensis, Glyptogenesis, Hinterland, Foreland.

8.13 QUESTIONS FOR SELF STUDY

1. Classify the mountains into different types and explain them.
2. Describe the phases of Mountain building.
3. Explain the Mountain building theory of Kober.
4. Explain Arthur Holmes theory of Mountain building.
5. Evaluate Plate tectonic theory and Mountain building.

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M.Sc.
GEOGRAPHY
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3

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Manasagangotri, Mysore - 6.

Developed by Academic Section, KSOU, Mysore

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UNIT : 9 FOLDS, FAULTS & RIFT VALLEY

Structure

9.0 Objectives

9.1 Introduction

9.2 Compressional Forces – Folds, Parts of Fold

9.3 Types of Fold

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9.3.2. Multiple folding:

9.3.3. Topographic features due to folding:

9.4 Tensional Forces – Faults

9.4.1 Faults

9.5 Parts of Fault

9.6 Types of Fault

9.6. 1. Normal Fault

9.7 Joints

9.8 Let us Sum up

9.9 Key words

9.10 Questions for self study

9.11 Further Readings

9.0 OBJECTIVES

This unit provides you all necessary information about Compression and Tensional forces.

After studying this unit, you will be able to-

- Explain the nature and intensity of compression force.
- Identify the Major relief features created by compression force.
- Identify the knowledge about the tensional force
- Evaluate the Various kinds of land forms formed by tensional force.

9.1 INTRODUCTION

As we already know that, there are two forces operating and modifying the features of the earth. They are- Endogenic and Exogenic. In the previous units we have studied the forces of these two. In this unit we will discuss in detail about Compression and Tensional forces and their resultant landforms.

9.2 COMPRESSIONAL FORCE - FOLDS

Horizontal compression force (⇨ ⇦) will form wave-like bend in the rock strata. These bends are called **'Folds'**. Folding mostly takes place in sedimentary rocks as they have a greater flexibility than igneous or the metamorphic rocks. Some parts of the rock strata bend upwards, which the others are bend downwards. The up folded rock strata in arch-like form is called **'Anticlines'**. The down folded structure forming trough like feature is called **'Syncline'**. The length and width of folds may vary from less than an inch to several miles. The shape and size of the folds depends upon the intensity and direction of the compressive forces and nature of the rocks.

9.2.1 Parts of the Fold : We should remember the parts of the fold. The two sides of a fold are called **'Limbs'** or **'Flanks'** of the fold. The limb which is shared between an Anticline and a Syncline is called **'Middle Limb'.**

'Hinge' of a fold is the line of maximum curvature in a folded bed. The hinges may be horizontal, inclined or vertical. The plane along which the rocks are bent as an Anticline or as a Syncline is called the **'Axis of the Fold'** or **'Axial Plane'**. Each fold has an axis of anticline and axis of syncline. The axis is a line parallel to the hinges.

The **'Crest'** is a line along the highest part of the fold or the line connecting the highest points on the same bed. There is a separate crest for each bed. The plane or surface formed by all the crests is called the **'Crestal Plane'.** The **'Trough'** is the line occupying the lowest part of the fold or the line connecting the lowest parts on the same bed. The plane connecting such lines may be called **'Trough Plane'**.

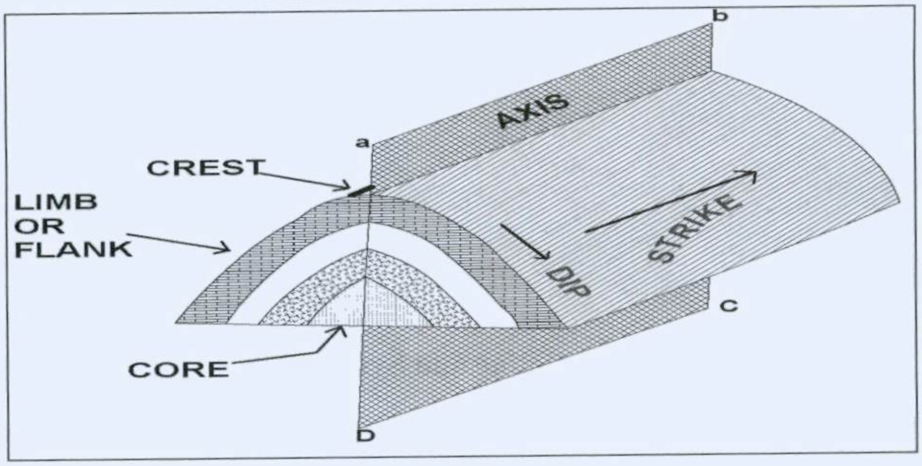


Figure 9.1 Parts of a fold

AC & AB = Limbs of the Fold,

B & C = Troughs

The inclination of rock beds with respect to horizontal plane is termed as **'Dip'**. The dip is measured with a help of an instrument called **'Clinometer'**. The **'Strike'** of an inclined bed is the direction of any horizontal line along a bedding plane. The direction of the dip is always at right angle to the strike.

Anticlines: The word is derived from the Greek, meaning **'opposite inclined'**. The up folded rock beds are called Anticlines. It is a fold that is convex upward. It has older rocks in the centre. When the slopes of both limbs and sides of anticline are uniform, the anticline is called **'Symmetrical Anticline'**. When the slopes are unequal, the anticline is called as **'Asymmetrical Anticline'.**

Synclines: The term Syncline is derived from the Greek, meaning **'together inclined'**. The two limbs dip toward each other. It is formed due to horizontal tangential forces. Normally younger rocks are in the centre of the fold.

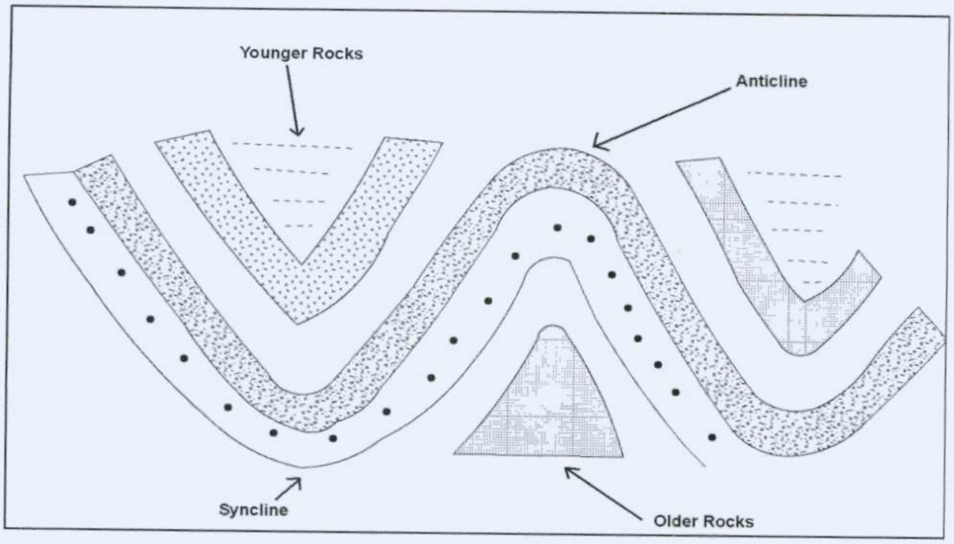


Figure 9.2 Anticline and Syncline

Anticlinorium: These are found in folded mountains. It consists of a series of minor anticlines and synclines within one extensive anticline. It is formed when the forces were applied unevenly and the rocks folded unequally. This type of structure is also known as **'Fan Fold'**

Synclinorium: It is an extensive syncline having number of minor anticlines and synclines. It is formed due to irregular folding upon irregular compressive forces.

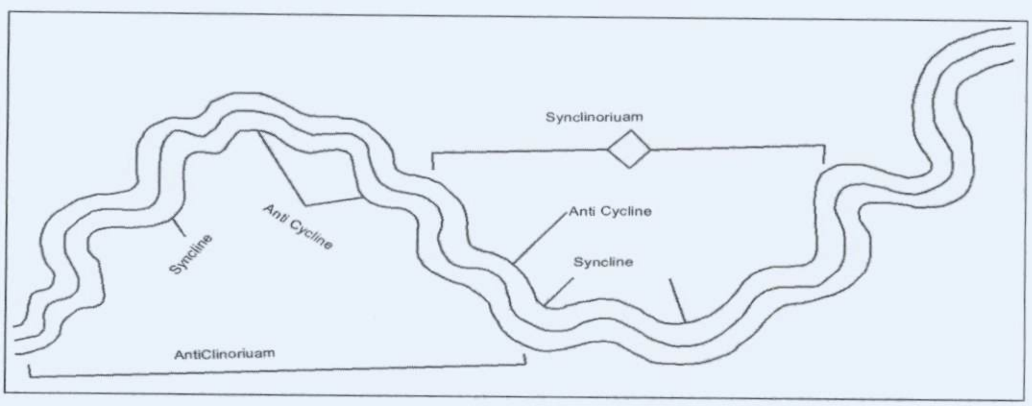


Figure 9.3 Anticlinorium & Synclinorium

Broad Wraps: Epierogenic movements usually result in Broad Unwrapped or Down wrapped areas of the earth's surface. These may extend from a few miles to hundred miles in length and width. The up wraped regions are **Geanticlines**. Ex: The great plains of Western North America, Mississippi basin and the Gulf of Mexico etc., Down wraped areas are called **Geosynclines**. Ex: Hudson Bay and Baltic Sea etc.,

Geosyncline: It literally means **'Earth Syncline'.** But this term should not be used for large synclines. It is a large depression of hundreds of miles long and tens of miles wide in which many thousands of feet of sediments accumulate.

Geanticline: It is a broad uplift, comparable in size to a Geosynclines. It may lie either out side or inside a Geosyncline.

9.3 TYPES OF FOLD

There are several factors affecting on the nature of the folds. Ex: Nature of rocks, intensity of compressive force, duration of compressive force and others. Based on the inclination of the limbs, folds are classified into five types. They are-

a. **Symmetrical Folds:** These are simple folds where both the limbs inclined uniformly. It is an example for open fold. It is found very rarely in the world.

b. **Asymmetrical Fold:** These are having unequal and irregular limbs. Both the limbs inclined at different angles.

c. **Monoclinal Folds:** In this, one limb inclines moderately with regular slope, while the other limb inclines steeply at right angle and the slope is almost vertical. It is formed due to vertical force and unequal compressive force.

d. **Isoclinal Folds:** When there is more intensity in compression both the limbs of the fold may be almost parallel. This type of fold is known as Isoclinal Fold.

e. **Recumbent Fold:** When compression is so strong that both limbs of the fold become parallel and horizontal.

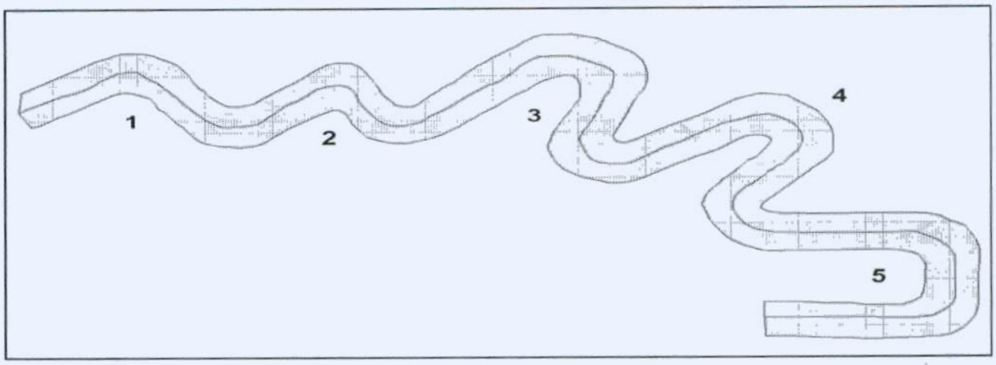


Figure 9.4 Types of Fold: 1.Symmetrical fold, 2. Asymmetrical Fold, 3. Monoclinal fold, 4. Isoclinal fold, 5. Recumbent fold.

The other types of folds are –

f. Over turned Folds: In this type, one limb of the fold pushes on another fold due to great compressive force. Limbs are rarely horizontal

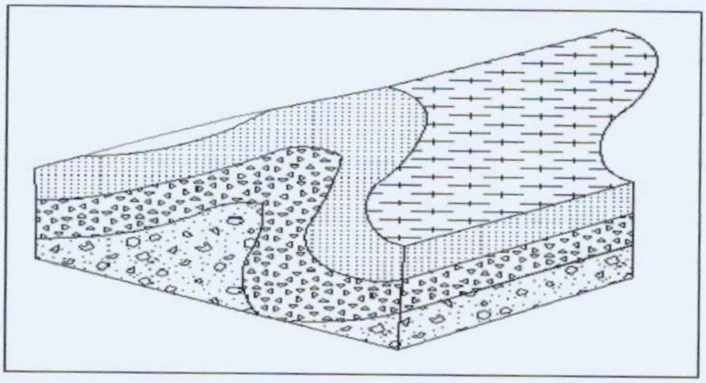


Figure 9.5 Over turned fold

g. Plunge folds: are formed when the axis of the fold instead of being parallel to the horizontal plane, it becomes tilted and forms plunge angle. It is the angle between the axis and the horizontal plane.

h. Fan Folds: It is one in which both limbs are over turned. In anticline fan fold, the two limbs dip toward each other. In the synclinal fan fold the two limbs dip away from each other.

i. Open Folds: In this type, the angle between the two limbs of the fold is more than 90^0, but less than 180^0 (obtuse angle).

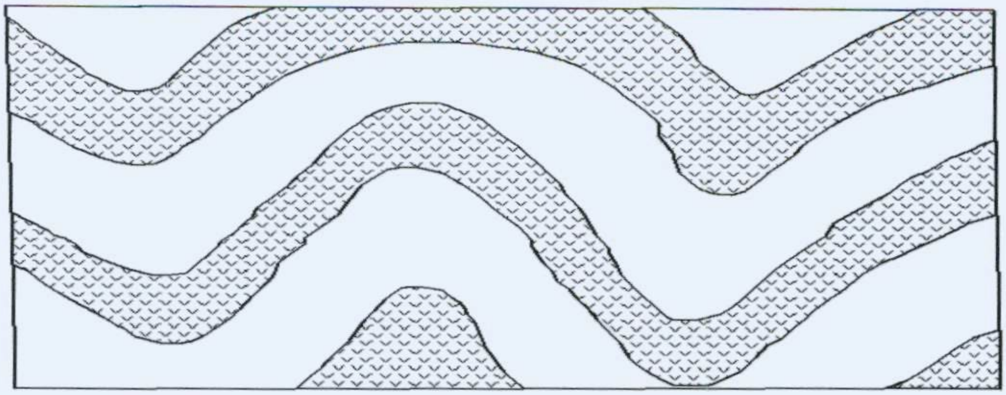


Figure 9.6 Open Fold

j. **Closed or Tight Fold:** In this, the angle between the two limbs of a fold is acute angle. These are formed due to intense compressive force.

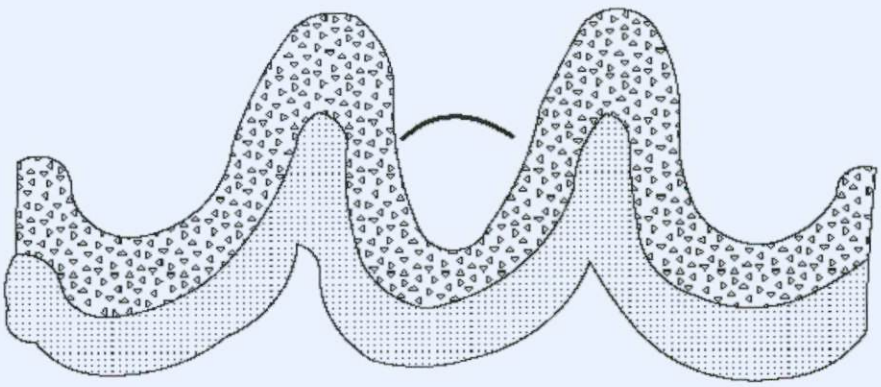


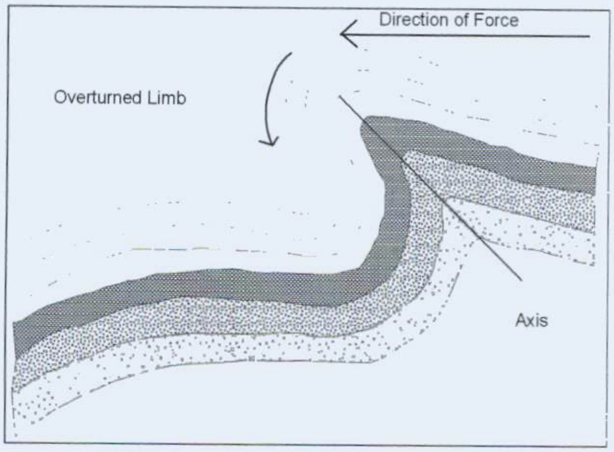
Figure 9.7 Closed Fold

a. **Box Fold:** It is one in which the crest is broad and flat. Two hinges are present one on either side of the flat crest.

b. **Chevron Fold:** In this type, the hinges are sharp and angular.

c. **Reclined Fold:** In this type the axis plunges directly down the dip of the axial surface. Many reclined folds form when steeply dipping beds are subjected to shearing parallel to the strike of the beds.

9.3.1.Nappes: It is formed due to complex folding caused by horizontal movement and resultant compressive force. Both the limbs of a recumbent fold are parallel and horizontal. When there is an increase in compressive force, one limb of recumbent fold slides over the other fold. This process is known as **'Thrust'**. The plane along which one part of the fold is thrust is called **'Thrust Plane'**. The up thrust part of the fold is called **'Over thrust fold'.** When the compressive force further increases the limbs of the fold are acutely folded that these break at the axis of the fold and the lower rock beds come upward. Due to continuous compression force, the broken limb of the fold is thrown far away from its original place and occupies the rock beds of distant place. Here the rock structure of the broken limb is different from the rock structure where it is situated. This broken limb of the fold is called **'Nappe'**. In the Swiss Alps, several Nappe have been identified. In Himalaya also Nappe has been found.



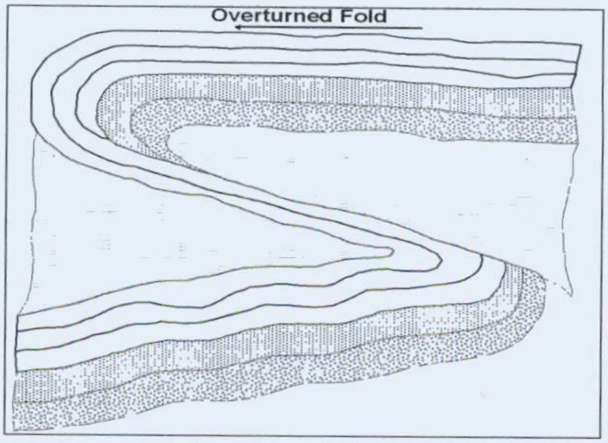


Figure 9.8 Formation of Nappe a. Stage of overturned fold, b. Overriding of one limb of the fold on another.

9.3.2. Multiple folding: In several places, layers of rock have a long history of deformation including several episodes of folding. The axial surface of the older folds is folded by the younger folds and in some areas folds of different ages may be super imposed upon one another.

9.3.3. Topographic features due to folding: As we discussed in the previous pages, due to variation in vertical and compressive force, their intensity, duration, nature of rocks, different kinds of folds were formed. It prepares ground work for a great variety of topographic forms. It provides evidences indirectly help to determine the land forms that are later produced by agents of denudation. Ex: Long parallel ridges and valleys carved out of up tilted sedimentary rocks of varying composition, straight regular shore lines developed by waves on rocks of uniform composition that dip toward the sea etc., The deformations of the earth whether large or small are of fundamental importance in determining the topography present in any region.

9.4 CRUSTAL FACTURES

We have already noticed the forces which are changing the landforms in the previous unit and you know that there are two types of Orogenic force – Tensional and Compression force. In previous pages we have studied about compression force, its effects and resultant landforms. Now we are going go know about Tensional force and its resultant landforms. Due to the exertion of these two forces in opposite directions Faulting and Joints are very common.

9.4.1.FAULTS : A fault is a fracture or fissure in the earth along which one side has moved with reference to the other side (P.G.Worcester-1965). Faults are ruptures along which the opposite walls have moved past each other (Maryland P.Billings -2005). Some faults may be quite small and some may be several miles and their displacement may be measured in inches to thousands of feet.

Fault plane is a place where the movement took place. The movement may be smooth or curved, vertical or inclined at any angle to a horizontal plane. The movement may occur vertically, horizontally or any other direction.

Faults are closely related to folds. Any kind of fold may turn into a fault. When there is an excessive force at one direction, the limb of the anticline may give rise to a fault. It depends on the strength of the rock and the amount of force. Faults usually represent weaker zones. In these places, there will be regular earth movements through a long time. These faults are known as **'Active Faults'**. Ex: San Andrea's Fault in 1906 caused California earthquake, movement along an old fault in 1935 caused Helena Montana earthquakes etc and there will be a rapid weathering and erosion along wide fault zones.

9.5 PARTS OF A FAULT

a. Fault Line : The trace of a fault on the earth's surface.

b. Fault Plane: The surface along which movement takes place.

c. Dip: The angle between a horizontal surface and the plane of the fault.

d. Strike: The trend of a horizontal line in the plane of the fault or it is the direction of its intersection with a horizontal plane.

e. Hade: The angle between the fault plane and a vertical Plane that strikes parallel to the fault or Hade = 90^0 – Dip.

f. Fault Trace / Fault Line / Fault outcrop: The intersection of the fault with the surface of the earth.

g. Hanging Wall: The upper wall of the fault or the block above the fault.

h. Foot wall: The block below the fault.

i. Fault Scrap: An upstanding structure with a steep side which is formed due to the relative displacement on either side of the fault line.

j. Slick sides: Highly polished rock surface in the fault scrap.

k. Fault zone: A place or zone which consist a number of faults.

l. Slip: It is used to indicate the relative displacement points on opposite sides of the fault.

m. Dip-Slip: The component of the net slip measured parallel to the dip of the fault plane.

n. Net-Slip: The total displacement due to a fault.

o. Fault throw and Heave: The vertical component of the clear displacement of a bed measured along the direction of dip of the fault. The horizontal component of displacement is known as Heave or Gape.

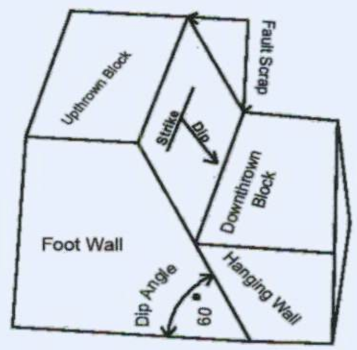


Figure.9.9 Parts of a Fault

9.6 TYPES OF FAULT

Based on nature of relative movement, fault pattern, value of dip of fault, altitude of adjacent beds etc., faults are classified into several types. They are –

1) Normal Fault
2) Reverse or Thrust Faults
3) Lateral / Strike Slip / Wrench Fault
4) Dip Slip Fault
5) Diagonal Slip Fault
6) Step Fault
7) Strike Fault
8) Bedding Fault
9) Dip Fault
10) Oblique / Diagonal Fault
11) Longitudinal Fault

12) Transverse Fault

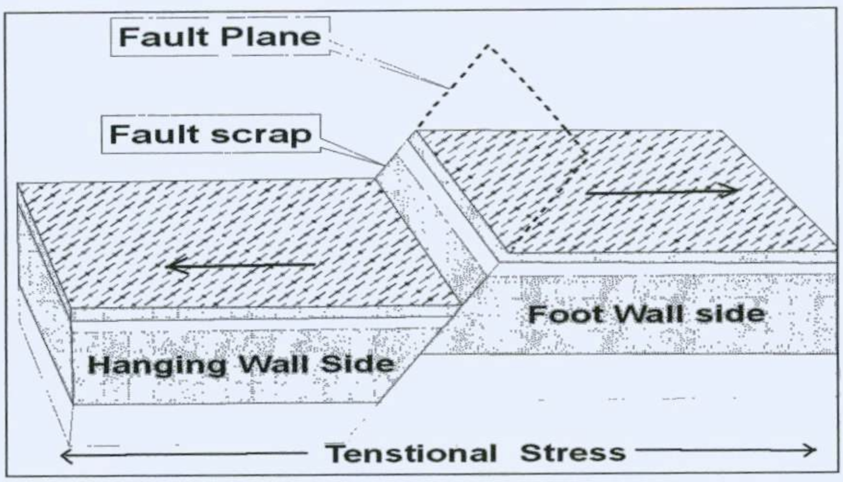
13) High and Low angle Fault

14) Parallel Fault

15) Peripheral Fault

16) Radial Fault etc.,

9.6. 1. Normal Fault : It is the common type of fault associated with crustal splitting. Faults having vertical movement are called Normal Faults. The fault plane is steep or nearly vertical. Steep sided scrap is called Fault Scrap or Fault Line Scrap. One side is raised (upthrown) and another is down thrown. Normal faults occur due to tension and lengthening or extension of the faulted beds. These faults are also known as **Gravity or Tensional faults.**



9.10 Normal Fault.

Normal fault create two major topographic features. They are – Block Mountain and Horst, Graben or Rift Valley.

9.6.1.a. HORST AND BLOCK MOUNTAIN: An up thrown block which stands above blocks of the earth is known as Horst. It is surrounded by at least two sides by fault planes. Horsts make block like plateau or mountains with flat top and steep and straight sides. Ex: Shillong Plateau.

Block Mountains are also known as **Fault Block Mountains or Horst Mountains.** These are formed by tension and compression forces. It is a land block between two faults or either side of a rift valley or a Graben. If there is faulting in the ground surface, block mountains are formed. There are two types of Block Mountain. They are –

a. **Tilted Block mountains** are having steep slope at one side (fault scrap) and gentle slope on another side.

b. **Lifted Block mountains** are like horst with flatness at the top, steep in both sides and represented by two boundary fault scraps.

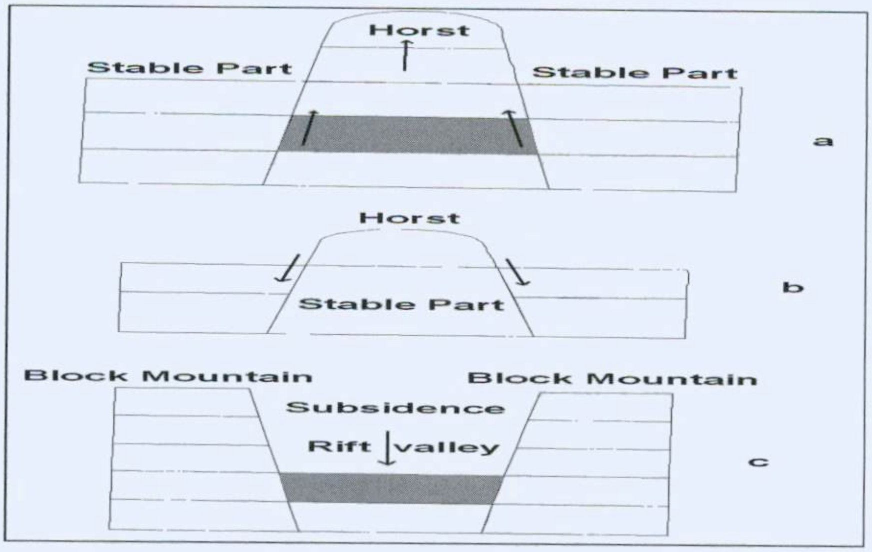


Figure 9.11. A. Block mountain formed due to rise of middle block

B. Due to downward movement of side blocks block mountain is formed

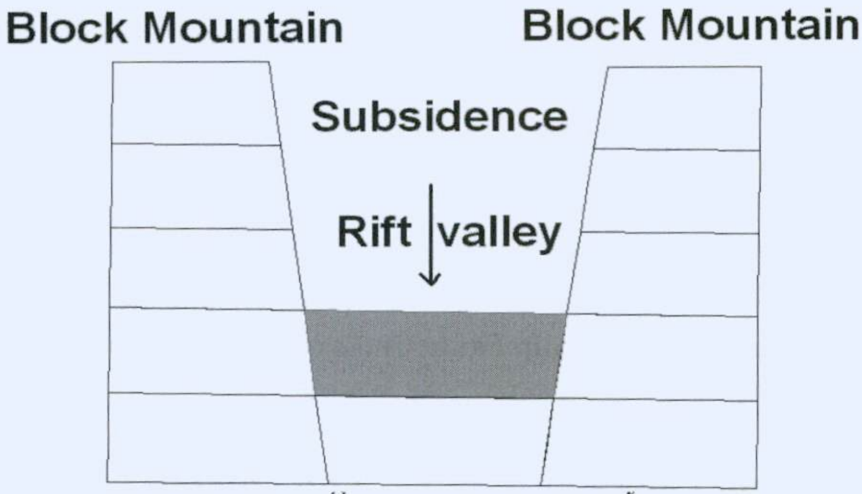
C. Formation of block mountain due to downward movement of middle block.

Block Mountains are found in all most all the continents. Ex: Steens Mountain district of Southern Oregon, Utah province of USA, Vosges and Black Forest Mountains bordering Rhine rift valley in Europe, Salt range of Pakistan etc.,

Sierra Nevada Mountains of California are probably the largest unit fault block in the world. It is 400 miles long by an average of 50 miles width and altitude ranging from 8000 to 12000 feet above the sea level.

There are differences of opinion regarding the origin of Block Mountains. Fault theory (Clarence King, G.K.Gilbert, G.B.Louderback and W.M.Davis supported this theory) and Erosion theory of J.F.Spurr have explained the origin of these mountains.

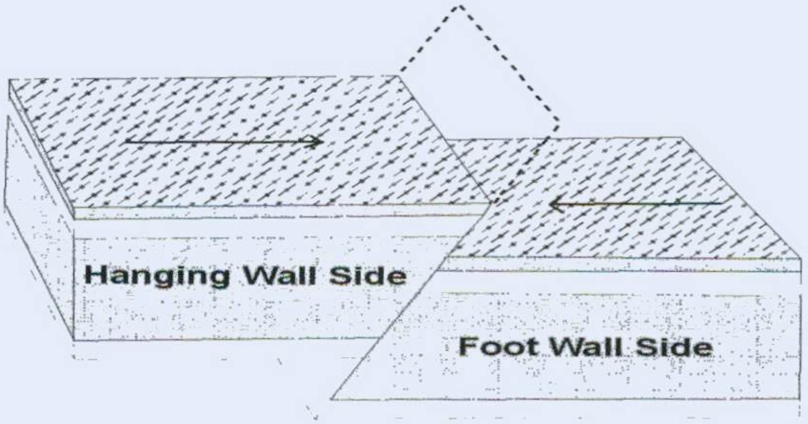
9.6.1.b. GRABEN OR RIFT VALLEY: Graben is a German word, which means that **'a trough like depression'.** It is a long fault trough dropped down between two normal faults or it is a long block lowered compared to blocks of either sides. It is a tectonic valley or trench like landform with steep slopes and parallel fault scraps with flat surface. This land form is closely associated with Horst. Ex: between the horst of the Black forests and the Vosges in Germany, Rhine river flows in a rift valley which is 300 km long and 30 km wide. Valley of Jordan river in Israel, Damodar river in Bihar of our country flows through a fault trough etc., We should remember that these valleys have not been carved by rivers. Here valleys are older than the rivers.



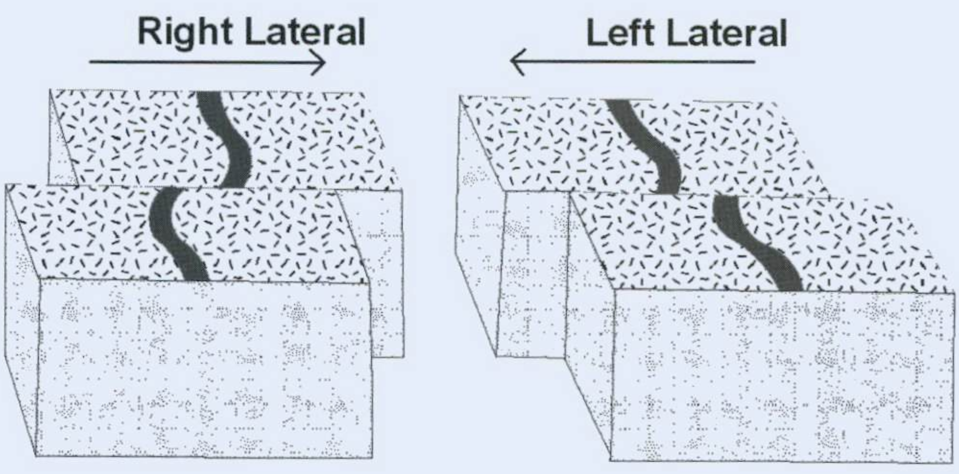
The term Rift Valley was first used by **Gregory** for the Great Rift Valley in East Africa, who recognized it as a tectonic feature due to faulting. Most of the rift valleys in the world have a width of 30 to 50 km.

Ramp Valley is a depression caused by compression (lateral pressure) under the strata due to reverse fault. The central block is down thrusted. Ex:Brahmaputra valley.

9.6.2. Reverse / Thrust Fault: It is caused due to the horizontal movement of the fractured rock blocks towards each other. Here the vertical pressure is less and horizontal stress is maximum. Due to excessive compression, one rock block over ride the other above the fault plane. In reverse fault the angle of the fault dip is more than 45^0. The term Thrust is used, when the dip is less than 45^0. Over thrust is a fault, where the dip is less than 10^0 and has a large net slip. These faults are found in Himalayas and Alps Mountain.



9.6.3. Lateral / Strike Slip / Wrench Faults: Due to horizontal movement, the rock blocks are horizontally displaced along the fault plane. Here the net slip is parallel to the strike of the fault. The strike is equal to the net slip and there is no dip slip component. The displacement is parallel to the strike of the fault. When the opposite wall of a fault moves toward right, it is known as **Right Slip Fault**. If the opposite wall moves toward left, it is called **Left Slip Fault**.



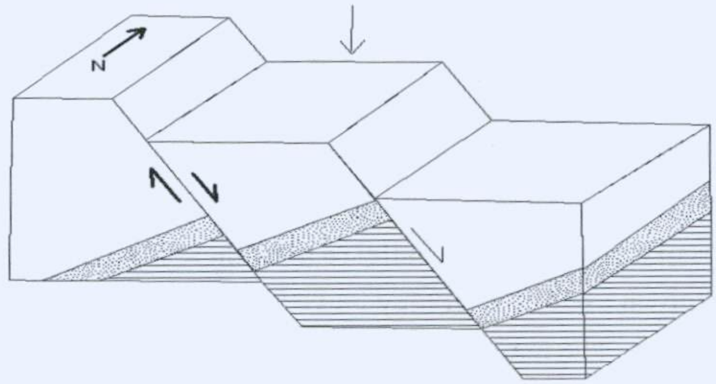
9.14 Strike Slip fault

Strike Slip Fault is called by different names like – ***Tear or Shear fault, Wrench fault and Transcurrent faults.*** **Tuzo Wilson** in 1967 has identified another type of Strike Slip fault known as **Transform Fault**. The best example for Strike Slip Fault is Great San Andreas Fault of California, USA. It is 1200 km long from Gulf of California to North of San Francisco with parallel faults.

9.6.4. Dip Slip Fault: In this type, the net slip is up or down to the dip of the fault. The dip slip is equal to the net slip and there is no strike slip component.

9.6.5. Diagonal Slip Fault: Here the net slip is diagonally up or down to the fault plane. In this type there is both strike slip and dip slip components.

9.6.6. Step Fault: When there is a continuous downward displacement of all the down thrown blocks, a series of fault occur in an area. It is known as Step Fault. If fault scraps have not been eroded, it looks like a gigantic stair case.



9.15 Step Fault

9.6.7. Strike Fault: It is parallel to the strike of the adjacent rocks.

9.6.8. Bedding Fault: It is a type of strike fault. Here the strike is parallel to the bed.

9.6.9. Dip Fault: Here the strike is parallel to the direction of dip of the adjacent beds.

9.6.10. Oblique / Diagonal Fault: Strike is oblique or diagonal to the strike of the adjacent rocks.

9.6.11. Longitudinal Fault: Here the strikes are parallel to the strike of the regional structure.

9.6.12. Transverse Fault: In this type the strike is perpendicular or diagonal to the strike of the regional structure.

9.6.13. High and Low Angle faults: It is based on the angle of dip of the fault. When the angle of the dip is more than 45^0, it is known as High Angle Fault. If the angle of the dip is less than 45^0, it is Low Angle Fault.

9.6.14. Parallel Faults: In some areas the faults have same dip and strike. These are known as Parallel Faults.

9.6.15. Peripheral Faults: These are bound to a circular area or part of a circular area.

9.6.16. Radial Fault: The fault which radiate out of a point.

Retreat Scrap: Through erosion, fault and fault line scraps may retreat. New cliffs parallel with the original scraps are formed. But they are located far away from the trace of the fault at the foot of the cliffs.

Significance of Faults: Many minerals and power resources are found along the fault regions. Petroleum is found in porous beds. There is the rise of ground water along fault planes. They also form water falls.

9.7 JOINTS

A joint is defined as a fracture in the crustal rocks where no substantial movement of rock takes place. But fracture becomes fault when there is a significant displacement of the rocks on both sides of a fracture and parallel to it. If there is no displacement of the walls in the fractures are known as Joints. It may be vertical or inclined to any angle. Joints are formed in several ways. The main reasons are –

- Earth movement – Tension, Compression
- Release of pressure on rocks due to erosion.
- Cooling and consolidation of lava
- Poorly cemented materials
- Rock weathering

Joints does not influences directly on topography, but they indirectly influences. The courses of small stream are often follow joint systems. Glaciers and waves have less effective in these places

9.8 LET US SUM UP

In this unit you have studied the compression and tensional forces. These forces are responsible for the occurrence of the Folds, Faults and Joints. You have studied that the types of fold and faults.

9.9 KEY WORDS

Anticlines, Synclines, Limb, Hinge, Axis of the Fold, Crest, Trough, Dip, Strike, Clinometer, Symmetrical, Asymmetrical, Geosyncline, Monoclinal fold, Isoclinal fold, Recumbent fold, Overturned fold, Fan fold, Open fold, Closed fold, Nappes, Fault, Fault line, Hade, Hanging wall, Foot wall, Fault scrap, Slip, Dip slip, Net slip, Horst, Graben, Step fault, Radial fault, Joints.

9.10 QUESTIONS FOR SELF STUDY

1. Explain the various type of folds with neat diagrams.
2. Discuss the different kinds of faults.
3. Write short notes on – Normal Fault, Rift Valley, Block Mountain.

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UNIT : 10 EXOGENETIC FORCES AND THEIR LANDFORMS, WEATH ERING AND MASS WASTING

Structure

10.0 OBJECTIVES

After studying this unit you will able to

- Evaluate the earth's different types of forces
- Identify the endogenic and exogenetic forces.
- Recognize the meaning of weathering and Mass wasting.
- Begin to appreciate and understand the types weathering.

10.1 INTRODUCTION

Many Physical and chemical process operate because of which the Earth's surface undergoes modification. These are known as geomorphic processes. At this time we study exogenetic forces which are in use on the earth surfaces in forming of land forms and labeling them to sea level or base land. Over the time of these operations, various processes underplay to give size to various kinds of land forms ranging from simple, compound to a number of landscapes. Exogenetic forces produce a lot of unevenness over the land. The forces which start to destroy the unevenness are known as exogenetic forces. Destruct ional work and convert mountains in to plateau, plains, etc, relief features produced by internal forces in short time takes a lone time to be damaged by exogenetic forces.

In the present unit you will be given the meaning of Exogenetic forces, types of land scape, weathering and its process. In this unit you will be given the clear picture about the mass wasting and it types.

10.2 MEANING OF EXOGENETIC FORCES

Exogenetic forces are produced and operate on the surfaced of the earth wind, water, and snow are such force which erode the surface of the earth and makes deposition on it.

The main exogenetic forces are running water, Moving Ice, Underground water, Sea Wind, Temperature, Rain, Frost, Vegetation, Animals, and man.

These forces do not only do the destruct ional work but are also engaged in constructive work. These activities are known denudation and deposition. The process of wearing away of rocks and leveling this is called Denudation.

Geomorphic evolution is more company. It is a track thing to find landscape assemblages attributed to one geomorphic process. The land forms may be simple, compound, Monocyclic, or Exhumed or resurrected landscapes multicyclic landscapes are more common than Monocyclic. Newly created land surface are restricted to uplifted portion of the ocean floor, Volcanic cone, lava plain or platen and beneath the Pleistocene glacial deposits the older forms are limited to the benches along the valley sides that is above the present valley floors. The geologic and climatic changes during the Pleistocene are also responsible for the complex Evolution of land forms most of the geomorphic forms are older than Tertiary by not older than Pleistocene. The geomorphic Evolution is due to the influence of more than one set of climatic condition and geomorphic process. Hence land scapes are of 3 types. 1) Relict landforms 2) buried and 3) exhumed land forms.

10.2.1 Relict Landforms :-

It is formed on a pre-existing landscape. The bits and pieces of former erosion surface in Africa and Australia example, ridges, cementation of rivers bed deposits and abandoned valleys, disruption drainage systems are few examples

10.2.2 Buried Landforms :

These are buried beneath some type of cover mass, commonly marine or terrestrial sediments have been preserved essentially intact. Buried Erosional surface are buried valleys. Buried submarine canyons, buried paleokarst plain, buried Pediplain or peneplain and buried sand bodies are good examples.

10.2.3 Exhumed landforms :

The Exhumed to topographic forms are most likely to be composed of the instant Bedrock material which has escaped destruction in the process of exhumation Sherman peneplain of Wyoming Precambrian Peneplain of Canada, Prekardo landscape in South Africa, peros depression in New Mexico, Oligocene ridges in Paris basin, are few examples of exhumed landforms.

10.3 WEATHERING AND MASS WASTING

Weathering refers to disintegration and decomposition of rocks and materials of the surface of the earth. It takes place in situ by Natural agents.

Weathering changes hard massive rock into finer material. It is the initial stage in the process of denudation. Weathering is of ten described as the primary necessary stage in the denudation of the landscape as it prepares rock materials for transportation by the other agents of land erosion, including mass movement of material down slopes.

10.3.1 Factors affecting weathering :

There are various factors which determines weathering they are as follows:

(a) Climatic Conditions.

(b) Chemical Composition of rocks

(c) Hard and texture of rocks

(d) Vegetation

10.4 TYPES OF WEATHERING

There are three types of weathering

(1) Physical weathering

(2) Chemical weathering

(3) Biological weathering

10.4.1 Physical Weathering:

Physical weathering is the mechanical disintegration of rocks. The main factors responsible for Physical weathering are temperature the crystallization of water into ice or other crystal growth the pressure release mechanism and the mechanical action of animals and plants.

Different types of Physical weathering are as following.

10.4.2 Block weathering:

The thermal expansion of rock has long been cited as an important cause of rock cracking and disintegration. The theory is that rocks are poor conductors of heat. This is brought about by the differential rate of expansion and contraction of the minerals composing the rock when exposed to sun shine in day time and cooling during the night. This is lead to the setting up of stresses in the rock, causing fracturing parallel of the surface. This process has been termed as exfoliation. When rocks break into block are called as block weathering.

10.4.2.1 Freeze thaw or Ice Crystal Growth:

This is characteristic of cold regions when water turns to ice, it undergoes a nine percent increase in volume. In the subarctic zones of the world or at high elevations, temperatures regularly vary about the freezing point, freezing during the night and liquid state during the day, exert pressure on the rock walls, causes crevices in the rocks and rapidly disintegration of such rocks creating a mass of post shattered debris or repeated freeze and thaw action on rocks cause breakage into small debris which is referred as freeze thaw disintegration.

10.4.2.2 exfoliation:

When rocks formed at great depth beneath the earth's surface under environment of great pressure get exposed at the surface by erosion. When the pressure reduces the rock expand developing concentric factures. The separation of successive concentric shells from massive rocks is exfoliation.

10.4.2.3 The Crystallization of Salts:

A number of salts such as sodium chloride (Common Salt) Calcium sulphate (Gypsum) and sodium carbonate may sometime enter rocks in dissolved state. On drying and crystallization they expand and set up a disruptive effect, this crystal growth in rocks can inevitably cause splitting salt crystallization produces cavernous weathering of which the small scale honey combing of rock surface is a good example.

10.4.2.4 Role of plants and animals:

Tree roots can occasionally be shown to have forced apart adjacent blocks of rock, worms, Rabbits, Rat, some barrowing animals may help in excavation of partially weathered fragments of rocks.

10.4.2.5 Thermal Expansion and Contraction:

Minerals as well as rocks tend to expand when heated and contract when cooled. The separated acts of expansion and contraction lead to disintegration of rocks.

10.4.3 Chemical weathering

Chemical weathering involves chemical changes in the structure of the rocks the process remarkably responsible for Chemical weathering are.

1. Oxidation
2. Hydration
3. Carbonation
4. Solution

10.4.3.1 Oxidation:

The process of oxidation occurs when minerals in freshly exposed rocks take up additional oxygen. Deep buried clays are often blue or grey in colour as long as air is excluded from them, but when they get exposed they are oxidized and turn red or brown as ferric compounds are formed. For example, the ferrous state of Iron changes into oxidized ferric state.

10.4.3.2 Carbonation : Under this course of action minerals containing calcium, Sodium and magnesium are changed to carbonates by action of carbonic acid known as carbonation, when rain water enters the pones of calcareous rocks like limestone or chalk this process occurs.

10.4.3.3 Hydration : It is a process where water is added to mineral or compound when certain types of mineral expand as they take up water, Causing additional stresses in the rock, Hydration is a mechanical effect, but it occurs intimately with hydrolysis in such a manner that it is difficult 40 draw any hard and fast line between mechanical and chemical weathering. It occurs along with other chemical processes during decomposition. This is particularly effective on some aluminum bearing mineral such as tells pars which is present more in Igneous rocks.

10.4.3.4 Solution : It is a process in which rocks get dissolved in the presence of water; rain water is able to dissolve certain minerals in the soil such as potash, rock salt and gypsum. These minerals are taken to the lower layers of the soil and the rocks chemical Composition changes this happens in wet regions.

10.4.4 Biological Weathering : Animals and plants help decay and disintegration of rocks, both chemically and mechanically. Biological weathering takes places in the following ways.

(1) Bio – Physical Processes

(2) Bio – Chemical Processes

Different Climatic regions are favorable to different types of weathering. In Equatorial regions where both temperature and humidity are high, chemical weathering is dominated. Whereas in desert area's are more prone for mechanical weathering.

10.5 SIGNIFICANCE OF WEATHERING

1) The fragments are produced by weathering is important for soil development.

2) Weathering plays an important role in breaking rocks down into their mineral components and in Creating New compounds through chemical changes.

3) It plays an important role in giving rise to various landforms.

10.6 MASS – WASTING:

Earth's gravity pulls all the materials downward continually ever where. Because of the gravity the rocks soil fall or slide to a new position of rest which are poorly held are much more susceptible to gravity movements

Taken altogether, all kinds of downs lope movements due to gravity is collectively termed as mass wasting, Constitute an important process in slope wasting and denudation of the lands.

10.6.1 Talus Cones:

Steep rock walls of gorges and high mountains shed countless rock particles under the attack of physical weathering processes. These accumulate in distinctive landforms called Talus cones. A talus slope or scree slopes has a remarkably Constant slope angle of 34° to 35°. As long as it is freshly formed and it contains little very fine material mixed in with the courses.

10.6.2 Soil Creep :

On almost any moderately steep soil covered slope a slow down slope movement of soil and overburden, is a process called soil creep. Heating and cooling of the soil growth of post Needles alternate drying and wetting of the soil, trampling and burrowing by animals, shaking by earth quakes all produce some disturbance o the soil and mantle. Because of the gravity exerts down, put down all this distributed particles, are urging them down slope to the base this is soil creep.

10.6.3 Earth flow :

In humid climate regions if slopes are steep, and the soil is saturated with water a over burden or weak bedrock may slide down slope during a period of few hours is called earth flows. An Earth flows may affect a few square yards, or it may cover an area of several acres. It the bedrock is rich in clay earth flow sometimes include millions of tons of bedrock, flowing like a great mass of thick mud A special variety of earth flowage characteristic of artic regions is called as solifluction (Latin word "soil" and to flow") That is in spring and summer soil gets saturated with water but it cannot flow down (landmass) wards because of underlying impermeable is a frozen mass (Pesma frost).

10.6.4 Mudflow :

A stream of fluid consistency which is pours down canyons in mountainous regions. I desert where vegetation does not protect the mountain soils, and purring heavy rain water runs down the slops it forms a thin mud, which flows down to the canyon floors. As it flows in its courses the mud continues to flow until it becomes so thickened that it must stop, even big boulders are carried along, mud flows also occur on slope of erupting volcanoes. The volcanic ash and dust is turned into mud by heavy rains and flows down slopes of the volcano. Down wards movements of a bed rock from a hill or mountain during rainy seasons is known as land slide. Similarly Rolling of single masses of rocks from a steep cliff is known as rock fall. Great masses of bedrocks sliding down wards from high cliff is known as –slump.

Therefore weathering and mass wasting aid in denudation of the Earth surface. The different Erosional agents act upon the earth's surface and they produce an orderly sequence of the land forms. The running water or river is the dominant processes modifying the earth surfaces.

10.7 LET US SUM UP

In this unit, you studied about the Exogenetic force and as well as Meaning of exogenetic forces, mass wasting, different types of weathering, physical, and chemical, weathering and also significance of weathering.

10.8 KEY WORDS

Endogenetic - : process that originate fro within the earth Exogenetic — : The external forces of denudation

Pliestocene - : The first of two epochs of the Quaternary, held conventionally to have lasted from approximately 2.0 Ma until the beginning of the Holocene about 10,000 years ago.

Oligocene - : The third of the five major worldwide divisions of the tertiary period extending from the end of the Eocene to the beginning of the Miocene.

Exfoliation -1 : A weathering process in which rock fakes off.

10.9 QUESTIONS FOR SELF STUDY

1) Discuss the exogenetic forces of the earth.

2) Discuss the different types of weathering

3) What is Mass wasting? Discuss the types of mass wasting

4) Write a short note on mechanical weathering.

5) Distinguish between Erosion and weathering. Show that the process of weathering in a coo humid region differ from those in a hot region.

10.10 FURTHER READING

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UNIT : 11 LAND FORMS BY AGENTS OF FLUVIAL AND GLACIER

Structure

11.0 OBJECTIVES

After going through this unit, you will able to

- Relate the River and Glaceir.
- Recognize the types of Glacier
- Analyze the Erosional features of the Fluvial and Glacial work
- Acquire the knowledge of depositional features of Fluvial and Glacial work

11.1 INTRODUCTION

The present unit describes the meaning of River (Fluvial) and Glacier and its types. This unit discusses the erosional work and its process and also related landforms. Depositional work, land forms by Fluvial and Glacial work of different stages.

Water flows in a more or less definite course, the mass of water is known as river. All types of river do erosion work. The gentler is the slope of the river course, the less is the erosional work.

11.2 ACTIVITIES OF A RIVER

11.2.1 Erosion

Removal of materials from its original place is called as erosion. Erosional work of a river depends upon the volume and velocity of water, nature of slope of land and the rocks structure in the channel.

Erosion increases with high volume of water. When the volume increases, the capacity to carry the materials also increases proportionately. Where the bedrock are soft or weak, the erosional work becomes predominant. Erosional activity consists of three actions,

(a) Hydraulic action

(b) Abrasion action

(c) Solution

11.2.1.1 Hydraulic action: The water of the stream lift the rock fragments and throws them onward.

11.2.1.2 Abrasion or corrosion: When the rock fragments strike against one another and wear them down the action is known as abrasion.

11.2.1.3 Solution: The flowing particles in the stream have also some soluble components. Some of them soluble components are dissolved in the flowing water.

11.2.2 Transportation :

River transport rock materials transported from one place to another this activity is known as transportation. Power of transportation depends on volume, velocity and size of the load. Transporting increases to the maximum extent at the time of flood. The materials in the river are transported in four ways.

11.2.2.1 By Traction: Weighted and large rock materials like gravel, pebbles etc., are by the flow of water to roll on the floor of the channel. Rolling, slipping and bumping are known as traction.

***11.2.2.2 By Saltation*:** Continuously the rocks are move onward by jumping, this type of transportation is called saltation.

11.2.2.3 By Suspension: In the stream weight of rock fragments is reduced by the buoyancy of water. The suspended rock particles such as clay silt. The amount of suspension in the rivers of dry areas is much more than that in humid areas.

11.2.2.4 By Solution: Stream water has dissolved rock fragments. The dissolved substances of the underground water also enter the stream water later on.

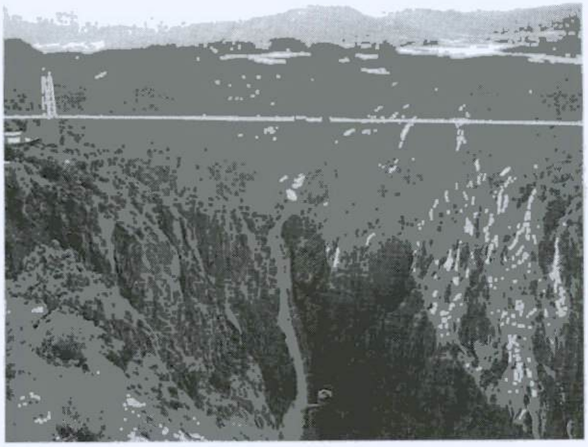
11.2.3 Deposition

There is a certain limit to the quantity of transported load. When the stream comes down to plain, its slope becomes gentle. This reduces the energy and the competence of the stream. As the competence decreases the rock fragments begin to settle down. This activity is known as "deposition". Deposition is both dependent upon slope and the amount of water.

11.3 LANDFORMS BY EROSIONAL WORK OF THE RIVER

Erosional work of river leads to the formation of specific landforms features such as Gorges, canyons, V-shaped valleys, pot holes, rapid and water falls.

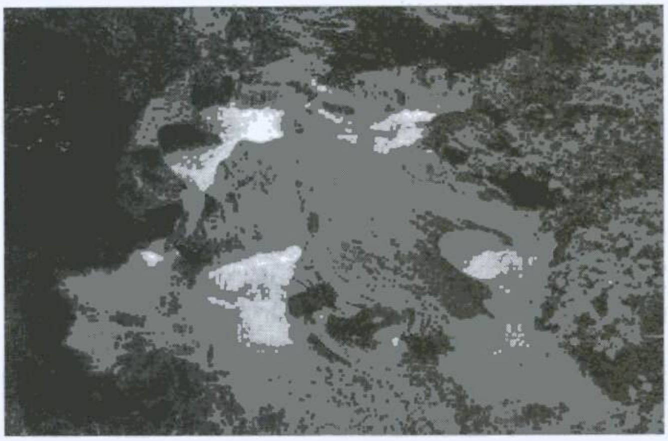
11.3.1 Gorges: Deep and narrow steep sided valleys due to the moving rivers. All the energy is spent mostly in vertical corrasion. In the Himalayas where rivers like the Sutlej, the Indus and the Brahmaputra have cut their way through the high mountain ranges



Gorge Canyon

11.3.2 Canyon: Extremely deep and wide valleys with sheep walk like sides, formed by vertical corrosion in the arid regions is called canyon. These are also formed where faults and fissures guide the course of the river.

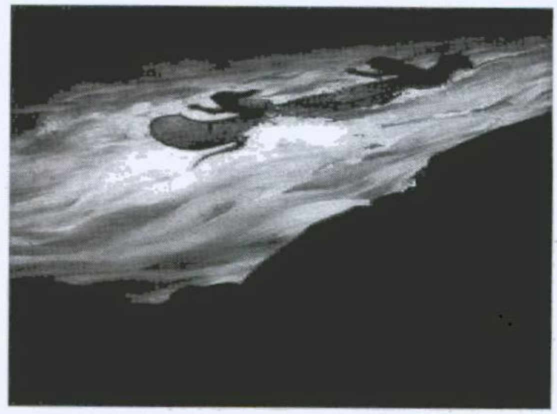
11.3.3 Pot holes: The circular motion of rock particles held in water produces hollows or depression. These are known as pot holes. It develops spirals and whirl pools at many places in its course. Since these whirlpools are equipped with rock fragments as cutting tools, they grind out nearly circular holes in the bedrock.



Pot Holes

11.3.4 'V' Shaped valley: 'V' shaped valleys are normally formed the upper course of a river. Weathering, slipping, mass movement and gully formation contribute to valley formation. Valley becomes wider at the top than at the bottom. Small 'V' shaped valleys are called as 'gully'. These are common features of the upper stage of a river.

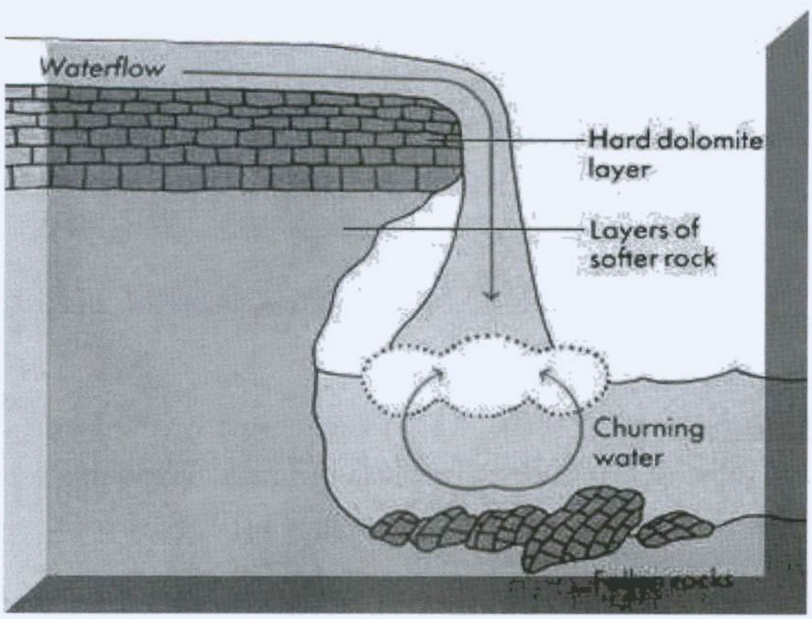
'V' Shaped valley



Rapid

11.3.5 Rapid: It is a stretch of a fast flowing river where there is a step slope in the river bed caused by a stratum of resistant rock that dips down stream. Rapids are common in the upper course of a river where alternate horizontal layers of hard and soft rocks.

11.3.6 Water Falls: The formation of waterfalls is a most characteristic feature in upper course of a river. The occurrence of the band of a hard-rock along the path of a river makes it jump over or fall downwards these are called was water falls. Niagara falls of North America (120 meters drop) and Victoria falls (50 meters) on Zambezi river, in South Africa are the examples. In our country Jog, or Gersoppa falls.



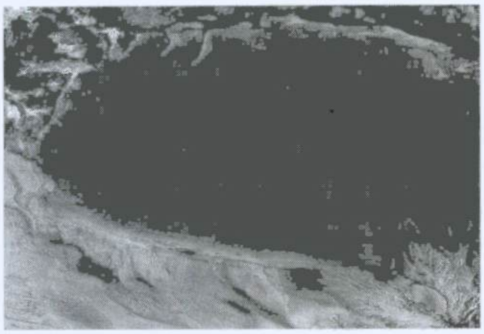
Water fall

11.4 DEPOSITIONAL FEATURES OF RIVER

Deposition is the characteristic process in both middle and lower course. It leads to the formation of flood plain. Alluvial fans and cones, natural levees, meanders, ox-bow lake and Deltas.

11.4.1 Flood Plain : The flood plain is the area of land which is flooded when a river overflows its banks. Particularly in times of flood, a river spreads a thin veneer of aluminum and builds a flood plain. This is an area of that land found on either side of a river. This usually becomes wider as the river near its mouth.

11.4.2 Alluvial Fans and Cones: Deposition takes place in the middle course where the velocity of the current is abruptly reduced for some reasons. Due to immediate change in gradient and where a narrow valley suddenly opens out into broad floor of the valley, alluvial fans and cones are formed.



11.4.3 Meanders

These are the bends in the river. Where the river flows in a plain it widens its valley instead of deepening it. Stream in plain nor composed of rocks of similar resistance. The stream therefore, cannot flow in a straight course. Many loop like bends and turns are common in the course of stream.

Meander

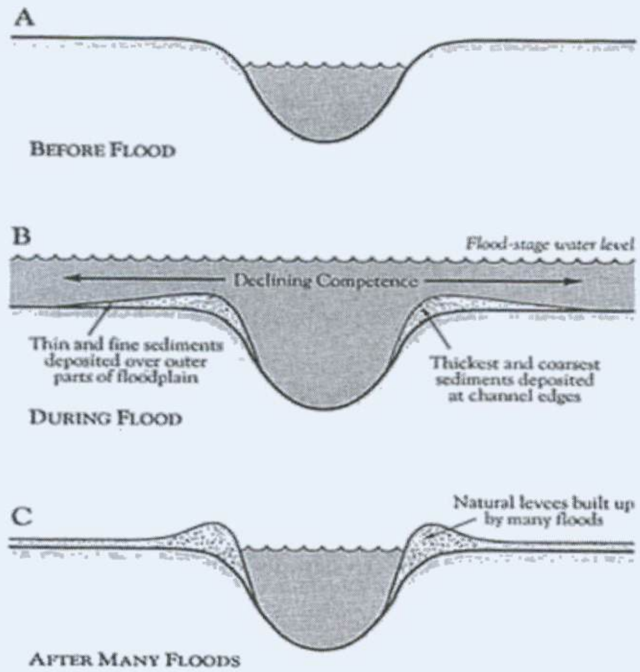
Ox-Bow Lake

11.4.4 Ox-bow lakes

The cut-off portion of the meander becomes a lake called an ox-bow lake or horse shoe lake. As the meanders swing wider and wider, high ends move closer together until they almost touch to each other. Large number of ox-bow lakes occurs on the flood plains of the Mississippi and the Ganga rivers.

11.4.5 Natural levees

These are mounds of aluminum piled up along the river's edge. These are formed by the river depositing the coursest part of pebbles, rock pieces and sand particles close to the river channel, when the river floods. Usually these formed by water flows the river bank its speed is greatly reduced. These are also built by people in an attempt to prevent the river flooding.



11.4.6 Deltas

Course material is deposited and leads to the building up of land form feature known as deltas. 'D' shaped sandy or muddy sediment built up into the open water where a river meets the sea or a lock. The speed of the river slowed down, and then deposition on its bed can lead to braiding taking place.

Delta can be divided into various types on the basis of its formation.

1. **Arcuate Delta:** Sand, gravels and other particles which the river deposits are loose. The distributaries of the river are not stationary but go on shifting across the sediment. The Nile delta is one of the ideal types where its pattern is similar to a rounded arcute.

1. **Bird's foot delta:** These distributaries appear extended like the foot of a bird. In these deltas, the sediments deposited is composed of those fine particle which are received from the lime stone rock, lime content water flows on the surface in the shape of some distributaries and their resembles like bird's foot.

Importance of Deltas

Deltas are economically very important. Deposition of aluminum in the delta every year, the deltas become very fertile. Agriculture is practiced very successfully. The deltas of the Nile, the Hwang Ho, the Ganga. The Sindh are intensely populated.

11.5 TYPES OF GLACIER

Ice like water moves and leaves behind a different land scape. It can be recognized in mountains and in high latitudes which were covered by glacier long ago. Where temperatures are below freezing point, precipitation falls as snow. Ice is a soft solid. If its height is 60 to 90 meters, the ice crystals beneath them get distored in shape and begin to flow out ward and down ward like a hard liquid. When the ice is so thick that it begins to flow, it is called Glacier. It was first of all in 1834 that a Swiss named Lious Agassiz proved the movement of ice in a glacier. Glaciers flow out from snow fields which are the large areas covered permanently under snow.

The lower area limit of the accumulating ice area is called snow line. The snowline. The snowline differs according to latitude, amount of snow fall, direction of the wind and the physical features of the region. There are many places where the average temperature is close to freezing point. As a result, most of the ice deposited in a year would have been lying unmelted.

The glaciers or ice masses of the world can be said to belong to two types.

(1) Mountain or valley glacier or Alpine glacier

(2) Continental glaciers

11.5.1 Mountain or valley glaciers:

The valley glaciers, also known as Alpine glaciers and flow like tongues of ice through the mountain valleys. These glaciers exist above the snowline. The glacier may range from 1 to 2 miles. The mountain glacier are ordinarily not very extensive, but certain mountain glaciers are so vast that they go on flowing for a distance of 50-60 miles and appear like rivers of ice. There are more than 1000 glaciers in U.S.A. alone. Gangotri is one of the most important glaciers of India.

11.5.2 Continental Glacier:

Continental glacier is also known as Ice sheet and it covering a vast area. It spreads like a sheet. In green land and Antarctica all the precipitation is in the form of snow. The result is that regions are covered by an extensive ice mass, a gigantic ice dome that hides beneath it all the surface irregularities irrespective of their height or depth. As an accurate knowledge about them is impossible, whatever we know is through inference. It is estimated that the thickness of the ice sheets of Greenland varies from 600 meters to 2000 meters, while the average thickness of the ice sheet of Antarctica is 1200 meters. The biggest continental ice sheet of the world is Antarctica which has an area of 13 million sq km with a maximum height of 4,267 meters.

Glacier performs the work of erosion, transportation and deposition like other agents of denudation.

In its course of movement, a glacier removes the lose rock debris (sediments) these materials are carried along with the Glacier which is known as Erosion. A glacier performs erosional work in mainly three ways.

(a) Abrassion

(b) Plucking

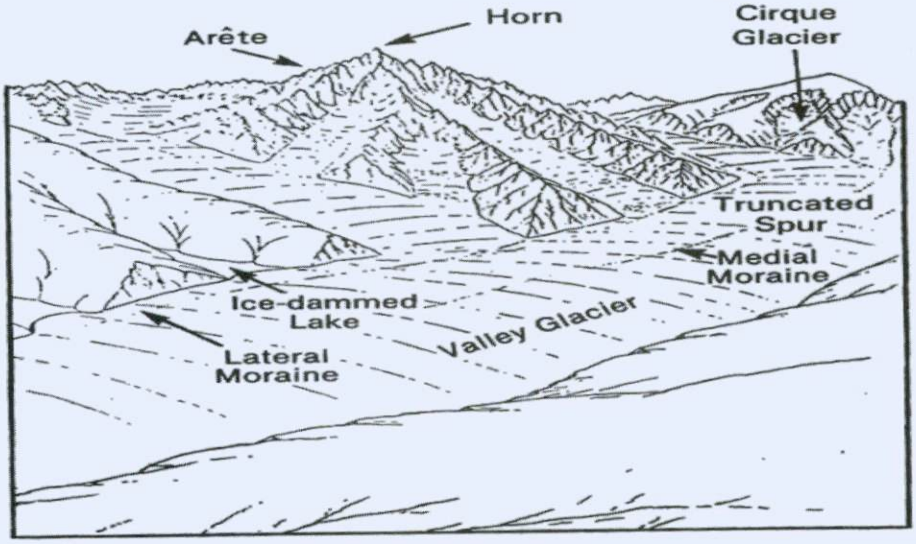
(c) Frost wedging activities.

11.6 LAND FORMED BY GLACIER EROSION

Various land forms are produced by glacial action and formed from the plucking nature of the Glacier.

11.6.1 Cirque

It is a semi circular or amphitheater shaped feature. This land form called by various names Cirque in France, Corrie in Scotland, Combe in Chamberland. It is a common feature found at the head of a glaciated valley. It is open at one end, has a flat bottom and very steep rocky slopes on three sides. It is separated from the main valley down its open end by a slightly higher ground.



11.6.2 Horns or Peaks

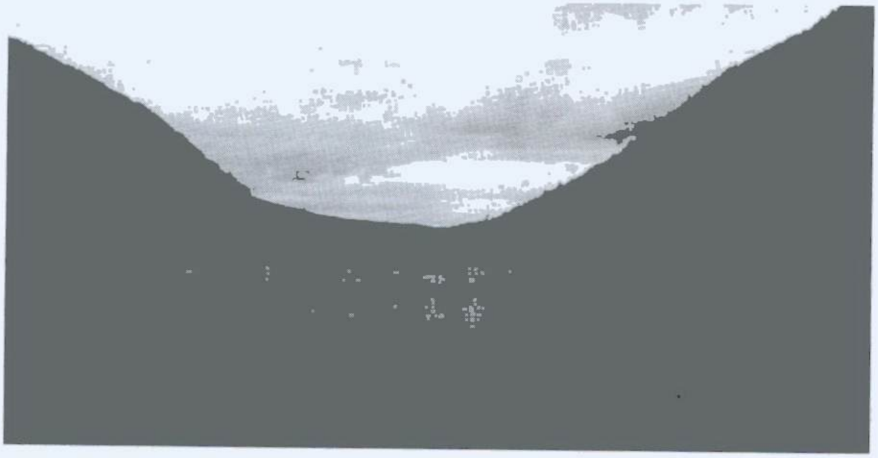
Horn is a peaked or pointed feature resulting from the formulation of a series of closely related cirques. When three and above cirques cut in to the sides of summit and meet one another on their backs. Matter Horn in Alps is famous in the world.

11.6.3 Arete

Arete is a jagged saw-tooth ridge formed between 2 adjacent glacial lobes moving to lower elevations. As a result, the summit line becomes serrated and thin like a knife. It is known as steep sided ridge.

11.6.4 'U' Shaped Valley:

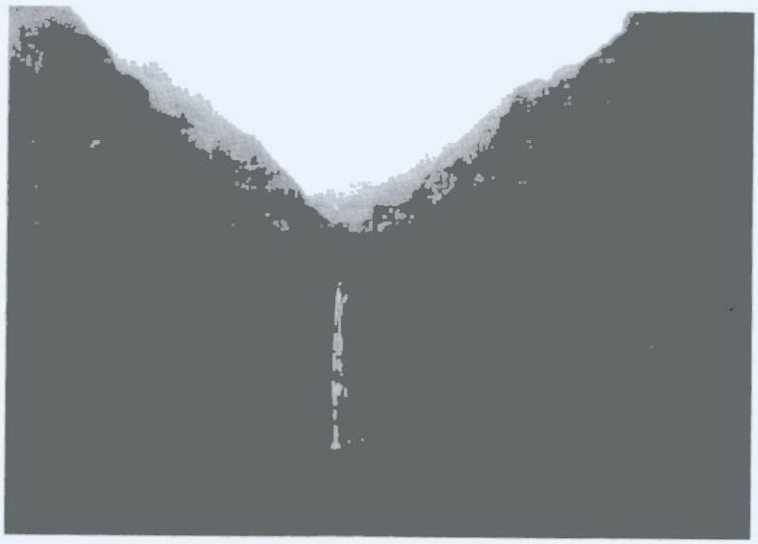
This is the shape of the valley curved by glacier and best seen in the front profile view. Glacier by them cannot excavate a new valley. They can only modify and widen a pre-existing V-shaped river valley to a U-shaped glacial valley. U-shaped **valley appears to be** quite large for the small stream that now flows in it.



'U' Shaped Valley

11.6.5 Hanging Valley:

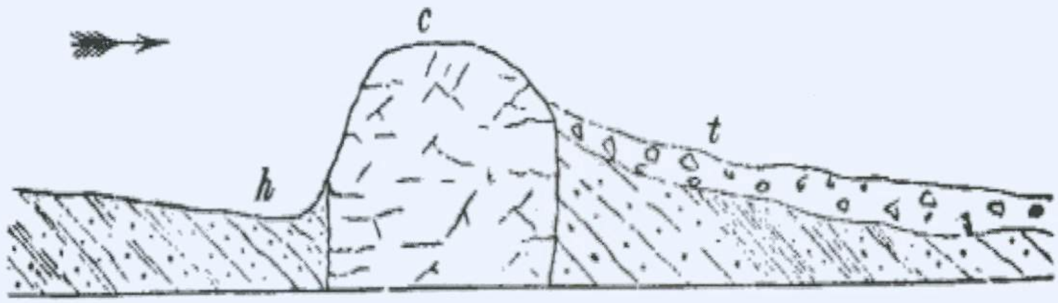
Hanging valley is a glacial valley formed from a tributary glacial lobe and appears over hanging the main glacial valley. The main glacier with greater amount of ice is able to erode deeper than the smaller tributary glacier due to differential erosion



Hanging Valley

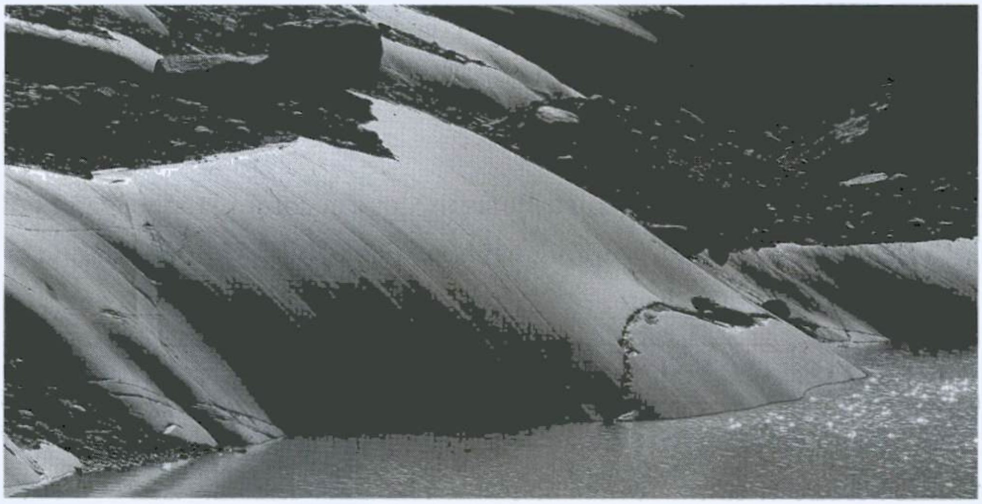
11.6.6 Crag and Tail:

It is a landform of glacial origin, which consists of a rocky slope on one side (crag) and a relatively gentle slope trailing away it its lee (tail). The soft strata on the descending side are protected by ice and therefore the descending side is gentle in slope. It appears as if the neck of basalt (crag) has a long tail attached to it. This shape is called Crag and Tail.



11.6.7 Roche Mountonnes (Sheep Rocks)

There are many swells of hard rocks in the course of a glacier. A glacier does not avoid hard out crops like cliffs tailing along its path. It rides or flows over them in a manner that the slope of the obstacle from the side the ice moved becomes gentler, while the other side where the ice flowed down is left rougher and steeper. These knolls having a crag and the tail look like sheep from a distance.



Roche Mountonnes

11.6.8 Rock-Steps:

In some areas, rock steps clearly occur below narrow valley sections. Longitudinal profile of a glacial valley reveals a series of rocks steps partly due to unequal eroding power of the ice and partly to the degree of resistance of erosion of the valley floor. Rock steps commonly occur when a tributary glacier join the main glacier to erode vigorously by extra mass of ice.

Rock Steps

11.7 TRANSPORTATION

Glacier are able to transporting huge quantity of materials such as boulders and angular fragments of various size on the surface, frozen into the ice and at the bottom.

There are two basic differences between the transportation done by rivers and glaciers.

(a) The load carried by glacier can be deposited either on the side or on the ice surface. It is not possible in a river.

(b) Ordinary running water distributes the load according to the weight of its fragments. A glacier carries all sorts of fragments small and big. The pebbles and other fragments are not stratified in a glacier.

11.8 DEPOSITIONAL WORK OF GLACIER

All glacial deposits are called "glacial drift" and are comprised of two types. Non stratified drift called "till" which non sorted meaning is comprised of many different particles sizes. It is found in its natural conditions, i.e., as it is freed by glacier or glacial stream. It contains small and big, striated pebbles, rock flour, particles of quartz and feldspar, etc., Till also known as boulders clay.

Stratified drift called "out wash" which is sorted meaning comprised of essentially the same size particle which results in stratification. A large part of till which is brought by glacier is spread by glacial streams near the glaciers. The pebbles and stones are graded according to their sizes.

11.8.1 Moraines:

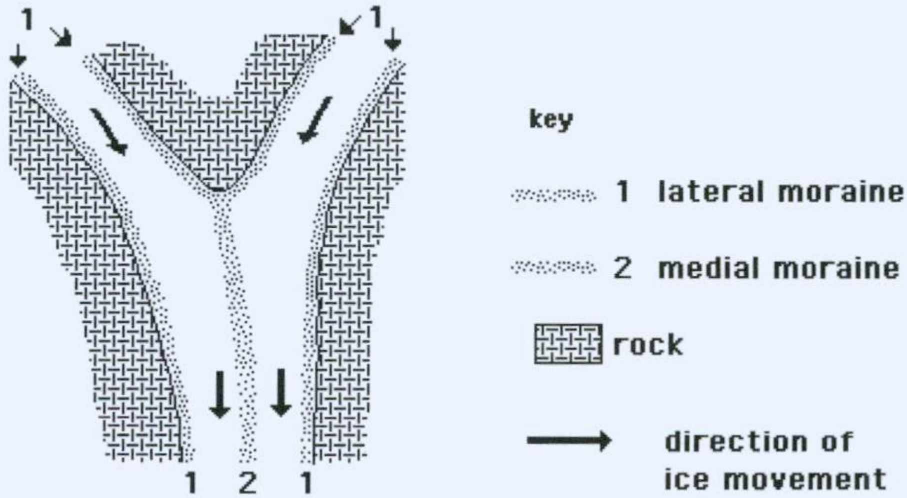
The materials removed from the mountain slopes is transported and deposited by glacier which is known as drift, while the accumulation of this drift in a large mass is known as "morain". Moraines are sufficiently long and their height is usually 30 meters.

Moraines may be said to be of various types, according to the place where they have been laid or deposited. For example, when the river cannot carry its load, the latter accumulates over the surface.

The following six types of moraines are especially worthy of attention.

11.8.1.1 Lateral Moraines:

*Lateral moraines form along the sides of an ice stream chiefly from materials which are contributed from the valley sides ab*ove the glacier by weathering, snowslides, avalanches and other types of mass movement. Moraines ridges are several hundred feet high and are formed due to the slow speed of the glacier as well as due to the dissipation of ice on the sides. These lateral moraines are in a single file and the rock material in them lacks consolidation.



11.8.1.2 Recessional Moraines:

The succession of terminal moraines is called recessional moraines. Recessional moraine a deposit shaped similar to the end moraine formed when there are periodic advances by the glacier during the overall retreat or demise of the glacier. Every moraine signifies that the glacier was stationary there for some time.

11.8.1.3 Medial Moraines:

Combined moraines are called as medial moraines. These formed when glacial lobes and lateral moraines merge. These are in the form of long narrow ridges arranged in the direction of the flow or the slope.

11.8.1.4 Terminal Moraines:

These are concentric ridges of an assorted rock material dropped by the ice as it melted and these are made of rock fragments. The terminal moraines are also known as marginal moraines because they widely varying in size and the shape. The height of the terminal moraine depends upon the stability of the glacier.

Terminal Moraine

11.8.1.5 Ablation Moraines:

Ablation moraines are those fragments of rock that are being transported on the surface of the glacier. These are trains of rock material either parallel to the direction of ice flow or parallel to eh margins.

11.8.1.6 Ground moraines:

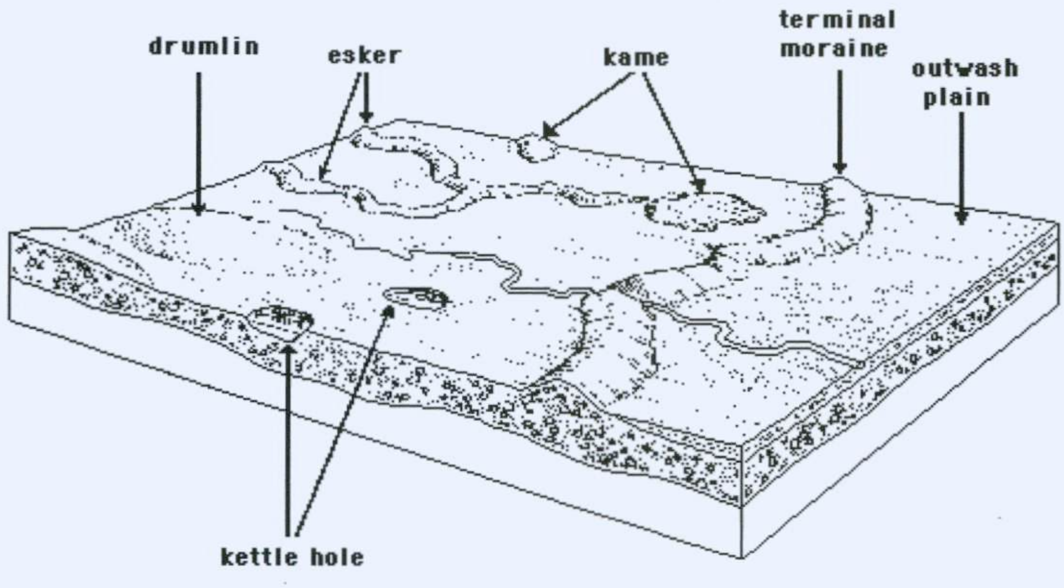
An undulating massive blanket like deposit formed where the ice mass was present. Generally found strewn (scattered) on the valley floor oater the glacier has dissipated. The nature of the ground moraine or boulder clay depends upon the nature of the rocks over which the glacier has passed. If the glacier has passed over weak rocks, the ground moraine will be deeper but in case it has passed over hard rocks, the ground moraine will be shallow.

11.8.2 Drumlines:

A streamlined symmetric inverted spoon head shaped hill whose steep side faces the direction from which the glacier advanced. Its long axis is parallel to the direction of the ice movement. Composed of boulder clay, this drumline range in size from mere, swelling of a few feet in height to hills, 200 to 300 feet high. Usually they are found in groups-radially arranged just behind the marginal moraines. Where drumlins occur, the topography resembles "eggs in a basket".

11.8.3 Esker:

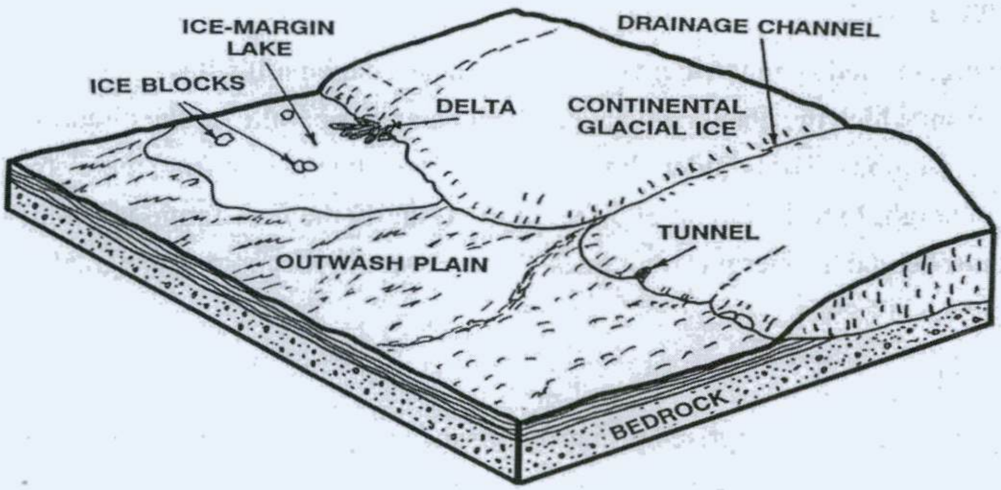
A winding ridge comprised primarily of sand and gravel layers deposited by a stream flowing in a tunnel beneath a glacier near its terminus. These Eskers, also known by the name of Osar in Scandinasia, are so narrow that they are never wides than a few feet and their height is also not much – never more than a few then of feet. Sometimes the eskers are found ascending a slope and at another, they may be found descending the valley.



11.8.4 Outwash Plain:

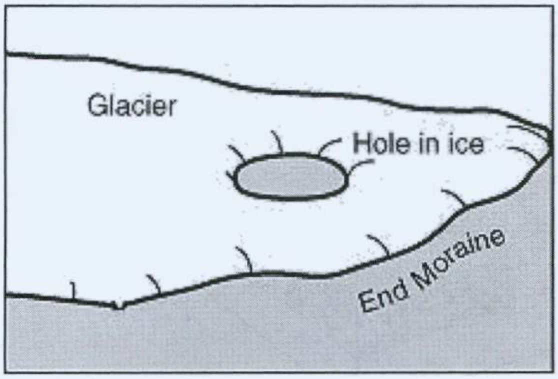
A relatively flat massive blanket like deposit consisting of layered materials deposited by melt water in front and on the sides of the margin of the ice sheet.

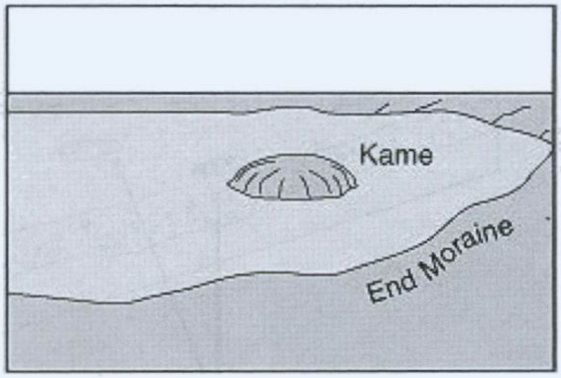
The plain area which is composed of material washed out beyond the terminal moraine is called an outwash plain. If the outwash in a valley is partially filled it is called a valley train.



11.8.5 Kame:

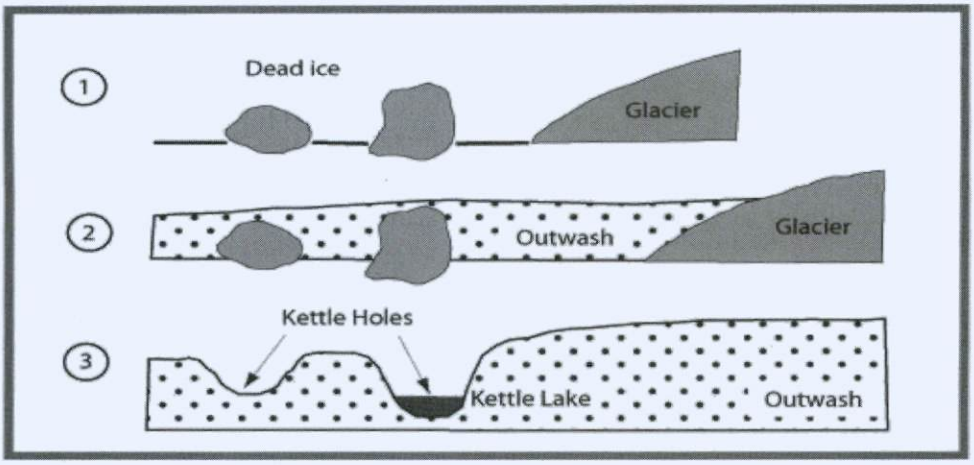
Kames are the undulating mounds of bedded sands and gravel deposited unevenly from melt-water along the ice-front. Kame is the term applied to a number of ridges and mounds but they are not terminal moraines. Kames are found widely on the formerly glaciated low lands of North America and north-west Europe.





11.8.6 Kettle Hole and Kettle Lake:

When the glacier melts, the pebbles and fragments subside and form a depression. These depressions are called kettle holes. A number of kettle holes are found in the prairies of North America.



11.9 LET US SUM UP

In the present unit, you learnt about the meaning of the River and Glacier as well as types of Glacier. This unit hve helped the students to understand more about fluvial and Glacial work. Learner extends his knowledge Erosional and Depositional features of Fluvial and Glacier work in different stages.

11.10 KEYWORDS

Traction : Process of moving particles along the bed of a stream

Meander : Bend in the course of a stream, developed through lateral shifting of its course. Toward the convex side of the bend.

Arcuate : A deltas with a rounded arcuate,

Glacier : Moving Ice

Plucking : The process involves the freezing of sub glacial melt water that steps into fractures and bedding planes in the rock

11.11 QUESTIONS FOR SELF STUDY

1) Explain systematically the work of river as an agent of gradation at each of the three stages of its course.
2) How water falls are caused? Why a gorge appears along the base of a waterfall.
3) Draw a list of landforms by erosional work.
4) Illustrate the landforms by depositional work

5) Explain how morning ice removes the topography and creates entirely new land scape in its place

6) Briefly describe the land forms associated with glaciated topography.

7) Compare and contrast the work of glacier as an agent of erosion, transportation and deposition.

11.10 FURTHER READING

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UNIT : 12 EOLIAN AND KARST AGENTS AND THEIR RESULTANT LANDFORMS

Structure

12.0 OBJECTIVES

At the end of the unit you should be able to

(i) Identify the Eolian (wind) and Karst (lime stone region.)

(ii) Realize the work of wind in Desert Region and Karst topography in lime Stone region.

(iii) Interpret the Erosional feature of Ekolian and Karst.

(iv) Analyze the depositional features of eolian and karst.

12.1 INTRODUCTION

The present unit describes the Eolian and Karst topography. You will study the Erosional and depositional features of Eolian and underground water (karst) wilth illustratios.

Eolian landforms are found in regions of the earth where erosion and deposition by wind are the dominant geomorphic forces shaping the face of the landscape. Region influenced by wind include most of the dry climates of the earth.

12.2 WIND EROSION

The quantity and the size of the loose material lifted and carried by the wind depends upon the speed and force of the wind. If the wind is slow, it can only carry very minute particles of sand and dust. The erosion by the wind is at its interest somewhere above, its effects are retarded. Therefore, the tenderness of the wind is neither to cut downwards nor to cut sideways.

Wind erosion is performed by three processes bye deflation, abrasion and attrition.

12.2.1 Deflation

The particles which are loosened on the rocks due to weathering are blown away by winds. The action is known as deflation. The combined works are lifting of loose weathered rock particles consisting of sand, silt and dust and their transportation by wind. Depressions of different sizes are formed due to deflation. This action is more intense where the earth's surface is deprived of its vegetation cover.

12.2.2 Abrasion

The sand and quartz grain particles present in the air float in the atmosphere. When the winds blow of great capability these particles act as tools of the wind and wear down the rocks by scrapping, rubbing, undercutting, scouring, grooving, etc., Wind action depends upon the speed of the wind and the number of particles present in the air. These particles i.e., the tools of the wind wear down the rocks as if a sand paper is used by the wind.

12.2.3 Attrition

Where the dust and sand particles are in air, friction and strike against one another and get smaller and rounded by friction. This process is called attrition.

12.3 EROSIONAL FEATURES OF WIND

12.3.1 Deflation Hallow

Various depressions are formed by the action deflation of wind. This depression is known as deflation hallow. Most of them have a diameter less than 1.5 km and depth of a few meters. More number of depressions are usually visible in an area ranging from Canada to 50 km in North America. Due to the depressions the Quattara in western Egypt has be so much lowered that it now lies 128 meters below sea level.

Deflation Hallow

12.3.2 Dreikanter

The stones which lie in a certain position and are subjected to abrasion action by wind blowing in one direction, develop single edged shape or also three edged shape. These stone pieces are known as Einkanter. Due to abrasion, their shape resembles a tetrahedron. Sometimes, they are also called ventifacts.

12.3.3 Inselberg

Inselberg is a German word. It means island mountain i.e., inselbergs look like islands situated in seas. Mountain top is raise suddenly from the plain surface of the desert. Inselberg are also known as Bornhardt after the scientist who explained its origin.

Inselberg

12.3.4 Grooves

The sand particles in wind produce groves on rocks. If the direction of the wind changes slowly, the rocks develop grooves which are usually parallel to one another.

12.3.5 Mushroom Rocks

When the wind blows, the heavier sand particles roll down the land but the lighter particles blow above the ground. Hence the top part of the rocks is eroded less than lower part. Due to more erosion of lower part, the rocks assume the form of mushroom. These rocks are also known as Gara in Sahara and pitzfelson in Germany.

Mushroom Rock

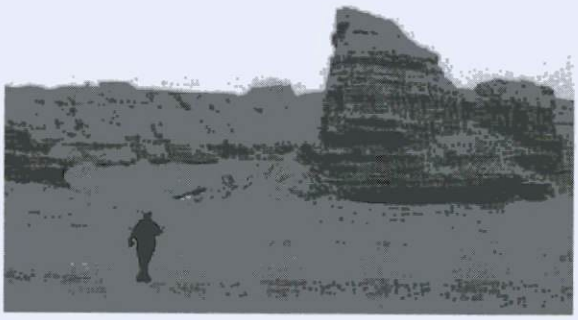
Zeugen

12.3.6 Zeugen

Where hard horizontal stratum lies above a soft one wind abrasion produces tabular masses called Zeugen which are completely undercut

12.3.7 Yardang

Very strange and fantastic forms appear in Mongolia due to the wind erosion of hard and soft rocks. They are known as Yardangs.



Yardang

Hammada

12.3.8 Hammada

Sometimes, the sand blown by winds in Sahara exposes the floor of hard rocks. When such floor develop a lot, they are known as hammadas.

12.4 DEPOSITIONAL WORK OF THE WIND

Deflation may be considered to be the dominant process of the wind after the erosional work in the desert has reached maturity. As the wind slows down, suspended particles drop down as the wind can no longer support them. The process is knows as deposition.

The sand deposit gives rise to many types of land forms. Some of the important landforms of deposition have been described.

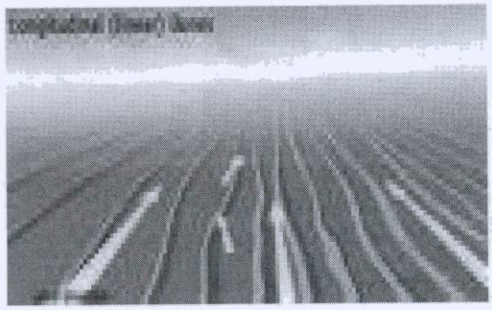
12.4.1 Sand dunes

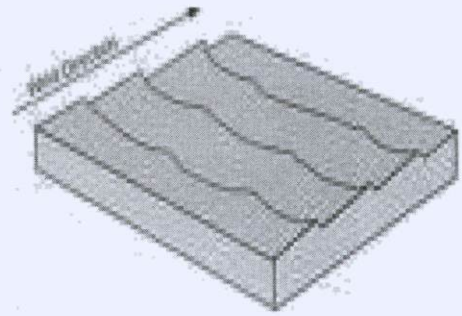
Deposition takes place in the form mounds. These mounds are called as sand dunes. Sand dunes are formed usually in these places where loose sand is amply available and the direction of wind remains almost uncharged. Many types of sand dunes and they form depends upon availability of sand, surface shape, wind direction and the presence of vegetation etc.,

Sand dunes can be classified into longitudinal dunes, transverse dunes, star sand dunes, Barkhan, parabolic dunes 'U'shaped dunes etc.,

12.4.2 Longitudinal Dunes

These are formed parallel to the direction of wind. These are formed where wind blows with high speed and maximum availability of sand. These dunes height between 24 to 100 feet's of height and about 160 k m broad. These dunes extend over 604 million km of land.





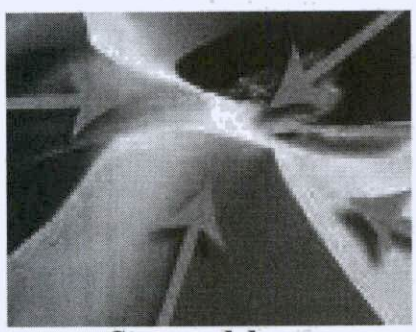
Longitudinal Dunes

12.4.3 Transverse Dunes

These are formed by winds of normal speed and extend transversely to the direction of wind. The sides of slope of these dunes are unequal. The leeward slope is steep than the windward side. Normally these dunes are formed at right angel to the direction of wind.

12.4.4 Star sand dunes

These are also called as pyramids sand dunes. It is a hill of sand whose base has a star like ends. These are grown vertically but do not migrate along the ground.



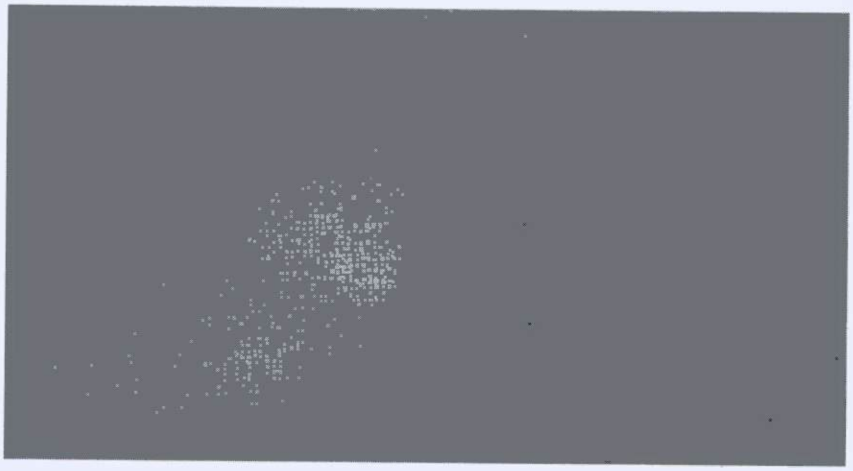
Star sand dunes

12.4.5 Loess Deposits

Loess is a major deposit created by wind. Loess is found over large areas of the earth. It is also important for humans because it creates very fertile soils. Loess is mainly composed of silt. Its colour is yellow due to a little oxidation.

12.4.6 Playa lake :

After the rain the rain water often gather into a small lake of muddy water. In course of time, the water evaporates leaving behind an extra ordinarily flat clay surface. This is known as playa



Playa Lake

12.5 KARST TOPOGRAPHY

The main source of water on this earth is the rainfall. As the rain falls a portion of it is evaporated into the atmosphere and some of it runs off. A portion of it is soaked by the earth and this is called Underground Water Sometimes the underground comes out on the surface in the form of springs. Water from springs has been an important source of drinking water from times immortal. The groundwater is also important from the point of view of landscape evolution, especially in areas of lime stock rocks.

12.5.1 Work of Underground Water

The Role of underground water in the formation and evolution of landforms is rather limited but at the same time it is exceedingly important in the areas of limestone rocks where it give rise to distinctive landforms. Like running water, underground water erodes, transports as well as deposits, but in reality the work of erosion is by far the most significant. Erosion includes four different activities: corrosion, attrition, solution and hydraulic action. While corrosion, attrition and hydraulic action are important process in the case of running waters solution by far the most important process in the case of underground water where the underground water passes through well-jointed rocks, it separates the loose fragments by solution and carries them with itself. But ordinarily the movement of underground water is so slow that it is not able to perform any erosion merely by hydraulic action.

12.5.2 Solution:

Pure water is not a good solvent, but it becomes an active solvent when it comes in contact with carbon dioxide gas. Since the underground water is largely derived from rain, it receives carbon dioxide in adequate quantities from the atmosphere, so that it becomes an active solvent.

When the rainwater percolates into the rocks, it dissolves some of the rock particles by solution. Of the soluble rocks, the most notable are limestone and chalk. Solution activity by underground water is, therefore, most evident and significant in those areas where these rocks are found.

The principle element of limestone and chalk is calcium carbonate which is easily soluble in rainwater which always contains atmospheric carbon dioxide. Therefore, when percolating water passes through limestone and chalk, some portion of the rock get dissolved by solution and are transported along with the water. In this way small holes are formed on the upper surface. Water naturally moves down through these holes, cracks and joints. The cracks and joints slowly become bigger as a result of solution and thus provide even easier passage for the downward movement of water. After some time the water collects in the passage and starts flowing in the form of an underground river. In course of time solution by underground water is able to produce distinctive landforms both on the surface and in the underground in limestone areas. Thus erosion by underground water is performed mostly through solution.

12.5.3 Transportational work :

The Transportational work of underground water is not very important. The underground water moves very slowly. Thus, when rocks are eroded even the small rock particles start settling down. Only the finest and the lightest particles are transported. Some small rock fragments also roll down with the water, but the speed and the extent of such movement are insignificant.

The transportation types of underground water. When surface rocks are loosened as a result of disintegration and decomposition by weathering, underground water may act as a lubricant for the mass movement of the rock waste down a hill slope. This kind of movement generated by underground water is called translocation of rock waste, and may cause landslides along the slopes of mountains.

12.5.4 Depositional Work:

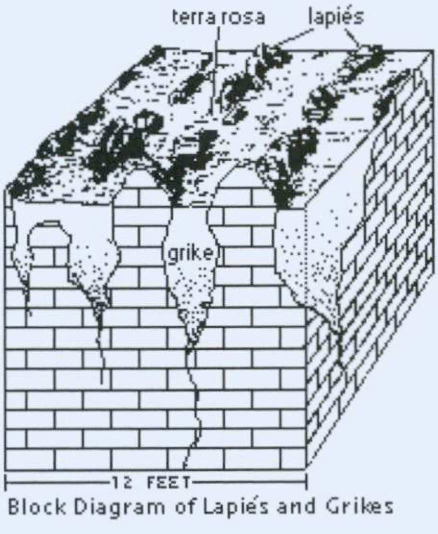
As a result of solution minerals mix with the underground water. When the underground water becomes thick with such debris, then the excess materials start getting deposited. As the movement of underground water is slow, the bigger fragments start settling down as soon as they are broken. The finer materials in the solution also start settling down after sometime. These happens particularly when the speed of movement suddenly declines due to some obstruction or when increase in temperature results in partial evaporation of water or decrease in temperature reduces the soluble capacity of the water, or for some reason there is decrease in the amount of carbon dioxide available. Deposition by underground water is done mostly in the underground caverns, resulting in the formation of such features as stalactites, stalastits and columns and pillars.

12.6 LANDFORMS OF KARST REGIONS

In limestone regions various distinctive landforms develop mainly by solution which are not found in other areas. Some of the more important landforms are described below.

12.6.1 Terra Rosa

When rainwater dissolves part of surface rock and enters the sub-surface, particles of red clay soil are deposited on the surface as well as in the opened joints. This is called terra rosa, and very much resembles later tic soil. It may not be present on steep slopes but can be seen in areas which are either flat or have gentle slope. Sometimes it may be several feet thick and entirely cover the rocky surface.



Block Diagram of Lapiés and Grikes

12.6.2 Lapies

Where the limestone surface is not covered with terra rosa, and the surface is undulating, solution action of water tends to enlarge the rock joints downwards. This results in the formation of a very rough topography where the surface is cut into narrow and deep clefts between thin and needle like pinnacles. The sharp pin-like vertical pinnacles are roughly parallel to one another, and between them are found narrow and deep trenches which are known respectively as clints and grykes in England. For this kind of serrated landscape, the French work lapies is used at the international level. In Germany this kind of landform is called Karren. On account of the existence of lapies, the surface becomes so rough and intractable that it is impossible to walk on such a surface. Lapies, however provides an excellent illustration of how the solubility of rocks, their permeability, joints, bedding planes and other physical and chemical attributes produce differences in the rate and localization of solution. Some scholars hold the view that lapies are not formed on rocks with horizontal stratification and it is essential to have some kind of sloping surface for their formation. Examples of lapis are around in the Dalmation Karst region.

12.6.3 Sinkholes and Associated Features.

When rain water percolates into limestone, it enters the rock joints and remove the soluble elements by solution. The joints increase in size by solution and provide even easier passage for the water. Thus prolonged solution results in the formation of holes along the joints which are known as sinkholes. Topographically, a sinkhole is a depression, mostly commonly ranging in depth from 10 to 30 ft, and in area from a few sq yards to several acres. These small holes are found in large numbers in the Karst regions where sinkhole terrain is quite common. They are usually funnel-shaped with rounded and open tops, though many variations of form are found. Similar dry holes are met with in the chalk areas of Britain which are cylindrical and are called "shallow holes" as these surface openings almost completely swallow the surface drainage during the rains.

Depending on their mode of formation, sink-holes are divided into tow types – one which have been formed entirely by solution and the other which have been formed by slumping. In fact, this distinction is not sharp and clear-cut even where the sinkholes have been primarily formed by slumping of the ground, there is usually the formation of sub-surface hole by solution into which the upper cover of rocks falls down by breaking or slumping. Sinkholes formed in this fashion are called collapse sinkholes, and their walls are usually steep and rocky. Funnel-shaped sinkholes formed by solution tend to be enlarged downwards because of the repeated action of solution. In the Karst region of Yugoslavia, these enlarge funnel-shaped sinkholes are called Dolines. Here they are usually 6 to 7 feet deep and have a diameter of 30 to 400 ft. Very often the bottom of the doline is closed as a result of the fall of debris from above so that water only percolates slowly instead of flowing down swiftly. As a result water may accumulated in the doline and form small lakes called Karst lakes or Sinkhole ponds depending upon their size. These lakes are temporary and when the debris blocking the passage way are removed, the water of the lake sinks below and the lakes dry up. In this way innumerable small seasonal lakes come into existence during the rainy season when all the rainwater is not able to flow down the dolines and collects in them. Vertical or inclined shafts leading from the sink-holes or dolines to the underground caves are known as ponor.

Dolines or sinkholes that develop slowly downwards by solution without physical disturbance of the rock, as well as collapse sinks resulting from collapse of the roof cover into an underground solution void, may be considered the most primary and fundamental feature of a karst terrain. The water which enters the dolines, goes underground by percolation and down-flow, and eventually takes the form of an under-ground stream. Where the land separating two adjacent dolines collapse, a portion of the under ground stream may become unroofed and the stream can be seen from the surface flowing out of a cavern on the side, across an open space into another cavern on the other side. Such an opening through which the course of the underground stream is visible, is called a Karst window. The opening may be very small or quite large. Some Karst windows may become so enlarged that the stream flows as a surface stream for some distance across alleviated floors. In a region where there are many dolines or sinkholes, they frequently expand in diameter and coalesce and form compound sinkholes or compound swallow holes. They usually consists of a large solutional depression, with the collapsed roof and walls of several dolines merged into them. These large depressions or compound sinkholes are also called Uvalas. An Uvala may have a diameter of upto one km. There is, however, some confusion in the use of this term, and sometimes the term Uvala has also been sued in the sense of a large depression resulting from the roof collapse over underground water courses i.e., in the sense of large karst window, but the former is probably the most correct and accepted usage. The development of karst windows and uvalas represents a significant stage in the evolution of karst landscape.

Depressions even large in size than uvala which owe their origin to solution of down-faulting or down-folded limestone blocks have been called Polje. It resembles an uvala in appearance, but differs in extent and origin. The area of a polije may cover several sq kms. The largest polje in Yugoslavia in the western Balkans is the Livno Polje which is 70 kms long and 5 to 11 kms wide. A typical polje is an alongated basin with a flat floor and steep sides. It is believed that it has been formed by the solution of down-faulted or down-folded limestone blocks and is thus a structure controlled solutional form. In Yugoslavia poljes are given extensively to maize cultivation on account of the flat surface and easy availability of water.

12.6.4 Other Karst Features

In limestone regions containing horizontal or gently dipping strata solution by rain water results in the development of a plain riddled with thousands of sinkholes through which this water sinks and is conveyed through underground routes. These sinkholes are so effective in collecting the surface run-off that hardly any surface stream exists, and almost the entire drainage is underground. It is only the larger streams which rise in the highlands beyond the plain and have cut deep valleys that are able to flow through the plain. The smaller streams lose their water in one or more sinkholes and are thus called sinking creeks and the point at which water sinks below is called its sink. The sinking creeks may flow as underground streams for some distance before again appearing as surface streams. For example, the Lost river in southern Indiana, USA, flows underground for 13 kms before it again starts flowing on the surface.

The little used portion of the valley beyond the point where the streams sink into the sinkhole, generally remains dry and is called the dry river bed. During heavy rainfall when the sink or swallow holes and the connecting underground passages are unable to accommodate all the water, that the streams may temporarily flow for a short period in their dry beds, otherwise they remain dry for most of the year. Where the stream terminates in a sinkhole and this situation continues for a longtime, the stream carves out a fairly deep valley below the level of the karst plain. Under such conditions the river valley ends at the sink or swallow hole and is called a blind valley.

A special kind of blind valley different from the onde described above, is also found in that karst regions and is known as karst valley or solution valley. In areas where the upper layer is composed of sand or shale and is underlain by a limestone layer, the surface streams developed on upper layer may in course of time cut down deep enough and start flowing on the limestone bed. In such a situation sand stone ridges may be found on both sides of the valley, but the river flows in a deeply entrenched valley on the limestone floor. Here on account of the presence of limestone, the river develops the tendency to sink underground and abandon the surface routes in favour of undergound ones. Similarly, the tributary streams which rise from the neighboring sandstone and shale hills, tend to disappear in sinkholes in the principal limestone valley. In course of time the main river may go completely underground and sinkholes and other karst features may be found on the valley surface. Thus, "a solution or karst valley represents a transitional stage between surface drainage and underground drainage". (Thornbury, 1969). This type of valleys can be seen in parts of Indiana and Kentucky, USA.

In limestone areas, after a long period of solutional erosion, some residual hills and hillocks remain resembles monadonorocks and bornhardts. These rounded limestone hills rise from the Polje surface. They are known as hums in the karst region of Yugoslavia. They are known as pepinohills or haystock hills in Puerto Rico and as Mogotes in Cuba. They are, however, not usually found in the karst region of the USA.

In recent years the development of karst topography in hot and wet regions has been studied in some detail. These studies which have been particularly conducted in Jamaica, Puerto Rico, Java and south China, show that the tropical Karst possesses some features which are not in the karst of temperate climates. Because of the higher incidence of rainfall in these hot regions, the sinkholes or dolines are less circular and more irregular in form Tropical karst has been divided into 2 types:-

a) Kegal Karst or Cone Karst and

b) Tower Karst or Turn Karst.

In Kegal Karst there are found several cone like hill features interspersed with irregular depressions known as cockpits. These landforms are found in Jamaica, East-Indies and other parts. In Tower Karst, groups of steep-sided hills are found and each hill or group of hills is surrounded by alluvial plain. Tower karst or pinnacle karst abound in Puerto Rico and south China.

Our knowledge about tropical karst and its development is still very inadequate. This much however can be said that in these hot and wet regions both solution and evaporation are fast resulting in extensive development of stalactites and stalagmites in the underground caverns.

12.7 UNDERGROUND STREAMS AND CAVERNS

Underground streams and caverns are distinctive features of limestones regions. The caverns or cave is subterranean hollow, formed essentially by the solutional and erosional activity of underground water. It is not however, necessary for a stream to be present in all caverns. Caverns with tow or more levels are referred to as galleried cavern. The influence of joint systems is clearly marked on the cavern pattern and both their horizontal and vertical extensions are largely controlled by joints and bedding planes which have been enlarged by selective solution by water moving along them.

As the sinking creeks to underground they flow horizontally along the joints and bedding planes or sometimes fall vertically down as waterfall. By prolonged solution their underground course becomes so wide that a series of underground caverns are formed which are interconnected by narrow pathways and extend for several miles. At places water may collect and form underground ponds. Thus in course of time under the surface there to be develop an extensive labyrinth of cavern, interconnecting galleries, rivers, waterfalls and lakes.

Besides solutional features, a variety of depositional features are formed on the floor, ceiling and walls of the caverns which greatly add to their beauty and interest. Cave travertine is a term which is collectively used for these diverse depositional forms. When the underground water drips from the cavern ceiling, it contains carbonate of lime. When the droplets of water are hanging by the ceiling, some water is evaporated and portion of the carbonate of lime is deposited on the ceiling. This process is repeated with every fresh droplets of water, and the deposit of lime goes on extending from the ceiling downward. In course of time this results in the formation of a long and thin column of carbonate of lime hanging downward from the ceiling. These are known as stalactites. They are wide along the ceiling and tapering downwards. The drops of water which fall from the ceiling down to the floor of the cavern also contain carbonate of lime and with every drop of water falling on the floor there is some deposit of carbonate of lime. Thus from the cavern floor also rises a pillar-like columns which is known as stalagmites. Stalagmites are usually broader but shorter in length than stalactites. Since the drops of water as they fall down get spattered on the floor, the base of the stalagmite is usually thick and wide and its outline is not so symmetrical, though it tapers towards the top. Sometimes the stalactites growing downward and the stalagmites growing upwards meet together and form a continuous column from the floor to the ceiling and are known as columns and pillars. Where the water drips more or less continuously along a roof joint, a fluted curtain or wavy screen may grow and hang downward from the ceiling.

12.8 LET US SUM UP

It is hoped that the detailed analysis and elaborate discussions of various aspects have helped the students to understand better and learner to extend his knowledge of Eolian and Karst work and their topography.

12.9 KEYWORDS

Deflation Hallow: Basin formed by the removal of fine material by wind, such as Qattara depression, Egypt

Abrasion : The mechanical or frictional wearing down of rocks by material, which forms the abrasive medium, transported by running water, wind and waves. It is the result of corrasion.

Attrition: The act of wearing and smoothing of rock surfaces by the flow of water charged with sand and gravel, by the passage of sand drifs, or by the movement of glaciers.

Karst: Which is characterized by typical limestone topography.

12.10 QUESTIONS FOR SELF STUDY

1) What are the process of Erosional activities of Eolian ?
2) Describe the Erosional features of erosional and depositional features of Eolian
3) Name the Erosional features of Coastal Geomorphology
4) Describe the Erosional and depositional features of Coastal Geomorphology.

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GEOGRAPHY
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Prof. Birdar D.O.S in Geography Karnataka University Dharwad.		Units – 14 to 16

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Developed by Academic Section, KSOU, Mysore

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UNIT : 13 COASTAL GEOMORPHIC AGENTS

Structure

13.0 OBJECTIVES

After studying of this unit, you will be able to

- Analyses the shore line process
- Identify the topographic features resulting from Erosional work
- Illustrate the depositional features of coastal geomorphic.

13.1 INTRODUCTION

When we look in to a physical map of the world we see a lot of coastal features of the universe. It is the continental shelf which occurs irrespective of structure, geological age, and climatic zoning of the globe. This continental shelf is a submarine floor which is less than 100 mts deep which might have formed due to several factors like Marine plantation, sediment filling between off shore islands and the mainland, or deltaic progradation etc., But this continental shelf are eternal hammering of the sea waves which is the dominant, powerful and universal factors.

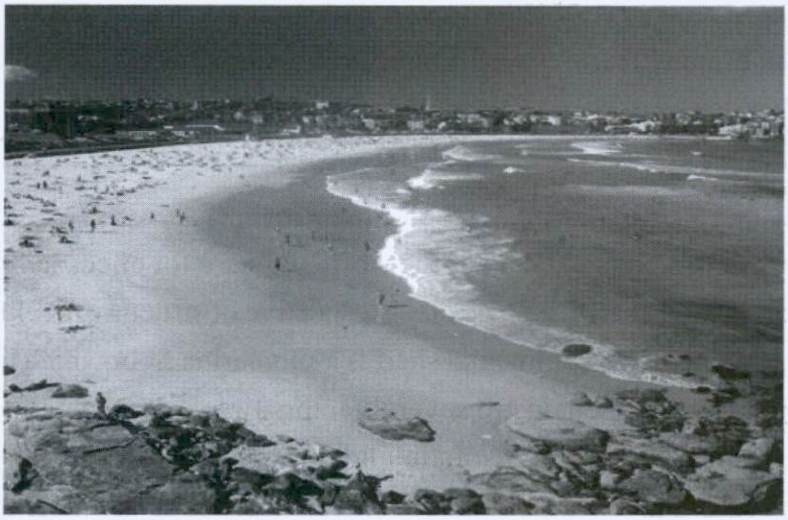
The coastline geomorphology provides a unique range of different environments. Wind and wave forces vary from place to place, both locally and globally. The character of the coastline itself varies considerably and this produces a wide range of changes in the rate of Morphological response to marine processes.

The shore includes both the foreshores, which stretches from the lowest tide limit to the mean high tide limit, on the other land backshore, continues along the shores to the extreme limit to high tides and storm waves.

In this uit describes ho the sea waves operating its erosive work. The unit analyze erosional and depositional work and their related landform like, cliff caves, beach etc, Also this unit light on coastal classification.

13.2 BEACHES

The term beach is used in this chapter to define an accumulation of marine deposited pebbles sand or silt. Beaches may extend for hundreds of miles along a shore or they may be patchy. Along ragged shorelines, beaches are mainly limited to strips at the heads of bays or coves. Their greater number in these locations is the result of the fact that ware converge upon leadlands and diverge in bays. Causes in bays causing an intensification of wave's erosion lead lands and a lessening of in bays. Longshore currents and beach drifting also tend to move sand in to the bays to either side of a leadland.



Beach

Movement of beach material goes on at all times, but reduction in beach thickness is most significant during an extreme storm waves, where as beach accreation takes place during periods of a quiet waves. Waves produced by tsunamis and hurricanes are especially destructive of beaches and may result in either pronounced landward movement of beach material or its complete removal.

The materials of a beach come both land and sea; probably the greater part comes from the land, contributed mainly by streams, landslides weathering of sea cliff, marine erosion of the sea cliff, and slope wash. It appears however that some beach material comes from the sea. For example chalk ballast dropped from 7 to 10 miles off the coast of Sunderland, [England] in water as much as 20 deep had been brought on shore by storm waves. Therefore the marine agents of erosion and deposition, waves, tides, and currents are controlled by oceanographic and climatic factors.

Man is also a fundamental factors in coastal geomorphology, and has affected coastal geomorphology, and has affected coastal processes through reclamation projects, coastal protection works, leisure activities and pollution.

The factor of sea-level change is one of the most important in coastal geomorphology sea level changes occur as a result of

(a) Eustatic or global changes in the level of the sea, as has occurred which occurred during a growth of ice sheets during the Pleistocene era.

(b) Tectonic changes in the level of land, related to folding and flexing of lands. These tectonic changes may be isostatic.

The level of the sea has been both higher and lower than now, has left emergent (raised) and submergent (drowned) features, on the same stretch of coastline, submerged effects includes "rias" (drowned river valleys) Fjords and submerged forests. Raised beaches and platforms and abandoned cliffines are the main emergent features.

In areas of tectonic changes we can see raised beaches often exist reflecting the interplay of isostatic causes.

Sea level changes are still taking place, on the evidence of tide gauge records. World wide sea-level has been rising for the past fifty years at an average of 1.2mm per year. Faster rates or land/sea level changes occur in areas undergoing crustal warping. For example North west Europe, The Baltic area is still rising at rates up to 10mm a year.

13.3 SHORE LINE PROCESS

13.3.1 Waves

Waves are by far the most important agents of shoreline modification. Apart from those wave very occasionally started by earthquakes, all other waves are produced by wind. Waves are the undulations on the surface of water caused by the force of blowing winds. The wind exerts a drag on the surface water particles and sets up small orbital motions in the water. They are largest near to the surface, and becomes less to the depth. The water particles move backward in the trough of the wave and forward in the crest. For example a toy paper boat or cork in the water. There are three factors which govern the size of the wave.

(1) The wind speed

(2) The duration of the wind

(3) The distance or 'tetch' over which the wave travels.

The waves break normally involves three stages.

(1) The wave plunge (that is tiding and falling over the upper part of the wave like a land ward facing hook)

(2) The waves rushes forward on the shallow ground and is known a 'swash'

(3) The third stage is that the water return of the uprising water after it has reached the inner landward limit. The return is called the backwash.

The largest waves will inevitably produced by prolonged gale force winds blowing over oceans. Surface waves reaching a coast after traveling long distance form a swell. When waves reach shallow water near a coast, the sea floor alters the dimensions of the wave. Although the wave period of time remains the same, the wave slows down, such that the wavelength is shortened, but the wave height increases. The wave steepness increases until it becomes so steep that it breaks. Therefore like as said before the breaker or surf zone the wave force is translated up the beach and creates a swash. This returns as backwash either in a sheet flow or a rip current a localized concentration of backwash, which can be very dangerous to bathers in the sea. Wave steepness is a critical parameter it may be either destructive or constructive.

Constructive waves (spring breakers) have a low index of steepness. Where as destructive waves (plunging breakers) have a relatively high ratio or steepness.

The erosional action of the waves is due to the several factors. The swash involves large mass of water beating on the shore. Waves are a force by being mass of water in motion but near the coast they are armed with the tool of rock fragments including mud, sand, stingle and boulders. This tool is called "land". These supply of load is form the beach off shore shallower marine floor, discharges from rivers and erosion of cliffs.

13.4 EROSIONAL FEATURES OF COAST LINE

There are certain features on the coasts which are primarily due erosion. They are (1) coastal cliffs (2) wave cut platforms (3) sea arch (4) stack (5) sea-caves (6) crenellate coast etc.,

3.4.1 Coastal cliff

It is also known as sea cliff. The surf strikes against the cliff at the coast with rock pieces. The lower past of the cliff is cut down in this action. The surf acts like a horizontal saw and cuts most actively at the base of the cliff. Slowly this cut takes the form of a concave shape. This concave cut is called a notch and nip.

When the notch grows, the upper part of the cliff look hanging. Gradually the over hanging part becomes undercutting by surf. One day it collapses due to the regular hitting of waves.

Another higher cliff appears if that collapsed cliff was part of a higher land area. This new cliff is also subjected to under-cutting. Due to this action, new cliffs continue to form behind the older cliffs. In other words, it is called cliffs retreats with erosion.

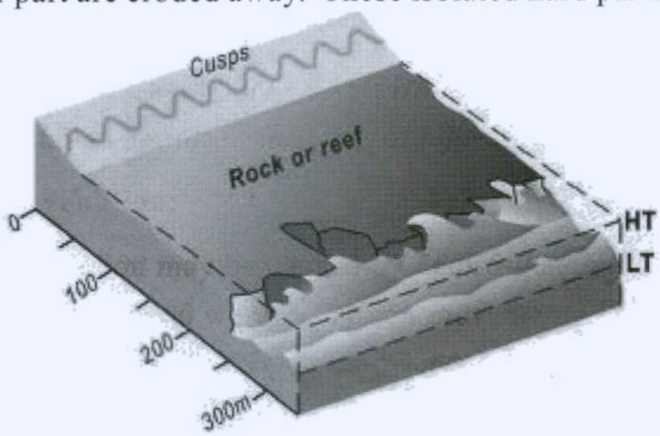
Cliff

13.4.2 Wave cut platforms:

It is also called as "terrace". When the cliff retreats a platform is formed in front of the cliff. It continues to be affected by surf (waves). As this platform is produced by erosion, It is called wave-cut platform. As the platform widens, the retreat of the cliff slows down. At some places platforms are called stand flat. The presence of furrows flutings, scour pits etc., thus the platform is built by surf alone.

13.4.3 Rock Reefs:

Many land parts of the platform stand erosion and look standing isolated on the platform because the softer part are eroded away. These isolated hard parts are called rock reefs.



13.4.4 Tidal Pool:

When the water of stormy waves strike against the rocks and comes back, water along with rocks pieces begins to rotate in the various depressions on the platforms. These deeper depressions are caused due to erosion is called tidal pool.

13.4.5 Sea caves:

The surf effects great erosion in the rocks which have closely spaced joints. If there is soft rock portion in it, the same is cut down very fast and the cut away portion grows bigger into a cave. These caves are known as sea caves. The sea caves in a limestone area are not due to the attack of surf but it is due the solution power of the sea water.

Sea Caves

13.4.6 Marine Arches:

Some narrow land area projects far into sea. It is known as head land. Sea caves develop on both the sides of the head land by surfs. When the sea caves on either side, it meets each other (the wave after a long period of erosion) sea water passes across the passage formed by the joining of the sea caves. The arch over the passage is called natural bridge.

Marine Arch

13.4.7 Stacks:

When roofs of the sea arch or the natural bridges collapse, the remains of the natural bridges stand as pillars, isolated and distant from one another. Such a pillar is called as chimney rocks or skerry. Many pillars are also formed by solution action. Soft rocks are also eroded away by solution action from the adjoining hard rocks. With the results are hard rocks stand out as pillars.

13.4.8 Blow holes (spouting horns):

If a hole is developed in the roof of a sea cave, it is known as blow hole or a spouting horn. It is called gloup in England. When this water enters the sea caves, the air of the cave is pressed up by the sea water and the air passes through the holes with a noise, spouting horns is the name given because of the noise the blow holes made.

13.4.9 Hanging valley:

If the rate of retreat of cliffs is faster than the rate of erosion of rivers flowing down the coast the rivers appears to be hanging over the sea. These river valley are called hanging valleys.

13.4.10 Plain of marine erosion:

The sea waves erode the coast. The plain formed by erosion initially grows into a bigger one. It is known as the plain of marine erosion.

13.4.11 Abrasion Platforms:

The base of the most violent stream is not more than 200 metre deep. If there is sediment fro abrasion available at this depth, it is possible to have some erosion work. With the movement to and from motion of water of the wave the stingles and pebbles also move and cut the plain by corrosion. If the wave-built platform does not have a sudden fall below 183 metrs in exterior portion, the platforms formed by corrosion is called abrasion platform.

Abrasion Platform

13.5 DEPOSITION OF COAST GEOMORPHOLOGY:

The rock flour produced by erosion on the coast and shore accumulates in the sea finally. The waves throw the rock flour on to the coast but same comes back rolling down a slope coast and shore. Undertow also shifts the rock flour towards the sea such features, are off shore bars and barriers, barrier chains, spits, tomholes, beach ridges, sand bars, beach eusps, bay bars etc.,

Beaches usually are temporary deposits on the shore. It generally consists of sediments as sand large sediments, that is pebbles also called shingle and boulders.

13.5.1 Wave built platform

It is also known as wave-built terrace. Wave produce a platform on the coast by erosion and contributes to the retreat of cliffs, which is called wave built platform. As the waves throw cliffs backward by erosion and expands the wave-cut platform, the amount of rock flour increases. This rock-flour helps the wave-built platform to expand towards the sea. If the sea suddenly gets very deep the expansion of this platform becomes slow.

Waves Built Platform

13.5.2 Beach

The entire area along the sea extending from the lined reached by the high tide and the highest storm waves to the low tide point is called beach. If the coast is surrounded by high hills of hard rocks, the beaches do not have deposition. If the coast is sandy the beaches are of various types.

13.5.3 Fulls or swells

Some ridges are formed parallel to the coast by sea waves. These are known as fulls or swells and the depressions between them are known as lows. Numerous swells and lows can be seen at the Lancashire coast.

13.5.4 Beach cusps

Many shores at the coast are found to have been divided into pointed projections. These pointed projections towards the sea separated from each other by depressions are called beach cusps. Their formation has not been fully understood. Many beach cusps are seen at the coast in the English Channel. Many times violent storms destroy them.

Beach Cusps

13.5.5 Bars and Barriers

The deposition is made by sea waves along the coast mostly have bars and barriers. The bars are submerged under the sea at time of high tides while the barriers do not submerge.

13.5.6 Longshore bars

Many low ridges are formed by surfs parallel to the coast. These are usually submerged under the sea. The coastal bars which do not submerge even under high tides are known as longshore barriers. Some call them off shore bars. The longshore bars have many names.

When these bars reach the coast, they are known as sounds. Example, there are many sounds near Miami (Florida).

13.5.7 Spits

At many places, a bar consisting of pebbles, stones and sands protrudes out of a headland. Its one end disappears in the open sea. If the bar is submerged under sea, it is called spit but if it appears above the sea, it is known as barrier.

13.5.8 Hook

The sea current which dumps sediment at the free ends of spits extends the spit towards the sea. Other currents and waves tend to turn it into other directions. If the current extending if it is weaker than the currents turning it, the bar takes a turn. Such bars whose ends have bent are called hooks, example sandy hooks of New Jersey (U.S.A) is a well known hook.

13.5.9 Loop

Sometimes the end of a hook bends in such a way that it forms a loop. Such hooks which have turned into a loop are called loops.

13.5.10 Bay Mouth Bar

When the bar at the mouth of a bay becomes large that it closes it is called Bay Mouth Bar. Bay mouth bar of Ontario lake is a famous one.

13.5.11 Tied islands and Tombolos

Many times islands situated away from the cast are connected by bars, such as island connected with the coast by a bar is called tied island and the bar connecting it to the coast is called Aombolo. There are numerous examples of tied islands and tombolos near the New England coast. At some places two tombolos develop towards a tied island. The area are between the two Tombolos collide into one forming a large land area. Such a structure is found at Gibraltar.

13.5.12 Barrier Islands

At many places there are islands near the coast. They are many km long but are not connected with the main land. Many sand dunes are formed on these islands with the sand received from the coast. These are known as barrier islands. Atlanta city is situated on such a barrier islands. Beach and Tom's beach are examples of barrier islands.

13.5.13 Tidal inlets

The opening between the barrier islands and the coast is called an inlet. Tides keep them open by removing the sand which tries to close the inlet. Such openings are called tidal inlets.

13.5.14 Lagoons

At many places, bars and barriers enclose the coast and form small lakes such lakes are known as lagoons. There are many lagoons found at the Eastern coast of India. Lake Chilka is a well known lagoon in this coast.

Lagoons

13.5.15 Progradation

Sometimes the pebbles, shingles and other sediment are accumulated to such an extent that these can not be thrown by sea action. Hence a thin layer of sand, pebbles, cobbles etc., is deposited over the wave-cut platform. When the deposits are wave-built platform becomes one with this sediment the process is called progradation.

13.6 COASTAL CLASSIFICATION

A wide variety of schemes for classifying coasts has been suggested numerical, descriptive and genetic but in many cases it is as difficult to remember the results of the classification as the individual land forms. In the past the most commonly used classification was that proposed by D.W. Johnson who recognized four categories of shore line.

(a) Shoreline of submergence

(b) Shoreline of emergence

(c) Neutral shorelines

In the exact form is due to neither emergence nor submergence, but to a new constructional or tectonic form such as a delta or a fault

(d) Compound shorelines, including all shorelines which have an origin combining at least two of the preceding classes.

In Johnson's simple genetic classification, but places heavy emphasis on one factor. Sea level change and requires that we know something about the past history of the coast lines strictly speaking all shorelines are compound. A most recent and potentially much more useful scheme is that proposed by J.L. Davies on the basis of energy environments. Lagoons Lagoons On a world map be recognizes

(a) storm wave environments where destructive storm breakers are frequent and shingle beaches are common,

(b) Swell environments, which are characterized by flat constructional wave and

(c) Protected environments, the low energy conditions of enclosed or partially enclosed seas.

13.7 LET US SUM UP

In the present unit, you learnt about Erosional and depositional features of coastal geomorphology. Learner also extends his knowledge about classification as well as shoreline process. Also you learnt types of beaches, shore lines, waves. Coastal cliff wave cut platforms, rock reefs, tidal pools, sea caves, marine arches, stacks, blow holes of erosional features of coastline. Waves built platform fulls or swells beach cusps, bars and barriers, long shore bars spits, hook, loops of depositional features were also discussed

13.8 KEY WORDS

Beach cusp : Succession of stony with sharp points toward the water, situated on the upper part of the beach.

Stack : An erosional remnant in the form of small bedrock island a sort distance off shore.

Tectonic : Pertaining to deforestation of the earths crust

Progradation : A shoreline that is advancing seaward

13.9 QUESTIONS FOR SELF STUDY

1) What is meant by deferential marine erosion ?

2) Briefly describe the erosional features of sea waves.

3) Explain the depositional features of sea wave action

4) Give an account of the of waves as an agent of gradation

5) Differentiate between the erosion by the sea and the running water

13.10 FURTHER READING

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UNIT : 14 THE CONCEPT OF CYCLE OF EROSION (GEOGRAPHICAL CYCLE)

W. M. Davis (1850-1934)

Structure

14.0 OBJECTIVES

The concept of cycle of erosion or geographical cycle put forth by W.M. Davis is one of the great landmarks in the history of geomorphology. This unit covers the following main objectives.

After studying of this unit, you will be able to

- Explain the Cyclic nature of the earth's history of landform evolution.
- Connect the influence of rivers and streams on the topography and the resultant landforms of erosion and deposition.
- Analyze the sequential changes in landforms.

14.1 INTRODUCTION

The concept of cycle of erosion is an important landmark in the history of geomorphology. Though it is no longer accepted wholly in its original form, it was so widely accepted in the English speaking world that its validity could hardly be questioned for more than half a century.

James Hutton (1726-1797), the Scottish geologist, was probably the first to postulate the cyclic concept in 1785, when he propounded the concept of 'cyclic nature of the earth's history.' The concept of cyclic nature of the earth's history was later transformed into the 'Principle of Uniformitarianism' which holds that the present is the key to the past', and that "the same physical processes and laws that operate today operated throughout geological time."

W.M Davis (1850-1934) based his concept of cycle of erosion on the Huttonian concept of the cyclic nature of the earth's history and the evolutionary concepts of Charles Darwin (origin of species through natural selection). Davis presented his geographical cycle of erosion' in 1899, though he had already propounded the concept of 'complete cycle of river life' in 1889. The Davisian model of geographical cycle of erosion was based on the concept of sequential change in landforms through time in the same way as the evolution of organic life.

14.2 LANDFORM IS A FUNCTION OF STRUCTURE, PROCESS AND STAGE

The cycle of erosion has been defined by Davis as 'geographical cycle' which is a period of time during an uplifted landmass undergoes its transformation by the processes of land sculpture, ending in a low featureless plain- a peneplain. It may be added that variations in altitudes, structures, diastrophic history and climatic conditions may result in notable departures form the sequence. Davis stated "landscape is a function of structure, process and stage." These are three principle controlling factors in the evolution of any landscape.

14.2.1 Structure:

The word structure has been used by Davis in a wider sense and includes not only regional geological structure, folds, faults and such other broad features, but also the nature of rocks and their physical chemical properties, their permeability and solubility, the nature of joints, beddings and cleavage, etc. Thus, on a permeable rock, there will be minimum run-off and so erosion by running water will be slower than on an adjacent impermeable rock. Soft shales erode more rapidly than massive quartzite, while limestone's or gypsum undergo solution by under ground water in addition to being, modified by any surface stream. As a rule, the influence of rocks on landscape is quite marked. Moreover, the structure, as a rule, is older than the landscape developed upon it and provides a base for the operation of various gradational processes which give rise to new sequential landforms.

14.2.2 Process:

The word process includes the action of all the forces which bring about changes in the configuration of the earth's surface. The forces include both the endogenetic (internal) and exogenetic (external) forces. The former includes volcanicity and diastrophism that produce irregularities on the earth's surface by building and uplifting mountains, plateaus and hills. On the other hand, exogenetic forces tend to level down the earth's surface. The agents of these external forces include running water, ground water, glaciers, wind and sea waves. These agents erode the uplifted land, transport the eroded materials and deposit then elsewhere. The total effect of all these processes is a general lowering and leveling down of the earth's surface.

14.2.3 Stage:

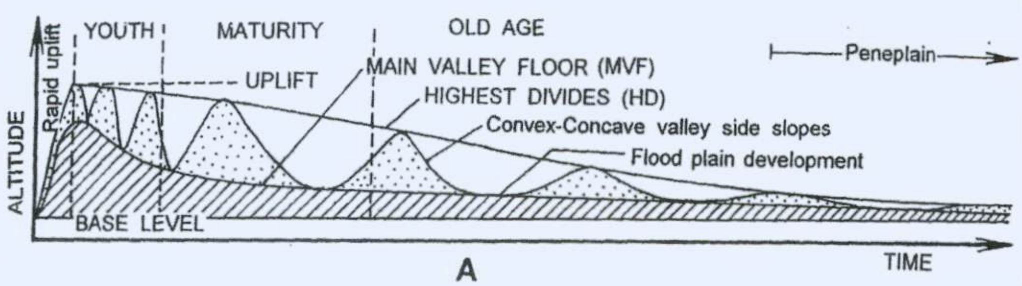
In the evolution of landscapes, Davis has identified three stages: youth, maturity and old age. Just as each process gives rise to distinctive landscape, so also each stage of the erosion cycle is characterized by distinctive landforms with the help of which it is possible to identify the stage of evolution of landscape. There is a direct relationship between the stage of development and the character of landforms. Davis lays great emphasis on the stage of development in his concept of cycle of erosion.

14.3 MAIN ASSUMPTIONS OF DAVISIAN MODEL OF GEOGRAPHICAL CYCLE OF EROSION

1. Landforms are the products of the interactions of endogenetic and exogenetic forces.
2. The evolution of landforms takes place in a sequential manner.
3. Streams erode their valleys rapidly downward until the graded condition is achieved.
4. There is short period of rapid rate of upliftment in the landmass.
5. Erosion does not start until the upliftment is complete. In other words, upliftment and erosion do not proceed simultaneously. (This assumption has been severely criticised by the subsequent geomorphologists).

14.4 NORMAL CYCLE OF EROSION

Normal cycle of erosion is synonymous with the fluvial cycle, or the cycle of erosion by river. Fluvial processes are widespread world over and most significant geomorphic agent. Water plays an important role even in the arid and glacial regions. Davis considered humid temperate areas as the most normal case of fluvial cycle.



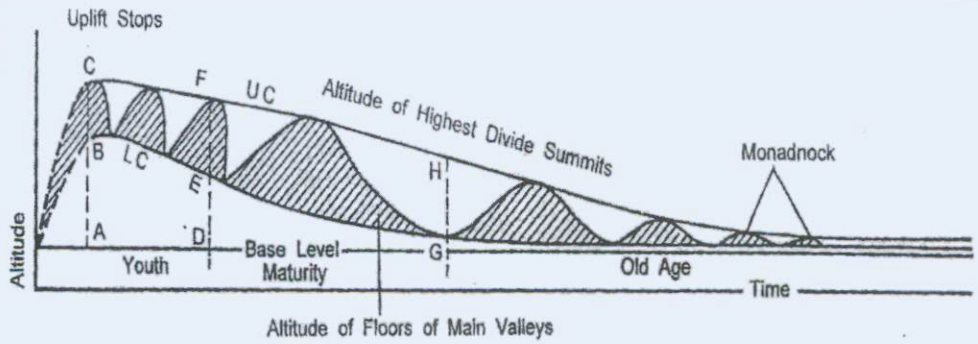
Landform Development: W. M. Davis

According to Davis, the normal cycle of erosion begins with the upliftment of any landmass with reference to sea level. As the land rises, the rivulets and streams are originated and their erosional work starts. In the beginning, the rate of uplift exceeds the rate of erosion. This results into an increase in the absolute and relative relief. After some time, upliftment of the land stops and erosion becomes more active. The land remains stable for a long period of time during which there is neither upliftment nor subsidence of the land area. There is progressive development of river valleys in sequential order and the whole land area passes progressively through three successive stages of youth, maturity and old. The land is ultimately transformed into a low featureless plain of undulating surface. Thus, the end product of the normal cycle of erosion is peneplain which is marked by undulating surface with residual low hills known as monadnocks, unakas and mosores.

The main characteristics of the successive stages of normal cycle of erosion are briefly discussed as under:

14.4.1 Youthful Stage

With the upliftment of land in the beginning, a few consequent streams are originated, which are short on length. Very few tributaries of the master consequent streams are originated. The slopes are dominated by numerous rills and gullies rather than big streams. These rills and gullies lengthen their longitudinal profiles (increases their lengths) through headward erosion. Gradually, the main streams deepen their valleys. The evolution of tributaries of master streams gives rise to dendritic drainage pattern. The rivers are continuously engaged in down cutting their valleys. The rivers have a high transporting capacity which enables them to carry big boulders. Pothole drilling of river beds is the most powerful process of vertical erosion in this stage.



Graphical presentation of geographical cycle presented by W.M. Davis

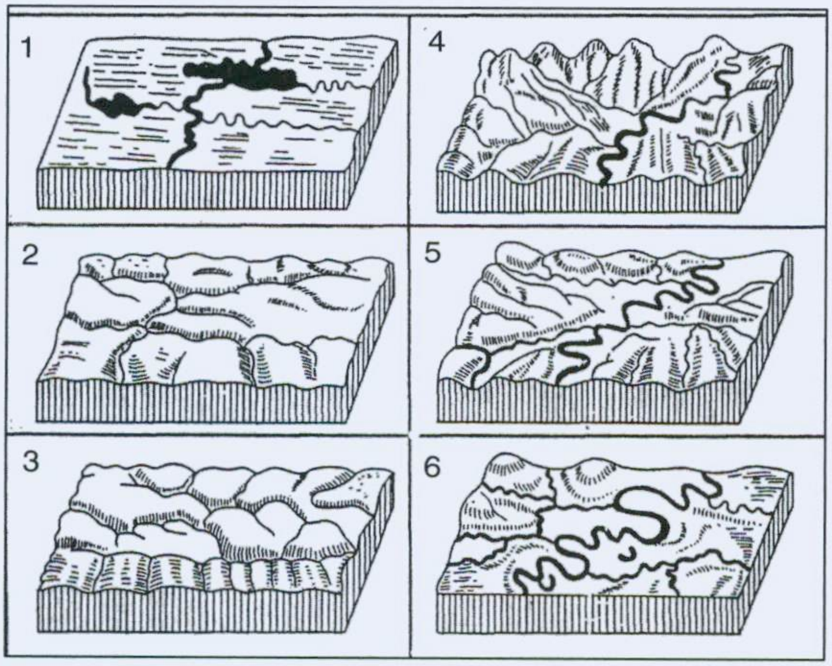
The valley becomes very narrow and deep, with almost wall-like sides. The V-shaped valley at this stage is called 'gorge' and canyon'. The valley floors are studded with pot holes. The water-divides are extensive and wide, as valley-widening by lateral erosion is less effective in the early and middle parts of the youth stage. He longitudinal profile of the river is characterized by numerous rapids and waterfalls. Maximum relative relief's are formed by the end of the youthful stage. River capture is in of the most characteristic feature of this stage.

14.4.2 Mature Stage:

Early mature stage is characterized by marked decrease in valley deepening due to decrease in channel gradient, river velocity and transporting capacity. Valley-widening becomes dominant due to active lateral erosion, Convex slope of valley side is transformed into uniform or rectilinear slope. Gorges and canyons are replaced by broad and flat valleys. Due to sudden decrease in channel gradient and a marked decrease in the transporting capacity, the rivers deposit boulders at the foot hill zone and form alluvial fans and alluvial cones. The coalescing alluvial and land alluvial cones form piedmont plains. Water divides become narrow due to backwasting, and the inter-stream areas are transformed onto narrow ridges. The major rivers become graded. The longitudinal profile of the master stream becomes the profile of equilibrium. Because of marked decrease in channel gradient rivers adopt winding courses and develop meanders and loops in their courses. Extensive flood plains are formed die to sedimentation of alluvium. Rivers frequently change their courses because of gentle slopes of the flood plain. Numerous ox-bow lakes are formed due to straightening of highly meandering loops. Deposition of sediments on either side of the river valleys lead to the formation of natural levees.

14.4.3 Old Stage:

The old stage is characterized by further decrease in channel gradient, almost total absence of valley deepening, decrease in the number of tributary streams, and flattening of valleys. Now tributary streams also become graded. Lateral erosion and consequent back wasting eliminates most of inter-stream areas. Valleys become broad and flat characterized by concave slopes of valley sides. The entire landscape acquires the shape of extensive flat plain called peneplain, which is marked by a few residual hills called monadnocks. The steams become sluggish due to gentle gradient. The main channel of the river is divided into numerous distributaries and the river becomes braided. Rivers form extensive deltas at their mouth. Swamps and marshes are the other characteristic features of the old stage. This stage represents the base level of the stream beyond which there is no erosion unless rejuvenation takes place.



Stages of Normal cycle of Erosion: 1. Initial stage, 2. Early youth, 3. Late youth, 4. Early maturity, 5. Maturity, 6. Old stage

The ideal normal cycle of erosion passes through all the three stages, provided the region remains stand-still for a long period of time. But such condition is a remote possibility only, as the earth is very much unstable. The smooth functioning and completion of normal cycle is very often disturbed due to several tectonic events as well as climatic changes.

The disturbance in the cycle of erosion is called interruption of normal cycle of erosion.

14.5 INTERRUPTIONS IN CYCLE OF EROSION

Davisian cycle concept envisages gradual sequential changes in the uplifted landmass through the stages of youth, maturity and old, culminating into the development of a low featureless plain called peneplain. The completion an the ideal cycle depends on tectonic stability of the region which is seldom possible in nature. In fact, partial (interrupted) cycles are more common than completed ones. The cycle of erosion is liable to frequent interruptions which cause inequilibrium condition in the cyclic model.

1. **Interruptions due to Volcancity:**

   A cycle of erosion may be interrupted due to volcanicity. The widespread fissure flow causes upwelling and pouring of immense volumes of basaltic lava which obliterates surface drainage and reliefs. As a result of this, the on-going fluvial cycle of erosion comes to an end. The fresh cycle of erosion may start only when the fissure flow ceases;

lava is cooled and solidified; new surface is formed; and new streams are originated. Such interruptions in the fluvial cycle occurred over the Indian Peninsula during the Cretaceous period, when Deccan lava flows covered vast areas of the Deccan and Chhotanagpur plateaus. After the solidification of the Deccan Trap lavas, the new Tertiary cycle was initiated.

2. **Interruptions Due to Climatic Changes:**

   Major climatic changes are known to have occurred during the geological times. Minor climatic changes have been quite frequent. If during the prevailing fluvial cycle in a humid region, sudden climatic changes occur thereby leading to the onset of extremely dry or extremely cold conditions, the current cycle of erosion comes to an end and another set of cycle (arid, glacial or periglacial) begins. Minor changes in climate are not likely to interrupt the cycle, rather the cycle is either augmented or slowed down.

3. **Interruptions due to Base Level Changes:**

   Sea level is the grand base level. Any changes in it causes interruptions in the cycle of erosion and may initiate a new cycle whether the previous cycle is complete or not. These changes in base level may be either positive (due to rise in sea level) or negative (due to fall in sea level). The base level changes due to sea level changes are eustatic. Tectonic factors e.g. subsidence of landmass and upliftment of landmass also cause changes in base level. Such types of movements may or may not be related to sea level. Such changes of base level accelerate erosion.

14.6 REJUVENATION

As said earlier, multi-cyclic evolution of landscapes is more common than the monocyclic development. Mature or old-age topography is likely to have superposed upon it youthful features as a result of rejuvenation. This result from any change which causes streams that had previously attained profiles of equilibrium, or were aggrading, to engaged again actively in valley deepening. Rejuvenation may result from causes which are dynamic, eustatic, or static in nature. A detailed outline of the types of rejuvenation is given below:

1. **Dynamic Rejuvenation:**

   Dynamic rejuvenation may be caused by epeiro-genetic uplift of a landmass, with accompanying tilting and warping. Such movements may be rather localised and associated with neighbouring orogenic movements, or they may be world wide in nature.

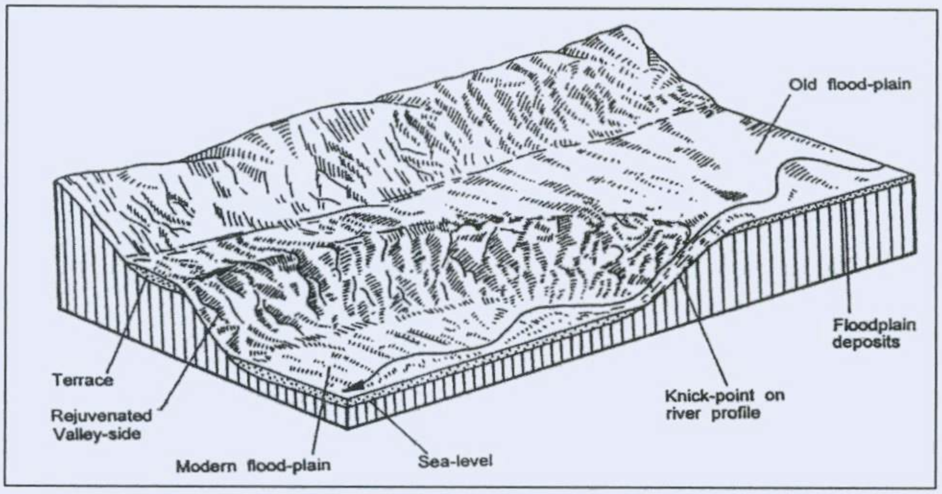
Localized down-tilting, warping or faulting of a drainage basin will result in a steepening of stream gradients followed by down cutting by the streams which now have increased power for transporting their loads. The effects of seaward tilting would be felt along the entire stream course and immediately reflected in valley deepening by the stream.

2. **Eustatic Rejuvenation:**

Eustatic rejuvenation results from causes that produce world wide lowering of sea level rather than localized changes in base level. Two types of eustatism is recognized:

i) Diastrophic eustatism is change of sea level resulting from variation in capacity of the ocean basins.

ii) Glacio-eustatism refers to changes in sea level produced by withdrawal or return of water to oceans, accompanying the accumulation or melting of successive ice sheets. Edward Suess was the originator of the idea of diastrophic eustatism. Baulig (1935) recognized the importance of glacio-eustatism but thought that there is evidence of world wide lowerings of sea level during the pliocene and pleistocene of a greater magnitude than would have been possible through glacial-eustatic changes. He thought that these lowerings of sea level were the result of epeirogenic movements to be associated with orogenic movements and a consequence of them, rather than independent orogenic movements, as thought by some geologists. "Eustatic lowering of sea level will cause rejuvenation of a stream at its mouth. Regarding of a stream toward the new base level will progress up valley. The result may be an interrupted profile with a point of intersection of the old and new base levels being marked by a nick point which proceeds upstream as the new base level is extended headward" (Thornbury, 1969).



Knick Point Formation and Terraces Indicating Rejuvenation

3. Static Rejuvenation:

Streams may exhibit signs of renewed youth from changes which involve neither uplift of the land nor eustatic lowering of sea level. Malott (1920) called it 'static rejuvenation'. Three changes may produce static rejuvenation: (i) decrease in load, (ii) increase in run-off due to increased rainfall, and (iii) increase in the stream volume through acquisition of new drainage by stream diversion or derangement.

Rejuvenation because of decrease in load has taken place during post-glacial times along many valleys that formerly received large quantities of glacial out wash. With change to non-glacial conditions, stream loads decreased and as a result valley deepening ensued, leaving the former valley floors partially preserved as gravel terraces.

Increased rainfall may cause an increase in stream volume without corresponding increase in load, as a result of which streams find themselves able to transport their loads over more gentle slopes. Valley incision may then result.

Stream rejuvenation because of an increase in stream volume through diversion of drainage is quite common. As a result of increase in volume the stream is able to incise its valley.

14.7 LET US SUM UP

According to this concept a landscape has a definite life history, and as the processes of land sculpture operate on it, the surface feature are marked by several changes in its life-time. The changes in the surface features follow a definite sequence where the initial forms pass through sequential forms and finally reach the ultimate form. Thus, the evolution of the landscape passes through a cycle, and the cycle follows a definite sequence of development. The gist of the cyclic concept is that commencing with an initial landscape, generally assumed to be one of low relief, the land surface passes through an orderly sequence of forms eventually to return to a surface of low relief, to an assemblage of forms which is identical to the original.

14.8 KEY WORDS

Structure	:	Refers the folds, faults and nature of rocks their physical and chemical properties which determine the rate of erosion.
Process	:	Includes volcanicity, diastrophism, building and uplifting mountains and erosion, transportation and deposition of materials.
Stage	:	Refers sequence of time to give rise to a distinctive landscape.
Paneplain	:	Extensive flat plain formed in the old stage of a river.
Base level	:	It is a river's condition, that it flows more or less at sea level and cannot erode its valley.
Eustatic	:	Refers changes in sea-level.
Knick point	:	It is a break in slope in the longitudinal profile of a river (caused by rejuvenation).

14.9 QUESTIONS FOR SELF STUDY

1. Explain the basic assumptions of Davisian concept of cycle of erosion.
2. Landform is a function of structure, process and stage 'justify.
3. Elucidate the characteristic features of different stages of a normal cycle of erosion.
4. Examine the interruptions in the cycle of erosion.
5. Discuss the evidence of rejuvenation.

14.10 FURTHER READINGS

1. **Wooldridge S.W. and Morgan**, An outline of Geomorphology.
2. **Thornbury W.D.,** Principles of Geomorphology.
3. **Strahler A.N.,** Physical Geography.
4. **Spark B.W.,** Geomorphology.
5. **Alka Gautam,** Geomorphology.

UNIT : 15 CONCEPT OF CYCLE OF EROSION

W. Penck (Germany-1924)

Structure

15.0 OBJECTIVES

The most fundamental discussion of the problem of cycle of erosion is that of W.Penck in his Die Morphologische Analyse. Walther Penck is the most prominent critic of Davis.

After studying this unit, you will able to

i) Demonstrate the divergent views of W.Penck on cycle of erosion concept.

ii) Assess the relationship between the tectonic history of a region and denudation process.

15.1 INTRODUCTION

Walther Penck, the German geologist, has been the most prominent critic of Davis. He has criticized Davis mainly for the latter's assumption that erosion starts only after uplift is completed and that uplift is short-lived, while the landmass stands still during the long period of erosion. Penck also disagreed with the stage concept of Davis. In his views, the cyclic evolution of landscape on a still-stand landmass for such a long time can be considered only exceptional.

According to Penck the landscape is the result of the relative intensity of degradational processes and the phase and rates of uplift. Penck mentions three phases in place of the three stages of Davis. These three phases are related to the rate of uplift. As the rates of uplift and degradation are different in three phases, different kinds of slopes develop in them resulting in the formation of different landscapes. The uplift is rapid in the beginning, moderate in the middle, and decreased in intensity towards the end. After some time, the uplift stops altogether and degradation continues.

Penck has presented his model graphically. He has assumed a low, featureless plain called 'primarrumpf' for the initiation of the cycle of erosion. The primarrumpf closely resembles a peneplain. Penck believes that in the universal initial geomorphic unit on which the landforms develop as a result of the differential rates of uplift and degradation. Endrumpf is the last phase of degradation and the ultimate landform of the cycle, which closely resembles the peneplain of Davis.

He used the term entwickelung (meaning development) in place of stage. He suggested three terms i.e. aufsteigende entwickelung, gleichformige entwickelung and absteigende entwickelung for waxing rate of development, uniform rate of development and waning rate of development, respectively.

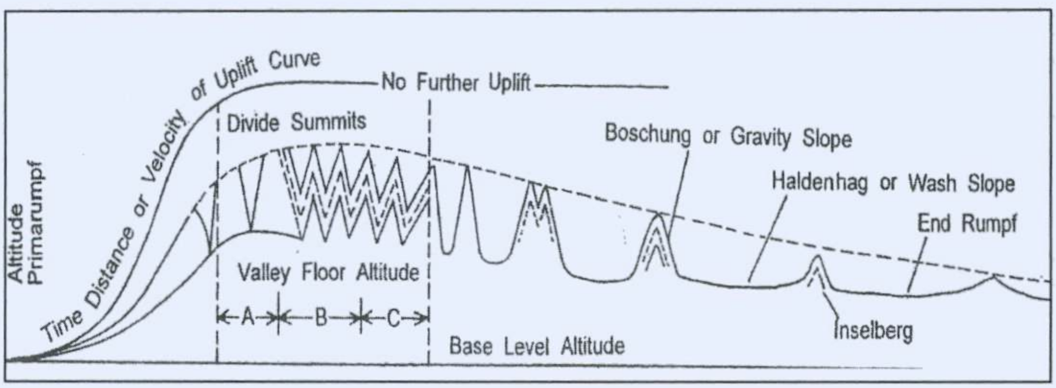
W.Penck is perhaps the most misunderstood geomorphologists of the world because of his incomplete work due to his untimely death, his obscure ideas in difficult German language, ill-defined terminology, faulty translation in English language and some contradictory ideas. His main goal was to find out the mode of development and causes of crustal movement on the basis of exogenetic processes and morphological characteristics. He sought the interpretation of diastrophic history of regions on the basis of the interpretation of present-day landform characteristics. He believed that the characteristics of landforms in a region are related to the tectonic activity of that region.

According to Penck, the mode of operation of exogenetic processes depends on the characteristics of regolith on hillslopes, mechanism of weathering and surface processes. He attached more importance to the process of mass movements than to other processes. He believes that the mechanism of surface processes is affected and controlled by the properties of forms and, in turn, the latter also undergo changes and transformation.

15.2 BASIC PREMISES

Penck's model is based on the following premises:

1. The form of hill slope is dependent on the relative rates of vertical erosion by streams at the slope base and denudation.
2. The form of hill slope is not directly controlled by slope processes because these act as agents of transportation of weathered slope debris downslopes. The major role of denudational processes is to expose bare rock slope surface for weathering processes.
3. The retreat of slope unit backward depends on the gradient of hill slope. Steeper gradient facilitates more active retreat than gentle gradient.

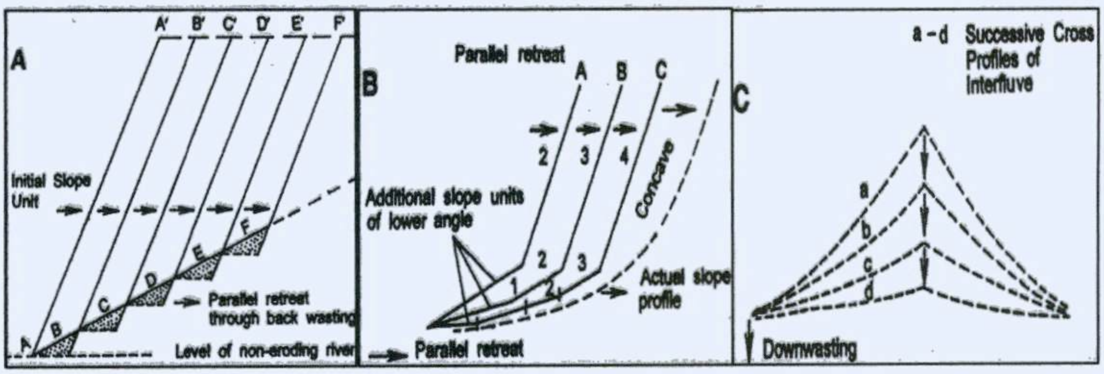


Graphical presentation of Penck's model of landform development

4. The slope retreat occurs in parallel manner, which results in the replacement of lower segment of slope profile by new unit of gentle segment.
5. Flattening of slopes takes place from below upward.
6. The form of valley-side slopes of streams depends on different rates of stream erosion i.e. accelerated rate, decelerating rate and constant rate, which produce convex, concave, and rectilinear slope forms respectively.
7. There is uniform rate of weathering of rocks of slopes.
8. When the required mobility is attained the removal of weathered material begins and the rate of removal (denudation) matches with the rate of weathering.
9. There are angular breaks of slope (gradient) having base-levels and the development of gradient of slope segment is independent of lower basal levels of breaks of gradient.

15.3 EXPLANATION OF MODEL

For the explanation of evolution of hill slope, Penck assumed a straight rock slope of homogeneous composition on which the rate of weathering is the same throughout. The upper surface of the slope unit is surrounded by level surface. There is a river at the foot of the slope which is neither eroding nor depositing, but it is capable of removing all the materials coming at the foothill from upslope segments. The weathered rock fragments fall downslope under the influence of gravity and collect near the base of the slope where the stream is flowing. After sometime the slope profile, shifts from AB to CD, and thence to EF, but the lowest part of the slope remains stationary because here the slope is insufficient for the rock fragments to move further down. In course of time, the lower section of the slope assumes a terrace-like form. It may noted that stepped slope profile due to parallel retreat of rock face of the slope as conceived by Penck is not possible in reality. R.J.Small (1970) attributes this to the arbitrary division of slope development into given intervals of time. In the field the slope would be rectilinear one. On this basal slope there is weathering, but as the gradient is small the debris is not transported till it has weathered onto fine particles. When this debris is transported down it stops near the base in the absence of slope, and in the lower section on the new basal slope, facets of gentler gradient are formed. In this way the new basal slope is divided into factors or sections of gradient. These facets slowly move back but on account of the accumulation of debris ion the lower facets, the upper facets move back faster than the lower ones. In course of time, a concave slope develops in which the upper steeper section is relatively short and the lower section is longer and has gentle gradient. On the slope summit convex slope may develop on account of soil creep, but Penck opines that flattering of slope from top downwards can take place only upto a limited extent, and basically flattening of slopes takes place from below upwards.



Parallel retreat and slope replacement model of W. Penck

If the parallel retreat is occurring on both the sides of an interfluve, then after the removal of free face or steep segments on both the sides the interfluve is subjected to down wasting and thus there is successive lowering of altitude and consequent slope flattening results in slope decline. Penck's model of slope development is nearer to reality in the field.

Penck has also proposed a model of development of slope forms on the basis of rate of stream erosion. In the case of accelerating rate of stream erosion, the valley side slope becomes convex, while decelerating rate of erosion causes the development of concave valley-side slope. On the other hand, constant rate of stream erosion results in the development of rectilinear slope.

15.4 EVALUATION OF THE MODEL

There exist several controversies regarding Penck's deductive model of slope evolution.

1. According to A. Young (1972) Penck nowhere mentioned angular break of slope in his original writings in the case of accelerating rate of stream erosion.
2. Some scientists question the development of slope taking place discrete stages.
3. It is also not clear whether slope profile, during its evolutionary stages, consists of several intersecting rectilinear segments or it becomes concave profile.
4. H.Mortensen (1969) has expressed doubt about the parallel retreat of cliff rock face by uniform rate of weathering. This model becomes valid where there is continuous and instantaneous removal of regoliths from slope.

The most fundamental discussion of the problem of slope is that by W.Penck in his Die Morphologische Analyse (1924). (English translation in 1953)

Penck's ideas are involved and nit readily understandable even in English, probably because some of them are radically different from those of all other geomorphologists. Penck attempted to establish a relationship between the nature of a slope and the tectonic history of a region.

- Convex slopes were formed in periods of accelerated uplift,
- Straight slopes were formed in periods of constant uplift; and
- Concave slopes in periods of decreasing uplift or stability.

Penck started with a straight rock slope and assumed equal weathering over the whole of it. The weathered fragments crumble and fall under the influence of gravity, all except the lowest adjacent to river level. This lowest fragment cannot move, as there is no gradient below it. Thus the slope profile moves back. In the next stage the profile moves further backward, but again the lowest fragment, is left in position, as the gradient below is not sufficient- to allow it to fall. The whole process extends until finally it may be assumed that the original slope has moved back to the maximum extent. The basal fragments left as successive slices of rock were weathered and removed from a new slope, which Penck termed the Haldenhang – and which has been translated as basal slope. He is not at all explicit (clearly express) on what determines the gradient of the basal slope formed at the expense of the initial slope, but, presumably, it has something to do with the size of the particles to which the rock was reduced by weathering. On the new basal slope weathering takes place, but the material must be reduced to a finer calibre before it can move away then was necessary on the steeper initial slope. With the removal of the weathered layer from the basal slope the lowest particle again cannot move away, and there is the beginning of the development of a new slope facet of even gentler gradient below the basal slope. The original slope thus breaks down into a series of slope facets of gentler and gentler gradients. The fragment at the base of each weathered layer would be infinitely small and would show give the irregularities and each one of them acting as the local base level for the facet above. But, as each lower facet requires a successively longer period for the weathering and removal of a layer of debris, due to the fact that on the lower angles of slope the debris has to be more comminuted, the higher, steeper facets recede more rapidly than the lower, gentler facets. The net result is a broadly concave slope, with long, gentle lower slopes and short, steep upper slopes. Penck realized that debris accumulating on the lower, gentler slope facets would retard their development and at the same time increase the rate of development of the upper steeper parts, which might become flattened, thus leading to an upper convexity.

These conceptions would seem to be far too rigid to fit natural slopes. If the initial assumptions are studied carefully it is obvious that they include equal weathering over the whole face and simultaneous removal of the waste from the whole face if parallel retreat is to be realised. It is very unlikely that these conditions could ever be realised naturally, as simultaneous removal would imply a rapid sliding of material from the whole of the slope as the only competent process. Again, it is not at all cleat that one should get a serried of successively gentler slopes each retreating parallel to itself. Infact, the slow migration of waste from the upper to the lower slopes would probably prevent and such action. Finally as mentioned earlier, it is difficult to see what determines the gradients of the slope facets which are said to replace each other successively.

15.5 LET US SUM UP

In this unit we discussed concept of cycle of Erosion by Walther penk, the German geologist who has been the most prominent critic of Davis. Penk has presorted his model graphically, and he believes that in the Universal initial geomorphic unit on which the landforms develop as a result of the differential rates of Uplift and degradation. The mode of operation of exogenesis processes depends on the characteristics of regality on hill slopes, mechanism of weathering and reface processes. Penk model is bused on some premises and he explained in his basic premises.

15.6 KEY WORDS

Regolith	:	Thin layer of loose, broken rock materials including soil.
Mass Movement	:	All types of down slope movement of loose weathered rock fragments along a hill slope under the action of gravity.
Weathering	:	Disintegration or decomposition of rocks due to exogeneic forces like temperature, rainfall, frost etc.
Diastrophic	:	Refers the combined effect of horizontal and vertical earth movements.
Tectonic	:	Refers the structural processes of crustal plate movement, subduction, faulting, earthquakes, and volcanes. etc.

15.7 QUESTIONS FOR SELF STUDY

1. Critically examine the basic premises of W. Penck's model.
2. Bring out the differences between the views of Davis and Penck on Cycle of erosion Concept.
3. Evaluate the Penck's model of cycle of erosion.

15.8 FURTHER READINGS

1. **Spark B.W.,** Geomorphology
2. **Bradshaw M. J., Abbott, A. J. and Gelstorpe, A. P.,** The Earth's Changing Surface.
3. **Thornbury W. D.,** Principles of Geomorphology.

   Alka Gautam, Geomorphology
4. **Bloom A.L.,** The Surface of the Earth.

UNIT : 16 RECENT TRENDS IN GEOMORPHOLOGY

Structure

16.0 OBJECTIVES

Modern geomorphology is a development of the nineteenth century. However, its roots lie deep in the philosophical ideas of the ancient Greek and Roman scholars. Herodotus, Aristotle, Strabo and Seneca richly contributed to the study of landforms.

After studying this unit, you will be able to

- Discuss the development of ideas,
- Interpret the concepts and principles in geomorphology through earlier times to the present.

16.1 INTRODUCTION

Herodotus (485-425B.C.), Known as the "father of history" made some geological observations. He studied the annual floods of the Nile, and noted the silt and clay deposited by the Nile. On the basis of these observations, he stated that "Egypt is the gift of the Nile". He also used the term 'delta' for the depositional feature at the mouth of the river. He also observed changes in the sea level.

Aristotle (384-322B.C.), a reputed Greek philosopher, presented many interesting ideas regarding spring waters, origin of streams, behavior of seas and oceans, causes of earthquakes and their relation with volcanoes, underground water, etc. He recognized the depositional work of streams citing examples from the Black Sea region.

Strabo (54 B.C.-A.D.25), a prolific writer, who traveled widely and observed carefully, although basically a historian, he significantly contributed to geomorphology. He studied the depositional work of the rivers and noted the formation and advance and retreat of delta. He rightly inferred that Mt. Visuvius as volcanic in origin. He also presented the concept of differential erosion indirectly.

Seneca(B.C.-A.D.65), recognized the local nature of earthquakes, and the power of streams to abrade their valleys.

After the decline of the Roman Empire, there was little or no scientific thinking in Europe, for many centuries. The long period of some fourteen centuries in the history of knowledge is termed as the "Dark Ages". In Arabia, however, a number of scholars contributed to the development of geography.

Ibn-Sina (980-1037 A.D.), for example, held views upon the origin of mountains and divided them into two categories: (i) those produced by uplifting and (ii) those which are the result of erosion of softer rocks by running water. Thus, the concept of mountains resulting from differential erosion was presented. It is to be noted that Ibn-Sina was greatly influenced by the work of a group of unknown Arabic scholars, known as "the Discourses of the Brothers of Purity written between 941-980 A.D.(Said, 1950). In this four volume work we find reference to erosion and transportation by streams and wind, weathering, and the idea of peneplanation.

16.2 CATASTROPHISM

Fenneman (1939) comments that there was little progress in Europe between first (A.D.) and the 15th Century. During 15th, 16th and 17th centuries landforms were explained largely in terms of 'Catastrophism', a philosophy according to which the features of the earth's surface were considered as the result of violent cataclysms which produced sudden changes in the surface of the earth. In those days, the age of the earth was calculated to be a few thousand years. As such, only those events could be given cognizance which occurred in the life-time of the people. Slow geologic processes (diastrophism) had little importance, while sudden movements (volcanism and earthquakes) were held responsible for the creation of landforms.

16.3 UNIFORMITARIANISM

The concept of catastrophism and the everlasting landforms was finally rejected, and gradual cyclic evolution of the earth was postulated by James Hutton (1726-1797 A.D.). Leonardo do Vinci (1452-1519 A.D.) was one of the representatives of the formative period in geologic thinking. He recognized that valleys were cut by streams carried materials from one part of the earth and deposited them elsewhere. Buffon (1707-1788 A.D.), the French Scholar, recognized the powerful erosive ability of streams to destroy the land that would eventually be reduced to sea level. He was one of the first to suggest that the age of the earth could not be measured in terms of a few thousand years.

James Hutton (1726-1797), the Scottish Physicist, was especially interested in chemistry and geology. He is famous as a leader of a group known as the Plutonists, which maintained that granite was igneous origin, in opposition to the Wernerian school, known as the Neptunists, which contented that granite was a chemical precipitate. He also recognized the evidence of metamorphism of rocks. His greatest contribution, however, is the concept that "the present is the key to the past" i.e., the doctrine of uniformitarianism in opposition to that of catastrophism. His views were first presented in a paper read by him before the Royal Society of Edinburgh in 1785, which appeared in the volume I of the Transactions of the society in 1788, under the title Theory of the Earth. His views in expanded form were published in 1795.

16.4 POST-HUTTON DEVELOPMENTS IN EUROPE

During the first half of the twentieth century, European school of geomorphology made significant contribution in the advancement of geomorphological thoughts. British geomorphologists made their mark as an entirely different school of geomorphology which laid emphasis on the chronological study of landform development in historical perspective, better known as denudation chronology. S. W. Wooldridge (1937) published his famous book entitled Physical Basis of Geography: An Outline of Geomorphology. J. A. Steers who earlier published The Unstable Earth (1932) made significant contributions in different branches of geomorphology.

The German geoscientists vehemently opposed the Davisian model of geographical cycle. The German critics of Davisian model of cycle of erosion fall in two categories: (i) those who pleaded for outright rejection of cyclic concept, and (ii) those who suggested modifications and presented entirely new model.

Walther Penck opined that landform development is not time-dependent as envisaged by Davis, rather it is time independent. He tried to reconstruct and interpret past events of crustal movements on the basis of exogenetic processes and morphological characteristics. He opined that landforms of a region are related to the tectonic activity of the region. The landforms thus reflect the ratio between the intensity of endogenetic processes (i.e. the rate of upliftment) and the magnitude to removal of materials by exogenetic processes.

16.5 DEVELOPMENTS IN NORTH AMERICA

According to Thornbury the period between 1875 and 1900 may be referred to as "the heroic age in American geomorphology" as during this quarter century there evolved most of the grand concepts in this branch of geology. Three men in particular (Major J. W. Powell, G. K. Gilbert and C. E. Duffon) laid the ground work upon which W.M.Davis later built the concept of a geomorphic cyclic.

Major J. W. Powell (1834-1902 A.D.) is considered to be the founder of the American school of geomorphology. After a thorough study of Colorado plateau and Uinta mountains (1876), Powell put forward a number of valuable concepts. He suggested the classifications of landforms on the basis of geological structure. On the basis of origin, he divided the river valleys into antecedent, consequent, and super imposed. He was the first to recognize and propound the concept of base level of erosion of rivers. It may be noted here that although Powell is generally given credit for being the first to propound the concept of base level, to a certain degree credit for this idea should go to Colonel George Greenwood, a Britisher (Chorley al, 1964), who as early as 1857 grasped the concept of temporary base level. Unfortunately, Greenwood never received the recognition that he deserved, because of his arrogant attitude toward his opponents.

G. K. Gilbert (1843-1918) has been called the first real geomorphologist of North America. He made a detailed analysis of the processes of sub-aerial erosion and the modification which valleys undergo as streams erode the land.

W.M Davis (1850-1934) is considered 'the father of American geomorphology'. He was a great definer, analyst, expositionist systematizer. The Davisian school of geomorphology and the American school are practically synonymous terms. Before his time, geomorphic description was largely in empirical terms. He instilled new life into geomorphology through introduction of his genetic method of landform description. However, he is best remembered for his concept of geomorphic cycle (1899), an idea perhaps vaguely glimpsed by Desmarest.

Davis was a prolific writer. Between 1880 and 1934 he published nearly 400 research papers and books.

The Davisian concept was based on the work of running water, which according to him was the process of normal erosion. The concept of normal erosion met with opposition in Germany and the Soviet Union. Between 1920-30, Walther Penck of Germany opposed the views of Davis. He stated that contrary to Davisian view that the cycle of erosion started on a relatively rapidly uplifted landmass, and thereafter there is a long period of stand-still during which the geomorphic cycle is completed, in reality, the uplift is slow initially and later it is so rapid that it prevents the landscape from undergoing through the various stages whose penultimate result is a featureless low lying surface. Several American geologists, particularly from the Pacific Coast "mobile belt" have been skeptical of the postulation that the earth's surface is ever stable long enough to allow a cycle to proceed to completion.

16.6 POST-1950 TRENDS IN GEOMORPHOLOGY

After 1950 geomorphology underwent sea-change in the methods, approaches, conceptual framework, paradigm and thrust areas of study. There followed a period of persistent questioning of the Davisian model, and a gradual change from the temporal mode of explanation and the inductive approach to processes response systems approach based on the use of the deductive scientific methods.

16.6.1 Increasing Criticism of the Davisian Model :

There has been increasing criticism of the views of W. M. Davis, especially those relating to his concept of cycle of erosion. The concept of pediplain proposed by L.C. King has been given more importance than the concept of peneplain as suggested by Davis, in the evolution of landscape, though they agreed that there are oscillations but no return to the initial stage.

16.6.2 Growth of Climatic geomorphology :

Another important development has been the growth of climatic geomorphology according to which the landscapes which develop in the different climates are different, and the processes of erosion differ significantly in different climatic regions. Based on this, the concepts of morpho-climatic systems have evolved which determines the processes of landform evolution and gives rise to a distinctive ensemble of landforms.

16.6.3 Growth of structural geomorphology :

An important development has been that modern approaches to the study of geomorphology have become more broadly based. Apart from the physical laws governing the operation of the agents of denudation, the materials upon which these agents act have come to be more closely studied in terms of their physical properties and relations. The creation of new crustal structures, crustal behaviour and deformation have increasingly become of vital concern and interest to geomorphologists. This field of study has come to be termed as structural geomorphology with the concept of sea-floor spreading and plate tectonics, physiography of the ocean basins has currently become an integral part of geomorphology. As consequences the study of geomorphology has come to have a global as well as a regional perspective.

16.6.4 Growth of applied geomorphology :

Applied geomorphology is a newly developed branch of geomorphology. D.K.C.Jones

(1980) defines applied geomorphology as "the application of geomorphic understanding to the analysis and solution of problems concerning land occupancy, resource exploitation, environmental management and planning". The main theme of applied geomorphology is to investigate the impact and changes brought in natural environmental systems and geomorphic processes by human activities; to suggest suitable remedial measures to problems; to study the impact of geomorphological/ environmental processes on different aspects of human society; and to attend the problems of resource management and monitor changes in the geomorphic/ environmental systems.

16.6.5 Rise of quantitative geomorphology :

There has been an increasing emphasis on field observations and laboratory experiments in recent decades. Quantitative geomorphology makes it possible to measure and establish the geomorphic processes and laws with greater precision and accuracy. In fact, quantitative methods have become a common tendency in all scientific subjects. Since the early fifties geomorphology has been progressing towards a more scientific foundation through its concern with measurement and scientific analysis of data, and the adoption of statical analysis as a means of testing hypotheses.

The most outstanding contribution to the advancement of geomorphological knowledge in this period is the adoption of quantitative approach based on deductive scientific method to the study of landforms and processes.

Environmental geomorphology is the latest development in the field of geomorphology. In fact, it is a significant aspect of applied geomorphology.

16.7 INDIAN CONTRIBUTIONS TO GEOMORPHOLOGY

Geomorphological studies stated quite late in India, i.e. in the early 1930's when Post Graduate teaching geography was started at Aligarh Muslim University in 1931, followed by Calcutta University (1941), Allahabad University and Bananras Hindu University (1946). However, there was no systematic teaching in the beginning, and only sporadic information in the form of reports, articles, essays, etc. were provided by administrators investigators, travelers and geologists. Like overseas development of geomorphology, independent status to geomorphology as a separate discipline was accorded by geologists in India too. Initial start was given by eminent geologists like Heren, Wadia , Dunn, West, S.C. Chatterjee, Auden, R.Krishnan, and by geographers like Chibber (basically geologist), S.P.chatterjee, S.C.Bose, R.P.Singh, E.Ahmed, K. Bagchi, R.L.Singh etc. These scientists primarily based their work on Davisian model of 'cycle of erosion' and 'denudation chronology approach'. Topographical maps and gazetteers provided the basic data.

During the decades 1950-60 and 1960-70, more attention was paid towards the study of physiographic regions of Peninsular India. R. P. Singh, A. K. Sengupta, E. Ahmed, S. C. Bose, W. D. West, V. D. Chaubey, R. Vaidyanathan, B. Venkatesh, G. V. Rao, etc. made significant contributions. The 21st International Geographical Congress held in 1968 in New Delhi aroused deep interest in geomorphological researches in the country. B. C. Acharya, G. K. Dutta, M. K. Bandopadhyaya, D. Suza, R. N. Mathur, H. S. Sharma, A. K. Sengupta, D. Niyogi, S. K. Sarkar, S. Mallick, A. K. Pal, S. Subba Rao, A. B. Mukherjee, S. Sen, E. Ahmed, H. R. Betal, S. C. Bose, R. S. Dubey, M. V. Kayerkar, S. K. Badhawan, etc. made rich contributions to systematic geomorphology.

Post IGC period witnessed a steep rise in geomorphological researches by Indian scientists in the fields of fluvial, arid, glacial, coastal, structural, and quantitative geomorphology. However, most of the works were still based on information derived from topographical maps and casual field observations.

Morphometric analysis of terrain Characteristics based on topographical maps was initiated by R. L. Singh in his presidential address at the joint session of geology-geography section of Indian Science Congress held in 1967. A few Ph.D. dissertations on 'landforms and settlements' were presented by K. N. Singh, 1967, V. K. Asthana (1988), S. C. Kharkwal (1969), Meera Agarwal (1970), O. P. Singh (1977), etc. in the Department of Geography, Banaras, Hindu University, Varanasi.

Significant contributions were made in different aspects of Indian Geomorphology by S. C. Mukhopadhyaya (Geomorphology of Suvarnarekha basin—1968). E. Ahmed (Ranchi to Rajaroppa, 1969), S. C. Chakravarti (Geomorphological evolution of West Bengal, 1970), Swami Pranavanad (Sources of four great rivers of India, 1970), J. P. Singh (Geomorphological evolution of Meghalaya, 1970), K. R. Dikshit (Erosion surfaces and polycyclic reliefs of Deccan Trap, 1970).

The Poona School of Geomorphology led by K.R.Dikshit, V.S.Kale, S.R.Jog, S.N.Karlekar etc. concentrated on fluvial geomorphology, river bed morphology, alluvial morphology, coastal geomorphology and structural geomorphology of Western coasts of Maharastra.

The Kolkata center of geomorphology is given the credit for early start in Geomorphological researches by S. P. Chatterjee and K. Bagchi. Presently, Calcutta University is known for researches in different branches of geomorphology. M. K. Bandopadhyaya is actively engaged in the study of glacial geomorphology of the Himalays. S. C. Mukhopadhyaya has made rich contributions in fluvial Geomorphology, while landslides in the eastern Himalayas are regularly monitored by S.R.Basu.

The Central Arid Zone Research Institute (CAZRI) at Jodhpur has made outstanding contributions in arid Geomorphology and applied Geomorphology on the basis of intensive field surveys and remote sensing. Geomorphologists like Bimal Ghosh, S.Singh, P.C.Vats and Amalkar have done commendable job in these fields.

16.8 LET US SUM UP

The study of landforms is known as Geomorphology- a science this has developed with the aid of geologists, geographers and engineers. The changing definition of Geomorphology has been accompanied by modifications in the methods adopted by geomorphologists in their investigations. The scientific and quantitative emphases have contributed much to the development of Geomorphology.

16.9 KEYWORDS

Catastrophism	:	Violent and sudden changes in the earth's surface due to volcanic and earthquake activities.
Uniformitrianism	:	A doctrine which states that whatever geomorphic processes are present today were also present in the past, in other words present is the key to the past.
Peneplain	:	A plain area without much irregularity formed due to erosion and deposition.
Pediplain	:	A plain formed by the process of denudation as per L.C. King.
Denudation	:	Combined processes of erosion and weathering of earth's materials.
Base-level	:	Maximum extent to which a stream can erode its valley and beyond base-level, erosion is not possible unless upliftment of valley takes place.

16.10 QUESTIONS FOR SELF STUDY

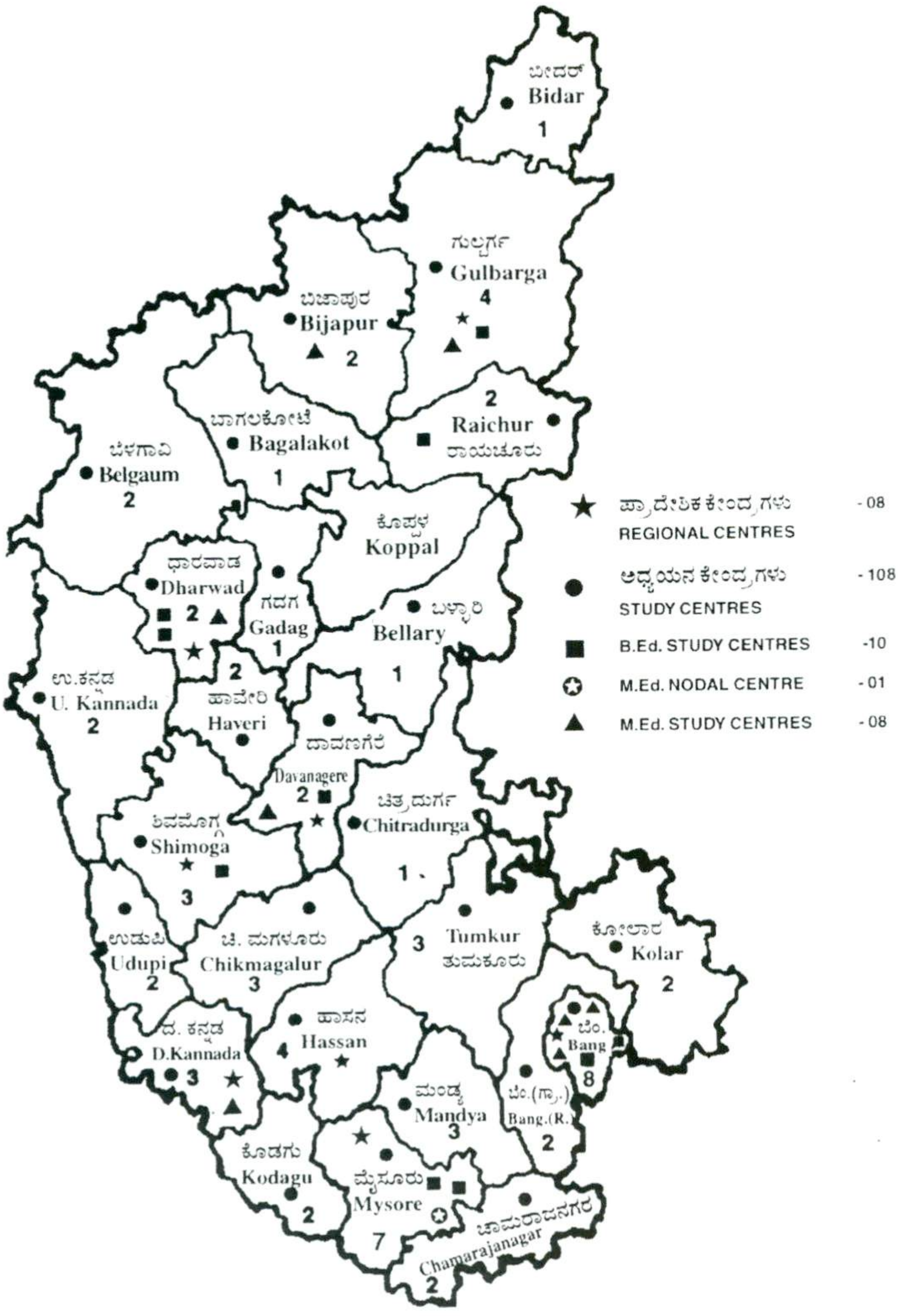
1. Discuss the early views on Geomorphology.
2. Explain the principle of Uniformitarianism.
3. Describe the development of geomorphology in North America during 1875 -1900.
4. Elucidate the recent growth of various branches of modern geomorphology.
5. Give an account of the Contributions made by Indian geographer to the growth of Geomorphological knowledge.
6. Critically examine the contributions of W.M. Davis to the development of geomor phological knowledge.

16.11 FURTHER READINGS

1. **Brown E. H. and R. S. Waters,** 1974 : Progress in Geomorphology British Geographers. London
2. **Bryan K.,** 1950 : The place of Geomorphology in the Geographic Sciences: AAAG.
3. **Peel R.F.,** 1967 : Geomorphology: Trends and Problems
4. **Merril G.P.,** 1959 : Geomorphology in North America
5. **Alka Gautam,** 2009 : Geomorphology: Sharada: Allahabad

ಕರ್ನಾಟಕ ರಾಜ್ಯ ಮುಕ್ತ ವಿಶ್ವವಿದ್ಯಾನಿಲಯದ ಪ್ರಾದೇಶಿಕ ಹಾಗೂ ಅಧ್ಯಯನ ಕೇಂದ್ರಗಳು

Regional and Study Centres of Karnataka State Open University



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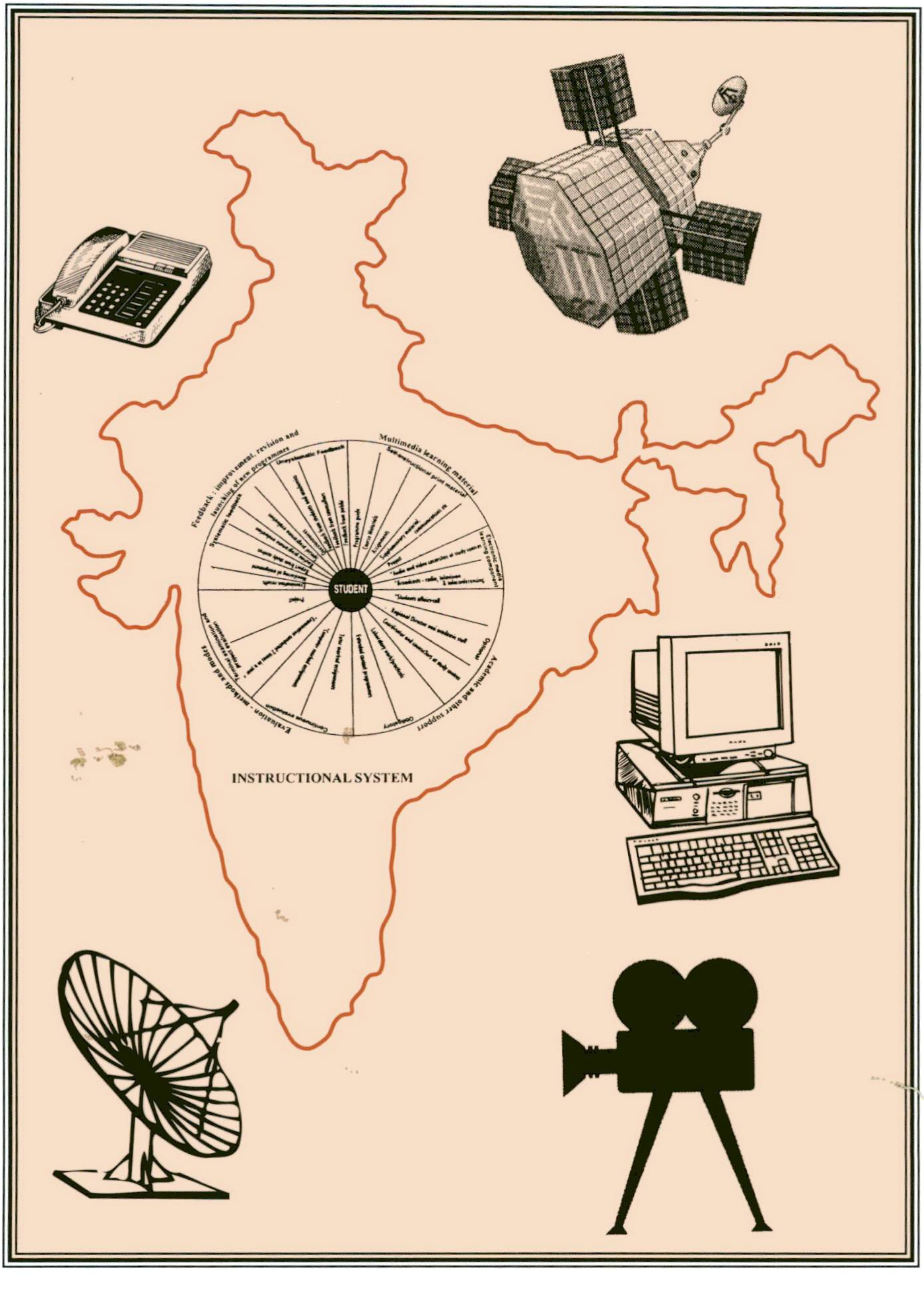
The Number Indicate the Total Number of Study Centres Existing in that Districts.


Multimedia learning material
Feedback : improvement, revision and launching of new programmes
Academic and other support
Evaluation - methods and modes
STUDENT
INSTRUCTIONAL SYSTEM