NETAJI SUBHAS OPEN UNIVERSITY

STUDY MATERIAL

POST GRADUATE GEOGRAPHY

Paper : 1

Groups : A & B

Group A
Geotectonics & Geomorphology
Group B
Hydrology and Oceanography

PREFACE

In the curricular structure introduced by this University for students of Post-Graduate degree programme, the opportunity to pursue Post-Graduate course in Subjects introduced by this University is equally available to all learners. Instead of being guided by any presumption about ability level, it would perhaps stand to reason if receptivity of a learner is judged in the course of the learning process. That would be entirely in keeping with the objectives of open education which does not believe in artificial differentiation.

Keeping this in view, study materials of the Post-Graduate level in different subjects are being prepared on the basis of a well laid-out syllabus. The course structure combines the best elements in the approved syllabi of Central and State Universities in respective subjects. It has been so designed as to be upgradable with the addition of new information as well as results of fresh thinking and analysis.

The accepted methodology of distance education has been followed in the preparation of these study materials. Co-operation in every form of experienced scholars is indispensable for a work of this kind. We, therefore, owe an enormous debt of gratitude to everyone whose tireless efforts went into the writing, editing and devising of proper lay-out of the materials. Practically speaking, their role amounts to an involvement in 'invisible teaching'. For, whoever makes use of these study materials would virtually derive the benefit of learning under their collective care without each being seen by the other.

The more a learner would seriously pursue these study materials, the easier it will be for him or her to reach out to larger horizons of a subject. Care has also been taken to make the language lucid and presentation attractive so that may be rated as quality self-learning materials. If anything remains still obscure or difficult to follow, arrangements are there to come to terms with them through the counselling sessions regularly available at the network of study centres set up by the University.

Needless to add, a great deal of these efforts is still experimental—in fact, pioneering in certain areas. Naturally, there is every possibility of some lapse or deficiency here and there. However, these do admit of rectification and further improvement in due course. On the whole, therefore, these study materials are expected to evoke wider appreciation the more they receive serious attention of all concerned.

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Netaji Subhas
Open University

PGGR-01
Geotectonics and Geomorphology Hydrology and Oceanography

Group A

Part I : Geotectonics

Part II : Geomorphology

Group B Hydrology

Oceanography

PART I

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UNIT 1 : MODERN THEORIES OF THE ORIGIN OF THE EARTH

1.1 SYNOPSIS

Two groups of hypotheses exist to explain the origin of the earth. They are ***1) Monistic hypotheses*** or ***Parent hypotheses*** and, *2)* ***Dualistic hypotheses*** **or** ***Bi-parental hypotheses*** Immanuel Kant and Marquis de Laplace put forward their Nebular hypothesis in the second half of the 18th century assuming that a rotating nebula was responsible to our solar system The advocates of the ***Dualistic hypotheses*** describe collision two stars or their mutual ap proach. Recently a more logistic theory, namely ***Big-bang Theory*** has come up to explain the origin of the universe as the earth.

1.2 INTRODUCTION

The concept of the origin of the earth is based much on speculation. The various theories put forward since Kant and Laplace have tried to be reasonable as for as possible at the time they were propounded. Subsequent discovery of facts about the heavenly bodies and other physical discoveries disclose the weakness of the various theories. The origin of the earth or the solar system is not an isolated subject. What may be accepted for the origin of the earth and the solar system must give a clue to the origin of the universe as well. This subject, therefore, is not under exploration. As one derides the past theories in the light of newly discovered physical facts, those theories which are deemed as modern may be discarded in future after the discovery of newer facts. When we try to understand the origin of the earth, we are concerned with vast space, long time, high temperature and unknown gravitational fields. To make such facts relatively comprehensible, mathematical calculations have been attempted within the framework of observed realities.

1.3 HISTORY OF THE DEVELOPMENT OF MODERN IDEAS

In the 2nd century A.D. Ptolemy, the Egyptian Astronomer developed the theory of Aristotle stating that the earth was the centre of the universe. Although his proposition was basically wrong his model provided a reasonably accurate system for predicting the positions of heavenly bodies in the sky. Nicholas Copernicus, a Polish philosopher and scientist, in 1514 first refuted Ptolemy's model of static earth and revolving sun; he said that the was stationary at the centre and the earth and other planets moved in circular orbits around the sun. In 17th century John Keppler (a German) and Galileo Galilee (an Italian) publicly supported Copernicus's theory as they viewed the movements of planets through the telescope-the elliptical orbit was supposed. In 1687 Sir Isaac Newton published his *Principia Mathematica* (the most important single work ever published in Physical Science). He postulated a law of universal gravitation according to which, a force attracted each body in the universe toward each other. According to this law gravity causes elliptical paths around the sun. According to Newton's law the universe cannot be static-it might be expending. The renowned German scientist Albert Einstein put forward his Theory of Relativity in 1915. He said that the light was the fastest and a planet's orbit around the sun arises from its natural trajectory in modified spacetime; there is no need to invoke, as Newton did, a force of gravity coming from the sun.

<u>Progress of ideas about the origin of the universe</u>

The theories explaining the possible origin of the solar as system as well as the earth can be put into two classes :

(a) ***Monistic hypotheses*** **or** ***Parent hypotheses*** in which the origin of the solar system is believed to have taken place from a single star or nebula *(the Nebular hypothesis).* This process is called the *evolutionary* process of the origin of the solar system. The chief protagonists of this school of thought are Kant, Laplace, Lockyer, Hoyle Weizsacker and Kuiper.

(b) ***Dualistic hypotheses*** **or** ***Bi-parental hypotheses*** in which the planets of the solar system are believed to have originated as a result of coming together of two stars. In this school of thought we may include the *Planetesimal hypothesis* of Chamberlin and Moneton, the *Tidal hypothesis of Jeffreys,* the Binary *Star theory* of Russel and a few others.

1.4 MONISTIC HYPOTHESES OR PARENT HYPOTHESES

1) The Gaseous Hypothesis of Immanuel kant

The German philosopher Immanuel Kant first proposed his *Gaseous hypothesis* in 1755 which had its basis in Newtonian's law of gravitation's law of gravitation. According to Kant, in the beginning, hard cold and motionless particles stated colliding and falling on one another. The collision generated heat as well as rotation. In course of time through this process the original cold and motionless cloud of matter was converted into a hot and rotating nebula. With further increase in temperature this nebula began to rotate with that buldge started developing in the middle part as a result of centrifugal force. When the centrifugal force became more intense, the central buldge separated from the nebula in the form of a ring which changed into planet in course of time. Nine successive rings came out of the nebula in this manner and they ultimately formed nine planets. The remaining central part of the original nebula formed the sun. Thus according to Kant the earth has originated by the aggregation and solidification of the materials, which separated from the nebula in the form of a ring also separated from the planets resulting in the formation of satellites. It is this manner that, according to Kant, the entire solar system has originated.

Criticism : Kant's hypothesis has been found to be against mathematical laws. Kant's assumption that the mutual collision of particles resulted in the generation of rotational movements in the nebula is against the principle of the conservation of angular momentum. The second assumption of Kant that the rotation of the nebula increased in speed with increase in size and when the speed increases, size will decrease. Thus the basic assumptions, on which Kant built his hypothesis, have been found to be untenable. The importance of this hypothesis, however, lies in the fact that this was the first hypothesis based on Newton's *Law of Gravitation* and was the forcunner of the famous Nebular hypothesis proposed by the French mathematician Laplace in 1796.

2) Nebular Hypothesis of Laplace

Laplace presented his views regarding the origin of the earth in 1796. His views had great resemblance with those of Kant, but in all probability he had no knowledge of Kant's publication. His views primarily influenced by two facts: a) existence of nebula in the universe, and b) the presence of a ring round the planet Saturn. Laplace starts with the assumption that there exists in the universe a massive hot and rotating nebula. The nebula went on decreasing in size as a result of constant cooling. He makes no mention of how this nebula originated, but by his imagining the existence of nebula, he saves himself from the criticism leveled against Kant's hypothesis about collision and primordial matter generating heat and movement.

As a result of the rapid rotational movement of the nebula, its outer part started losing heat by radiation. Cooling led to contraction of the nebula and decrease in its volume, the reduction in volume resulted in increase in its speed of rotation. The increased rotation led to increase of centrifugal force, until a stage was reached when there was an exact balance between the centrifugal force and the gravitational force at the equator of the rotating nebula. When this stage was reached the ring of material near the equator would have no weight and this part therefore started bulging out. Laplace accounted for the formation of the seven planets then known through this process, and further repetition of the same process led to the birth of the satellites of the planets. The central residual mass of the nebula remained as the sun.

The hypothesis of Laplace had the merit of being simple, and with its help it was possible to explain the uniformity in the direction of rotation and revolution of all the planets and the satellites. Further, this hypothesis could also explain why the orbits of the different planets were roughly circular and in the same plane. According to this hypothesis, the earth and the other planets were first in a gaseous state, and later on they passed through a molten stage and Finally the solid crust was formed.

■ **CRITICISM** : For the above reason of simplicity and apparently logical explanation this hypothesis continued to hold ground for more than a hundred years, but several objections started being raised against it by the beginning of the twentieth century and the theory came to be seriously doubted in the light of new scientific facts. The main objections are as follows :

(i) British physical James Clerk Maxwell proved with the help of his investigations that if we assume the total mass of all the planets to be a ring around the sun, then this mass is so small that it was impossible for it to condense in planets under the influence of gravitational attraction.

(ii) The second important objection is related to the distribution of angular momentum in the solar system. As the moment 98% of the total angular momentum of the solar system is present in the planets and only 2% is found in the sun. If the hypothesis of Laplace is correct then the sun should have several times its present angular moment and its speed of rotation should be 200 times more than its present speed.

(iii) Laplace and his supporters have not pointed it out as to how the gaseous rings collected into rounded planets. According to the laws of dynamics it is more probable that the rings would break into smaller and roughly equal parts and several small planets would be formed in the same orbit.

(iv) It is more probable that on account of the small degree of cohesion between the particles of the nebula, the formation of the rings would be a continuous and not an intermittent process. The contraction of nebula would also be continuous and not intermittent.

(v) If the rings were composed of extremely hot gases, then the chances are that they would escape from the gravitational field of the sun and thus the gaseous rings would be lost in space.

(vi) According to this hypothesis all the satellites should revolve in the direction of their parent planets, but the direction of revolution of some of the satellites of Uranus, Neptune, Jupiter and Saturn are retrograde to the normal direction of the revolution of the planet's.

1.5 DUALISTIC HYPOTHESES OR BI-PARENTAL HYPOTHESES

1) The Planetesimal Hypothesis of Chamberlin and Moulton

T. C. Chamberlin and F.R. Moulton of the University of Chicago proposed this hypothesis in 1905. Through this hypothesis they tried to explain not only the origin of the earth but also the origin of the atmosphere and the oceans. Contrary to the views then prevailing they thought that the planets have not originated from a nebula the remnant of which is the sun, but that they originated as a result of the coming together of the sun and another star.

According to them as another star big star happened to pass close to the sun, the severe tidal distortion due to the approach of the star together with the eruptive tendency inherent in the sun, caused a disruption of the sun's mass. The tidal disruption led to the ejection of jets of solar matter to great distances, the passing star drawing them forward in the line of its own motion. The total mass that was ejected from the sun was much greater than the total mass of the existing planets, but a large part of it fell back on to the sun's surface. The portion that remained out of the sun, condensed from the gaseous state into tiny solid particles called planetesimal. The planetesimal developed a nucleus round which the scattered tiny planetesimals collected, and thus through the aggregation of innumerable planetesimals around separate nuclei the different planets were formed. According to this hypothesis it is not necessary to assume that the earth was ever in a molten state. The earth has been formed as result of the aggregation of planetesimals round a nucleus. As the planetesimals collected round the nucleus, the size of the sun went on increasing, first rapidly and then slowly, until it reached its present size and form.

Possibly there was no atmosphere in the early stages of the earth's formation. But as the size of the earth increased with the aggregation of then planetesimals, the atmospheric elements also started developing.

In the course of evolution of the earth the pressure in its interior went on increasing resulting in increasing temperature. Volcanic activity started from the internal molten reservoirs and the first Achaean igneous rocks were formed. Chamberlain has envisaged three principal statges of the earth's evolution : *a) period of planetesimal accretioin, b) period of dominant volcanism,* and *c) the actual geological period.*

■ **CRITICISM** : Although the basic assumptions of this hypothesis namely, the formation of planets by planetesimal accretion have been considered important concepts, vairous objections have been raised against this hypothesis as follows :

(i) The basis of this hypothesis is the passing star close to the sun at a sufficiently high speed, in order that matter may be drawn out from the sun, the passing star must have come within a distance of the sun not more than the diameters of the two stars themselves. This seems to be an extremely unlikely event. Further, their closing velocity must have been at least 3,000 miles per second. This figure is considered unreasonable because it exceeds the escape velocity of the galaxy.

(ii) This hypothesis has been built on a catastrophic and extraordinary event. It is unreasonable to base any concrete scientific hypothesis on such an event.

(iii) If the planets have been formed by planetesimal accretion, then they should possess much less angular momentum than they actually have.

(iv) According to Jeffreys the nucleus of the planet was incapable of attracting the atmospheric elements. Thus in his view the hypothesis presents a wrong picture of the origin of the atmosphere and is unable to solve the other problems relating to the origin of the earth.

2) The Tidal Hypothesis of James Jeans and Harold Jeffrey

The British astronomer Sir James Jeans propounded his tidal hypothesis of the origin of the solar system in 1919 and Sir Harold Jeffrey introduced some important modifications in it in 1926. The names of both Jeans and Jeffreys are therefore associated with *tidal hypothesis*.

According to this hypothesis the solar system has been formed as a result of the coming together of the sun and another passing star. A huge star, many time bigger than the sun, happened to pass close to the sun. The gravitational attraction of the passing star had a powerful tidal effect on the sun and through tidal action a part of the sun was raised in the form of a large cigar-like gaseous filament, which ultimately broke lose and separated from the sun on account of the high gravitational attraction of the star. The outer fragments of this filament were lost in space ; its inner part fell back upon the surface of the sun. The filament, according to Jeans, was unstable lengthwise and soon broke up into several sections, each forming a distinct aggregation of matter later to develop by cooling and contraction into a planet. Jeffrey suggested, however, that the aggregations might come into being shortly after the ejection of the corresponding solar material. In other words, the filament may not be strictly regarded as continuous but rather as a series of condensations whose masses and spatial distributions are shown by him to be roughly in accordance with the present position and characteristics of the planets in the solar system.

■ **CRITICISM** : The tidal hypothesis of Jeans and Jeffrey received wide acceptance for some time, but more recently several objections have been raised against it as follows :

(i) Levin (1958) put forward the view that the stars lie at such vast distances from each other in the space that the possibility of their coming close together or their mutual encounter can easily be ruled out.

(ii) Where did the big star which was responsible for the tidal ejection of solar materials go? No satisfactory answer is available to this question.

(iii) The gaseous matter, which would be ejected from the sun, would be so hot and there would be so much momentum in the gaseous particles that they would soon be lost in space.

(iv) The planets have been formed from the solar matter, then the sun and the different planets should all be composed of similar materials. But in fact, this is not so. There is predominance of lighter elements (hydrogen and helium) in the sun, while the planets are composed mostly of heavier elements like iron, silicon, aluminum etc.

(v) N. N. Parisky has tried to show by mathematical calculations that this hypothesis is unable to explain the distances between the sun and the different planets. American astronomer Russell has also pointed out that on the basis of this hypothesis the planets should be much closer to the sun but they are in fact much farther apart.

3) The Binary Star Hypothesis of H. N. Russell

The principal weakness of the hypotheses that we have considered so far is that they are unable to provide satisfactory explanation for the great distance of the planets from the sun and their circular orbits round the sun. This difficulty can be removed if it is assumed that materials, which formed the planets, were far removed from the sun from the very beginning. Accordingly H.N. Russell suggested that there was another companion star of the sun and the two together formed a binary star or a twin-star system. A third star happened to pass close to the companion star of the sun, and this resulted in the ejection of gaseous matter from the latter in the form of a filament which ultimately separated from it. The planets were formed from this gaseous filament of matter in course of time. The beginning the planets were closer together and the satellites owe their birth to the mutual gravitational attraction between them.

Other hypothesis on the origin of the solar system and the earth

A number of other hypothesis regarding the origin of the earth solar system have been put forward by several scientists during the first half of the 20^{th} century. Among them following are important to mention : 1) The Fission Hypothesis of Ross Gun, 2) The Cepheid Hypothesis of A.C. Banerjee. 3) The Nova Hypothesis of F. Hoyle and R.A. Lyttleton, 4) The Electromagnetic Hypothesis of Hannes Alfven, 5) The Inner-Stellar Dust Hypothesis of Otto Schimdt, 6) The Nebular-Cloud Hypothesis of Dr. Von Weizscacker, and 7) The Protoplanet Hypothesis of Gerald Kuiper.

1.6 RECENT THEORIES EXPLAINING THE ORIGIN OF THE UNIVERSE AND THE SOLAR SYSTEM

The scientists of Cosmology and Astrophysics today are more concerned with study to explore how the present universe came into being. Since 1920's several theories have been put forward among which the most important are the ***Big Bang Theory*** and the ***Steady State Theory.***

1) The Big Bang Theory: Alexander Friedmann (the Russian physicist) and Edwin Hubble (the American physicist), during 1922-24, through their independent work, reached a decision that the universe was created (10,000 to 20,000 million years ago) by a sudden explosion. Before that all space and matters of the universe was squeezed into a hot super dense state, called ***Black Hole.***

2) The Steady State Theory : The Steady State Theory was an alternative view put forward in 1948 by Fred Hoyle, a British Scientist. He said that the universe had no origin ; the matters continuously being created with this expanding universe because new matter is continuously created.

In the present day the Big Bang Theory has been universally accepted and further studies are in progress through NASA (National Aeronautics and Space Administration) of U.S.A. The renowned astronomer Jeal Tarter has opened a new project NASA SETTI on 12th October 1992 to explore through the universe for any possible life in other planets.

1.7 QUESTIONS

1) Discuss in detail about the Parent Hypothesus of the origin of the Earth.
2) What are the recent theories explaining the origin of the universe and the solar system.

1.8 SELECT READINGS

1) A Brief History of Time - Stephen W. Hawking
2) The Universe - Stephen W. Hawking
3) An Outline of Geomorphology - S. W. Wooldridge & R. S. Morgan
4) Physical Geography - Ahmed, E.

Unit 2 ☐ The Concept of Isostasy and Related Theories

Unit 2 : THE CONCEPT OF ISOSTASY AND RELATED THEORIES

2.1 SYNOPSIS

i.e., if anything occurs to modify the existing state, a compensating change will occur to maintain a balance. The most obvious example of this is the deep roots of mountain chains; as erosion of the mountain occurs, reducing their height, compensation in the forms of renewed uplift occurs. Continental blocks may be depressed under the load of an ice sheet, recovering when the ice melts. In this way variations in the relative levels of land and sea may be explained. The concept of Isostasy depends upon the model of the earth's crust in which lighter continental masses float on a denser substratum. Scientists Pratt and Airy explained the pattern of Isostatic balance of the earth's crust with their formulated theories.

2.2 DEFINITION AND INTRODUCTION

Isostasy is the theory or concept, which supposes that the adjoining regions of the earth's crust are in balance among them. Some scientists have subjected this theory to strongly adverse critisism. It was described as a denied fact, an 'illusion' by Glennie (1932 & 1933). Heiskanen, on the other hand, advocated as early as 1931 that isostatic compensation was 'an established principle'not by mere'hypothesis'.

Heiskanen's acceptance of isostasy rested on the fact that both old and new observations had proved prevalence of isostatic compensation in the crust of the earth. At the same time he admitted that there were examples both of small as well as large regions, which were not isostically adjusted.

Wooldridge and Morgan defined isostasy as a complex body of ideas dealing with the relation between the outer of the rotating earth and underlying layers.

The entire concept supposes that there is a hydrostatic balance of the hard and rigid earth's crust with reference to an underlying weak crust, which is either liquid or can behave as a liquid under great pressure.

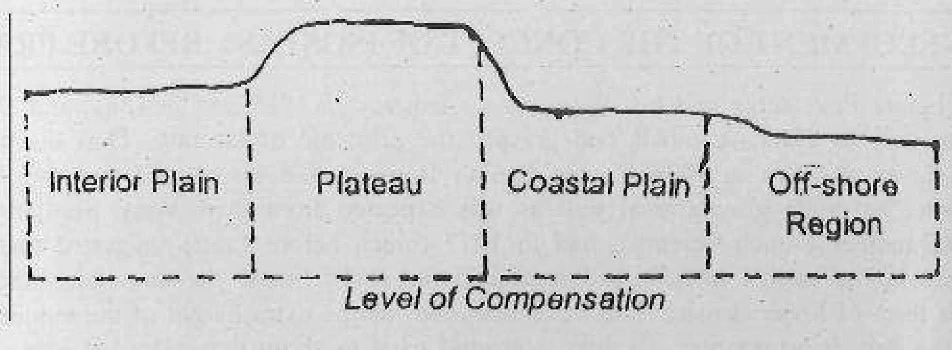


Figure 1: An interpretation of Isostasy

There are geological and seismic evidences about this liquid or potentially liquid substratum or asthenosphere. The geological evidence is in the form of liquid lava from central or linear volcanic eruptions. More recently geophysical investigations in connections in connection in connection with *Plata Tectonics* along the midoceanic ridges prove the continued up-welling of liquid basalt along the rifts that characterize the crests of these oceanic ridges.

Isostasy can be understood with reference with reference to some familiar examples relating to hydrostatic balance. We may see two boats standing side by side quietly in water. If we put load in one of them, water below this loaded boat will be pressed down and flow out raising the adjoining boat. If one of the boats is deloaded, the water relieved of pressure will raise it from below. There will be flow of water from below the adjoining boat so that this moved-in water takes the place vacated by raising water below the adjoining boat so that this moved-in water takes the place vacated by raising water below the deloaded boat. All these are characteristics of hydrostatic of hydrostatic balace, which is found in all liquids. The force of buoyancy produced by the immersion of a solid in a liquid works in a direction opposite to that of gravity. The force of buoyancy is equal to the volume of displaced fluid multiplied by the acceleration due to gravity. The force of buoyancy is equal to the volume of displaced fluid multiplied by the acceleration due to gravity. As mentioned earlier two or more adjoining boats standing quietly in water may have been built of different materials, e.g. lightwood, heavy wood, iron and aluminum. But despite their variety in built and size they may be made to stand side by side in mutual quiet. This means that there is some level in the water above which the mass on the adjoining sides including the boats and the water below is mutually equal assuring the equal assuring the quiet position of the adjoining boats of different, size composition and load. As a crude illustration of isostasy we may consider the above-noted hydrostatic characteristics

Definition given by Dutton : As the geologist Holmes mentioned the term isostasy *(Greek word 'isostasios 'meaning equipoise)* was proposed by the American geologist Dutton in 1889 who said that *for the ideal condition of gravitational equilibrium that controls the height of continents and ocean floors in accordance with the densities of their underlying rock.*

2.3 DEVELOPMENT OF THE CONCEPT OF ISOSTASY BEFORE PRATT

Much before Pratt submitted his discussion of isostasy in 1855 and in 1861, and Dutton coined the term in 1889, scientists had grasped the principle of isostasy. Thus during the geodetic survey of Peru in 1735-45, the French Bouguer had discovered that the Andes did not have as much gravitational pull as was expected from their mass. Similarly R.J Boscovich, another French Scientist, had in 1777 (much before Pratt) suggested that higt temperature in the earth's interior had expanded the rocks below the mountains and had thus made them of lower density. This 'Compensated for the extra height of the mountains'. In 1839 the British astronomer, sir John Harschel tried to show that a loaded part of the earth's crust subsided due to the 'plasticity' of the interior. In 1838 Babbage also discussed in a manner similar to that of Boscovich, *i.e.* thermal attenuation of rocks below the earth's surface. In 1849 Petit suggested that the Pyrenees had a deficiency of mass as detected in geodetic survey at Toulouse.

View of Pratt on Isostasy

During the triangulation survey of India by Sir John Everest in the middle of the nineteenth century, certain facts came to light, which sparked off the discussion and interpretation of isostasy. He believed that gradual changes of the earth's surface occur constantly due to miner-alogical and chemical changes within the interior below such surface.

According to Pratt, the earth at the time of its soldification process must have been a complete shperoid. With the gradual formation of the solid crust and its increase in thickness thermal expansion must have caused elevation. In the areas of expansion like High Asia if the density of rocks was low to a depth of hundred miles there would be no attraction of the plumb line at all at stations in northern India. Having considered the weak attraction of the High Himalaya in the north and the oceanic waters in the south Pratt assumed a 2% excess of density in central Indian belt between Kaliana and a deficiency of mass below High Asia as well as in Deccan.

Thus Pratt by means of mathematical calculations qualified a line of thought which was 'propounded a century earlier by Bougher and later by Babbage and Petit.

The views of Bowie and Hayford

Bowie : The American geodesist, W. Bowie was one of the two leaders along with J.F. Hayford, who guided the geodetic survey of the U.S.A. coast for 20 years. Hayford and Bowie tried to show the relation between gravity on the one hand and isostasy and topography on the other. The diagram after Bowie shows something of a laboratory experiment where eight metallic columns of equal cross sectioin stand side by side in a denser metallic medium *i.e.,* mercury. All columns extend into mercury up to the same depth known as isopiestic (i.e., level of equal pressing) level or level of compression. This simple example tries to show that the adjoining parts of the earth's crust roughly of equal extent or area may remain in balance with one another despite their different composition and density and that their base may extend to the same depth.

Hayford: The concept is shown by another diagram is said to illustrate to illustrate Pratt-Hayford type of isostatic compensation. The main points brought out by this diagram are that: i) density of the regions of the earth's crust vary above the level of compensation horizontally, not vertically ; ii) the higher the surface, the lower is the density of a column or region ; iii) the supposed depth of compensation under this concept is 112 km below the sea level. This means that by taking such an isopiestic level and assuming the densities and heights mentioned in the diagram the mass of the different columns would be mutually equal. The result would be a state of'quiet' which is the meaning of isostasy.

Examining the gravity anomalies in the Indian region which also suggested the distribution of densities in the crust of the sub-continent Gnennie remarked that "although isostasy as a fact is denied (in India), as an illusion it persists, hence the presentation of gravity results in the form of Hayford anomalies still remains the best method for universal application as a first step towards the investigation of the structure of the earth's crust. But like Glennie Hunter was critical of Hayford and maintained that isostasy in the sense that Hayfordian compensation was unjustified and misleading and should be dropped.

The views of Airy on Isostasy

Pratt read his first paper in the Royal Society of London in December 1854. Within about 7 weeks Airy submitted a paper explaining why the plumb-line was not attracted by the Himalaya to the same extent as it was expected. Airy emphasized that mountains and a rigid crust could not support other uplands. Airy supposed that the interior of the earth below the crust was of yielding medium. He supposed to be 'perfectly fluid' to present his ideas effectively. He suposed for the sake of convenience that the spheroid earth contained a plateau 2 miles high and 100 miles wide. He also supposed that the interior below the crust was fluid and of greater density than the crust which was ten miles thick.

In brief Airy argued that all regions of the earth above the sea level, *e.g.,* continents, plateaus and mountains are supported by a projection of their body into the substratum as 'root'. But this was generally regional *i.e.,* for larger areas and topographic features. It was not for individual hill or mountain, which was supported by its own rock strength and that of the adjoining areas.

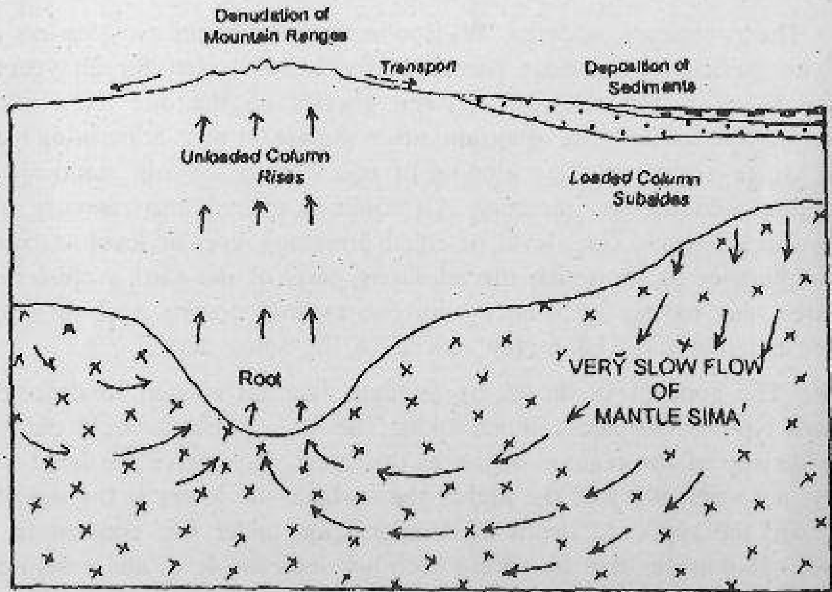


Figure 2 : The pattern of Isostatic re-adjustment as assumed by the earth scientists.

Airy is said to be the first scientist to have offered a clear and relatively full statement of the isostatic hypothesis. Airy's view is also preferred to Pratt-Hayford-Bowie concept because of two well-known facts : i) the density layers in the earth, as indicated by geological seismological findings are concentric, not columnar ; ii) the geological history of the earth indicates the dominance of compressional or tensional horizontal movements in the crust, not the vertical ones which is the impression created by Pratt-Hayford-Bowie concept.

View of Joly on Isostasy

Joly (1925) assumed a zone of compression rather than a single level as assumed in Pratt-Hayford-Bowie concept. It is a simplified presentation of the view of irregular roots of Airy. According to him the difference between the Pratt and Airy concepts is not so fundmental as would appear. The concept of equal mass beneath equal area accepted by hayford and Bowie is an acceptance of Floatation.

His zone of density variations is a 16 km layer. This occurs below the upper layer whose density is uniform. Thus, like Airy, Joly suggests a zone of uniform density occupying the upper part of the earth. In the lower 16km zone the sections of lower density are analogous to to Airy's roots. Horizontal variation of density in upper crust is not acceptable to Joly and if at all these were the case the geologic process of erosion and deposition would see remove such density variation.

The views of Arthur Holmes

In support of the views of Airy, Holmes agreed that the higher relief features of the earth's surface are composed of lighter materials and their major portions lie buried in the heavier and denser rocks below to keep them in a state of hydrostatic balance. He supported the root hypothesis of Airy and states that exploration of the crust by earthquake waves confers the inference that mountain ranges have roots largely composed of sialic rocks, going down to depths of 50 to 60 kms or less and beneath large parts of the deep ocean floor the sial is either extremely thin or totally absent. Figure 3 given below, based on Holmes shows a diagrammatic section through the crust and the upper part of the mantle and illustrates the relationship between surface features and crustal structure. In reality Holmes observation is the confirmation of Airy's views in the light of more recent knowledge about the distribution of sial, crustal sima and mantle sima as revealed by earthquake waves.

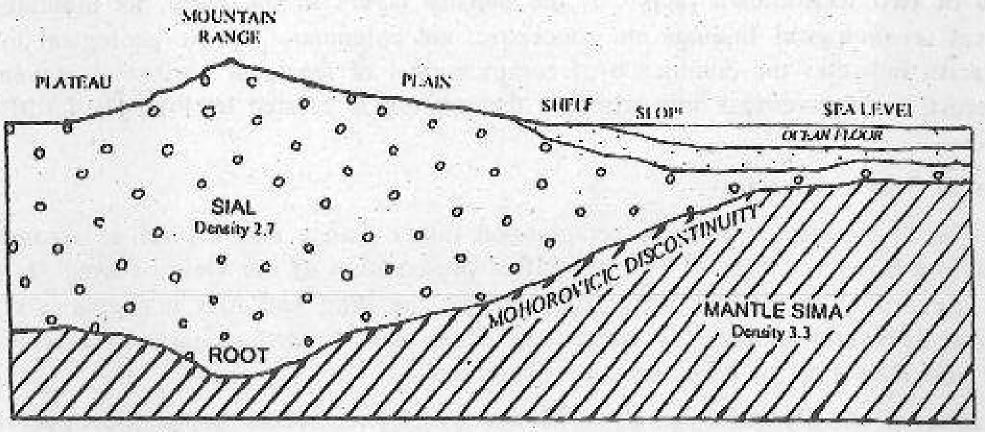


Figure 3 : Depth of sial below mountains, plateaus, plains and the ocean floor as conceived by Holmes

Heiskanen's concept

W. Heiskanen's contribution to the theory of isostasy is significant. This scientist was the author of the report on isostasy submitted in 1939.

Heiskanen modified Airy's concept in the sense that he showed variation of density within the sialic columns themselves. Although he accepted the root concept of Airy he also showed that the density may vary horizontally from column to column. According to him the sialic layer under oceans is extremely thin (5 km or so). Heiskanen was the scientist who for the first time extensively applied Airy's concept and he called his modified theory as Heiskanen Hypothesis. The basis of discontinuities for him in lithosphere was siesmological evidence.

Heiskanen tested isostasy in different areas. He found the thickness of sial in the Alps as 41 km. for Caucasus the figure was 77 to 104 km. He found the Alps, the Harz Mountains, Spitsbergen and West Indies in isostatic balance. He found that Airy's concept was better supported by the Alps and the Caucasus than Pratt-Hayford theory showing that isostatic compensation prevailed in the earth's crust. Yet he argued that there were both small as well as large areas, which were not, yet in isostatic equilibrium but were in the process of becoming so.

It was Heiskanen who had said as early as 1931 that isostasy was no longer a hypothesis but an established principle.

2.4 ANTIROOT HYPOTHESIS OF R.A. PALY

Although isostasy is an established principle, there can be several possibilities, which can satisfy the conditions of isostasy, as, illustrated by Daly's Antiroot hypothesis, which can be regarded partly as the reverse of Airy's root hypothesis. Daly's theory can be summarized as follows:

a) **The isopiestic depth** or level of compensation is 77 km below the sea level.

b) **A continent** as a whole has an anti-root, *i.e.*, a part of the plastic substratum is projected upwards below the continent. Such a phenomenon may be seen in salt domes where the plastic salt is injected upward by the pressure of the underlying matter and the covering layer may be domed up. Under the mountains there is a higher anti-root within the more extensive anti-root of continents.

c) As conceived by Heiskanen and as supported by geological observations density increases with depth in the continental as well as sub-oceanic crust.

d) A significant to point to note is that the density in the substratum is lower than in the underlying crust not only in *sima* but also in the lower part *ofsial.* This is due to the fact that the substratum is more expanded and has larger volume because of liquid nature than the overlying solid crust.

e) The *sialic* column containing the mountain chain is larger and has a 'root' *i.e.,* it is projected deeper than the other parts of the continents. Thus Daly's theory partly represents Airy's root concept as well.

f) The substratum is 'too hot to crystallise' and the source of heat is radioactive heating. About 77 km as the isopiestic level and the value of density or no attracting body.

2.5 ISOSTASY AND THE PHYSICAL ENVIRONMENTS OF THE EARTH

Rift valleys and Isostasy

Most of the rift valleys are sunken segments of the crust between normal faults. As these down faulted segments are relatively light upper rocks thrown down, they for zones of deficient mass. Thus Bullard's gravity anomalies for the East African Rift valley showed marked negative isostatic anomalies in the Lake Albert, South Tanganyka and Lake Magadi regions.

The heights of peaks and Isostasy

In all high mountain ranges particularly of geologically recent origin we can find a number of high pinnacles or peaks standing above the general level of the mountain ranges. The highest and the largest number of such peaks adorn the Himalaya from Godwin Austen and Nanga Parbat in the west to Namcha Barwa in the east.

There might be many causes for the elevation of mountain ranges but there is a ready explanatioin for the abnormal height of the peaks from isostasy. In all such mountain regions there is various down cutting by streams and huge gorges have been formed, e.g., between the head streams of the Indus, Ganga and the Brahmaputra systems.

In the peak region because of the permanent snow cover is seasonal due to the lower elevation, the peaks being in divide areas, characterized only by small incipient streams, will be marked by limited erosion and degradation. One of the evidences of continued uplift is the uplifted recent deposit particularly on the south of the Himalaya. Another is a series of river terraces.

Glacial adjustment due to Isostasy

One of the clearest evidences of the operation of isostasy is seen in the glaciated regions. No doubt the isostatic process of the inflow of deep-seated matter below a rising eroded region or the outflow of such matter from beneath a sediment-loaded area is slow and therefore there may be considerable time lag between the relatively rapid melt of ice-sheets and isostatic response which occurred in North America and Europe between about 8,000 and 11,000 years ago. The consequent uplifts are still continuing. Thus along the coasts of northern Scotland there are series of raised beaches showing successive uplifts of land following deglaciation in the post-Pleistocene period.

Lines joining places which were equally depressed underline load of Pleistocene ice-sheets, and those joining points which underwent equal post-glacial uplift since 6,800 B.C. to date in Scandinavian region are impressive instances of isostatic adjustments.

Evidences of Isostatic adjustments in the continental shields

The continental shields like Peninsular India, most of Africa, most of Australia, Brazilian Highland, Canadian Shield and Russian Platform have such characteristics, which support the theory of isostatic adjustment. These shields are built mostly of ancient, coarse-grained crystalline rocks. They lack marine beds. They also lack the evidences of compressive elevation. The general absence of marine rocks shows that they have escaped marine transgression during most of their life history.

The predominance of coarse-grained crystalline rocks and the frequency of deep-seated plutonic rocks like granite show that the overlying cover has been eroded and the deeper rock; have been exposed at the surface. The enormously long time that has marked the geologica history of these shields was sufficient for the base leveling of these land areas. But they have mostly remained above the sea. This means that there has been a strong continuously operativ and universally distributed elevating factor. And this appears to be the isostatic uplift follov ing continuous and extensive erosion and consequent deloading of the shields.

Submarine canyons and Isostasy

Submarine canyons form of the controversial problems of submarine topography. The troug like steep-sided, relatively flat-floored, winding valleys occurring on the lower parts oft continental shelves and upper part of the continental slopes may extend their lower ends uj 2,000 metres below the sea-level.

Many types of origin have been assigned to the submarine canyons. According to Shepard they represent the extended parts of the valleys from land over the adjoining marine floor. Such extension occurred during Pleistocene glaciations when due to the abstraction of oceanic water in the form of continental ice-sheets, the sea level had fallen exposing the continental submarine margins and on these surfaces the land streams cut and extended their valleys.

The general consensus is that the maximum fall of sea level during Pleistocene glaciations was probably of the order of 100 metres or so. Shepard is of the view that the sea level had fallen to the extent of about 1,100 metres. He advanced several evidences (inclusing biological ones) in support of his thesis. In if this be accepted, it can explain only half the fact that the depth of the canyons is as much as about 2,000 metres below the sea level.

Reduction of mountains and Isostasy

It is known that the huge mountains have been reduced to humble hills during the course of geological history by the process of erosion. Examples are the Aravallis, the Eastern Ghats, the Appalachians, the Scottish mountains etc. According to isostasy there should have been an inflow of matter in the substratum corresponding to the thickness of mountains eroded from above. This should have resulted in subsequent elevation of the mountains. How have the mountains then been eroded down to humble hills ? Here also the answer comes from isostasy. Isostasy demands the *equality of mass* in the adjoining regions of equal extent. The rocks that flow in below the eroded mountains are dense and heavier. Therefore uplift will be less than the thickness of eroded sediments. In course of time the mountains would go on losing heights till they become humble ridges.

2.6 VOLCANOES AND EARTHQUAKES

The location and distribution of the major belts of volacnoes and earthquakes also suggest the influence of isostatic adjustment. There are two major volcanic and seismic belts where volcanoes and earthquakes generally coexist. One of these is the Mediterranean belt extending from the Atlantic through the Mediterranean and South Europe, Turkey, Iran, Baluchistan, Himalaya, Burma, towards Indonesia. The other belt is the circum-Pacific zone.

If the physiography of these belts in can be found that they are marked by immense relief. On the landward side there are high mountains, which are areas of maximum erosion and deloading and must have a maximum tendency of uplift. On the other side there are great depressions or landwards or oceanic trenches which are the recipients of eroded sediments. The great oceanic trenches on the circum-Pacific belt are well known.

Thus, in the volcanic and seismic zones we have opposite tendencies of uplift of the mountainside and of subsidence on the depression side. In the zones of high opposite tendencies there is the hinge zone, which undergoes tearing, and dislocation. Tearing of the crust may induce volcanrsm and dislocation of the crust along the rift or faults will cause earthquakes. Both these phenomena either severely or together are experienced and isostatic adjustment is their cause.

2.7 CONSOLIDATION:

The theory of Isostasy is no longer a theory but is accepted as a fact. It helps us to under stand the internal structure of the earth, the relief features of the earth's surface, the drifting of continents, the relative rise and fall of land and sea and a host of other problems. In conclusioion the following statements may be made :

i) As indicated by Heiskanen and others isostasy is now an accepted principle and it cannot be contradicted by regional exceptions.

ii) Probably the Indian region presents the most remarkable exception to the principle of isostasy. Here except the Himalayan region, where, by and large, isostasy is in existence, i.e., where there is isostatic compression, there is no isostatic compensation. Plumb-line deviation and intensity and directions of gravity are unexpectedly large.

iii) Oldham and Glennie tried to explain the abnormal 'isostatic anomalies' in the Indian region by assuming deep-seated warping. Glennie's explanation may be deemed plausible but there appear to be several objections. One of these is that while the Tethyss might be regarded as the surface expression of the northern down warp there is no such topographic depression in Deccan to match Glennie's trough in that region.

But a more serious objection is based on recent survey upon satellite data, which suggest up warping of dense matter in the Himalayan region and adjoining Indo-Gangetic plain.

iv) Although the Indian region as a whole lacks compression and is marked by a deficiency of mass, there are various evidences of the operation of isostatic principle. Thus the ' impressive' array of the highest peaks in the Himalaya with intervening gigantic gorges can be readily explained as a result of isostatic uplift following the deloading associated with the erosion of vast amounts of sediments from the gorges.

Other evidences of such continued isostatic uplift are the frequent river terraces in the Himalaya, earthquakes and growing desication of the Tibetan lakes. As mentioned earlier, the predominance of deep-seated coarse-grained crystalline rocks exposed at the surface in the peninsular upland along with the relative paucity of marine sediments lends support to isostatic uplift due to long continued extensive erosion.

2.8 QUESTIONS

1. Discuss the theories of Isostasy as postulated by Pratt, Bowie and Hayford.
2. What are the views of Airy on Isostasy ?
3. Discuss the views of Joly and Arthur Holmes on Isostasy.

2.9 SELECT READINGS :

1) The Earth's Changing Surface - Bradshaw et. al.
2) The Great Geological Controversies - Hallam (Edited)
3) Principles of Physical Geology - Holmes
4) Physical Geography - Strahler & Strahler
5) Physical Geography - Enayat Ahmed
6) A Text Book of Geomorphology - P. Dayal
7) Professional Paper (Survey of India - 1932) by Glennie, E.A.

Unit 3 ❐ Vulcanicity and Related Landforms

UNIT : 3 VULCANICITY AND RELATED LANDFORMS

3.1 SUMMARY:

In the popular sense the term 'vulcanicity' covers all those processes in which molten rock material or *magma* rises into the crust, or poured out on its surface and then solidify as a crystalline or semi-crystalline rock. The name suggests a connection with volcanoes. Volcanism is the case of igneous activity in which the molten rock or magma is transferred from below or within the crust to the outer surface. But it can be emphasized that volcanic (or extrusive) rock erupted at a surface, are not as important as intrusive rocks injected into the crust and subsequently get exposed by erosion of the surface rocks. Volcanic landscapes consist of assemblages of very distinctive landforms built largely by accumulations of solidified lava and of fragmentary volcanic products. Though in some cases they may be partly modified by erosion, they contrast strongly with most other landscapes, which are largely shaped by the processes of erosion.

3.2 INTRODUCTION

Geomorphic significance of vulcanism : In the process of volcanism magma is conveyed to the surface essentially along tube-like conducts and the extrusion of lava builds distinctive conical or dome-shaped landforms which owe their origin entirely to endogenic forces and are in no way related to gradational processes. Volcanic activity produces dramatic and strikingly beautiful landforms in a relatively short period of time. Localised volcanic activity may inpose these features upon a landscape with dramatic suddenness, completely burying the existing landscape and presenting an entirely a new type of initial surface to the agents of erosion.

The volcanic landforms may form in any latitude and climate but have an unmistakably similar, distinctive and symmetrical appearance. In course of time they are, of course, modified by the climatically control led processes and thus afford an opportunity to study varying erosional rates and forms under different cilmatic conditions on the initial volcanic landscape.

Volcanoes have gained renewed geomorphic interest in recent years because of new techniques, which have made possible the exact dating of eruptive rocks. By measuring the amount of rock eroded from dated volcanic landscape, it is now possible to measure the of landscape modification and to reconstruct the original volcanic features.

It is important to remember that the products of volcanism form most of the oceanic crust and part of the continental crust, oceanic volcanism, which mainly takes the form of non-explosive fissure eruption from the active mid-oceanic ridges, is responsible for building almost all the crust beneath the ocean floor. Much of the ocean floor has constructional topography of lava flows and in addition to a large number of volcanic islands, thousands of eroded volcanoes present, as seamounts lie hidden below sea level.

Essentially similar basaltic lavas form some of the largest plateaus on the continental surfaces, such as Deccan plateau of peninsular India and the plateaus of Iceland and the northwestern United States. About 2 million square kms of land surface have been covered to depths of 500-3,000 metres by lava flows in geologically recent times, and probably the entire earth has received a layer of volcanic ash and dust of varying thickness.

3.3 PRODUCTS AND TYPES OF VOLCANIC ERUPTION

Products of volcanic eruption : The products of volcanic eruption may be soild, liquid or gaseous. The soild rock fragments of different sizes, which are ejected with the eruption, are together called *pyroclasts*. When the volcanic eruption is explosive, a lot of rock fragments are thrown into the air, which falls down near the vent or the adjacent areas. First to come out are the rock fragments which are present in the vent. In the dormant volcano the vent is plugged with solidified lava, and this is thrown out in fragments before the lava is ejected. Together with these are also the rocks, which constitute the wall of the vent. Sometimes the top of the hill may be blown off due to the explosion. In most eruptions, considerable solid fragmental materials are ejected, and the adjacent areas experience virtually a rainfall of ashes and stones. Besides the broken rock fragments, parts of the lava which is thrown up with the rapidly rising gases also solidify before falling down on the surface of the earth in the form of bomb-rains.

The pyroclastic materials are sometimes collectively called *tephra*. It consists of fragments of different sizes and shapes and varies from fine dust to big angular fragments. They have been given different names according to their size. The largest angular rock fragments are called *blocks* or *breccias*. When the molten lava is thrown into the atmosphere and its bigger drops solidify before falling down, they assume round, oval or pear-shaped forms. These solid rounded matreials are known as *volcanic bombs*. When their size resemblesw peas or they are small as glass marbles, they are called *lapilli*. When they have a vesicular structure, they are referred to as *pumice, scorae* or *cinders*. When the volcanic material consists of sand size and finer tephra, it is called *volcanic ash*, and when the ash materials are still thinner, they an called *volcanic dust*. On account of the heavy rainfall which sometimes accompanies the erup tion, the volcanic dust and ash start flowing as mud and may cause almost as much damage as the hot lava.

The bigger fragments, like lapilli, cinder, bombs and blocks fall down close to the voles noes, but the volcanic dust and ash may be air-borne for many kilometers before settling dow The rock, which is composed of a mixture of ash, dust, lapilli and cinder, is referred to as *tuffs* Sometimes this may also contain admixture of bombs and blocks along the slopes of the volcanic hill.

The most important product of volcanic eruption is, of course the liquid lava. Its tempeiture is usually between 900° to 1200°C. the lava containing a higher percentage of silica is called acid lava, while lava with a lower percentage of silica is called basic lava. The acid lava has a high melting point and is usually viscous. It therefore flows slowly and cannot travel very far. On the other hand, the basic lava has a low melting point. It is more liquid and flows to longer distances before it solidifies. Further its speed of movement is also faster. The cooling of basic lava results in the formation of basalts. The composition of the molten lava is a major factor in landform development because of its influence on viscosity. Silicic or acid lava builds high steep-sided cones while basaltic or basic lava produces a flatter cone of great diameter.

Sometimes the surface of the solidified lava may be smooth but more usually it is quite rugged. In the case of both acid and basic lavas, the escaping gases make the surface of the lava vesicular and full of small holes. Besides, the upper surface cools earlier and forms a crust while the lava underneath the surface continues to flow. This results in cracks in the crust and the parts thus broken are carried down. These vesicular fragments of the lava crust, sponge-like in texture, are called *scoriae.* The surface formed by the lava deposit is thus normally rough and irregular and is full of cracks and holes into which rainwater can easily penetrate. Two contrasting surface textures may develop on the lava flows which are commonly known by their Hawaiian names; as *aa* for the angular vesicular scoriaceous surface and *pahoehoe* (or ropy) for smoothly twisted, convolute surface which develop on hotter and more fluid lava. An extreme case *of pahoehoe* lava occurs when the hot fluid lava either erupts under water or quietly flows into water. Lobes of lava up to a metre in diameter form tough flexible skins and pile up like sandbags or pillows while their interiors are still molten. This is called *pillow lava.* It is an evidence of subsequent eruption and is commonly found on the ocean floor.

Among the volcanic gases the most important is steam. A huge amount of steam is ejected with the eruption and its condensation usually results in heavy rainfall. Besides steam (60 to m90%), other volcanic gases include carbon dioxide, nitrogen and sulphur dioxide, and there are very small quantities of hydrogen, carbon monoxide, sulphur and chlorine as well. After being ejected, these gases mix in the atmosphere and they do not have any influence on the volcano as such. But these gases are quite active and full of energy having high temperature, and it is possible that upward rise of these powerful gases from the mantle is an important cause of the volcanic eruption.

Types of volcanic eruption : Volcanic eruptions are classified on the basis of the mode of eruption, as- *a) Central eruption,* and *b) Fissure eruption*

a) ***Central eruption:*** This type of eruption takes place through a central vent or mouth. The rock fragments, ash, lapilli as well as liquid lava are ejected with more or less explosion and collect around the mouth. This volcanic eruption is confined to a pipe-like vent and after the eruption, cone and crater structure is developed. A good example of this type is the Cotopaxi volcano in Ecuador.

Subsequent to the development of the main hole a number of satellite holes may develop around through which lava may escape at lower elevations. Etna volcano is an example of this type of central eruption.

In central eruptions, the nature and intensity of the eruption show great variation according to the amount and pressure of gases and the viscosity of the lava. It is said that when the lava is basic (basalt), having low viscosity the eruption is relatively quiet and there is absence of explosion. On the contrary, when the lava is acid and therefore more viscous, the eruption is explosive.

b) Fissure eruption : Some eruptions, instead of being restricted to central vents take place along a fissure or series of fissures or cracks without any explosive activity. On account of the absence of explosion pyrocalstic material are absent. Fissures eruptions do not build large volcanic cones but more commonly build lava plateaus and plains. In some places small cones and craters may be formed after the eruption has slowed down and the cracks have closed and volcanic action is possible only at a few points. Layers of ash are sometimes found between the various lava flows, but the total amount of ash in comparison to the huge volume of the lava ejected is very small.

In fissure eruption there is no pipe leading directly to the magma in the earth's interior but there is a long fissure and the eruption may be either along the entire fissure or at selected points along the fissure.

Examples of fissure eruption are rare in the present day world, but excellent examples are available from the geological past resulting in the formation of several extensive lava plateaus, built mostly of basaltic lavas. An excellent example is the Deccan lava plateau of India covering an area of over five hundred thousand square kilometers. The eruption took place towards the end of the Cretaceous age. The basalt lava which was poured out of the fissures inundated an area of nearly eight hundred thousand square kilometers, as the remnants of the old lava plateau are to be found as far as Ranchi district in Jharkhand in the east to Rajamundri in the south. The Deccan lava plateau is built up of succession of lava flows, which form different, layers one above the other. The region is commonly referred to as Deccan Trap as the successive lava flows with their different thickness have resulted in step-like structure. Another good example of lava plateau built by fissure eruption is the Columbia plateau in the U.S.A. spread over the states of Washington, Oregon, Nevada and Idaho. Here the basalt lava covers an area exceeding one hundred fifty thousand Square kilometers and has an average thickness of 1,00 to 1,200 metres. This eruption took place in the Miocene times and the plateau contains thin layers of lava flows. The Snake River has cut deep canyons in it going at places to depths of 1,700 metres below the surface and has exposed the different basalt layers.

3.4 PROCESSES AND LANDFORMS PRODUCED BY VULCANICITY

Basically there are two main processes involved in vulcanicity:

Extrusive process : This is the extrusion of the molten rock material on to the surface. Molten rock material may be simply poured out on to the surface or forcibly ejected through explosive volcanic activity. Such material solidifies to form *exetrusive rocks.*

Intrusive process: This is the intrusion of masses of magma into the upper crust. Magma is a general term for molten rock material; such rocks, which are injected into the crust, are termed. The rocks produced thereby are called *intrusive rocks.*

3.5 EXTRUSIVE PROCESSES AND RESULTANT LANDFORMS

Among the landforms produced by the extrusive processes the constructional volcanic land-forms may be said to fall into two broad categories-a) cones and fields of cones, domes and related features, volcanic plateaus and plains, b) volcanic plateaus and plains. There are, however, complexes consisting partly of extruded domes of lava and partly of volcanic plateaus. Negative features - explosively blown out hollows, may further diversify the volcanic landscape the largest of which are calderas. Lakes may occupy some of these explosion-made depressions but they also occupy valleys dammed by solidified lava or warped by differential subsidence caused by vulcanicity.

The viscosity of the magma is a major factor determining the type of volcanic features produced, as viscosity determines both the type of eruptive activity and the products that are erupted.

1) Basaltic Domes or Shield volcanoes : Lava of basic composition is less viscose and hence less explosive than andesite. Consequently the proportion of tephra or pyroclastic materials is very small. There is voluminous lava flow, which spreads out over a large area like a thin sheet because of its low viscosity, covering the pre-existing topography. Such outflows of basaltic lava build large lava domes, shield volcanoes and also lava plains and plateaus. Basaltic domes and shield volcanoes are essentially the same; the difference being in size only; the basaltic domes grade upward in size to become shield volcanoes. Both the basaltic domes and shield volcanoes are built as a result of repeated accumulation of lava of successive flows piled around localized vents, the resulting dome being relatively flat, with gentle surface slopes and composed entirely of lava. Both these characteristics are related to the mobility of basaltic lava due to its low content of silica and the associated property of releasing gas rapidly and quietly, so that explosive activity is minimal and the lava travels a considerable distance before solidifying, thus covering a large area like a thin sheet.

Basalt domes and shield volcanoes would thus appear to originate in a manner somewhat similar to andesite cones, i.e., as a result of emission from localized vents, but in other respects they have more in common with lava plains and basalt plateaus. Basalt emerges from fissures rather than pipe-like vents, though the distinction between these is somewhat arbitrary, as lava rising up along fissures may reach the surface only at isolated points or pipes may develop where feeding fissures intersect.

The basaltic domes built of successive flows piled around a central vent are called exogenous domes, to distinguish from endogenous domes or cumulo-domes of very viscous acid lava which may rise upward into a crater but be too stiff to flow and too degassed to explode, resulting in a skinned over or bulbous protrusion of lava from the vent.

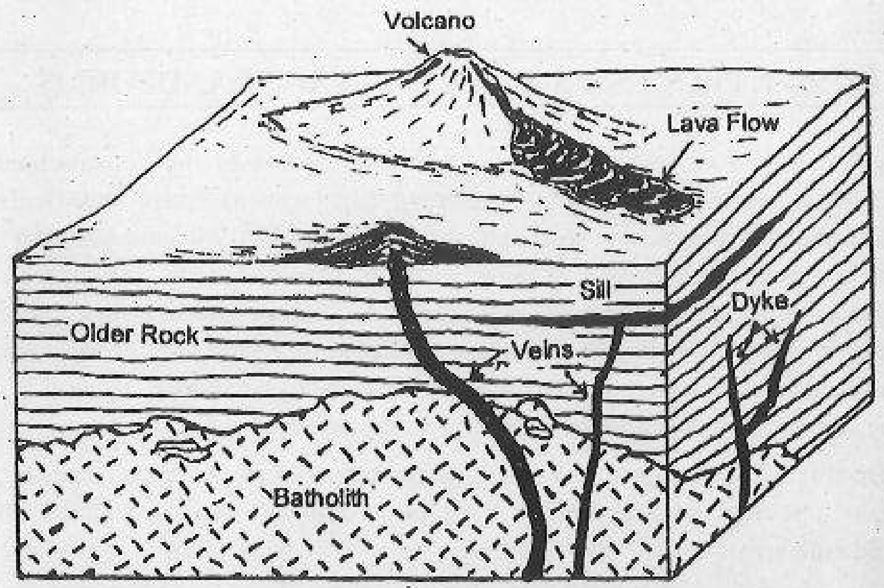


Figure 1 : Forms of igneous rock bodies

Exogenous domes when sufficiently large and extensive become shield volcanoes, though there is no definite size criteria. Shield volcanoes typically developed in Iceland .re between 100 m and 1,000 m high and their base diameter is about twenty times their height. They are very flat cones of moderate size with small summit craters. Basaltic domes or shield volcanoes of the Hawaiian type, found in the Hawaii islands, Samoa and other volcanic islands in the Pacific and Indian Oceans have a more domical form and are generally elongated because of concentration of feeding fissures beneath the volcano along rift zones of faults that encircle the growing dome. The crest of the dome becomes broad, convex upward plateau around a rimless crater or a summit caldera. The basalt domes or shield volcanoes of the Pacific and Indian Ocean volcanic islands are very large. The size of the Hawaiian shield volcanoes is particularly large - two large and three smaller domes merge to form the large island of Hawaii. Mauna Kea and Mauna Loa, the two major shields have summits elevations of 4,206 m and 4,175m above sea level. Including its submerged portion (>8,000 m) Mauna Kea forms the highest mountain on the earth. Among islands of the Pacific Ocean, there are basalt domes in all stages of dissection by erosion.

2) **Basalt Plateaus and Plains** : Related closely in origin to basalt domes and especially to dome such as that of the Hawaii Island, are basalt plateaus. These have been built by lava 'which has risen through fissures, not grouped in rift zones but sporadically distributed, so that flows from a multitude of sources have spread out and interfingered to make a pile of sheet thousands of feet thick, thus forming a plateau' (Cotton, 1968). Ancient basalt plateaus are found in various parts of the world. The most extensive is the Deccan plateau of India spread over an area of over 5,00,000 sq. km. The other well-known basalt plateau is the Columbia plateau of western U.S.A. covering an area over 2,50,000 sq. km. These are now in various stages of erosion and the landscapes so produced are characterized by stepped escarpments, mesas and buttes. A recently built and comparatively little dissected example is the Snake river basalt plain, 52,000 sq.km. in extent, in Idhao, U.S.A.

Basalt plains are, as it were, embryonic forms of basalt plateaus. Consisting of much thinner and less extensive piles of lava sheets, they are common throughout the world; they are indeed, with associated accumulation of coarse scoriaceous material forming mounds and cones, the most prevalent of volcanic landscapes. They may consist of single layers or at the most a few superposed layers of lava which solidified on gentle slopes or after running down on to the valley floors. They form nearly level surfaces hundreds of square metres in extent. Some valleys may be blocked by lava and may form lakes. When the plains forming lava sheets are partly destroyed by erosion, distinctive landforms develop. Basalt is commonly more resistant than the underlying rocks. Consequently as the margins are undercut, they become escarpments. Gorges are formed and where the impounded rivers overflow across lava dams waterfalls result. Of these, these are good examples in the North Auckland district of Newzwaland. Because of the hardness of lava that buries a plain or valley floor, inversion of relief commonly develops as the land surface is lowered by erosion, and the lava-filled valley becomes in its turn a ridge.

3) **Andesitic volcanic forms** : While basaltic lava builds basalt plateaus and plains with associated domes and mounds consisting almost entirely of lava with little pyroclastic materials, andesitic landscapes are characterized by great cones and cone clusters with surrounding plains built up by deposits of shower, lahar and nuee ardent origin. Andesite is lava of intermediate compositioin with medium silica content. Most of such lava are explosive and 50 to 90 per cent of their product consists of fragmental materials, much of which is built into cones. Cones may consist either entirely of pyroclastic materials heaped around the crater (ash or cinder cones) or of alternating layers of pyroclastic and of lava (strato volcanoes). With an increasing proportion of lava layers the outer layer may

consist entirely of lava producing a lava cone. Ash cone and strato volcano forms are, however, more common. Many of the world's largest volcanic mountains are cones consisting of andesitic materials.

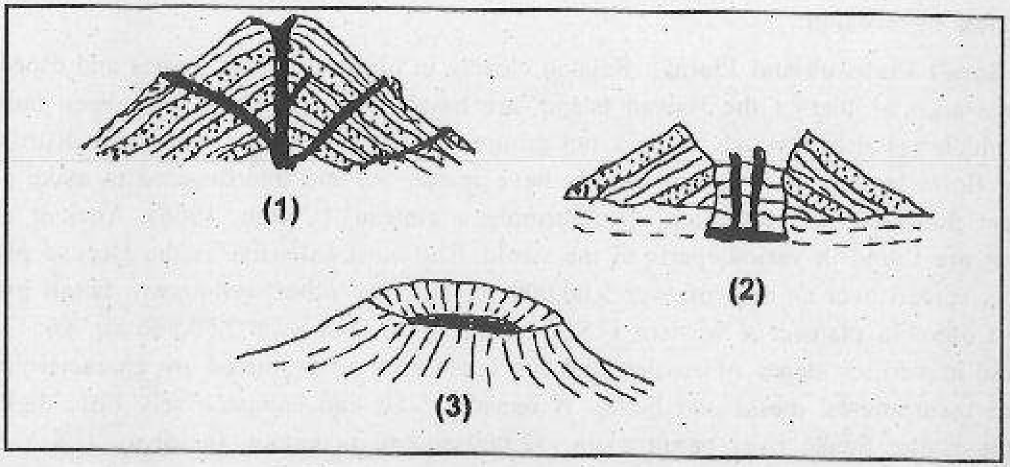


Figure 2 : Some distinguished volcanic forms

(1) Composite volcano, (2) Caldera, (3) Crater Lake

Ash and cinder cones are built where irruptions are of the explosive type and there is predominance of pyroclastic materials, such as rock fragments, lapilli and ash. The pyroclastii materials collect round the crater and their deposit becomes less as one moves away from th crater. Successive eruptions result in the accumulation of different layers of pyroclastics whicl slope outwards. But in the crater the deposits slope inwards as the ash tends to fall towards th crater. In general the ash or cinder cones are perfectly conical and symmetrical, for on thei slopes the material has come to rest at the angle of repose. As a result of explosive ejection the carries pyroclastic materials to a distance beyond the upper slopes, and partly as a result of th washing down of ash and its deposition as alluvial fans and of the avalanching of newly depo; ited hot and mobile lava, the base of the cone is long and stretched and the lower slopes of the cone are gentler than its upper slopes.

The feeding pipe that leads up through the crater to the summit where the cone-buildir eruptive ejection takes place does not change appreciably during the growth of the cone. Thi large cones are sharp and steep at the apex, while the small cones are better described as mounds than as cones.

Composite or Strato-Volcanoes: When the cones have a layered structure, with

alternating ash and lava, they are described as strato-volcanoes or composite volcanoes. Most of the volcanic hills of the world are of the composite type and include the Fujiyama in Japan, Visuvius of Italy, Popakatapatal in Mexico, Cotopaxi in Ecuador and several others.

Andesitic Volcanic Fields : Around and among the clusters of andesitic volcanic cones are fields of widespresd ash and coarse debris, which may sometimes be of regional dimensions. The fragments of exploded lava yield large quantities of dust, sand, pumiceous blocks and blocks. Apart from the layers of ash, which are deposited near the crater to build the cone, much fine materials as well as coarse fragments are ejected with such force that they fall beyond the cone slopes. The finest materials are carried by the wind and deposited over a wide area. The surrounding country is thus covered and built by debris that fall as shower and accumulate over the nearer parts to considerable depths, partly or wholly burying the original erosional features.

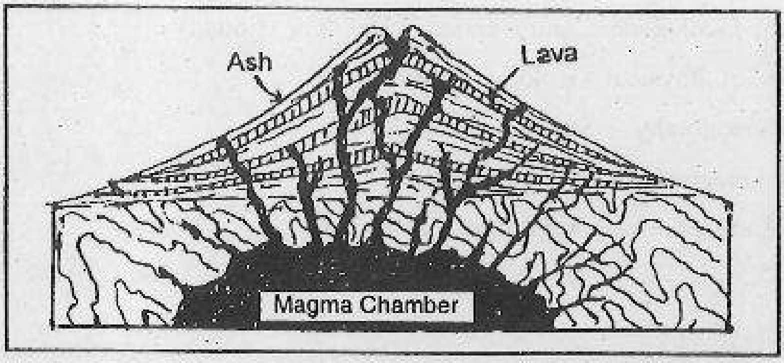


Figure 3 : Possible cross-section of a composite volcanic cone with feeders from magma chamber beneath

Acid Domes : Sometimes even when the eruption is not explosive and the lava wells up and overflows quietly, the lava may be acid and not basic. Where the lava is acid with a high percentage of silica, it is viscous and pasty and can not flow far from the vent. The deposits consist entirely of lavas with no rock fragments or ash is dome-shaped. The dome formed is quite convex with steep sides and usually there is no sign of the crater. It resembles an inverted bowl in form and is called *cumulo-domes.* Examples of such domes are found in the Reunion Island, north of Madagascar in the Indian Ocean as well as the Auvergne region in France.

Sometimes the lava solidifies soon as it comes out of the vent and then a vertical dome may be formed in the crater itself. Such domes are called *plug domes* or *volcanic necks.* The crater dome of Mont Pelee, Martinique, in the West Indies, provides a good example of this. Volcanic necks that occupy former conduits today form geomorphic features as a result of the differential erosion of the various materials and appear quite striking in mature landscapes of low relief. In most cases they stand up like sturnp, crag or tower. A famous volcanic neck is the Arthur's Seat, the site of Edinburgh castle, Scotland consisting of compact igneous rock of massi basalt called plugs.

3.6 QUESTIONS

1. Define vulcanism and product and types of volcanic eruption.
2. Discuss the landforms produced by vulcanicity.

3.7 SELECT READINGS:

1) The Earth's Changing Surface - Bradshaw et. al.
2) The Great Geological Controversies - Hal lam (Edited)
3) Principles of Physical Geology - Holmes
4) Physical Geography - Strahler & Strahler
5) Physical Geography - Enayat Ahmed
6) A Text Book of Geomorphology - P. Dayal

Unit 4 ◻ Plate Tectonics and Mountain Building

UNIT 4 : PLATE TECTONICS AND MOUNTAIN BUILDING
(with special reference to the Himalaya)

4.1 SUMMARY:

The new theory **of Plate Tectonics,** to explain the tectonic activity through the earth's crust, links together the ideas of sea-floor spreading with older hypothesis of continental drifting. Tuzo Wilson (1965) first put forward the idea and W.J. Morgan (1967) developed the hypothesis afterward. This theory advances the idea that the earth's outer crust is divided up into a number of rigid, shifting paltes of varying size—six major ones which are of continental proportions and a number of others which are quite small - and that as these plates slide past one another, converge or move apart, continental drift, mountains are formed, and new crusts come into being. Three types of plate margins as identified are: *constructive, destructive* and *conservative,* plate margins. Plate tectonic theory offers a reasonable general explanation of the mountain buliding. According to this when two plates collide the leading edge of one is subducted or forced under the edge of the other. Since the continental crust of the second plate is too buoyant to be forced down into the sub-crustal zone, mountains are formed along the edge by crumpling of the marginal rocks and their up thrusting by the subsiding palte. It is believed that the Himalaya may well have been formed when the plate of the Indian Deccan, an ancient plateau block, came into collision with the old Asian plate in mid-Tertiary times; the Indian plate was forced under the Asian plate causing it and the accumulated sediments upon its margin to buckle and be lifted up.

4.2 HISTORY OF DEVELOPMENT OF THE THEORY OF PLATE TECTONICS

The concept of **Plate Tectonics** is an extended and more comprehensive version of the theory of sea-floor spreading proposed by Harry Hess and confirmed by Fred Vine and Matthews by their interpretation of linear magnetic anomalies. This hypothesis, actually attempted to draw sea-floor spreading, continental drift, crustal structures, and world pattern of seismic and volcanic activity together as aspects of one coherent picture. The Canadian geogphysicist Tuzo Wilson in his paper published in the internationally famous journal 'Nature' in 1965. He was impressed by the fact that movements of the earth's crust were largely concentrated in three types of structural features marked by earthquakes and volcanic *activity,* namely mountain ranges, including island arches, mid-oceanic ridge and major faults with large horizontal displacement. Wilson proposed that a continuous network,which divides the earth's surface into several large rigid plates in fact, connects the "mobile belts". Such a junction was called a *transform.* However, W.J. Morgan of the Princeton University first outlined the complete form of the theory of Plate Tectonics in

1967, basing himself in the findings of Wilson regarding transform faults and their relationship with the mid-oceanic ridges. More or less concurrently but independently D.P, Mackenzie of Cambridge and Parker of the United States of America had arrived at conclusions similar to those of Wilson. Thus Wilson, Mackenzie and Parker through their published research findings laid the foundations of this new hypothesis, though it was really proposed by Morgan.

Plate Tectonics : the basic concept: On the contrary to the theory of Continental Drift of Alfred Wagener it has been proposed by W.J. Morgan that the entire surface of the earth comprises a series of internally rigid, but relatively thin (100-150km) plates. These plates are continuously in motion both with respect to each other and to the earth's axis of rotation. Morgan divided the earth's surface into 20 plates and determined their poles of rotation by drawing great circles at right angles to the relevant groups of transform faults. La Pinchon (1968), however, simplified the concept of plate tectonics by dividing the earth's surface into six major plates and a few smaller ones after taking into consideration the spreading rates calculated from magnetic anomalies as well as the strike of the transform faults intersecting the mid-oceanic ridges.

According to the hypothesis of plate tectonics *the earth's crust can be divided into six major lithospheric plates and six minor plates,* and the major crustal processes may be explained by reference to the relative movement of these plates. Virtually all seismicity, vulcanicity and tectonic activity are localised around plate margins and is associated with different motions between adjacent plates.

Plates and the Plate Boundaries: Morgan identified the following lithospheric plates :

Major Plates : *1) Pacific Plate, 2) American Plate, 3) Eurasian Plate 4) Austral-Indian Plate, 5) African Plate, and 6) Antarctica Plate*

Minor Plates : *1) Nazca Plate, 2) Cocos Plate, 3) Philipping Plate 4) Caroline Plate 5) Bismark Plate, 6) Arabian Plate, 7) Caribbean Plate, 8) Juan de Fuca Plate, and 9) Scotia Plate.*

Morgan also divided the Plate boundaries into three types : *1)* ***ocean ridges,*** where new crust was created, 2) **ocean trenches,** where crust is neither created nor destroyed.

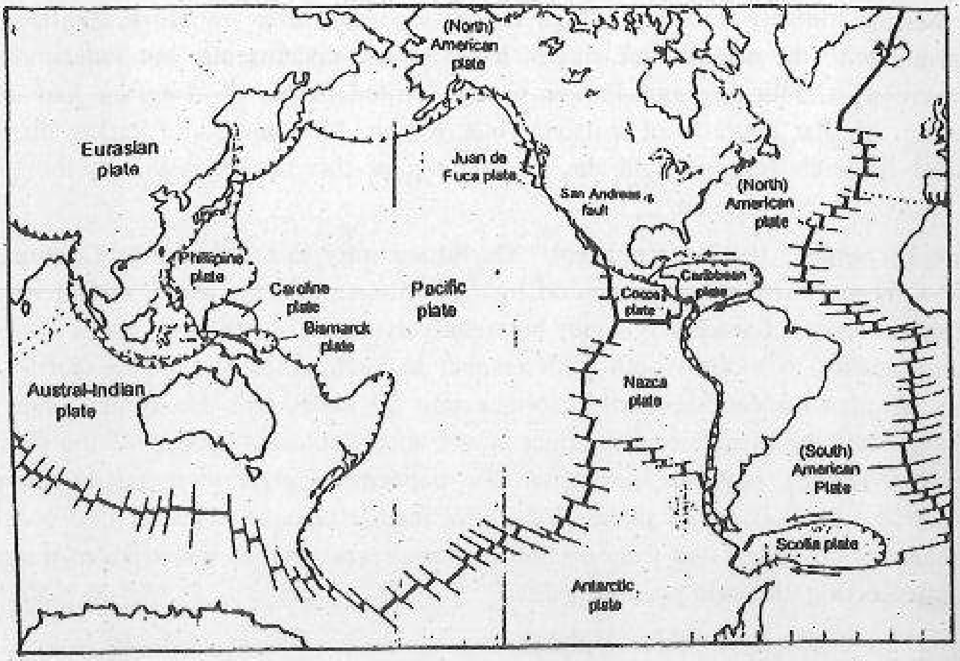


Figure 1: Distribution of major plates and plate margins over the globe

The characterstic features of the Plates

The plates are the inert seismic regions of the earth bounded by narrow mobile belts, which are characterized by seismic and volcanic activity or by orogenic belts (where continents form the leading edges of plates. Each plate is about 70 to 100 kms thick and its configuration is not related to the distribution of land and water. Most of the plates include both continent and oceanic crust. The area of plates is fairly large in comparison to their depth or thickness and the depth of the plates become even less under the oceanic crust. All the plates are mobile and their mobility is made possible by the viscous and plastic upper layer of the mantle called the asthenosphere or the Low Velocity Zone. These plates are continuously in motion both with respect to each other and to the earth's axis of rotation. Three types of motions are possible between the plates—separation or *divergence,* closing together or *convergence* and friction or *shearing.*

The characterstic features of the Plates boundaries and plate margins

Nearly all seismic, volcanic and tectonic activities are confined to the plate margins and are related to the differential motion of the neighbouring plates. The boundaries between the different plates have therefore a special significance. The distinction between plate margins and plate boundaries must be clearly understood. The plate margin is the edge or marginal part of a particular plate, while the plate boundary is the surface trace of the zone of motion between two plates. Two neighbouring plate margins meet a common plate boundary.

There are three types of Plate margins - ***1) Constructive Plate Margins, 2) Destructive Plate Margins,*** *and* ***3) Conservative Plate Margins.*** The first type is known as ***Constructive Plate Margins.*** During the spreading process *constructive plate margins* occur as ocean ridges, new crust is created and moved away from the ridge along with the inderlying uppermost mantle. The newly generated crust and its upper mantle are effectively welded to the plate's trailing edge. On the mid-oceanic ridges the plates move in the opposite directions, but they do not separate from each other as new ocean crust is continuously being added on the margins of the two plates. Such boundaries where the net effect of the movement is the creation of new crust are called *Sources.* The second type of margin is called a *Destructive Plate Margin,* which occures at the deep ocean trenches. At trenches two plates approach each other and one slips down under the margin of the other at an angle of about 45°. As one plate is subdued under the other this zone is also known as the *Subduction zone.* Plate boundaries at which the net effect of the motions is to destroy surface are called *sinks.* There is also a third type of plate margin, which is known as ***Conservative Plate Margin.*** This is a margin at which the plates neither gain nor lose surface area, but simply slip past each other.

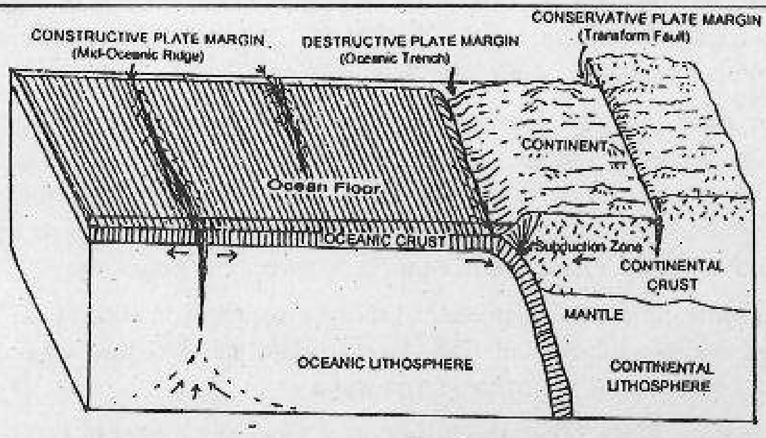


Figure 2 : Characterstics of the major plates and plate margins

Geologists and geophysicists in the present day believe that the development of the Alpine fold mountains (the Alps, Himalayas, Rockies, Andes etc.) over different parts of the earth is directly associated with relative movement of plates. This means that the *Orogenic* processes are active along the destructive, constructive and the conservative plate margins. Best examples are the Himalaya and the Alps, as the rise along the destructive plate margin (the line of seismicity) between the Indian/African plates and the Eurasian plate. With continuous process of convergence between these plates uplift of the Himalaya and the Alps remains unabated.

Recent evidences of Plate genesis : Evidences of the creation of new plates have also been reported. Recently British scientists have explored a lake of molten rock beneath the floor of the Atlantic Ocean. The magma chamber, 500km southwest of Iceland forms like a ribbon along the Mid-Atlantic Ridge and acts as a reservoir from which a new rock is created. The report says that up to 42 km long, 5km cross and 400m deep the lake lies 5km below the ocean floor. The magma chamber discovered by seismic and electromagnetic surveying contains sufficient amount of molten rock to generate new crust for 11,000 years.

4.3 THE GLOBAL SYSTEM OF PLATES

As described earlier the global system of lithospheric plates, with their major characteristics, have been described below :

Several lesser plates and sub-plates are also recognised. They range in size from intermediate to comparatively small.

The great ***Pacific Plate*** occupies much of the Pacific Ocean Basin and consists almost entirely of oceanic lithosphere. Its relative motion is northwesterly, so that it has a subduction boundary along most of the western and norhtern edge. The eastern and southern edge is mostly a spreading boundary. A silver of continental lithosphere is included and make up the coastal portion of California and all of Baja California. The California portion is bounded by an *active transform fault* (the San Andreas Fault).

The ***American Plate*** includes most of the continental lithosphere of North and South America as well as the entire oceanic lithosphere lying west of the mid-oceanic ridge that divides the Atlantic Ocean Basin down the middle. For the most part, the western edge of the American Plate is a subduction boundary, with oceanic lithosphere diving beneath the continental lithosphere. The eastern edge is a spreading boundary.

The ***Eurasian Plate*** is mostly continental lithosphere, but it is fringed on the west and north by a belt of oceanic lithosphere. The African plate has a central core of continental lithosphere nearly surrounded by oceanic lithosphere.

The ***Austral-Indian Plate*** takes the form of a long rectangle. It is mostly oceanic lithosphere but contains two cores of continental lithosphere - Australia and peninsular India. Recent evidence shows that these two continental masses are moving independently and may actually be considered to be parts of separate plates. The Antarctic Plate has an elliptical shape and is almost completely enclosed by a spreading plate boundary. This means that the other plates are moving away from the pole. The continent of Antarctica forms a central core of continental lithosphere completely surrounded by oceanic lithosphere.

Of the nine Lesser plates, the ***Nazca* and *Cocos plates*** of the eastern Pacific are rather simple fragments of oceanic lithosphere bounded by the Pacific mid-oceanic spreading boundary on the west and by the subduction boundary on the east. The ***Philippine plate*** is note worthy as having subduction boundaries on both east and west edges. Two small but distinct lesser plates - ***Caroline*** and ***Bismark*** - lie to the southeast of the Philippine plate. The ***Arabian plate*** has two transform fault boundaries, and its relative motion is northeasterly. The ***Caribbean plate*** also has important transform fault boundaries. The ***Juan de Fuca*** plate is steadily diminishing in size and will eventually disappear by the subduction beneath the American plate. Similarly the *American and Antarctic plates* are consuming the ***Scotia plate.***

Basic assumption of Plate Tectonics

There are three basic assumptions underlying the hypothesis of Plate Tectonics as follows :

(i) There is spreading of the sea floor, and new oceanic crust is being continuosly created at the active mid-oceanic ridges and destroyed in the trenches.

(ii) The area of the earth's surface is fixed and during the last 600 million years the radius of the earth does not appear to have increased by more than 5%. In other words, the amount of crust consumed almost equal the amount of new crust created.

(iii) The new crust that is formed becomes a part and parcel of a plate, which normally includes both continental and oceanic crusts, although there are some plates which are almost wholly composed of oceanic crust. The process whereby one plate is consumed by and disappears under another plate is called *subduction.*

Subduction Tectonics

Converging plate boundaries with subduction in progress are zones of intense tectonic and volcanic activity. The narrow zone of a continent that lies above a plate undergoing subduction is therefore an active continental margin. The oceanic trench receives sediment coming from two sources. Carried along on the moving oceanic plate is deep ocean sediment - fine clay and ooze that has settled to the ocean floor. From the continent comes terrestrial sediment in the form of sand and mud brought by streams to the shore and then swept into deep water by currents. In the bottom of the trench, both types of sediments are intensely deformed and are dragged down with the moving plate. The deformed sediment is then scraped off the plate and shaped into wedgse that ride up one over the other, on steep fault planes.The wedges accumulate at the plate boundary, forming an *accretionary prism* in which metamorphism takes place. In this way new continental crust of metamorphic rock is formed, and the continental plate is built outward. The accretionary prism is of relatively low density and tends to rise, forming a tectonic crest. The tectonic crest is usually submerged but in some cases it formes an island chain paralleling the coast - that is a *tectonic arc.*

4.4 MECHANISM OF PLATE CREATION AND MOVEMENT

Creation of plates and the causes of their movement are an extremely complex and controversial subject as we know comparatively little about the physical properties, temperature distribution, distribution of radio activity etc. in the earth's interior. In any event, in any explanation of the causes of plate movements, it is necessary bear in mind the following facts, because any possible mechanism will have to operate within the framework of these limitation and conditions.

(i) High heat flow is found on the active mid-oceanic ridges, and decreases with distance from the ridge. On the contrary in the oceanic trenches now heat flow is found, though in the neighbouring island-arcs heat flow is met with at depth.

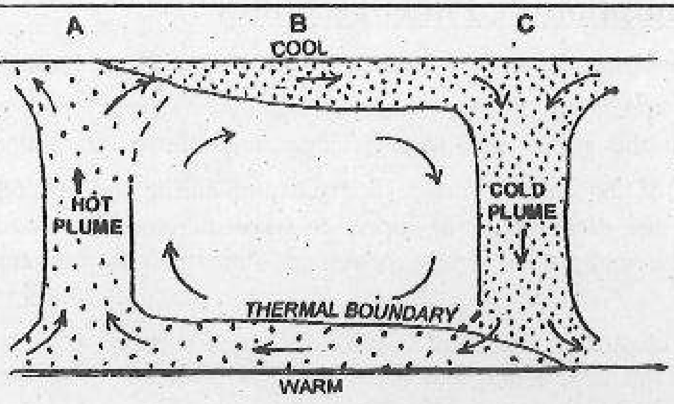


Figure 3 : Mechanics of conductive heating and possible creation of plates

(ii) Near the mid-oceanic ridges the spreading of the ocean floor goes on symmetrically on either side of the ridge and the rate of spreading varies from less than 1 centimeter to 6 centimeters per year. In the oceanic trenches the rate of consumption or the destruction of the crust is between 5 to 15 centimeters per year.

(iii) Whatever the process of transformation of new crust on the mid-oceanic ridges, the thickness of the newly formed crust has been found roughly to be the same irrespective if its rate of spreading.

(iv) In the centre of spreading the ridge rises 2 to 4 kms above the ocean floor, and the slope on either side of the summit become less in a symmetrical manner.

(v) It has been found from gravity observations that the ridge is in a state of isostatic equilibrium. On the other hand, the trenches (where deposit of sediment is found) are in a state of isostatic disequilibria and here we find the maximum negative gravity anomaly.

(vi) There are great differences in the distance between sinks and sources. At some places this is only a few hundred kilometers while at other places it is up to 3,000 kms.

(vii) The lithosphere has strength and the big lithospheric plates can also move considerable distance without internal deformation. The length of some plates is twenty times or more than their thickness. In this kind of length to thickness ratio it is not possible for compressional or tensional stresses to travel from one edge of the plate to the other unless the frictional resistance at the base of the plate is very poor.

On account of the presence of high heat flow near the ridges several persons have suggested that the movement on the surface is related to some sort of thermal convection in the earth's interior. Recently D.L. Turcotte and E.R Oxburgh have put forward the concept of thermal boundary layers based on thermal convection. On account of thermal instability in the mantle, heat is conducted upwards through the movement of the molten material. Once this kind of movement has started, the pattern takes the form as shown in the following figure.

As the fluid moves across the hot lower surface it is heated by conduction from below, but its conductivity is so low that by the time it reaches the beginning of its ascent conductive heating has extended only a small way into the flow a warm thermal boundary layer has formed. The ascending is formed by the coalescence of two warm boundary layers to give hot 'plume'. As it approaches the upper surface the plume flow diverges once more to give a symmetrical upper horizontal flow. The hot fluid now moves along a cold surface, and as it flows laterally it loses heat by conduction upwards with the generation of a progressively thickening cold boundary layer. The interior of the cell plays no part in the heat transfer process, and within it there is an adiabatic temperature gradient. The heat is picked up, transported, and lost by a kind of thermal conveyor formed by the outside of cell.

According to this hypothesis the plate represents the cold thermal boundary layer which is highly viscous but where the upper part is quite rigid. Asthenosphere or the low velocity zone is the only layer, which can generate and support such a convection flow. But this layer is relatively thin. Therefore some people have suggested that the source of the convection flow lies in the mantle. It is pointed out in support of this view that seismic evidence shows that the descending flow in the trenches goes to depths of 700kms, which is deeper than the low velocity zone.

In order to explain plate movement some scientists have suggested that plates slide from the ridges to the trenches under the influence of gravity. Others are of the view that the sinking crust beneath the trench systems constantly pulls the crust in that direction and this is being compensated by the upwelling of magma at the ridges and its spreading generates movement in the plates and they are pushed apart by mantle upwelling and in order to maintain the surface area of the earth one plate is being subducted under another plate in the trenches.

Although several possible driving mechanisms for plate movements have been suggested, it seems probable that plate movements are not solely attributable to any one of these but result from a combination of all acting in varying degrees on individual plates. The process of convective movements would appear to be the most probable mechanism, but nothing definite can be stated about the source of the convective flow in our present state of knowledge.

4.5 PLATE TECTONICS AND MOUNTAIN BUL1D1NG

Influence of Plate Tectonic process on Mountain Building: From the above discussion it can be visualized the situation in which two continental lithospheric plates converge along a subduction boundary. It has been seen that at one margin of a crustal plate there exists the mid-oceanic ridge where new crust is being formed by the rise of basalts through rifts. Here there is divergence of plates, and the newly formed oceanic crust diverges and moves towards its other margin to be subducted in the oceanic trenches and the mantle. Here near the oceanic trenches there is convergence of two plates and oceanic plates under-rides the continental plate and reenters the mantle. On the remaining two margins of the plates, the plates merely pass across each other and there is only frictional movement. Thus three types of plate boundaries may be assumed - a) *Divergent boundaries* or junctures at the mid-oceanic ridges or rifts, b) *Shear boundaries* or junctures where two plates pass across each other, and c) *Convergent boundaries* or junctures where two plates collide with each other, and one of the two plates is lost by subduction into the trenches. The divergent and the convergent boundaries are particularly important, because oceanic ridges and rift valleys are formed on the divergent boundaries, and the folded mountain ranges are built on the convergent boundaries.

The young fold mountains of the world - the Alps-Himalayan mountain system as well as the circum - Pacific belt of mountains, are located on convergent plate boundaries where there is a state of collision between two plates. It may therefore be stated as a general rule that where there is convergence or collision of two plates; mountains are formed as a result of compression in the earth's crust.

The convergence of plates is possible under three different conditions : i) collision between a continental and an oceanic plate or continent-ocean collision, ii) collision between two continental plates or continent-continent collision, and iii) collision between two oceanic plates or ocean-ocean collision.

i) Continent-ocean collision : This is the most common type of collision, and the mountain ranges encircling the Pacific Ocean are all located at places where there is collision of continental and oceanic plates. Its simplest and best example is found along the Pacific coast of South America. Here there exists a steady-stale continuous collision between the oceanic and the continental plates, and the oceanic plate is thrust down under the continental plate in the trenches. As a result of the intense pressure the deposits on the continental margin are compressed and folded. On account of the collision between the two plates, so much heat is generated in the Benioff zone that rocks of the down-going oceanic plate as well as the lower layer of the continental plate get melted. These melted rocks are intruded as igneous rocks below the surface, and some are erupted on the surface as andesite magma. The downward movement of the oceanic plate is recorded by a series of earthquakes in the Benioff zone whose focus is 300 to 400km or more deep. As the mobile core of the erogenic belt develops, the deformation of the plate margins increases with increasing temperature and intense perssure. There is gravity sliding on account of uplift and thrusting on account of compression. The mobile core pushes the metamorphosed rocks towards the continent and the continental edge is uplifted to form mountains.

According to the plate tectonics theory the Andes were formed during the early Mesozoic era. The subduction of the oceanic plate beneath the South American plate started about this time resulting in the deformation of the Palezoic marine sediments. After this the South American plate started moving west which intensified the process of mountain formation in the mid Mesozoic and early Cretaceous limes, and in addition to the folding of the marine sedimentary deposits there started intrusion of igneous rocks and vulcanicity. As the oceanic plate descended further the pressure against the South American plate also increased and there was further intensification of these activities and the area of orogenesis also increased. The eastern part of the Andes is composed of Paleozoic metamorphosed sediments, in the western Cenozoic part there are Mesozoic and volcanic materials and shallow water oceanic deposits and batholiths ranging in age from Jurassic to the Cretaceous, and in between these two zones is a relatively lower inter-montane zone.

(ii) Continent-Continent collision : Continent-continent collisions occurred in the Cenozoic Era along a great tectonic line that marks the southern boundary of the Eurasian plate. The line begins with the Atlas Mountains of North Africa, and it runs across the Aegean Sea region into western Turkey. Beyond a major gap in Turkey, the 1 ine takes up again in the Zagros Mountains of Iran. Jumping another gap in southeastern Iran and Pakistan, the collision line sets in again in the great Himalayan Range, where it is still active.

A European segment containing the Alps was formed when the African plate collided with the Eurasian plate in the Mediterranean region. A Himalayan segment represents the collision of the Indian continental portion of the Austral-Indian plate with Eurasian plate.

Continent-continent collisions have occurred many times since the late Precambrian time. Several ancient structures have been identified in the continental shields. The Ural Mountains, which divide Europe from Asia, are one such structure, formed near the end of the Paleozoic Era.

Geologists belive that continental collision during the Cenozoic (beginning from the early Tertiary through to the recent) Era has occurred along the great tectonic line forming the southern edge of the Eurasian Plate. This line ofcollision extends from the Himalayan Ranges in the east, through the Zagros Mountains of Iran in the centre, through Turkey, the European Alps, and the Atlas mountains in the west. The Himalayan sector results from the collision of Indian-Australian Plate with Eurasian Plate.

The general features of a continental collision have particular characteristics. As the ocean basin between converging continental blocks narrows, the sediments of marginal geosysclines and accretion prisms are tightly compressed and deformed as the oceanic basaltic crust is broken in to thrust-faulted blocks which are pushed up into the sediments. The thrust blocks ride up one over another in an imbricate pattern. The upper part of each thrust sheet of sediment bends over, under the force of gravity, into the horizontal position and the strata form very elongated flat-lying folds called *napps*. Segments of oceanic metamorphic crust incorporated into the *nappes*, or between them, as ophiolites mark the collision boundary of the converging plates.

iii) *Ocean-Ocean Collision :* Where oceanic plates exist on both sides of a convergent plate boundary, the oceanic crust of one plate is subducted under the other plate in the trenches, and the resultant compression leads to the formation of island festoons and island-arcs. This type of mountain is especially found of the western coast of the Pacific Ocean and the northeastern coast of the Indian Ocean. Suess was the first to point out that this arc-like island groups are tops of drowned young folded mountain ranges and are extensions of the mountain systems found on the continents. Between the continents and the island arcs are shallow seas, which are called *back-arc* basins. The sea of Japan is a good example of a back-arc basin. Towards the oceanic margin of each island-arc is a deep oceanic trench. It appears as if the trenches owe their origin to the descent of the plate. Here the oceanic plate together with the deposited sediments descends under the adjacent oceanic plate on account of compression on the continental margins of the trenches, there is formation of metamorphic rocks. When the descending plate reaches a depth of more than 100 kms it starts melting on account of intense heat, and the molten magma rises up as volcanic rocks. The volcanic action takes place at a horizontal distance of 200kms from the trench towards the continent. The resultant increase in heat and pressure causes further metamorphism of the rocks. With the downward movement of the plate there is further increase in vulcanicity.

The Japanese island-arc provides a good example. Here in the main island of Honshu there are 3,000 - 4,000 metre high mountains and they are all volcanic. They do not come in the Category of Fold Mountains like the Himalaya or the Alps. But they contain several characteristics of Fold Mountains. Existence of belts of metamorphic rocks belonging to two different ages of the eastern and western parts of Japan suggests that Japan has been formed by the union of two island-arcs of different ages.

It may be pointed out that sometimes mountains maybe formed where there is collision of continent and island-arc. This kind of situation exists in New Guinea where the mountains of New Guinea have come into existence about 20 million years ago as a result of the convergence of the island are lying to the north and the northern edge of Australia.

Assessment: If it accepted that the mountains are formed on account of compression of the crust where plates converge then we may identify four major geological effects of such converging movements :

(i) The first possibility is that such movements may result in down-warping of the crust, and geosynclines or linear basins may be formed in which the sediments derived from the adjacent land will be deposited.

(ii) The other effect will be the deformation of the crust resulting from compression. The evidence of this is to be found not only in folds and thrusts of the-mountain chains but also in the rocks like slate, which have been flattened and have developed a wholly new structure as a result of the pressure.

(iii) The third effect is heat produced by metamorphic and magmatic activity. In many mountain ranges, the occurrence of granite is limited to the zones of orogeny. An excellent example may be found in the Andes where the Mesozoic granite is found in a narrow belt of the mountain.

(iv) The fourth effect is uplift whereby the mountains really emerge on the surface. The evidence of uplift may come from the sudden change in the nature of new deposits, the cessation of all plutonic activity and other factors.

The significance of the above four effects lies in the fact that they help us in establishing the geological history of a mountain belt.

4.6 PLATE TECTONICS AND THE HIMALAYA

The Himalaya form an interesting but controversial topic in geology, orogeny and Plate Tectonics. According to Crawford the Gondwana plate extended not only up to the Himalaya but also up to the Thian Shan mountains. Thus there is no question of the Himalaya having originated due to continental collision between the Gondwana and Angaran plates. The Himalaya, according to him is of intracontinental origin, *i.e.*, disturbances within the body of the same plate. In this very plate there was a crustal fracture going down to the mantle level. The 'Indus Suture Line', *i.e.*, the crack in the crust represented by the Indus-Tsangpo fault, which has been closed by the volcanic material erupting from below, marks a localized sea-floor spreading.

Tibet formed an offshore region of the Gondwana land during the Paleozoic era while the boundary of the Gondwana plate lay north of the Tarim basin.

It is believed that the present altitude of the Himalaya is much beyond its expected height, as an orogenic formation, and morphogenic elevation e.g., removal of large amount of material by erosion and consequent isostatic elevation is responsible for the stupendous height of the Himalaya.

The Tibetan part of the Gondwana plate, however, is thought to have started rising before the main Himalayan orogeny. Crawford thought that the Himalaya, instead of having resultion from the collision of two continental plates, are a pile of fractured slices of the same plate near the region where its Paleozoic shore lay. He also believed that after the formation of the Himalayan mountain the Thian Shan had acted as the barrier for the

Gondwana plate. The Indian or Gondwana plate has attempted to approach the Tarim region, producing in the process the arc of the Pamir. The Indian section of the plate is believed to have been thrust under the Tibetan mass which was consequently elevated. Large areas of geosynclinal deposits might have buckled down. Continent-to-continent collision and subduction along the Indus Suture without geosynclinal development is the pattern of thinking regarding the origin of the Himalaya according to plate tectonics. The frontal portion of the Indian plate was sliced up a wedges and the Himalaya was built out of such material. The Main Central Thrust occurring roughly at the base of the Great Himalaya is believed to mark the rupture in the Indian plate consequent upon the thickening of the plate northwards but its relation with Indus Suture is not clear.

An Assessment: Over the long periods of geologic time, the earth's surface is shaped and reshaped endlessly. Oceans open and close, mountains rise and fall, rocks are folded, faulted and fractured. These activities are byproducts of the mountains of lithospheric plates and are described by plate tectonics. For geographers the great value of plate tecton ics is that it provides a grand scheme for understanding the nature and the distribution of the largest and most obvious features of the earth's surface.

4.7 SELECT READINGS

1. Discuss the concept of Plate Tectonics as proposed by Hess and Vine.
2. What are the characteristic features of the plate boundaries and plate margins.
3. Describe the nature of the different plates that are found in the global system.
4. What are the mechanisms of plate creation.
5. How is mountain building related to plate tectonics ?

4.8 SELECT READINGS

1. The Earth's Changing Surface - Bradshaw et.al.
2. The Great Geological Controversies - Hallam (Edited)
3. Principles of Physical Geology- Holmes
4. Physical Geography - Strahler & Strahler
5. Physical Geography - Enayat Ahmad
6. A Textbook of Geomorphology - P. Dayal

PART II

Unit 1 ❒ Development of Modern concepts in Geomorphology (with special reference to India)

UNIT : 1 DEVELOPMENT OF MODERN CONCEPTS IN GEOMORPHOLOGY (with special reference to India)

1.1 GEOMORPHOLOGY : DEFINITION AND HISTORICAL PERSPECTIVES

Geomorphology is the systematic scientific study of the geometric features and evolution of landforms under the exogenic or external processes of the earth's surface. The term 'Geomorphology' has been derived from the Greek word *'Geomorphelogos' (Ge :* earth, *morphe :* form, *logos :* a discourse). To be precise geomorphology includes the study of the relationships between structures and landforms at the basic level ; but then has two major branches : the *inductive study* of the existing landforms, from which the processes of their evolution are inferred, and the *deductive study* and measurement of actual processes operating, inferring their ultimate influence on the landscapes on which they are acting. These two are complimentary, as they approach the cause and effect relationships between landforms and processes from two contrasted viewpoints. The deductive branch is older than the more scientific inductive branch.

The study of Geomorphology before William Morris Davis

The origins of geomorphology are obscure. Geologists, probably W. J. McGee, and J.W. Powell in the USA developed the term itself in 1880s. Therefore before W.M. Davis there was no science called geomorphology, but there were certain developments in geology and natural science that can be recognized as early geomorphological thought (Chorley, *et.al.,* 1964).

Aristotle, the 4^{th} century BC Greek philosopher and natural scientist was perhaps the pioneer of environmental thoughts on meteorological cycle, streams and their carving works on the surface of the earth. He had several ideas about the existing natural environment of the earth as he observed that some streams resulted from the downward percolation of rainwater. He also observed that streams carved the surface of the earth and made the existing landscape.

Before W.M. Davis the development of geomorphology passed through four distinct phases, namely ***1) Catastrophism, 2) Uniformitarianism, 3) The Glacial Theory,* and *4) Process Geomorphology.***

J) Catastrophism: During the Middle Ages biblical beliefs controlled the ideas. The basis idea was that the earth had been shaped during a very short period of time (6 days of creatin and 40 days of flood. Adherents to sucn a view were called 'Catastrophists'. According to them the earth was about 6000 years old. Till the end of the 18^{th} century Catastrophism had a complete command upon the geomorphological thoughts. During the 15^{th} and 16^{th} century (the period of Renaissance) engineers such as Leonardo da Vinci and B. Palissy recognised the slow rate of operation of geomorphological processes. Leonardo was convinced that rivers erode their beds and excavate valleys.

From the end of the Middle Ages to about the end of the 18th century particularly the French workers and engineers (e.g. Pierre Perrault) working on the Saine basin made many advances and as a result the hydromechanics developed. However, till 1800 the concept of the valley was a confusing one- every depression was considered as such, even the Atlantic was valley. There was no clear distinction between igneous and sedimentary rocks, geological time was still measured in thousands of years.

By 1840 Catastrophism had been refuted with the emergence of the concept of Uniformitarianism and the Glacial Theory.

2) Uniformitarianism: This was based on the thought *'the present is the key to the past'*, meaning that the processes and the natural laws which existed in geological time (in the past) are basically the same as the ones that may be observed in the landscape today. This is the antithesis of the Catasdtrophism. Mutton, a Scottish geomorphologist, established this idea in his book ***Theory of the Earth*** (1788); this was formally presented by Lyell (1830). The ideas pointed the way forward. Hutton realised that the slow operation of geological processes required long time periods.

3) The Glacial Theory: The belief of Catastrophism was completely wiped off by the rise of a quite different branch of geomorphology - glaciation. Earlier Scheuchzer (1723) put forward a theory of glacial movement. The theory that the ice can mould the landscape and that the ice was much more extensive in the past, was lodged by Louise Agassiz (1840), who studied certain landscapes of the mainland Europe, then in Britain and afterward in North America. Later Ramsay (1860) increased suppord for this theory in Britain. Geikie (1865) accepted the importance of fluvial activity on the evolution of landscape.

4) Process Geomorphology : This branch of geomorphology developed in the late 19th century by Powell, Dutton, McGee and Gilbert through a series of exploratory surveys under the U.S. Geological and Geographical survey. They made direct observations of the landforms, structures and processes in the plateaux, mountains and deserts of the west. Most of the work was concerned with slope form, process and evolution and with fluvial processes. Many geological terms and ideas in use today were introduced *(e.g.* consequent, antecedent). Gilbert's classic work is contained largely in *Geology of the Henry Mountains* (1877).

At this juncture there strode into the stage a geomorphologist, whose ideas and techniques rocked the world of geomorphology, dominating geomorphological thought for over 50 years. He was William Morris Davis of the United States of America.

1.2 Contribution of William Morris Davis in Geomorphology

William Morris Davis (1850-1934) is known as the father of modern geomorphlogy. He was the Chairman of the Department of Geology at the Harvard University of U.S.A., but while developing his ideas he preferred to project himself as a geographer. His impact on geomorphology was greater than that of any other single geographer of his time. Davis was a great definer, analyst and systematiser. He introduced genetic method of landform description, the most important being the cycle concept: youth, maturity and old age and said that landform depends on the three elements - structure, process and stage. In a long series of influential publications between 1880 and 1934 Davis was a prolific and productive writer. He synthesized the scattered elements of geomorphology and made it into a coherent subject for the first time.

According to W. M. Davis *"Landscape is a function of structure, process and stage"*. By *Structure* he meant something more than is usually meant; the word includes the rock bodies, the structure, the dip of the beds, their folds and faults, but also lithology of beds, the nature of rocks, their relative hardness and permeability. *Process* includes the different agents of weathering and erosion *e.g.* water, wind, ice, gravity. Finally the length of the time during which the processes have acted obviously must have a profound effect on the landforms. For this purpose Davis divided the landforms produced during a cycle of erosion into three distinct *Stages* : youth, maturity and old age.

Ideal conditions for Fluvial Cycle as Davis proposed: Davis suggested the following four environmental conditions : i) The region has just uplifted from beneath the sea by dystrophic movement and processes and it has considerable amount of absolute relief; ii) the sea-level acts as the base level of erosion and remains sufficiently stable allowing the cycle to run its full course ; iii) the region should be of simple horizontally bedded sedimentary rocks of varying resistance ; and iv) the action of running water is predominant on the landscape development.

Graphical explanation of the Davisian Cycle of Erosion : Davis presented his cycle concept in a very simple manner. He suggested a rapid uplift during which no effective erosion takes place ; and thereafter a period of long still-stand., during which the denudation continues through the stages of youth, maturity and old age ; ultimately to form peneplain. During the early stage of cycle the valley bottoms are quickly lowered while the ridge tops remain virtually unaffected. The relief thus increases, is as shown by the divergence of the two curves on the graph. It reaches at of just before the beginning of maturity. Thereafter the ridges begin to diminish in height faster than the valley bottoms are lowered. The two curves thus approach one another, representing gradually diminishing relief.

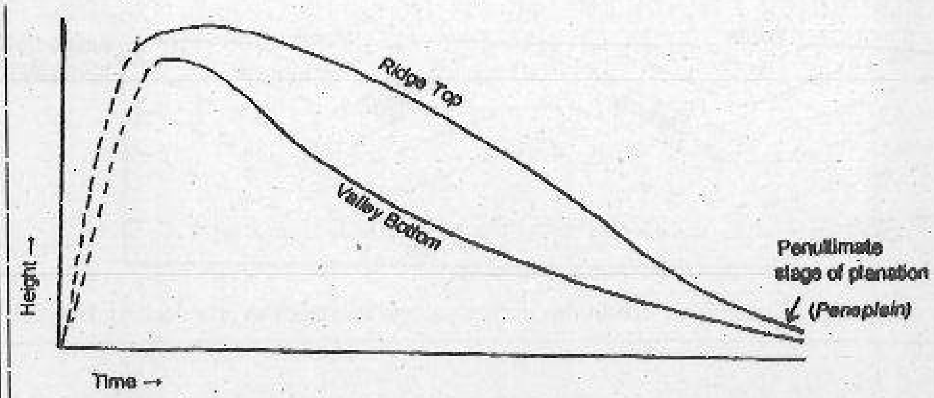


Figure 1 : Graphical representation of landscape evolution as proposed by Davis

The stages of the fluvial cycle (characteristic drainage and the landform features) :

I. Youth : i) Existence of a few consequent trunk streams and numerous short tributaries, headward erosion by gullies developing valley systems ; ii) valleys will have V-shaped cross profiles; iii) valley-sides will rise from near the stream edges; iv) extensive and poorly drained inter-stream tracts; v) water-falls and rapids would exist; vi) stream meanders will occur only under structural control.

II. Maturity :i) Valleys have extended themselves giving rise to well-integrated drainage system; ii) Existence of some longitudinal streams (tributaries) along belts of particularly weak rock ; iii) Stream-divides will be sharp and ridge-like, resulting in a minimum of inter-stream uplands ; iv) any lakes or waterfalls that existed in the youth have disappeared; v) Flood-plain tracts constitute a considerable portion of the valley floor; vi) Meanders are conspicous and free the shift their positions over the flood-plains; vii) The width of the valley-floor will not greatly exceed the widths of the meander belt; viii) he maximum possible relief exists ; ix) Slope of hill-sides and valley-sides cover greater parts of the topography.

III. Old Age : i) Tributaries to trunk streams are usually fewer in number than in maturity but more numerous than in youth ; ii) Valleys are extremely broad and gently sloping ; iii) There is marked development of flood plains over which streams flow in broadly meandering courses ; iv) Valley-widths are greater than the meandering belt; v) Inter-stream areas have been reduced in height; vi) Lakes, swamps and marshes may be present on the flood-plains; vii) Mass-wasting and chemical denudation are dominant over fluvial process ; viii) Extensive areas are at or near the base level of erosion.

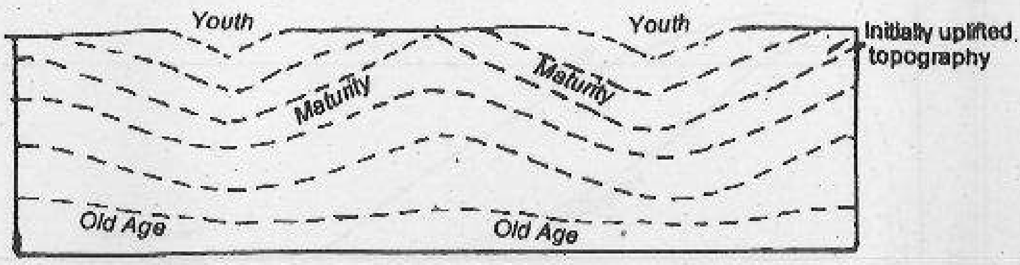


Figure 2 : Topographic conditions during successive stages as proposed by Davis

Indian geomorphologists accepted the Davisian cycle concept of landscape evolution almost overwhelmingly from the beginning of the 20th century and till the 70s of this century the influence of Davis in the geomorphological understanding remain unabated. Geomorphologists in this country attempted to fit all their studies and field investigation in the framework designed by Davis. They also attempted to find the instances of many Davisian landforms, *e.g.* accordant of summit levels, peneplain etc. in several parts of India particularly in the peninsular plateau region.

Contribution of Walther Penck ; In the 1920's W. Penck, the German geomorphologist, staged a minor revolt against some of Davis's ideas by publishing his paper *Die Morphologische Analyse* (1924), and found some adherents. Davis assumed that relatively rapid initial uplift of the land might be followed by a period of still-stand, which permitted a cycle to run its full course. Penck suggested that this was not the normal sequence, since more commonly the rise of land should be so slow and continuous one (diastrophism) in relation to denudation that there should be neither actual net rise of the surface, nor increase of its relief. Penck thus presented another diagram to replace that of Davis.

Penck did not deny completely the validity of the geomorphic cycle. Davis's *'oldfrom birth Peneplains'* will be theoretically similar to Penks's *'Primarrumpf,* He replaced Davis's Structure, process and stage by endogenic and exogenic forces by three main phases of relative mobility *Aitfsteigende Entwicklung* (waning development ; Stages 1 & 2), *Gleichformige Entwicklung* (uniform development : Stage 3) and *Ahsteigende Entwicklung* (waning development: Stages 4 & 5).

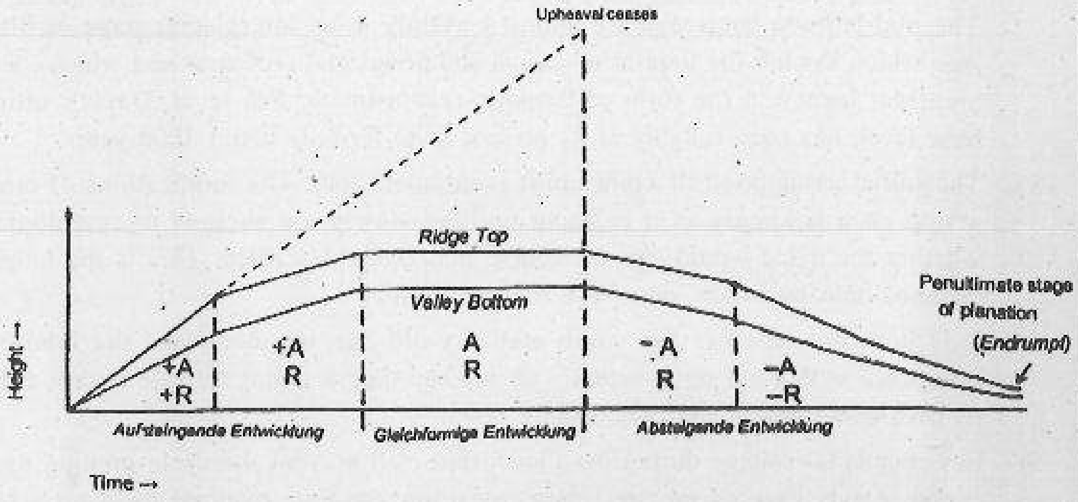


Figure 3 : Graphical representation of landscape evolution as proposed by Penck

In Stage 1 the flat interfluves are little eroded and gain in altitude by the amount of the upheaval. In Stage 2 valley widening sharpens the interfluves. They now gain in altitude more slowly. In Stage 3 the stream still cutting down, deepen their valleys as faster as the uplift proceeds. In Stage 4 upliftment has ceased, valley deepening continues for a time with concurrent reduction of the ridges. In Stage 5 the process of valley deepening slackens, so that both relief and altitude slowly diminish. The landscape from passing through the stages of development would then terminate in a region of low relief-the *Endrumpf,* simulating the Davisian peneplain.

Criticisms of Davis and Penck of their Cyclic concept: Although some students, perhaps regrettably, are still taught geomorphology using Davisian approach, modern geomorphology contains little or no Davisian thinking. The main criticisms of Davis's work can be summarised as follows:

1) Davis overemphasized stage and paid less importance to structure. By doing so he did less than justice did to his on dictum about landform being a 'function of structure, process and stage'. To many process geomorphologists, recalling Gilbert's work, Davis was responsible for delaying the development of geomorphology for over 50 years.

2) Davis's greatest omission was the study, both in the field and in theory, of the detailed mechanics and nature of present-day processes. To some extent this reflects the descriptive and non-quantitative nature of Davis's work. The neglect of biological processes was significant. Davis's landscape look like deserts : not a plant, not a tree.

This is surprising since Davis based his work on the well-vegetated temperate latitudes. Also regarding process Davis's use of the term *normal* was never explicitly defined. The mid-latitude landscape are almost certainly in an interglacial stage of the Ice Age which has left the imprint of glacial and periglacial processes and which ; leaves a current legacy in the form of Isostatic readjustment. Sea level, Davis's ultimate base level, has been roughly at its present level for only about 3000 years.

3) The initial assumption of rapid uplift is unsatisfactory. The implications of erosion acting on a landmass as it is being uplifted slowly are such as to cast doubt on whether the cycle would run the course that Davis described. This is the loophole fastened onto by Penck, on of Davis's early critics.

4) It is doubtful whether the youth-maturity-old age sequence and the landforms associated with each stage actually occur. The theory is not testable except against its own assumptions and conclusions.

5) Environmental change during the Pleistocene will prevent the cycle running its full course. Davis gave no precise figures regarding the time required for a cycle to do so.

6) The concept of grade, as defined by Davis, has proved elusive. As envisaged earlier, it is difficult to assume graded rivers and graded hill-slopes co-existing with a long term regarding the landscape.

7) The cycle of erosion has a deceptive simplicity, which has tended to have a blinking effect on its adherents. They then tend to find it hard to view landscapes in terms other than those proposed by Davis.

8) Davis never measured form. Impressions of slope form are notoriously inaccurate and misleading.

9) The final criticism is more profound than all the others. It deals with Davis's basis method. His work is an example of the deductive approach. This means basing an argument on certain assumptions, and inferring from the general to the particular. This is unscientific. Today scientific method is the inductive approach, which builds on experimental evidence from particular instances to produce general inferences. This is the source of many specific errors made by Davis.

Development of non-cyclic concept in geomorphology

With the passage of time a number of shortcomings of Davisian hypothesis, concerning cyclic evolution of landscape, has been raised by the geomorphologists working in different parts of the world and subsequently a search for more viable and acceptable hypothesis of landscape evolution continue particularly from the early second half of the Twentieth century. Actually development of the *Non-cyclic concept* in geomorphology about the landscape evolution is the result of some major shortcomings of the Davisian concept due to which a number of questions on the landscape denudation process remained unsolved.

Some modern geomorphologists, J. T. Hack (1960) and A. N. Strahler (1952) of U.S.A., and R. J. Chorley (1962) of England have developed a thesis that, So long as the factors which control denudation processes remain the same, the form of the land need undergo no change with time, or in other words landform evolution will not take place. Such landforms will be 'time-independent'. This is in contrary to that of the cycle concept, which, by giving emphasis on stage, implied that landforms are always 'time-dependent'. In a sense this non-evolutionary interpretation was foreshadowed in the writings of the German geomorphologist Walther Penck. As it has been seen, his theory of rectilinear slope formation at a constant angle, in response to constant stream erosion, envisages no progressive change of form. It can not be too strongly emphasized that such landforms are not to be regarded as static ; they will continue to be affected by weathering and slope retreat, and the land-surface as a whole will be lowered, but throughout the whole process no change in the dimensions and angles of the landforms will be effected.

The concept of dynamic equilibrium: The above-mentioned arguments stem from an entirely new theory' of landform development, known as ***dynamic equilibrium.*** In this it is assumed that all aspects of the landform geometry of an area (such as relief, slope length, mean and maximum slope angles, channel gradient, and so on) are intimately related to each other. Indeed it has recently been suggested that in favourable circumstances all the main components of a landscape (valley bottoms, valley-side slopes and divide summits) will experience lowering at an uniform rate. In order that this should happen, a delicate condition of 'energy balance' (here the term dynamic 'equilibrium') must be established. On a slope, for instance, the 'energy input' (related to the intensity of the active denudation processes) must be such as to produce the continuous an efficient evacuation of all detritus material; such a slope, like in a condition of quasi-equilibrium, is referred to in modern terminology as a 'system in a steady state'. In order that the energy input should be just sufficient, the slope itself will undergo adjustment of form until, under the prevailing conditions, its height and angle are 'correct'.

The Indian geomorphologists realised the essence and viability of the non-cyclic concept of landscape evolution not before the early 70s of the last century. Geomorphologists like K.R. Dikshit, Savidra Sing. Vaidyanadhan and others extended their geomorphological field studies in different parts of India under the realization of this new emerging concept.

1.3 Emergence of Modern Applied Geomorphology

Over the last fifty years or so the study of geomorphology has observed a radical change. It has been possible basically through the introduction of applied geomorphology. *Applied geomorphology* is the study of the interaction between geomorphology and human activity, covering : 1) the specialized mapping and landforms, such as slope elements, which affect or may be affected by human activity, and which are not mapped by other disciplines ; 2) the interpretation of features shown on aerial photographs or by remote sensing methods ; 3) the monitoring of changes in the environment, especially when those changes bring risks to society; 4) the assessment of the causes of these changes, notably of those which develop as hazards to man ; 5) the remedies to such hazards and 6) the recognition of the consequences of human avtivity in geomorphology.

It has already been mentioned that the early development of geography observed mere descriptive studies of natural and human phenomena. Till the third half of the 19th century geography continued to be a part of the natural history and it concerned mainly the statement or description of facts and figures of the surrounding earthly elements, as mountains and hills, rivers, cities and towns etc. From the last part of the 19th century the study of geography started taking a new shape as explanations and interpretations of geographical elements (physical, economic and cultural) started taking place with models and quantifications. For example, W.M. Davis put forward graphical model to explain geomorphic evolution of landscape ; and later W. Penck and L.C. King furthered this type of graphic-system analysis through the first half of the 20th century. Also in 1930s' Christaller brought quantitative techniques to explain development and spacing of towns and cities.

After the World War-II geography, as a mixture of natural science and social science, geography started taking a new dimension having orientation towards application. This application-oriented geography became known as applied geography and this also entered in the arena of geomorphology as well, thus developing applied geomorphology.

This new wave of endeavor of study entered slowly in geomorphology of India from the sixties of the last century. The outcome was that the application-oriented geomorphological works started gathering momentum as well as popularity. Geomorphologists from this stage continued to devote more quantitative, fieldwork-based and application-oriented works.

Background and development of the applied geomorphological studies

Applied geomorphology has a long history. Evidences show that the origins of geomorphology were marked by numerous applied studies between the 17th and 19* centuries, not least those by Gilbert himself. This tradition was carried on into the first half of the 20* century, by for example, Glenn (1911), Sherlock (1922), Bryan (1925), Hoiton (1924,1932,1933,1945) and Jacks and White (1939). Thornbury (1954) also devoted an excellent chapter to applied geomorphology in his widely read textbook. In spite of these works it is clear that even as recently as 1960s geomorphology did not have a strong applied content.

There are several reasons for which the development of applied geomorphology was delayed.The main reasons are 1) the long association of geomorphology with geography at a time when geography itself had little applied content, and 2) the long preoccupation with the cycle of erosion and denudation chronology, neither of which had any obvious applications to practical problems. But probably the most important reason was the delay in the development of process geomorphology. To a large extent, applied studies and process studies go together ; because applied studies rely on their being an explanation for geomorphological phenomena, and explanation is impossible without understanding process. So applied geomorphology had to wait for process geomorphology to develop through the 1950s and 1960s. It can be said that process geomorphology became strong enough by the end of 1960s for applied geomorphology to take off. By that time other relevant developments had also taken place ; namely landform and landscape evolution, the land systems approach and geomorphological mapping.

Around 1970 it was observed that geomorphologists had realized that the results or process studies were of practical as well as purely academic value, and showing that applied geomorphology was being born as a recognizable discipline : in 1967, Douglas's article on man's effect on the sediment yield of the rivers ; in 1969, Chorley's widely read *Water, earth and man ;* in 1970, Brown's much quoted article on man as a geomorphic agent, and Craick's pioneer work on man's perception of the physical environment, indicating that the relevance of geomorphology has to be seen in the context of man's response to what he thinks the environment is like rather than what it is actually like; and in 1971, Detwyler's *Man's impact on environment,* and Douglas's two widely-quoted case studies; and Chorley and Kennedy's *Physical geography: a system approach,* not only a milestone in itself, but showing that man's impact on landscape has to be seen in the context of his place in complex systems.

The most remarkable work that culminated the development of concept of process geomorphology was the book of Cook and Doornkemp *Geomorphology in Environmental Management,* which was published in 1974. This was a masterly work defining a coherent area of study, summarizing a vast existing literature, and pointing the way forward. Applied geomorphology is now the main area of growth in the subject; over the past 20 years or so there have appeared countless magazine articles and textbooks, or chapters in textbooks on the aspects of applied geomorphology.

The need for applied geomorphology : It is true that geomorphology has not always had strong applied content. However, it is pertinent to ask 1) what justification is there for the applied branch of the subject, and 2) what demand is there for it. The answer is that there is a need for applied geomorphology from two quarters. One is an intellectual demand from within geomorphology itself; the other is a practical demand from society in general.

The first is a general feeling among geomorphologists that in this rapidly changing world with a wide range, of practical application, the subject cannot survive as a purely academic discipline. The subject must be justified in terms of its practical value to the community. There are three reasons for this. *First,* government money is being spent on undergraduate courses and postgraduate research, so there should be some tangible return from these courses and researches. *Secondly,* it would be absurdly wasteful to have a subject, which could make practical contributions yet did not do so. *Thirdly, a* number of geomorphologists have seen applied studies as the ideal outlet for their expertise and have deliberately set about promoting the subject However, the second reason for the development of applied geomorphology has been a genuine demand for it from outside the subject, from the community in general. This demand takes a number of forms, and this is in turn defines what applied geomorphology consists of, there is no point in providing a service that nobody wants. It is therefore possible to classify modern applied geomorphology into various branches and, although the branches have links and overlaps, they provide a convenient basis for describing the subject.

The branches of modern applied geomorphology

Among the various branches of modern applied geomorphology the following three are most important : 1) Natural hazards, 2) Environmental management, and 3) Evaluation of resources.

1) ***Natural hazards:*** Natural hazards include soil erosion, various types of slope failure, sea and river floods, volcanoes, earthquakes and faulting. Sometimes the *hazard* occurs, at least partly, because man himself has acted unwisely in some way. This can happen with soil erosion. Sometimes the *hazard* is completely natural; for example earthquakes. Whatever man's own role in the initiation of the hazards the professional geomorphologist has a role to play. He has some measure of understanding of the combinations of events that produce the hazards, and he is therefore, in an unique position to advise on such matters as predicting the occurrence of a hazard, protecting against it so as to reduce its effects, and perhaps in reducing the dimensions of the hazard itself.

2) ***Environmental management:*** This is the geomorphologist's role in the man's deliberate and controlled impact on the landscape : the geomorphologist joins others in planning, managing and developing the environment. There are close links with hazard control, and in a sense environmental management includes all the work on hazards, but environmental management does not necessarily imply the presence of a major hazard. For example, geomorphologists are called upon to advise on the building of roads.

3) ***Evaluation of resources :*** There is a general concern that we should be aware of the existence of the resources that are available to us, and that those resources should be subject of suitable conservation measures. The geomorphologist has a variety of role here. *First,* sometimes a resource has a particular geomorphological setting, as with the occurrence of sand and gravel deposits as river terrace, so that the evaluation of such deposits has an obvious geomorphological element. *Secondly,* at a more general level, most land resources are closely linked to the geomorphology of the earth's crust, so the trained geomorphologist can assess rapidly the resource potential, including the mineral resources of an area from the interpretation of its landforms.

Thirdly, the geomorphologist is also conversationalist. Conservation is important for all resources, but especially perhaps the soil, and the geomorphologist, with his knowledge of what creates and destroy soil, has a crucial role to play here. Conservation is also important for some things that we do not immediately think of as resources - scenery for example. Therefore the techniques of scenic evaluation are part of environmental management. *Fourthly,* terrain analysis is also important for some things that we do not immediately think of as geomorphological. For example it has military applications. Not only is an appreciation of terrain instilled into every soldier during his basic training, but also at higher-level classifications of landscape now play an important part in the planning of military operations, as in the Jatnmu & Kashmir sector.

Sources and types of geomorphological information for application : The demand for geomorphological information comes from a variety of organizations concerned with developing or managing the environment. These may be government bodies, including authorities, or consulting engineers, land developers, land managers, and those involved in the legal aspects of planning. Also with the rapid development of information technology particularly over the last two decades, land and topographic information received from the Remote Sensing satellites has become very powerful tool for applied geomorphology.

The type of information that the geomorphologist can, and is, asked to supply depends partly on the subject of the investigation but also on the scale of the planning or development problem as India needs very badly in the present day. At a national level the emphasis tends to be on resource inventory and appraisal, leading to the selectioin of suitable regions and locations for development. At the regional and local levels more importance is attached to detailed field mapping of geomorphological features and to process studies as bases for determining the risks associated with development. More detailed investigations are required at the scale of the individual site when the proposals of the plan are implemented. Studies at this stage are concerned with the nature of the surface materials, slope stability and earth-moving or land-forming operations. As a planner, therefore, the geomorphologist is making a variety of contributions at different times and at different scales to numerous organizations and authorities.

Working as a private consultant or as a full-time employee a geomorphologist brings a combination of skills to the job that arises from basic training as a geographer. This can be as follows:

a) An ability to think in spatial terms : to appreciate location and to cope with several phenomena at a time.

b) An ability to detect spatial correlations.

c) An ability to change one's scale of thinking in accordance with the nature of the problem.

d) An ability to comprehend the significance of the time dimension.

e) An ability to use plan documents : the map, plan or aerial photograph.

Pattern of contemporary development of applied geomorphology

Over the past 25 years or so applied geomorphology has gradually gathered momentum to the point where it is now a major branch of the subject. But it has not developed in isolation. There have been other developments, some within the subject and some outside it. The link with applied geomorphology is obvious and strong, but it is difficult to speak of cause and effect. .

1) ***The rise of process studies*** : Of the developments within geomorphology itself, the first was the rise of process studies.

2) ***Development of numerical techniques*** : The second is closely related to the above : the development of numerical techniques and their application to the subject. The relevant aspect of this development of applied geomorphology is that it allows the geomorphologist to speak in precise, numerical terms all the time. The applied geomorphologist has to deal in such precision. When there is a problem to be solved, and people's lives and vast sums of money are involved, then it is essential to speak in quantitative terms.

3) ***Increasing awareness of man as a geomorphological agent*** : The third development is the increasing awareness of man as a geomorphological agent. This is an appreciation of shear scale of man's intervention. Man's intervention is has often been ill judged and harmful. Man himself therefore seeks to take corrective measures and to avoid making such mistakes again.

4) ***Emergence of systems analysis as a paradigm*** : The fourth development is the emergence of general systems analysis as a paradigm for geomorphology. General systems analysis provides an accurate and logical framework for appreciating and studying the complexity of the geomorphological environment. There is always a variety of factors involved, factors which interlink and affect each other. So if a practical problem needs to be solved, this complexity needs to be not just recognized but also accurately understood. General systems thinking allow this.

5) ***Appearance of an abundance of techniques*** : A fifth and final internal development has been the appearance of an abundance of techniques. The applied geomorphologist, perhaps faced with a landform or process to measure that he has not measured before in an environment that he has not worked in before to solve a problem, that he has not thought about before, needs a veritable armory of techniques at his disposal, and this is exactly what he has got. Geomorphologists themselves have developed some of the tecnhiques, while others are the products of science in general. It can be obseved that the applied geomorphologist's job of resource evaluation is greatly facilitated by the development of the techniques of remote sensing.

The second groups of developments that need to be stressed are those that have occurred outside geomorphology but still gone hand in hand with the growth of applied studies.

1) ***Geomorphology as a part of ecosystem study:*** The first of this group would regarded as a part of geomorphology anyway - ecosystems. The ecosystem concept is new, but its central position in physical geography has come about only in the last 20 years or so. If one thinks in terms of ecosystems then one is thinking in terms of ecosystems of varying scales that are influenced by a wide range of inter-related factors. Among other things it provides a framework for assessing biological factors and the hand of man. That is exactly what the applied geomorphologist has to do. So the ecosystem is a vital concept in applied geomorphology.

2) ***Concern about conservation*** : The second external development is a general concern about conservation. This is a vast subject. The applied geomorphologist, indeed the geographer, is only one of many professionals involved in the decision-making process. It is a certain fact that the fairly recent and sudden increase in interest in conservation issues has added a new dimension to the applied geomorphologist's role in the environmental management.

3) ***Accelerating exploitation of the developing countries and remote areas by the developed countries*** : The third development is the accelerating knowledge of, and exploitation of, the developing countries and remote areas of the developed world. Applied geomorphologists' are frequently called upon to assist in the investigation of the resource potential of an undeveloped area in the Third World and, to judge from the frequency with which they appear in the academic articles, hazards are affecting the Third World countries more than ever before.

4) ***Man-land interaction*** .'Another external development is man-land interaction. The idea that man and the land form a mutually interacting system in an attractively simple one, and at various times it has been put forward as the central, crucial and distinctive theme in geography. As recently as in 1980s, the consensus among geographers was that gradually but inevitably dividing into two separate subjects-human *geography* was being absorbed into the social sciences, *physical geography* into the earth sciences -the implication being that one had little contanct with the order. Now there is a swing back the other way. The unity of geography is being stressed again, with man-environment interaction as the core idea. If this approach develops strongly, it should assure the future of applied geomorphology.

5) ***Development and association with modern tools:*** Finally the development of modern tools like Remote Sensing (RS) and Geographic Information System (GIS) have boosted the popularity of geomorphological research works in different parts. From the late Eighties of the 20^{th} century India, with her own remote sensing satellites (IRS-I, II & III and very recently (6.5.2005) launched *CARTOSAT*), had opened the scope and new horizon of extensive and systematic geomorphological studies in the country.

Position of applied eeomorphology In the present day

Now it has become an well-accepted fact that to be successful planners, environmental managers and developers need to be well informed about the nature of geomorphological problems, and therefore need the services of the professional applied geomorphologist. However, since in studying applied geomorphology we are analyzing the relevance of geomorphology to the general needs of society, it is pertinent to establish exactly what the role of the geomorphologist is in the decision-making process. The answer is that effective control lies with an enormous number of individuals, not all of who are trained environmental scientists. Therefore, the crucial aspect of environmental management is to bring the scientist and environmental decision-maker together. There is also an element of public consultation, including the farmer, forester and tourist.

Many private firms and government agencies exist which deal with some aspect of the earth's geomorphological systems. From this it follows that geomorphological information is required by all kinds of organizations concerned with developing or managing the environment. At the international level UNESCO, in its concern for the welfare of mankind, has acknowledged the important role of applied geomorphology. At the national level there are a number of government bodies, such as national planning units and departments of hydrology and agriculture, which require such information. Regional and local planners also make use of geomorphological contributions.

1.4 QUESTIONS

1. Discuss the contribution of W. M. Davis in the study of geomorphology.
2. Critically analyse the cycle of erosion as postulated by Davis.
3. Discuss the criticisms of Davis and Penck of their cyclic concept.
4. Analyse the development of non-cyclic concept in geomorphology.
5. Discuss the emergence of Modern Applied geomorphology. What are the branches of modern applied geomorphology.
6. Discuss the pattern of contemporary development of applied geomorphology, with its present position.

1.5 SELECT STUDIES :

1) Geomorphology : Pure and applied (1986)—M.G. Hart *(George Alien and Unwin, London).*

2 Principles of Geomorphology (1954)—W.D. Thornbury *(John Willey and Sons, New York)*

3) The Study of Landforms (1987)—R.J.Small *(Cambridge University Press, Cambridge)*

4) Contemporary Dimensions in Geography (2000)—Eds. N. Prasad and FLBasu *(Acad. Staff College, University of Burdwan, Burdwan)*

Unit 2 ❐ Theories of Slope Evolution

UNIT : 2 THEORIES OF SLOPE EVOLUTION

2.1 RELEVANCE OF STUDIES OF SLOPE :

In the study of geomorphology it is now universally accepted that the physical landscape is an assemblage of slopes, and the dimensions and the appearance of the slope give to any area its essential geomorphological character. The main problem of slope studies lies in the following :

i) to determine the nature, rate of operation and precise effects of the processes and the work of slopes, and

ii) trace the changes of form and angle that slopes undergo with the passage of time. Thus the geomorphologists have to obtain the answer of the following questions :

a) What are the various forms assumed by slopes?

b) How do slopes change their form and gradient with the passage of time?

c) What is the relationship between the slope form and the various denudational processes operation of the slopes?

d) Are slopes, like rivers, able to attain a state of equilibrium or grade ?

e) What is the influence of geological structure and rock-type on slope form and steepness?

f) Is there a relationship between the prevailing climatic condition and slope form?

Nomenclature of slopes

All landscape is composed of slopes. Nomenclature of slope can be summarized by the following two diagrams, assigned as : ***a) Slope Segments* and *b) Slope Elements.***

Slope Segments : In geometric terms Slope Segments are the three distinct segments of slopes. The uppermost segment is called *crest slope*, the middle part is called *middle slope*, and the lower part is called *foot slope.*

Slope Elements: In the consideration of geomorphological processes a number of distinct element and facets of slope have further been identified. All slopes consist of a number of distinct parts, and each part is termed as segment. Rectilinear segments are called *facets* and those, which have a convex or concave profile, and called *elements.* When a facet is at an angle of more than 45° it is know as a *free face* or *fall face.*

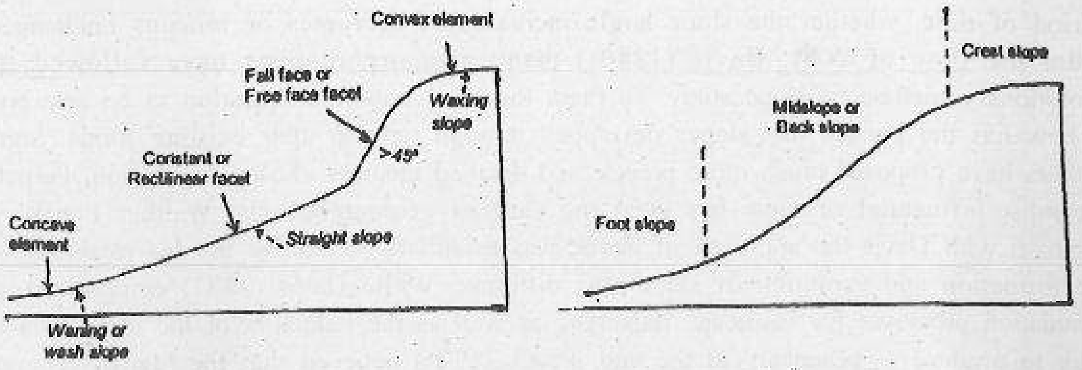


Figure 1 : Nomenclature of slope (Slope segments and Slope elements)

The uppermost part with low angle is the *convex element.* Here the slope grading is waxing continuously as result of weathering process operating upon it. Adjacent to it lies the cliff wall, known as *free-face facet,* and from this part rock fall material is derived. Lower down this cliff is the middle slope, geomorphologically designated as *rectilinear slope.* Most of the slope washing and material transportation occurs over this slope. At the bottom the foot slope is called *concave element.* As a result of continuous deposition of washout material received from the rectilinear slope adjacently upper part of it, the gradient continues to become less, and therefore, this part is known as *wash slope.*

Processes of Slope Development

It is a well-known fact that degradation and disloding of material and thereby transportation of removal or it due to gravity are responsible for the development of slope.

Some slopes, such as activity eroding sea cliffs or the free face of high valley sides, may consist of bare rock. A covering of weathered rock resting on bedrock as is found is some scree may also form a slope. Third type of slope, the most usual in temperate humid screes, consists of bedrock (forming the basal slope) covered by a regolith *(i.e.* weathered rock often include a surface layer of soil.) It is with slopes of the third type that this section is concerned.

There is yet no comprehensive empirical knowledge to explain slope development. Because the processes, which modify slopes under normal conditions, work very slowly and the instrumentation to measure slope changes is of recent development, there has not yet been time for much observational evidence to accumulate. For these reasons hypothesis concerning slope evolution must be partly speculative. Because of this, much attention is given to day to the study of process.

2.2 THEORIES OF SLOPE EVOLUTION

Introduction: In slope evolution the change of slope with time is studied. A basic question is, under certain given conditions and after the processes have worked for a period of time, whether the slope angle increases of decreases or remains unchanged. From the time of W.M. Davis (1880s) many geomorphologists have followed the evolutionary method of slope study. To them the most important question to be answered is how has the present day slopes developed through time to their existing forms. Some authors have proposed much more precise and detailed theories of slope evolution, Perpahs the most influential of them has been the German geomorphologist Walther Penck. In common with Davis the approach of Penck was essentially deductive but his treatment on the formation and evolution of slope was different. While Davis (1887) emphasized on denudation processes for landscape reduction, as well as the reduction of the inclination of land, to produce a 'peneplain' at the end, Penck (1924) believed that the rate of removal of weathered material from a landscape depend upon its steepness of gradient (i.e., the slope) so that a steep slope will retreat more rapidly than a gentle one, ultimately producing an almost flat land, the 'endrumpf'. Later on L.C. King (1948) argued that slope steepness is maintained almost to the stage of old age, and that the most important evolutionary change in slope form entails the extension of concave basal slopes or 'pediment'.

In this connection the following three important theories have been put forward :

i) Slope decline theory of W.M. Davis

ii) Slope replacement theory of W.Penck, and

iii) Parallel retreat theory of L.C.King

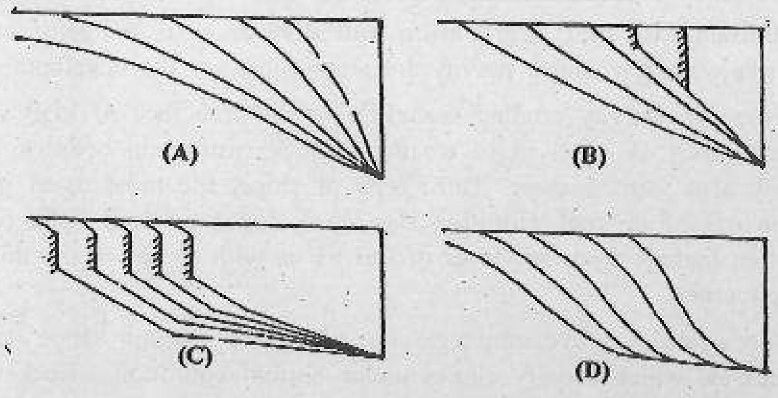


Figure 2 : Diagrammetic representation of different concepts of slope evolution
A - Slope decline (W.M.Davis) B - Slope replacement (W.Penck),
C - Parallel retreat with free face (L.C. King), D - Parallel retreat without free face

In *slope decline* the angle of the steepest part of the slope goes on progressively decreasing and there is the development of convexity and concavity. In *slope replacement* the decline of the maximum slope is achieved through the establishment of gentle slope from below until the entire slope becomes concave or is divided into concave sections. In Parallel retreat the maximum angle remains constant, the length of the concavity goes on increasing but the slope angle of the concave part goes on decreasing. Paral lei retreat can take place with or without free face.

2.3 SLOPE DECLINE THEORY OF W.M. DAVIS

W.M.Davis expressed his views on slope evolution in the context of his geomorphic cycle. According to him as cycle of erosion advances the slope from changes with time and ultimately the gradient of slope declines. The slope form is dependent upon time or the stage of the erosion cycle. In the youthful stage of the cycle there is the development of steep convex slope on account of vertical down cutting by rivers. In the mature stage lateral erosion becomes more important and the summit of the divides also comes under the effect of erosion. Thus there is a progressive decline in the slope angle as a result of the wasting of the divides, and the form of the divides tends to become rounded or convex and, simultaneously the rounded divides suffer reduction in height. With the approach of old age the slopes become flatter, and in the end the slope angle declines so much that the entire surface in reduced to an almost level featureless peneplain.

Davis has laid stress on the fact that the upper convex part of the slope is produced by soil creep. As we move down the slope the amount of surface wash goes on increasing but at the divide summit soil creep is far more important than surface wash.

Davis also put forward the concepts of graded slope or graded valley sides and graded waste sheets. In his view the river as well as the mobile debris sheet presents basically a moving mixture of rock debris and water in different proportions. The establishment of grade starts from the lowest part of the slope and extends from below upwards. From any point on the graded slope the debris is being transported down into the river. In fact he equates a graded slope with a graded waste sheet. A graded slope is one having a continuous soil cover, while graded waste sheet is one, which there is equality between supply and removal of debris. To use his own words 'just as graded river slowly degrade their courses after the period of maximum load is past, so graded waste sheets adopt gentler and gentler slopes.....When the graded slopes are first developed they are steep and the waste that covers them is coarse and of moderate thickness...In a more advanced stage of the cycle the graded slopes are moderate, and the wastes that covers them is of fine texture and greater depth than before' (1899). 'The retreat of a valley side is usually accompanied by a decrease in the steepness of its slope as well as by the development of a convex profile at its top and a coarse profile at its base' (1932).

After this Davis comes to his theory of slope decline. As the cycle of erosion progresses an relief gradually decreases, slope profiles change from steep and straight during early maturity to convex-concave by late maturity. As the cycle advances both the convex and concave elements become longer and the radius of curvature goes on increasing. Slopes decrease with declivity as relief is reduced and there is a reclining slope retreat and a decline in both height and inclination. His theory is empirical and based upon direct observation in nature and topographic maps and pure deduction. He expressed his theory in a composite profile drawing lacking units of measure and without a time scale, but the decline of slopes with time was made clear enough, according to Davis principal reason for the decline of slopes is that debris is being transported from the upper convex part of the slope to the lower part. As the cover of debris increases in the lower section the rocks in the lower part are protected from erosion. In his opinion slope decline prevails in the humid regions and even in the arid regions there is decline of slopes with time, though in his later studies (1930) recognized that parallel retreat occurs in arid climates. The principal merit of Davis's theory is that in the context of geomorphic cycle it emphasizes the fact that slope form is time dependent.

2.4 SLOPE REPLACEMENT THEORY OF W. PENCK

It has already been stated that the most fundamental concept of slope was given by the German geomorphologist Walther Penck. His original work : *Die Morphologische Analyse,* written in German is 1924. A full English translation of this work, however, was published in 1953.

The views of Penck are at variance with those of Davis. He did not agree with the Davisian assumption that during an erosion cycle uplift is complete before erosion, which in turn, is largely determined by the nature of the uplift. As an introduction to this theory Penck assumed the simple case of a steep slope unit bordering a valley in which the river had reached a stage where it was neither eroding nor depositing. As there is a steep slope of homogeneous composition and uniform gradient rising directly from a non-eroding river, it has its initial base level. This initial steep slope is termed *Steilwand.* The whole slope surface *(steicwamd)* having the same exposure, retreats everywhere equally under the attack of the weather and the gravitational fall or down slope movement of detached fragments. The process is repeated and with parallel retreat the slope successively to *3\-3, 4\-4* and so on. In each case the lowest fragment remains unmoved. The small ledges there left jointly form the second stage slope from $t\text{-}t^1$ for which Penck used the term *haldenhung,* and this can be considered as the basal slope. The geometric representation of this process, as designed by Penck, is given below :

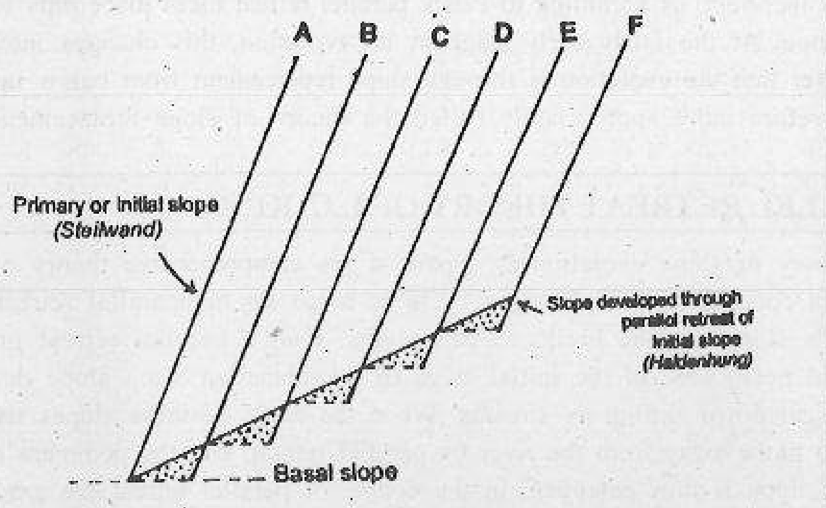


Figure 3 : Pattern of the parallel retreat of slope as Penck assumed

The initial steep slope thus migrates upslope, maintaining its original gradient, with a basal slope developing below it, as its expense. The retreat is related not to river level, the general base level, but to the break of slope at the top of the basal slope. The basal slope will similarly retreat parallel with itself. Since its gradient is smaller, a greater degree of reduction, i.e., a longer period of time, will be necessary to render a unit layer mobile. A new, even further slope will inevitably form below it. Thus in Penck's view flattening *(Abflachung)* of slopes takes place from below upward due to the fact that new and even further slopes will appear at the general base level (river level) and grow at the expense of those above them.

Penck also considered that there must be a constant ratio between the intensity of denudation on the slope and the intensity of erosion by the stream. The three cases discussed by Penck, giving respectively a concave break of slope, simple parallel retreat and a convex break of slope are distinguished by him as *Aufsteigende Entwicklung* (waxing development), *Gleichformige Entwicklung* (uniform development) and *Absteigende Entwicklung* (waning development)

The essence of Penck's theory remains, however, that slope form and angle are primarily determined by the rates of erosion by rivers. It is with this idea that many geomorphologists have disputed with each other. Whilst there is undoubtedly a tendency for slopes to react to river incision in the ways described by Penck, other factors must also be taken into account. Many authors would argue that of these factors rock type, climate and structure could be locally or even regionally dominant to control slope development and slope processes.

Penck's theory was initially called the theory of parallel retreat. In the opinion of some people this is incorrect, as according to Penck parallel retreat takes place only on the initial rectilinear slope. At the fairly early stage in its evolution, this changes into a concave slope, and after that the evolution is through slope replacement from below upwards. The theory is therefore more appropriately called the theory of slope replacement.

2.5 PARALLEL RETREAT THEORY OF L.C. KING

King's theory of slope evolution is a part of his comprehensive theory of landscape evolution. His concept of pediplanation cycle is based on the parallel retreat of slopes. While Davis's slope decline produces peneplains, King's parallel retreat gives rise to pediments and pediplains. In the initial stage of pediplanation steep slope develops as a result of vertical down cutting by streams. When the angle of these slopes stabilizes, the slope tends to move away from the river by parallel retreat, and the pediment between the river and the slope is thus extended. In the course of parallel retreat the gradient of the slope remains constant. In course of time slopes start disappearing as a result of the extension of pediments of neighbouring streams, and at the end of the cycle a multi-concave landscape is formed. But it is likely that at the slope summits convex slopes may develop on a limited scale due to weathering and creep.

King accepts the hill slope elements of Wood and states that these elements are part and parcel of slope evolution. Full development is dependent upon local conditions in which the hard bedrock and adequate relief are especially important. If one of the two conditions is not present, then both scarp as well as debris slope will be absent and only an convex-concave slope will develop. But in the opinion of King the existence of scarp in a slope is a normal feature, and in the evolution of slope it is the scarp element, which wears back parallel to it and control the evolution of the slope as a whole. As a result of the retreat of the upper element the pediment extends in length. Since the concave curve, which the pediment acquires early in its growth would, if extended upslope, progressively eliminate the upper elements, it must be that the pediment is regarded ; that is, as it extends in length its angle is slightly but continuously reduced. Kind contended that slopes develop similarly virtually in all climates, and his theory was true for all climates except for the very cold and the very arid climates.

Davis (1930) admitted that humid and arid slopes might sometimes be similar in form but he did not accept that they were similar in origin. Despite the insistence of King, most geomorphologists seem to believe that slope forms and processes do vary with climate. However, there are many other factors, which control slopes. Further there are some slopes whose origin is related to past climatic conditions.

One of the principal weaknesses of King's theory is that it is not based on field observation and nowhere do we find a measurement of eigher form or process. But even important than this is the criticism that King has not given adequate evidence in support of his views and has in fact sometimes ignored adverse evidences, and has employed repeated assertion in place of evidence as a means of establishing his hypothesis. There is lack of objectivity in his writings. But the value of his work lies in the fact he has put forward some valuable hypotheses for testing and analysis, though he himself has failed to prove them.

2.6 HYPOTHESES PUT FORWARD BY OTHER GEOMORPHOLOGISTS ON SLOPE EVOLUTION

The concept of Wood: In order to put forward his hypothesis A. Wood (1942) starts with a debris-free cliff slope. He calls it free-face. The retreat of the cliff starts on account of weathering and debris received from the weathering of the free-face collecting near the base of the slope in the form of talus or scree. Gradually the talus is extended upwards and the debris is deposited at a fixed angle in the lower section of the free-face slope. This has been called constant slope.

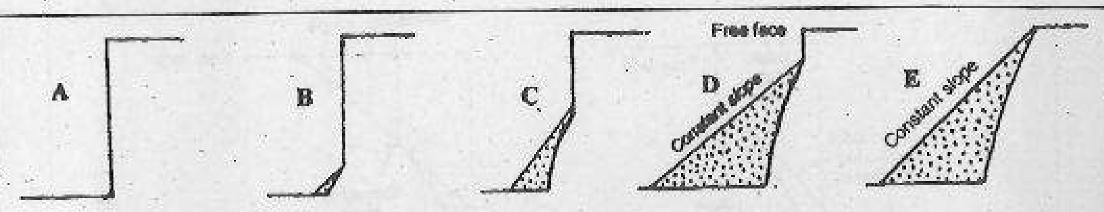


Figure 4 : Development of constant slope according to A. Wood

In the early stages the talus grows from below upwards at a rapid rate because it receives the debris from the weathering of the entire free-face. But with the passage of time as the lower section covered more and more with talus, the uncovered upper section of the free-face is proportionately reduced and the amount of debris received from the above consequently decreases. Thus the rate of vertical growth of the talus is greatly retarded as the area as the area of the free-face is reduced. As each higher portion of the free-face is exposed to longer periods of weathering than the portion immediately below it and suffers erosion corresponding to those periods, there is the development of convex rock slope below the cover of debris. Through this process ultimately the entire slope is covered by talus and forms a constant slope and underneath the debris is the convex buried face as shown in the diagram below :

This is an ideal situation and Wood admits that for various reasons there may be variations in this. The first important fact to bear in mind is that the volume of scree is more than the volume of the weathered rock, because there is interstitial space between the rock fragments. Vertical growth of the talus is normally much faster than assumed in Wood's model and the steepness of the convex buried face is also more marked. If the finer materials in the scree are transported down by rain-wash or the debris particles become smaller by chemical weathering then the upward growth of the scree is slowed down and the slope of the buried face also becomes gentle, Further, if the weather rock fragments are coarse, the talus growth will be more rapid, and if the nature of the rocks is such that weathering produces finer fragments the growth of the scree will be steeper than in the second case where the debris produced by the parent rock are fine.

After the formation of the constant slope is pushed back into the bedrock and repeats parallel to itself. The debris on the constant slope are affected by rain wash whereby the finer particles tend to move lower down leaving the coarser fragments above, and near the base of the constant slope there is development of concave slope. As the debris particles become finer, smaller gradient is needed to keep them at rest. In course of time, the slope, still retaining the angle of the scree, is pushed back into the solid rock behind the scree and continues to retreat parallel to itself. In this way the convex rock slope underneath the debris is transformed into a concave slope.

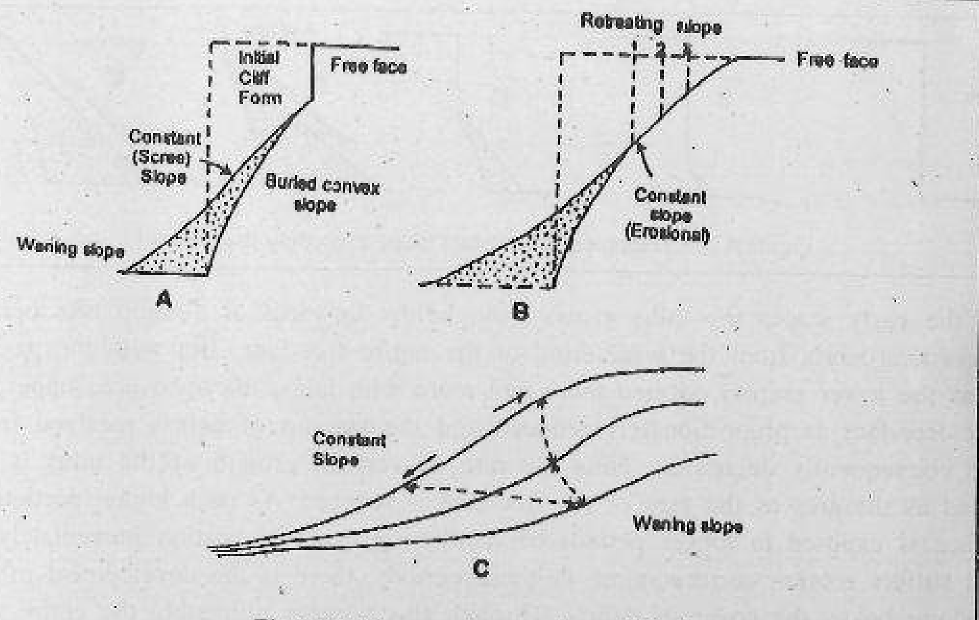


Figure 5 : Slope cycle according to Wood
A. Development of scree slope at the initial stage.
B. Retreating stages of slope, C. Successive stages of slope deformation.

On the cliff summit, under the influence of weathering the form of the initial angular intersection becomes rounded as a result of which there develops a summital convexity. This is known as waxing slope. Thus along the longitudinal profile of the entire slope we find three major elements - summital convexity, basal cancavity and middle rectilinearity.

In the course of evolution, both the concave and convex sections tend to be lengthened and the length of rectilinear section is reduced. Finally the rectilinear section disappears altogether resulting in the development of convexo-concave slope, which tends to flatten in a uniform manner but their evolution varies with structure, climate, tectonic activity and other factors. Under specific conditions, one or more of the factors may be absent, and in the course of evolution the form of character of the four slope elements keep on changing.

The principal contribution of Wood lies in the fact that in his hypothesis he has determined and defined the elements of slope, and has suggested that even in apparently dissimilar slopes it is possible to identify the four principal elements.

2.7 THE CONCEPT OF STRAHLER :

Over the last sixty years attempts have been made to make statistical and quantitative studies of slopes. Among these the most notable are the statistical investigation of A.N. Strahler (1950). He carried out extensive field studies and made measurements of maximum slope angles in regions of different climates, relief, soils and vegetation and came to the decision that if all the slope forming processes and the age of the slope are similar, the average maximum slope angle is the same and the variations in the maximum angle of the different slopes in negligible.

Strahler has explained that the development of the same slope gradient in all the slopes is due to the fact that they may be able to transport their debris easily down slope. Such slopes are in a state of equilibrium and may be called *equilibrium slopes.* But the various slope-forming processes govern the equilibrium slopes. Change in the nature of processes and their activities will result in readjustments of the equilibrium. According to Strahler in all areas of maximum angle of retreating slopes is similar, even though they are of different age. On slopes having similar maximum angles, parallel retreat is more important than slope decline.

Strahler has also shown, on the basis of his field investigations, that maximum slope angle and channel gradient are inter-related. This confirms the fact that channel slope is adjusted in accordance with the debris obtained from the valley-side slopes. In other words the entire system is in equilibrium. Where the valley-side slope is steep the channel slope is also steep so that it may transport the maximum amount of debris. On the other hand, less debris is available from gentle valley-side slope and consequently the channel slope is also gentle. There are, however, some exceptions to this general rule. For instance, even where the valley-side slope has similar gradient, the river receives less debris if the slope has a cove of vegetation than in the case of a necked slope, and consequently the channel gradient is also less.

Strahler has also shown that where the stream is close to the foot of the slope, the slope is steep. In such a situation the stream transports rapidly the debris obtained from the valley-side slope, the slope is gentle and the river is not able to transport all the debris. There is accumulation of debris on the slope which is thus protected from erosion.

2.8 THE CONCEPT OF SAVIGEAR :

R.A. Savigear (1952) studied the development of profiles of slopes located at the head of Carmarthen Bay in South Wales and came the conclusion that both parallel retreat and slope decline are important in the evolution of slopes, and sometimes both the processes may be operating simultenously in particular region. In the eastern part of his study area he found slopes which have a basal free-face, middle rectilinear slope and limited convex slope at the bottom. The western part has receded long ago from the sea and the eastern part has receded from the coast recently. Consequently the slopes become flatter as one moves from the east to west. Nor only are the slopes steeper in the eastern part but are predominantly convex whereas in the western part the slope is mostly concave. From this it may be concluded that where the debris are transported rapidly by the sea waves, the sea cliff is vertical but after recession of the sea the gradient of the slope starts declining i.e., the slope becomes more gentle. In other word as there is a close correlation between slope angle and the active agent at the foot of the slope. These active agents can be waves on the seacoast or a stream on the land. Thus it is necessary to have an active agent at the foot of the slope for parallel retreat. In the absence of an active agent the debris begin to be deposited which provided protection to the lower section of the slope, while retreat continues in the upper section as a result of continued weathering. In such a situation there is decline and the slope becomes flatter. Savigear has also suggested that the summital convexity develops at quite a late stage. His analysis appears very close to reality.

2.9 CONCLUSION

It becomes clear from the above discussion that the slope-forming processes are extremely complex and inter-related, and our knowledge about them is incomplete and rather general. Evens so it is possible to imagine a general cycle of slope development. In the initial stages of development there is increase in slope gradient with time. In the middle stage there is parallel retreat under the influence of active streams and constant basal erosion, and in the later stages there is decline is steepness as the active eroding agent gets separated or becomes far removed from the foot of the slope.

2.10 QUESTIONS

1. What are the processes of slope development.
2. Critically discuss the slope decline theory of W. M. Davis and the slope replacement theory of W. Penck.
3. Analyse Parallel retreat theory of L. C. King.
4. What are the hypothesis put forward by word, Strahler, Savigear on slope evolution?

2.11 SELECT STUDIES

1) An outline of Geomorphology - S.W. Wooldridge & R.S. Morgan
2) The study of Landforms - R.J. Small.
3) Modern concept in Geomorphology - P. McCullagh.
4) A Text Book of Geomorphology - P. Dayal

Unit 3 ❒ Concept of Grade, Profile of Equilibrium and Base Level Concept of Grade

3.1 The basic concept

3.2 Profile of Equilibrium and Base Level

3.3 Base-level of Erosion

3.4 Questions

3.5 Select Studies

UNIT : 3 CONCEPT OF GRADE, PROFILE OF EQUILIBRIUM AND BASE LEVEL CONCEPT OF GRADE

3.1 THE BASIC CONCEPT :

Grade is a system of equilibrium in a system such as hillslope or river. It implies the idea of a balance, on average, between erosion and deposition, or between transporting power and amount of load. From the early days of modern geomorphology students of fluvial activity have believed that streams can achieve a condition of equilibrium, whereby the total energy of a river is exactly sufficient to move the water and its load. Such streams are redescribed as being in a ***state of grade, in graded condition,*** or quite simply as ***graded***. To be precise a river or stream may be said to be 'graded' or 'at grade' when it is transporting its entire load. Hence a graded stream may be regarded as down cutting at an infinitesimally slow rate and taken over a short term (tens of years), is neither down cutting nor infilling its channel. The term grade is also applied to the long profile of a river when it is smooth and without major irregularities, i.e., waterfalls, rapids and lake basins. Indeed a river cannot be graded if these irregularities are present, since they themselves lead to rapid down cutting or deposition. However it is possible for a river to be graded without its profile being a continuous smooth curve. Streams, which have succeeded in fashioning a smoothly curving long profile, are considered to have attained the graded, condition, hence the term ***profile of equilibrium.***

Conditions for grading : The first geomorphologist to outline the concept of grade clearly was the American O.K. Gilbert (1909), who devised the following classic definition. 'Where the load of a given degree of communication is as great as the stream is capable of carrying, the entire energy of the descending water is consumed in the translation of the water and its load, and there is none applied to corrasion.' Thus Gilbert believed that graded streams were incapable of deepening their valleys or changing the form and gradient of their long profiles directly, though he did consider that fully loaded streams were capable of lateral erosion, presumably on the grounds that moving water is always capable of undermining and attacking the channel banks whatever the conditions of erosion, deposition and load transport on the river bed.

W.M. Davis also adopted the concept of grade, though he modified it in some important essentials. He did not accept that graded rivers had no power to attack their beds, and he considered that the graded condition was established relatively early in the cycle of erosion (normally by the onset of the mature stage). However, if Gilbert's definition were true, grade must be late development, since it marks the end of vertical erosion. Davis argued that in fact maintenance of the graded state necessarily involved some erosive lowering of the streambed. 'In virtue of continual variations of stream volume and load, through the normal cycle, the balanced condition of any stream can be maintained only by an equally continous, through small, change of river slope'. Thus as valley-side slopes steadily undergo wasting, and the load entering streams becomes smaller in total amount and finer in caliber, streams will possess more and more surplus energy (that is will tend to become ungraded), unless they succeed in reducing their channel gradients by erosion and so experience a lessening of available energy. Presumably, therefore, for a stream to maintain its graded state in the long term, for short periods it must become ungraded and have the ability to attack its bed.

Following Davis three instances in the long profile of a river as follows can be assumed where grading usually takes place. Figure 1 (a) shows how the initial uneven long profile of the thalweg of a river becomes graded with the passage of time. Figure 1 (b) demonstrates how a river, flowing through a lake gradually obliterates the trough and finally attains the graded condition and Figure 1 (b) shows how grading in succession takes place with the changes of sea level or the base level.

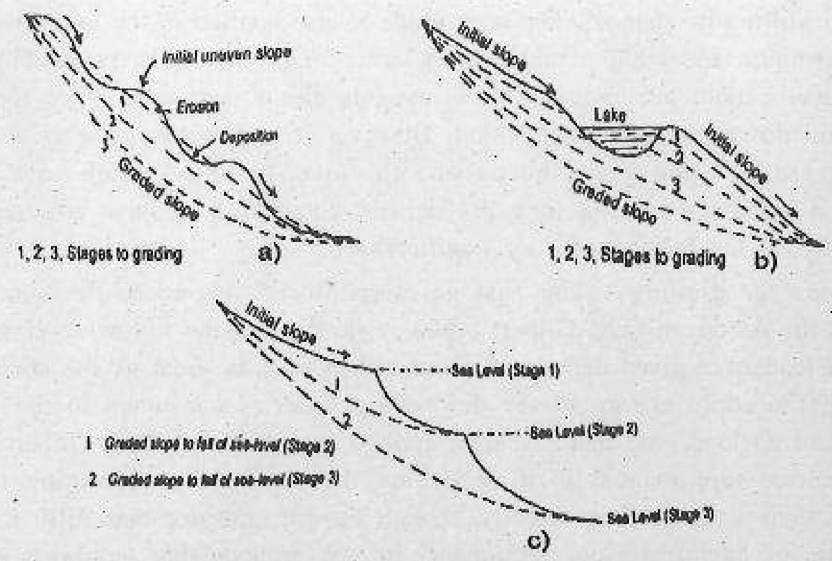


Figure 1 : Three conditions under which grading along the long profile of the river takes place
a) Grading upon uneven slope, b) Grading upon occurrence of lake,
c) Grading upon changes of the sea-level

Problems of the concept of grade: Although the concept of grade as been accepted by most geomorphologists, for the reason that it offers a working hypothesis of why at some times streams erode vertically (because they are ungraded), and at others they deposit (when they change from graded to an overloaded condition), some have been skeptical. The main difficulties are to prove the existence of this delicately balanced equilibrium and to recognize a graded stream in the field. Davis himself believed that streams, which lacked waterfalls and rapids, the typical features of a youthful profile, were graded, but obviously this does not constitute final proof of a condition of balance between energy and transportation. It might be thought that the state of grade could be demonstrated by the finding of a stream which is neither eroding its bed nor depositing alluvium - in other words, is poised between an underloaded and an overloaded state. The problem here is that a stream may be attacking its bed in order to maintain or restore the balanced condition; such a stream is merely 'degrading' its course. Similarly, deposition of alluvium might indicate only 'aggradation'. or deposition to maintain grade. It has been argued that in many streams there is an upper section where vertical erosion is pronounced, as a result of underloading of the stream, and a lower section where deposition is dominant, owing to overloading. Between the two there must logically be a section where the stream is fully loaded or at grade. However, no one has been able to prove that the change from underloading to overloading occurs over a section of the stream rather than at a point.

In spite of these difficulties, grade can still be a useful concept; at least in the view of Mackin (1948), proving it is not applied too rigidly and is difmed with care. Mackin's own definition of grade is as follows : *A graded stream is one in which, over a period of years, slope is delicately adjusted to provide, with available discharge and the prevailing channel characteristics, just the velocity required for the transportation of all the load supplied from above.* It is clear that Mackin, like Davis, regards grade is an average condition, which from time to time and for short periods may be departed from, but which is always reestablished by an adjustment of the channel slope, either by erosion or by deposition.

There are certainly some reasons for accepting Mackin's view. It is noticeable that many river valleys possess terraces, planed across the solid rock and veneered by alluvium or gravel, whose down-valley gradients are virtually the same as that of the present stream channel. How can this be explained, except by the interference that the channel slope is 'delicately adjusted' to conditions of discharge and load, and that so long as these are unchanged, even though there are interruptions resulting from an uplift of the land or a fall of sea-level, this precise slope will always be restored? Mackin has also argued that the graded stream is a 'system in a state of equilibrium'. Any change in one of the controlling factors (discharge, load, climate and so on) will cause a 'displacement of the equilibrium in a direction that will tend to absorb the effect of the change'. Mackin's meaning may be illustrated by reference to simple example. The load of a stream may be suddenly increased, perhaps as a result of climatic change inducing more rapid weathering and the graded condition will be replaced by overloading. Some of the extra load will therefore be deposited immediately below the point of influx, thus causing steepening of the channel slope. The energy of the stream thereby be increased, and in time it will be able to transport the increased load. Thus the overloaded condition will be overcome by an increase of channel slope, involving aggradation, and grade will be restored.

Final assessment: Today students of fluvial processes regard the term grade as somewhat outmoded, though accepting that streams are able to achieve a state of apparent equilibrium ('quasi-equilibrium'). Furthermore, though Mackin's view is considered to be useful starting point, it is thought that he places too much emphasis on channel slope. In the words of Leopold, Wolman and Miller (1964), 'there are eight inter-related variables involved in the downstream changes in river slope and channel form; width, depth, velocity, slope, sediment load, size of sediment debris, hydraulic roughness and discharge'. Any state of stream equilibrium must involve all of these, and a change in one may have repercussions on all or some of the others. For instance, an increase in sediment load may be compensated not just by a change of slope, but by an alternation in the depth and width of the channel, the velocity of the stream, and so on.

3.2 PROFILE OF EQUILIBRIUM AND BASE LEVEL

Profile of Equilibrium

The basic concept : The concept of the profile of equilibrium is very much associated with that of the concept of grade. By virtue of this the profile of equilibrium is also called as the graded hypsometric curve. As assumed by W.M. Davis sea level acts as a base level of erosion with reference to which the grading of the river takes place. It is in fact, the fundamental base level, which controls the whole process of water denudation on the land. Similarly the point of confluence of a tributary with the main stream is a local base level in relation to the grading of the tributary. Eventually neither sea level nor the levels of confluence points are fixed and immutable over long periods of time, but for short periods they represent the limit of'terminal' down-cutting, i.e. down-cutting at the mouth of the water-course.

The basic idea is that if there is no interruption of any kind of tectonic movements, then in course of time the river destroys all the irregularities in its bed and develops a smooth curve from its mouth to the source, which is called the *curve of water-eras ion* or the *graded curve of water-erosion* (Figure 2). This stage in the life of a river is reached when the river has degraded its bed to the maximum and no further deepening is possible. This is that state of equilibrium when deposition equals corrasion and at every point course the strength of the river is just sufficient to enable it to carry its load. In other words, when a balance is reached between the transportation capacity of the river and its load, then the river is said to *be graded or at grade* (as has been discussed earlier), and the long profile of the river thus developed is the ***profile of equilibrium.***

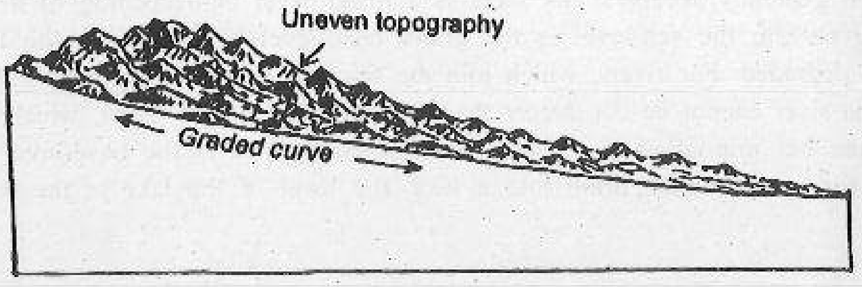


Figure 2 : Graded curve of water erosion

It will be readily seen that in all cases the graded curve or the profile of equilibrium will be first attained near the mouth or base level point, for here the amount of necessary down-cutting is least. With the progress of time it proceeds backwards, i.e. headwards, from the lowest point. The grading of stream course or the development of the profile of equilibrium thus involves *headword erosion.*

In the light of the geomorphological as well as geometric considerations it can be seen that not only may actual profiles differ in varying degree from the profile of equilibrium, but that the later, if developed, will be of a relatively complex form, which may defy simple mathematical expression. Since it is impossible to associate any rigid form with condition of grading, the question inevitably arises - how is the condition to be recognized? Consideration will show that the only practical method is to demonstrate that neither aggradation nor degradation is in progress. This cannot be done by examination of the stream itself, but it is, nevertheless, possible to see whether it has recently trenched itself in its flood-plain, or show any signs of recent upbuilding. In practice, the problem rarely arises in this simple and direct form, for recent changes of base level have thrown most rivers out of adjustment, and the existing curves are composite.

3.3 BASE-LEVEL OF EROSION

By definition *base -level* of *erosion* is the topographic level down to which erosion of degradation is possible. In other words there is a limit up to which a river can cut and degrade its channel. The limit is known as the *base-level of erosion.* Thus theoretically base-level is the lowest level to which the course of a river can cut down. This level may be sea level, the junction between a tributary and the main river, or the level of a waterfall or lake, but streams rarely erode as far as base-level. Base-level may alter due to eustatic or isostatic change, and may be termed positive changes of base level if the land sinks relative to the sea, or negative change of base-level if it rises. Marine base-level, or the sea-level is considered to be the lowest point at which marine erosion occurs.

The base-level concept was first proposed and elucidated by Powell in 1875. Since then it has been generally accepted that there is a lower level of deepening of a river valley. According to him the sea-level is the grand base-level below which the land surface cannot be degraded. For rivers, which join the sea, sea level is the base-level or erosion, because the river cannot be cut deeper than the sea-level. But for river, which do not falls into the sea but join other rivers, the level of confluence is the base-level of erosion. Similarly for rivers, which drain into a lake, the level of the lake is the base level of erosion.

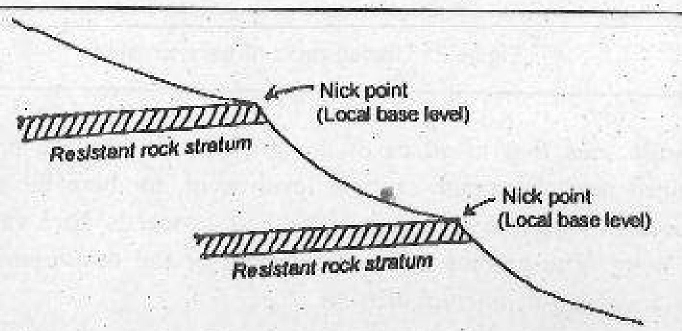


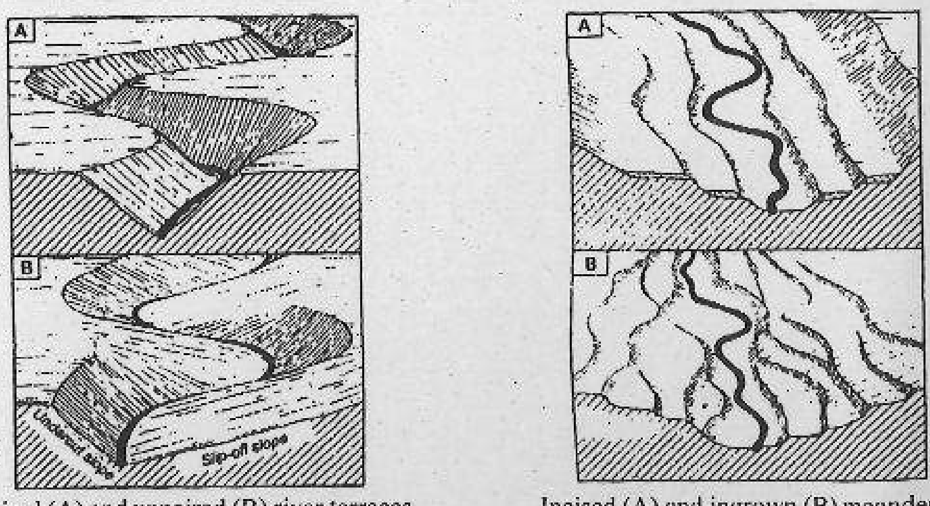
Figure 3 : Development of local base levels due to the occurrence of resistant rock masses

Influence of base level on stream action: It is one of the most basic facts of geomorphology that fluvial activity is strongly influenced by the base level of erosion. The vast majority of rivers flow ultimately into the sea, the surface of which provides a limit below which erosion cannot proceed. As mentioned earlier lakes can act as temporary base-levels for streams flowing into them, but as they are susceptible to draining (as a result of vertical erosion by streams draining from them) of infilling by alluvium they cannot exert a long-term effect. In fact one of the features of the development of graded river profiles, under conditions of stable sea-level, is the obliteration not only of rapids and falls but also lakes. The influence of base levels on the profile of equilibrium is obvious, for in their lower parts such profiles are very approximately tangential to the sea surface. To be more precise, river profiles are asymptotic; in other words, their gradients continue to be increasingly gentler downstream, but never become quite horizontal, for the reason that some slope, however slight, is necessary produce water flow.

The effect of a rise of sea-level (sometimes rather confusingly referred to as a 'positive' movement of base level) will be to flood the lower part of a river valley, producing an estuary in which extensive alluviation will eventually occur.

The effects of a fall of sea-level (a 'negative' movement) are rather more complex. The immediate result will be an extension of the river course from the old to the new shoreline. Since the offshore gradient is normally greater than that of the lower course of a river, the added section will be characterized by greater stream energy and renewed capacity of downward erosion, more appropriate to a youthful stream. Thus rejuvenation will affect the mouth of the stream, and in favourable circumstances the steep new section will undergo headward recession as a nickpoint. In time the original river profile will thereby be regarded to the new sea-level. This process may operate many times, a series of intermittent base-level falls resulting in a succession of nickpoints. Because of the numerous changes of base-level in the Quaternary, most British rivers exhibit several nickpoints, each separated by a gentle reach graded to a sea-level higher than at present.

The effects of base-level falls on the cross profiles of river valleys are most striking when the stream has previously beglin to meander, planning off the valley floor and spreading gravel and alluvium over the resultant plain. A sudden lowering of sea-level will cause incision of the stream, leaving remnants of the former valley floor standing up as terraces. A sequence of such falls, each separated by a 'stillstand' of sealevel and valley grading, will produce a staircase of terraces. River terraces resulting from rejuvenation of this type will be paired across the valley. Unpaired terraces or meander terraces are formed when laterally shifting streams are cutting down steadily probably because base-level is also falling continuously. It must be added that river terraces do not result only from intermittent or continuous falls of base-level. Certain climatic conditions, especially glacial and periglacial, promote the movement of very large quantities of weathered and eroded material into streams. These will become overloaded and considerable aggradation will result. A change of climate, leading to a reduction of the debris supply and a condition of stream underloading, will be accompanied by incision of the rivers into the deposits, which are left upstanding as terraces.



Paired (A) and unpaired (B) river terraces

Incised (A) and ingrown (B) meanders

Figure 4 : Types of river terraces and meanders

Other important results of vertical erosion induced by a falling base-level are incised meanders (which are formed by the rapid incision of an already meandering river) and ingrown meanders (which develop where the stream is cutting down more gradually and at the same time enlarging its meanders). Characteristic features of ingrown meanders are slip-off slopes, which may show signs of terracing if the fall of base-level has been interrupted by stillstands, and sharply undercut river cliffs. Base level changes also have wider repercussions on the development of valley-side slopes, the angle and form of which may be intimately related to the rate of downward river erosion.

3.4 QUESTIONS

1. Discuss the concept of grading.
2. What are the problems of the concept of grade?
3. What do you mean by base level of erosion ?
4. What influence does base level does on stream erosion ?

3.5 SELECT STUDIES

1) An outline of Geomorphology-S.W. Wooldridge & R.S. Morgan.
2) The study of Landforms-R.J.Small.
3) Modern concept in Geomorphology - P.Mc Cullagh.
4) A Text Book of Geomorphology-P.Dayal

Unit 4 ❒ Non-Cyclic Concept in Geomorphology

UNIT 4 ; NON-CYCLIC CONCEPT IN GEOMORPHOLOGY

Introduction : Cyclic concept of landscape evolution, put forward by W.M. Davis, stating that landscape changes continue to take place through cycles of erosion was a ruling hypothesis in geomorphology for more than three decades from the late nineteenth century through to the first quarter of the nineteenth century. However, with the passage of time a number of shortcomings of this hypothesis have been raised by the geomorphologists working in different parts of the world and subsequently a search for more viable and acceptable hypothesis of landscape evolution continue partifularly from the early second half of the Twentieth century.

STANDPOINT OF THE RISE OF THE NON-CYCLIC CONCEPT

Development of the Non-cyclic concept in geomorphology is the result of some major shortcomings of the Davisian concept due to which a number of questions on the landscape denudation process remained unsolved. The main criticisms that are leveled against the Davisian cycle concept are as follows :

Firstly, adherents of the cycle concept have been too concerned with making generalizations about landform development, without attempting to measure those landforms objectively or to make a proper study of the processes moulding them. As soon as the study of the process was applied in the field. The drawback of the concept has been realised. *Secondly,* acceptance of the cycle concept has often led to an over-emphasis on 'historical studies' of landforms, in which reconstruction of the development of the latter through time to their present condition is seen as the primary objective of geomorphology. *Thirdly,* and the most serious of all, there has been little attempt to the landforms actually do evolve, along a set course, towards an inevitable end-form the peneplain. One may certainly observe in the field slopes of a wide variety of angle, but there are usually no grounds at all for the assumption that the steeper slopes are 'younger' and the gentle slopes 'older'- indeed, within a single small valley apparently of one 'age', slope forms and angles may differ greatly.

The rise of Non-cyclic concept

Some modern geomorphologists, J.T. Hack (1960) and A.N. Strahler (1952) of U.S.A. and R.J. Chorley (1962) of England have developed a thesis that, so long as the factors which control denudation processes remain the same, the form of the land need undergo no change with time, or in other words landform evolution will not take place. Such landforms will be 'time-independent'. This is in contrary to that of the cycle concept, which, by giving emphasis on stage, implied that landforms are always 'time-dependent'. In a sense this non-evolutionary interpretation was foreshadowed in the writings of the German geomorpho legist Walther Penck. As it has been seen, his theory of rectilinear slope formation at a constant angle, in response to constant stream erosion, envisages no progressive change of form. It cannot be too strongly emphasized that such landforms are not to be regarded as static; they will continue to be affected by weathering and slope retreat, and the land-surface as a whole will be lowered, but throughout the whole process no change in the dimensions and angles of the landforms will be effected.

4.2 THE CONCEPT OF DYNAMIC EQUILIBRIUM :

The above mentioned arguments stem from an entirely new theory of landform development, known as ***dynamic equilibrium.*** In this it is assumed that all aspects of the landform geometry of an area (such as relief, slope length, mean and maximum slope angles, channel gradient, and so on) are intimately related to each other. Indeed it has recently been suggested that in favourable circumstances all the main components of a landscape (valley bottoms, valley-side slopes and divide summits) will experience lowering at an uniform rate. In order that this should happen, a delicate condition of'energy balance' (hence the term dynamic 'equilibrium') must be established. On a slope, for instance, the 'energy input' (related to the intensity of the active denudation processes) must be such as to produce the continuous an efficient evacuation of all detritus material, such a slope, like in a condition of quasi-equilibrium, is referred to in modern terminology as a 'system in a steady state'. In order that the energy input should be just sufficient, the slope itself will undergo adjustment of form until, under the prevailing conditions, its height and angle are 'correct'.,

It will be apparent that the energy balance of a landform or landscape will be affected by a number of controlling factors. Among these are rock type, jointing, angle of dip, permeability, climate, vegetation, rate of uplift, and so on. Since these factors are not necessarily constant, so the conditions of balance may from time to time be altered, together with the form of the land itself. However, there may well be times when no such changes occour, in which case the form of the land-surface will remain constant or time-independent. Furthermore, when changes occur they need not result in landforms evolving always in the same direction towards an inevitable form. Instead, the landforms will merely undergo adjustment to meet the requirements of the new conditions.

Illustrations of the Dynamic Equilibrium Theory : The theory of dynamic equilibrium may be further illustrated by a very simple example. The figure (Figure I) given below depicts and area underlain by three horizontal strata, the upper and lower comprising resistant sandstone and middle composed of weak clay. It will be assumed for convenience that all controlling factors other than rock-type remain constant. At first, the land surface will be developed only in the upper sandstone (A). Because of the resistance of the rock, the valleys will be narrow, the relief considerable, and the valley-side slopes steep. These features will remain unchanged so long as only the upper sandstone is exposed. In time, however, this will be removed by river erosion and slope retreat. In the now uncovered clay, because of the lack of resistance the valleys will become broader, relief will be reduced, and the valley-side slopes will become gentle (B). Finally, with the removal of the clay, and the exposure of the lower sandstone, the landscape will revert to its original form (C). This sequence of changes is non-evolutionary. What has happened is that the landscape has merely adjusted its form to maintain a state of equilibrium in relation to the controlling factors.. In this particular instance, rock-type-the only one to change — was in effect the most influential. Similar effects might well have been produced in, say, an area of homogenous rocks by a change in climate or changes in the rate of stream erosion. In reality, of course, the changes that do occur are more complicated, and several factors may be undergoing alteration concurrently. Theoretically, at least, it is possible for these changes to counterbalance each other, and for the form of the land to remain the same.

Major points of observation on the concept of dynamic equilibrium: In terms of the above discussion to major points must be discussed in brief.

Firstly, it was assumed in the example described that no impediment to downward river corrasion existed, so that the rivers were able to occupy successively positions within the three rock layers. However, if the structure concerned had lain close to sea-level, and were not effected by progressive uplift, this should not have been possible. The rivers might, for instance, have penetrated only to the clay before proximity to base-level halted downward erosion. However, the clay interfluves would still be subject to weathering, creep and \v ash, and a reduction of cliff involving an eventual decline of slope angle would be inevitable, as in the Davisian cycle. The crux of the matter seems to lie in whether or not stability of base level can exist over a long period and thus impose its influence on landform development. The supporters of the dynamic equilibrium theory Figure 1 : Pattern of Landform development would evidently regard a 'fixed' base-level as a in horizontal rocks according to dynamic rare occurrence. It is true that in the recent geo- equilibrium theory logical past, changes of base level have been almost continuous.

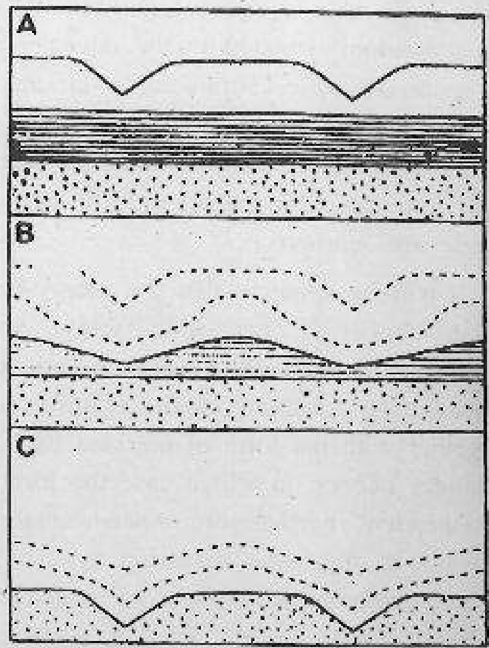


Figure 1: Pattern of Landform development in horizontal rocks according to dynamic equilibrium theory

Secondly, it might be considered that the widespread occurrence of erosional plains, in many parts of the world and under various climatic conditions, must indicate the cycle concept, proving as they do that the factors which control landscape form have altered in such a way that landform evolution has taken place. However, even this is disputed, and proponents of the dynamic equilibrium theory, such as J.T. Jack (1960) of the United States, have suggested that many so called 'peneplains' particularly those indicated by accordance of hill-tops and inter-fluve summits have in fact arisen in a different way. They argue that in any area of rocks which are reasonably uniform in terms of resistance, where the stream spacing (drainage density) is uniform, and where the slope are at the same maximum angle, it is to be expected that the summits and the divide crests will all reach to about the same height and so give the impression of a former level surface which has, subsequent to its formation, been dissected by valleys. Hack has even gone so far to propose that such a landscape which he has referred to as *'ridge-and-ravine topoigraphy', is the normal expression of a condition of dynamic equilibrium* (Figure 2) There would still seem to remain the problem of explaining, say, the pediplains of Africa, many of which are in a remarkable state of preservation and suggest that base-leveling of the landscape on a large scale can occur.

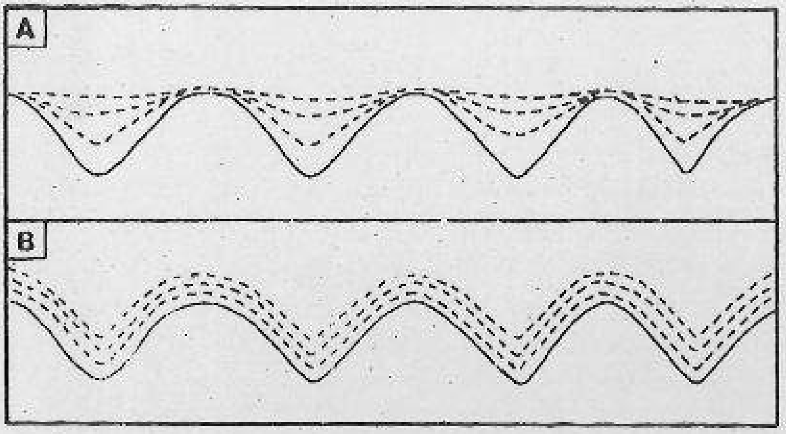


Figure 2 : A theoretical comparison between the cyclic and non-cyclic landforms
(A) A dissected peneplain and (B) A ridge-and-ravine topography

Decision: It would be most appropriate to conclude that the theory of dynamic equilibrium opens up interesting possibilities in the analysis of landforms, and that it has already served a particularly useful purpose in focusing attention on the relationship between process and form rather than the historical development of landforms.

4.3 QUESTIONS

1. Discuss the development of the non-cyclic concept in geomorphology
2. Discuss the Dynamic Equilibrium Theory.

4.4 SELECT STUDIES

1) The Study of Landforms - R.J. Small

2) Geomorphology : Pure and Applied - M.G. Hart

HYDROLOGY

Unit 1 ☐ Estimation and Measurement of Hydrological Parameters

Structure :

1.1 Definition

Etymologically hydrology is the science that relates to water. More precisely it is the study of the occurrence of water in the earth, its physical and chemical reactions with the rest of the earth. It also includes the description of the earth with respect to its waters.

1.2 Concept

The central concept in the science of hydrology is the so called hydrologic cycle a convenient term to describe the circulation of the water from the sea, through the atmosphere, to the land; and thence with numerous delays, back to there by overland and subterranean routes, and in part, by the way of the atmosphere. Also there are many short circuits of the water that is returned to the atmosphere without reaching the sea.

The science of hydrology is especially concerned with the second phase of this cycle, that is, with the water in its course from the time it is precipitated upon the land until it as discharged into the sea or returned to the atmosphere. It involves the measurement of the quantities and rates of movement of water at all times and at every stage of its course - rain and snow gauging to determine both the quantities and rates of rainfall and snowfall in all parts of the earth; snow surveying to determine the quantities of water stored as snow on the surface and the rates of its accumulation and disappearance; observations of the advance and retreat of glaciers and surveys the giaciers to determine the quantities of water that they contain and their rates of gain or loss; the gauging of streams, both large and small, to obtain continuous records of their flow at many points and during long periods; the gauging of lake levels to compute the gains and losses in their storage; measurements of their rates and quantities of infiltration into the soil and the movernent of the soil moisture; periodic or continuous measurements of the water level in the wells to compute the gains and losses in the underground storage; determinations of the permeability of the water-bearing formations and the rates at which they are transmitting water; measurements of the discharge of rings and of total effluent seepage; determinations of the loads of dissolved and svspended matter which the water contain in every position and the rates at which they carry it from one position to another; the quantities of water lost by evaporation and the rates of loss from the lakes, ponds, swamps and streams, from the land svrface and from the soil and the qvantities lost by transpiration from the leaves of growing plants. Hydrology is concerned with the development of accurate and feasible methods of making these measurements of diverse kinds and with the accumulation and compilation of the great mass of quantitative data. Finally, it is concerned with the great task of making rigorous studies of all the base data to determine the principles and laws involved in the occurrence, movement and work of the waters in the hydrologic cycle.

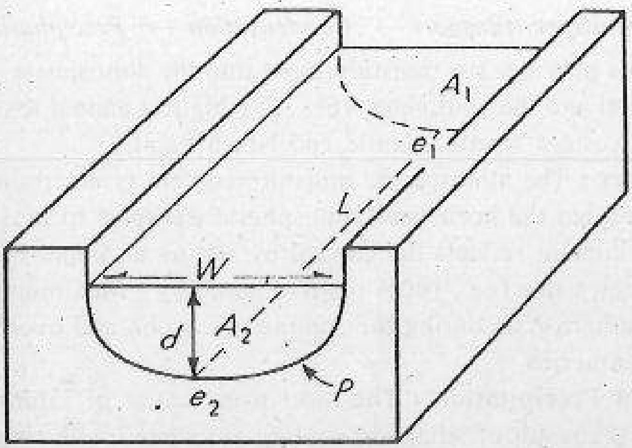
1.3 Kinds of water included in the study of Hydrology

In it broadest sense, hydrology relates to all the waters of the earth, but for practical reasons it has been limited in several respects. The greatest reservoir of water on the earth is the ocean. The science relating to the ocean is however, called oceanography, and is not generally included in hydrology except as to the relations of the ocean to the waters of the land.

The study of the water in the interstices of the rocks, even the water at comparatively great depths below the land surface, belongs unquestionably to the science of hydrology. From time to time some of this internal water reaches the surface or the rock interstices near the surface, it also at one of the fringes of the science of hydrology, The study of springs belongs definitely to hydrology whether it is of internal origin or is derived from rain and snow. A very small but very active and important part of water of the earth occurs in the atmosphere. Hydrology deals entirely with the water of atmospheric origin. Hence it is concerned with the geographic distribution of precipitated with quantities precipitated at each place, with the rates of precipitation and with the whole complex subject of variations in quantity and rate. It is concerned with the source of the atmospheric water, whether from the sea or the land with movements from the points of origin to the points of precipitation. It is also concerned with the return of the water to the atmosphere.

1.4 Hydrological Parameters

1.4.1 Stream Channel Morphology



Water is a fluid and it cannot resist stress. Any stress upon it causes movement. In order to measure the amount of water passing through a cross-section of a channel (CA) and the velocity at which the water is flowing (V), scientic methods should be applied. In order to ruasure the CA, one has to survey the river with suitable instrument at the point of measurement and the CA is to be determined in the laboratary after drawing the cross-section according to scale and the area of the water covered portion of the channel to be determined by a planimeter. The velocity of the same section of the river will have to be estimated by a current meter. By multiplying CA×V = Discharge can be determined. So, $A_1V_1 = A_2V_2 =$ Q (Discharge). If the scale is in ft, the discharge will be in cusecs (cubic feet per second) or in cumecs (cubic metre per second) if the scale is in mt. The wet bottom of the CA, is called wetted perimeter (WP). CA ÷ WP = Hydraulic radius, which is the average depth of water. All these measurements will help in camparing various CA of a river quantitavely.

1.4.2 Hydrological Cycles and Water balance

a) Global Hydrological Cycle and Water Balance

The oceans (mean depth: 3.8 km & covering 71% of the earth's surface) hold 97% of all the earth's water. 75% of the total fresh water is locked up in glaciers and ice-sheets, while almost all the remainder is ground water; the atmosphere ha a mere 0.035%. The circulation of water from ocean to atmosphere back to land and ocean is known as the Hydrological Cycle.

By heat from the sun water is evaporated from the surface of land and ocean. In vapour form this water is carried in the atmosphere, later it is precipitated as rain or snow. The precipitated water, not taken in by the soil runs off the surface and enters directly into the network or surface channels. Some water which infiltrates into the ground surface moves only a short distance as ground water, to reappear as stream-flow. Some infiltrated water may be stored as ground water.

Thus exchange of water involved in the various stages of the hydrological cycle is :

Evaporation → Moisture transport → Condensation → Precipitation - Runoff

Evaporation : This provides the moisture input into the atmosphere; the oceans provide 84% of the annual total and the continents 16%. The highest annual losses (>200cm) occur in the subtropics of western North Atlantic and North Pacific.

Moisture transport : The atmospheric moisture content is determined by local evaporation, air temperature and the horizontal atmospheric transport of moisture. The distribution of mean vapour content reflects the control by setting an upper limit to water-vapour pressure - the saturation value (i.e., 100% relative humidity). Maximum vapour contents of 5 - 6 cm are over southern Asia during the summer monsoon and over equatorial latitudes of Africa and South America.

Condensation and Precipitation : The most usual cause of saturation is when air is cooled. This may he the result of adiabatic cooling associated with rising air. Then the air is cooled, its capacity for holding water is reduced. The relative humidity rises until it is 100% at which point the air is saturated and precipitation begins. The major: types are drizzle, rain, snow hail. The significant features of precipitation over the globe are: 1) the equatorial maximum; 2) the west coast maxima of middle latitudes associated with the belt of traveling disturbances in the Westerlies, 3) the dry areas of subtropical high pressure cells, which include the world's major deserts as well as the vast oceanic expanses; and 4) low precipitation in high latitudes.

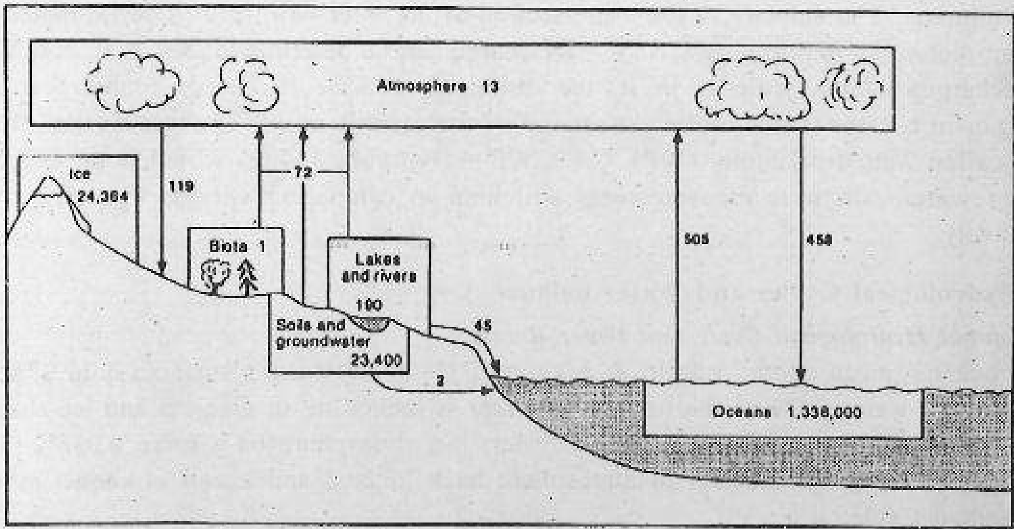


Figure 1: Global Hydrological Cycle showing major stores and flows.
The values in stores are in thousand km^3, values of flows in thousand km^3 per year

The seasonal variation in global detention is matched by an inverse pattern of storage in the oceans. In October the seas are estimated. to hold 7.5 X 10^{18} cm^3 more water than in March, although this is equivalent only to a sea-level change of wily 1 - 2cm.

Ground water is a stable component of the hydrological cycle. Most around water represents precipitation which has percolated through the soil layers into the zone of saturation where all interstices are water-filled. Water of this origin is termed meteoric. Minor sources of water are located in the earth's crust; they are connate water, representing water trapped during the formation of sedimentary rocks.

The Global Water Balance as proposed by Budyko et. al of Soviet Union is given in the tables below:

Table 1: Water balance of the oceans (cm/year)

Oceans	Precipitation	Runoff from the adjacent lands	Evaporation	Water exchange
Pacific Ocean	121	6	114	13
Atlantic Ocean	78	20	104	–6
Indian Ocean	108	7	131	–30
Arctic Ocean	24	23	12	35

Table 2 : Water balance of the continents (cm/year)

Continents	Precipitation	Evaporation	Runoff
Asia	61	39	22
Africa	67	51	16
North America	67	40	27
South America	135	86	49
Europe	60	36	24
Australia	47	41	6

Table 3: Global water balance (cm/year)

Areas	Precipitation	Evaporation	Runoff
Oceans	112	125	–13
Continents	72	41	31
Entire Earth	100	100	0

(b) Basin Hydrological Cycle and Water Balance

Within the framework of Basin Hydrological Cyle it is possible to draw up a water balance and assess water resources; estimate the probability of the occurrence of extreme events (floods t droughts) end mobilize hydrological information. Hence in order to analyse hydrological cycle it is important to identify basin inputs, storages, transfers and outputs.

The Basin Cycle : 'The basin cycle can be viewed simply as inputs of *precipitation (p)* being distributed through a number of storages by a series of transfers, leading to outputs of *basin channel runoff (q), evapo-transpiration (a),* and *deep outflow of ground water (b).* Thus the gross operation of the basin hydrological cycle may be approximated as:

Precipitation = Basin channel runoff + Evapo-transpiration + Changes in storage.

Precipitation falls on vegetation, bare rock, debris and soil surfaces, as well as directly into the bodies of standing water and stream channels. Later in transit is stored on the vegetation leaf and stem strfaces as *interception storage (1),* which *either evaporates* (ei) or reaches the ground by *stream flow (i).* The drainage of water from vegetation, together with direct precipitation on to the ground surface and surface water contributes to *surface storage (R),* which *evaporates directly 1* er), flows over the surface to reach to adjacent stream channels as *overland, flow (qo)* or *infiltrates into the soil (f).* The water of the soil is similarly depleted by the *transpiration of plants (em),* by *through flow (m)* of water down lope witlrin the soil protile to augment the *channel storage (S)* or by *vertical seepage (s)* into the *aeration zone, (el).*

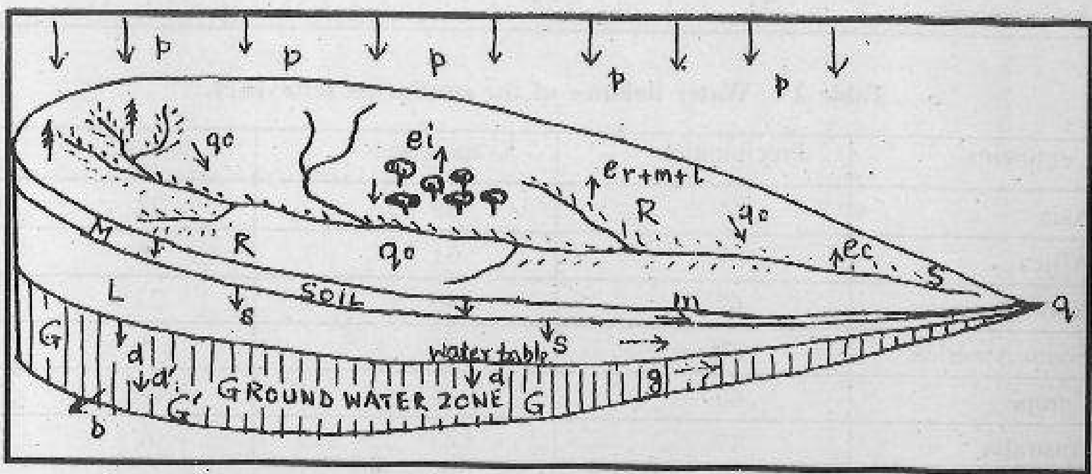


Fig. The pattern of Basin Hydrological cycle

Water in the rock pores and fissures between the base of surface weathering and the water table is depleted by interflow (1), that reaching the adjacent stream channels by flow sub-parallel to the surface slopes without becoming ground water, and by deeper percolation downwards to the water table as ground water discharge (d). It is possible that under prolonged, dry conditions appreciable evapo-transpiration takes place from the aeration zones. The deep percolation enters the ground-water storage (G) from which water either flows laterally into the stream channels as base flow (g), or slowly percolates (d') into deep storage (C.,), some of which may be ultimately destined to from deep outflow (b).

Of course, all the water entering a given basin storage zone is not necessarily released over a short time period and basin water-budget studies mast take place into account changes in water storage.

1.4.3. Atmospheric Moisture

Moisture is an absolute essential in our atmosphere. Without moisture there would be no clouds, precipitation, and probably no life! Fortunately there is a limited amount of moisture available in the atmosphere. It appears in three forms : gas (humidity), liquid (precipitation), and solid (ice and snow).

The Earth's reservoirs are the global oceans, glaciers, lakes, rivers, and streams. They proved the principal sources of water evaporation that escapes into the Earth's atmosphere to form clouds. Precipitation occurs in clouds when rapid condensation takes place. The fallen moisture returns to the oceans, rivers and streams as rurtoff and ground water where it evaporates again. This recycling of moisture is the hydrologic cycle.

The transition of atmospheric moisture from a gaseous state into a liquid state is condensation. Water vapor is the invisible source of clouds and rain and is also a form of heat transfer Clouds develop when water vapor attaches itself to microscopic matter called nuclei. Atmospheric dust comes from many sources. fine dust swept up from farmlands, soot from fires. auto pollution, and minute particles of sea salt from distant turbulent oceans. The particles are tiny and less than one micron in diameter (a thousandth of a millimeter). They are so light that they can stay airborne for weeks at a time. The airborne nuclei form cloud droplets that develop into clouds. All nuclei, especially salts, have a natural affinity for moisture. This is an extremely important characteristic. When nuclei grow too heavy from absorbing other cloud droplets and can no longer remain suspended, they drop to earth as a form of precipitation. While individual raindrops may not appear particularly large, they are giants compared to cloud droplets. One raindrop is equivalent to 1 to 10 million cloud droplets. The type of precipitation that falls depends upon the cloud type in which it originates. Not all clouds yield precipitation, in fact most does not.

Water vapor is not only important in the development of clouds, contrails, precipitation and fog, but it is also important in our lving environment. The amount of water vapor in a given air sample is measured in several different ways either as dew point and or relative himidity. The dew point is the temperature to which air must be cooled to become saturated. Dew point. when related to air temperature, indicates how close the air is to saturation. Relative himidity, on the other hand, relates the actual water vapor present to the which *could be* present. A relative humidity of 75% means that three fourths of the maximum amount of moisture the atmosphere can hold is present.

An example of the relationship between air temperature and dew point is fog, which is no more than a cloud whose base rests on the ground. Fog will usualy form when the temperature and dew point are within a few degrees of one another. Two processes involved in the formation of fog : (1) The air temperature is lowered to the dew point or, (2) the dew point is increased to the air temperature. In the first process, air temperature can be lowered as it crosses a colder surface such as chill ocean waters or a large snow covered area. In the second process atmospheric moisture usually increases when wind flow is from a maritime source such as the Gulf of Mexico or other ocean areas.

Of the two types of fog, radiation and advection, radiation fog is the least hazardous, more localized and usually less enduring. It occurs most often during cool autumn nights when the sky is clear and the Earth's surface cools, rapidly. Although it may be present in the morning, it usually dissipates within hours after sunrise. This type of fog is also known as ground fog.

The moisture holding capacity of air varies with temperature. If there is no change in the total moisture content during also hour perilod relative humidity will increase at night. The highest readings occur about sunray—which is plains damp lawns and fogged car windows. Realtive humidity decreases as the day heats up because warm air has a greater capacity to contain moisture than cold air.

1.4.4 Surface Runoff

Water which can not in helabade over the ground surface until it reaches more permeable soil, where it can in helabade down slope as threads of water which may gradully merge until a detiner in helabade. This is known as ***surface runoff.***

Factors affecting surface unitl Discharge water over the surface of the ground is known as surface runoff. Surface system of hydrology, exercise control over the basin hydrological cycle the important factors influencing surface runoff are lighology, structure, slope, sunshine, raintall, snowfall, show melt water, forest and evapo-transpiration.

(1) Lithology and surface runoff. Characteristics of the lithological setting has a significant control upon the surface runoff. Rocks may be of various types ; hard or soil, pervious or imperivous. porous or nonporous. Upon hard and impervious rock (granite, basalt) floors surface flow becomes maximum under the given amount of water discharge, wherease upon porous rocks (sandstone, shale) a part of water enter in to the pore spaces reducing, the rate of surface runoff. Again upon pervious and soluble rocks (limestone) discharged water rapidly enters into the cavities through dolins or sinkholes thereby almost suspending the surface runoff.

(2) Structure and surface runoff : Geological structures also have a certain impact upon the surface runoff. Upon horizontally bedded homogeneous rock structure surface runoff is greater than that upon vertically inclined rock structure.

(3) Slope and surface runoff : Velocity of surlace runoff increases with the increase in slope gradient runoff is possible upon the slope as low as 1° and can be catastrophic upon slope gradient exceeding 20° provided the volume of water excessive.

(4) Sunshine and runoff : Rate of evaporation is a decisive factor controlling runoff. Normally under strong sunshine the rate of evaporation is high and velocity of runoff is checked considerably. In the tropics evaporation under strong sunshine is great hence in the humid tropical areas very high degree of surface runoff is observed. On the other hand in the higher latitudes the intensity of sunshine is reduced rate of runoff also comes down.

(5) Rainfall and surface runoff : The supply of water received through rainfall primarily decides the rate and strenght of surface runoff. Thus the regions of high aunnual rainfall exhibits the highest the highest rate of surface runoff.

(6) Snowfall and surface runoff : Snowfall often inhibits both seepage and surface runoff as the accumulated snow stand as a barrier to the discharge of water overland. Hence the humid regions under cold climate have a large degree of seasonal variation in surface runoff. During cold season of the year when snow fall occurs runoff becomes markedly restricted.

(7) Snow melt and surface runoff : In cold climatic regions where seasonal snow melting occurs a large degree of variation the surface runoff is exhibited. Excessive amount of snow may be accumulated during winter and on the following spring as the snow starts melting rapidly supply of water enhance surface runoff particularly upon the sloping grounds.

(8) Forest and surface runoff : Natural vegetation has a certain influence upon the runoff. It is usually found in detailed studies that interception losses are greater beneath evergreen than beneath deciduous trees. Plants consequently have a major effect upon the supply of water to the soil and upon total runoff into streams during short duration storms, but once the vegetation surfaces are saturated interception gets limited and the influence on runoff is greatly reduced.

(9) Evapo-transpiration and runoff : The rate of evapo-transpiration decisively controls surface runoff. Under dry climatic condition where the rate of evapo-transpiration is exceedingly high the possibility of surface runoff is reduced accordingly.

1.4.5 Drainage density

Drainage density is also an important parameter to identify the hydrological condition and processes over an area. It is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow.

Drainage density depends upon both climate and physical characteristics of the drainage basin. Soil permeability and underlying rock type affect the runoff in a watershed; impermeable ground or exposed bedrock will lead to an increase in surface water runoff and therefore to more frequent streams. Rugged regions or those with high relief will also have a higher drainage density than drainage other drainage basins if the other characteristics of the basin are the same.

Drainage density can affect the shape of a river's hydrograph during a rain storm. Rivers that have a high drainage density will often have a more 'flashy' hydrograph with a steep falling limb. High densities can also indicate greater flood risk.

1.5 Model Questions

1) Briefly describe the concept of Hydrology and the kinds of water included in the study of Hydorology.

2) Discuss the process through which Global Hydrological Cycle works and comment on the concept of Global water balance.

3) Account for the parameters and processes of Basin Hydrological Cycle.

4) Assess the pattern and characteristics of the atmospheric moisture.

5) What is Surface Runoff ? Describe the factors affecting surface runoff.

1.6 Select Readings

1) Hydrology - Meinzer

2) Water, Earth and Man — R. Chorley

3) The Basin Hydrological Cycle - R.J. Moore (in Water, Earth and Man - R. Chorley)

4) Fluvial Processes in Geomorphology — L.B. Leopold, M.G. Wolman and J.P. Miller

5) The Streams — Morisawa.

Unit 2 ❑ Unit Hydrograph and its Applications

Structure

2.1 Definition

A hydrograph or ***a unit hydrograph*** is a record of the stage and/or discharge of a river as a function of time. It is a basic tool for evaluating the response of a watershed (area above a hydrometric station) to precipitation or snow melt. Stream response to hydro-climatic events reflects the relative contributions of surface and subsurface runoff and thus all aspects of the physical and cultural geography of drainage basins. These controls on the flood hydrograph range from transient (storm characteristics) to permanent (basin physiography) with land use in between since it can be relatively stable (e.g., forest) or change annually (crop rotation). Stream hydrograph rises following rainfall or snowmelt. The gradual decay in flow after the peaks reflects diminishing supply from groundwater

2.2 Variations in the shape of a Hydrograph

The shape of a hydrograph is determined by the speed in which flood waters are able to reach the river. The nature of the drainage basin therefore has a great influence on the way a river responds to a river as it will determine the types and speeds of the flow of water to the river.

The fastest route to the river is via **overland flow**. If most of the water in a drainage basin travels in this way, a river will respond quickly to heavy rainfall and the hydrograph shape will be 'peaky' (graph A) with steep rising and recessional limbs. The lag time will be short and there will be a greater risk of flooding. Where more water is able to pass into the soil and travel to the river via **throughflow / groundwater flow**, there will be a slower rise in discharge and the river will respond slower (graph B). The lag time will be longer and the risk of flooding will be much lower.

2.3 Surface water hydrograph

In surface water hydrology, a hydrograph is a time record of the discharge of a stream, river or watershed outlet. Rainfall is typically the main input to a watershed and the stream flow is often considered the output of the watershed; a hydrograph is a representation of how a watershed responds to rainfall. They are used in hydrology and water resources planning.

A watershed's response to rainfall depends on a variety of factors which affect the pattern of a hydrograph:

- Watershed topography and geology (i.e. bedrock permeability)
- The area of a basin receiving rainfall
- Land-use (e.g. agriculture, urban development, forestry operations)
- Drainage density
- Duration of rainfall and precipitation intensity and type
- Evapo-transpiration rates
- River geometrics
- The season
- Previous weather
- Vegetation type and cover
- River conditions (e.g. dams)
- Initial conditions (e.g. the degree of saturation of the soil and aquifers)
- Soil permeability and thickness

2.4 Terminology

The discharge is measured at a certain point in a river and is typically time variant. The following terms are often used to describe and interpret a hydrograph:

- **Rising limb** - The part of the hydrograph up to the point of peak discharge.
- **Falling limb** - The part of the hydrograph after the peak discharge.
- **Peak discharge** - The highest point on the hydrograph when there is the greatest amount of water in the river.
- Lag time - Period of time between peak rainfall and peak discharge.

2.5 Types of Hydrograph

Types of Hydrograph include : **a) Storm Hydrograph, b) Flood Hydrograph and c) Annual Hydrograph**

(a) Storm Hydrograph

A storm hydrograph shows how a river's discharge responds following a period of heavy rainfall. On a hydrograph, the flood is shown as a peak above the base (normal) flow of the river. Analysis of hydrographs can help hydrologists to predict the likelihood of flooding in a drainage basin. The response of a river to a rainfall event can be measured in terms of the lag time - the time between peak rainfall and peak discharge. Rivers with a short lag time respond rapidly to rainfall events and are therefore more prone to flooding than rivers with a longer lag time.

River discharge does not respond immediately to rainfall inputs as only a little of the rainfall will fall directly into the channel. The river will start to respond initially through inputs from surface runoff (the fastest flow of water) and its discharge will later be supplemented through inputs from throughflow and groundwater flow.

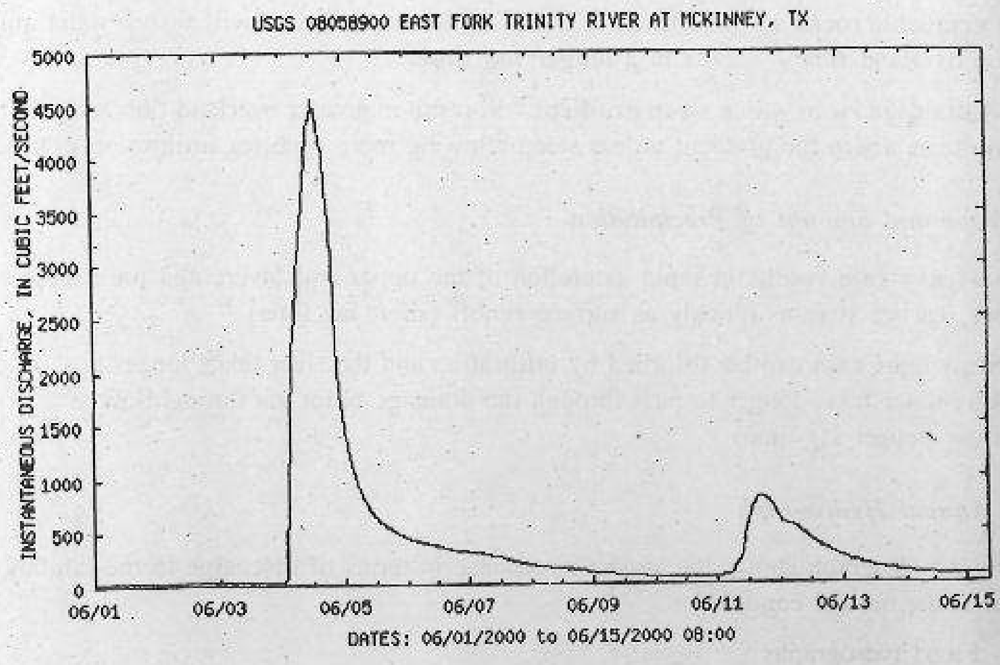


Fig. 1 : Normal shape of a Storm Hydrograph

(b) Flood Hydrograph

In some drainage basins, discharge and river levels rise very quickly after a storm - they are described as having a "flashy" response to inputs of precipitation. This can cause frequent, and occasionally serious, flooding. Following a storm in these basins, both discharge and river levels fall almost as rapidly, and after dry spells, become very low. In other drainage basins, rivers seem to maintain a more even flow. The **flood (storm) hydrograph** is a graph showing the discharge of a river at a given point (e.g. at a gauging station) over a period of time. A flood or storm hydrograph shows how a river responds to one particular storm. When a storm begins, discharge does not increase immediately as only a little of the rain will fall directly into the channel. The first water to reach the river will come from surface run-off, and this will later be supplemented by water from thoughflow. The increase in discharge is shown by the rising limb. The gap between the time or peak rainfall and peak discharge (highest river level) is called lag time. A river with a short lag time and a high discharge is more likely to flood than a river with a lengthy lag time and a low discharge

Factors affecting a flood hydrograph

a) Characteristics of the Drainage Basin

i) **Impermeable rocks** (e.g. granite) and soil (e.g. clay) will not allow water to pass through, resulting in large amounts of surface runoff and a greater flood risk as rivers respond quickly - results in a **short lag time.**

ii) **Permeable rocks** and soil have a high infiltration capacity and will absorb water quickly, reducing overland flow - results in a **longer lag time.**

iii) A drainage basin with a **steep gradient** will result in greater overland flow and a **shorter lag time** than where the gradient is less steep allowing more time for infiltration to occur.

b) Type and amount of Precipitation

i) **Heavy rain** results in rapid saturation of the upper soil layers and the excess water therefore reaches streams quickly as surface runoff (short lag time).

ii) **Slow light rain** can be absorbed by infiltration and the river takes longer to respond to rainfall as water takes longer to pass through the drainage basin via throughflow and ground-water flow (longer lag time)

(c) Annual Hydrograph

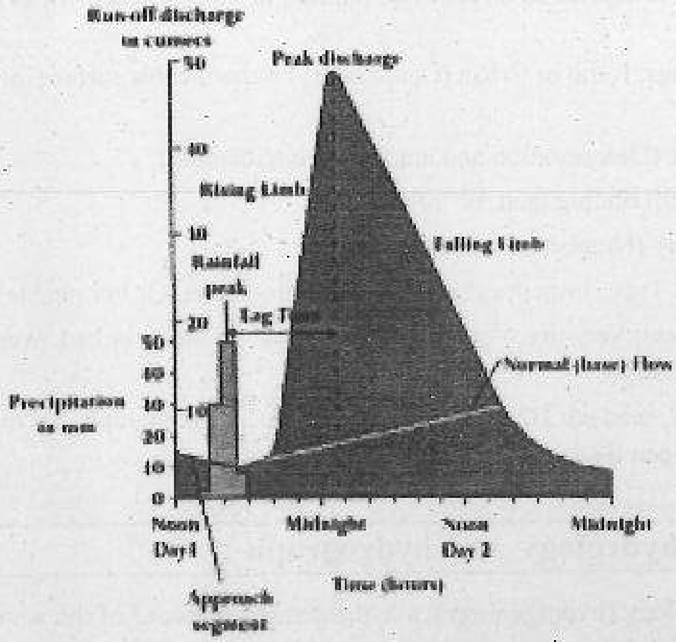
Annual hydrograph shows the stream's response in terms of discharge to the rainfall over the year under normal condition.

- Flood hydrographs
- Annual hydrographs

- Flood hydrographs
- An

A hydrc

A flood hydrograph



2.6 Application of Unit Hydrograph

A unit hydrograph is used to more easily represent the effect of rainfall a particular basin. It is a hypothetical unit response of the watershed to a unit input of rainfall. This allows easy calculation of the response to any arbitrary input (rainfall), by simply performing a convolution between the rain input and the unit hydrograph output.

An **instantaneous unit hydrograph** is a further refinement of the concept; for an IUH, the input rainfall is assumed to all take place at a discrete point in time (obviously, this isn't the case for actual rainstorms). Making this assumption can greatly simplify the analysis involved in constructing a unit hydrograph, and it is necessary for the creation of a **geomorphologic instantaneous unit hydrograph.**

The creation of a GIUH is possible given nothing more than topologic data for a particular drainage basin. In fact, only the number of streams of a given order, the mean length of streams of a given order, and the mean land area draining directly to streams of a given order are absolutely required (and can be estimated rather than explicitly calculated if necessary). It is therefore possible to calculate a GIUH for a basin without any data about stream height or flow, which may not always be available.

2.7 Factors affecting the hydrograph

- Soil Saturation is dependant on previous rainfall, or otherwise known as Antecedent rainfall.
- The surroundings; Rural or Urban (Could be less impermeable surface, or the surface type could vary)
- Vegetation type (Deforestation and amount of interception)
- Steepness of surrounding land, or 'relief land
- Drainage density (Number of tributaries)
- Geology (Rock Type; Impermeable=flashier hydrographs. Or Permeable)
- Season dependant; Very dry weather creates a crust on the river bed. Wet winters create increase in discharge.
- Soil Type (Clay, sand etc.) Clay would create a flashy hydrograph, but there could be a continium between the two.

2.8 Subsurface hydrology and hydrograph

In subsurface hydrology (hydrogeology), a hydrograph is a record of the water level (the observed hydraulic head in wells screened across an aquifer).

Typically, a hydrograph is recorded for monitoring of heads in aquifers during non-test conditions (e.g., to observe the seasonal fluctuations in an aquifer). When an aquifer test is being performed, the resulting observations are typically called drawdown, since they are subtracted from pre-test levels and often only the change in water level is dealt with.

2.9 Consolidation

- the unit hydrograph is the hydrograph that results from unit (e.g. 1 inch) excess rainfall uniformly over the watershed at a uniform rate during a given period of time
- when developing a unit hydrograph, be sure the area under the curve is equivalent to 1 area-in (approximate unit hydrographs are often needed because rainfall is rarely spatially uniform)
- an observed rainfall distribution is convolved with the unit hydrograph to calculate the outlet discharge for the basin of interest (Fig. 2).
- with computers, idealized unit hydrographs are often used, e.g. the SCS dimensionless unit hydrograph in TR-20 (Fig. 9)
- this technique often yields predicted flood peaks within 25% of observed values (i.e. sufficient for planning).

2.10 Model Questions

1) What is a Unit Hydrograph? Discuss how hydrographs vary in shape.
2) In the context of surface water hydrology identify the factors affecting the pattern of hydrograph.
3) Describe the characteristics of a) Storm Hydrograph, b) Flood Hydrograph and c) Annual Hydrograph.

2.11 Select Readings

1) Hydrology - Meinzer
2) Water, Earth and Man - R. Chorley
3) The Basin Hydrological Cycle - R.J. Moore (in Water, Earth and Man - R. Chorley)
4) Fluvial Processes in Geomorphology - L.B. Leopold, M.G. Wolman and J.P. Miller.

Unit 3 ❑ Wetland Ecosystem and its management

Structure :

3.1 Introduction and Definition

In true sense Wetlands are swamps and marshes formed in low-lying areas but can not be called permanent water bodies. There is much ambiguity about the definition of wetlands. In England wetlands comprise large tracts and therefore are synonymous with the name of the region itself like the Fens, Broads, Carrs, Mosses and Levels. Terms such as Moors and bogs were often used to describe a particular landscape comprising peat lands and swamps.

Gardiner (1994), the National Rivers Authority of the United Kingdom defines wetlands as, "areas of waterlogged and periodically inundated land which support a distinctive and characteristic wetland vegetative type (marshes, grass, rushes, sedges etc)".

Williams (1990) mentioned that "... the distinctiveness of wetlands lie in their ecological composition and character which arises from the fcact that they are situated at the junction between dry-land terrestrial ecosystems and permanently wet aquatic ecosystem".

Wetlands are thus transitional environments located between terrestrial and aquatic systems around inland lakes and rivers. In the temporal context, these regions may either transform into dry land due to lowering of water table or even may be submerged due to rise in water table, sea-level changes or climatic changes. Geologically wetlands are ephemeral features because of the dynamic nature of its spatial location. Wetland ecosystems have one main feature in common, i.e., their temporary or permanent water logging. Thus hydrology is the basic feature that defines a wetland and determines the specificity of its soil type, characteristic vegetation and composition. In spite of this similarity, there exists a very wide range of habitat types depending on salinity, succession stage, climate etc.

'The Ramsar Convention, signed in 1971, was an intergovernmental treaty, which provided a framework for international cooperation for conservation of wetland habitats; the aim was to give recognition to the wetlands, especially as an important habitat for the migratory waterfowl. Accordingly, the wetland is defined as "Areas of shallow lakes, marsh, fen, peat land or water, nutural or artificial, permanent or temporary, with water that is static or flowing, fresh or brackish or salt, including areas of marine water, depth of which at low tide does not exceed six metres".

3.2 Importance of Wetlands

Wetlands are one of the most productive ecosystems, comparable to tropical evergreen forests in the biosphere and play a significant role in the ecological sustainability of a region. They are an essential part of human civilisation meeting many crucial needs for life on earth such as drinking water, protein production, water purification, energy, fodder, biodiversity, flood storage, transport, recreation, research-education, sinks and climate stabilizers. The values of wetlands though werlapping, like the cultural, economic and ecological factors, are inseparable. The geomorphological, climatic, hydrological and biotic diversity across continents has contributed to wetland diversity. Across the globe, they are getting extinct due to manifold reasons, including anthropogenic and natural processes. Burgeoning population, intensified human activity, unplanned development, absence of management structure, lack of proper legislation, and lack of awareness about the vital role played by these ecosystems (functions, values, etc.) are the important causes that have contributed to their decline and extinction. With these, wetlands are permanently destroyed and lose any potential for rehabilitation. This has led to ecological disasters in some areas, at large-scale devastations due to floods, etc.

3.3 Classification of Wetlands

Wetlands are most difficult to classify because of the wide variety of environmental, geographical and geological determinants that lead to its formation. Their formation is determined by the structural and geological conditions, on the one hand, and climatic and the vegetation characteristics, on the other. The most important determinant, during the last few years, has been human intervention, which has invaded the natural spatial extent and the characteristics of wetlands.

Williams (1991) is of the opinion that the three most important criteria for their classification are hvdrographic vegetation, hydroid soils and the degree and frequency of flooding and/or soil saturation.

A simple classification given by the Environmental Protection Agency of USA is as follows:

1) Marshes a) Tidal and b) Non-tidal (Wet meadows, Prairie Potholes, Vernal Pools and Playa Lakes)

2) Swamps a) Forested Swamps - Bottomland hardwoods and b) Shrub Swamps - Mangrove Swamps. 3) Bogs a) Northern Bogs and b) Pocosins.

4) Fans

Willims (1990) gave two major divisions as in coastal and interior and then subdivides them into two categories as follows:

l) Coastal wetlands: a) Marine and b) Estuarine.

2) Interior wetlands: a) Riverine, b) Lacustrine, c) Palustrine

The classification attempted by Orme (1990) as demonstrated in Table: 1 below is comprehensive and takes into account the system, water regime and water chemistry and vegetation type. The approach to the classification makes it most scientific and holistic.

Table l: Classification of wetlands as per Orme (1990)

System	*Location*	*Water Regime*	*Water Chemistry*	*Vegetation Type*
Marine	Open Coast	Supratidal	Euhaline Mixohaline	Shrub Wetland
		Intertidal	Euhaline	Salt marsh mangrove
		Subtidal	Euhaline	Sea grass, algae
Estuarine	Coastal Sabkha	Supratidal	Mixohaline	Algae barren sabkha
	Delta	Supratidal	Mixohaline-fresh	Brakish marsh, shrub
	Lagoons	Intertidal	Euhaline-Mixohaline	Salt marsh, mangrove
Riverine	River channels	Perennial	Fresh	Aquatics, algae
		Intermittent		Aquatics, Wetland
		Ephemeral	Fresh	– Do –
	Flood Plains	Ephemeral or Stagnant	Fresh	Emergent Wetland, Shrub, Forest Wetland
Lacustrine	Lakes	Perennial > 2m deep	Fresh limnetic	Aquatics, algae
		Per-intermit, < 2m deep	Fresh littoral	Aquatics, Emergent Wetland, shrub
Palustrine	Ponds	Perennial	Fresh littoral	Aquatics, algae
	Troughs	Intermittent	Fresh	Aquatics, emergent
	Lowland Mires	High water tables	Fresh	Aquatics, sphagnum moss, bog plants
	Upland Mires	Perennial to ephemeral surface water	Fresh	Emergent Wetland, Shrub and forest Wetland

Source: Orme (1990)

3.4 Distribution of Wetlands

Wetlands comprise 6% of the earth's surface and usually do not occupy large continuous stretches of land. They may be found in any climatic zone from the Tundra to the Tropical regions, as can be seen in the Table 2 below.

Table 2: Estimated area of Wetlands and their primary production by Climate Zones

Sl. No.	*Zone*	*Climate*	*Area*		*Production*	
			Sq. km	*% of total*	*T/ha×10t*	*% of total*
1.	Polar	Humid-semi-humid	2,000	2.5	43	3.2
2.	Boreal	Humid-semi-humid	25,580	1.1	1086	7.2
3.	Sub-boreal	Humid	5,390	7.3	278	3.0
		Semi-arid	3,420	4.2	382	5.7
		Arid	1,360	1.9	177	8.9
4.	Sub-tropical	Humid	10,770	17.2	6502	40.8
		Semi-arid	6,290	7.6	2511	21.9
		Arid	4,390	4.5	3951	55.3
5.	Tropical	Humid	23,170	8.7	24273	31.4
		Semi-arid	2,210	1.4	1326	5.9
		Arid	1,000	0.8	400	15.2
	World total		**85,580**	**64**	**40929**	**24.0**

Source: Williams (1991)

The global distribution of wetlands is not very precise, as there exist problem of definition and the large stretches of wetlands in the developing countries have not yet been explored. The only country in which wetland surveys have been done extensively is the USA. In the USA, 14 estimates between 1907 and 1987 have also produced little agreement over the exact extent - the estimates are around 50 $\times 10^6$sq. kms.

3.5 Functions of the Wetlands

The need to conserve wetlands is debated widely over the recent years. In order to evaluate the need to conserve the wetland systems it is necessary to identify their values and functions in terms of environmental processes and the ecosystem services. Given the limitations, there have been many attempts to categorise the functions and values of wetlands. Among those the two important approaches are:

1) The categorization by Tiner (1984) who gives three categories -

i) Fish and wildlife values,

ii) Environmental quality value and

iii) Socio-economic value.

2) The Office of Technical Assessment Report of USA (1984) makes two categories -

i) Intrinsic value,

ii) Ecological services and resource values.

However in order to make detailed and precise discussion it is considered appropriate to proceed with four categories: physical/hydrological, chemical, biological and socio-economic. It is also to be note in this context that none of these categories are exclusive.

Physical and Geo-hydrological Functions

a) Natural flood mitigation

b) Bank stabilization

c) Foreshore protection

d) Recharging aquifer

e) Sediment tapping

f) Atmospheric and climatic purification

Chemical Functions

a) Trapping and removal of wastes

b) Pollution trapping

Biological Functions

a) Productivity maintenance

b) Fish and wildlife habitat maintenance

Benefits to Society-livelihood in agriculture and fishing etc.

3.6 Conservation and Management of Wetlands

From the above discussions it can be realized that with increase in knowledge on wetlands and simultaneous realization that they are rather invaluable to mankind. Thus conservation and management of wetlands are absolutely essential. A range of policies has been adopted depending upon the state of knowledge and the scientific and human capabilities.

3.7 Wetlands in India

Notified Wetlands in India

Name of Wetland	State	Water Spread (Post monsoon) Ha.
1	2	3
Bhoj	Madhya Pradesh	32,29
Harike	Punjab	8,280
Kanjli	-do-	3,79
Ropar	-do-	220,60
Wular	Jammu & Kashmir	11562.5
Tso Morari	-do-	12,838
Pichola	Rajsthan	604
Sambhar	-do-	2,270
Chilika	Orissa	9,400
Ujini	Maharashtra	27,935
Ashtamudi	**Kerala**	**5071.07**
Sasthamkotta	**–do-**	**354.69**
Kollleru	Andhra Pradesh	28.375
Loktak	Manipur	1,156
Sukhna	Chandigarh	1 53
Renuka and Pong dam (combined)	Himachal Pradesh	27,878
Chandratal	-do-	
Kabar	Bihar	82
Nalsarovar	Gujarat	14818.75
East Calcutta	West Bengal	11067.5

Source: Quoted in Parkih and Datye. 2003

3.8 Types of processes contributed by the wetlands

Types of processes and change	*Discrete events*	*Gradual long term processes*
Physical Changes in topography or elevation	Filling or excavation Mining, dredging & filling Natural erosion or deposition Floods	Waterborne sediment increase Denuding watersheds Waterborne sediment decrease Reservoirs, flood-control levees
Changes in local or	Reduction in available water Draining agricultural land Diverting water Increases in water Flooding from reservoir	Reduction in available water Increasing upstream withdrawal Ground water overdraft Increased water amount depth Watershed clearing Coastal submergence
Chemical Change in nutrient levels	Increase loading Point-source discharge Decreased loading	Increased loading Agricultural run-off Wetland waste water disposal Decrease loading Up land reforestation
Change in Toxic substances or Contaminants	Increased loading Pesticide application Oil or toxic spill	Increased loading Chronic low-level disposal Pesticide run-off Industry waste water discharge Deposition from air
Changes in salt levels		Increased level Reduced fresh water inflow Canal construction Decreased levels Reduced irrigation return flow
Change in pH Change in temperature		Increase acidity Acid precipitation Acid mine drainage Natural bog succession Decreased acidity Increased irri gation return flow
	Discharge of heated effluent	Climate change
Biological Changes in biomass Changes in community composition	Biomass decrease Fire, clearing, lumbering	Biomass decrease Grazing, many adverse physical and chemical changes
	Biomass increase Planting Selective harvesting Introduction of exotic species	Natural succession Selective harvesting Habitat loss Change in hydrology, noise
Changes in landscape pattern through clearing, selective forest harvest, modified hvdrology		All kinds of cumulative impacts

Source: Gosselink and Malthy (1990)

3.9 Wetland conservation policy in developed countries

Ecologists and conservationists have recognized the importance of the wastelands and now this realization is fast spreading among people of all walks of life. The reason for this realization is that wetlands are multifunctional and can be considered as a valuable capital asset. Under appropriate management regime wetlands can produce a flow of functions such as nutrient purification, groundwater buffering and biodiversity conservation. This flow generated by species dynamically interacting with one another and the environment constitutes the "life support systems" for the environment. Since the Ramsar Convention, there has been a shift in public attitude and the dominant paradigm that has emerged is conservation and not reclamation.

The policies of the conservation paradigm in the 1980's have led to the replacement of natural wetlands, wherever they have been converted. This is assumed to be the 'Mitigation Approach' towards solving the problem of loss. The process involves artificial creation of a water body of the same magnitude as the one converted for development projects. Attempts made for saving the wetlands within the framework of restoration ecology is also popularly known as No Net Loss or NNL Policy. The United States National Research Council report "The Restoration of Aquatic Systems" called for restoration of 10 million acres of wetlands in the US within a 2 year life frame. An example of the prioritisation is found in the restoration of 500kms of floodplain wetlands by removing levees along the Missouri River. This approach has been criticized as the original ecosystem characteristics once lost can never regenerated in absolute terms.

Under the Clean Water Act of 1972 wetlands are officially identified by the U.S. Army Corps of Engineers. Most developers hire consultants to determine if there are wetlands on the property and, if so, to create a plan to protect them to get permits. Where wetlands exist, a developer must get a 404 permit from the Corps. To qualify for the permit, a developer may be required to design a project, incorporate buffers, realign roadways or build bridges over wetlands. The developer may also turn to mitigation, which is a way to compensate for the loss of wetland. This permits development, but a builder must pay a fee to the state's Wetlands Restoration Programme, participate in a mitigation bank or create wetlands at another site.

3.10 Uses and management of Kolkata Wetlands

The wetlands around the Kolkata Metropolitan city have emerged as a boon in disguise. The waterlogged complex is a mosaic of environment diversity with their multifarious uses. A probe into the traditional resource recovery system of the wetlands can provide a low cost alternative to environment protection. Managing urban wastes, both solid and sewage, is a tricky problem. Use of the conventional mechanical treatment plats has been the common practice. Kolkata has built-in natural and environment-friendly system of waste treatment through a network of sewage-fed wetlands. These 12,000 acre low-lying wet depressions, which exist on the eastern and south-eastern edge of the city, detoxify the urban waste water flowing the nature's way. The entire waterlogged complex is a mosaic of environment diversity. A series of eco-zones, ranging from the typical dry lands (garbage farm) to totally aquatic water bodies (fish-pond) intermixed with transitional wet paddy fields, characterize the landscape. Being a storehouse of activity growing green plants, the area pumps surplus oxygen into the air of the metropolis. Due to the excess input of sewage-derived nutrients, this marshy area excels in biological productivity. For this reason it sustains a good number of life forms including the commercially important species.

East Kolkata wetlands, being a low-lying depressed area and situated on the city fringe, function as spongy water receptacles for the collection and retention of city sewage and run-off waters. The wetlands, more specifically the fish ponds, function as natural stabilization tanks for the purification of waste water. Also water hyacinth, which grows along the pond margins, in concert with the multitude of microbes, helps the process of water treatment.

3.11 Model Questions

1) Define the term 'Wetland' and describe its environmental importance.

2) Classify wetlands according to origin and describe their pattern of distribution, water regime, water chemistry and vegetation types.

3) Give an account of the world distribution and functions of wetlands.

4) Account for the distribution of wetlands in different parts of India mentioning their size variations.

5) Elucidate the uses and management of the Kolkata wetlands.

3.12 Select Readings

1) Hydrology - Meinzer

2) Water, Earth and Man - R. Chorley

3) The Basin Hydrological Cycle - R.J. Moore (in Water, Earth and Man - R. Chorley)

4) Fluvial Processes in Geomorphology - L.B. Leopold, M.G. Wolman and J.P. Miller.

5) Bandyopadhyay, S. (2004): East Kolkata Wetlands: their uses and management. Ph.D. Thesis (unpubl), IIT, Bombay.

6) Bhakat, R.K. (1993): Uses of Calcutta's Wetlands. Yojana; pp.17-19.

Unit 4 ❑ Criteria for river basin management

Structure

4.1 Introduction

Worldwide, recognition is increasing that individual water resources projects and policies have implications for other water users within a river or lake basin, both upstream and downstream. Increased stresses on a basin's natural resource base caused by development pressures are leading to degradation that is felt well beyond the immediate area of a particular project. Integrated river basin management has been the primary mechanism to address these issues and impacts.

4.2 Criteria for river basin management

Key Challenges

Basin management is anchored in the principle of decentralization of decision making to the lowest appropriate level. While it seems to be comparatively easy to translate this concept into laws and regulations, its actual application often encounters obstacles due to the varying interests of different stakeholder groups, including those that would have to promote the decentralization.

What are river basin districts ?

Areas of land and sea identified as the main managment unit are known as river basin districts. These regions can include one or more neighbouring river basins together with their associated groundwater bodies and coastal waters. The Danube River Basin District covers the Danube River Basin, the Romanian Black Sea coastal catchments and the Black Sea coastal waters along the Romanian and partly the Ukrainian coast.

River basin - a natural unit

Water does not stop at administrative or political boundaries, so the best way to protect and manage water is by close international co-operation between all the countries within the natural geographical and hydrological unit of the river basin - bringing together all interests upstream and downstream.

A drainage unit can be classified as follows.

Drainage area	*Unit*
> 1,00,000 he	Catchment
40,000-1,00,000he	Sub catchment
4000-40,OOOhe	Water shed
2000-4000he	Sub water shed
400-2000he	Mini water shed
<400he	Micro water shed

Basin Management

Sound basin management requires attention to basin-wide water use efficiency and water quality management. In some circumstances, field efficiency is important because return flows degrade land and water resources. In other circumstances, one farmer's water loss is another larmer's recharge, and improved farm-level irrigation efficiencies often result in only paper, not real, water savings. Or savings in one sector are off set by wastage in another user group. What is required is improved; customized understanding of water balances and water quality in specific basins, so that the benefits from often costly interventions to reduce losses are assessed in terms of the contribution to overall basin water use efficiency and water quality. Such understanding includes determining how much water can be consumptively used on a sustainable basis while still meeting environmental and other in-stream flow requirements without overexploitation of groundwater.

The Water Framework Directive

To meet the challenge of ensuring a sufficient supply of clean water for future generations the European Community adopted in December 2000, the EU Water Framework Directive (W FD) - a new and effective tool for water management.

The WFD establishes a legal framework to protect and enhance the status of aquatic ecos'ystems; prevent their deterioration and ensure long-term, sustainable use of water resources. The Directive provides for an innovative approach for water management based on river basins, the natural geographical and hydrological units, and sets specific deadlines for EU Member States. The WFD addresses inland surface waters (rivers and lakes), transitional waters, coastal waters, groundwater and, under specific conditions, water dependent terrestrial ecosystems and wetlands. It establishes several integrative principles for water management, including public participation in planning and the integration of economic approaches, and also aims for the integration of water management into other policy areas. For better coordination, the WFD calls for the creation of international districts for river basins that cover the territory of more than one EU Member State. EU Member States should aim to achieve good status in all bodies of surface water and groundwater by 2015, respectively by 2027 at the latest.

Information and Consultation of the Public Involvement of the public and proactive information sharing is key principles for river basin management. Therefore, the ICPDR publishes all basin-wide strategic documents and analysis reports.

The latest strategic document is the interim overview on the Significant Water Management Issues in the Danube River Baisn District, which is the basis for the Danube River Basin Management Plan.

4.3 Model Questions

1) Give an account of the importance and criteria for river basin management.
2) Classify drainage areas in terms of unit. And give the outline of an ideal basin management scheme.

4.4 Select Readings

1) Hydrology - Meinzer
2) Water, Earth and Man - R. Chorley
3) The Basin Hydrological Cycle - R.J. Moore (in Water, Earth and Man - R. Chorley)
4) Fluvial Processes in Geomorphology - L.B. Leopold, M.G. Wolman and J.P. Miller.
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OCEANOGRAPHY

Unit 1 ❑ Distribution of ocean water over the globe- salinity and temperature of ocean water

Structure :

1.1 Introduction

An ocean is a major body of saline water, and a principal component of the hydrosphere. The area of the Earth surface is equal to 510,100,000 km². Land covers 148,800,000 km² (29.2%) and the World Ocean covers 361,300,000 km² (70.8%). The World Ocean is a continuous water "blanket" over the Earth adjacent to all of the continents and islands and possesses a generally salty structure. More than half of this area is over 3,000 meters (9,800 ft) deep. Average oceanic salinity is around 35 parts per thousand (ppt) (3.5%), and nearly all seawater has a salinity in the range of 31 to 38 ppt.

1.2. Distribution of water in Hemispheres

In the Northern Hemisphere, the World Ocean occupies 61 % of the area and in the Southern Hemisphere, 81%. If we were able to arbitrarily divide the Globe into two equal parts so that in one hemisphere the land predominated, and in the other the water, water will appear to cover more than half of the area (53%). The oceanic hemisphere takes up about takes 91 % of the area. The land and sea are also non-uniformly distributed on the planet. Land predominates only between latitudes of 45° N and 70° N, and to the south, from latitude 70° S to the South Pole. Water predominates over the remaining part of Globe. The shapes of the shorelines, bottom relief, and systems of oceanic currents, tides, atmospheric circulation and a number of other criteria subdivide the World Ocean into the Pacific, Atlantic, Indian and Arctic Oceans.

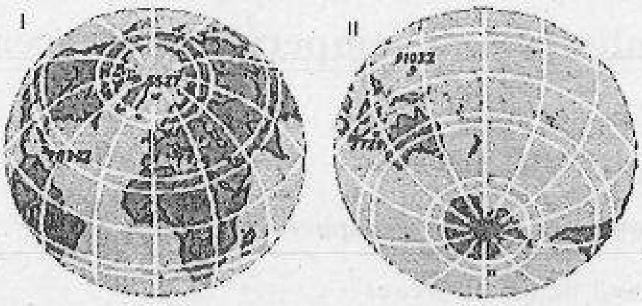


Figure 1: Land and Water Hemispheres of the Earth.
[I. Continental hemisphere II. Oceanic hemisphere]

With the broadening of knowledge about Antarctic waters as a unified, physical-geographical area, some scientists now separate the waters surrounding the Antarctic continent, an area of 86 million km^2, into a different water body: the Southern Ocean. Although widely used in scientific and other literature, the term "Southern Ocean" has not yet received official status.

1.3 The areas and Depth of Oceans

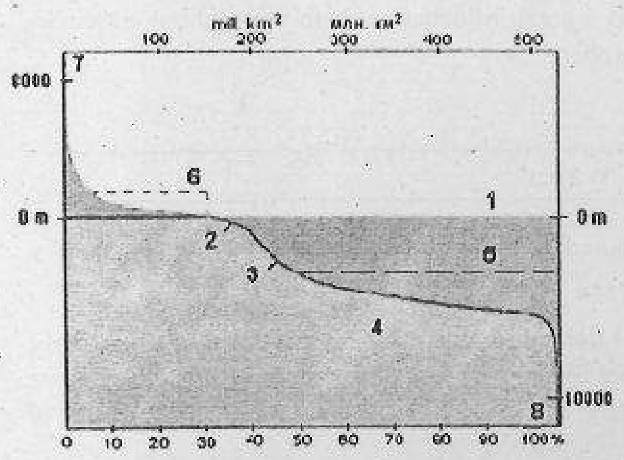
Though generally recognized as several 'separate' oceans, these waters comprise one global, interconnected body of salt water often referred to as the World Ocean or global ocean. This concept of a global ocean as a continuous body of water with relatively free interchange among its parts is of fundamental importance to oceanography. The major oceanic divisions are defined in part by the continents, various archipelagos, and other criteria: these divisions are (in descending order of size) the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, the Southern Ocean the southern portions of the Pacific, Atlantic, and Indian Oceans), and the Arctic Ocean (which is sometimes considered a sea of the Atlantic). The Pacific and Atlantic may be further subdivided by the equator into northerly and southerly portions. Smaller regions of the oceans are called seas, gulfs, bays and other names. There are also some smaller bodies of saltwater that are totally landlocked and not interconnected with the World Ocean, such as the Caspian Sea, the Aral Sea, and the Great Salt Lake - though they may be referred to as 'seas', they are actually salt lakes.

Geologically, an ocean is an area of oceanic crust covered by water. Oceanic crust is the thin layer of solidified volcanic basalt that covers the Earth's mantle where there are no continents. From this perspective, there are three oceans today: the World Ocean and the Caspian and Black Seas, the latter two having been formed by the collision of Cimmeria with Laurasia. The Mediterranean Sea is very nearly a discrete ocean, being connected to the World Ocean through the Strait of Gibraltar, and indeed several times over the last few million years movement of the African continent has closed the strait off entirely. The Black Sea is connected to the Mediterranean through the Bosporus, but this is in effect a natural canal cut through continental rock some 7,000 years ago, rather than a piece of oceanic sea floor like the Strait of Gibraltar.The Areas and Depth of Ocean Water are shown below :

Table 1 : Areas (10^6km^2) and Depths (m) of the Oceans

Oceans	Area	Percent	Mean Depth	Greatest Depth	Locations of Greatest Depths
Pacific	178.8	49.5	3 976	11 022	Marianas Trench
Atlantic	91.7	25.4	3 597	8 742	Puerto Rico Trench
Indian	76.2	21.0	3 711	7 729	Sunda Trench
Arctic	14.7	4.1	1 225	5 608	Greenland Sea (Molloy Deep)
World Ocean	361.3	100.0	3 711	11 022	Marianas Trench

On the surface of the Earth, altitudes less than 1,000 m and depths from 3,000 up to 6,000 m predominate. It is shown on a hypsographic profile constructed from the areas derived from various kinds of charts, showing the heights of the land and the depths of the Ocean over the entire planet. The distribution of land and water in terms of latitude are shown by the following diagram:



1. Sea level
2. Continental shelf
3. Continental slope
4. The Ocean floor
5. Mean depth of the World Ocean 3711m
6. Mean altitude of the land 840m
7. Jomolungma 8848m
8. Marianas Trench 11022m

Fig. 2 : Hypsographic Profile

1.4 Volume of waters of the World Ocean

The water cover of the Earth (called the "Hydrosphere") has volume of 1,389,500,000 million km^2, and 97.4% consists of salt water. Of this volume, 96.5% is in the World Ocean, and 0.9% is in salty underground and lake waters.

Fresh water comprises only 2.6% of the total volume of the Hydrosphere. This is the water contained in the atmosphere, rivers, lakes, glaciers, underground and ground water, and also the waters contained internally in animals and plants.

The waters of the World Ocean are distinguished from fresh water by their differing physical and chemical properties. By well-defined differences and . a complex exchange of energy and matter peculiar to the animal and plant kingdoms, a subclass of the Hydrosphere exists, called the "Oceanosphere", can be separated from the rest of the hydrosphere. The Oceanosphere has a great influence on the formation and changes of the natural world.

The World Ocean (Oceanosphere) contains on the order of 1,340.7 million km^3 of water, making up 1/800th of the total volume of the Earth (1,083.3 billion km^3). Alternatively, the volume of fresh water is about 35.8 million km^3. If the Oceanosphere was shown in the form of a sphere, its radius would be equal to 690 km, or 0.11 mean radii of the Earth (6,371 km).

In the process of exchanging water with the atmosphere and continents, World Ocean annually produces atmospheric precipitation of about 458,000 km^3; both rivers and ground water produce about 48,000 km^3 of water. Evaporation from the surface of the Ocean produces 506,000 km^3.

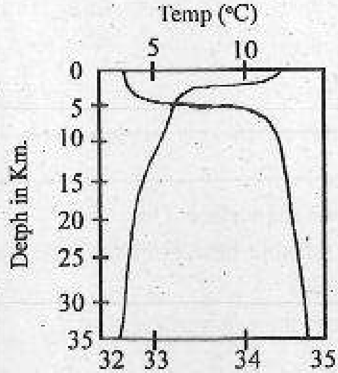
In comparison with the total volume of oceanosphere, these figures of exchange are insignificant. There is a much greater exchange between waters of the different oceans, that is, about 18,370 km^3 of water is annually exchanged between the oceans. This process redistributes the oceanic reserves of heat and salt, and has a great influence on both atmospheric processes and the characteristics of the whole Oceanosphere.

1.5. Temperature of the ocean water

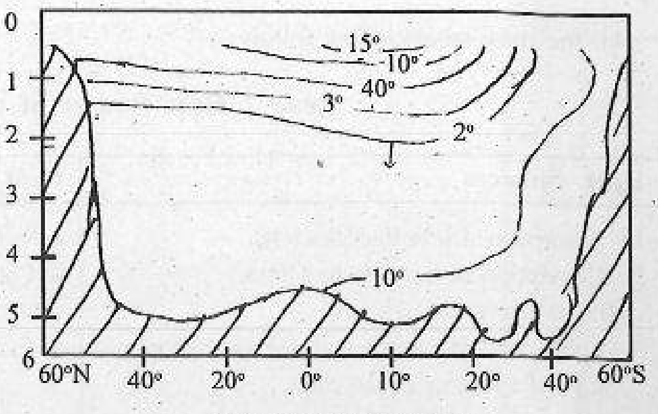
The temperature of the sea water is measured in degrees centigrade to an accuracy of + 0.020°C, oceanic temperature ranges between -2°C and +30°C; at the lower limit ice forms.

The potential temperature of sea water is defined as the temperature that it . would have if it were raised adiabatically to the surface. The freezing-point of sea water depends on the salinity, ranging from - 0.5°C at a salinity of 10‰ to just below - 2°C at a salinity of about 36‰.

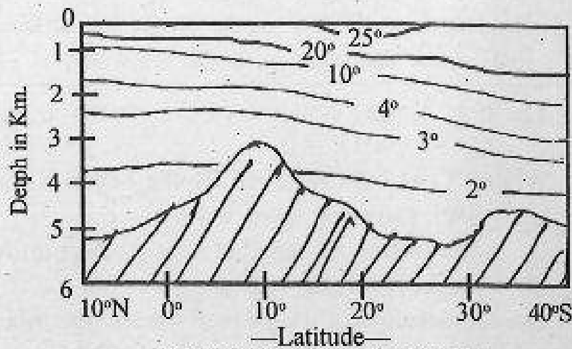
The distribution of temperature in the surface layers of the ocean reflects the general distribution of heat supply from the sun. received from the sun the value of heat received fromthe sun sis greatest at the equator and decreases towards the poles, but not at the same rate. Thus a surplus of heat occurs between the equator and 30° latitude and a net defit from there to the poles.



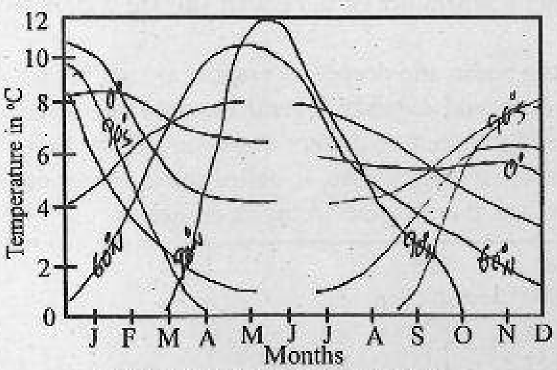
S (‰)
—— A Thermocline
—— A Halocline



• Temperature in Pacific



• Temperature in Indian Ocean.



Temperature in Atlantic oceans

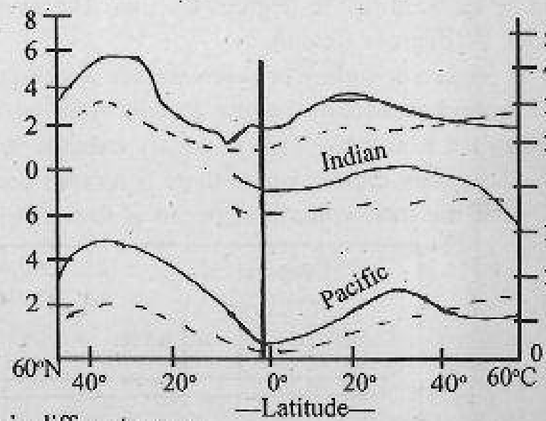


Figure : Temperature in different oceans

Heat Budget of the Oceans

All the supply of radiation energy received from the sun is balanced by equally large losses of energy. The important factors are :

1. The radiation energy received from the sun.
2. The interchangeof sensible heat with the atmosphere.
3. Evaporation from the sunface of the sea or the condensation of atmospheric water vapour.

All the may tabalatied as follows :

Table 2 Heat Budget of the Oceans

Heat Sources	Heat Losses
1. Absorption of Solar Radiation (Qs) 2. Convection of Sensible heat from atmorphere to the sea 3. Conduction of heat through the sea bottom from the interior of the earth. 4. Conversion of Kinetic energy into heat. 5. Heat produced by bio-chemical processes 6. Condensation of water vapour on the sea surface 7. Radioactive disintegration in the sea water.	1. Radiation from the sea surface (Qb) 2. Convection of sensible heat from sea to atmoshere (Qa) 3. Evaporation from the sea surface (Qe)

The heat budget equation of the oceans is given below :

$Q_s - Q_b - Q_h - Q_e = 0$

Where, Q_s = heat received by the ocean surface ;

Q_b = back radiation from sea surface ;

Q_h = convection of sensible heat to the atmosphere ;

Q_e = the heat of evaporation

The temperature of the surface waters (the mixed layer) varies mainly with latitude. The polar seas (high latitude) can be as cold as - 2 degrees Celsius while the Persian Gulf (low latitude) can be as warm as 36 degrees Celsius. The average temperature of the ocean surface waters is about 17 degrees Celsius.

There is a boundary between surface waters of the ocean and deeper layers that are not mixed. The boundary usually begins around 100-400 meters and extends several hundred of meters downward fromthere. This boundary extends several hundred of meters downward from there. This boundary region, where there is a rapid decrease of temperature, is called the thermocline. 90%₀ of the total volume of ocean is found below the thermocline in the deep ocean.

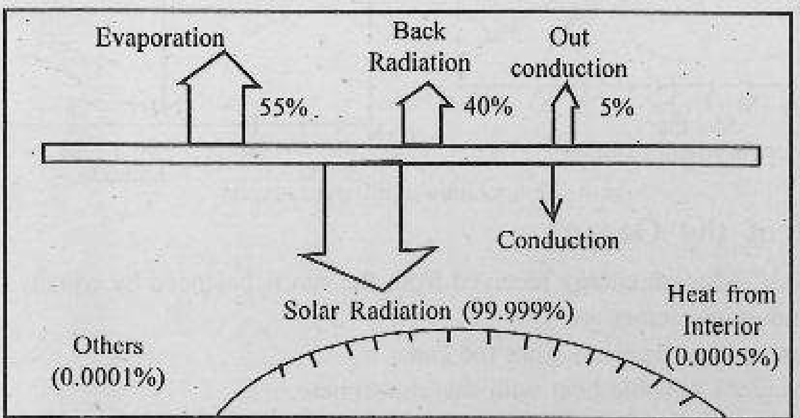


Figure : Heat budget of the Oceans

The density of ocean water continuously increases with decreasing temperature until the water freezes. Ocean water, with an average salinity of 35‰ freezes at - 1.94 degrees Celsius.

1.6 Salinity of the ocean water

1.6.1 Introduction

The amount of chlorine is normally used to determine the salinity, and its ratio to that of the other chemicals is constant, the total salinity can be obtained, It is expressed as parts per thousand by weight, g./kg. or usualy ‰. In the open ocean the salinity normally varies between 33‰. and 37‰ it can reach values below the level where much fresh water enfers from large rivers, or exceed in areas where the influx from the land is negligible and where the surface evaporation is considerable, as for example, in the Red Sea, where it exceeds 40%.

1.6.2 Controlling factors of salinity :

The major controlling factors of salinity are describes as follows:

a) Evaporation : The process of evaporation on the sea water is responsible for the concentration of salts which in turn increases the salinity of the oceans. According to Wust, the total evaporation from the ocean amounts to 331,000 KM^3 per year. This may be excessive in regions of higher temperature, strong steady winds and less rainy days. In fact, the process of evaporation in the sea water increases the boiling point and decreases the vapour tension slightly and the ratio between the temperature and the humidity gradients of the air is small or nearly constant throughout the year in low latitudes, but greater in the middle latitudes. Thus due to excessive evaporation and higher temperature, humidity ratio in the lower middle latitudes near Tropic of Cancer and Tropic of Capricorn is lower and salinity is higher. On the contrary, salinity is relatively low in equatotial regions due to evaporation and high relative humidities. he salient features of evaporation as a controlling factos of salinity are the following:

i. The evaporation varies from the eastern to the western parts of the ocean and also from one season to another.

ii. Evaporation increases with strong winds like trade winds and westerlies and also when the sea water is warmer than the air.

b) **Precipitation :** It is another factor controlling the salinity of the oceans. In equatorial regions, in spite of high temperature, the salinity is less because these are the zones of heavy rainfall which reduces salinity. Again in the polar and sub-polar regions there is an excessive amount of precipitation in the form of snow and when the melt water subsequently reaches the sea, it adds fresh water and hence reduces salinity.

c) **River water :** The amount of salinity of sea water also varies due to the influx of fresh water by the rivers. Hence near the mouths of rivers Amazon, Congo, Niger, Ganges, and St. Lawrence comparatively lower salinity is recorded. Such effect is also noticed along the coasts in the enclosed seas such as Baltic Sea, the Gulf of Bothnia and also in the Black Sea where the rivers like Danube, Dneister and Dneiper pour fresh water in to the sea. On the other hand the salinity is appreciably higher in the Mediterranean Sea where the influx of fresh water is comparatively less than the amount of evaporation.

d) **Atmospheric Pressure and Wind Direction :** Salinity changes slightly due to winds resulting from difference in atmospheric pressure. For instance, Winds from high pressure area over the North Sea move towards the low pressure area over the Baltic, thereby raising the amount of salinity of the Baltic sea to a slight extent. Similarly, the strong winds blowing throughout the year carry much of the warm and saline water from the western shores of the land in lower middle latitudes and from the eastern shores of the land in the lower middle latitudes and from the eastern shores in the higher latitudes resulting in the variation of salinity distribution of sea water.

e) **Movement of sea water :** Tidal currents, cold and warm currents and drifts are also considered as controlling factors of salinity since the latitudinal movements of sea water and mixing of water affect the salinity of oceans.

f) **Periodic variations of salinity :** The difference between Precipitation and evaporation is also responsible for the periodic variation of salinity. Bohnecke has computed the oceanic water budget and observed that salinity is higher in spring than in Fall.

1.6.3 Composition of Sea Water

The salinity in the oceans is generally between 33‰ and 37‰. In the region of high rainfall on dilution by large rivers the surface salinity may be considerably less and in certain semicircular areas, such as Gulf of Bothnia, it may be less than by 5‰. On the other hand in isolated seas in intermediate latitudes where evaparalion is exessive as in the Red sea, salinity may reach 40‰ or higher. As the range in the open ocean is rather small, it is sometimes convinent to be the salinity of 35‰ as an average of all the ocean.

The normal chemical content of sea water with a total salinity of 35‰ is as follows :

1. Chloride	19.353 (in gm/kg.)
2. Sodium	10.760
3. Sulphate	2.712
4. Magnesium	1.234
5. Calcium	0.413
6. Potassium	0.387
7. Bi-Carbonate	0.142
8. Bromide	0.067
9. Strontium	0.008
10. Boron	0.004
11. Fluoride	0.001

1.6.3a. Definition

Salinity is defined as the ratio between the weight of the dissolved material & the sample of sea H_2O expressed in parts per 10 million (ppm).

Dessolved salt present is sea H_2O : When salts are added to H_2O they dessolve is salt crplels clissociate into ions which are & vely or-vely charged atoms. known as caterns or Anions resp

Eg. when NaCl is added to H_2O is dessolved by H_2O into & positively (+ve) charged Na ions & negetively (–ve) charged chloride ions. This chem reaction may be expressed as :

$NaCl$ —— $Na^+ + Cl^-$

1.6.4. Major comtetuents of Salinity :

6 ions make up > 99% of the salts. dessolved is sea H_2O 4 of these are cations + 2 are anress.

Name	Symbol	Percentage
1. Chloride	Cl^-	55.07
2. sodium	Na^+	30.62
3. sulphate	SO_4^{-2}	7.72
4. Magnesuim	Mg^{2+}	5.68
5. Calcuim	Ca^{2+}	1.17
6. Potassium	K^+	110
Total		99.36

Remaining 4% are Trace Elements (diluted cond) other elements in sea H_2O are present in conc of < 1 ppm + are called Trace Element.

1.6.5 Determination of salinity :

Prob. faced in such detemenations : These are –

1. among to the complexity of sea H_2O its impassible by chem analysis to determine the total quantiry of dessolved salt is a gives sample of sea H_2O.

2. Its unpossible to obtain the result by evaporating sea H_2O its drepress & weighing the residre as same of the materiale pressent viz. chloride is lost is the last stages of drying.

To overcome this diffeculty an Internal comression was estd acc to which the salinity is deferein as the total amt. of solid mat in gms containsed in 1kg of sea H_2O when all the carbonates has been converted to oxides. The Bromine & Iodine replaced by Cl + all organic mat. Completely Oxidized. The method is too defficult at the same time v.

We determine saluraty by—

(a) Inrech Method

(b) Indirect Method

(a) (i) Chlorinely, (ii) Density

(b) (i) Electric Cohduclurty (ii) Refractrive Index.

Direct Method : Cholrinity Determunation

By titration Cl de less make up approy 55.07% of the dessolved solids + can be letermuned with cons derable case + accucacy by Trtration with selver Netrate using Potassum Chlorate as the endrcator the unperical rel'ship bet chlorinety + salinity as estd by Internal —S% = 1.80655×Cl %.

Density

Salinity of sea H_2O sample can also be found by determining density of sample of known temp emperical rel'ships have estd by which the salinity can be = ed as a func of slinity at the given density + temp.

Indirect

Electric Conductinity

By measuring the E'cal C'vity at a known temp the E C may be measured to determine the satimity.

Refractive Index

The R I of any H_2O sample may be measured + compared with samples of known salinity.

1.6.6. Variation in the Distribution of Salinity

Its gen'lly bet 33 ppm to 37 ppm. The character estres of vareation of surface salinity may be presented as.

1. In reg of hgr rainfall or delution by lg river The surface salinity may be cons berbly ed + in certain semi enclosed areas such as guly of Bothnia, Deat sea, its bel 5 ppm.

2. In esolated areas (seas) in the Intumediate Lats where evap is excossive such in Red sea salinity may reach 40 ppm more. As the rain in the open accan is rather small its comeunity to use a salinity of 35 ppm as an avg for all occans.

1.6.7 Horizontal Distribution of Surface Salinity

In all oceans the surface salinity varies with latitude in a similar manner. It is at a minimum near the equator. reaches at a maximum in about 20°N and 20°S and again decreases towards high latitudes.

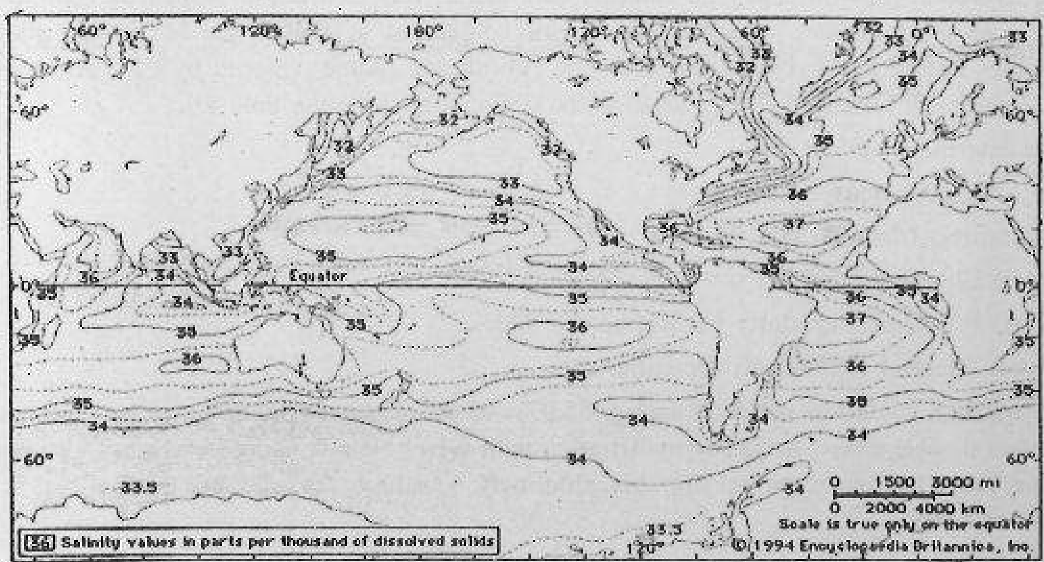


Fig. 3 : Distribution of Salinity

Table 3 : Surface Salinity

Latitude	N o r t h e r n				s o u t n e r n			
	S‰	E cm/yr	P cm/yr	E-P	S‰	E cm/yr	P cm/yr	E–P
0°	35.08	119	102	17	35.08	119	102	17
10°	34.72	129	127	2	35.34	130	96	34
20°	35.44	133	65	68	35.69	134	70	64
30°	35.66	120	65	55	35.62	111	64	47
40°	34.54	94	93	1	34.79	81	84	–3
50°					33.99	43	84	–41

S–Salinity, E–Evaporation and P–Precipitation

on the basis of these values, Wiist has shown that for each ocean the elevation of the surface salinity form a standard value is directcly proportional, on the following diagram are plotte. surface Salinity for all the oceans and the difference E-P, as function of latitudes, and the corresponding values of salinity & the difference, E-P, are plotted against each other in the scatter diagram. The value fall nearly on a straight line leading to the empirical relationship. S = 34.60 + 0.0175 (E-P)

Wiist point out that such an empirical relationship is found because the surface salinity is mainly determined by these processes :

(1) Decrease of salinity by precipitation.

(2) Increase of salinity by evaporation.

(3) Change of salinity by the process of mixing.

1.6.8 Vertical Distribution of Salinity

Salinity in the ocean decreases or increases towards the bottom according to the nature of the water mass. Although the salinity generally decreases at depth, the role of cold or warm water mass is significant in bringing about drastic changes in the vertical distribution of temperature. For example, at the southern boundary of the Atlantic, surface salinity is 33‰ increasing to 34.5‰ at 365.8 m and still deeper at 1097.3 m it reaches up to 34.75‰. Again, at 20° S the surface salinity of 37‰ decreases up to 35‰ at the bottom. At the equatorial region of Indian

Ocean, the surface salinity of 34‰ increases with the depth to 35‰ due to greater mixture of fresh water at the surface.

Generally it can be said that in high latitude salinity increases with depth due to dense water found at the bottom, whereas in the middle latitudes, salinity increases with depth up to 365.8m and then decreases with increasing depth of the oceans.

1.7 Temperature - Salinity Relationship

1.7.1 T-S Diagram :

Temperature and Salinity are represented in a scatter diagram called T-S Diagram.

The characteristics of water (H_2O) masses by T-S diagram are represented :

(1) Temperature is a function of salinity.

(2) Practical significance of TS curve.

(3) T-S curve + mixing of H_2O masses (water masses).

(a) Temperature is a function of salinity.

Temperature + salinity vary with depth. An investigation of these corelating features based mainly on a graphical of the variation of these quantities with depth. Assuming salinity as a function of Temperature or plotting Salinity against T in a system of coordinates (say in Katesian (Co-Ordinates System) S as 'x' and T as 'y'. The Plotting for each depth are not distributed at random over the diagram but fall on a definite more or less smooth curve called T-S curve / T-S Diagram. For open ocean with uniform oceanographic, spatial, climatic as well as undistrubed flow continued. The T-S relationship is quite characteristic. A given temperature corresponds to a given salinity regardless of the depth. Any given H_2O type the H_2O mass is characterised by a definite T-S diagram. If this H_2O mass is homo then oceanographic facts is it are constant and it can be represented on a TS diagram by a single plot.

Beneath the top layer with distrubance however continued in the ocean are quasi Standard or T-S curves can thus be constructed different oceanic region and conclusion can be drawn about the origin & a spreading of H_2O mass for the development of the value at a parts of station from these of the standard curve.

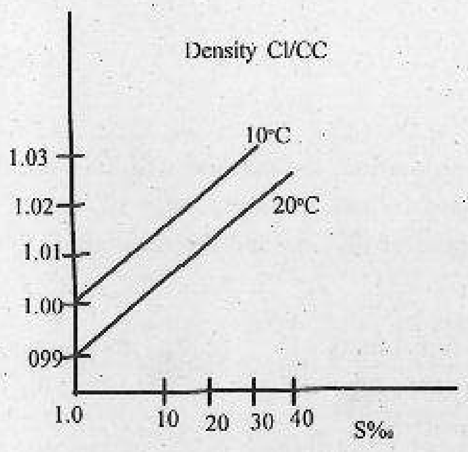
(b) Practical Significance of T-S curve

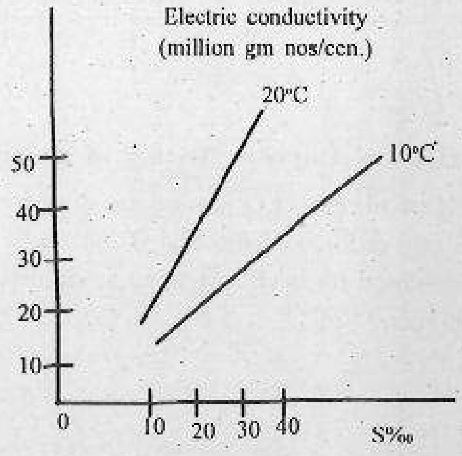
The practical significance was first plotted out by Helland & Hausen (1918), and then it has become important in oceanographic summarised as follows.

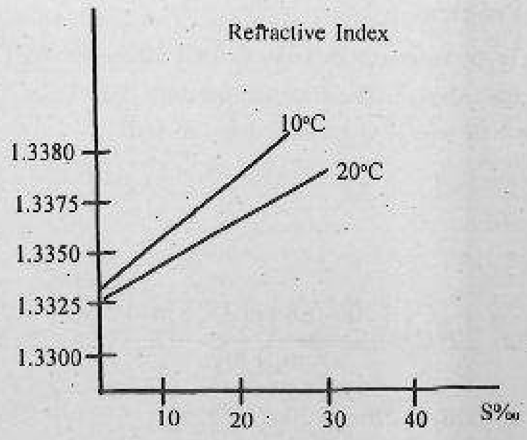
1. T-S curve offers advance in the scientific preparation of the oceanographic data.

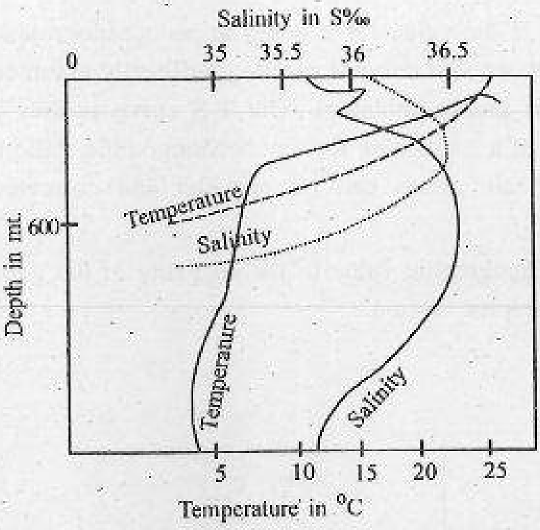
2. Used to detect errors & to make it homo. If the value for a depth at an oceanographic station does not fall on a simple curve and usually smooth curve it can be confidently assumed that there is an observational error or a fault is the computation. The T-S curve is thus a reliable criteria of the accuracy and homogeneity of a set of data for any oceanographic station. The curve for neighboring station are similar, all values can be checked and corrected immidiately.

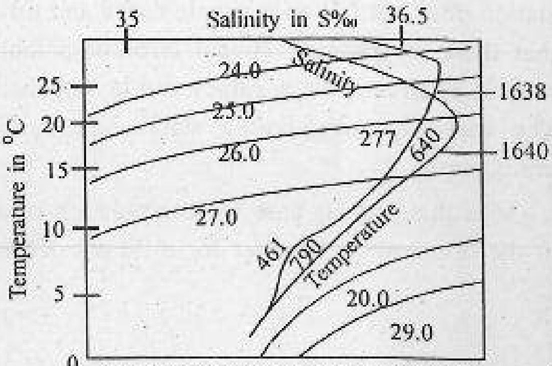
3. In this way its pass by interpolation of oceanographic value to fill up many of the gaps in the observational matter for different oceanographic station.











T-S Curves and mixing of water mass

(C) T-S Curve + Mixing of water Masses

If two homo H_2O masses are mixed in a given proportion, the mixture will have a definite T-S cruve. Each of these H_2O masses is characterised by two plots say $w_1 + w_2$ with T & S represented for each as $t_1s_1 + t_2s_2$ are mixed is the ratio of $m_1 : m_2$ and the resulting H_2O mass is bigger.

$$T = \frac{m_1t_1 + m_2t_2}{m_1 + m_2} \qquad S = \frac{m_1s_1 + m_2s_2}{m_1 + m_1}$$

$$\therefore \quad T_o = \frac{\sum Tm}{m} \qquad S_o = \frac{\sum Sm}{m}$$

Problem : 1

Two water masses W_1 (20°C, 30‰) + W_2 (25°C, 35‰) are mixed in an unknown ratio, so that for the mixture. The final temperature is 22°C (ie To = 22°C and So = 32‰). Determine the properties in which two H_2O masses were mixed.

$$\text{or,}\ 22^oC = \frac{(20^o \times m_1) + (25^o \times m_2)}{m_1 + m_2}$$

or $22m_1 + 22m_2 = 20m_1 + 25m_2$

or, $2m_1 = 3m_2$

or 2 : 3

Problem : 2

W_1 = 20°C, 30‰, W_2 = 22°C, 32‰, W_3 = 25°C, 35‰ are mixed in ratio 3 : 2 : 1. Determine value of $T_o + s_o$ for the mixture.

$$To = \frac{\Sigma Tm}{m} \qquad S_o = \frac{\Sigma Sm}{m} \frac{n!}{r!(n-r)!}$$

$$To = \frac{(3\times20)+(2\times22)+(1\times25)}{6} \qquad So = \frac{(3\times30)+(2\times32)+(35\times1)}{6}$$

$$= \frac{60+44+25}{6} \qquad = \frac{90+64+35}{6}$$

$$= \frac{129}{6} \qquad = \frac{189}{6}$$

$$= 21.5 \qquad = 31.5$$

1.7.2 Water Masses of Different Oceans

Like air masses water masses are relatively hemo viz. temperature, salinity.

Accuracy study T-S relationship in different oceans leads to a systematic classification of water types : The graphical representation of T-S relationship gives a good insight into the thermal & allied structure of water masses. This helps to classify the form, spreading of H_2O and mixing of individual H_2O mass. Thus it precipitates a quantitative description of the oceanic curves of different layers. Water masses can be classified.

Depth Basis

1.	surface	→(a) upper	→	< 300	m
		→(b) Lower	→	300-800	,,
2.	Intermediate		→	800-2000	,,
3.	Deep		→	2000-4000	,,
4.	Bottom		→	> 4000	,,

Controlling Factors Basis :

1. Latitude of regions.
2. Degree of Isoline.
3. Types of Current.

10

Indian Ocean

Indian Ocean	T (°C)	S (‰)
1. Indian Central	6-15	34.5 - 35.4
2. Indian Equatorial	4-16	34.8 - 35.2
3. Indian deep & Antarctic cum polar	5-2	34.7 - 34.7
4. Antaretic Interregion	2-6	34.4 - 34.7
5. Red sea	9	35.5

Oceanographically the seris limit of the ocean can be placed in a regression of sub-convergence which extends approx to about 40°S latitude. The ocean is close to the N to continent and all H_2O masses in the up layers are such of the Intermediate latitude and Equational Region. No sub polar H_2O mass enters the Indians ocean.

Temperature :

Within surface water temperature increases towards the N from Tropical comeryene. In Equalorial region its uniformly high of the year (25°C – 29°C). In August lower temperature (about 22°C) are found along the S.E. coast of Arabia.

In February lower temperature are found in Gulf of Oman and in Bay of Bengal due to the NW Monsoon.

Salinity

The surface salinity shows the maximum of 41‰ in the Equatorial and northern region is subject to variation under the influence of precipitation and changing characteristics of monsoon.

1. The Central water Mass

Southern limit of Central H_2O Mass coincides with sub tropical convergence. Northern limit can not be determined accurately due to lack of observation. The T-S relationship at several station show that all obsarved T + S fall on a straight line with T = 6°C – 15°C and S = 34.5 – 35.4 ppm.

In region of convergence the surface Temperature and Salinity varius rapidly with latitude and the horizontal temperature in certain region agrees very well to the vertical temperature and salinity in the central water mass.

2. Equatorial water Mass

Not as well defined as the previous one, but at many station, to the North of Equator, a considerable similarity exist in the T-S relationship (T = 4 -16°C, S – 34.3 – 35.2 prm). At

Southern Station H_2O occur which is intermediate in between the two. The Red sea is located in the region which is charaeterisal by such an that evaporation from H_2O and region surface exceeds the small ppm. Thus no runoff as no river enters the Red sea. In summer T = 30°, in winter as low temperature is as 18°C, in the northward spreading of Red sea H_2O in Indian ocean is similar of that of Mediterranean and Atlantic ocean.

Repeated obsesvation at same station in Gulf of Aden have given many different values which strongly indicate that outflow is intermittent.

Atlantic Ocean

(i) North Polar H_2O Mass

T = –1 to 2°C S = 34.9%

North Atlantic	T	S
2. Sub Arctic	3°C - 5°C	34.7-34.9‰
3. North Atlantic Central	4°C-17°C	35.1-36.2‰
4. „ Deep	3°C–4°C	34.9-35.0‰
5. „ Bottom	1°C-3°C	34.8-34.9‰
6. Mediterranean	6°C-10°C	35.3-36.4‰
South Atlantic		
7. South Atlantic Central (Intermediate)	5-16	34.3-35.6‰
8. Antarctic	3°C-5°C	34.1-34.2‰
9 Sub „	3°C-9°C	33.8-34.5‰
10. Atlantic Circumpolar	0.5°C-2.5°C	34.7-34.8‰
11. South Atlantic deep and bottom	0°C-2°C	34.5-34.6‰
12. South bottom	–0.4°C	34.65‰

Pacific Ocean

North Pacific	T	S(‰)
1. North Pacific sub Arctic	2°C-10°C	33.5-34.4
2. Pacific Equatrial	6°C–16°C	34.5-35.2
3. Eastern North Pacific Central	10°C-16°C	34.0-34.6
4. N.W Pacific	7°C-16°C	34.1-34.6
5. Arctic Intermediates	6°C-10°C	34.0-34.1
6. Pacific Deep + Bottom	(–)1°C-(–)3°C	34.6-34.7

South Pacific

7. S.E Pecific	9°C-16°C	34.5-35.1
8. SW ,,	7°C-16°C	34.5-35.5
9. Antarc intermediate	4°C-7°C	34.3-34.5
10. Sub Antarctic Pacific	3°C-7°C	34.1-34.6
11. Pacific deep & Antarctic circumpolar	(-)1°C-(-)3°C	34.6-34.7

1.9 Reference

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Unit 2 ❑ Coastal Geomorphology Mangroves and coral Reefs

Structure :

2.1. Mangroves

2.1.1. Introduction

Mangroves are trees and shrubs that grow in saline coastal habitats in the tropics and subtropics.

2.1.2 Ecology

A mangal is plant community and habitat where mangroves thrive. They are found in tropical and sub-tropical tidal areas, and as such have a high degree of salinity. Areas where mangals occur include estuaries and marine shorelines. Plants in mangals are diverse, but all are able to exploit their habitat (the intertidal zone) by developing physiological adaptations to overcome the problems of anoxia, high salinity and frequent tidal inundation.

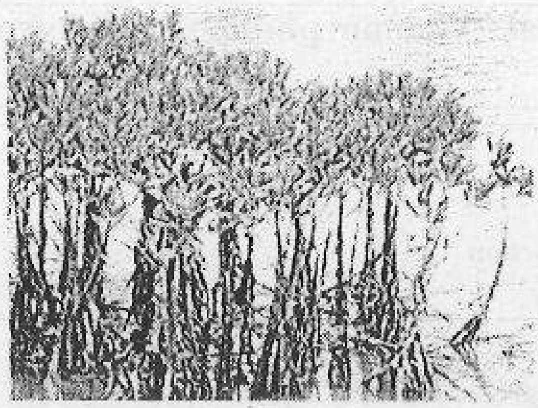

Fig. 4 : A cluster of mangroves on the banks of Vellikeel river in Kannur District of Kerala, India

Mangroves protect the coast from erosion, surge storms, especially during hurricanes, and tsunamis. Their massive root system is efficient at dissipating wave energy. Likewise, they slow down tidal water enough that its sediment is deposited as the tide comes in and is not re-suspended when the tide leaves, except for fine particles. As a result, mangroves build their own environment. Because of the uniqueness of the mangrove ecosystems and their protection against erosion, they are often the object of conservation programs including National Biodiversity Action Plans.

Mangroves support unique ecosystems, especially on their intricate root systems. In areas where roots are permanently submerged, they may host a wide variety of organisms, including algae, barnacles, oysters, sponges, and bryozoans, which all require a hard substratum for anchoring while they filter feed. Mangrove crabs improve the nutritional quality of the mangal muds for other bottom feeders by mulching the mangrove leaves. In at least some cases, export of carbon fixed in mangroves is important in coastal food webs. The habitats also host several commercially important species of fish and crustacea.

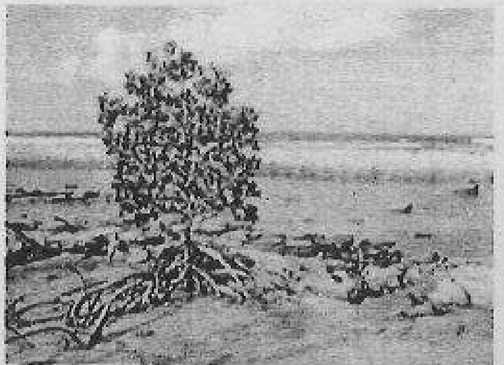

Fig. 5 : A red mangrove, *Rhizophora* sp.

2.1.3. Biology : A wide variety of plant species can be found in mangrove habitat, but of the recognized 110 pecies only about 54 species in 20 genera, from 16 families constitute the "true mangroves", species that occur almost, exclusively in mangraove habitats and rarely elsewhere.

2.1.4. Geographical regions : Mangroves occur in numerous areas worldwide as discusssed below:

a. **Africa :** There are important examples of mangrove swamps in Kenya and Madagascar, the latter even admixed at the coastal verge with the Madagascar dry deciduous forests. Nigeria has the largest concentration of mangroves in Africa

b. **Americas :** Mangroves are found in many parts of the tropical and subtropical coastal parts of the Americas.

North America : Because of their sensitivity to sub-freezing temperatures, mangroves in the continental United States are limited to the coastal Florida Peninsula.

Central America & Caribbean : Mangroves also occur on the west coast of Costa Rica, on the Pacific and Caribbean coasts of Nicaragua, Belize, Guatemala, Honduras, and Panama and on many Caribbean Islands, such as Antigua and St. Lucia. Significant mangals include the Marismas Nacionales-San Blas mangroves in Mexico. Mangroves can also be found in Puerto Rico, Cuba, Dominican Republic, Haiti, Jamaica, and the Pacific coast of El Salvador.

South America :

Brasil : contains approximately 15% of the world's total.

• Ecuador and Peru Also : have significant areas of mangroves mainly in the Gulf of Guayaquil-Tumbes mangroves.

• Colombia : also possesses large mangrove forests on both Caribbean and Pacific coasts.

Figure 7: The mangrove species Sonneratia, showing abundant pneumatophores, growing on the landward margin of the reef flat on Yap.

c. **Asia :** Mangroves occur on the south coast of Asia, throughout the Indian subcontinent, in all the southeast Asian countries, and on islands in the Indian Ocean, Arabian Sea, Bay of Bengal, South China Sea and the Pacific. The mangal is particularly prevalent in the deltas of large Asian rivers. The Sundarbans is the largest mangrove forest in the world, located in the Ganges delta in Bangladesh and West Bengal, India. There are major mangals in the Andaman and Nicobar Islands and the Gulf of Kutch in Gujarat. Other significant mangals include the Bhitarkanika Mangroves and Godavari-Krishna mangroves. In Vietnam, mangrove forests grow along the southern coast, including two forests: the Can Gio Mangrove Forest biosphere reserve and the U' Minh mangrove forest in the Sea and Coastal Region of Kien Giang Province biosphere reserve.

d. **New Guinea and environs :** In Australasia, mangroves occur around much of New Guinea, Sulawesi and the surrounding islands. Australia has mangle primarily on the northern and eastern coasts of Australia. Australia has approximately 11,500km2 of mangroves with occurrences as far south as Corner Inlet in Victoria and Barker Inlet in Adelaide, South Australia.

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2.2 Coral reefs

2.2.1. Introduction :

Coral reefs are organically structures produced by living organisms. In most reefs the predominant organisms are colonial cnidarians that secrete an exoskeleton of calcium carbonate. The accumulation of this skeletal material, broken and piled up by wave action and bioeroders, produces massive calcareous formations that make ideal habitats for living corals and a great variety of other animal and plant life.

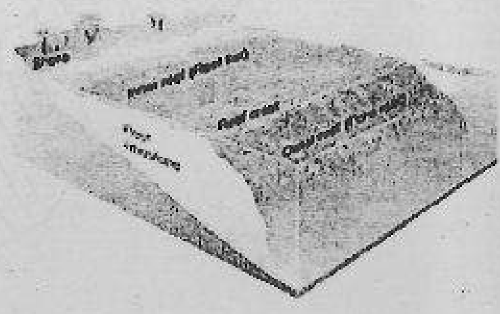
2.2.2. Forms : Coral reefs can take a variety of forms, defined in following:

- **Fringing reef** - a reef that is directly attached to a shore or borders it with an intervening shallow channel or lagoon.
- **Barrier reef** - a reef separated from a mainland or island shore by a deep lagoon (see Great Barrier Reef).
- **Patch reef** - an isolated, often circular reef, usually within a lagoon or embayment.
- **Apron reef** - a short reef resembling a fringing reef, but more sloped; extending out and downward from a point or peninsular shore.
- **Bank reef** - a linear or semi-circular shaped-outline, larger than a patch reef.
- **Ribbon reef** - a long, narrow, somewhat winding reef, usually associated with an atoll lagoon.
- **Atoll reef** - a more or less circular or continuous barrier reef extending all the way around a lagoon without a central island.
- **Table reef** - an isolated reef, approaching an atoll type, but without a lagoon.

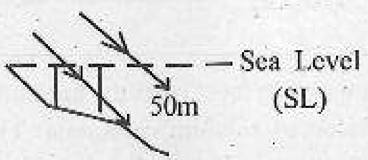
2.2.3. Factors of formation of Coral Reefs & Atolls :

Reef ecology :

1. Depth of water
2. Temperatare of water
3. Condition of water
4. Circulation of water
5. Salinity of water
6. Bottom condition
7. Level of H_2O
8. Action of wave.



(1) Coral growth is restricted to the areas of shallow waters, so that the organisms can bare sufficient light & Oxiganeted water that help photosynthesis of plants & symbiotic living of the organism. Corals are found upto an average depth of 50m.



(2) All of the water temperature of 18° – 20°C can be tolerated by coral. Coral grow more abundantly at temperature between 20°–30°C & the must ideal temperature for the growth of coral. The upper limit is 35°C, so it ranges between 20°C–35°C.

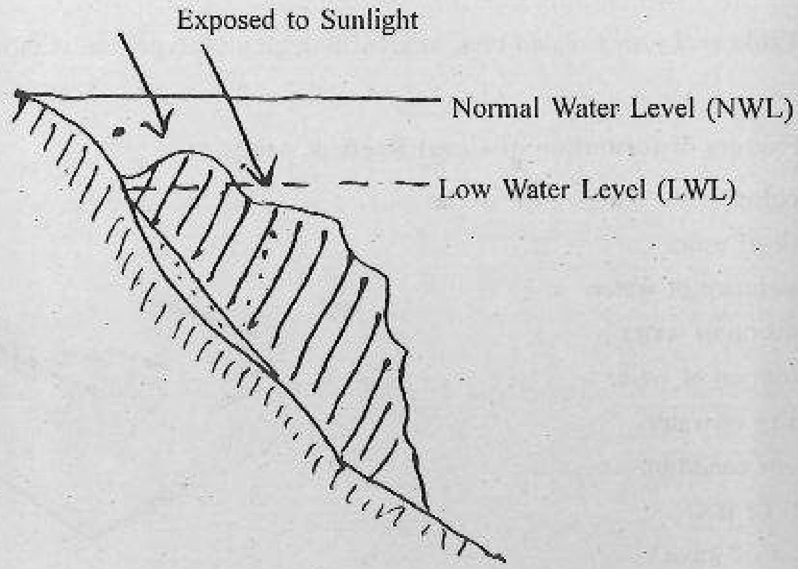
(3) A long amount of silt is detremental not only because of its interference with light penetration but also because of sediment on the organism & thereby obstrecting their growth.

(4) Active circulation water are also essential for the growth of corals. corals are sedentary organism & depend upon the depth of waves for the supply of theri food, plantion & organism.

(5) Reef corals are also dependent on the proper salinity condition of 27-40 pp milion lack of sufficient salinity also may for the absence of reef parts to the opppsite of the mount of the large river as in the Bay of Bengal.

(6) Reef building corals prefer a faundation & do not thrive on muddly bottom.

(7) Another factor which is essential both for regorous growth & survival of coral colonies is that they will be covered with H_2O except at extremely low tides.



(8) The action of the wave has a quite impact in saving the coral reef. In calm water they may develop branches like stag horn.

2.2.4 Type of Reefs

(1) Genetic Classification (mode of formation)

- Major Types
  - (A) Fringing Reefs
  - (B) Barrier Reefs
  - (C) Atolls
- Minor Types
  - (A). Faros
  - (B) Table Reefs or Coral Banks
  - (C) Patch reefs, Krolls or Pinades.

2.2.5 Theories of Origion of Coral Reef.

No of proposed theories no one theory is adequate to account for many narred condition under which atolls are firmed. Most difficulty arises regarding origin of lagoons behind the barriar reefs & atolls. However theories explaning origin of reef & may be classified into three groups :

(1) Anticedent platform theory.

(2) Glacial control theory.

(3) Subsidence theory.

1. Anticedent platform theory : Those which postulate change of sea level is not required for their formation but that they were formed on steel standing platform, which existed beneath the sea anticident to the attach of the corals.

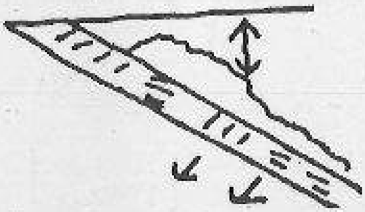
This theory is a modified form theory belemed that any submarine platforms whether the result of wave platforms or the result of long continent upbuilding by pelagie organismor by volcanic eruption in a proper depths is located in the troprial coral reef zone is potentially a reef formation and with grow upward to the ocean surface without progressive sea level change.

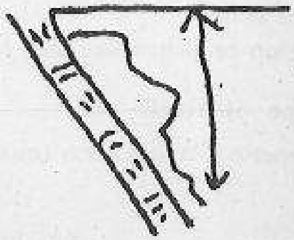
Objection :

Falls to explain the commonly ideal which lie that of the barrier reef. Thickness of the coraline rocks in the lagoons as shows by recent borings and ideas seems to be too great is hare been produced by the depositions of Pelagic debris and organisms.

Depth of many lagoons are too great to permet corals to established themselves on submarine platforms.

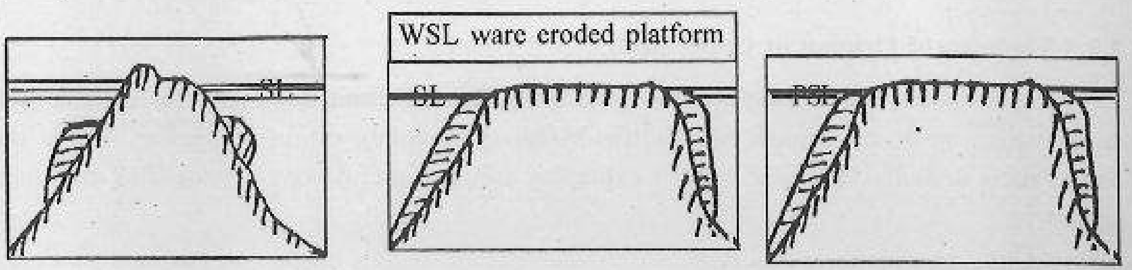
2. Glacial Control : Those which explain them has a result of the effects of sea level change. –ve during pleistocene & +ve during past pleistocene period).





The idea that atolls are the result of influences of changing sea levels of the pliestocene is generally associated with Daly (1934-42). Although his theory was based on idea Originally put forward by Albred Penck (1894). The essentral parts of Daly's hypothesis are :

Depth of the lagoos, that of the Atolls and Barrier Reefs is remarkably uniform & rarely exceeds 80m. It unplies a cause of world wide.



Glacial controlled could result in cooling of seas & increase trubidity and thus involve kill the reef building organism substructess of these organism permitted marine to attack the islands unopposed & produce at a lower sea level, a great no of truacated islands or benches around the islands.

Rise of the sea level, end of glacral age with warmer & clearer water favors reestablishedment of corals & associated organism. On some what abraded platform when resulting is development of an atoll or barrier reef depending on whether the island had been completely truncated or had a marine bench cut arrount it. Completely truncated atoll, Not completely truncated atoll and reef.

Objection :

1. Lagoon depth are hardly as uniform as derived by Daly.

2. Daubt exists as to the efficiency of the theory about maine abrasion to cut submarine platform. Its questionable whether condition of low temperture & turbidety presented by Daly could have exterded so far from the glaciated area, (which are located in the mid latitude but coral reefs is tropical area).

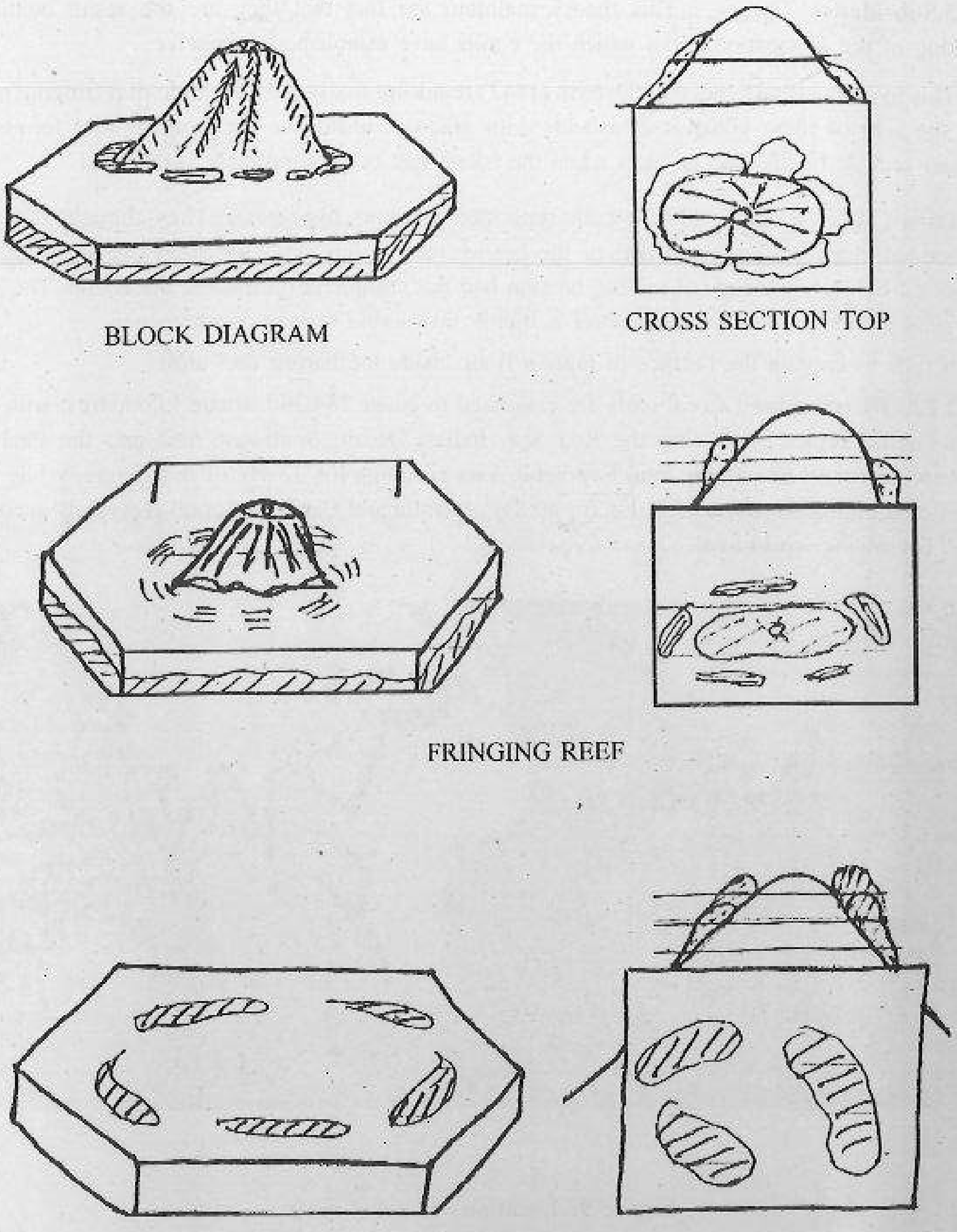


Figure 8: Different Coral reefs

3.Subsidence Theory : This theory maintain the fact that they are the result continue sinking of the foundation about which the corals have established themselve.

This hypothesis poslulated by Darwin (1842) requiring firstly the formation of a fringing reef. On the side of them volcanic or islands with gradual subsidence the fringing reef formed a barrier reef & finally into an atoll when the island has been completely submerged.

Dana (1885) & Davis (1928) both supported Darwins hypothesis. They thought that the embedded coast of the island that of the barrier reef rearely has cliff shoreline as would be expected by Daly's theory of marine erosion had not completely truncated the island. The geo physical evidence from Britanny Atoll is highly favourable to long submergence.

It fails to explain the flatface of lagoon floor inside the barreir reef atoll.

2.2.6. Distribution : Coral reefs are estimated to cover 284,300 square kilometres, with the Indo-Pacific region (including the Red Sea, Indian Ocean, Southeast Asia and the Pacific) accounting for 91.9% of the total Southeast Asia accounts for 32.3% of that figure, while the Pacific including Australia accounts for 40.8%. Atlantic and Caribbean coral reefs only account for 7.6% of the world total.

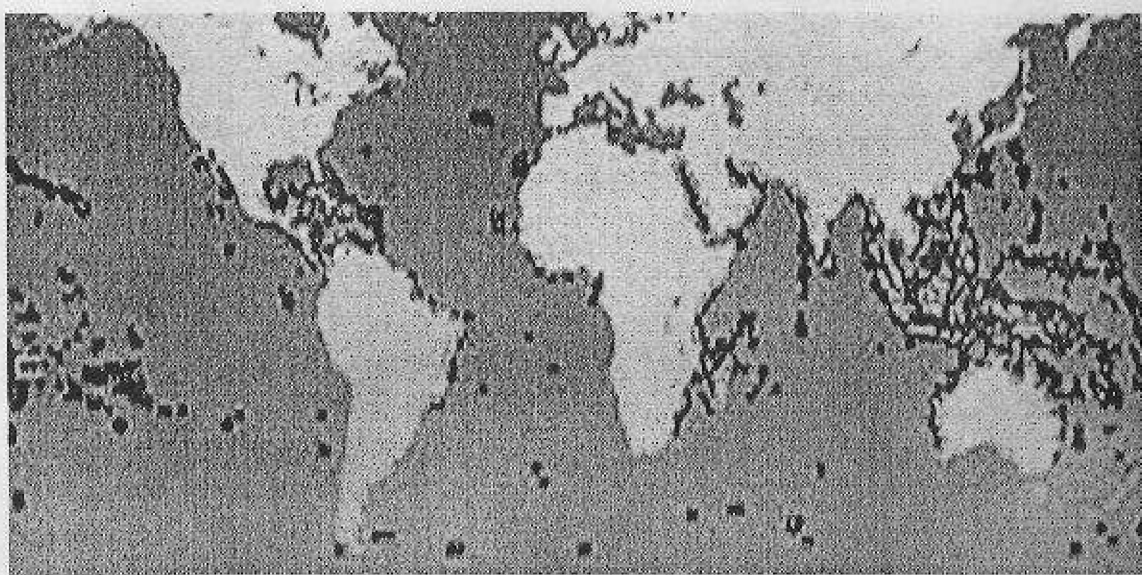


Figure 9: Locations of coral reefs

Coral reefs are either restricted or absent from the west coast of the Americas, as well as the west coast of Africa. This is due primarily to upwelling and strong cold coastal currents that reduce water temperatures in these areas. Corals are also restricted from off the coastline of

South Asia from Pakistan to Bangladesh. They are also restricted along the coast around north-eastern South America and Bangladesh due to the release of vast quantities of freshwater from the Amazon and Ganges Rivers respectively.

Although corals are found in temperate and tropical waters, shallow-water reefs are formed only in a zone extending at most from 30°N to 30°S of the equator. This zone is very important to whales because many types of plankton live there. Tropical corals do not grow at depths of over 50 m (165 ft). Temperature has less of an effect on the distribution of tropical coral, but it is generally accepted that they do not exist in waters below 18 °C. and that the optimum temperature is 23-25°C for most coral reefs. If it is over 27°C, it causes health problems for the coral reef. The reefs in the Persian gulf however have coral adapted to changing temperatures of 13°C in winter and 38°C in summer, thus having significantly colder and hotter ambient environments respectively than most coral reefs. Also, deep water coral is more exceptional still as it can exist at greater depths and colder temperatures. Although deep water corals also form reefs, very little is known about them.

Famous coral reefs and reef areas of the world :

- The Great Barrier Reef - largest coral reef system in the world, Queensland, Australia;
- The Belize Barrier Reef - second largest in the world, stretching from southern Quintana Roo, Mexico and all along the coast of Belize down to the Bay Islands of Honduras.
- The New Caledonia Barrier Reef - second longest double barrier reef in the world, with a length of about 1500 km.
- The Andros, Bahamas Barrier Reef - third largest in the world, following along the east coast of Andros Island, Bahamas between Andros and Nassau.
- The Red Sea Coral Reef - located off the coast of Israel, Egypt and Saudi Arabia.
- Pulley Ridge - deepest photosynthetic coral reef, Florida
- Many of the numerous reefs found scattered over the Maldives**2.2.7. Biological Characteristics :** The coral is made up of individual organisms.modular unit like forms called polyps, the building blocks of coral reefs which generate reef-building. Reefs are built when polyps along with other organisms deposit calcium carbonate, the basis of coral, as a skeletal structure beneath and around themselves, pushing the coral's "head" or polyps upwards and outwards. Waves, grazing fish (such as parrotfish), sea urchins, sponges, and other forces and organisms break down the coral skeletons into fragments that settle into spaces in the reef structure. Many other organisms living in the reef community contribute their skeletal calcium carbonate in the same manner. Coralline algae are important contributors to the structure of the reef in those parts of the reef subjected to the greatest forces by waves (such as the reef front facing the open ocean). These algae contribute to reef-building by depositing limestone in sheets over the surface of the reef and thereby contributing also to the structural integrity of the reef.

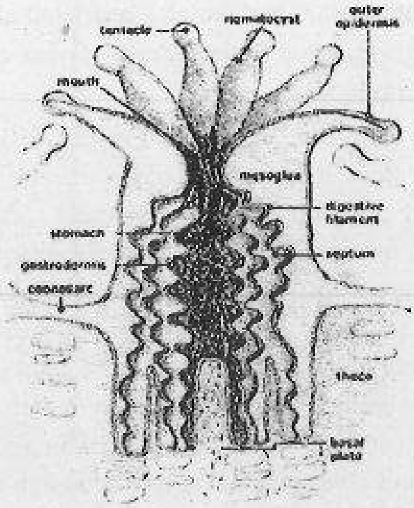


Figure 10 : Coral

Reef-building or hermatypic corals are only found in the photic zone (above 50 m depth), the depth to which sufficient sunlight penetrates the water for photosynthesis to occur. The coral polyps do not photosynthesize, but have a symbiotic relationship with single-celled organisms called zooxanthellae; these cells within the tissues of the coral polyps carry out photosynthesis and produce excess organic nutrients that are then used by the coral polyps. Because of this relationship, coral reefs grow much faster in clear water, which admits more sunlight. Indeed, the relationship is responsible for coral reefs in the sense that without their symbionts, coral growth would be too slow for the corals to form impressive reef structures. Corals can get up to 90% of their nutrients from their zooxanthellae symbionts.

2.2.8. Ecology and biodiversity : Coral reefs support an extraordinary biodiversity; although they are located in nutrient-poor tropical waters. The process of nutrient cycling between corals, zooxanthellae, and other reef organisms provides an explanation for why coral reefs flourish in these waters: recycling ensures that fewer nutrients are needed overall to support the communit.

Cyanobacteria also provide soluble nitrates for the coral reef through the process of nitrogen fixation. Corals absorb nutrients, including inorganic nitrogen and phosphorus, directly from the water, and they feed upon zooplankton that are carried past the polyps by water motion. Thus, primary productivity on a coral reef is very high, which results in the highest biomass per square meter, at 5-l Og C m-2 day. Producers in coral reef communities include the symbiotic zooxanthellae, sponges, marine worms, seaweed, coralline algae (especially small types called turf algae), although scientists disagree about the importance of these particular organisms.

Coral reefs often also depend on other habitats as seagrass meadows and mangrove forests in the surrounding area for the supply of nutrients. Seagrass and mangroves supply dead plants and animals, which are rich in nitrogen and also serve to feed fish and animals from the reef by supplying wood and vegetation to eat. Reefs in turn protect mangroves and seagrass from fierce waves and produce sediment for the mangroves and seagrass to root in.

Coral reefs are home to a variety of tropical or reef fish which can be distinguished. These include:

- Fish that swim right adjust the coral (such as Labridae and parrotfish) These types of fish feed either on small animals living near the coral, seaweed, or on the coral itself. Fish that feed on small animals include cleaner fish (these fish eat them from between the jaws of larger predatory fish), bullet fish and Balistidae (these eat sea urchins) while fish eating seaweed include the Serranidae. Serranidae even tend to cultivate the weed by removing creatures feeding on it (as sea urchins), and they even remove inedible seaweeds. Fish that eats coral includes the parrotfish and butterflyfish.
- Fish that swim above and in the surrounding area of the coral reef. These include predatory fish like pompanos, groupers, Horse mackerels, certain types of shark, Epinephelus marginatus, barracudas, snappers. They also include herbivorous and plankton-eating fish. Fish eating seagrass include Horse mackerel, snapper, Pagellus, Conodon. Fish eating plankton includes Caesio, manta ray, chromis, Holocentridae, pterapogon kauderni.

Generally, fish that swim in coral reefs are just as colourful as the reef itself. Examples are the beautiful parrotfish, angelfish, damselfish, Pomacanthus paru, Clinidae and butterflyfish. At night however, some change colour to a more less catchy colour. Also, it should be noted that besides colourful fish swapping their colour to that of the environment, other fish (eg predatory and certain herbivorous fish as Lampanyctodes hectoris, Holocentridae, Pterapogon kauderni) as well as aquatic animals (Comatulida, Crinoidea, Ophiuroidea) emerge and become active and certain go to rest.

Other fish groups found on coral reefs include groupers, grunts and wrasses. Over 4,000 species of fish inhabit coral reefs. It has been suggested that the high number of fish species that inhabit coral reefs are able to coexist in such high numbers because any free living space is rapidly inhabited by the first planktonic fish larvae that occupy it. These fish then inhabit the space for the rest of their life. The species that inhabit the free space are random and have therefore been termed "a lottery for living space".

Figure 11: Great Barrier Reef Australia

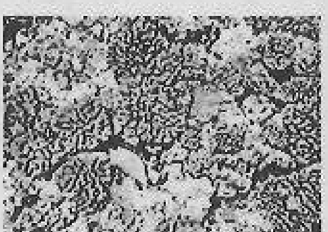


Figure 12: Different colors of corals are due to symbiotic algae

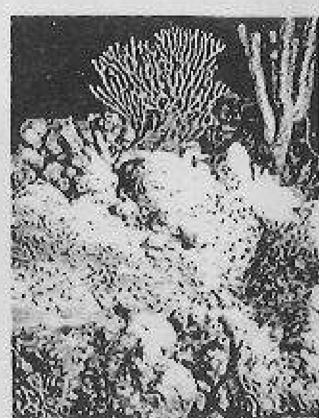


Figure 13:Elephant ear sponge

Reefs are also home to a large variety of other organisms, including sponges, Cnidarians (which includes some types of corals and jellyfish), worms, crustaceans (including shrimp, cleaner shrimps, spiny lobsters and crabs), molluscs (including cephalopods), echinoderms (including starfish, sea urchins and sea cucumbers), sea squirts, turtles such as the sea turtle, green turtle and hawksbill turtle and sea snakes. Aside from humans, mammals are rare on coral reefs, with visiting cetaceans such as dolphins being the main group. A few of these varied species feed directly on corals, while others graze on algae on the reef and participate in complex food webs.

These other organisms also have their part in the food-chain of the reef. Sea urchins for example eat seaweed, while the Hawksbill turtle eats sponges. Nudibranchia eat sponges too, as well as sea anemones. Dotidae and sea slugs eat seaweed.

A number of invertebrates, collectively called cryptofauna, inhabit the coral skeletal substrate itself, either boring into the skeletons (through the process of bioerosion) or living in pre-existing voids and crevices. Those animals boring into the rock include sponges, bivalve molluscs, and sipunculans. Those settling on the reef include many other species, particularly crustaceans and polychaete worms.

Researchers have found evidence of algae dominance in locations of healthy coral reefs. In surveys done around largely uninhabited US Pacific islands, algae consists of a large percentage of the surveyed coral locations. The algae population consists of turf algae, coralline algae, and macroalgae.

2.2.9. Threats : Human activity may represent the greatest threat to coral reefs living in Earth's oceans. In particular, global warming, coral mining, pollution (organic and non-organic/ chemical), over-fishing, blast fishing and the digging of canals and access ways into islands and bays are the most serious threats to these ecosystems. Runoff from agricultural areas may also threaten reefs by encouraging the growth of harmful algae.

Researchers are currently working to determine the degree various factors impact the reef systems. The list of factors is long but includes the oceans acting as a carbon dioxide sink, changes in Earth's atmosphere, ultraviolet light, ocean acidification, biological virus, impacts of dust storms carrying agents to far flung reef systems, various pollutants, impacts of algal blooms and others. Reefs are threatened well beyond coastal areas and so the problem is broader than factors from land development and pollution though those are too causing considerable damage.

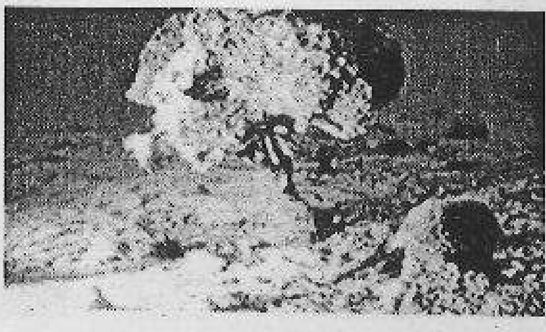


Figure 14 : Bioerosion (coral damage) by coral bleaching.

❑ **Overfishing :** The live food fish trade has been implicated as a driver of decline due to the use of cyanide and disaster for people living in the tropics. Hughes, et al., (2003), writes that "with increased human population and improved storage and transport systems, the scale of human impacts on reefs has grown exponentially. For example, markets for fishes and other natural resources have become global, supplying demand for reef resources far removed from their tropical sources." Overfishing (and particularly selective overfishing) also creates another problem. They promote the abundant growth of certain fish and organisms that can be damaging to the reef if they appear in great numbers. For example the fishing of bullet fish, Balistidae and other natural predators as lobsters promote the population growth of sea urchins. Also, acanthaster planci, Drupella, tapiro, Terpios, and Rhodactis have been known to destroy reefs when their population became too big.

❑ **Pollution :** Coral reefs are biological assemblages adapted to waters with low nutrient content, and the addition of nutrients (called eutrofication) favors species (as algae, seaweed) that disrupt the balance of the reef communities. Some algae are toxic, and both plants reduce the levels of sunlight and oxygen, killing of other marine organisms as fish and coral. Especially the addition of nutrients such as phosphates and nitrates are very damaging to reefs. High nitrate levels are toxic to corals, while phosphates slow down the growth of coral skeleton.

❑ **Soil runoff :** Extensive and poorly managed land development can threaten the survival of coral reefs. Runoff caused by farming and construction of roads, buildings, ports, channels, and harbors, can carry soil laden with carbon, nitrogen, phosphorus, and minerals. This nutrient-rich water can cause fleshy algae and phytoplankton to thrive in coastal areas, known as algal blooms, which have the potential to create hypoxic conditions by using all available oxygen.

❑ **Windborne materials :** In addition to local soil runoff, additional soil (sand) is blown in from other regions. Dust from the Sahara moving around the southern periphery of the subtropical ridge moves into the Caribbean and Florida during the warm season as the ridge builds and moves northward through the subtropical Atlantic. Dust can also be attributed to a global transport from the Gobi and Taklamakan deserts across Korea, Japan, and the Northern Pacific to the Hawaiian Islands. Dust events have been linked to a decline in the health of coral reefs across the Caribbean and Florida, primarily since the 1970s.

❑ **Sewage :** Another major pollutant is those generated by the people themselves. Most islanders use traditional sewage which often goes unfiltered into the sea. Filtering the sewage is something which is normally done in the first world, but in developing countries, this very important step is often skipped. Also, most experts now agree that composting toilet alongside a ecological sanitation approach is best followed in small island nations, yet these countries already implemented such system and for the moment prefer to keep using it.

❑ **Mines :** Inland mines of copper, gold and others where minerals are collected also form a major center of pollution. Most of the pollution is simply soil, which ends up in rivers flowing to the sea and ultimately covers the coral, but small mineral fractions may also introduce trouble. Copper, a common industrial pollutant, has been shown to interfere with the life history and development of coral polyps.

❑ **Non-organic materials :** Leaked oil and chemicals (e.g. from detergents, paints) flowing into the sea from factory outlets are another key threat.Chemical fertilizers (based on ammonium nitrate) are another pollutant.Radioactive waste is often dumped by the USA near its military installations (Mororua, Fangataufa, Johnston Atoll, Also, nuclear tests (eg at Kwajalein, Bikini, Enewetak) may also caused some nuclear pollution, yet compared to the other forms of pollution noted, they remain only small.

❑ **Global warming :** Global warming introduces sea level rise, effectively asking the coral to grow faster to keep up. Also, the sea temperature increases, which is very disturbing to the coral. Global warming is also the basis of a new emerging problem: increasing coral diseases. Due to global warming (which is the main cause of coral bleaching), corals have been weakened. In their weakened state, the coral is much more prone to disease. As such, coral diseases have been beginning to spread more rapidly. These include Black band disease and White band disease. With the projected 2°C temperature increase, it is likely that coral will not be able to adapt enough physiologically or genetically to keep up with climate change.

❑ **Ocean acidification :** A related problem to global warming is ocean acidification, which is caused by one and the same problem; namely increasing CO_2 emissions.The decreasing ocean surface pH is of increasing long-term concern for coral reefs. Increased atmospheric CO_2 increases the amount of CO_2 dissolved in the oceans. Carbon dioxide gas dissolved in the ocean reacts with water to form carbonic acid, resulting in ocean acidification. Ocean surface pH is estimated to have decreased from approximately 8.25 to 8.14 since the beginning of the industrial era, and it is estimated that it will drop by a further 0.3 - 0.4 units by 2100 as the ocean absorbs more anthropogenic CO_2.

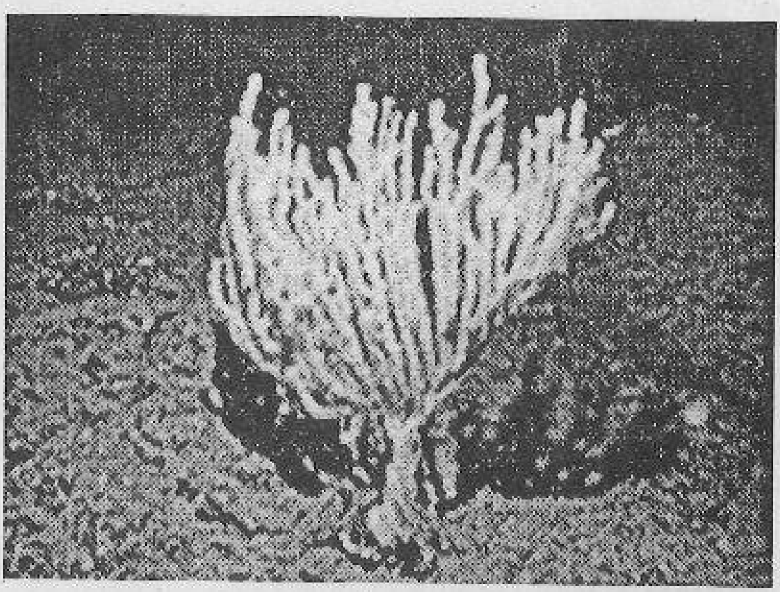


Figure 15: Bamboo coral is an early harbinger of ocean acification

2.2.10. Protection and restoration : It is estimated that about 60% of the world's reefs are at risk due to destructive, human-related activities. The threat to the health of reefs is particularly strong in Southeast Asia, where an enarmous 80% of reefs are considered endangered.Many governments worldwide take measures to protect their coral reefs.

One method of coastal reef management that has become increasingly prominent is the implementation of Marine Protected Areas (MPAs). MPAs have been introduced in Southeast Asia and elsewhere around the world to attempt to promote responsible fishery management and habitat protection. Much like the designation of national parks and wild life refuges, potentially damaging extraction activities are prohibited. The objectives of MPAs are both social and biological, including restoration of coral reefs, aesthetic maintenance, increased and protected biodiversity, and economic benefits. Conflicts surrounding MPAs involve lack of participation, clashing views and perceptions of effectiveness, and funding.

Biosphere reserves are other protected areas that may protect reefs.Also, Marine parks, as well as world heritage sites can provide protection for coral reefs. World heritage designation is something that is not immediately thought of for the protection of coral reefs, yet also play a vital role. For example the Chagos archipelago, Sian Ka'an, the Great Barrier Reef, Henderson Island, the Galapagos islands, Belize's Barrier reef and Palau have been designated as protected by nominating it a world heritage site.In Australia, the Great Barrier Reef is protected by the Great Barrier Reef Marine Park Authority, and is the subject of much legislation, including a Biodiversity Action Plan.

2.2.11. References

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Unit 3 ❑ Morphology of the Oceans : Ridges, Submarine canyons and oceanic deposits

Structure

3.1. Ridges

3.1.1. Introduction

A mid-ocean ridge or mid-oceanic ridge is an underwater mountain range, typically having a valley known as a rift running along its spine, formed by plate tectonics. This type of oceanic ridge is characteristic of what is known as an oceanic spreading center, which is responsible for seafloor spreading. The uplifted sea floor results from convection currents which rise in the mantle as magma at a linear weakness in the oceanic crust, and emerge as lava, creating new crust upon cooling. A mid-ocean ridge demarcates the boundary between two tectonic plates, and consequently is termed a divergent plate boundary.

The mid-ocean ridges of the world are connected and form a single global midoceanic ridge system that is part of every ocean, making the mid-oceanic ridge system the longest mountain range in the world. The continuous mountain range is 65,000 km (40,400 mi) long and the total length of the system is 80,000 km (49,700 mi)

Mid-ocean ridge

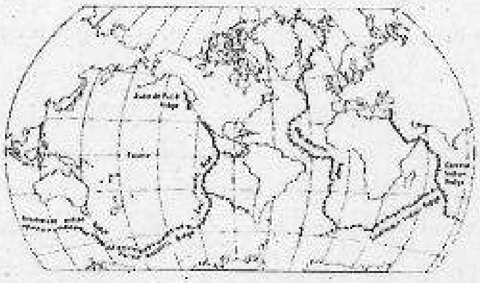

Fig. 16 : World Distribution of Mid-Oceanic Ridges ; USGS

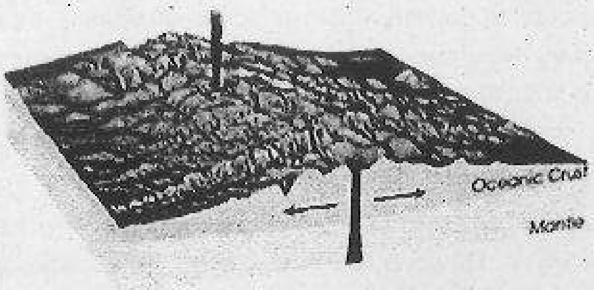

Fig. 17 : Oceanic ridge

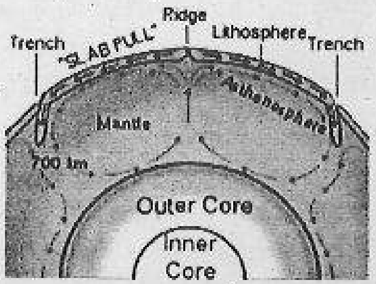

Fig. 18 : Oceanic crust is formed at an oceanic ridge, while the lithosphere is subducted back into the asthenosphere at trenches

3.1.2. : Description

Mid-ocean ridges are geologically active, with new magma constantly emerging onto the ocean floor and into the crust at and near rifts along the ridge axes. The crystallized magma forms new crust of basalt and gabbro.

The rocks making up the crust below the sea floor are youngest at tfie axis of the ridge and age with increasing distance from that axis. New magma of basalt

composition emerges at and near the axis because of decompression melting in the underlying Earth's mantle.

The oceanic crust is made up of rocks much younger than the Earth itself most oceanic crust in the ocean basins is less than 200 million years old. The crust is in a constant state of "renewal" at the ocean ridges. Moving away from the mid-ocean ridge, ocean depth progressively increases; the greatest depths are in ocean trenches. As the oceanic crust moves away from the ridge axis, the peridotite in the underlying mantle cools and becomes more rigid. The crust and the relatively rigid peridotite below it make up the oceanic lithosphere.

3.1.3. Formation processes

There are two processes, ridge-push and slab-pull, thought to be responsible for the spreading seen at mid-ocean ridges, and there is some uncertainty as to which is dominant. Ridge-push occurs when the weight of the ridge pushes the rest of the tectonic plate away from the ridge, often towards a subduction zone. At the subduction zone, "slab-pull" comes into effect. This is simply the weight of the tectonic plate being subducted (pulled) below the overlying plate dragging the rest of the plate along behind it.

The other process proposed to contribute to the formation of new oceanic crust at mid-ocean ridges is the "mantle conveyor" However, there have been some studies which have shown that the upper mantle (asthenosphere) is too plastic (flexible) to generate enough friction to pull the tectonic plate along. Moreover, unlike in the image above, mantle upwelling that causes magma to form beneath the ocean ridges appears to involve only its upper 400 km. The relatively shallow depths from which the upwelling mantle rises below ridges are more consistent with the "slab-pull" process. On the other hand, some of the world's largest tectonic plates such as the North American Plate are in motion, yet are nowhere being subducted.

The rate at which the mid-ocean ridge creates new material is known as the spreading rate, and is generally measured in mm/yr. The common subdivisions of spreading rate are fast, medium and slow, whose values are generally >100 mm/yr, between 100 and 55 mm/yr and 55 to 20 mm/yr, respectively for full rates. The spreading rate of the north Atlantic Ocean is ~ 25 mm/yr, while in the Pacific region, it is 80-120 mm/yr. Ridges that spread at rates <20 mm/yr are referred to as ultraslow spreading ridges (e.g., the Gakkel ridge in the Arctic Ocean and the Southwest Indian Ridge) and they provide a much different perspective on crustal formation than their faster spreading brethren.

The mid-ocean ridge systems form new oceanic crust. As crystallized basalt extruded at a ridge axis cools below Curie points of appropriate iron-titanium oxides, magnetic field directions parallel to the Earth's magnetic field are recorded in those oxides. The orientations of the field in the oceanic crust record preserve a record of directions of the Earth's magnetic field with time. Because the field has reversed directions at irregular intervals throughout its history, the pattern of reversals in the ocean crust can be used as an indicator of age. Likewise, the pattern of reversals together with age measurements of the crust is used to help establish the history of the Earth's magnetic field.

3.1.4. Discovery

Beçause mid-ocean ridges are generally submerged deep in the ocean, their existence was not even known until the 1950s, when they were discovered through surveys of the ocean floor conducted by research ships.

More specifically, the Vema, a ship of the Lamont-Doherty Earth Observatory of Columbia University, traversed the Atlantic Ocean, recorded data about the ocean floor from the ocean surface. A team led by Marie Tharp and Bruce Heezen analyzed the data and concluded that there was an enormous mountain chain running along the middle of the Atlantic. The mountain range was named the Mid-Atlantic Ridge; it remains the most famous part of the mid-ocean ridge. It is the reason for the "midocean" part of the title of this article, since it is only in the Atlantic that the ridge system is in the center of the ocean.

At first, it was thought to be a phenomenon specific to the Atlantic Ocean, because nothing like such a massively long undersea mountain chain had ever been discovered before. However, as surveys of the ocean floor continued to be conducted around the world, it was discovered that every ocean contained parts of the midocean ridge.

3.1.5. : Impact

Fig. 19 : Plates in the crust of the earth, according to the plate tectonics theory

Alfred Wegener proposed the theory of continental drift in 1912. However, the theory was dismissed by geologists because there was no mechanism to explain how continents could plow through ocean crust, and the theory became largely forgotten.

Following the discovery of the mid-ocean ridge in the 1950s, geologists faced a new task: explaining how such an enormous geological structure could have formed. In the 1960s, geologists discovered and began to propose mechanisms for sea floor spreading. Plate tectonics was a suitable explanation for sea floor spreading, and the acceptance of plate tectonics by the majority of geologists resulted in a major paradigm shift in geological thinking.

It is estimated that 20 volcanic eruptions occur each year along earth's mid-ocean ridges and that every year 2.5 square kilometers of new sea floor is formed by this process. With a crustal thickness of 1 to 2 kilometers, this amounts to about 4 cubic kilometers of new ocean crust formed every year.

3.1.6. List of oceanic ridges

- Chile Rise
- Cocos Ridge
- East Pacific Rise
- Explorer Ridge
- Gakkel Ridge (Mid-Arctic Ridge)
- Gorda Ridge
- Juan de Fuca Ridge
- Mid-Atlantic Ridge
- Pacific-Antarctic Ridge
- Reykjanes Ridge
- Central Indian Ridge
- Southeast Indian Ridge
- Southwest Indian Ridge

3.1.7. List of ancient oceanic ridges

- Phoenix Ridge
- Izanagi Ridge
- Kula-Farallon Ridge

- Pacific-Kula Ridge
- Pacific-Farallon Ridge
- Bellingshausen Ridge
- Aegir Ridge
- Seafloor spreading
- Divergent boundary
- Plate tectonics
- Iceland
- List of Oceanic Landforms

3.1.8 References

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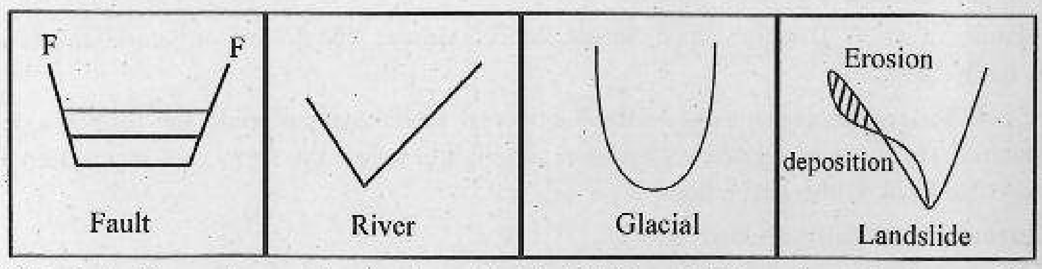
3.2 Submarine canyon

3.2.1. Introduction : A submarine canyon is a steep-sided valley on the sea floor of the continental slope. Many submarine canyons are found as extensions to large rivers; however there are many that have no such association. Canyons cutting the continental slopes have been found at depths greater than 2 km below sea level. They are formed by powerful turbidity currents, volcanic and earthquake activity. Many submarine canyons continue as submarine channels across continental rise areas and may extend for hundreds of kilometers.

3.2.2. Definition : Canyons resembling land carved moslty from continental are called valleys once submerged – submarine canyons. Land canyons quite are of variety.

Example : Fault canyons, River curred canyons, Glacially excarated canyons, Landslide valleys crnyons etc.



Echo Sounding system and seismic studied led differential formation of marine valleys.

3.2.3. Examples :

- Congo canyon, the largest river canyon, extending from the Congo river, is 800 km long, and 1200 metres deep.
- Amazon canyon, extending from the Amazon river.
- Hudson Canyon, extending from the Hudson river.
- Ganges canyon, extending from the Ganges river.
- Indus canyon, extending from the Indus river.
- Monterey Canyon, off the coast of central California.
- La Jolla and Scripps canyon, off the coast of La Jolla, southern California.
- Whittard Canyon, Atlantic Ocean off southwest Ireland.
- Bering Canyon, in the Bering sea.
- Zhemchug Canyon the largest submarine canyon in the world, also in the Bering sea

3.2.4. Types :

Submarine Canyons : Restricted to steep walled sinuous valleys with 'V' shaped cross section. Axis sloping outward as consistently as river cut land canyon & relief comparable even to largest of land canyon. Example : Grand canyon, Colorado. Tributaries are found in most of the canyons & rock outcrops abound on their walls.

2. Delta Formed Trough : Resemble Submarine Canyon but have 'U' shaped transversed section. Comparatively straight courses. Tributary if any, are few and are located exclusively on the front of a few long deltas. No rock outcrop heve been found on their walls.

3. Fan Valley : The seaward continent of submarine canyon and delta formed trough across the sediment fans at the base of continental slopes. Many have bordering levees that are built above the fans. Most have distribed but few have tributary. Walls are locally steep and are cut into unconsolidated fan sediments.

4. Slope Gullies : These continent valleys of small with few tributaries found mostly on prograding slopes such as delta fans.

5. Fault Valleys : Trough shaped, broad floored valleys that follow structural trends are called Fault Valleys.

6. Shelf Valleys : Found mostly on the continental shelfs & types sometime formed a deep sea channel. These are elongated valleys that cut slightly below the surface of many deep sea fans to extend out to the basin floor.

Canyons Genetically divided into :

(a) Glaciated Canyons

(b) Non Glaciated Canyons

(a) wide trough like canyons croded & cut by glaciers only.

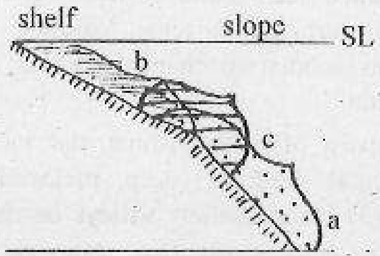
(b) Deep elongated furrows entrenched in the shelve by some agencies other than glacier.

Locationally divided into :

(a) Small gorges originafing near the edge of continental shelf run down the slape to a great depth.

(b) Similar to above these can extend right across the shelf & often start mear the mouth of small rivers.

(c) Has a branching dendritic pattern which is deeply unused into the edge of the shelf of the slope.



3.2.5 Characteristics of Submarine Canyons :

The question of submarine canyons formation has caused must disagreement. To explain successfully these sea canyons it is importent to consider some of their significant features :

(1) Submarine canyons are found on all the different types of continental shelves and slopes.

(2) These occur worldwide (high and low latitudes). These are found in the Arctic region as well as in other regions.

(3) Submarine canyons are often found off relatively straight coast rather than deeply indented coastlines.

(4) Canyons are found off the stable coast as well as off the unstable coast where Quarternary and Tertiary movement hac taken place.

(5) Canyons are formed either infront of large rivers or near the localities where rivers existed in the remote past.

(6) Canyons are found off deltas or are associated with estuaries without any delta.

(7) The majority of the canyons are directly off river valleys, but the latter usually have much wider flows and much gentler gradients than the adjoining sea-floor canyons.

(8) A number of canyons also appear in enclosed seas and oceans such as the Mediterranean where they extend for below the shelf depth.

(9) Typical Submarine canyons have v-shaped profiles like river canyons, winding courses, dendrith tributaries and almost continuous seaward sloping floors.

(10) Most canyons can be traced to the base of the continental slope.

(11) Rocks on canyon walls are mostly soft shales, but include hard rocks, such as granite and even quartzite.

(12) Sediments on the canyon floor include an abundance of sand and even gravel, although coarse sediments are often covered with mud.

(13) Current ripple marks are common at all depth on the canyon floors.

(14) The organisms contained in sand layers, both on the canyon floors and on the adjoining fan valleys, include many shallow-water forms and land plants that apparently have been transported down-valley.

Many deep valley-like trenches cut mainly in the continental slopes but to some extent back into the continental shelves are known as submarine canyons. A submarine canyon is a steep-sided valley on the sea floor of the continental slope. Many submarine canyons are found as extensions to large rivers; however there are many that have no such association. Canyons cutting the continental slopes have been found at depths greater than 2 km below sea level. They are formed by powerful turbidity currents, volcanic and earthquake activity. Many submarine canyons continue as submarine channels across continental rise areas and may extend for hundreds of kilometers.

- Submarine canyons consist of three distinct and interconnecting parts: (1) shallow valleys on the continental shelf, (2) deep, rockwalled canyons or furrows in the continental slope, and (3) broad shallow valleys on the floor of the ocean basins.
- They are apparently global in distribution. They are known to exist off almost all continents.
- Most of them lie seaward from the axial lines of streams on land and some actually can be traced across the continental shelf into the estuaries of rivers or to be more correct, into drowened valleys in these esuaries.
- Deep canyons are interspersed with furrows and ridges and seeem to be restricted mainly to the continental slopes.
- Submarine canyons are of recent geologic age.
- Most canyons are cut in sedimentary rocks.
- Canyons are scarce or lacking where the continenmtal slopes are less than 2 degrees.
- They are found off submerged coasts, off emergent coasts, off mountainous coasts, both young and old, off glaciated coasts, and off deltaic and alluvial coasts.
- The seemingly have many striking similarities to canyons on land, such as V-shaped cross profiles, great depths, sinuous courses, rock walls, and tributary canyons which commonly join the main canyons accordantly.
- Although the cross profiles of submarine canyons seem to resemble those of canyons on land, there is a significant difference in the longitudinal profiles of the two. In fact, the long profiles of the canyons in the continental slopes show gradients that average about ten times those of canyons on land.
- The canyons extend seaward to depths in excess of 2000 fathoms.

3.2.6. Formation : Many mechanisms have been proposed for the formation of submarine canyons, and during the 1940s and 1950s the primary causes of submarine canyons were subject to active debate.

An early and obvious theory was that the canyons present today were carved during glacial times, when sea level was about 125 meters below present sea level, and rivers flowed to the edge of the continental shelf. However, while many (but not all) canyons are found offshore from major rivers, subaerial river erosion cannot have been active to the water depths as great as 3000 meters where canyons have been mapped, as it is well established (by many lines of evidence) that sea levels did not fall to those depths.

The major mechanism of canyon erosion is now thought to be turbidity currents and underwater landslides. Turbidity currents are dense, sediment-laden currents which flow downslope when an unstable mass of sediment that has been rapidly deposited on the upper slope fails, perhaps triggered by earthquakes. There is a spectrum of turbidity- or density-current types ranging from "muddy water" to massive mudflow, and evidence of both these end members can be observed in deposits associated with the deeper parts of submarine canyons and channels, such as lobate deposits (mudflow) and levees along channels.

Mass wasting, slumping, and submarine landslides are forms of slope failures (the effect of gravity on a hillslope) observed in submarine canyons. Mass wasting is the term used for the slower and smaller action of material moving downhill; and would commonly include the effects of bioerosion: the burrowing, ingestion and defecation of sediment performed by organisms. Slumping is generally used for rotational movement of masses on a hillside. Landslides, or slides, generally comprise the detachment and displacement of sediment masses. All are observed; all are contributory processes.

It is now understood that many mechanisms of submarine canyon creation have had effect to greater or lesser degree in different places, even within the same canyon, or at different times during a canyon's development. However, if a primary mechanism must be selected, the downslope lineal morphology of canyons and channels and the transportation of excavated or loose materials of the continental slope over extensive distances require that various kinds of turbidity or density currents act as major participants.

3.2.7. Theories of formation of Submarine canyons :

Various attempts have been made to account for the formation o su marine canyons. An attempt has been made here to consider only those that have been given serious considerations.

It is now understood that many mechanisms of submarine canyon creation have had effect to greater or lesser degree in different places, even within the same canyon, or at different times during a canyon's development. However, if a primary mechanism must be selected, the downslope lineal morphology of canyons and channels and the transportation of excavated or loose materials of the continental slope over extensive distances require that various kinds of turbidity or density currents act as major participants.

A large number of hypothesis have been put forward by geologists & geomorphologists to explain the origin of Submarine Canyons. In recent years most of the hypothesis have been gradually discarded, leaving only the following.

1. Turbidity current thypotheis
2. Combined sub areal erosion theory

3. Combined Submarine processes theory.

I. Discredited Typothesis :

(a) Artesian spring theory by Johnson(1939) :

According to him submarine canyon could be related to the seaward dipping coastal plain formation.

Objection raised :

1. It doesn't explain why canyon cut in granite and other resistant rocks.
2. No sufficient underground circulation to produce the deep canyon beytnd the shelf.
3. Absence of sink holes or other basins along the length of the canyon.

(b) Tsunami Thoery :

This theory was suggested by Butcher (1940). Due to the fact that these catastropic waves with long time barrier transmits some of then to the deep ocean flour to carve submarine canyon.

Objections

According to many geomorphologists tsunamis are significant in very shallow water. But on the slopes (average 300 metre) waves be concentrated only on the ridges.

Secondly canyons are not confused to the areas where trenches are common. Canyons are located is high and low latitudes.

(c) Diastrophic Mont Theory :

Canyons have been explained by this theory particularly by geomorphologists like Alfred Wegner is 1924. According to him valley like depression can be produced by faulting & folding on continental slopes.

Objection :

(i) Fault Valleys would have been straight and would assured shape, but the canyons are of windring pattern and V shape of the cross section and the dendritie tributary can not be explained by this theory.

(ii) There is no indication that canyons are more common in unstable areas where diastrophic mountain have taken place.

(d) **Landsliding Theory :**

This theory was suggested by Shepard (1931) and Emery (1941). According to them, land sliding would be effective on all steep submarine slope having unconsolidated sadiments.

Objection :

(i) Shape of landslide valleys is very different from typical submarine canyon.

(ii) The dendritic tributarien parallel to the coast, can't be explained by landslide.

(iii) They deep granite walled canyons couldn't be explained by mass movement, because these landslide are effective in areas of unconsolidated sediment. However, relation of large no of canyon eg. californa canyan cut on granite and other crystalline rocks can't be explained by the theory.

e. Sub-areal Erosion Theory :

This theory was suggested by Shepard (1948). According to him canyan might have been cut by the rivers duing a low stand of the sea level caused by continental glaciers.

Objection :

(i) If the sea level was greatly lowered there should be shallow water deposits of age on the flat topped sea mounts called Gyots. They are not found although older shallow water for mount have been raised there.

(ii) The huge glacier would have covered the entire arctic basin, but a no of researches have indicated much of the arctic shelf was not glaciated.

(iii) Submarine canyons found in Arctic slope indicate the absence of Arctic lee-cap during that period.

II. Recent Theories

1. Turbidity Current Hypothesis :

This idea originally put forward by Daly (1936). According to him such a current with a load of sediment would have desity than normal sea water and would flow down slope and gather more sediment and velocity to erode the shelf and slope of continental margin. These are considered as one the causes by Kunen (1953) or as a sole cause of excavating subrnarie canyons by Huzen.

Objection :

It appears that turbidity current are capable of cutting through soft sediments and unconsolidated formation but quite unsuitable to erode granite and other crystalline and resistant rocks. For this doubtful capacity of Turbidity current, this is not fully satisfactory. Recent investigation have shown objection may not be valid. Turbidity current based on lab experiment favor high velocity of 92 kmph or more. With this velocity its capacity of cutting harder resistant rocks unfortunately we shill have no clear evidence that will accept or contradict the theory.

2. Combined subiareal Erosion Theory :

Shepard submitted this theory. He put forward an arguement of physical character of the most will founded submarine canyons provide strong arguement for their having been originally cut or shaped by river erosion.

Dendritic pattern of submarine canyons are the result of an erosional agency attacking the entire surface. The 'V' shape of the typical submarine canyons can't be explained by any other theory, particularly turbidity current typothesis.

Granite walls of California canyons have crystalline walls, elsewhere be cut by turbidity current but sub-areal erosion.

Objection :

(i) Very wide spread marginal submergence.

(ii) Presence of knick point between the profiles of canyon heads and adjacent river valleys would be significant if the submarine canyons had been submerged in recent times.

3. Combined submarine processes theory :

As submarine canyon studies have continue results appear to favor a combination of submarine processes as the cause of excavation of submarine canyons. Much support is found for mass movement especially as canyon heads. (Shepard+Sill in 1956, article) perhaps gravity induced slides and stumps are not important except being steeper heads. In general the shape of canyons, is the denritic tributary comparable with river erosions may also be produced by descending sea floor currents. In addition to that current theory giving evidence that other currents are also important. The record for up and down can floor measured especially in La Zolla canyon are of low velocity, but down the canyon mary be treated. Recent discover suggest that probably various types of flows still not well understood may be equally important.

Example : Cascading current due to pulling of the water along the coast may be significant.

3.2.8. Distribution of Submarine Canyons :

A world wide investigations of the continental shelves by F. Shepard and C. Beard to point out the existence of 102 canyons in the world.

(A) Submarine canyons in the Atlantic Ocean :

The Atlantic Ocean is particularly known for the existence of some of the great canyons in the world—

(i) **Hudson Canyon :** This canyon of the Atlantic coast of the United States in front of the mouth of Hudson is traceable accross the shelf, even upto the mouth of the river. The canyon takes its origin in the form of a deep channels Sandy Hook and extends for about 150km. At the head it is 1.5 km. wide, but 80 kms downward it widens to 8 to 9.5 km. The depth of the canyon is estimated to be 1129 mt.

Chesapeake canyon just south of the Hudson canyon is another submarine canyon in front of Chesapeake Bay. These the canyons have lowest gradient among all the canyons off the east coast of USA. Their average gradient is 5%.

(ii) **Mississppn Canyon :** In the gulf of Mexico the Mississippi trough extend about 35 km. continental shelf, the average gradient being 1%.

(iii) **Caribbean Canyon :** Off the Caribbean coast of Panama near the Coasta Pican boundary four 'V' shaped canyons are noted at the edge of continental shelf. Two of them are associated with large rivers like Sinaole and Changricnole and their average depth is about 915m.

(iv) **Fosse de Cape Breton Canyon :** In the West European continental shelf the most important submarine canyon is Fosse de Cape Biscay near the coast of South-Western France. It penetrates 48kms into the shlef and is about 300m deep.

(v) **Nazari Canyon :** A similar phenomenon is also traceable off the river Gironde in France and than the coast of Portugal, first discovered by Hall. It extends for about 80 kms on the continental shelf. Its deepost part extends below 4000 mt.

(vi) **Congo Canyon :** This canyon near the mouth of the Congo river extends for about 150 kms. At the head of the canyon width of gullies is about 4.5 km. and depth is about 610m. After 55 kms. the width of the canyon is 9 kms. and the floor at the gully is 1833 m. below the level of the plateau in which it is curved.

(vii) **Mediterranean Canyon :** Among the tributary seas of the Atlantic, the Mediterranean has canyon off the coast of French Rivers, where the average slope is about 10%.

(B) Canyons in the Pacific : In the Pacific Ocean on the west coast of America few canyons are found, they are : (i) La golla and scripps Canyons in off the coast of N. California.

(ii) Coronande Canyon off Sanlingo

(iii) San lucas Canyons off the coast of S. California.

(iv) Monterey Canyon off the coast of Central California. It is about 112Km. long and about 3200 m deep.

(v) Panama Canyon off the coast of Panama at the mouth of Bayaro river.

(vi) Piken chiyong Canyon off the coast of Korea.

(vii) Philipine Canyon off the coast of Lagon.

(viii) Tokyo Canyon at the mouth of Takyo Bay.

(ix) Hawaii Canyons at the mouth of Honolulu Bay.

(C) Canyons in the Indian Ocean :

(i) Ganges Canyon off the coast of the Sundarbans

(ii) Indus Canyon off the Indus delta.

(iii) Trineonnalee Canyon off the coast of north-eastern Srilanka.

(iv) Zangibar Canyon off the eastern coast of Africa in front of the river Zanzibar.

(v) Recent finding of International Indian Ocean Expendition have revaluate various submarine canyons off the coast of India. These are Cuddater canyon, Pondichery Canyon, Paler Canyon, Penner Canyon, Nageryon Canyon, Godavari Canyon etc.

3.2.8. Conclusion : It is now understood that many mechanisms of submarine canyon creation have had effect to greater or lesser degree in different places, even within the same canyon, or at different times during a canyon's development. However, if a primary mechanism must be selected, the downslope lineal morphology of canyons and channels and the transportation of excavated or loose materials of the continental slope over extensive distances require that various kinds of turbidity or density currents act as major participants.

Unit 3.3 : Oceanic Deposits

3.3.1 Introduction

Most of the ocean bottom is covered by sediment deposits brought in by rivers, glaciers and winds. Oceanic sediment deposits record the earth's history during the past 200 million years. Deep sea deposits are contain arecord of the earth's history.

3.3.2. Type of deposits and their description :

Ocean deposits are classified in two different ways :

(1) Basis of sources of origin

(2) Basis of particle size.

(1) Sources of origin :

Sediment type	Source	Examples	Distribation	% (of all ocean floor area)
Terrigenous	• Erosion of land • Volcanic erruptions • blown dust	Quartz sand, clays, esturine mud	Dominant on continental margin, abyssal plain, polar ocean floor	45%
Biogenous	• Organic • accumulation of hard parts of some marine organisms	• Calcareous & • Sillicious oozes	Dominant on deep ocean floor.	55%
Hydrogenous	• Precipitation of dissolved minerals from water	• Manganese nodules, • phosphorite deposits	Present with other more dominant sediments	<1%
Cosmogenous	• Dust from space, • meteorites debris	Tektite spheres, glassy nodules	Mixed in very small proportion with more dominant sediments	0%

Source : Kennett, 1982, Weihaupt, 1979 ; Sverdrup, Johnson and Fleming, 1942.

Lithogenous deposits : This deposits are composed of sediments derived from the mechanical and chemical breakdown of silicate rocks on land by the process of weathering, mass wasting etc. (Terra-Earth ; generare-to produce).

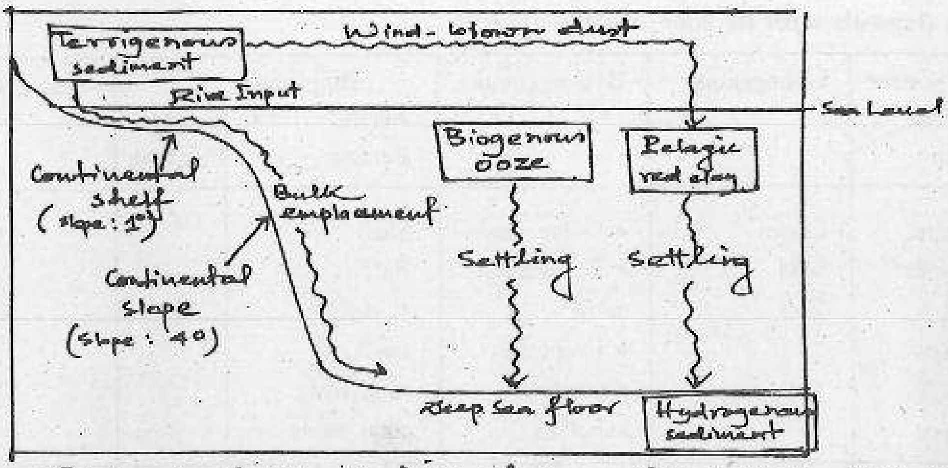
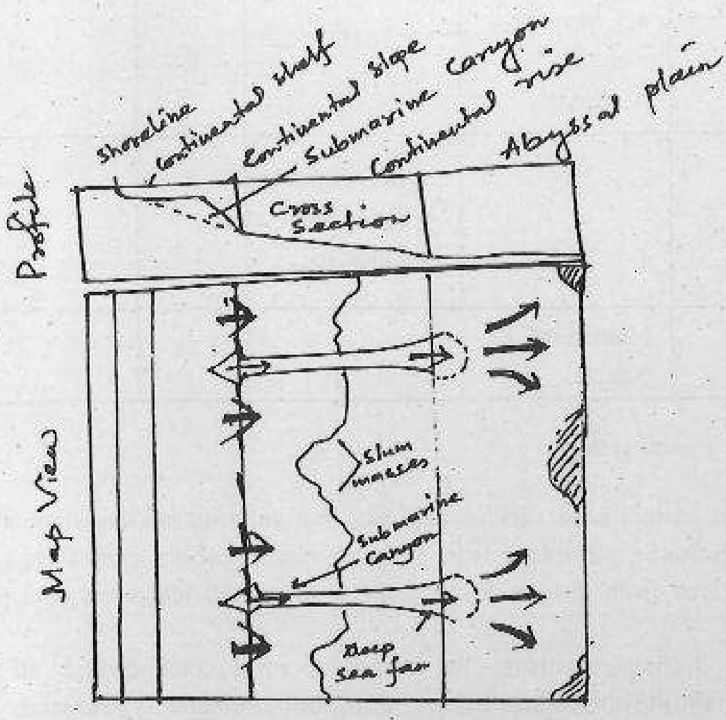


figure: Sedimentation of deposits in the deep sea



Terrigenous Muds : Bordering the continents in a zone along the upper and middle cotinental slope are terrigenous muds, It may different in colour, like —

- Black mud
- Blue mud
- Green mud
- Red mud

Ocean deposits with its zone of deposition :

Source / Zone of deposition	Lithogenous	Hydrogenous	Biogenous		Cosmogenous
			Neritic Benhos	Pelagic Plankton	
Littoral zone, Shallow water or Neritic Zone	Gravel Sand, Mud	• Oolite sands • Calcareous muds • Evaporites cementing materials	Shell Irarcls & shell sands, coral reefs coral sands		
Bathyal Zone	Deep Sea Muds and Sands	• Glauconite • Pyrite etc. • Cementing materials phillipsite	Coral muds		
Abyssal Zone	Turbidites — Red clay		• Deep sea Ooze • Calcareaous • Siliceous		
		Manganese Nodules			

Source : Duff, Holmes, Principles of plysical geology.

Hydrogenous deposits : In certain area various deposits like carbonates (limestone type deposits), phosphorites (phosphorus in phosphate from in crusts and nodules), evaporites (salt and gypsum deposits), are derived from the sea water itself by chemical and biological processes.

Biogenous deposits : The marine organisms that contribute most conspicuously to the sediments of the littoral and shallow water zones belong to a group collectively known as the *benth os*. In some local reef environments biogenic component does dominate. Corals tend to grow in shallow waters. The two main sources of deep ocean sediments are the tiny skeletons or tests of micro organisms (Oozes) and the very fine clays of continental origin (Red clays). The organic Oozes and red clay of the abyssal zone are known as *Pelagic deposits*.

Ooze : Ooze consists of the shelly and skeletal remains of microscopic marine organisms belonging to a group called *Plankton*.

Types of Ooze : (a) Calcareous ooze
- Globigerina Ooze
- Pteropod Ooze
- Cocco-lithosphere Ooze

(b) Siliceous Ooze
- Diatom Ooze
- Radiolaria Ooze

Cosmogenous deposits :

This deposits are derived from the meteoritic debris that continously bombards the Earths. It is of miniscule contribution to total sediments cover, amounting to an equivalent of an additional small grain of sand / sq. cm. every few years.

(2) Size of particles : The size of the particles may be different, like—

		diameter ranges (mm)
(a) Gravel : (It is a very coarse material, too heavy)	**Boulder**	256
	Cobble	64-256
	Pebble	4-64
	Granule	2-4
(b) Sand (This may be coarse to fine, resulfing from wearing of rocks	Very coarse sand	1-2
	Coarse sand	0.5-1
	Medium sand	0.25-0.5
	Fine send	0.125-0.25
	very fine	0.0625-0.125
(c) Mud : (This is much finer sands, contains heterogenous particles)	Silt	0.0039-0.0625
	Clay	<0.0039

Unit 4 ☐ Marine Resource

Structure

4.1 Introduction

Oceans cover 70 percent of Earth's surface, host a vast variety of geological processes responsible for the formation and concentration of mineral resources, and are the ultimate repository of many materials eroded or dissolved from the land surface. Hence, oceans contain vast quantities of materials that presently serve as major resources for humans. Today, direct extraction of resources is limited to salt; magnesium; placer gold, tin, titanium, and diamonds; and fresh water.

Ancient ocean deposits of sediments and evaporites now located on land were originally deposited under marine conditions. These deposits are being exploited on a very large scale and in preference to modern marine resources because of the easier accessibility and lower cost of terrestrial

These mounds of sea salt were mined from deeply buried beds deposited when sea water evaporated in an ancient environment. The beds were preserved by being covered and then uplifted in a modern terrestrial setting. Mining accounts for most of the annual salt production, even though it also can be obtained by evaporating ocean water.

resources. Yet the increasing population and the exhaustion of readily accessible terrestrial deposits undoubtedly will lead to broader exploitation of ancient deposits and increasing extraction directly from ocean water and **ocean basins.**

4.2 Major Resources or the Ocean

We regard ocean as food, renewable energy resource, fossil fuel, minerals, chemical fertilzer, and medicines.

Food - We have fishes, vegetation grown under weed.

Energy - Wave energy + oceans thermal structure.

Fuel - Found under strata. Deposited in the form of oil and gas.

Minerals - Diamond, sand, gravel.

Fertilizer - Different chemical fertilizer.

Under UN, the law of sea countries say they have right to explore oceans. Right to claim Exclusive Economic Zone (EEZ) extending to 370Km i.e. 200 nautical miles offshore. [NM = Knots, NM = Distance on surface of earth measuring exaclly on inch at the centre of the earth.]

4.2.1 Food :

Fishes are caught not only for consumption but also to turn less edible to turn fish meal etc. Disposition of world fish production :

Years (% production)

Type	**1981**	**1991**	**2001**
Fresh	21.7	22.6	23.7
Freezing	23.8	25.0	26.5
Curing	12.8	10.9	5.0
Canning	14.5	12.9	10.6
Paultry Feed	27.2	28.6	30.2
Total	100.0	100.0	100.0

World Fish Catch (106 tonnes - mile metric tonnes)

Type	**1985**	**1990**	**1995**	**2000**
Marine	75.7	82.8	90.2	100.5
Inland	10.6	14.6	17.5	21.2
Total	86.3	97.4	107.7	121.7

Although fishing has traditionally been most important resource exploited by humans in such a increasing evidence, that these valuable resource are being destroyed by polluting coastal zone, breeding grounds, overfishing capturing and destroying young fish, marin life and organism.

Example : Coast of sunderban, prawn culture.

World Producer	(fish production in %)
China	13.1
Japan	9.3
USSR/CIS	9.3
Peru	6.5
Chili	6.0
US	5.5
India	4.0
Total	54.4
Other countries	45.9

sea weeds have long been recognised as a major food resouree. India for pharmaceutical purpose extracted from sea weed and used as sterilizers and gels for food medicine as well as rubber, textile, ceramic production.

4.2.2 Energy

Sunderbans, has only 15% electrified. Intermitten electric, oil and gas, like coal are finite, non renewable resources. Knowing that they will last forever, more effort is being put into alternative sources of energy to which renewable energy like solar, waves and wind etc.

The ocean has been abundant in its wind, waves and tides, currents in thermal structure of the water masses.

Winds : Ocean wends are a source of energy for coastal community and small island. Sure in planning to utilize by windmill to generate electricity. US has installed a wind turbuine on Hawai coast. In India wind driven power is being utilised coastal areas particularly in W.B. coast and as in Fraiegunj and Sagar Island, and in Goa in Kerala, Gujrat and elsewhere.

Waves : The experiment on sea wave was conducted in France about 150 years back. In 1967 Japan generated power by using sea waves (37 yrs back). Ocean energy group of IIT (Chennai) designed a device installed is Trivandrum for generating of electric sea waves. Prof. Salter of Edinburgh University and Mr. Biswas of Eastern Railway (India) invented different measures for extracting power from sea waves but in experimental stage.

Tides and Currents : Kinetic energy can be obtained from flow of water (H_2O) due to the tide motion. This energy can be converted to electricity in this method. Sea water during high tide is allowed to enter reservoir through such gates. As the water enters the reservoir rotates the turbine and generates electric. In the River Rance estuary (Françe) 240 mil. watts of electric is produced. In India one to power project is established Kuchh with 900 megawatt capacity.

Thermal structure - Difference between temperature of sea and surface at lower levels can be utilise to harvess electricity. In this method low boiling liquid like Ammonia, Propane, Freon are heated by hot sea water near the sea. The vapors produced protect the turbine to the generator. This vapor are condenced into cool water in lower levels of sea water and reused by the method of producing electricity Ocean Thermal Energy Conservation systems (OTECS). It first came into existence in Cuba, 1927. India with its 5000 km. wide shoreline has potential location both in East and West for developing OTECS.

4.2.3 Fossil Fuel

The world presently release heavily on the energy stared in fossil fuel as they are cheap and easy to extract. Coal found in beds near surface and gas can be reneased with little more effort than drilling holes in the ground. Due to both, the case of recover their rich energy content fossil fuel censumption has grown quickly so much so that these result will be adjusted within a short period.

World Reserves of Fossil Fuel

Fuel	Reserve	1991	Years left to be exhausted
Coal	15,000	90	170
Petroleum	3,500	127	28
Natural Gas	2,000	66	30
Uranium	5,800	17	47

World Energy Use

	Years		
Fuel	**1901**	**1951**	**1991**
Coal	20	40	90
Petroleum	0	20	127
Natural gas	0	10	66
Hydro Electric	0	5	25
Nuclear Power	0	0	15
Wood	10	5	1

Oil was first produced from beneath the sea in 1894 off the Pacific coast of California. Production was costly and it was not until 1936 that operations began in Gulf of Mexico. By 1948 the first offshore platform out of right (in open ocean) of land had been completed off the coast of USA. At present oil is produced in substantial amount off California coast, Gulf of Mexico, North Sea, Black sea, Coast of Angola of Brazil, off S.E. Australia, E. Indies, Persian gulf and many other places.

Natural gas is also produced in huge amount offshore. The North Sea being a major source. According to UK Petroleun annual worldwide production of and natural gas reached 3.2 bill tonnes which about 40% beyond continental slopes. However the natural gas subject to constraints faced for oli extraction. It readily be trapped from deep ocean sediments. Its estimated that there are 3×10^{15} walt of clean not gas trapped in the deep oceans.

4.2.4 Minerals

The raw material for building trade so they have been used for generation in different parts of the world for construction. About 25% of sand and gravel for in S.E. England comes from offshore. But of aggregrate world production is from Japan. Beaches around the world have been mined for many minerals including Nambia, gold off Alaska, Bromide off Oregon, Indonesia, Thailand, pure quarls is mexid from the beach in W. North Iceland. On tropical island fringed with coral reef white sands containing $CaCO_3$ are used for cement industry. Elsewhere in sea bed parts in deep sea floor (4000-5000 m deep) Fe, Manganese oxide minerals, are deposited in the size and shape of potato in shallow H_2O (<2000m deep). Flanks of volcanic islands and sea minerals,, MgO_2 are reach in cobalt. Its now established that hydrothermal activity and associated massive sulphide deposit rich in Cu and Zn are common along the crest of mid oceanic ridges. The ocean has been used as a source of salt for many 1000 yrs. fresh water is commercially extracted from oceans. The most common method of devoling it is Distillation.

Principal Mineral Resources of the Oceans

Resources presently extracted from the sea or areas that were formerly in the sea range from common construction materials to high-tech metals to water itself. Chemical analyses have demonstrated that sea water contains about 3.5 percent dissolved solids, with more than sixty chemical elements identified. The limitations on extraction of the dissolved elements as well as the extraction of solid mineral resources are nearly always economic, but may also be affected by geographic location (ownership and transport distance) and hampered by technological constraints (depth of ocean basins).

The principal mineral resources presently being extracted and likely to be extracted in the near future are briefly considered here.

Salt

Salt, or sodium chloride, occurs in sea water at a concentration of about 3 percent and hence constitutes more than 80 percent of the dissolved chemical elements in sea water. The quantity available in all the oceans is so enormous that it could supply all the human needs for hundreds, perhaps thousands, of years. Although salt is extracted directly from the oceans in many countries by evaporating the water and leaving the residual salts, most of the nearly 200 million metric tons of salt produced annually is mined from large beds of salt. These beds, now deeply buried, were left when waters from ancient oceans evaporated in shallow seas or marginal basins, leaving residual thick beds of salt; the beds were subsequently covered and protected from solution and destruction.

Potassium

Like the sodium and chlorine of salt, potassium occurs in vast quantities in sea water, but its average concentration of about 1,300 parts per million (or 0.13 percent) is generally too low to permit direct economic extraction. Potassium salts, however, occur in many thick evaporite sequences along with common salt and is mined from these beds at rates of tens of millions of metric tons per year. The potassium salts were deposited when sea water had been evaporated down to about one-twentieth of its original volume.

Magnesium

Magnesium, dissolved in sea water at a concentration of about 1,000 parts per million, is the only metal directly extracted from sea water. Presently, approximately 60 percent of the magnesium metal and many of the magnesium salts produced in the United States are extracted from sea water electrolytically. The re~rnaining portion of the magnesium metal and salts is extracted from ancient ocean deposits where the salts precipitated during evaporation or formed during diagenesis. The principal minerals mined for this purpose are magnesite (MgC03) and dolomite (CaMg[C03]2).

Sand and Gravel

The ocean basins constitute the ultimate depositional site of sediments eroded from the land, and beaches represent the largest residual deposits of sand. Although beaches and near-shore sediments are locally extracted for use in construction, they are generally considered too valuable as recreational areas to permit removal for construction purposes. Nevertheless, older beach sand deposits are abundant on the continents, especially the coastal plains, where they are extensively mined for construction materials, glass manufacture, and preparation of silicon metal. Gravel deposits generally are more heterogeneous but occur in the same manner, and are processed extensively for building materials.

Limestone and Gypsum

Limestones (rocks composed of calcium carbonate) are forming extensively in the tropical to semitropical oceans of the world today as the result of precipitation by biological organisms ranging from mollusks to corals and plants. There is little exploitation of the modern limestones as they are forming in the oceans. However, the continents and tropical islands contain vast sequences of limestones that are extensively mined; these limestones commonly are interspersed with dolomites that formed through diagenetic alteration of limestone. Much of the limestone is used directly in cut or crushed form, but much is also calcined (cooked) to be converted into cement used for construction purposes. Gypsum (calcium sulfate hydrate) forms during evaporation of sea water and thus may occur with evaporite salts and/or with limestones. The gypsum deposits are mined and generally converted into plaster of paris and used for construction.

Manganese Nodules

The deep ocean floor contains extremely large quantities of nodules ranging from centimeters to decimeters in diameter (that is, from less than an inch to several inches). Although commonly called manganese nodules, they generally contain more iron than manganese, but do constitute the largest known resource of manganese.

Despite the abundance and the wealth of metals contained in manganese nodules (iron, manganese, copper, cobalt, and nickel), no economic way has yet been developed to harvest these resources from the deep ocean floor. Consequently, these rich deposits remain as potential resources for the future. Terrestrial deposits of manganese are still relied on to meet human needs.

Phosphorites

Complex organic and inorganic processes constantly precipitate phosphate-rich crusts and granules in shallow marine environments. These are the analogs (comparative equivalents) of the onshore deposits being mined in several parts of the world, and represent future potential reserves if land-based deposits become exhausted.

Metal Deposits Associated with Volcanism and Seafloor Vents

Submarine investigations of oceanic rift zones have revealed that rich deposits of zinc and copper, with associated lead, silver, and gold, are forming at the sites of hot hydrothermal emanations commonly called black smokers. These metal-rich deposits, ranging from chimneyto pancake-like, form where deeply circulating sea water has dissolved metals from the underlying rocks and issue out onto the cold seafloor along major fractures. The deposits forming today are not being mined because of their remote locations, but many analogous ancient deposits are being mined throughout the world.

Placer Gold, Tin, Titanium, and Diamonds

Placer deposits are accumulations of resistant and insoluble minerals that have been eroded from their original locations of formation and deposited along river courses or at the ocean margins. The most important of these deposits contain gold, tin, titanium, and diamonds.

Today, much of the world's tin and many of the gem diamonds are recovered by dredging near-shore ocean sediments for minerals that were carried into the sea by rivers. Gold has been recovered in the past from such deposits, most notably in Nome, Alaska. Large quantities of placer titanium minerals occur in beach and nearshore sediments, but mining today is confined generally to the beaches or onshore deposits because of the higher costs and environmental constraints of marine mining.

Water

The world's oceans, with a total volume of more than 500 million cubic kilometers, hold more than 97 percent of all the water on Earth. However, the 3.5-percent salt content of this water makes it unusable for most human needs.

The extraction of fresh water from ocean water has been carried out for many years, but provides only a very small portion of the water used, and remains quite expensive relative to land-based water resources. Technological advances, especially in **reverse osmosis**, continue to increase the efficiency of fresh-water extraction ; However, geographic limitations and dependency on world energy costs pose major barriers to large-scale extraction.

4.3 References

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মানুষের জ্ঞান ও ভাবকে বইয়ের মধ্যে সঞ্চিত করিবার যে একটা প্রচুর সুবিধা আছে, সে কথা কেহই অস্বীকার করিতে পারে না। কিন্তু সেই সুবিধার দ্বারা মনের স্বাভাবিক শক্তিকে একেবারে আচ্ছন্ন করিয়া ফেলিলে বুদ্ধিকে বাবু করিয়া তোলা হয়।

—*রবীন্দ্রনাথ ঠাকুর*

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—*সুভাষচন্দ্র বসু*

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—*Subhas Chandra Bose*

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