GEOMORPHOLOGY

The scientific study of the origin of landforms based on a cause and effect relationship.

Geomorphology is closer to geology and is moving away from geography.

Recent trends:

1. Geomorphology is slipping out of the hands of geography.
2. Development of Regional Geomorphology.
3. Practical Application of Geomorphology
4. Quantification and Experimentation Application of laws of hydro dynamics to the study of geomorphic processes.

1. Landform:

A landform is an individual topographic feature, of whatever size; thus the term could refer to something as minor as a cliff or a sand dune, as well as to something as major as a peninsula or a mountain range. The plural-landforms-is less restrictive and is generally considered synonymous with topography.

2. Topography:

The surface features of the Earth's surface, including the relief, the terrain, the vegetation, the soils and all the features created in the landscape by human endeavour. It is not synonymous merely with relief.

3.Uniformitarianism:

Fundamental to understanding topographic development is familiarity with the doctrine called uniformitarianism, which holds that 'the present is the key to past'. This means that the processes that formed the topography of the past are the same ones that have shaped contemporary topography; these processes are still functioning in the same fashion and, barring unforeseen cataclysm, will be responsible for the topography of the future. The processes involved are not temporary and, with only a few exception, not abrupt. They are mostly permanent and slow acting. The development of landforms is a virtually endless event, with the topography at any given time simply representing a temporary balance in a continuum of change.

4. Geomorphic process:

Process considers the actions that have combined to produce the landform. A variety of forces – usually geologic, hydrologic, atmospheric and biotic – are always at work shaping the feature of the lithospheric surface, and their interaction is critical to the formation of the feature(s).

5. Geological structure:

Structure refers to the nature, arrangement, and orientation of the materials making up the feature being studied. Structure is essentially the geologic underpinning of the landform. It is a dominant control factor in the evolution of landforms. It is the overall relationship between rocks together with their large scale arrangements and dispositions. Structure includes faults, folds, rock massiveness, rock harness, constituent minerals, permeability or impermeability and the like. According to W.M.Davis "Landforms are a function of structure, process and stage".

6. Relief:

It is the character of the land surface of the earth. It comprises a wide variety of landforms, which can be grouped into different types of terrain. (Terrain is the physical characteristics of the natural features of and area, i.e. its landforms, vegetation and soils.)

7. Geomorphic stage:

a)A Davisian idea , b) The point to which a landform has evolved during a cycle of erosion ,c) As a result of the different processes the landforms pass through different stages – a series of orderly and sequential changes.

8. Drainage:

Drainage refers to the movement of water (from rainfall and snowmelt) either over Earth's surface or down into the soil and bedrock. Although moving water is an outstanding force under the 'process' heading, the ramifications of slope wash, stream flow, stream patterns, and other aspects of drainage are so significant that generally the topic or drainage is considered a basic element in landform analysis.

9. Slope:

An inclined surface, the gradient of which is determined by the amount of the inclination from the horizontal, and the length of which is determined by the inclined distance between its crest and its foot. A slope may be concave, straight or convex when seen in profile.

10. Complexity:

Usually, most of the topographic details have been produced during the current cycle of erosion, but there may exist within an area remnants of features produced during prior cycles, and, although thee are many individual landforms which can be said to be the product of some single geomorphic process. Horberg (1952) classified landforms into five major categories:

1. **simple**
2. **compound**
3. **monocyclic**
4. **multicyclic, and**
5. **exhumed or resurrected landscapes**.

- Simple landscapes are the product of a single dominant geomorphic process,
- Compound landscapes are those in which two or more geomorphic processes have played major roles in the development of the existing topography.
- Monocyclic landscapes have been produced during more than one cycle of erosion. Monocyclic landscapes are less common than multicyclic and are in general restricted to such newly created land surfaces as a recently uplifted portion of the ocean floor, the surface of a volcanic cone, lava plain or plateau, or areas buried beneath a cover of Pleistocene glacial deposits.

- Polyclimatic landscapes it has become evident in recent years that many landscapes have evolved under more than one set of climatic conditions with accompanying variation in the dominant geomorphic processes. Many of these varying climatic conditions were associated with the fluctuating climates of Pleistocene time, but are some areas certain aspects of the topography reflect climatic conditions that existed during Tertiary times.
- Exhumed or resurrected landscapes are those which were formed during some past period of geologic time, then buried beneath a cover of igneous or sedimentary origin, then still later exposed through removal of the cover. Topographic features now being exhumed may date back as far as the Precambrian or they may be as recent as the Pleistocene.

11. Appreciation of world climates:

Climate variations may affect the operation of geomorphic processes either indirectly or directly. The indirect influences are largely related to how climate affects the amount, kind, and distribution of the vegetal cove. The direct controls are such obvious ones as the amount and kind of precipitation, its intensity, the relation between precipitation and evaporation daily range of temperature, whether and how frequently the temperature falls below freezing point, depth of frost penetration, and wind velocities and directions.

12. Pleistocene climate:

There is indisputable evidence that many regions that are today arid or semiarid had humid climates during the glacial ages. Freshwater lakes existed in many areas which today have internal drainage. We know also that many regions now temperate experienced during the glacial ages temperatures such as are found now in the sub arctic portions of North America and Eurasia, where there exists permanently frozen ground or what has come to be called permafrost conditions. World sea levels were also affected. Withdrawal of large quantities of water from the oceans to form great ice sheets produced a lowering of sea level of t least 300 feet and perhaps as much as 500 feet.

13. Internal and external Geomorphic processes:

The topography of Earth has infinite variety, apparently being much more diverse than on any other known planet. This variety reflects the complexity of interaction between process and structure – the multiplicity of shapes and forms that result as the geomorphic processes exert their inexorable effects.

These processes are relatively few in number but extremely varied in nature and operation. Basically they are either internal or external. The internal processes operate from within Earth, energized by internal heat that generates extremely strong forces that apparently operate outside of any surface or atmospheric influences. These forces result in crustal movements of various kinds. In general, they are constructive, uplifting, building forces that tend to increase the relief of the land surface.

14. Historical extension:

Geomorphology concerns itself primarily with the origins of the present landscape but in most landscapes there are present forms that date back to previous geologic epochs or periods. A geomorphologist is thus forced to adopt an historical approach if he is to – interpret properly the geomorphic history of a region. Application of the principle of uniformitarianism makes this approach possible an historical approaches if he is to interpret properly the geomorphic history of a region. Application of the principle of uniformitarianism makes this approach possible, an historical approach if he is to interpret properly the geomorphic history of a region. Application of the principle of uniformitarianism makes this approach possible.

15. Pursuit of Pattern:

A prime goal of any geographic study is to detect patterns in the areal distribution of phenomena. If features have a disordered and apparently haphazard distribution, it is more difficult to comprehend the processes that formed them and the relationships that exist among them. If there is some perceptible pattern to their distribution, it becomes simpler for us to understand both the reasons for the distribution pattern and the interrelationships that pertain.

16. Scale:

In any systematic study of geomorphic processes, two general, topics should be kept in mind-scale and pattern. The question of scale is fundamental in geography. Regardless of the subject of geographic inquiry, recognizable features and associations are likely to vary considerably depending on the scale of observation. This simply means that the aspects of the landscape one observes in a close up view are different from those observed from a more distant view.

At lest five orders of relief can be recognized on the surface of lithosphere.

1.First-order relief represent the small-scale end of the spectrum, which means that the features are the largest that can be recognized continental platform and ocean basins. Although the shoreline at sea level appears as a conspicuous demarcation between land and water, it is not the accepted boundary between platform and basins, each continent has a margin that is submerged, called the continental shelf. At its outer edge, the slope pitches more steeply and abruptly into the ocean basins.

2. Second-order relief consists of major mountain systems and other extensive surface formation of sub continental extent(such as the Mississippi lowland or the Amazon basin) Second- order relief features (like those of all other orders) may be found in ocean basins as well as on continental platforms, most conspicuously in the form of the great undersea mountain ranges usage referred to as ridges.

3. Third-order relief encompasses specific landform complexes of lesser extent and generally of smaller size than those of the second order, with no precise separation

between the two. Typical third-order features include discrete mountain ranges, groups of hills, and large river valleys.

4.Fourth-order relief comprises the sculptural details of the third-order features, including such individual landforms as a mountain, mesa, or hill.

5.Fifth-order relief consists of small individual features that may be part of the fourth-order relief such as sandbar, cliff, or waterfall.

ORGIN OF EARTH

Two sets of theories about origin or earth:

a. **Catastrophic**
b. **Evolutionary**

- the catastrophic theories have hardly any evidence
- uniformitarianism supports evolutionary theories
- Nebular theory – Laplace
- Dust cloud Hypothesis – Weizsaker
- Nebular Hypothesis suggests that the matter which forms the Sun and the Planets originated as a disc shaped cloud of gas or nebula which eventually contracted into discrete bodies.

STRUCTURE OF THE EARTH

Earth has a layered structure

- **Core**
- **Mantle**
- **Crust**

The Nature of Seismic Waves

1. The velocity of seismic waves depends on the density and elasticity of the intervening material. Seismic waves travel most rapidly in rigid materials.

2. Within a given layer, the speed of seismic waves generally increases with depth because pressure increases and squeezes the rock into a more compact elastic material
3. Compressional waves (P waves) travel through solids as well as liquids, because when compressed, these materials behave elastically. Shear waves (S waves) cannot travel through liquids because, unlike solids, liquids have no shear strength.
4. In all materials P waves travel faster than S waves
5. When seismic waves pass from one material to another, Based upon the seismological data, the earth has been divided into various layers.

CORE:

- $1/3^{rd}$ of mass
- $1/6^{th}$ of the earth's volume
- Pressure: millions of times that of atmospheric pressure at the surface.
- Temperature $4000^{o}C$ - $5000^{o}C$
- Relative Density at the center 13.5 relative density.

INNER CORE

- Solid
- Predominantly Fe; also Nickel

OUTER CORE

It is in liquid form.

1. Addition of lighter elements, which when mixed with iron, lower its melting point.
2. In outer core, the pressure is comparatively lesser, to allow the hot iron to melt.

- There is a gradual flow of molten iron in the outer core and is very important for maintaining earth's magnetism.

- The core behaves like a self sustaining dynamo
- The driving forces- Earth's rotation and unequal distribution of heat in the earth's interiors

The existence of a liquid outer core when the inner core, which must be hotter, is solid. Most probably in its formative stage the entire core was liquid. Further, this liquid iron alloy was in a state of vigorous mixing . However, during the last 3.5 billion year's the material of the core has been slowly segregating. As the core cooled, a portion of the iron components gradually migrated downward while some of the lighter components floated upward toward the outer edge of the core. The sinking iron rich components, depleted of the lighter elements which act to depress the melting point, began to solidity.

MANTLE

- 80% of the earth's volume is contained within the mantle.
- Mantle is described as a solid rocky layer, and the most common rock is peridotite
- Peridotite – ultra basic rock, consisting largely of olivine, hence its predominantly dark green colour (olivine – silicate of magnesium mg_2SiO_4 to silicates of iron Fe_2SiO_4).
- The crust increases its temperature with depth, but this trend does not continue downward into the mantle.
- This means mantle has an effective method to transmit heat outward i.e., some form of convection.
- Material in this zone exhibit plastic behaviour, i.e., when the material encounters short lived stresses, such as seismic waves, the material behaves like an elastic solid. However, in response to long term stresses, this same rocky material will flow.

- So S waves can penetrate through mantle, yet, this layer is not able to store elastic energy like a brittle solid and is thus incapable of generating earthquakes

ASTHENOSPHERE

- Asthenosphere is located between 100 to 400 kms.
- P and S waves show a marked decrease in velocity one. The most probable explanation for the observed slowing of seismic energy is that this zone contains a small percentage of melt.
- But Asthenosphere is not continuous and is absent below the older shield areas.

The asthenospher is the layer of Earth that lies at a depth 100 – 400 km beneath Earth's surface.

It was first named in 1914 by the British geologist J. Barrel, who divided Earth's overall structure into three major sections: the lithosphere, or outer layer of rock like material; the asthenosphere; and the centrosphere, or central part of the planet.

The asthenosphere gets its name from the Greek world for weak, asthenis, because of the relatively fragile nature of the materials of which it is made. It lies in the upper portion of Earth's structure traditionally known as the mantle.

The material of which the asthenosphere is composed can be described as plastic-like, with much less rigidity than the lithosphere above it. This property is caused by the interaction of temperature and pressure on asthenospheric materials. Any rock will melt if its temperature is raised to a high enough temperature. However, the melting point of any rock is also a function of the pressure exerted on the rock. In general, as the pressure is increased on a material, its melting point increases.

The temperature of the materials that makeup the asthenosphere tends to be just below their melting point. This gives them a plastic-like quality that can be compared to glass. As the temperature of the material increases or as the pressure exerted on the material increases, the material tends to deform and flow. If the pressure on the material is sharply reduced, so will be its melting point, and the material may begin to melt quickly. The fragile melting point pressure balance in the asthenosphere is reflected in the estimate made by some geologists that up to 10% of the asthenospheric material may actually be molten. The rest is so close to being molten that relatively modest changes in pressure or temperature may cause further melting.

In addition to loss of pressure on the asthenosphere, another factor that can bring about melting is an increase in temperature. The asthenosphere is heated by contact with hot materials that make up the rest of the mantle beneath it.

In order for plate tectonic theory to seem sensible, some mechanism must be available for permitting the flow of plate. That mechanism is the semi-fluid character of the asthenosphere itself. Some observers have described the asthenosphere as the lubricating oil that permits the movement of plates in the lithosphere.

INNER OUTER MANTLE

- After about 400 kms, the velocity of seismic waves increases as a result of phase change.
- A phase change occurs when the crystalline structure of a mineral changes in response to change in temperature and pressure.
- The mineral olivine $(Mg,Fe)SiO_4$, which is one of the main constituents of the rock peridotite, will collapse to a more compact high pressure mineral – spinel.
- This structural change to a denser crystal form could explain the increased seismic velocities observed.

INNER MANTLE

- Another boundary at a depth of around 700 kms because, mineral Spinel, undergoes transformation to the mineral Perovskite $(Mg,Fe)SiO_4$,
- Since Perovskite is the predominant mineral of lower mantle, it is the most abundant mineral in the earth.

LITHOSPHERE

- Situated above the asthenosphere is the cool brittle layer about 100km thick called the lithosphere
- Lithosphere included the entire crust as well as the uppermost mantle and is defined as the layer of the earth cool enough to behave like a brittle solid.
- But it is not a single layer. A density discontinuity is there in the lithosphere. It is broken/fractured along several lines. The different segments are known as plates.
- So plates are essentially lithospheric plates are capable of sliding or, moving over the plastic asthenosphere. Thus plates move from one point to another.

THE EARTH'S MAGNETIC FIELD

Anyone who has used a compass to find direction knows that the earth's magnetic field has a north pole and a south pole. In many respects our planet's magnetic field resembles that produced by a simple bar magnet. Invisible lines of force pass through the earth and out into space while extending from one pole to the other. A compass needle, itself a small magnet free to move about, becomes aligned with these lines of force and points toward the magnetic poles. It should be noted that the earth's magnetic poles do not coincide exactly with the geographic poles. The north magnetic pole is located in northeastern Canada, near Hudson Bay, while the south magnetic pole is located near Antarctica in the Indian Ocean south of Australia.

CONTINETAL DRIFT

Early in the 20th century Geologic thought was dominated by a belief in the antiquity and Geographic permanence of oceans and continents, mountains were thought to result from Earth's cooling and contraction and were compared to the wrinkles on a dried out piece of fruit, changes in sea level and occurrence of fossils at depth were explained using the contraction model. Dramatic changes have taken place over the past few decades.

Earth Scientists now realize the non-permanence of landmasses and ocean basins, creation and continued destruction of crust. This profound reversal of scientific opinion was termed as scientific revolution. An appreciable length of time elapsed between the inception of the idea and its general acceptance. After heated debates the idea of drifting continents was rejected, only to be resurrected during the 1960's.

HISTORICAL DEVELOPMENTS/LANDMARKS IN THE REVERSAL OF THE SCIENTIFIC OPINION

Continental Drift:

An idea before its time

Although modern plate tectonics became an acceptable scientific theory within only the past few decades, the concept of breaking up of an early super continent into fragments that drifted apart is many decades old. Almost as soon as good navigational charts became available to show the continental outlines, persons of learning became intrigued with the close correspondence in outline between the eastern coast line of South America and the Western coastline of Africa.

As early as 1668 a Frenchman interpreted the matching coastlines as proof that the two continents became separated during the biblical flood.

In 1858 Antoni-Snider-Pelligrini produced a map to show that the American continents nested closely against Africa and Eurasia, and also suggested that the reconstructed single continent explains the close similarity of fossil plant type in coal bearing rocks in both Europe and N.America.

In 1910 two American Geologist, Frank B. Taylor and Howard B. Baker, whose published articles presented evidence favouring the hypothesis that the New World and Old World continents had drifted apart.

Nevertheless, credit for a full-scale hypothesis of continental drift goes to a German Scientist, Alfred Wegner, a Meteorologist and Geophysicist who worked on several lines of geologic evidence to prove that the continents had once been united.

He first presented his ideas in a lecture in 1912, the expanded version of which was published in his book " The Origin of continents & Oceans" in 1915.

His Major work on the subject appeared in 1922 and his work was translated into English in 1924.

EVIDENCE OR ARGUMENTS TO SUPPORT WEGNER'S HYPTHESIS

1.Fit of the Continents:

There is Striking/Remarkable similarity / parallelism between the opposing coasts of the Atlantic and (the mid Atlantic Ridge*), India-Africa-Madagascar, Greenland, Baffinland etc and several other coasts in the world. If they are drawn together they make a rough zig saw fit.

However his use of present day shorelines to make a fit of the continents was challenged immediately by earth scientists. The opponents correctly argued that shorelines, which are dynamic and are being continuously modified by erosional processes, upliftment & subsidence are a temporary phenomenon, the use of which, to prove the existence of Pangea and its break-up would be untenable.

A much better approximation of the outer boundary of the continents is the seaward margin of the continental shelf. In early 1960s Sir Edward Bullard and his two associates, with the aid of computers produced a remarkable fit of continents using the 900 meters isobaths. The fit of better than what even the supporters of the continental drift theory suspected it would be. The continents overlap in a few places, these are places where streams have deposited large quantities of sediments, thus enlarging the continents.

2.Fossil evidences:

To add credibility to his argument for (the existence of) Pangea, Wegner used the already documented evidence regarding the existence of strikingly identical fossils, particularly of Mesozoic life forms, on the widely separated landmasses.

Fossil fern GLOSSOPTERIS was known to be widely dispersed in the Southern continents of Africa, Australia, and S. America during the Mesozoic era. Later the remains were also discovered in Antarcitica.

Fossils of Mesosaurus (reptiles-capable of swimming in shallow waters) were found in eastern S. America and West Africa.

Distribution of modern day species with common ancestries-the Australian Marsupials have a direct fossil link to the marsupilal Opposum found in the Americas. For Wegner fossils provided undeniable proof that the landmasses were joined together as the super continent Pangea.

Most Paleontologists were in agreement that some type of land connection existed. Land Bridge hypothesis conjectured the existence of some land bridge between Africa and S.America. We are now quite certain that land bridges of this magnitude did sea level, but are nowhere to be found.

Wegner’s proposals were quickly countered using the logic of parallel evolution-but in the process of evolution there are scores of random factors-how could then the evolution be strikingly so similar? Land seeds and shells are transported for thousands of kilometers across oceans. Floral similarities could be explained by this mechanism.

3.Back type and structural similarities:

Anyone who has worked a picture puzzle knows that in addition to the pieces fitting together, the picture must be continuous as well. The picture that must match in the "Continental drift Puzzle" is represented by rock types and mountain belts found on the continents. If continents were once together, the adjacent rocks should match in age and type. Wegner made a good correlation between rocks found in N, W Africa and Eastern Brazil.

Recent re-examination of this early evidence has supported Wegner's claim. In both regions, 550 million years-old rocks lie adjacent to rocks dated at more than 2 billion years in such a manner that the line separating them is continuous when the two continents are brought together.

Several mountainous belts which appear to terminate at one coastline only to reappear again on a landmass across the ocean. For instance, the mountain belt that includes the Appalachians trends northeastwards through the eastern U.S.A and disappears off the coast of Newfoundland. Mountains of comparable age and structure and found in Greenland and Northern Europe. When these landmasses are reassembled, the mountain Chains form a nearly continuous belt.

Numerous other rock structures exist that appear to have formed at the same time and were subsequently split apart.

In the words of Wegner "It is just as if we were to refit the torn pieces of a newspaper by matching their edges and then check whether the lines of print run smoothly across. If they do, there is nothing left to conclude except that the pieces were in fact joined this way".

4.Paleoclimatic evidences:

Since Wegner was a Climatologist by training, he was keenly interested in obtaining pale climatic data in support of the continental drift. His efforts were rewarded when he found evidence for apparently dramatic climatic changes.

Glacial deposits indicated that near the end of the Palezoic era(220-300 million year), ice sheets covered extensive areas of S. Hemisphere, layers of Glacial till were found at the same stratigraphic position in southern Africa, S.America, India and Australia. Much of the evidences of late Paleozoic glaciation come from land areas which presently lie within 30^{o} of equator in a subtropical – tropical climate.

Could the earth have gone through a period sufficiently cold to have generated extensive continental glacier in what is presently a tropical region. Wegner out rightly rejected this explanation because during the same period large tropical swamps existed in the northern Hemisphere. These swamps with their lush vegetation eventually became the major Coal Fields of the eastern United States, Europe and Siberia. How could these two situations co-exist?

As Wegner proposed, a better explanation is provided if the landmasses are fitted together as a super continent and moved nearer to the South Pole. This would account for the conditions necessary to generate extensive expanses of glacial ice over much of the Southern Hemisphere. At the same time this shift would place the Northern landmasses nearer the tropics and account for their vast coal deposits.

In spite of compelling evidences as these – it took almost 50years for the scientific community to accept the idea of continental drift and the logical conclusions to which it led.

THE GREATE DEBATE

Wegner's proposal did not attract much open criticism until 1924 when his book was translated into English. From this time on, until his death in 1930, his drift hypothesis encountered a great deal of hostile criticism.

To quote the American Geologist Chamberlin "Wegner's hypothesis in general is of the foot-loose type, in that it takes considerable liberty with our globe and is less bound by restrictions or tied down by awkward, ugly facts than most of its rival theories. Its appeal seems to lie in the fact that it plays a game in which there are few restrictive rules and no sharply drawn code of conduct". SCOTT described in much fewer worlds, the theory as "Utter Damned Rot!"

Objections:

One of the main objections to Wegner's hypothesis stemmed from his inability to provide a driving mechanism for continental drift. Wegner proposed two possible energy sources for drift.

1. The Tidal force/influence of the moon was presumed by Wegner to be strong enough to give the continents a westward motion. However, the prominent Physicist Harold Jeffrey's quickly countered with the argument that the tidal friction of the magnitude needed to displace the continents would bring the earth's rotation to a halt in a matter of few years.
2. Further Wegner proposed that the larger and sturdier continents broke through the oceanic crust, much like icebreakers cut through ice.

However no evidence existed to suggest that the ocean floor was weak enough to permit passage of the continents without themselves being appreciably deformed in the process.

Despite criticisms from all corners he wrote the fourth and final edition of his book in 1919, maintaining his basic hypothesis and adding supporting evidence.

1930, Wegner made his 3rd and final trip to the Greenland ice sheet to test his hypothesis by precisely establishing the locations of specific points and measuring the changes over a period of years, he could demonstrate the westward drift of Greenland with respect to Europe. In November, while returning from Eismitte (an experimental station) Wegner perished. His intriguing idea, however, did not die with him.

Although the hypothesis was correct in principle, it also contained many incorrect details. The hypothesis was criticized largely on grounds of its inability to suggest a satisfactory means of engineering continental movements.

It must be conceded that the cumulative evidence supporting the theory of continental drift was massive and the theory was very attractive. If all the points in the theory could be established and an adequate motive force discovered then as Professor SHAND has said".

"We would have to credit (prof.) Wegner with the greatest piece of geological synthesis that has ever been accomplished"(1933).

Wegner himself in response to his critics said "Scientists still do not appear to understand sufficiently that all earth Sciences must contribute evidence towards unraveling the state of our planet in earlier times, and the truth of the matter can only be reached by combining all this evidence".

'As one derides the past theories in the light of newly discovered Physical facts, those theories which are deemed as modern, may be mocked at in the future after the discovery of newer facts.'

Although most of Wegner's contemporaries opposed his views, even to the point of openly ridiculing him, a few considered his ideas plausible. Amongst the noted supporter were.

Arthur Holmes (1928) contributed to the cause by proposing a plausible driving mechanism for continental drift. Since the time he first proposed, he kept on modifying his hypothesis and in his book Physical Geology (1966) he suggested that convection currents operating within the Mantle were responsible for propelling the continents across the globe. Although, even to this day geologists are not in agreement on the exact nature of the driving mechanism, the concept proposed by Holmes is still one of the most appealing.

Wegner also in 1929 suggested thermal convection currents. 1930 Death of Wegner.

South Africa Geologist ALEXANDER DU TOIT (1937) published "Our Wandering Continents" in which he eliminated some of Wegener's errors and added a great deal of new evidence in support of the drift idea.

Very little new light was shed on the continental drift hypothesis between the time of Wegner's death and the early 1950s.

PALEOMAGNETISM

During 50s initial impetus for the renewed interest in continental drift came from Rock – Magnetism – a comparatively new field of study.

Certain rocks containing magnetic minerals (Magnetite is common in Basaltic lava flows) serve as fossil compasses.

When heated above a certain temp called the Curie point (about $580^{o}C$) these magnetic minerals lose their magnetism. However, when these iron rich grains cool below their Curie point, they become magnetized in the direction of the magnetic field. Once the Minerals solidify the Magnetism they possess will remain **FROZEN** in this position.

Rocks thus formed thousands or millions of years ago thus **REMEMBER** the location of the Magnetic Poles at the time of their formation and are said to possess **FOSSIL MAGNETISM or PALEOMAGNETISM**.

Rock Magnetism not only indicates the direction of the poles they also provide a means of determining the Latitude of their origin i.e. the Latitude at the time of formation/ solidification of the rock (From the DIP-needle's angle of inclination in a vertical plane-one can determine the Latitude)

Studies during 50s in Europe – The magnetic alignments in the iron-rich minerals in lava flows of different ages were found to vary widely. The paleomagnetic curves drawn for Europe revealed that the North Pole had gradually wandered from Hawaii through eastern Siberia to the present position over the last 500 million –year.

This was clear evidence that either the magnetic poles had migrated through time, and idea known as **POLAR WANDERING** or the continents had drifted.

Although the magnetic poles are known to move, studies of the magnetic field indicate that the average position of the magnetic poles correspond closely to the positions of the Geographic Poles, which themselves are not believed to wander. Therefore, a more acceptable explanation for the apparent Polar wandering was provided by the continental drift hypothesis. If magnetic poles remain stationary their apparent movement can be produced by moving the continents.

The latter idea was further supported by comparing the latitude of Europe as determined from rock magnetism with evidences from Paleoclimatic Studies, which places Europe near the Equator during the carboniferous Period.

Continental drift was further reinforced when the polar wandering curve was constructed for N. America and compared with that for Europe. To nearly everyone's surprise, the two curves has similar path except that they were separated by 30^o (approx.) longitude. Could there have been two magnetic poles, which migrated parallel to each other? Very unlikely! The problem is resolved if the two presently separated continents are placed next to one another prior to the opening of the Atlantic Ocean.

Palaeomagnetic studies did not cause a major swing in opinion. The technique was new & untested, rock magnetism tends to weaken with time, rocks acquire secondary magnetization etc. in spite of all these limitations, and a new era (of scientific thinking) had begun.

A SCIENTIFIC REVOLUTION BEGINS

Developments in the field of marine geology

During the 50s and 60s great technological strides permitted extensive and detailed mapping of the ocean floor. From here came the discovery of a global oceanic ridge system.

The mid-Atlantic Ridge revealed a trend which parallels the Continental margins of both sides of the Atlantic.

Also of great importance was the discovery of a central rift valley extending for the length of the Mid Atlantic Ridge an indication that great tensional forces were at work. In addition high heat flow and some volcanism were found to characterize the oceanic ridge system. Seismic studies along trenches suggested activity at great depths. Seamounts showed signs of formerly being Islands. Dredging of oceanic crust was unable to bring up rocks that was older than Mesozoic.

SEA FLOOR SPREADING

In the early 1960s all these newly discovered facts were put together by HARRY HESS of Princeton University into a hypothesis, later to be termed Sea –Floor Spreading. Hess was so lacking in confirmed data that he presented his paper as an. "Essay in Geopoetry" Unlike its forerunner, continental drift, which essentially neglects the ocean basins, Sea floor Spreading is centred on the activity beyond our direct view.

In Hess' now classic paper-he proposed

1. Ocean ridges are located above upwelling portions of large convection cells in the mantle.
2. As rising material from the mantle spreads laterally, Sea floor is carried in a conveyer belt fashion away from the ridge crest.
3. Tensional tears at the ridge crest produced by diverging lateral currents provide pathway for magma to intrude and generate new oceanic crust. Thus, as the sea floor moves away from the ridge crest, newly formed crust replaces it.
4. He further proposed that the downward limbs of these convection cells are located beneath the deep ocean trenches. Here, according to Hess, the older portions of the sea floor are gradually consumed as they descend into the mantle. As one researcher summarized "No wonder the ocean floor was young it was constantly being renewed".

   With the sea floor spreading hypothesis in place, Harry Hess had initiated another phase of this Scientific Revolution.

The conclusive-evidence to support his ideas came a few years later from the work of a young English graduate student, FRED VINE and his Supervisor, D.H. MATHHEWS. The greatness of Vine & Matthew's work was that they were able to connect tow previously unrelated ideas: Hess' sea floor spreading hypothesis and the newly discovered Geomagnetic Reversals.

Geomagnetic reversals and Sea Floor Spreading:

About the same time when Hess formulated his ideas, Geophysicists had begun to accept the fact that the Earth's Magnetic field periodically reverses polarity, i.e. the North magnetic Pole becomes the South magnetic Pole and vice Versa.

The cause of these reversals is apparently linked to the fact that the earth's magnetic field changes in intensity. It has weakened by 5% over the past century (Waxing & Waning)

During periods when the earth's magnetic field is very weak, some external influence such as sunspot activity, could possibly contribute to a reversal of Polarity (Normal Polarity when polarity is same as today; Reverse Polarity – when opposite).

Using the Potassium – Argon method of radiometric dating the polarity of earth's magnetic field has been reconstructed for a period of several million years.

Very sensitive instruments called magnetometers were lowered by research vessels across a segment of the ocean floor located off the coast of western United States. Alternating stripes of high and low intensity magnetism which trended in roughly a North South direction was discovered.

This relatively simple pattern of magnetic variation defied explanation until 1963, when Fred Vine and Matthews tied the discovery of high and low intensity stripes to Hess' concept of Sea Floor Spreading.

They reasoned that as new Basalt was added to the ocean floor at the oceanic ridges, it would be magnetized according to the existing magnetic field. Since the new rock is added in approximately equal amounts to both trailing edges of the spreading oceanic floor, we should expect strips of equal size and polarity to parallel both sides of ocean ridges.

This explanation of the alternating strips of Normal and Reverse polarity, which lay as mirror images across the ocean ridges, was the strongest evidence so far presented in support of the concept of Sea floor spreading, This proposal was supported by several studies and by 1968, magnetic variation having similar pattern were identified paralleling most oceanic ridges.

Rate of Spreading:

Now that the dates of recent magnetic Reversals have been established, the rate at which spreading occur along various ridges can be determined accurately. [North Atlantic Ridge 1-2 cms; East Pacific Ridge 3-8 cms.]

Thus, not only had Vine & Matthews discovered a magnetic tape recorder that detailed changed in the earth's Magnetic field, this recorder could also be used to determine the rate of Sea floor spreading.

There is now general agreement that palaeomagnetism was the most convincing evidence set forth in support of the concepts of continental drift and Sea floor spreading.

In 1965 J.T Wilson became the First to suggest that the Earth's lithosphere is made of individual plates and he also identified the zones along which relative motion between the plates is made possible.

PLATE TECTONICS

A MODERN VERSION OF AN OLD IDEA

By 1968, the concepts of continental drift and seafloor spreading were united into a much more encompassing theory known as Plate Tectonics. The implication of plate tectonics are so far reaching that his theory can be considered as the frame work which can view most other geologic processes Since this concept is relatively new, it most surely will be modified, as additional information becomes available; however the main tenets appear to be sound and are presented here in their current state of refinement.

Idea of moving continents is not new and goes back to the beginning of 20th century, although it was inadequately substantiated. Several dramatic discoveries And recent researches in the fields of Paleomagnetism polar wandering, Marine Geology and Sea floor spreading led to the resurrection of the old idea (of Wegner's continent drift) in a rather different form. The most comprehensive and Synthetic theory of PLATE TECTONICS was advanced during the late 1960s which provided for the best and the most rational explanation for the distribution of oceans and continents; ridges and trenches; and orogenic, volcanic and seismic zones and the various processes leading to these.

Samuel and Matthews in 'This Changing Earth' stated: "The Atlantic widens, the pacific narrow's the Alps grow higher, Los Angeles slides northwards and Africa splits apart". The theory of plate tectonics can most beautifully be summarized the words of Samuel and Matthews.

The integrated concept of continental drift, Sea floor spreading and plate tectonic is termed the New Global tectonics.

Theory of plate tectonics:

As the name/expression suggests the theory have two parts to it:

1) **Geometric part and**
2) **Kinematic part**

The geometric part:

The theory of Plate Tectonics states that the outer rigid lithosphere consists of a mosaic of stable, rigid segments called PLATES. Alternatively the Earth's lithosphere is like an eggshell which has been cracked in a number of places.

These plates may be large or small; oceanic or continental or partly oceanic and partly continental and their thickness varies from 80-100kms in the oceans to over 100kms (and in some regions may approach 400kms.) in the continents.

About 18plates of various sizes have been identified. Of these the largest is the pacific plate, which is located mostly within the ocean proper, except for a small sliver of North America that includes SW California and the Baja peninsula. All the other large plates contain both oceanic and continental crust a major departure from the continental drift theory, which proposed that the continents moved through, not with the ocean floor.

Most of the smaller plates on the other hand consist exclusively of oceanic material e.g. The NAZCA plates located in the West Coast of S America. One Small plate that roughly coincides with TURKEY is located exclusively within a continent.

There are 6 Major plates and at least 12 Minor plates and Sub and Sub-plates.

According to some Geologists there are only TWELVE MAJOR Plates (6+6). Of the twelve, six are of enormous extent-THE GREAT PLATES –where as the remaining six range from intermediate in size to comparatively small. Geologists have identifies and named a number of even smaller plates within the twelve major plates.

Today, a fairly good consensus exists in the geologic community as to the number and name of the major plate, the nature of their boundaries, and their relative motions, Differences of interpretation persist in many boundary details. Also a few sections of certain plate boundaries are of uncertain classification or location.

For a particular lithospheric plate to be identified and named, its boundaries should all be active. In other worlds, there must be good evidence of present or recent relative motion between the plate and all its contiguous (adjoining)plates.

The **GREAT PACIFICPLATE** occupies much of the Pacific Ocean basin and consists almost entirely of oceanic lithosphere. Its relative motion is Northwesterly, so that it has a converging (Subduction) Boundary along most of its Western & Northern edge. The Eastern and Southern edge is mostly spreading boundary. A sliver of continental lithosphere is included, making up the coastal portion of California and all of Baja California.

The California portion of the plate boundary is the San Andreas Fault, an active transform 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-Atlantic ridge that divides the Atlantic ocean basin down the middle.

For most part, the Western edge of the American Plate is a converging boundary with active subduction extending from Alaska through Central America to Southern most S America.

THE EURASIAN PLATE is largely a continental lithosphere, but is fringed on the east and north by a belt of oceanic lithosphere

A FRICAN PLATE can be visualized as having a central core of continental lithosphere nearly surrounded by oceanic lithosphere .

THE AUSTRAL INDIAN (also called the Australian) plate takes the form of an elongate rectangle. It is mostly oceanic lithosphere, but contains two cores of continental lithosphere – Australia and the Peninsular India.

THE ANTARCTIC PLATE has an elliptical outline ad is almost completely enclosed by a spreading. The continent of Antarctica forms a central core of continental lithosphere completely surrounded by oceanic lithosphere.

Of the remaining six plates, the **NAZCA AND COCOS** plates of the eastern pacific are rather simple fragments of oceanic lithosphere boundary, on the West and by a converging boundary on the east.

The **PHILIPPINE PLATE** is noteworthy a having converging boundaries on both eastern and western edges.

The **ARABIAN PLATE** has two transform boundaries and its relative motion is northeasterly.

The **CARIBBEAN PLATE** also has important transform boundaries on parallel sides

The tiny **JUAN DE FUCA PLATE** is steadily diminishing in size and will eventually disappear by subduction beneath the American Plate.

Geologists recognize one or more Sub plate is a plate of secondary certain major plates. A sub plate is a plate of secondary importance set apart from the main plate by a boundary that is uncertain or questionable, either as to its true nature of the level of its activity.

An example is the **SOMALIAN SUBPLATE** of the African Plate. It is bounded by the East African ***RIFT VALLEY*** System and there is a good reason to think that this portion of the African Plate is beginning to split apart and will become an independent plate.

THE KINEMATIC PART

(Kinematic means relating to motion) Suggests than the various Plates are in constant relative motion. They move slowly on the semi fluid Asthenosphere.

Plates themselves are ASEISMIC but their boundaries/margins are SEISMIC.

One of the main tenets of the theory of Plate Tectonics is that each Plate moves as a distinct unit in relation to other Plates. Mobile behaviour of the rock within Asthenosphere is believed to allow this motion in the earth's rigid outer shelf.

DIVERGENT BOUNDARIES

- Atlantic Ocean – 165m years old.
- Red Sea – recent divergent boundary is Gulf of California.
- Another linear sea, produced by divergent boundary is Gulf of California.
- If the spreading center develops within a continent, the landmass may split – Pangea.
- African Rift Valley.
- The first activity in such a situation is up warping.

- Up warping will lead to fissures/faults.
- Along the fault lines subsidence takes place and hence rift valley is formed.
- As spreading continues, the rift valley lengthens and deepens eventually extending out into the ocean.
- Finally an expansive ocean basin and ridge system is created.

CONVERGENT BOUNDARIES

- Since the total surface area of the earth remains constant, lithosphere must also be constant.
- The zone of plate convergence is the zone where lithosphere is reabsorbed into the mantle.
- The region where an oceanic plate descents into the asthenosphere because of convergence is called a subduction zone.

OCEAN-CONTINENT CONVERGENCE:

- During such a collision, the oceanic crust s bent, permitting its descent into asthenosphere.
- When descending oceanic plates reaches a depth of about 100kms, partial melting of the water rich ocean crust and the overlying mantle takes place.
- The newly formed magma, created in this manner is less dense than the rocks of the mantle and it rises up.
- The volcanic portion of the Andes Mountains has been produced by such activity when the NAZCA plate melted as it descended beneath the continent of South America.
- Mountains such as Andes that are believed to be produced in part, by volcanic activity associated with the subduction of oceanic lithosphere are called volcanic arcs.

OCEAN-OCEAN CONVERGENCE

- Volcanic island arcs will be created e.g. Aleutian, Mariana, Tonga etc.,

- These Islands are located a few hundred kilometers from an ocean trench where active subduction of the lithosphere is occurring.

CONTINENT-CONTINET CONVERGENCE

- In addition to the Himalayas, several other major mountain systems, including the Alps, Appalachians, and Urals are thought to have formed during continental collisions.
- In Himalayas, the leading edge of Indian plate is forced partially under Asia, generating an unusually great thickness of continental lithosphere.

TESTING THE MODEL

1.Plate tectonic and Earthquakes

The cause of intermediate and deep focus earthquakes occurring between 70kms and 700kms has been a long standing problem in Geology.

- According to Plate Tectonics, as the dense oceanic lithosphere plunge into the mantle, deep focused earthquakes are generated.
- The zones of inclined seismic activity that extend from the trench into the mantle are called Benioff Zones.
- Experimental evidence indicates that brittle fracturing within a cold descending slab may occur at great depths up to 300-400kms. Thus intermediate Eos
- Beyond this depth, one hypothesis is, during subduction, increasing pressures can cause minerals like Olivine to go through a phase change. This can cause high pressure faulting which in turn produces deep focus earthquakes.
- The absence of deep focus EQs along divergent and transform boundaries support the PT theory.

2. Evidence from Ocean Drilling:

Some of the most convincing evidence confirming the sea-floor spreading hypothesis has come from drilling directly into ocean-floor sediment. From 1968 until 1983, the source of these important data was the Deep Sea Drilling Project, an international programme sponsored by several major oceanographic institutions and the National Science Foundation. The Primary goal was to gather firsthand information about the age and processes that formed the ocean basins. Researchers felt that the predictions concerning sea-floor spreading that were based on paleomagnetic data could best be confirmed by the direct sampling of sediments from the floor of the deep ocean basins. To accomplish this, a new drilling ship, the Glomar Challenger, was built. This ship represented a significant technological breakthrough, because it was capable of lowering drill pipe thousand of meters into the sediments and underlying basaltic crust.

Operations began in August, 1968, and shortly thereafter important evidence was gathered in the South Atlantic. At several sites holes were drilled through the entire thickness of sediments to the basaltic rock below. An important objective was together samples of sediment from just above the igneous crust as a means of dating the sea floor at each site. Since sedimentation begins immediately after the oceanic crust forms, remains of microorganisms found in the oldest sediments (that is those resting directly on the basalt can be used to date the ocean floor at that site.)

1. When the oldest sediment from each drill site was plotted against its distance from the ridge crest, the plot revealed that the age of the sediment increased with increasing distance from the ridge. This finding was in agreement with the sea-floor spreading hypothesis which predicted that the youngest oceanic crust is to be found at the ridge crest and that the oldest oceanic curst flanks the continental margins.

2. Further, the rate of sea – floor spreading determined from the ages of sediments was identical to the rate previously estimated from magnetic evidence. Subsequent drilling in the Pacific Ocean verified these findings. These excellent correlations were a striking confirmation of sea-floor spreading.
3. The data from the Deep Sea Drilling Project also reinforced the idea that the ocean basins are geologically youthful because no sediment with an age in excess of 160 millions years was found. By comparison, some continental crust has been dated at 3.9 billion years.
4. The thickness of ocean-floor sediments provided additional verification of sea-floor spreading. Drill cores from the Glomar challenger revealed that sediments are almost entirely absent on the ridge crest and that the sediment thickens with increasing distance from the ridge. Since the ridge crest is younger than the areas farther away from it, this pattern of sediment distribution should be expected if the seafloor spreading hypothesis is correct.
5. Furthermore, measurements in the open ocean haven shown that sediment accumulated at a rate of about 1 cm per 1000 years .Therefore, if the ocean floor were an ancient feature, sediments would be many kilometers thick. However, data from hundreds of drilling sites indicate that the greatest thickness of sediment in the deep-ocean basins is only a few hundred meters, equivalent to intervals of only a few tens of millions of years. Thus, here is yet another fact that strongly suggests the ocean floor is indeed a young geologic feature.

3. Hot Spots

- Hotspots arise from plumes of partially molten rock that are believed to originate in the deep mantel near the mantle-core boundary.

- These ascending plumes of hot rocks will develop a mushroom shaped head and a long narrow tail
- Upon reaching the comparatively low pressure environment at the base of the cooler lithosphere, the hot plume flattens and melts, producing enormous quantities of basaltic magma.
- It is this event that generates the mama to feed the fissure eruptions that form the flood basalt provinces
- Studies about the age of Hawaii-Emperor sea mount chain reveal that, the age of seamounts, increased as we move away from Hawaii.
- Hotspots help in understanding the movements of plates over a period of time.
- Although the existence of mantle plumes is well documented, their exact role in Plate Tectonics is not altogether clear.

4. Modern Technologies

Scientists are nor able to confirm the fact that the plates shift in relation to one another in the way that the plate tectonics theory predicts.

The new evidence comes from two different techniques which allow distances between widely separated points on the earth's surface to be measured with unprecedented accuracy. Called Satellite Laser Ranging (SLR) and Very Long Baseline Interferometer (VLBI), these methods can detect the motion of any one site with respect to another at a level of better than 1 cm per year. Thus, for the first time, scientists can directly measure the relative motions of the earth's plates. Further, because these techniques are quite different, scientists use them to cross-check one against the other by comparing measurements made for the same sites.

1. The Satellite Laser Ranging system employs ground based stations that bounce laser pulses off satellites whose orbital positions are well established. Precise timing of the round-trip travel of these pulses allows scientists to calculate the precise location of the ground based station. By monitoring

these stations over time, researchers can establish the relative motion of he sites.

2. The Very Long Baseline Interferometer system uses large radio telescopes to record signals from very distant quasars. Since quasars (quasi-stellar objects) lie billions of light years from the earth, they act as stationary reference points. The millisecond differences in the arrival time of the same signal at different earth-bound observational sites provide a means of establishing the distance between receivers.

Confirming data from these two techniques leave little doubt that real plate motion has been detected. Calculations show that Hawaii is moving in northwesterly direction and approaching Japan at a rate of 8.3 centimeters per year. Moreover, a site located in Maryland is retreating from one in England at a rate of about 1.7 centimeters per year. This rate is roughly equal to the 2.2 centimeters per year of sea-floor spreading that was established from paleomagnetic evidence.

THE DRIVING MECHANISM

The plate tectonics theory describes plate motion and the effects of this motion. Therefore, acceptance does not rely on knowledge of the force or forces moving the plates. This is fortunate, since none of the driving mechanisms yet proposed can account for all major facets of plate motion. Nevertheless, it is clear that the unequal distribution of heat is the underlying driving force for plate movement.

One of the first models used to explain the movements of plates was originally proposed by the eminent English geologist Arthus Holmes as a possible driving mechanism for continental drift. Adapted to plate tectonics, this hypothesis suggested that large convection currents drive plate motion. The warm, less dense material of the mantle rises very slowly in the regions of oceanic ridges. As the material spreads laterally, it drags the lithosphere along.

Eventually, the material cools and begins to sink back into the mantle, where it is reheated. Partly because of its simplicity, this proposal had wide appeal. However researchers employing modern researchers, employing modern research techniques have learned that the flow of material in the mantle is far more complex than that exhibited by simple convection cells. Furthermore, there is considerable debate as to whether mantle circulation is confined to the upper 700 kilometers or involves the whole mantle.

Many other mechanisms that may contribute to or influence plate motion have been suggested. One relies on the act that as a newly formed slab of oceanic crust moves away from the ridge crest, it gradually cools and becomes denser. Eventually, the cold oceanic slab becomes denser than the asthenosphere and begins to descend. When this occurs, the dense sinking lab pulls the trailing lithosphere along. This hypothesis is similar to another model which suggests that the elevated position of an oceanic ridge could cause the lithosphere to slide under the influence of gravity. However, some ridge systems are subdued, which would reduce the effectiveness of the slab-push model. Further, some ocean basins, notably the Atlantic, lack subduction zones: thus the slab-pull mechanism cannot adequately explain the spreading occurring at all ridges. Nevertheless, the slab-push and slab-pull phenomena appear to be active in some ridge-trench systems.

One version of the thermal convection model suggests that relatively narrow, hot plumes of rock contribute to plate motion. These hot plumes are presumed to extend upward from the vicinity of the mantle-core boundary. Upon reaching the lithosphere, they spread laterally and facilitate the plate motion away from the zone of upwelling. These mantle plumes reveal themselves as long-lived volcanic area (hot spots) in such places as Iceland. A dozen or so hot spots have been identifies along ridge systems where they may contribute to plate divergence. Recall, however that many hot spots, including the one which generated the Hawaiian Islands, are not located in ridge areas.

In another version of the hot plume model all upward convection is confined to few large cylindrical structures. Embedded in these large zones of upwelling are most of the earth's hot spots. The downwards limbs of these convection cells are the cold, dense sub ducting lithospheric plates. Moreover, advocates of this view suggest that subduing slabs may descend all the way to the core mantle boundary. However, convincing seismic evidence for the existence of this sheet like structures below 700 kilometers is lacking.

Although there is still much to be learnt about the mechanisms that cause plates to move, some facts are clear. The unequal distribution of heat in the earth generates thermal convection in the mantle which ultimately drives plate motion. Whether the upwelling is mainly in the form of rising limbs of convection currents or cylindrical plumes of various sizes and shapes is yet to be determined. Studies do show, however, that the oceanic ridges are not closely aligned with the active upwelling that originates deep in the mantle. Except for hot spots, upwelling beneath ridges appears to be a shallow feature, responding to the tearing of the lithosphere under the pull of the descending slabs. Furthermore, the descending lithospheric plates are active components of down welling, and they serve to transport cold material into the mantle.

Convective Flow in the Mantel

Convective flow in the mantle-in warm, less dense rocks rise and cooler, denser material sinks- is the most important process operating in the earth's interior. Thermal convection is the driving force that propels the rigid lithospheric plates across the globe, and it ultimately generates the earth's mountain belts and worldwide earthquake and volcanic activity. Furthermore, the upward flow of hot material from the core-mantle boundary is responsible for transferring most of the heat that is lost from the earth's interior. Driving this flow is heat given off by the decay of radioactive elements within the mantle, as well as heat transferred by conduction from the core to the mantle.

Recently, some new techniques have become available that may significantly enhance our knowledge of convective flow in the mangle. One analytical tool, called seismic tomography, is similar in principle to CAT scanning (computer aided tomography) which is used in medical diagnoses.

Whereas CAT scanning uses X-rays to penetrate the human body, information on the earth's interior is obtained from seismic waves triggered by earthquakes. Like CAT scanning, seismic tomography uses computers to combine data to build a three-dimensional image of the object that the waves have traversed. In tomographic studies, the information from many criss-crossing waves is combined to map regions of "slow" and "fast" seismic velocity. In general, regions of slow seismic velocity are associated with hot, upwelling rock, whereas regions of fast seismic velocity represent areas in which cool rock is descending.

Early seismic tomography studies reveal that the flow in the mantle is far more complex then simple convection cells, in which hot material gradually rises at ridge crests and cold material slowly descends at subduction zones. It appears that upwelling is confined to a few large cylindrical structures, one of which is centered beneath west central Africa and another located beneath the south central Pacific. Embedded in theses zones of upwelling are most of the earth's hot spots. Furthermore, these studies show down welling beneath convergent boundaries where plates are being sub ducted. This flow appears to extend to the lower mantle, but other interpretations of the data are possible. Although seismic tomography has provided new information about convective flow in the mantle, its usefulness has been limited by an inadequate number of digital seismic stations. To overcome this limitation, a project is underway to improve quality by increasing the number of seismic stations carrying out this kind of research.

Another innovative technique called numerical modeling has been employed to simulate thermal convection in the mantle. Simply, this method uses high speed computers to solve mathematical equations that describe the dynamics of mantle like fluids. Because of a number of uncertainties, including precise knowledge of the mode of mantle heating, a range of conditions are simulated. The results of these studies can be graphically represented. One study concludes that down welling occurs in sheet like structures, supporting seismic evidence that descending lithospheric slabs are an integral part of mantle circulation. Furthermore, large cylindrical mantle plumes were found to be the main mechanism of upwelling in the mantle. These simulations also verify that mid-ocean ridges are not a consequence of active upwelling from deep in the mantle. Rather, upwelling beneath ridge crests is a shallow and passive response to fracturing of the plates under the pull of sinking slabs.

LIMITATION/CRITICAL EVALURATION OF PLATE TECTONICS

1. Now days, scientists explain PT as Global Tectonics or New Global Tectonics. This is a unified concept of sea floor spreading, continent drift and plate tectonics. The new global tectonics deals with the entire history of earth; but plate tectonics has a much shorter time frame.
2. In 1968 when plate tectonics theory was propounded, the 1st assumption was that the surface area of the earth is constant. If this is true, the rate of creation of crust along divergent boundaries should be equal to rate of destruction. But today it is found that the length of diverging boundaries is much longer than converging boundaries. That means creation is greater than destruction and this implies expanding earth. This idea of expending earth was 1st propounded by JKE Halm, a South African geologist in 1935.

According to him the earth was only 60% of what it is today when it formed. Moreover, there is already evidence for slowing down of earth's rotational speed. This further corroborated the idea of expanding earth but there is no existing proof.

3. Plate tectonic is inadequate to explain why certain boundaries developed and some die down without fully developing (why African rift valley die down? Why no movement?)

4. Why the converging/ transform/ divergent boundaries are there where they are? Why rising limb of convection current is there where they are? This explanation is possible only if we understand the exact behaviour of the convection currents.
5. Consider the Indian Ocean ridge system. If Himalayas fuse with the Eurasian plate, the diverging boundaries of Austral-Indian plate in southern Indian Ocean will be affected. What will be the effect of this fusion is not being explained by the palate tectonic theory. After the fusion, will the divergent boundary cease to operate.
6. The most important confusion is on the Driving Mechanism itself. Though the theory is not relied on the Driving mechanism, the theory will be more complete if the Driving Mechanism is also explained.

VALCANOES

Principal types of Volcanoes:

1. Shield:

Shape and size: Broad, gently sloping mountain, much broader than high; size varies greatly.

Structure: Layers of flows.

Magma & Eruption Style: Magma usually basaltic; characterized by quiet eruption of fluid lava.

Examples: Hawaiian, Island Tahiti.

2. Composite:

Shape and size: Large, steep-sided, symmetrical cone; heights to over 12,000 ft (3700m)

Structure: Layers of lava flows, pyroclastics & hardened mudflow deposits.

Magma & Eruption Style: Magma usually intermediate in chemistry, often andesitic; long life spans; characterized by both explosive eruptions of phyroclastics and quiet eruptions of lava.

Example: Mt. Fuji, Japan, Mt. Rainier, WA, Mt. Shasta, CA Mt. Vesuvius, Italy, Mt.St. Helens, WA.

3. Lava Dome (Plug Dome):

Shape and size: Usually small, typically less than 2000ft (600m) high; sometimes irregular shape.

Structure: Solidified lava that was thick viscous when molten; plug of lava often covered by pyroclastics; frequently occur within the crater of composite volcano.

Magma & Eruption Style: Magma usually high in silica, often rhyolitic; dome grows by expansion of viscous lava from within ; explosive eruptions common.

Example: Lassen Peak, CA , Mono Craters, CA

4. Cinder Cone:

Shape and size: Small, steep-sided cone; maximum height 1500ft(500m)

Structure: Loose pyroclastic material; may be composed of ash or cinder-size pieces.

Magma & Eruption Style: Chemistry of magma varies, often basaltic; short life span; pyroclastics ejected from central vent; occasionally produce lava flows.

Example: Paricutin, Mexico, Sunset Crater, AZ.

NSTRUSIVE VULCANISM

When magma solidifies below Earth's surfaces, it produces igneous rock. If this rock is pushed upward into the crust either before or after solidification, it is called an igneous intrusion. In many cases, the intrusion is exposed at the surface. When intrusions are thus exposed to the external processes, they often become conspicuous because they are usually resistant to erosion and with the passage of time stand up relatively higher than the surrounding land. Although there is almost infinite variety in the formats assumed by igneous intrusions, most can be broadly classified according to a scheme that contains only halfdozen types.

BATHOLITHS:

By far the largest and most amorphous intrusion is the batholith, which is a subterranean igneous body of indefinite depth and enormous size [it must have a surface area of at least 40 square miles (100 square kilometers) to be a batholith]. Batholiths often from the core of major mountain ranges, their intrusive uplift being a fundatmental part of the mountain-building process.

STOCKS:

Similar to batholith but much smaller is a stock. It is also amorphous and of indefinite depth, but it has a surface area of only a few square miles at most. Many stocks apparently are off shoots of bathliths.

LACCOLITHS:

A specialized form of intrusion is the laccolith, which is produced when slow-flowing, viscous magma is forced between horizontal layers of preexisting rock. If this dome is near enough to Earth's surface, a rounded hill will rise, like a blister, above the surrounding area.

Batholiths, stocks, and laccoliths are sometimes grouped under the general heading plutons, which simply means any large intrusive igneous body.

DIKES:

Probably the most widespread of all intrusive forms is the dike, a vertical or nearly vertical sheets of magma thrust upward into preexisting rock, sometimes forcing its way into vertical fractures and sometimes melting its way upward. Dikes are notable because they are vertical, narrow and usually quite resistant to erosion.

SILLS:

A sill is also a long, thin intrusive body, but its orientation is determined by the structure of the preexisting rocks. It is formed when magma is forced between strata that are already in place; the result is often a horizontal igneous sheet between horizontal sedimentary layers.

VEINS:

Least prominent among igneous intrusions but widespread in occurrence are thin veins of magma that may occur individually or in profusion. They are commonly formed when molten material force itself into small fractures in the preexisting rocks, but they can also result from melting by an upward surge of magma.

VOLCANISM AND PLATE TECTONICS

The origin of magma has been a controversial topic in geology almost from the very beginning of the science. How do magmas of different composition arise? Why do volcanoes located in the deep-ocean basins primarily extrude basaltic lava, whereas those adjacent to oceanic trenches extrude mainly andesitic lava? Why are basaltic lavas common at the earth’s surface, whereas most granitic magma is emplaced at depth? Why does an area of igneous activity commonly called the “Ring of Fire” surround the Pacific Ocean? New insights gained from the theory of plate tectonics are providing some answers to these questions. We will first examine the origin of magma and then look at the global distribution of volcanic activity as viewed from the model provided by plate tectonics.

ORIGIN OF MAGMA:

Based on available scientific evidence, the earth’s crust and mantle are composed primarily of solid rock. Further, although the outer core is a fluid, this iron- rich material is very dense and remains deep within the earth. If this is true, what is the source of magma that produces the earth’s volcanic activity?

Since the molten outer core is not a source of magma, geologists conclude that magma must originate from essentially solid rock located in the crust and mantle. The most obvious way to generate magma from solid rock is to raise its temperature. In a near surface environment, silica-rich rocks of granitic composition begin to melt at temperatures around 750^{o}C, whereas basaltic rocks must reach temperatures above 1oo5r0^{o}C, before melting commences.

What is the source of heat that melts rock? One source is the heat liberated during the decay of radioactive elements that are found in the mantle and crust. Workers in underground mines have long recognized that temperatures get higher as they descend to greater depths. Although the rate of temperature increase varies from place to place, it averages between $20^{o}C$ and $30^{o}C$ per kilometer in the upper curst. This gradual increase in temperature with depth is known as the geothermal gradient.

The geothermal gradient is thought to contribute to magma production in tow important ways. First, at deep-ocean trenches, slabs of cool oceanic lithosphere descend into the hot mantle. Here hear supplied by the surrounding rocs is thought to be sufficient to melt the subducting oceanic curst and produce basaltic magma. Second, a hot, mantle derived magma body as just described could migrate to the base of the crust and intrude silica-rich. Because granitic rocks have melting temperatures well below those required to melt basalt, heat derived from the otter basaltic magma could melt the already warm crustal rocks. The volcanic activity that produced that vast ash flows in Yellowstone National Park is believed to have resulted from such activity. Here basaltic magma from the mantle transported heat to the crust, where the melting of silica-rich rocks generated explosive lavas.

If temperature were the only factor that determined whether or not rock melts, the earth would be a molten ball covered with a thin, solid outer shell. This, of course, is not the case. The reason is that pressure also increases with depth. Since rock must expand when heated extra heat is required to melt buried rocks in order to overcome the effect of confining pressure. In general, an increase in the confining pressure causes an increase in the rock's melting temperature, and a reduction in confining pressure causes the rock's melting temperature to decline. Consequently, a drop in confining pressure can lower the melting temperature, and a reduction in confining pressure causes the rock's melting temperature to decline. Consequently, a drop in confining pressure can lower the melting temperature of rock sufficiently to trigger melting. This occurs whenever rock ascends, thereby moving into zones of lower pressures.

Another important factor affecting the melting temperature of rock is its water content, in general the more water present, the lower the melting temperature. The effect of water on lowering the melting point is magnified by increased pressure. Consequently , "wet" rock under pressure has a much lower melting temperature that "dry" rock of the same composition. For example at a depth of 10 kilometers, wet granite has a melting temperature of about 657^{o}C,whereas dry granite begins to melt at temperatures approaching 1000^{o}C. Therefore, in addition to rock's composition, its temperature, confining pressure, and water content determine whether the rock exists as a solid or liquid.

One important difference exists between the malting of a substance that consists of a single compound, such as ice, and the melting of igneous rocks. Which are mixtures of several different minerals. Whereas ice melts at a definite temperature most igneous rocks melt over a temperature range of a few hundred degrees. As a rock is heated, the first liquid to form will contain a higher percentage of the low-melting temperature minerals than the original rock. Should melting continue, the composition of the melt will steadily approach the overall composition of the rock from which it is derived. Most often, however, melting is not complete. This process, known as partial melting produces most, if not all magma.

An important consequence of partial melting is that it generates a melt with a chemical composition that is different from the original rock. In particular, partial melting generates a melt that: (1) is enriched in the elements found in the low-melting-temperature silicate minerals; and (2) is higher in silica than the original material. Recall that ultramafic rocks contain mostly high-melting –temperature minerals that are comparatively low in silica, whereas granitic rocs are composed primarily of low-melting-point silicates that are enriched in silica. Consequently, magmas generated by partial melting are nearer the granitic end of the compositional spectrum then the material from which they formed.

Most basaltic magmas are believed to originate from the partial melting of the rock peridotite, the major constituent of the upper mantle. Laboratory studies confirm that partial melting of this dry; silicapoor rock produces magma having a basaltic composition. Since mantle rocks exist in environments that are characterized by high temperatures and pressures, melting often results from a reduction in confining pressure. This can occur, for example, where mantle rock ascends as part of a slowmoving convection cell.

Due to the fact that basaltic magmas form many kilometers below the surface, we might expect that most of this material would cooled and crystallize before reaching the surface. However, as dry, basaltic magma flows upward, the confining pressure steadily diminishes and further reduces the melting temperature. Basaltic Magmas appear to ascend rapidly enough so that as they enter cooler environments the heat loss is offset by a drop in the melting point. Consequently, large outpourings of basaltic magmas are common on the earth's surface.

Conversely, granitic magmas are thought to be generated by partial melting of water-rich rocks that were subjected to increased temperature. As a wet granitic melt rises, the confining pressure decreases, which in turn reduces the effect of water on lowering the melting temperature. Further, granitic melts are high in silica and thus more viscous than basaltic melts. Thus in contrast to basaltic magmas that produce vast outpourings of lava, most granitic magmas lose their mobility before reaching the surface and therefore tend to produce large intrusive features such as batholiths. On those occasions when silicarich magmas reach the surface, explosive pyroclastic flows, such as those that produced the Yellowstone Plateau, are the rule.

Even though most magma is thought to be generated by partial melting, once formed the composition of a magma body can change dramatically with time. For example, as a magma body migrates upwards, it may incorporate some of the surrounding country rock. As the country rock is assimilated, the composition of the magma is altered. Further, magma often undergoes magmatic differentiation. This produces a magma quite unlike the parent material. These processes account, at least in part, for the fact that a single volcano can extrude lavas with a wide range of chemical compositions.

DISTRIBUTION OF IGNEOUS ACTIVITY

For may years geologists have realized that the global distribution of igneous activity is not random, but rather exhibits a very definite pattern. In particular, volcanoes that extrude mainly andesitic to granitic lavas are confined largely to continental margins or volcanic island chains located adjacent to deep-ocean trenches. By contrast, most volcanoes located within the ocean basins, such as those in Hawaii and Ice-land, extrude lavas that are primarily of basaltic composition. Moreover, basaltic rocks are common in both oceanic and continental settings, whereas granitic rocks are rarely observed in oceanic regions. This pattern puzzled geologists until the development of the plate tectonic theory which greatly clarified the picture.

Most of the more than 600 active volcanoes that have been identifies are located in the vicinity of convergent plate margins. Further, extensive volcanic activity occurs out of view along spreading centers of the oceanic ridge system. In this section we will examine three zones of volcanic activity. These active areas are found along the oceanic ridges, adjacent to ocean trenches, and within the plates themselves.

1. Spreading Center Volcanism

As stated earlier, perhaps the greatest volume of volcanic rock is produced along the oceanic ridge system where seafloor spreading is active. As the rigid lithosphere pulls apart the pressure on the underlying rocks is lessened. This reduced pressure, in turn, lowers the melting temperature of the mantle rocks.

Partial melting of these rocks (primarily peridotite) generates large quantities of basaltic magma that move upward to fill the newly formed cracks.

Some of the molten basalt reaches the ocean floor, where it produces extensive lava flows or occasionally grows into a volcanic pile. Sometimes this activity produces a volcanic cone that rises above sea level as the island of Surtsey did in 1963. Numerous submerged volcanic cones also dot the flanks of the ridge system and the adjacent deep-ocean floor. Many of these formed along the ridge crests and were moved away as new oceanic crust was created by the seemingly unending process of sea-floor spreading.

2. Subduction Zone Volcanism

Recall that trenches are sites where slabs of water-rich oceanic crust are bent and descent into the mantle. Considerable evidence suggests that magma is generated within the descending slab, as well as in the wedge-shaped area of the mantle overlying it. By the time the subducting plate reaches a depth of 100 kilometers, it has been heated enough to drive off water and other volatile components. The upward migration of water into the wedge of peridotite in the mantle above lowers the melting temperature of the rock sufficiently to promote partial melting. Ultimately, the descending slab is heated sufficiently that it too begins to melt. The processes just described are thought to generate basaltic as well as andesitic magmas.

After a sufficient quantity of magma has accumulated, the melt slowly migrates upward because it is less dense than the surrounding rock. When subduction volcanism occurs in the ocean, a chain of volcanoes called an island arc is produced. Examples are numerous in the Pacific and include the Aleutian Islands, the Tonga islands, and the Mariana islands.

When subduction occurs beneath continental crust, the magma generated is often altered before it solidifies. In particular, magmatic differentiation and the assimilation of crustal fragments into the ascending magma body can lead to a melt exhibiting an andesitic to granitic composition. The volcanoes of the Andes Mountains, from which andesite obtains its name, are examples of this mechanism at work.

Many subduction volcanoes border the Pacific Basin. Because of this Pattern, the regions has come to be called the Ring of Fire. Here volcanism is associated with subduction and partial melting of the Pacific sea floor. As oceanic plates, sink, they carry sediments and oceanic crust containing abundant water downward. Because water reduces the melting point of rock, it aids the melting process. Further, the presence of eater contributes to the high gas content and explosive nature of volcanoes that make up the Ring of Fire. The volcanoes of the Cascade Range in the northwestern United States, including Mount St. Helens, Mount Rainier, and Mount Shasta, are all of this type.

3. Intraplate Volcanism

The processes that actually trigger volcanic activity within a rigid plate are difficult to establish. Activity such as in the Yellowstone region and other nearby areas produced rhyolitic pumice and ash flows, while extensive basaltic flows cover vast portions of our Northwest. Yet these rocks of greatly varying composition actually overlie one another in several locations.

Since basaltic extrusions occur on the continents as well as within the ocean basins, the partial melting of mantle rocks is the most probable sources for this activity. Recall that earth tremors indicate that the island of Hawaii does in fact tap the mantle. One proposal suggests that the source of some intraplate basaltic magma comes from rising plumes of hot mantle material. These hot plumes which may extend to the core-mantel boundary, produce volcanic regions a few hundred kilometers across called hot sports . More than 100 hot sports have been identified and most appear to have persisted for a few tens of millions of years. A hot spot is believed to be located beneath the island of Hawaii and one may have formerly existed beneath the Columbia Plateau.

Generally lavas and ash of granitic composition are extruded from vents located landward of the continental margins. This suggests that remelting of the continental crust may be one of the mechanisms responsible for the formation of these silica- rich magmas. But what mechanism causes large quantities of continental material to be melted? One proposal suggests that a thick segment of continental curst occasionally becomes situated over a rising plume of hot mantle material. Rather than producing vast outpourings of basaltic lava as occurs at oceanic sites such as Hawaii, the magma from the rising plume is emplaced at depth. Here the incorporation and melting of the surrounding country rock, coupled with magmatic differentiation, result in the formation of a secondary, silica-rich magma which slowly migrates upward. Continued hot spot activity supplies heat to the rising mass, thereby aiding its ascent. The activity in the Yellowstone region may have resulted from just this type of activity.

Although the plate tectonics theory has answered many of the questions which have plagued volcanologists for decades, many new questions have arisen; for example, why does sea-floor spreading occur in some areas and not others? How do hot spots originate? These are just two of many unanswered questions that are the subject of continuing scientific research.

MOUNTAIN BUILDING PROCESS

Orogeny is fundamental process in the differentiation of earth's crust. The term Orogeny was coined by GK Gilbert (1890) to describe the process of mountain building. Mountains are landforms of the second order distributed all over the globe not only upon the continents but also upon the ocean floors. The problem of mountain building has long puzzled geologist though there has been no lack of theories to account for the process. Geologists have known for a long time that the Fold Mountains have been built up of vast accumulation of sedimentary deposits which have been squeezed, folded and uplifted but the precise mechanism whereby this was affected has long eluded them.

Since Fold Mountains represent the world's a major and most complex mountain systems the process of mountain building is usually described in terms of their formation. However mountains can be classified according to their most dominant characteristics and the process of formation.

1. **Residual/Relict Mountains** are remnants of former (old) mountains and plateaus, which have been subject to severe denudation. They are formed by differential erosion because of differing solubility and erodability of rocks in the region. Certain resistant areas may withstand the lowering by agent of denudation as in mountain Monodnock USA and also a plateau may be dissected by rivers as in Deccan Plateau, by leaving behind residual mountains.
2. **Volcanic mountains** are formed by the accumulation of volcanic material round the zone of volcanic eruption. Oceanic ridges are formed by spreading boundary volcanism. Converging boundary volcanism produces island arc like Japanese arc. In-pate volcanism at hotspots may produce volcanic mountains like in Hawaii.
3. **Fault/Block Mountains** are formed by vertical movements of blocks along faults because of tensional forces or occasionally compressional ones at work in a region. As a result the block is moved up relative to the neighbouring areas, forming the mountains. Black Forest, Vosges and Hunstruck mountain present good example.
4. **Up warped Mountains** are formed by up warping of continental crust relative to the surrounding. Magmatic intrusion which usually causes the up warping is ultimately exposed due to erosion of the overlying material. Up warping in a limited area forms dome mountains which look like blisters in the earth's surface. Large scale up warping when dissected by agents of denudation forms a mountain range.

5. **Fold Mountains** comprise the largest and the most complex mountain systems. Although fold mountains differ from one another on particular details but all possess some common features:
    a. They are arranged in linear belt generally consisting of roughly parallel ridges.
    b. They consist of thick sedimentary sequences most of which are of shallow marine origin.
    c. They all have folded structures.
    d. Faulting, thrusting, metamorphism and igneous activity are present in varying degree. Examples of Fold Mountains are Himalayan, Alps, Andes, Appalachian, Urals etc.

    Several theories have been suggested to account for successive orogenies during the course of earth's history. The major orogenies have occurred at intervals of 20 to 100my. For practical purposes, however, these periods of mountain building may be divided into three broad groups.

    a. Young mountain building
    b. Old mountain building
    c. Ancient crystalline shieds

6. **Early theories** of Fold Mountain Orogeny were dominated by contractionist approach. The contractionists considered the earth as a heat engine running down i.e. cooling and contracting. Based on this basic premise they put forward teir theories of mountain building e.g.

a) **HAROLD JEFFERYS** suggested that Fold Mountains are simply wrinkles in the earth's crust produced as the earth cooled from its original semi molten state.

b) **JOLY** suggested periodic melting and solidification of thesimatic layer due to radioactive heat and consequent sinking or buoying up of sialic layer (continental crust). Thus process creates horizontal compressive forces causing folding, thrusting and upliftment of sediments at the continental margins resulting into the formation of mountains.

These two and many other early theories could not gain wide acceptance. Any viable theory must explain the deposition of thick sedimentary sequences in shallow marine water their compaction, folding, upliftment, faulting, thrusting, metamorphism and the associated igneous activity.

Geosynclinal theory

Geocyncoinal theory was the first theory to receive wider acceptance because it threw light on most of the characteristic of Fold Mountain and the process involved in their formation. It was during 1850s by James Hall and later modified by Dana during 1870s. They were the first to talk about the existence of long linear troughs called syncline and subsidence of crust under the weight of deposition. These theorists essentially explain Orogeny in five stages:

a)Geosynclinal stage:

In this stage vast amounts of sediments accumulate on a large linear trough which keeps subsiding under the weight of deposition. Due to isostatic adjustments the layer below sediment deposition in the continental shelves becomes synclinal.

b) Lithogenesis:

It is the process by which deposited sediments are converted into solid rocks by compaction and cementation.

c) Tectogenesis:

It is the process by which the earth's crustal rocks are deformed and their structures created. When such process acts regionally they contribute to orogenesis.

d) Orogenesis: It is a process which includes folding, faulting and thrusting during which sediments within geosynclines are bulked and deformed as they are compressed into long linear mountain chains. Simultaneously some sediment, on being pushed much deeper, melts to generate magma, which moves upwards and intrudes the overlying sediments. Thus a complex mountain chain consisting of folded and faulted sedimentary and metamorphic rock is created. This stage is comparatively short lived.

e) Glyptogenesis: It is a post orogenetic phase during which the characteristic surface forms are sculptured by erosion. Removal of material from the top and consequent upward isostatic adjustment exposes the batholith from underneath the mountain ultimately forming a shield.

Although the geosynclinal theory proves for the basic steps in mountain building the underlying cause of orogenesis was not explained and there were Raised against the theory. What produced the subsidence in the geo-syncline? Why did sediments accumulate, relatively undisturbed for millions of year's and suddenly go through a period of deformation? Such unanswered questions forced geologists to continue to evaluate the complex problem of mountain building.

Plate tectonic modal:

It is an improvement over the geosynclinals idea. It explains the various process in mountain building and decipher many of the puzzling aspects

Orogenesis results as large segments of earth's lithosphere are displaced according to this theory. Fold mountain orogeny occurs along converging plate boundaries. Here the colliding plates provide for the Compressional stress to fold, fault, metamorphose, thrust and uplift the thick sedimentary accumulations along the margins of continents while melting of the sub-ducted oceanic lithosphere provides a source of magma that intrudes and extrudes, further deforming and metamorphosing theses deposits.

However the characteristics of mountain belts and the sequence of events vary depending on the type of interaction at plate margins and the type of rock sequence involved in the deformation.

There are three type of converging interactions ocean to ocean, continent to ocean and continent to continent collisions.

1. Orogenesis at Island Arc (Ocean to Ocean Oreogenesis); Island arc are formed where two oceanic plates converge and one is sub-ducted beneath the other. Simple ocean-to orogensis is restricted largely to volcanic activity and does not involve widespread metamorphism or granitic intrusions. An example is the Tongan island arc in south Pacific. Complex Ocean to ocean orrogenesis involves crustal deformation, metamorphism and granitic intrusions as well as volcanic activity producing a complex island arc. An example is the Japanese arc.
2. Orogenesis along continental margins (cordilleran type- continent to ocean orogenesis): In This situation continental and oceanic plates collide and the later is sub-ducted and consumed beneath the former. Sediments and topographical features upon the oceanic crust will be chipped off and get accumulated at the continent thus thickening the sequence of sediments. This material is deformed into a folded mountain belt with miogeoclinal sediments (clean, well stored, shallow marine sand shale and limestone) located near the continental interior and the eugeoclinal deep marine turbidities located near the oceanic margins, granitic batholiths and metamorphosed sediments occur in the peeper zones of the orogenic is common resulting in silica rich magma placed upon or within the continental crust. The Andes, Rockies and Appalachian mountains offer good examples of such orogenesis
3. Continent to continent Orogenesis – Eurasian type : In the tectonic system, virtually all-oceanic crust is destined to descend into the mantle by the subduction processes at convergent plate margins. Eventually tow continents collide to produce the Eurasian type of Orogeny.

It involves the deformation of oceanic and geoclinal sediments and commonly produces the most complex and the most imposing high mountain ranges. As two continents converge the oceanic crust is caught between then and deformed. A double layer of continental crust can be produced resulting in abnormally high topography. The descending oceanic plate becomes detached in the sub-duction zone and sinks independently when this slab is consumed, volcanic activity and deep focus earth quakes cease to exist. The Himalayas , Alps, Ural and Atlas mountains provide good example of such orogenesis.

The question of why earth has mountains has not been satisfactorily answered until recently. The question becomes more important with the recognition of the fact that folded mountain belts are unique to earth. Mountains provide a record of ancient plate motion and a history of Earth's dynamics. The knowledge of orogeny will demystify orogenic puzzles and help us in better understanding of the origin and evolution of earth's crust and several other geological process. Fold mountain orogeny, which is a fundamental process in density differentiation and leads to continental accretion.

MOUNTAIN BUILDING (ADDITIONAL)

Mountain Building and Island Arcs

Over an extended period, numerous episodes of volcanism coupled with the buoyancy created by intrusive igneous masses, gradually increase the size and elevation of the developing arc. The arc's greater height accelerates the erosion rate and consequently the amount of sediment added to the adjacent sea floor and to the back-are basin. In addition to the sediments derived from land, deep-water deposits are also scraped off the descending oceanic plate. As these sediments are piled up in front of the overriding plate, they form what is known as an accretionay wedge that is eventually large enough to stand above sea level.

Landward of the trench, in the volcanic arc, sediments are also being deformed and metamorphosed. Whereas metamorphism in the accretionary wedge is primarily the result of strong compressional forces created by the converging plates, metamorphism in the vicinity of the volcanic arc is associated with the emplacement of large magma bodies.

These diverse activities result in the creation of a mature island are composed of two roughly parallel orogenic belt.

Geologist has only recently come to realize the significance of island arcs in the process of mountain building. There is now general agreement that the processes operating at modern island arcs represent one of the stages in the formation of the earth's major mountain belts. Because island arcs are carried by moving oceanic plates, it is possible for two arcs to collide and sutured together to form a larger crustal fragment. Moreover, island arcs may also be accreted to continent-sized blocks, in which case they become incorporated into a mountain belt.

SUBDUCTION- TYPE OROGENESIS ALONG CONTINENTAL MARGINS:

The first stage in the development of an Andean- type mountain belt occurs prior to the formation of the subduction zone. During this period the continental margin is passive; that is, it is not a plate boundary but a part of the same plate as the adjoining oceanic crust. Here deposition of sediment on the continental shelf is producing a thick wedge of shallow-water sandstones, limestones, and shales. Beyond the continental shelf, turbidity currents are depositing sediments on the continental slope and rise.

At some point the continental margin becomes active; a subduction zone forms and the deformation process begins. A good place to examine an active continental margin is the west coast of South America. Here that Nazca plate is being subducted beneath the South American plate along the Peru-Chile trench.

Once the oceanic plate descends to about 100 kilometers, partial melting generates magma that migrates upward, intruding and further deforming these strata.

Andean-type mountain belts, like mature island arcs, are composed of two roughly parallel zones. The landward segment is the volcanic arc, which is made up of volcanoes and large intrusive bodies intermixed with hightemperature metamorphic rocks. The belt located seaward of the volcanic arc is the accretionary wedge. It consists and volcanic debris.

Continental Collisions:

The development of a mountain system produced by a continental collision is believed to occur as follows:

1. After the breakup of a continental landmass, a thick wedge of sediments is deposited along the passive continental margins, thereby increasing the size of the newly formed continent.
2. For reasons not yet understood, the ocean basin begins to close and the continents begin to converge.
3. Plate convergences results in the subduction of the intervening oceanic slab and initiate an extended period of igneous activity. Thus activity results in the formation of a volcanic are with associated granitic intrusions.
4. Debris eroded from the volcanic arc and materials scraped from the descending plate add to the wedges of sediment along the continental margins.
5. Eventually, the continental blocks collide. This event, which often involves igneous activity, severely deforms and metamorphoses the entrapped sediments. Continental convergence cause these deformed materials, and occasionally slabs of crustal material, to be displaced up onto the colliding plates along thrust faults. This activity shortens and thickens the crustal rocks, producing an elevated mountain belt.
6. Finally, a change in the plate boundary ends the growth of the mountains. Only at this point do the processes of erosion become the dominant forces in altering the landscape to the average thickness of the continents.

This sequence of events is thought to have been publicated many times though out geologic time. However, the rate of deformation and the geologic and climatic settings varied in each instance. Thus, the formation of each mountain chain must be regarded as a unique event.

A Geosyncline is a large subsiding trough of deposition, a huge but gentle depression in the crust that slowly fills with sediments from higher adjacent land areas. It looks like the simple depression i.e. sometimes called a syncline, but it is so large that the term Geosyncline is used.

TYPES OF GEOSYNCLILNES WERE LATER IDENTIFIED:

- Miogeosynclines developed along continental shelves, are found where rivers bring enough sediment to the sea for huge, subsiding deltas to form, as at the mouths of the Nile and the Mississippi. They mainly consist of limestones and well-sorted quartzose sandstones and from the evidence of shallow-water formation of geosynclines. These rocs generally from in the inner segment of geosyncline.
- Eugeosynclines,, developed seaward along continental rises, coincide with the deep ocean trenches that form where one plate of the earth's curst plunges (is subducted) beneath another. Thick volcanic sequences, together with graywackes (sandstones rich in rock fragments with a muddy matrix) cherts, and various sediments reflecting deepwater deposition or processes, were deposited in eugeosynclines, the outer, deepwater segment of geosynclines. Sediments and volcanic rocks in theses trenches have been crupled and thrust up from the ocean floor to from mountains such as the Coast Ranges of western North America.
- Taphrogeosyncline, a depressed block of the Earth's crust that is bounded by one or more hig-angle faults and that serves as a site of sediment accumulation.
- Paraliageosyncline, a deep geosyncline that passes into coastal plains along continental margins.

The filling of a geosyncline with thousands or tens of thousands of feet of sediment is accompanied in the late stages of deposition by folding, crumpling, and faulting of the deposits,. Intrusion of crystalline igneous rock and regional uplift along the axis of the trough generally complete the history of a particular geosyncline, which is thus transformed to a belt of folded mountains.

CHARACTERISTICS OF GEOSYNCLINES:

1. Geosynclines are long, narrow and shallow depressions of water.
2. Geosynclines are characterized by gradual sedimentation and subsidence.
3. Geosynclines are generally bordered by two rigid masses which are called forelands.
4. The nature and patterns of Geosynclines have not remained the same throughout geological history, rather these have widely changed.

THE OCEAN FLOOR ,

SEAFLOOR SPREADING

The concept of sea-floor spreading was formulated in the early 1960s by Harry H. Hess of Princeton University. Late, using deep-diving submersibles, geologists were able to support Hess thesis that sea floor spreading occurs along relatively narrow zones located at the crests of ocean ridges. Along the East Pacific Rise the active zones of seafloor formation appear to be only about a kilometer wide, whereas along the Mid-Atlantic Ridge these zones may extend for tens of kilometers. As the plates move apart, magma intrudes into the newly created fracture zone and generates new sections of Oceanic crust. This apparently unending process generates new lithosphere that moves from the ridge crest in a conveyor-belt fashion.

The East Pacific Rise has a relatively fast rate of spreading that averages about 6 centimetres per year and reaches a maximum of 10 centimetres per year long a section of the ridge located near Easter Island. Bu contrast, the spreading rate in the North Atlantic is much less, averaging about 2 centimetres per year.

Apparently the rate of spreading strongly influences the appearance of the ridge system. The slow spreading along the Mid-Atlantic Ridge is believed to contribute to its very rugged topography and large central rift valley. By contrast, the rapid spreading of the East Pacific Rise is thought to account for its more subdued topography and the lack of a well- defined rift valley through much of its length. Despite these differences, all ridge systems are thought to generate new sea floor in a similar manner.

The ocean floor consists of three distinct layers. The upper layer is composed mainly of pillow basalts. The middle layer is made up of numerous interconnected dikes called sheeted dikes. Finally the lower layer is made up of gabbro, the coarsegrained equivalent of basalt that crystallized at depth. This sequence of rocks is called an ophiolite complex.

PROCESS:

The magma that migrates upward to create new ocean floor originates from partially melted peridotite in the asthenosphere. In the region of the rift zone, this magma source may lie no more than 35 kilometers below the sea floor. Being molten and less dense than the surrounding solid rock, the magma gradually moves upward where it is believed to enter large reservoirs located only a few kilometers below the ridge crest. As the ocean floor is pulled or pushed apart, numerous fractures develop in the crust, permitting this molten rock to migrate upward. During each eruptive phase, the initial flows are thought to be quite fluid and spread over the rift zone in broad, these sheets. As new lava flows are added to the ocean floor, each is cut by fractures that allow additional lava to migrate upward and form overlying layers. Later in each eruptive cycle, as the magma in the shallow reservoir cools and thickens, shorter flows with a more characteristic pillow form occur. The magma that does not flow upward will crystallize at depth to generate thick units of coarse grained gabbro.

Because newly formed sections of the ocean floor are warm, they are also rather buoyant. This buoyancy is thought to cause large blocks to shear from the sea floor and be elevated. Along the Mid Atlantic Ridge, uplifted sections from nearly vertical walls that border the central rift zone. As sea-floor spreading continues, the earlier-formed blocks are wedged away from the ridges axis and replaced by more recently formed segments of ocean crust. This process contributes to the imposing height of the Mic-Atlantic Ridge as well as to its topography.

The primary reason for the elevated position of a ridge system is the fact that newly created oceanic crust is hot, and therefore it occupies more volume then cooler rocks of the deep-ocean basin. As the young lithosphere travels away from the spreading centre, it gradually cools and contract. This thermal contraction accounts in part for the greater ocean depths that exist away from the ridge. Almost 100 million years must pass before cooling and contraction cease completely. Bu this time, rock that was once a part of a majestic ocean mountain system is located in the deep-ocean basin, where it is mantled by thick accumulations of sediment.

OPENING AND CLOSING OF THE OCEAN BASINS:

A great deal of evidence has been gathered to support the fact that Wegener's vast continent of Pangea began to break apart about 200 million years ago. The breakup of Pangea and the formation of the Atlantic Ocean basin apparently occurred over a span of nearly 150 million years, with the last phase.

It seems reasonable to assume that the slow movement of mantle material could initiate continental margins and the large number of hot spots located along ridge crests led some geologists to a different conclusion. They have proposed that hot sports initiate continental fragmentation.

Hot spots are generally characterized by large outpourings of basaltic lava for relatively long periods of time. Worldwide, as many as 120 isolated volcanic sites have been attribut4ed to hot spot activity. Since hotspots appear to remain nearly stationary over extended time periods, they form volcanic trails, such as the Hawaiian chain, upon the moving oceanic plates above.

The Canadian geologist J Tuzo Wilson and his associated have suggested that when a thick segment of continental lithosphere remain stationary over a hot spot for an extended period, the conditions are right for continental rifting. Initially, upwelling of material from below generates a dome, roughly 200 kilometres in diameter, within the overlying continental crust. As the dome enlarges, it fractures with a characteristics three-armed pattern. Rifting continues along tow of the arms, resulting in the development of a new ocean basin, while the third arm often fails to develop further. An example of such a three-armed rift system is believed to be represented by the Red Sea, the Gulf of Aden and the Afar lowlands. Here the arm extending from the Afar Lowlands into the interior of Africa is the failed arm. The two active arms have subsequently generated long, narrow seas.

Professor Wilson suggested that about 20 hot spots guided the fracturing of Pangea.

In 1966, Willson also proposed that several times in the geologic past the continents joined to form a supercontinent, which later broke apart. The term Willson cycle is now applied to the cyclic processes that are responsible for the rifting of continents to form ocean basins and the subsequent closing of ocean basins to produce supercontinents. In their modern form, Wilson cycles begin with a stationary supercontinent composed of thick continental crust. Because continental crust is a poor conductor of heat, it acts like a thick blanket retarding the outward flow of heat from the mantle. Thus, a buildup of heat causes the supercontinet to bulge upward and eventually break apart. Upwelling of hot material between the rifted continental fragments produces a new ocean floor. This activity also increases the rate of heat flow from the mantle. As the ocean basin grows in size, the sea floor cools and becomes denser. After perhaps 200 million years, the oldest part of the ocean floor becomes dense enough to sink into the mantle. The subduction of the continents, which eventually collide to once again form a supercontinent. The time period of each complete cycle, from breakup to reassembly of the continents, is thought to take about 500 million years.

Although the Wilson cycle has not yet gained general acceptance, it does seem to explain the evolution of the continental margins surrounding the Atlantic. In particular, the closing of the proto-Atlantic is believed to have caused a collision between North America and Africa and Europe that resulted in the formation of the Appalachian mountain belt. The breakup that followed this event is once again dispersing these continental fragments around the globe.

When an ocean closes and reopens, the zone of fragmentation may not occur at the same location as the suture where the landmasses were joined. During the closing of the proto-Atlantic about 400 million years ago, the suture formed along a mountainous belt extending from Alabama to the British Isles and Norway. However, when the Atlantic began to reopen about 200 million years ago, the split occurred along a some what different trend. Thus the sizes the shape of continental fragments appears to change through time.

ISOSTASY

The state of balance which the earth's crust tends to maintain or to return to by isostatic compensation if anything occurs to upset that balance. This is based on the principle of buoyancy first outlined by Archimedes. It is best illustrated by a high mountain chain, which rises above the surface of the earth, but has to be compensated by deep roots.

Isostasy is a condition of equilibrium between floating landmasses and the asthenosphere beneath them, maintained despite the forces that tend to change the landmasses all the time. **Historical Background**:

- In 1840's Sir George Everest conducted the first topographical survey in India.

- He surveyed the distance between two towns Kalianpur and Kaliana, located South of Himalaya.
- He surveyed by both triangulation as well as Astronomical methods
- But astronomical calculation placed these two cities closer by 150m
- JH Pratt estimated the mass of Himalayas and discovered that the error should have been 3 times than that of observed
- George Airy suggested lighter crustal rocks inside mountains, that extend far beneath them and these mountains would exert a smaller gravitational attraction than that Pratt has calculated.

THEORIES PRATT'S CONCEPT:

According to him, there is an inverse relationship between the height and their respective densities

Different relief features are standing only because of the fact that their respective mass is equal along the line of compensation because of their varying densities.

Thus Pratt's concept of isostasy is related to the law of compensation and not to the law of floatation

AIRY'S CONCEPT

According to him the density of different Colums of land (eg mountains, plateaus, plains etc) remains the same.

This means the continents are made of rocks having uniform density, but their thickness of length varies from place to place.

Airy's concept is based on law of floatation i.e. "Uniform density with varying thickness"

If we apply Airy's concept then in the case of the Himalayas 8848m height, there must be a root, 9 times more in length than the height of the Himalayas, in the substratum. Thus, for 8848m part of the Himalayas above, there must be downward projection of lighter material beneath the mountain reaching a depth of 79632m.

LIMITATION

If we accept the Airy's views of isostasy, then every upstanding part must have a root below in accordance with the height. Thus, the Himalayas would have a root equivalent to 79632m. It would be wrong to assume that the Himalayas would have a downward projection of root of lighter material beneath the mountain reaching such a great depth of 79632m because such a long root, even if accepted, would melt due to very high temperature prevailing there, as temperature increases with increasing
depth at the rate of $1^{o}c$ per 32m.

ISOSTATIC ADJUSTMENTS- TYPES.

1. When denudation lowers the mountains, compensation causes the mountains to be uplifted to maintain isostatic equilibrium.
2. Because of isostatic mechanism, continental masses which are depressed under the load of an ice sheet will gradually recover as the ice melts-glacio-isostasy.
3. River mouths will sink due to the great accumulation of sediments.
4. Development of coral reefs will result in gradual sinking
5. Adjustment due to large scale volcanic eruption.

GLOBAL ISOSTATIC ADJUSTMENT

There is no complete isostatic adjustment over the globe because the earth is so unresting and thus geological forces (endogenetic forces) coming from within the earth very often disturb such isostatic adjustment.

When an uplifted landmass or mountain is worn down by the agents or erosion, the load on the underlying column of the crust is reduced by the weight of the material that has been eroded away. At the same time a neghbouring column underlying a region of delta and seafloor where the denuded material is being deposited, receives a corresponding increase of load. At the base of the crust the pressure exerted by the unloaded column is decreased, while the pressure exerted by the loaded column is increased. In response to this pressure difference in the mantle there is a sub-crustal slow flow is sima from under the loaded column therefore sinks while the unloaded column rises. This process whereby isostatic equilibrium is restored is call isostatic adjustment. This is made possible by a compensating transfer of materials in the subcrust.

ISOSTASY AND EROSION

Scientific experiments have indicated that, at present rates of erosion, the earth's mountain ranges would be leveled in a single geologic period, certainly within 50 million years. But mountains hundreds of millions of years old, such as the Appalachians of the eastern United States, still stand above their surroundings. What seems to happen is that as erosion removes the load from the ridges, isostatic adjustment raises the rocks to compensate. Rocks formed deep below the surface, tens of thousands of meters down, are thereby exposed to our view and t weathering and erosion.

The sialic mountains along the plate margin may have been pushed beyond the elevation justifies by the depth of their roots, and isostatic readjustment will not commence until the overload has been removed. After that, the mountain masses undergo isostatic uplift as mass is eroded, a process that ensures their persistence for a long time.

Slow accumulationis now taking place in the Mississippi Delta. For millions of years, the great river has been pouring sediments into its delta, but these deposits have not formed a great pile nor have they filled in the Gulf of Mexico. Isostatic adjustment constantly lowers the material to make room for more.

PLAINS AND UPLANDS

The sisalic crust has certain rigidity. It does not behave, as in Airy's model, as a series of discrete columns. Therefore, isostasy affects plains and plateaus in phases for a certain period; the amount of material removed does not trigger isostatic readjustment because the hardness of the crust prevents continuous uplift. Thus, at any given moment, an area may not be in isostatic equilibrium. Instead, it waits the time when readjustment is forced by the removal of a sufficient mass of landscape.

Scientists suggest that this periodic adjustment may also occur in mountain ranges, especially older ones. In the beginning, when the sialic root is deep, almost continuous isostatic uplift occurs. But as time goes on the root becomes shorter, erosion continues, and comparatively more eroded material must be removed for readjustment to occur.

EARTHQUAKES

- It is estimated that over 30,000 Earthquakes, strong enough to be felt occur world wide annually
- About 75 significant earthquakes take place each year
- The shaking of the ground coupled with the liquefaction of some soils wreaks havoc on buildings
- Also when a quake occurs, power and gas lines are often ruptured, causing numerous fires.

Earthquake:

An earthquake is the vibration of the earth produced by the rapid release of energy. This energy radiates in all directions from its source, focus.

The energy released by atomic explosions or volcanoes can also produce an earth quake, but are usually weak and infrequent.

The Plate Tectonic Model proposes that large slabs of the earth are continually in motion. These mobile plates interact with the neighbouring plates, straining and deforming their edges.

It is along faults associated with plate boundaries that most earthquakes occur. Moreover earthquakes are repetitive.

MECHANISM

1. Tectonic forces slowly deform the crustal rocks on both sides of the fault.
2. Under these conditions, rocks bend and store elastic energy
3. Eventually, the forces holding the rocks together, are overpowered
4. Slippage occurs at the weakest point and displacement will take place along the fault
5. Rocks behave elastically and vibrations occur, as the rocks return to its original shape.

Thus earthquakes are produced by the rapid release of elastic energy stored in rock that has been subjected to great differential stress. Once the strength of the rock is exceeded, it suddenly ruptures, which results in the vibrations of an earthquake.

- In addition, several small earthquakes called foreshocks often precede a major earthquake by several days or even years. Monitoring these foreshocks help in predicting a major earthquake.

MOVEMENT

- Vertical movement along the faults can result in earthquakes. This can result in either crustal upliftment or even large scale subsidence.
- In many cases horizontal movement along large faults are seen eg: In 1906 San Francisco earthquake, the Pacific Plate slid as much as 4.7m in a northward direction past the adjacent North American Plate.

But the displacements along discrete segments are different.

1. Some portions exibit a slow gradual displacement known as creep which occurs with little a noticeable activity.
2. Some other segments regularly slip producing small Earthquakes
3. Still some other segments remain locked and store elastic energy for hundreds of years before rupturing in great Earthquakes. This process is described as stick slip motion.

It is estimated that great earthquakes occur every 50 to 200 years along those sections of San Andreas Fault that exibit stick slip motion.

Vertical displacement, in which a cliff is formed, is known as a fault scrap

DESTRUCTION AND WAVES

- EQ produces 3 types of waves. But surface waves are responsible for maximum destruction.
- Two types of motion are there in a surface wave
- In addtition to the up and down motion it generates lateral motion. This lateral motion is particularly damaging to the foundations of structures.
- In any solid material, P waves travel about 1.7 times faster than S waves and surface waves travel about 0.9 times the velocity of the S waves.
- But S waves have slightly greater amplitude then P waves, while the surface waves which cause the greatest destruction exibit even greater amplitude.
- Since the surface waves are conferred to a narrow region near the surface, they retain their maximum amplitude for longer time,. Surface waves also have longer periods, and are often referred to as Long Waves.

EARTHQUAKE BELTS

- 95% of EQs are along plate boundaries
- 3 types

1. Shallow

2. intermediate

3. **deep**

EARThQUAKE INTENSITY AND MAGNITUDE

Intensity is the measure of the effects of an earthquake. It not only depends on the strength of the EQ, but also the distance from the epicenter, the nature of the surface materials and building design e.g: Mercalli Scale Magnitude: Richter scale.

ENDOGENETIC FORCES

The forces operating within Earth are complex of unimaginable strength, and largely mysterious.

Energized by awesome forces within Earth, the internal processes actively reshape the crustal surface. The crust is buckled and bend, land is raised and lowered, rocks are fractured and folded, solid material is melted, and molten matcrial is solidified. These actions have been going on for billions of years and are fundamentally responsible for the gross shape of the lithospheric landscape at any given time.

The forces affecting changes in the landforms can be divided into the following two categories.

1.Endogenetic Force:

This force is generated in the interior of the earth and cause mountains, plateaus, etc., to subside.

2.Exogenetic Forces:

These forces are produced and act on the surface of the earth. Wind, water and snow are such forces which erode the surface of the earth or make depositions on it. These external (exogenentic) forces are also called processes.

On the bases of intensity, these forces can be divided into two sub-groups:

i)Sudden Endogenetic Forces:

The main forces in the sub-group are volcanic or of earthquake. Landscape undergoes disintegration suddenly. For example, production of deep fissures in plain areas, the sudden changes in the routes of river, the formation of small hills, etc., are some of the effects of these forces.

ii)Diastrophic Forces:

These forces act very slowly. Their effect becomes discernable after thousands of years. For example, the coast of the Baltic sea rises by 1.3 metres in a century. There are a large number of places where the coast is either rising or sinking. The diastrophic forces from the point of view of areal distribution can be divided into two further subgroups.

a)Epeirogenetic Force:

This word is formed of the word Epeirs meaning Continent. In other words, the continents either rise or sink due to the play of these forces. These forces act along the radius of the earth. Hence, it is also called Radial Force. According to direction it can be divided as upward Force and Down ward Force.

Upward Force:

Many landforms have been formed by upward force. For example, there are many up-raised terraces where the sea fossils are found buried in abundance. Such terraces are found at a height of 34.5 metres in Britain. It proves that these terraces were once submerged in the seas. Such terraces are found Norway even at the height of 183 metres. Other examples which prove the rise of areas are sea-caves which are found at great heights nowadays. There are many examples of the rise of coast in Kathiawar peninsula. Coral Reefs are found at a great height in the Indian and Pacific oceans.

Downward Force:

Many landforms displaying the action of this force can be quoted. Many forest areas have been submerged in sea, near the coast of Devon and Corwall in

UK. Excavation near Tirunelveli on the eastern coast of India, the submerged Peat and lignite near Pondicherry and the vegetation fossils in the Ganga delta all go the prove the submergence of areas.

b)Orogenetic Forces:

These forces act on the earth's mantle in a horizontal direction. Hence, these forces are also called Tangential Forces. When tension is produced by these forces, the earth surface displays fissures and when compression is produced, folds result in the sedimentary rocks.

FAULTS

The nature of faults; Faulting can be caused by either radial or tangential forces (tensional and Compressional). The rocks of the earth's crust are subjected to tension and compression when radial or tangential forces operate. If one part of the crust is compressed then clearly another part must be stretched, i.e. put under tension. Rock under tension usually faults, but under compression they may fault or fold.

Tension causes a normal fault, compression causes a reverse fault and lateral movement (parallel to the fault) causes a tear fault. Escarpments, called fault scarps, develop if faulting is accompanied by upward or downward movements of adjoining parts of the crust.

JOINTS

Cracks often develop in rocks when they are subjected to strain produced by compression or tension. The strain may be caused by earth movements, or by contraction when molten rocks solidify, or by the shrinking or sedimentary rocks on drying. The cracks formed are called joints.

FOLDS

When tangential forces operate as forces of compression, folding usually takes place. The layers of rock which bend up form an up form an up fold or anticline. Those that bend down form a down fold or syncline. The sides of the fold are called the limbs. The line of the highest points along the anticline is called the crest of the anticline.

If compression continues then a simple fold is first changed into an asymmetrical fold where one limb is steeper than the other, then into an over fold and finally into an over-thrust fold.

EARTH MOVEMNTS BEHIND LANDFORMS

The face of the earth is forever changing. Earth movements within and below the crust produce landforms of great area and often of great height, while the agents of denudation, i.e. rain, frost, river, ice, wind and wave, constantly work on the landforms modifying their appearance. In doing so, the agents of denudation transport vast quantities of sediment (rock debris which they have derived from the land) most of which is eventually deposited in the seas.

As denudation wears away the continents, their weight decreases by this does not necessarily mean that they are being lowered. It is thought that a re-adjustment takes place in the crust which causes the continents to rise.

MAJOR LANDFORMS

We have seen that earth movements cause rocks to fault and fold, and that they are the cause of earthquakes and vulcanicity. In general terms lateral (tangential) movements produce features such as Fold Mountains while up and down (radial) movements produce features such as Block Mountains and rift valleys, plateaus and basins.

Major landforms can be put into three main groups, these are: mountains, plateaus and plains.

MOUNTAIN

PLATEAUS AND RELATED LANDFORMS

Vertical earth movements can cause the crust to warp and sometimes large areas of it are uplifted whilst others are depressed. The uplifted areas form plateaus, sometimes called tectonic plateaus, and the depressed areas basins. There are two types of tectonic plateaus. Some slope down to surrounding lower land e.g. the Deccan Plateau of India. Other plateaus slope up to surrounding mountains and these are called intermountain plateaus. The Tibetan and Bolivian plateaus are example.

PLAINS AND RELATED LANDFORMS

A plain is an area of level or gently undulating land usually near to sea level or a few hundred metres above it. Plains are one of the most important landforms because they are the home of the bulk of the world's population. Most of the fertile soils are located on plains and they are both extensively and intensively cultivated. Plains are basically the product of denudation and because of this they will be examined in relation to the water cycle.

GEOMORPHIC IDEAS OF DAVIS AND PENCK

DAVIS

W.M. Davis published his basic thesis on the cycle of erosion in 1899, considered some complications associated with the cycle in 1904 and brought out his main ideas together in a single work in 1909, and went on modifying and extending his views in a number of ways for the next 30 years.

Davis coined the familiar phrase "landforms are a function of structure, process and stage."

There are probably none who doubt the importance of structure and process in landform development. But, today many doubt the validity of stage as a major factor. The following statement brings out Davis's idea of stage:

"As the differential erosional agents act upon the earth's surface there is produced an orderly sequence of landforms having distinctive characteristics at the successive stages of their development".

Based on this idea of stage Davis organized the orderly sequence of landforms into the concept of geomorphic cycle and its concomitant stages of **YOUTH, MATURITY** and **OLD STAGE**. Using a simple, descriptive, interpretive, deductive approach and using simplifying assumption (some of which he knew not to justifiable in nature to make the exposition easier, he explained how the cycle operated. An Initially flat or nearly flat landscape is rapidly uplifted. Erosion then proceeds under prolonged tectonic stability and the landscape passes through the stages of youth maturity and old stage, each having a distinctive and recognizable characteristic. The end product is a surface of low relief nearly a flat landscape- which Davis termed as PENEPLAIN. The peneplain is almost similar to the initial land surface, and thus a CYCLE of events has truly been run, since renewed uplift would trigger off the same sequence of events once again.

INTRODUCTORY EPISODE:

There is a short introductory episode of uplift (represented by dotted lines). The vertical distance AB is the measure of the average initial relief.

INITIAL STAGE:

In the initial stage of the cycle the floor of the valleys suffer down-cutting and are lowered but the summit of mountains remain relatively unaffected. This increases the relief, which is visible from the two lines of the graph getting away from each other. When the characteristics of the initial levels are eroded away the relief becomes maximum. This is the beginning of the mature stage represented by CD.

MATURE STAGE:

As the land form enters the mature stage, Vertical erosion slows down and horizontal erosion becomes important. During this stage mountain tops are eroded fast and their heights reduced actively. The floors of the valleys, however, are lowered slowly. As a result, the two lines AC and BD come closer to each other, representing reduction in relief.

OLD STAGE:

In the later stages of the cycle the convergence of the curves continues but the process is immensely protracted in time. On account of the reduction in heights, and, the gentler slopes the process of erosion and slope reduction is slowed down. The continuance of the curves on the extreme right represents the old stage.

Devis's cycle of erosion has distinct stages along with special characteristics. Here an attempt has been made to outline some of the characteristic features of the fluvial cycle of erosion.

THE TERN "NORMAL":

The processes eroding the landscape were grouped together by Davis under one heading, 'NORMAL'. He did not explicitly define 'normal' but by implication he meant the assemblage of processes dominating the temperate landscapes of N.America and Europe (where he worked) and especially the action of running water. That is, by the term 'normal' he meant the fluvial cycle of erosion.

BASE LEVEL, INTERRUPTIONS IN CYCLE: PARTIAL CYCLES

The concept of base level is crucial to Davis's thesis, and he examined the effect of minor uplift in detail. Late he acceded that due to intermittent and differential uplifts partial cycles instead of completed cycles may result. Many landforms are polycyclic with partial cycles.

He was also aware that the cycle might not be able to run its full course because of climatic changes. He viewed glaciation, aridity and called them accidents. Later he was even convinced of the need to formulate a separate cycle for arid regions.

CRITICISM OF DAVIS'WORK

1. **In over- emphasising** stage Davis has given relatively lesser attention to structure as an important controlling factor and thereby ahs done injustice to his own statement that landforms are a function of structure, process and stage.
2. **Davis did not make a detailed study of the mechanics** and nature of the present day processes neither in theory nor in the field.

3. His use of the term 'normal' has been severely criticized. By implication his normal cycle mean the assemblage of processes dominating the temperate landscapes of N. America and Europe, where he worked, especially the action of running water i.e. The fluvial cycle of erosion. Since the humid temperate mid latitude landscapes cover proportionately very small area on the globe, application of the term normal is questionable. In the temporal sense also the term is inappropriate because the mid-latitude landscapes are just emerging from an orogenic period. They are also just emerging from the ice age (to be more precise they are almost certainly in an interglacial stage). In the context of conditions that have occurred in the geological past, present conditions re not normal but unique.
4. **The concept of grade** as defined by Davis has proved elusive.
5. **The assumption of initial rapid uplift and erosion proceeding only after complete upliftment and under prolonged Tectonic stability is unsatisfactory.**
6. Davis has comparatively neglected depositional processes as a factor in landform formation. This is faithfully reflected in the title-cycle of erosion.
7. Davis **neglected biological processes completely**. This is quite surprising because he based his work on well vegetated mid latitudes.
8. Environmental changes may cause interrupted cycles giving rise to partial cycles and polycyclicity. Davis conceded this fact but this is not enough. The point is, the environmental changes mean periodic changes or processes also, so landforms will be polygenetic not just polycyclic.
9. Davis never measured form. Impressions of slope form are notoriously inaccurate and misleading.
10. The cycle of erosion has a descriptive simplicity and is a gross generalization useful only at elementary level, but inadequate when a more sophisticated approach to landform evolution is attempted.

11. Davis's work is a deductive approach. This means basing an argument on certain assumptions, and proceeding or inferring from the general to the particular. This is unscientific; Scientific method is the inductive approach, which builds on experimental evidence from particular instance to general references.

MERITS

Inspite of all these limitations the Davision concept of cycle of erosion provides for a very useful framework with in which to investigate the evolution and change of the landscape. But for his ideas we would possibly never have talked about slope changed and landscape evolution. He is the founder of the idea of Geomorphic Cycle or the Cycle of Erosion.

CRITICAL ANALYSIS OR DAVIS' GEOMORPHIC IDEAS

Most geomorphologists do believe that landforms have an orderly and sequential development. However they are not convinced that stages of youth, maturity, and old age as postulated by Davis have reality. They consider Davis's concept as a gross generalization useful only at the elementary level, but inadequate when a more sophisticated approach to landform evolution is attempted. Thus, whether there are distinctive and expectable characteristics at each stage of development is a point about which there has been increasing skepticism. Especially there has been increasing doubt on the reality of peneplain as the end product of an erosion cycle.

Most geomorphologist now believe that the term geomorphic cycle carries with it the implication only of orderly and sequential development, but carries no implication that designation of the topography of a certain area as youthful, mature and old means that the topography of another region in the same stage of development has full comparable characteristics. Actually under varying conditions of geology, structure and climate, landform characteristics may vary greatly even though the geomorphic process may have been acting for comparable periods of time.

Moreover, although passage of time is implied in the concept of geomorphic cycle, it is in the relative rather than an absolute sense that it is accepted today. There is no implication that two areas that are in comparable stages of development have required the same length of time for their attainment.

Much confusion has arisen because of considering geomorphic cycle as the period of time required for reduction of an area to base level rather than as changes through which a landmass passes as it is reduced tot the base level.

Partial cycles are a corollary to the concept of complete geomorphic cycle. In fact, partial cycles are more likely to occur than completed ones, for most of the earth's crust is restive and subject to intermittent and differential uplift. Only sometimes, the portions of earth's crust remain essentially stable for sufficient periods of time to permit the attainment of advanced stages of landscape evolution. Even in this case, partial cycles leave back some of their imprints. Polycyclic landforms, with partial cycles are much common than, with successive completed cycles

Again, landforms are rarely carved out by a single geomorphic process. In most cases landforms are polygenetic.

PENCK

In the 1920's while he was still publishing frequently, Davis attracted criticism from a German geologist, Walter Penck. Penck worked for many years in S. America. In his "Die Morphologische Analyse" (1924) he offered a philosophy of geomorphology which some have considered a serious challenge to the teaching of Davis. His work is in difficult German prose. But its English version "Morphological Analysis of landforms" was brought out by Czech and Boswell (1953).

DAVOS AND PENCK SAW GEOMORPHOLOGY THROUGH DIFFERENT EYES

According to Davis the primary goal of geomorphic studies is the effective description of the features of he earth's surface.

Penck on the other hand held the view that the main purpose of geomorphological research is to obtain information that might contribute to the understanding of the earth's crustal movements i.e. of the endogenetic forces that had acted upon and are acting to influence the topographic feature of any particular region.

PENCK'S IDEAS ON SLOPES

He made the following assumptions:

1) Any slope, even if curved is in effect made up of a number of straight slope segments called slope units.
2) All slope units undergo parallel retreat.
3) The rate of slope retreat =f (gradient) i.e. steep slopes retreat quicker than gentle slopes. The above three assumptions were build into a theory of slope and landscape evolution that rested on one more vital assumption.
4) The shape of slope (and thus shapes of landscapes in general) was determined by the relative importance of exogenetic and endogenetic processes.

He thought that the slopes of any region are essentially similar in gradient and that the "intensity of erosion" determined the characteristics of the slopes. Three situations were visualizes:

a) Convex Valley Side Slopes:

This results from an increasing intensity of erosion (which also implies an accelerating rate of uplift

b) Straight Valley Slide slope:

This result from a constant intensity of erosion. The resultant landscape is Mitterelief (medium relief) Slope steepness would depend on the rate of incisions.

c) Concave Valley slide Slopes:

This result from a declining intensity of erosion (which also means a decelerating rate of uplift)- waning development. Though factors other than crustal movements also influence the intensity of erosion, Penck considered the endogenetic processes to be the most important.

CRITICIAM

Probably majority of geologist are unwilling to accept Penck's view that the shape of slopes depends on the intensity of erosion as conditioned by the nature of endogenetic processes Valley side slopes are undoubtedly affected by numerous other factors such as lithology, structure, climate, nature of debris produced by weathering and its mode of transport. It is too much to assume that they reflect mainly the nature of crustal movements, which have affected a particular area.

PENCK'S BACKWASTING AND DAVIS' DOWNWASTING

One of the most recognized concepts of Penck is that of slope replacement from below. As a given straight slope unit retreats parallel to itself it is replaced from below by another straight slope unit of gentler gradient. Since the steeper slope units will retreat more rapidly than the gentler once, the gentler slope will eventually replace the steeper one above it.

As the process continues each slope is successively replaced by progressively gentler slopes from below.

To a degree both Penck and Davis believed that flattening of slopes take place as land dissection goes on but they arrived at progressively flatter slopes in different ways. Penck believed that flattening of slopes took from below upwards through extension of the lower gradient slopes at the expense of the higher gradient slopes. Thus, according to him reduction of a landmass is largely a matter of back wasting of slopes. Davis, however, believed the slope flattening took place from above downwards. Thus, reduction of landmass according to him was a matter of down wasting.

PENCK'S PRIMARUUMPF AND CYCLE FO EROSION:

COMPARISON WITH DAVIS' CYCLE OF EROSION AND PENEPLAIN CONCEPT

Penck considered that the diastrophic conditions necessary for the progress of an erosion cycle, as envisaged by Davis, with its resultant peneplain represent a special and uncommon case an not a normal one. He was particularly dissatisfied with Davis' assumption of very rapid uplift followed by a prolonged period of structural stability Penck built his whole body of the theory on the alternative assumption of uplift so protracted in time that the landscape would be eeroded at the same time as it was being uplifted i.e. rates are such that the relief remains practically the same. Such a condition would give rise to a low, rather featureless plate which he called primarrumpf (called primary peneplain by Sauer).

As Penck pointed out, the primarrumpf looks like an end peneplain, but is actually at the beginning of a sequence of landforms. Primarrumpf forms the universal initial geomorphic unit for all the topographic sequences that follow. After it formation, the subsequent history of the primarrumpf depends upon whether it is under waxing, waning or constant development e.g. with waxing uplift may be elevated high above sea level, but It remains a primarrumpf even though it undergoes degradation.

Penck termed the terminal plain which resulted from the degradation of a landmass which has had high relief as endrumpf. Thus, primarrumpf is the initial stage in a period of diastrophism marked by accelerated uplift (waxing development) and the endrumpf is the end stage of a period of degradation marked by declining uplift (waning development).

Penck opposing Davis's rapid uplift concept said that the process of uplifting continues for a long time. It is not reasonable to think that erosion does not start till the upliftment is complete. Penck also emphasized that the rate of upliftment is not uniform.

1.First Stage:

It is evident from the figure that the height of the summits of interfluves (by A) increases with the rise of the land. As the downcutting by rivers is not brisk, the height of the lower part (by B) also rises, and does not keep pace with the upheaval, so that both absolute altitude and relief increases. The flat interfluves are little eroded and gain in altitude by the amount of upheaval.

2.Second Stage:

Even in this stage the rate of downward cutting of valleys is less than that of upliftment. The land as a consequence rises slowly. Due to horizontal cutting by rivers the land becomes narrow and sharp. The irregularities of the surface remains almost the same (i.e. relief remains almost constant)

3.Third Stage:

The rate of downward cutting to the same as the rate of upliftment. Both, the height (altitude of the interfluves and the relief remains constant).

4.Fourth Stage:

In this stage upliftment has ceased. Valley depending continues. The higher of interfluves also decreases. Relief remains constant.

5.Fifth Stage:

The deepening of the valleys is slowed down. The height of interfluves begin to decrease and ridges get rounded and their height decreases. Both altitude and relief decrease slowly.

6.Formation of Pedeplains.

THE OTHER CYCLES OF PENCK

Penck in the first cycle supposed that the upliftment of land was long and continuous process. Some of the results derived by Penck in his studies of different parts of Europe are important. The stages of this cycle proved to be true in the middle parts of the Alps but Penck's cycle could not be successfully applied to the peripheral parts of the Alps. Hence Penck thought of other cycles.

PENCK'S SECOND CYCLE

If land is uplifted in a short period of time, its stages of evolution will not be similar to those of Penck's frist cycle. The interfluves are not angular but their ridges are directly converted into rounded shapes. In the initial stage when the slopes are steep, the valley deepening process is not much rapid.

PENCK'S THIRD CYCLE

The cycle is applicable when the land rises slowly Valley is deepened as fast as the land is raised and widened faster than they are deepened. The flat topped interfluves would be degraded as fast as they are raised and thus, sharp relief could never be attained.

The second and Third cycles of Penck were found true in the peripheral regions of the Alps. Critics say that many similar cycles can be imagined to exist by supposing different rates of upliftment of land. Hence not much can be given to the cycles.

MERITS OF PENCK'S CYCLES

1. Penck has done his work on a large scale. He has given a lot of details. The whole work was carried in a systematic manner.
2. Since he followed a deductive approach his results are not limited to any special condition of development.
3. The important contribution of Penck lies in the fact that the cyclic stages depend upon the mutual relation between upliftment and the rate of degradation.

The balance between uplift and degradation as envisaged in stage-3 is true in the middle parts of Alps.

Penck emphasizes the continuous rise of the land and does not believe that the land did not rise once it was uplifted. This is why Penck's hypothesis is known as forward looking.

DEMERITS OF PENCK'S CYCLE

1. It is imaginary to think that all stages of the Penck cycle look place in the same order.
2. Penk's too much emphasis on mutual relation between rises of land and deepening of valley has been severely criticized.
3. Our knowledge of the initial condition of land is inadequate. Hence the facts and estimation of Penck appear to be imaginary.
4. Aspects other than geological are also important but have been given less importance by Penck.

FLUVIAL CYCLE

DRAINAGE:

Youth

A few consequent streams present. Numerous Short tributaries and gullies present which will be extending themselves by headward erosion and developing a valley system.

Maturity

Valleys have extended themselves so that the region has now a well integrated drainage system. Subsequent streams are dominant as tributaries.

Old Stage

Tributaries to trunk streams usually fewer in number than in mature but more numerous than in mature but numerous than in youth.

VALLEY PROFILE

Youth:

Valleys have V shaped cross profiles.

Maturity:

Valleys have open V shaped cross profiles. Interlocking spurs are common.

Old stage:

Valleys are extremely braod and sloping both laterally and longitudinally.

INTERSTREAM TRACTS:

Youth:

Interstream tracts are extensive and poorly drained. Lakes and swamps may exist in the interstream areas if these are not well above the local base levels. Stream divides are broad and poorly defined.

Maturity:

Stream divides are sharp and ridge like resulting in a minimum of interstream uplands.

Old stage:

Interstream areas have been reduced in height and stream divides are not seen as in maturity. Lakes, swamps and marshes may be present but they are in floodplains and not on interstream tracts as in youth.

WATERFALLS ETC:

Youth:

Waterfalls, rapids may be present potholes may present.

Maturity:

Waterfalls, rapids not present.

FLOODPLAINS:

Youth:

There is a general lack of floodplain development.

Maturity:

A slight development of floodplain may occur.

Old stage:

There is a marked development of floodplain.

MEANDERS

Youth:

Stream meandering may exist, but the meanders are those on a flat and undissected initial surface or as closely confined meanders in valleys incised below the upland surface.

Maturity:

Meanders may be conspicuous but as contrasted to those of youth they are free to shift their positions over the flood plain. The widths of the valley floors do not greatly exceed the widths of the meander belt.

Maximum possible relief exists at the beginning of the mature stage.

OLD STAGE:

The river meanders are very broad in the floodplain. The valley widths are considerably more than the widths of meander belt.

Mass wasting and chemical denudation are dominant over fluvial processes. Extensive areas are at or near the base level of erosion.

KARST LANDFORMS AND CYCLE

- The word karst is a comprehensive term applied to limestone of dolomite areas that passes a topography peculiar to and dependent upon underground routes. The term comes from a province of Yugoslavia on the Adriatic sea coast where such formations are most noticeable. Karst topography is the named after rock formation.
- The conditions contributing to maximum development of karst include.

a) location of soluble, highly jointed and thinly bedded, dense rocks near or at the earth's surface

b) Presence of deeply entrenched valley of a master stream and

c) A moderate amount of rainfall.

- The groundwater moves vertically downwards, rises in capillaries, percolates and flows turbulently through large openings. Basic processes involved in the development of topography are solution, corrosion and deposition.

- Features of the karst topography develop on the surface as well as below it. LAPIES are highly rugged surface with marked relief. SINK HOLE is a funnel shaped depression underneath which cylindrical SWALLOW HOLE lies at some depth. These holes virtually forming a BLIND VALLEY DOLINE is formed by unification of many sink holes. As a result of subsidence several doline may merge to form an UVALA – a very large elongated depression occurring on steep slopes. Block movement of limestone due to faulting forms a large and deep depression called POLJE. THE KARST LAKE is formed by lateral colescence of sink hole. Natural bridge represents the remnant of the roof a natural tunnel or subterranean cut off.
- CAVES and CAVERNS are formed by solution and contain some characteristic underground features formed mainly due to deposition of Calcium by evaporating and drying water drops which trickle down from the cave roof. Sharp, slender, downward growing pinnacles hanging from the roof are kwnon as STALALCTITES. The stalagmites RISE UPWARDS FROM THE CAVE FLOOR AND ARE SHORTS, FATTER AND MORE ROUNDED. Eventually they join to form a pillar known as COLUMN.
- Relatively uniform solubility of limestone makes karst landscape simples and more amenable to cyclic evolution.

KARST CYCLE

- While certain karstic features are common to limestone areas, the individual peculiarities of the major karst regions can be better explained in terms of an orderly sequential development by the introduction of a cycle the Dinaric Karst.
- Whether there exists a distinct cycle of landform evolution in karst region or is it better to consider it as karst phase of a fluvial cycle, is a disputed question.

However in most, if not all, karst areas we start with surface drainage and end with it.

- Conditions contributing to maximum development of karst include.

a) location of soluble highly jointed and thinly bedded, dense rocks near or at the earth's surface

b) Presence or deeply entrenched valley of a master stream and

c) A moderate amount of rainfall

- Karst cycle operates, through them movement of groundwater and an intricate combination of basic processes of solution, corrosion, corrosion and deposition.
- INTIATION of karst cycle maybe

a) through uplift above base level of a limestone terrain on which fluvial on erosion and been in progress or

b) Through uplift of an area of elastic rocks beneath with are limestone's lying above the new base level.

- The **Stage of Youth** marked by the presence of lapis, increasing in number and enlarging sink holes and gradually merging doline. There is progressive increase of underground drainage at the expense of surface streams leading to more solution, abrasion and thus enlargement of caves and caverns. Blind valleys are formed by eventual disappearance of surface streams, which also marks the end of youth and beginning of maturity.
- In **The Stage of Maturity** vigorous underground action by solution and abrasion and enlargement of passageways, caves and caverns continues. Such action tends to lower the water table towards the underlying impervious bed, which is the effective base level of underground erosion. Solution action from above and below leads to the thinning of the roof of caverns and their eventual collapse forming uvalas and polies. Karst windows may be seen which are the parts of subsurface stream revealed by

the collapse of a section of cavern roof. Arches, bridges and polie lakes are some other characteristic features of this stage.

- **The stage of old** marks the reappearance of streams and deep entrenched valleys on the surface. All remaining underground caverns will be revealed by continued surface wasting. Over time remaining masses of limestone will be removed and the 'karst peneplain' is left dotted withbay stock like isolated residual hills called hums which are last surviving remnat of cavern walls.
- In a karst region the various stages of karst cycle may be present. The areas remote from the lines of maximum entrenchment by streams will be younger in cycle.

Karst cycle is unique in the sense that term 'cycle' has been applied to the evolution of landforms fashioned from a certain type of rock, instead of under particular climatic condition or by a particular process. Thus disruption in homogeneity of limestone may obstruct wide application and utility of the concept of Karst cycle. Inadequate knowledge about the behaviour of underground water and controversial origin of caverns are other limitations.

Coastal landforms

- Water is ocean is in constant motion. As it moves, it constantly modifies the shore producing a distinctive assemblage of landforms called coastal landforms.
- Waves particularly stem waves and tsunamic, armed with rock fragments are the most powerful agent of marine erosion. Tides extend the line of erosion and currents mainly help in transportation of debris.
- Besides wave strength , there factors, influencing rate of marine erosion include

a) structure, composition and durability of rocks along the shore

b) depth of water offshore, stability of sea level and tidal range,

c) configuration of coastline and openness of shore to wave attack,
d) abundance and size of abrasive tools and
e) Human interference.

- Processes contributing significantly to marine erosion are corrosion, corrosion or abrasion, attrition, hydraulic action and the shock pressure of breaking waves.
- Confined to narrow coastal zone, many topographic features result from marine erosion and deposition. The softer rocks on the coast are worn back into INLETS, COVES or CAPES. When the coast facing the sea has a scarp face resulting from wave erosion, it is known as CLIEF. As a cliff receded landwards due to undercutting, an eroded base called WAVE CUT PLATFORM is left behind, long shore drift may deposit the sediments in deeper waters to form a WAVE BUILT hanging valleys when cliff receded.
- Wave action may hollow out a SEA CAVE IN ZONES OF WEAKNESSES, WHICH ARE LOCI OF ACCELERATED CROSION. Two caves unite to form as ARCH. Eventually the arch collapses and seaward portion o f headland remains standing as an isolated pinnacle called STACK which is further worn down to form a STUMP.
- Wave action on the zone of weakness in cave roof forms a natural shaft called GLOUP or blow hole. When roof collapses a long narrow inlet or geo is formed.
- TIDAL POOLS are deeper depressions on the wavecut platforms. ROCK REEFS are isolated hard resistant parts of platform, which have withstood erosion.
- Sediments transported by waves and long shore drift is deposited to produce a variety of landforms. Sands and gravel loosened from the land are moved by waves to be deposited along the shore as BEACHES. Deposition tangential to the headland, resulting in a ridge or embankment attached to

land at one end and projecting in the open sea at the other is called SPIT. Oblique waves may curve the spit into HOOK. BAR is the ridge formed across the mouth of a river or the entrance to a bay. Connecting bar that joins two landmasses is better known as TOMBOLO.

- BARRIER BEACHIES are elongated sand ridges running parallel to the shore and rising slightly above high tide. A series of these features extending for considerable distance is known as BARRIER CHAIN.
- Scholars like D W JOHNSON have presented a theoretical scheme to explain the sequential development of shorelines passing through the stages of YOUTH, MATURITY and OLD AGE.
- Shorelines and spectacular landforms are especially important to us because of the concentration of population on or near the coast. To live in harmony with this rapidly changing environment, we must understand the coastal dynamic and resultant landforms.

COASTAL CYCLE OF EROSION

Process of erosion and depositions along a shoreline tend to develop along and straight or gently curving coastline. The configuration of the shoreline evolves until energy is distributed equally along the coast, and neither large-scale erosion nor deposition occurs. In the process of attaining such equilibrium, a shore may be regarded as resulting from an initial form, erosion and deposition giving rise to succession of sequential forms passing through the stage of YOUTH, MATURITY and OLDAGE.

D W HONSON (1919) prevented a theoretical scheme to explain the sequential development of shorelines based on Davisian concept of cycle. He accepted that the cycle. He accepted that the cycle may be interrupted by crystal movements, and the coastal topography will vary according to the nature of rocks, the configuration of coastline and the strength of waves and current. He proposed different cycles for submergent and emergent coastlines.

SHORELINE DEVELOPMENT ALONG SUBMERGED COASTLINES:

INITIAL STAGE is marked with an irregular coastline and numerous islands if there was moderate relief.

YOUTHFUL STAGE starts with wave attack concentrated on the headland sea cliffs arches and blow holes may abound as a wavecut platform is developed. Spits, hooks and bars extend out from the cliff and islands often connecting them.

MATURE STAGE the headlands cut back to the level of intervening bays and the coastline is straightened. Connecting bars are removed.

OLD AGE is achieved when waves and currents have reduced the sore to a gently sloping plain while land agents have reduced the relief almost to the sea level.

SHORELINE DEVELOPMENT ALONG EMERGENT CASTLINES:

INITIALSTAGE is an uplifted marine plain into which the waves cut a notch. Offshore bars are common.

YOUTHFUL STAGE sees the growth of the offshore bar and the formation of lagoons linked to the open sea by tidal inlets. The offshore bar is now driven landwards obliterating the lagoon.

MATURE STAGE is the point at which the waves have destroyed the protecting bar and are actively attaching the former raised shoreline.

OLDSTAGE is a theoretical concept. The evolution in profile, hereafter, will not materially from those of shorelines of submergence.

Naturally, the development of a shoreline is also affected by special conditions of structure and topography and by fluctuations of sea level or tectonics. However, the process of erosion of headlands by wave action and the straightening of the shoreline by both erosion and deposition follow the general sequence of these idealized models, although actual shorelines rarely proceed though all of these stages, because fluctuations of sea level upset the previously established balance. Despite the persuasiveness of arguments in favour, it is still not wholly clear whether the cycle of marine erosion has any, any theoretical value.

ARID CYCLE OF EROSION

Based on Davis's idea, the arid cycle of erosion is an idealized cycle, which applies only to mountain deserts where block faulting has produced many enclosed basins. As to open low level deserts the concept of cycle largely fails. Besides wind, water also plays a very important role in cycle. Davis regards this as modification imposed upon the humid cycle by a change to aridity, one of his so called climatic accidents.

Davis envisaged some difference between the humid (normal) cycle and arid cycle as

1. Contrast in run off.
2. Maximum relief in the youthful stage of arid cycle(not in maturity)and progressive decrease thereafter,
3. A prevalence of consequent drainage into enclosed basins, streams are activiely dissecting the mountains,
4. Considerable aggradation of basins in the youthful stage when streams are actively dissecting the mountains.
5. Predominance of local base levels of erosion with few streams showing exorheic tendencies and
6. A 'desert penenplain' in the old age largely by wind removal. In recent years, the tendency has been to emphasis the formation and extension of pediments as the major geomorphic process in the development of the desert landscape. I.C. king who outlined the 'Pediplanation cycle' was perhaps the most ardent supporter of this line of thought.

King started that with the passage of time the low angled slopes gradually extended themselves at the expense of adjacent upland thereby leading to pedimentation. This process of parallel retreat of slope is referred to as ' scarp retreat' or back wearing by king. The twin processes of pedimentation and carp retreat are considered to combine in the cycle of Pediplanation with its distinct stages of youth, maturity and old.

THE STAGE OF YOUTH

The stage of youth is marked by river incision and valley development, increasing relief and the beginning of lateral pediments along the valley side. Pediments become more extended with scarp retreat. However, the remnants of the original pediplain will exist on all summits. By late youth many interfluves will have already been converted into inselbergs, many of which would take the form of remarkably rounded domes i.e. bonhardts and castle koppies. There is an independent centripetal drainage in each basin. If rain water survives strong evaporation a Playa may be formed. The centers of these basins would be the base level of erosion. Ravines and canyons develop in the slopes of highlands which undergo dissection and recession. The divides between the basin would be thus lowered and narrowed. On lower parts of the slope, fans and cones are formed and further down Bajadas may grow. The floodwater emerging from the Canyon mouths after storm rains may tear the fans, into wide channels called wadis.

THE STAGE OF MATURIETY

The Stage of maturity is characterized by shrinking of inter stream hills tracts through extension of pediments by scarp retreat and near destruction of the initial topography. There will be a progressive reduction in the number of inselbergs as these are weathered into Koppies and finally destroyed. The widening pediments of adjacent valleys will begin to coalesce. In this stage, the relief would be further decreased and divides breached by recession of slopes and lowering of ridge summits the higher basins will become tributaries to lower larger ones thus forming a somewhat integrated drainage. By middle maturity continuous uninterrupted gradient may be established from the highest point to the lowest local base level.

In the old stage, the residual uplands of the original topography disappear through intersection of pediment scraps from opposing sides of the uplands. There is an ever-increasing coalescence of pediments culminating in the formation of a multi-concave topographic surface to which the name pediplain is commonly applied. It is marked with minimum relief, achieved not by rivers by gradual lowering of the area by wind action which now dominates though active from the beginning of the cycle.

The eroded surfaces of the end stage may be even below the sea level because of inland drainage and dominance of wind action. The lower limit of deflation, however, may be set by the water table.

The earlier stages of the arid cycle of erosion can be matched in many places. However, considerable dubiety has existed concerning the old stage and the true character and origin of the ultimate plain feature, if any.

Formation of inselbergs and bonhardts especially in the Savana region (inselbergland schaft has evoked diverse explanations. Some schools like Budel, Cotton, Twidale, Ollier and Thomas have suggested that in the savanna landform, 'down wearing' rather then 'back wearing' is the dominant process. They believed that Bonhardts represent residual rock masses that were resistant to chemical weathered rock were eroded away. Amidst such controversies, now, the concept of arid cycle with limited applicability has few adherents.

GLACIAL CYCLE OF EROSION

Based on Davis's idea, W. Hobbs (1992) out lined a scheme to explain the sequential destruction of uplands by back wearing of cirque walls. In this cycle 3 landforms – cirques, arêtes and pyramidal peaks are fundamental. The concept is based in the erosive power of moving ice.

In the youthful stage the pre-glacial surface will be dissected by cirques forming 'grooved uplands'. The cirques will be relatively widely sperced and much of the pre-glacial surface remains intact.

In the adolescent stage smooth topped ridges are broken by well proportioned and enlarging cirques to form ‘early fretted uplands’.

In the mature stage the pre-glacial surface is eaten up by the further enlargement of cirques. Residual summits are now pyramidal peaks and the intervening ridges arêtes. This is an ‘advanced stage of fretted uplands’.

The old stage is the ‘mommental upland’ when arêtes are broken through by cols. The pyramidal peaks are reduced to comb ridges. This stage completes the destruction of the original surface.

Some geo-morphologists have pointed out that the lowering of mountains by ‘glacial peneplanation’ is merely a theoretical abstraction, not matched in the modern landscape, but others suggest that a surface of glacially induced low relief probably exists beneath thick ice-sheets in Antarctica and Greenland.

The attempt to establish a glacial sycle is attractive and useful, but it is as yet not based on sufficient numerous carefully studied examples. It would by premature to accept the theory in it’s entirely.

- COL is the lowest point on a mountain ridge between 2 peaks.

POLYCYCLIC LANDFORMS

- The concept of Polyclicity is a by-product of the idealistic “Davisian Geomorphic Cycle” and its inadequacies to explain the complete process of landscape evolution through time.

  Partial cycles are far more likely to occur for much of the earth’s crust is restive and subject to intermittent and differential uplift causing – **interruptions** in the cycle. Mature or old age topography is likely to have superposed upon it, youthful features as a result of **Rejuvination** which are DYNAMIC, EUSTATIC or STATIC in nature.
- In nature as is the Complexity of Landscape evolution more common than Simplicity so is the polycyclic evolution more common than Monocyclic Development.

- HORBERG presented a five fold classification of Landforms:

1) SIMPLE (one dominant process)
2) COMPUND (two or more process)
3) MONOCYCLIC
4) POLYCYCLIC or MUTICYCLIC
5) DXHUMED or RESURRECTED

- MONOCYCLIC Landscapes bear the imprint of only one cycle of erosion and are restricted to newly created Land Surfaces such as a volcanic cone of a Lava Plateau.
- PLYCYCLIC Landscapes have been fashioned by two or more partial cycles. Much, of not most, of the world's topography is Polycyclic and are found on all continents except Antarctica.
- Polycyclic landscapes can be simple or compound.
- Polycyclic can also result from changes in the climatic conditions with accompanying variationin the dominant geomorphic processes and are alternatively referred to as-
    i. POLYCLIMATIC landscapes e.g. the Great Lakes of North America, Fjord coasts of Norway etc.
    ii. Other Example: The Rejuvenated Landforms e.g. paired rive terraces – older Alluvial plains, two cycle valleys, incised meanders are all Polycyclic in Origin.

GROUNDWATER

Of all the world's water only about six-tenths of one percent is found underground. When the oceans are excluded and only sources of freshwater are considered, the significance of groundwater becomes more apparent. The largest volume occurs as glacial ice. Second in rank is groundwater, with slightly more than 14 percent of the total. However, when ice is excluded and just liquid water is considered, more than 94 percent is ground water.

Geologically, groundwater is important as an erosional agent. The dissolving action of groundwater is responsible for producing the surface depressions known as sinkholes as well as creating subterranean caverns. Another significant role is as an equalizer of stream flow. Much of the water that flows in rivers is not transmitted directly to the channel after falling as rain. Groundwater is thus a form of storage that sustains streams during periods when rain does not fall.

DISTRIBUTION OF UNDERGROUND WATER

When rain falls, some of the water runs off, some evaporate, and the remainder soaks into the ground. This last path is the primary source of practically all subsurface water. The mount of water that takes each of these paths, however, varies greatly both in time and space. Several influential factors include steepness of slope, nature of surface material, intensity of rainfall, and type and amount of vegetation.

THE WATER TABLE

The water table, the upper limit of the zone of saturation, is a very significant feature of the groundwater system. The water table level is important is predicting the productivity of wells, explaining the changes in the flow of springs and streams, and accounting for fluctuations in the levels of lakes.

A number of factors contribute to the irregular surface of water table. For example, variations in rainfall and permeability from place to place can lead to uneven infiltration and thus to difference in the water table level. However, the most important cause is simply the fact that ground water moves very slowly and at varying rates under different conditions. Because of this, water tends to ‘pile up’ beneath high areas between stream valleys. If rainfall were to cease completely, these water table ‘hills’ would slowly subside and gradually approach the level of the valleys.

Even during dry periods, the movement of groundwater into the channel maintains a flow in the stream. In situations such as this, streams are said to be effluent. By contrast, in arid regions, where the water table is far below the surface, groundwater does not contribute to stream flow. Streams that provide water to the water table in this manner are called influent streams.

POROSITY AND PERMEABILITY

Depending upon the nature of the subsurface material, the flow of groundwater and the amount of water that can be stored are highly variable. Water soaks into the ground because bedrock, sediment, and soil contain voids or openings. These openings are similar to those of a sponge and are often called pore spaces. The quantity of groundwater that can be stored depends on the porosity of the material; that is the percentage of the total volume of rock or sediment that consists of pore spaces.

Sediment is commonly quite porous, and open spaces may occupy form 10 to 50 percent of the sediment's total volume.

Porosity alone is not a satisfactory measure of a material's ability or capacity to yield groundwater Rock or sediment may be very porous and still not allow water to move through it. The permeability of a material, its ability to transmit a fluid, is also very important. Groundwater moves by twisting and turning through small openings.

MOVEMENT OF GROUDWATER

Once relatively common misconception regarding groundwater is that it occurs in underground rivers that resemble surface stream. Most groundwater must migrate through the pore space in rock and sediment. The movement of most groundwater is exceedingly slow.

The nearly responsible for groundwater movement is provided by the force of gravity.

The modern concepts of groundwater movement were formulated in the middle of the nineteenth century. During this period Henry Darcy, a French engineer studying the water supply of the city of Dijon in east-central France, formulated a law that now bears his name and is basic to an understanding of groundwater movement. Darcy found that if permeability remains uniform, the velocity of groundwater will increase as the slope of the water table increases.

SPRINGS

When the water table intersects the earth's surface, a natural flow of groundwater results, which we call a spring.

WELLS

The most common device used by humans for removing groundwater is the well, an opening bored into the zone of saturation. Wells serve as reservoirs into which groundwater move and from which it can be pumped to the surface.

ARTESIAN WELLS

The term artesian may be applied correctly to any situation in which groundwater under pressure rises above the level of the aquifer. This does not always mean a free-flowing surface discharge.

For an artesian system to exist, two conditions must be met: 1. water must be confined to an aquifer that is inclined so that one end can receive water; and 2.aquicludes, both above and below the aquifer, must be present to prevent the water from escaping. When such a layer is tapped, the pressure created by the weight of the water above will cause the water to rise

ROBLEMS ASSOCIATED WITH GROUNDWATER WITHDRAWAL

As with many of our valuable natural resources, groundwater is being exploited at an increasing rate. In some areas, overuse threatens the groundwater supply. In addition, a number of costly problems related to the withdrawal of groundwater may accompany and compound the difficulties associated with tapping ground water resources.

The tendency for many natural systems is to establish or attempt to establish a condition of equilibrium. The groundwater system is no exception. The water table level represents the balance between the rate of infiltration and the rate of discharge and withdrawal. Any imbalance will either raise or lower the water table. Long-term imbalances can lead to a significant drop in the water table if there is either a decrease in groundwater recharge, such as occurs during a prolonged drought, or an increase in the rate of groundwater discharge or withdrawal. As we would expect, water tables have gradually dropped in many areas where withdrawal has increased steadily.

SUBSIDENCE

Surface subsidence can result from natural processes related to groundwater. However, the ground may also sink when water is pumped from wells faster than natural recharge process can replace it. This effect is particularly pronounced in areas underlain by thick layers of unconsolidated sediments. As the water is withdrawn, the water pressure drops and the weight of the overburden are transferred to the sediment. The greater pressure packs the sediment grains tightly together and the ground subsides.

SALTWATER CONTAMINATION

In many coastal areas the groundwater resource is being threatened by the encroachment of salt water. Since fresh water is less dense than salt water, it floats on the salt water and forms a large, lens-shaped body that may extend to considerable depths below sea level. In such a situation, If the water table is 1 meter above sea level, the base of the freshwater body will extend to a depth of about 40meters below sea level. Stated another way, the depth of the fresh water below sea level is about 40 times grater than the elevation of the water table above sea level. Thus, when excessive pumping lowers the water table by a certain amount, the bottom of the fresh water zone will rise by 40 times that amount. Therefore, if groundwater withdrawal continues to exceed recharge, there will come a time when the elevation of the salt water will be sufficiently high to be drawn into wells, thus contaminating the freshwater supply. Deep wells and wells near the shore are usually the first to be affected.

GROUNDWATER CONTAMINATION

The pollution of groundwater is a serious matter, particularly in area where aquifers supply a large part of the water supply. A very common type of groundwater pollution is sewage. Its sources include ever-increasing number of septic tanks, as well as inadequate or broken sewer systems and barnyard wastes.

Other sources and types of contamination also threaten groundwater supplies. These include widely used substances such as highway salt, fertilizers that are spread across the land surface, and pesticides. In addition, a wide array of chemicals and industrial materials may leak from pipelines, storage tanks, landfills, and holding ponds.

Since groundwater movement is usually slow, polluted water may go undetected for a considerable time. Most contamination is discovered only after drinking water has been affected. By this tie, the volume of polluted water may be very large, and even if the source of contamination is removed immediately, the problem is not solved. Although the sources of groundwater contamination are numerous, the solutions are relatively few. Once the source of the problem has been identified and eliminated, the most common practice in dealing with contaminated aquifers is simply to abandon the water supply and allow the pollutants to be flushed away gradually.

GEOMORPHOLOGY

Geomorphology, if we go by the Greek roots of the term, would mean 'a discourse on forms of the earth's surface'. Initially, the subject was concerned with unraveling the history of land form development, but now it is also concerned with understanding the processes which create landforms and how these processes operate. In many cases, geomorphologists have tired to model these processes and, of late, some have taken into consideration the effect of human agency on such processes. Basically, geomorphology is the study of the nature and history of landforms and the processes which create them.

Geomorphology is often identified with geology, or considered a branch of geology. The systematic study of landforms, indeed, requires some fundamental knowledge of geology as the genesis and development of all types of landforms is dependent upon the materials of the earth's crust and the forces that emanate from within the earth.

Some fundamental concepts are enumerated by W.D. Thornbury which come into use in the interpretation of landscapes. These are:

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

This is the great underlying principle of modern geology and is known as the principle of uniformitarianism. It was first enunciated by Hutton in 1785, restated by Playfair in 1802, and popularised by Lyell. Hutton taught the "the present is the key to the past," but he applied this principle somewhat too rigidly and argued that geologic processes operated throughtout geologic time with the same intensity as now. We know now that this is not true. Glaciers were much more significant during the Pleistocene and during other periods of geologic time than now; world climates have not always been distributed as they now are, and thus, regions that are now humid have been desert and areas now desert have been humid; periods of crustal instability seem to have separated periods of relative crustal stability, although there are some who doubt this; and there were times when vulcanism was more important than now. Numerous other examples could be cited to show that the intensity of various geologic processes have varied through geologic time, but there is no reason to believe that streams did not cut valleys in the past as they do now or that the more numerous and more extensive valley glaciers of eh Pleistocene behaved any differently from existing glaciers.

2. Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them.

The term structure here is not applied in the narrow sense of such rock features as folds, faults and unconformities but it includes all those ways in which the earth materials, out of which landforms are carved, differ from one another in their physical and chemical attributes. It includes such phenomena as rock attitudes; the presence or absence of joints, bedding planes, faults and folds; rock massiveness; the physical hardness of the constituent minerals; the susceptibility of the mineral constituents to chemical alteration; the permeability or impermeability o rocks; and various other ways by which the rocks of the earth's crust differ from one another. The term structure also has stratigraphic implications, and knowledge of the structure of a region implies an appreciation of rock sequence, both in outcrop and in the subsurface, as well as the regional relationships of the rocks strata. Is the region one of essentially horizontal sedimentary rocks or is it one in which the rocks are steeply dipping or folded or faulted? A knowledge of geologic structure in the narrow sense thus becomes essential.

3. To a large degree the earth's surface possesses relief because the geomorphic processes operate at different rates.

The main reason why gradation of the earth's surface proceeds differentially is that the rocks of the earth's crust vary in their lithology and structure and hence offer varying degrees of resistance to the gradational processes. Some of these variations are very notable while others are very minute, but none is so slight but that it affects, to some degree, the rate at which rocks waste. Except for regions of very recent diastrophism, it is usually safe to assume that areas which are topographically high are underlain by "hard" rocks and those which are low by "weak" rocks, relatively specking. Differences in rock composition and structure are reflected not only in regional geomorphic variability but in the local topography details, or what we may call the mictotopography, is related to rock variations often too minute in nature to be readily detectable.

4. Geomorphic processes leave their distinctive imprint upon landforms, and each geomorphic process develops its own characteristic assemblage of landforms.

Just as species of plants and animals have their diagnostic characteristics, so landforms have their individual distinguishing features dependant upon the geomorphic process responsible for their development. Floodplains, alluvial fans and deltas are products of stream action; sinkholes and caverns are produced by groundwaters; and end moraines and drumlins in a region attest to the former existence of glaciers in that area.

The simple fact that individual geomorphic processes do produce distinctive land features makes possible a genetic classification of landforms. Landforms are not haphazardly developed with respect to one another but certain forms may be expected to be associated with each other. Thus, the concept of certain types of terrain becomes basic in the thinking of a geomorphologist. Knowing that certain forms are present, he should be able to anticipate to a considerable degree the other forms that may be expected to be present because of their genetic relationship with one another.

5. As the different erosional agents act up the earth's surface there is produced an order sequence of landforms.

Under varying conditions of geology, structure and climate, landform characteristics may vary greatly even though the geomorphic processes may have been acting for comparable periods of time. Similarity in the topographic details of two regions would be expectable only if the initial surface, lithology, structure, climate and diastrophic conditions were comparable. Although passage of time is implied in the concept of the geomorphic cycle, it is in a relative rather than an absolute sense. There is no implication that two areas that are in comparable stages of development have required the same length of time for their attainment. Much confusion has arisen from the fact that numerous geologists have defined a geomorphic cycle as the period of time required for reduction of an are to base level rater that as the changes through which a land mass passes as it is reduced toward the base level

6.Complexity of geomorphic evolution is more common than simplicity.

The serious student of landforms does not progress far in his study of them before he come to realise that little of the earth's topography can be explained as the result of the operation of a single geomorphic process or a single geomorphic cycle of development. Usually, most of the topographic details have been produced during the current cycle of erosion, but there may exist within an area remnants of features produced during prior cycles, and, although there are many individual landforms which can be said to be the product of some single geomorphic process, it is a rare thing to find landscape assemblages which can be attributed solely to one geomorphic process, even though commonly we are able to recognize the dominance of one.

7. Little of the earth's topography is older than Tertiary and most of it no older than Pleistocene.

Older discussions on the age of topographic features refer to erosion surfaces dating back to the Cretaceous or even as far back as the Precambrian. We have gradually come to a realisation that topographic features so ancient are rare, and, if they do exist, are more likely exhumed forms than those which have been exposed to degradation through vast periods of geologic time.

It is, of course, true that many geologic structures are very old. It has been previously stated that geologic structures are in general much older that the topographic features developed upon them. The only notable exceptions are to be found in areas of late-Pleistocene and Recent diastrophism. The Cincinnati arch and the Nashville dome began to form as far back as the Ordovician but none of the topography developed on them today goes back of the Tertiary; the Himalayas were probably first folded in the Cretaceous and later in the Eocene and Miocene but their present elevation was not attained until the Pliocene and most of the topographic detail is Pleistocene or later in age; the structural features which characterise the Rocky Mountains were produced largely by the Laramide revolution, which probably culminated at the close of the Cretaceous, but little of the topography in this area dates back of the Pliocene and the present canyons and details of relief are of Pleistocene of Recent age.

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

Correlative with the realisation of the geologic recency of most of the world's topography is the recognition that the geologic and climatic changes during the Pleistocene have had far -reaching effects upon present -day topography. Glacial outwash and wind-blown materials of glacial origin extended into areas not glaciated, and the climatic effects were probably worldwide in extent. Certainly, in the middle latitudes the climatic effects were profound. There is indisputable evidence that many regions that are today arid or semi-arid had humid climates during the glacial ages. Freshwater lakes existed in many areas which today have interior drainage.

We also know that many regions now temperate experienced during the glacial ages temperatures that are found now in the subarctic portions of North America and Eurasia, where there exists permanently frozen ground or what has come to be called permafrost conditions. Stream regimens were affected by the climatic changes, and we find evidence of alternation of periods of aggradation and downcutting of valleys

Although glaciation was probably the most significant event of the Pleistocene, we should not lose sight of the fact that in many areas the diastrophism which started during the Pliocene continued into the Pleistocene and even into the Recent.

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

Climate variations may affect the operation of geomorphic processes either indirectly or directly. The indirect influences are largely related to how climate affects the amount, kind and distribution of the vegetal cover. The direct controls are such obvious ones as the amount and kind of precipitation, its intensity, the relation between precipitation and evaporation, daily range of temperature, whether and how frequently the temperature falls below freezing, depth of frost penetration, and wind velocities and directions. There are, however, other climatic factors whose effects are less obvious, like how long the ground is frozen, exceptionally heavy rainfalls and their frequency, seasons of maximum rainfall, frequency of freeze and thaw days, differences in climatic conditions as related to slope facing the sun and those not so exposed, the differences between conditions on the windward and leeward sides of topographic features transverse to the moisture-bearing winds, and the rapid changes in climatic conditions with increase in altitude

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

Geomorphology concerns itself primarily with the origins of the present landscape but in most landscapes there are present forms that date back to previous geologic epochs or periods. A geomorphologist is thus forced to adopt a historical approach if he is to interpret properly the geomorphic history of a region

The historical nature of geomorphology was recognised by Bryan (1941) when he stated.

"If landforms were solely the result of processes now current, there would be no excuse for the separation of the study of landforms as a field of effort distinct from Dynamic Geology. The essential and critical difference is the recognition of landforms or the remnants of landforms produced by processes no longer in action. Thus, in its essence and in its methodology, physiography (geomorphology) is historical. Thereby, it is a part of Historical Geology, although the approach is by a method quite different from that commonly used."

The origin of the earth is linked to the origin of the solar system which is linked to the evolution of stars, which, in turn, is linked to the origin of the universe itself. Therefore, the origin and evolution of earth's crust should be understood in a broad context.

The Hindus considered the earth to be half of a golden egg balanced on the back of a turtle with the help of four elephants. The ancient Egyptians visualised the earth as a floating sphere in a sea, while the Polynesians though the earth to be an egg floating in the sea.

It was only around the eighteenth century and with advancements in science, especially in phusics and mathematics, that theories with some scientific basis began to be put forward to explain the origin of the earth.

Some theories on origin of the earth

1. GEORGES DE BUFFONS THEOTY.

Buffon, a French scientist, proposed that a huge comet must have collided with the sun, resulting in the release of a lot of matter. This matter, so freed, got condensed and transformed into planets, while smaller masses turned into sub-plants. Some matter disappeared into the space.

Although this theory has some scientific basis and the collision between the sun and the comet seems probable. Some questions remain unanswered. Compared to the sun, the comet is composed of small particles and has a very low density, which makes it unsuitable to cause a collision of such a magnitude which will cause large masses of material to be released from the sun. Moreover, the sun has a lower angular momentum (a measure of the swirling motion) than the planets. How can a body with low angular momentum create fragments with a higher angular momentum? Finally, Buffon's theory fails to explain the peculiar position of planets around the sun which are arranged in such a manner that the largest ones occupy the middle orbits while the smaller ones occupy the marginal orbits.

2. EMANUEL KANT'S THEORY OF GASEOUS MASS (1755)

kant proposed that the primordial matter was in the form of small and cold primordial matter was in the form of small and cold particles which got attracted towards each other as a result of the gravitational pull. In the process, the angular velocity and the temperature of these particles rose to such a level that they got transformed to a gaseous state. A high centrifugal force was generated due to high angular velocity which caused concentric rings of material to separate from the hot gaseous mass. On cooling down, these rings became the present-day planets, while a similar process caused the sub-planets to emerge from these planets. The remaining mass of the gaseous matter became the sun.

Although kant's theory appeared to be simple and reasonable, he failed to explain the sudden coming into play of the gravitational pull and the source of angular motion for the particles.

3. THE NEBULAR THEORY OF LAPLACE (1796)

Laplace, a French scientist, proposed that the primordial matter existed in the form of a gaseous mass called 'nebula', which was hot and rotating. This mass started cooling down and in the process lost some of its volume. Because of a reduced size, the rotational speed of the nebula increased. This had a cascading effect as the centrifugal force of its mass also increased. As a result, the mass of the nebula started concentrating along its equator. This mass was, on the other hand, being pulled inwards by a gravitational pull. But, as the centrifugal force increased further, some of the mass from the equator separated from the main nebula in the form of a ring which was also rotating. This ring, when cooled down and condensed, gave rise to planets and sub-planets, as it got broken into many smaller rings. The remaining mass became the sun.

Laplace's proposition seemed probable to the extent that all the planets of the sun revolve around proposition seemed probable to the extent that all the planets of the sun revolve around the sun in the same plane and are composed of the same elements which makes the "ring breaking into planets" thesis seem probable. But then the angular momentum of the intial nebula should be equal to the angular momentum of the entire solar system. Although the sun's mass accounts for 99.9% of the entire solar system, the angular momentum of the sun is only 2% that of the solar system. Moreover, for a ring of such a magnitude to separate from the nebula, the nebula should have contracted to the size of the planet Mercury, which does not seem probable. Also, this theory fails to explain the revolution in the opposite direction by some of he sub-planets of Saturn and Uranus. Finally, going by the processes involved in this theory, more rings should have separated from the nebula and not just one such ring. The theory does not explain this factor.

Roche modified Laplace's theory by arguing that a huge gaseous mass with low density could not have given rise to a huge, thick ting. He proposes that many small rings would have separated from the nebula forming planets and sub-planets.

4.CHAMBERLAIN-MOULTON'S PLANETESIMAL HYPOTHESIS (1904)

According to this theory, the planets have a biparentalorigin, i.e planets were born out of two nebulas. The sun, with it very high temperatures, projects hot material called the 'prominences', thousands of kilometres away from it. Another nebula, passing by the sun, attracted some of this projected material through its gravitational pull, which now started revolving around it instead of around the sun. The particles of this material got coalesced to from the planets. A lot of heat was generated in the process. Partly out of the gas particles attracted from the material floating around and partly acquired from the volcanic eruptions, the atmosphere around the earth was formed.

This theory sounds probable on account of the fact that the total mass of the planets is about 1/700 of the solar system which points to the formation of the planets from the sun. However, the theory fails to explain why, on collision, the particles grew in size instead of turning into a gaseous form. The theory also fails to explain the low angular momentum of the sun compared to that of the planets.

5. THE TIDAL HYPOTHESIS OF JEANS AND JEFFREYS

According to this theory, the sun was originally, a gaseous mass. A huge star came so close to the sun that its gravitational pull created "tides" on the surface of the sun and a part of the sun's material got ejected. This material, so separated, began revolving around the sun and acquired an inflated, cigar shape because of the bipolar force being exerted on it-from the sun and the star. This force was in the form of the gravitational pull. The gaseous material in the cigar-shaped mass-swollen in the middle and thinner towards the end-cooled down and got condensed into solid spheres which became the planets in our solar system, the larger ones in the middle and the smaller ones towards the ends. A similar process involving the gravitational pull of the sun created sub-planets out of these planets. In this case too, the large sub-planets occupy the middle positions.

Although the peculiar arrangement of the planets and the sub-plants in the solar system is in accordance with the tidal principle of Jeans and Jefferys, apart from the fact that all the planets are made up of the same elements some doubts remain. The low angular momentum of the sun, for instance, cannot produce the high angular momentum of the planets. Secondly, the distance between stars in the universe is so great that ejection of material from the sun does not seem probable. Thirdly, the ejected material had a very high temperature- not conducive to the formation of such large planets.

6. INTER-STELLAR HYPOTHESIS OF OTTO SCHMIDST

A Russian scientist, Schmidst, opined that space was originally filled with dust particles. Then dust particles were attracted by the sun and began revolving around it. These particles underwent collisions and their speed decreased. They united to from large planets. The matter, which remained unconsolidated, took the form of sub-planets.

According to Schmidst, the heavier particles remained closer to the sun due to a stronger gravitational pull there, while the lighter ones drifted away. This is borne out by the fact that "inner planets" of the solar system – Mercury, Venus, Earth and Mars are composed of heavy elements and the "outer" ones- Jupiter, Saturn, Uranus, Neptune and Pluto are composed of lighter elements like hydrogen, helium nitrogen and simple compounds like methane. And since the planets were not carved out of the sun's material, there remains no ambiguity about the angular momentum of the solar system. But Schmist failed to explain the primordial existence of dust clouds, and their attraction towards the sun considering the great distances between stars in the universe.

7. FASENKOV'S HYPOTHESIS (1951)

According to Fasenkov, originally there existed clouds of dust and gas which got consolidated into the sun, the planets and the sub-planets. This theory explains the different angular momentums of the sun and the planets, but fails to explain the varying composition of different planets-some with heavy elements and some with light ones.

8.BINARY STAR HYPOTHESIS BY RUSSEL AND LITTLETION

According to this theory, the sun existed in "binary companionship" with a "companion star". A third star happened to pass by this binary arrangement. This star and the sun exerted a bipolar gravitational pull on the companion star. A tidal situation occurred and some material got separated from the companion star which began to revolve round the star. This revolving material gave rise to the planets.

The fact that binary stars are a common feature in the universe makes this theory sound feasible. The vast distances between the planets and the higher value of angular momentum of the planets are also accounted for by this theory. But this hypothesis does not explain the placement of the planets in different orbits at varying distances from the sun.

9. NOVA HYPOTHESIS BY HOYLE AND LITILETION

Certain stars in the universe increase their brightness several times suddenly. These stars are known as nove. A supernova contracts very rapidly; this increases its speed tremendously. Due to contraction, the temperature of the supernova increases to a very high level and in the presence of large amounts of energy, the lighter elements change into higher ones. Because of its small size, rotational speed of the supernova increased and a centrifugal force came into play. The sun had such a supernova as its companion star and it attracted the material ejected from the supernova due to the centrifugal fore. This material started revolving around the sun and got transformed into the planets on condensation.

This theory explains the existence of different angular momentums and planets with heavier and lighter elements in the solar system. But the theory fails to explain satisfactorily the creation of planets and sub-planets.

EVOLUTION OF THE EARTH

It cannot be said with certainty as to what exactly led to the formation of the earth, but one of the most favoured theories suggests that it is an outcome of a star formation. The earth after having been formed, had to pass through several phases to attain its present form. These phases are discussed below in a chronological order.

GEOLOGICAL TIMESCALE			
This is basically a division of time since the formation of the earth (4.6 billion years ago approximately into eras, periods, epochs and ages (in descending order) and the relationship of this division to the formation of the rocks			
ERA	PERIOD	EPOCH	YEARS AGO
CENOZOIC	QUARTERNARY	HOLOCENE	10,000
		PLEISTOCENE	1 MILLION
		PLIOCENE	12 MILLION

		MIOCENE	25 MILLION
		OLIGOCENE	35 MILLION
		EOCENE	60 MILLION
		PALAEOCENE	70 MILLION
MESOZOIC	CRETACEOUS		136 MILLION
	JERASSIC		195 MILLION
	TRIASSIC		225 MILLION
PALEOZOIC	PERMIAN		280 MILLION
	CARBONIFEROUS		345 MILLION
	DEVONIAN		395 MILLION
	SILURIAN		440 MILLION
	ORDOVICIAN		500 MILLION
	CAMBRIAN		570 MILLION
PRE – CAMBRIAN	PRE - CAMBRIAN		4.6 MILLION (FORMATION OF THE EARTH

PRE-CAMBRIAN (From the birth of the earth to 500 million years ago)

During this phase, the earth cooled from a hot gaseous to a molten state. Further cooling produced an outer thin solid crust-the first rock! Further cooling condensed the water vapours into liquid water. A probable reference to this condition has been made in ancient Hindu texts (Pralaya) and in Christian texts (Deluge of Noah). The inner molten, liquid part experienced violent volcanic activity. These conditions were not suitable for emergence of life, so the rocks of this era are unfossiliferous. The solid material so formed underwent large-scale erosion and the eroded sediments were deposited in the sea. These sediments got transformed due to earth movements. These is evidence for three orogenic movements:

LAURENTIAN – which started 1billion years ago and the evidence of which is found in FEnnoscandia, European Russia and Britain.

ALGOMAN

KILLARNEAN

This era also witnessed the metamorphosis of the sedimentary rocks. The Pangea continent got broken into four shields-the Canadian Shield, the Siberian Shield, the Gondwana Shield and the Baltic Shield.

PALAEOZOIC ERA (From 570 million years ago to 225 million years ago)

During this era, life appeared for the first time-mainly non-floral vegetation and invertebrate animals, followed by the vertebrates. This era is divided into six periods.

CAMBRIAN (570 million to 500 million years ago)

During this phase, further sedimentation of the sea produced the sedimentary rocks. These rocks contain the fossils of the oldest life.

ORDOVICIAN (500 million to 440 million years ago)

The expansion of the pecans submerged half of northern USA, while eastern USA was affected by the Taconian orogenic movement. This period is characterised by the evolution of the trilobites and birth of the mlluscs.

SILURIAN (440 million on 395 million years ago)

Almost all the continents were affected by the Caledonian earth movements. Expansion of vegetation and proliferation of invertebrates took place. This period is characterised by the appearance of animals with lungs and the fish.

DEVONIAN (395 million years to 345 million years ago)

As a result of the Caledonian movements, high mountain ranges developed on all continents, evidence of which can be seen in Scandinavia, South-west, Scotland, North Ireland and Eastern America. During this period, the fish were found in abundance and the formation of the corals took place in the oceans. The first amphibians and vertebrates appeared on land.

CARBONIFEROUS (345 million years to 280 million years ago)

The Caledonian earth movements were succeeded by the Armorican movements and all the continents, especially U.K. and France, were affected.

Temperature and humidity rose. Heavy rainfull turned large land masses into marshes. Dense forests covered vast areas. Subsequently, these forests were submerged deposits. When these submerged areas emerged above the water level, forests appeared on these only to submerge in water again. This process was repeated many times with the result that these forests were subjected to intense pressure and were converted into coal beds

PERMINA PERIOD.

EARTH'S INTERIOR

An understanding of the earth's interior is essential to follow the nature of changes going on over the earth's surface which are related to the deep laid internal forces operating from within the earth. This understating of the earth's interior is based mainly on indirect sources, because so far it has not been possible to have access to the inner levels of the earth's structure.

EVIDENCES ABOUT EARTH'S INTERIOR

HIGH LEVELS OF TEMPERATURE AND PRESSURE DOWNWARDS

The recurrent volcanic eruptions throwing out extremely hot, molten material from the earth's interior and the existence of hot springs, geysers etc. point to an interior which is very hot. Although the average rise in temperature from the surface downwards is 32°C per metre, this rise is not uniform throughout. In the upper 100 km the increase is estimate at 12°C per km, while it is 2^{o}C per km in the next 300 km and 1^{o}C per km after that. As per this calculation, the temperature is 2000^{o}C at the earth's core. The high temperatures are attributed to the internal forces, automatic disintegration of the radioactive substances, chemical reaction and other sources.

Although ideally the innermost part of the earth should be in a liquid or a gaseous state due to the high temperatures, yet, because the pressure also increases with depth, the core is a rigid mass. The layer enveloping the core is in a semi-solid ir plastic state.

2. BEHAVIOUR OF EARTHQUAKE WAVES

The earthquake waves are measured with the help of a seismograph and are of three types-the 'P' waves or primary waves (longitudinal in nature), secondary waves or 'S' waves (transverse in nature) while the surface waves are long or 'L' waves. The velocity and direction of the earthquake waves undergo changes when the medium through which they are traveling changes. Thus, the velocity of P waves decreases towards the interior pointing to a less solid layer (a characteristic of longitudinal waves), but increase for a while when passing through the inner core only to a solid core surrounded by partially molten layer. Similarly, the S waves cannot pass through a liquid medium and are only transmitted through a rigid or solid medium. The S waves get defected while traveling inwards and come out at the earth's surface. This again points to a molten, semi-solid layer below the crust and mantle. The L waves do not pass and do not go deeper inside the earth.

EVIDENCE FROM THE METEORITES

The meteorites are solid bodies freely traveling in space which accidentally come under the sphere of influences of the earth's gravity and as a result fall on earth (or collide with it). Their outer layer is burnt during their fall due to extreme friction and the inner core is exposed. The heavy material composition of their cores confirms the similar composition of eh inner core of the earth, as both evolved from the same star system in the remote past.

From the above scientific evidence, a fairly convincing picture of the earth's interior can be drawn.

A SECTIONAL PROFILE OF EARTH'S STRUCTURE

The structure of the earth's interior's is layered, and broadly three layers can be identified – crust, mantle and the core.

CRUST is the outer thin layer with a total thickness of around 100 km. it forms 0.5 per cent of the earth's volume. The outer covering of the crust is of sedimentary material and below that be crystalline, igneous and metamorphic rocks which are acidic in nature. The lower layer of the crust consists

CORE lies between 2900 km to 6400 km below the earth's surface and accounts for 83 per cent of the earth's volume. The central core has the heaviest mineral of highest density. It is composed of nickel and iron (ferrous)and is, therefore, called "nife", while a zone of mixed heavy metals + silicates separated the core from outer layers.

SOME NUMERICL FACTS ABOUT EARTH

SIZE AND SHAPE

EQUATORIAL SEMI AXIS - 6374.4 KM

Polar semi-axis - 6356.6 km

Mean radius - 6371.0 km

Equatorial circumference - 40,077.0 km

Pular (meridian) circumference - 40,009.0 km

Area

LAND (29.22%) - 149 MILLION SQ KM.

OCSAN AND SEAS (70.78%) - 361 MILLION SQ KM.

TOTAL AREA OF THE EARTH - 510 MILLION SQ KM.

LAND

GREATEST KNOWN HEIGHT - MT EVEREST - 8,848 METRES

AVERAGE HEIGHT - 840 METRES

OCEAN

GREATEST KNOWN DEPTH - CHALLENGER DEEP IN MARIANA TRENCH (PACIFIC OCEAN)- 1022 METERS (BELOW SEA LEVEL)

AVERAGE DEPTH - 3808 METERS

(thus, the maximum difference in elevation on the earth's surface is about 20 kiloMetres - not much really, considering the size of the earth.)

Earth Movements

Classification and Character of Forces and the Earth Movements Involved in Creation of Landforms

Our earth is undergoing deformations imperceptibly but inexorably. These deformations are caused by the movements generated by various factors which are not completely understood and include the following:

The heat generated by the radioactive elements in earth's interior

Movements of the crustal plates due to tectogenesis.

Forces generated by rotation of the earth.

CLASSIFICATIN OF EARTH MOVEMENTS

EARTH MOVEMENT

ENDOGENETIC EXOGENETIC

DIASTROPHISM SUDDEN

WEATHERING EROSION

EARTHQUAKE VOLCANO PHYSICAL ICE

EPERIOGENIC OROGENIC CHEMICAL RIVER

BIOLOGICAL SEA

UPWARD DOWN WARD TENSION COMPRESSION WIND

Climate factors

Isostacy-according to this concept, blocks of the earth's crust, because of variations in density would rise to different levels and appear on the surface as mountains, plateaux, plains or ocean basins (See box for details)

ENDOGENETIC MOVEMETS

The interaction of matter and temperature generates these forces or movements inside the earth's. the earth movements are mainly of two types – diastrophism and the sudden movements.

1. DIASTROPHISM is the general term applied to slow bending, folding, warping and fracturing. Such forces may be further divided as follows.

(i)EPEIROGENIC or continent forming movements act along the radius of the earth; therefore, they are also called radial movements. Their direction may be towards (subsidence) or away (uplift) from the center. The results of such movements may be clearly defined in the relief. Raised beaches, elevated wave-cut terraces, sea caves and fossiliferous beds above sea level are evidences of uplift. One of the reasons for believing that the Deccan was uplifted is that the nummulitic limestones rest uncomfortably on the basaltic lavas near Surat well above sea level. Raised beaches, some of them elevated as much as 15 m to 30 m above the present sea level, occur at several places along the Kathiawar Orissa, Nellore, Madras, Madurai and Thirunelveli coasts several places which wer on the sea some centuries ago are now a few miles inland. For example, coringa near the mouth of the Godavari, Kaveripattinam in the Kaveri delta and Korkai on the coast of Thiruvelveli, were all flourishing sea ports about 1,000 to 2,000 years ago.

Evidence of marine fossils above sea level in parts of Britain in and Norway is another example of Epeirogenic uplift.

Submerged forests and valleys as well as buildings are evidences of subsidence. In 1819, a part of the Rann of Kachchh was submerged as a result of an earthquake. Presence of peat and lignite beds below the sea level in Thirunveli and the Sunderbans is an example of subsidence. The Andamans and Nicobars have been isolate from the Arakan coast by submergence of the intervening land. On the east side of Bombay island, trees have been found embedded in mud about 4 m below low water mark. A similar submerged forest has also been noticed on the Thirunelveli coast in Tamil Nadu. A large part of the Gulf of Manner and Palk Strait is very shallow and has been submerged in geologically recent times. A part of the former town of Mahabalipuram near Chennai (Madras) is submerged in the sea

(ii) OROGENIC or the mountain-forming movement act tangentially to the earth surface, as in plate tectonics. Tension produces fissures (since this type of force acts away from a point in two directions) and compression produces folds (because this type of force acts towards a point from two or more directions. In the landforms so produced, the structurally identifiable units are difficult to recognise.

In general, diastrophic forces which have uplifted lands have predominated over forces which have lowered them.

2. SUDDEN MOVEMENTS These movements cause considerable **deformation over a short span of time, and may be of two types.**

(i) EARTGQUAKE It occurs when the surplus accumulated stress in rocks in the earth's interior is relieved through the weak zones over the earth's surface in form of kinetic energy of wave motion causing vibrations (at times devastating) on the earth's surface. Such movements may result in uplift or subsidence. For instance, an earthquake in Chile (1822) caused aone-metre uplift in coastal areas. Another earthquake in New Zealand (1885) caused an uplift of upon 3 metre in some areas while some areas in Japan (1891) subsided by metres after an earthquake.

Earthquake may cause change in contours, change in river courses, "tsunamis: (seismic waves created in sea by an earthquake, as they are called in Japan) which may cause shoreline changes, spectacular glacial surges (As in Alaska), landslines, soil creeps, mass wasting etc.

(ii) VOLCANOES A volcano is formed when the molten magma in the earth's interior escapes through the crust by vents and fissures in the crust, accompanied by steam, gases (hydrogen sulphide, sulphur dioxide, hydrogen chloride, carbon dioxide etc.) and pyroclastic material. Depending on chemical composition and viscosity of the lava, a volcano may take various forms.

Conical or Central When cooled lava particles from successive vulcanite eruptions form a cone around the vent, a conical mountain shape emerges. This is a central type of volcano. Example: Fujiyama (Japan) and Mount Vesuvius (Italy). The magma in such volcanoes is viscous, acidic and silicate.

Shield Type The less viscous, less acidic and less silicate magma flows out slowly and quietly and gives rise to a wide based plateau-like formation with a gentle slope. Thus a "shield shaped" volcano with thin horizontal sheets emerges. Example: Mauna Loa (Hawaii)

Fissure Type Sometimes, a very thin magma escape through cracks and fissures in the earth's surface and flows after intervals for a long time, spreading over a vast area, finally producing a layered, undulating, flat surface. Example: Deccan traps (peninsula India)

Caldera Lake After the eruption of magma has ceased, the crater frequently turns into a lake at a later time. This lake is called a "caldera". Example: Lonar in Maharashtra and Krakatao in Indonesia.

Volcanic Landforms These are large rock masses formed due to cooling down and solidification of hot magma inside the earth. Batholiths form the core of huge mountains and may be exposed on surface after erosion.

Batholiths

Laccoliths

Dykes silla

Process of "degradation" and "aggradation". The exogenetic forces involve two stages-firstly, the landforms (in form of rocks) weaken, break up, rot and disintegrate. This stage comes into play as soon as the newly created landform is exposed to the influence of weather. This stage is called **WEATHERING**. Then comes a stage of scraping, scratching and grinding on the surface rock. It includes removal or transportation of the weathered rock material from one place to another. This stage is called **EROSION.** The act of erosion is performed by a number of natural agents, such as running water, ground water, moving ice, wind, waves and currents of the sea. These agents use the eroded material as cutting tools to crave out and shape the landscape. (The distinctive features created by some of these agents are discussed in detail under relevant topics, later in the chapter.)

Erosion is a mobile process of filling up of depressions on the earth's surface by the material deposited by the same agents of erosion is called aggradation or deposition. Weathering may be physical chemical or biological depending on the nature of agents and the processes involved and the products created.\

1**. PHYSICAL WEATHERING** The disintegration of rocks by mechanical forces is called physical or mechanical weathering. This type of mechanical force produces fine particles from massive rock by the exertion of stresses sufficient to fracture the rock, but does not change its chemical composition. Physical weathering may take place in many ways. These are discussed below.

GRANULAR DISINTEGRATION Rocks composed of coarse mineral grains commonly fall apart grain by grain or undergo granular disintegration.

EXFOLIATION A rock mass disintegrates layer by layer leaving behind successively smaller spheroidal bodies and forming curved rock shells by disintegration. This type of rock break-up is also called spalling. These layers. Separate due to successive cooling and heating with changes in temperatures.

BLOCK SEPATATION: This type of disintegration takes place in rocks with numerous joints acquired by mountain-making pressures or by shrinkage due to cooling. This type of disintegration in rocks can be achieved by comparatively weaker forces.

SHATTERING: A huge rock may undergo disintegration along weak zones to produce highly angular pieces with sharp corners and edges through the process of shattering.

FROST ACTION: This type of weathering is common in cold climates. During the warm season, the water penetrates the pore spaces or fractures in rocks. During the cold season, the water freezes into ice and its volume expands as a result. This exerts tremendous pressure on rock walls to tear apart even massive rocks.

MASS WASTING Since gravity exerts its force on all matter, both bedrock and the products of weathering tend to slide, roll, flow or creep down all slopes in different types of earth and rock movements grouped under the term “mass wasting”. This may take place in a variety of ways:

Talus Cones Rock particles created by processes of mechanical weathering move down high mountain slopes and steep rock walls of gorges. These particles tend to get deposited in a distinctive landform, the talus cone. A talus slope or scree slope has a constant slope angle of 34^{o}

Earthflow In humid climate regions where there are steep slopes, the masses of soil saturated with water, overburden or weak bedrock may slide downslope during a period of a few hours in the form of earthflow.

Landslide This is rapid sliding along hill slopes of rock mass. It may take place either by rockslide along a relatively flat inclined rock plane or by slump mechanism involving a rotating motion of the sliding rockmass on a slightly curved slope.

Soil Creep This is the extremely slow downslope movement of soil and overburden on almost all moderately steep, soil-covered slopes. Soil creep occurs as a result of some disturbance of the soil and mantle caused by heating and cooling of the soil, growth of frost needles (by frosting procees), alternate drying and wetting of the soil, trampling and burrowing by animals and shaking by earthquakes. Because gravity exerts a downhill pull on every such rearrangement, the particles are urged progressively downslope. Rock gragments of larger size may accumulate at the mountain base to produce a boulder field.

Mudflow In regions with sparse vegetation to check the flow or water, the sudden flow of water due to rain acquires a muddy character on its journey downslope. As it follows the stream course, it gets thicker and thicker until it becomes so overburdened as to come to a stop. It may carry huge boulders on its way. Such mudflows may cause massive loss of life and property.

Solifluction This form of mass wasting is common in the Arctic regions. In late spring and early summer, the water penetrates and saturates the upper few feet of the soil, but is unable to go deeper because of frozen conditions below. The upper saturated soil mass starts flowing along slopes. This movement causes the formation of terraces and lobes due to punctuated deposition.

Prominent examples of products of physical weathering in India include granite blocks near Jabalpur in Madhya Pradesh, the granite domes of Mahabalipuram-especially Krishna's butter ball", dolerite blocks in Singhbhum district of Bihar and frosting action in the Himalayam rocks

2. CHEMICAL WEATHERING This causes rocks to decay i.e. to decompose instead of disintegrating. The minerals contained in the structure of rocks undergo chemical changes when they get in contact with atmospheric water and air. These chemical changes cause rock particles to break up due to decomposition. Atmospheric water contains oxygen, carbon, sulphur, hudrogen, etc. and the air also contains oxygen, nitrogen, carbon dioxide. High levels of temperature and water content enhance the pace of chemical reactions. The chemical reactions may be classified as follows.

CARBONATION It takes place in rocks containing calcium, sodium, magnesium, potassium etc. when they come in touch with rain water which contains dissolved carbon dioxide. This process is common in lower humid climates.

CHLORANATION It takes place when chloride salts are formed as a result of chemical reaction.

OXIDATION This occurs in iron-based salts. The atmospheric oxygen present in rainwater unites with mineral grains in the rock, especially with iron compounds. This results in the decomposition of the rock and it starts crumbling. This process is called oxidation and is similar to the process of rusting

HYDRATION The chemical of water detaches the outer shell of aluminium-bearing rocks through the process of hydration.

DESILICATION Removal of silica from rocks also leads to their weakening and eventual disintegration due to desilication

SOLUTION Some minerals, such as rock-salt and gypsum are removed by the process of solution in water.

This chemical reaction of rain water brings about decomposition of minerals more rapidly than its mechanical action. The chemical weathering is capable of breaking up even a hard crystalline rock into minute particles.

BIOLOGICAL WEATHERING This refers to disintegration, break up and decomposition of rock masses by plants, animals and activities of man.

Plant roots penetrate the cracks in rocks or at the rock base and dislodge large blocks from the cliffs. Roots may also cause break up of the rock. The burrowing by earthworms, ant, rats and the like make channel through the rock and contribute to their destruction. The excretion of many of these animals provide acids that bring about a gradual decay of the rock. Many activities of man, such as mining, quarrying, deforestation and unscientific agriculture practices (like shifting cultivation) etc. add to the weathering of rocks. Biological weathering may be physical or chemical in nature.

EFFETS OF WEATHERING Weathering and erosion tend to level down the irregularities of landforms and create a peneplane. Weathering may cause visibly identifiable change in the general landscape. A general darkening of rocks, especially in dry climates due to chemical action, creates desert varnish and patination which basically involves changes in rockskin without change in the volume. The strong wind erosion leaves behind whale-back shaped rocks in arid landscape. These are called inselberg or ruware. Sometimes a solid layer of chemical residue covers a soft rock, through a process known as rind or case hardening. The hollowing action of weathering produces weathering pans or pits, which are also known as gnamma or taffoni. Sometimes, differential weathering of soft strate exposes the domelike hard rock masses, called tors. Tops are a common feature of South Indian landscape.

PLATE TECTONICS

The evidence obtained from investigation of the sea floor points to the movement of large sections of the earth's crust, in relation to each other. This movement takes place primarily due to three factors-polar wandering, continental drift and sea floor spreading.

Polar wandering is the relative movement of the earth's crust and upper mantle with respect to the rotational poles of the earth. Continental drift refers to the movement of the continents relative to each other. Sea floor spreading describes the movement of oceanic plates relative to one another.

CONTINENTAL DRIFT THEORY (ALFRED WEGENER, 1922)

Wegener was a climatologist and wanted to investigate the relative distribution of land and sea and the climatic aberrations of the past. He postulated that originally there existed one big landmass which he called **PANGAEA** which was covered by one big ocean called **PANTHAKASSA.** A sea called **TETHYS** divided the **PANGAEA** into two huge landmasses.- **LAURENTIA** to the north and **GONDWANALAND** to the south of Tethys. The landmasses consisted of SIAL (lighter) crust mostly, while the ocean had a **SIMATIC (**heavier) base.

According to Wagener, the drift started around 200 million years ago (Mesozoic Era), and the continents began to break up and drift away from one another. The drift was in two directions-equatorwards due to the interaction of forces of gravity and buoyancy, and westwards due to tidal currents because of the earth's motion. According to Wegener, the drift is still continuing

CRITICAL ANALYSIS OF EVIDENCE FOR CONTINENTAL

1. APPARENT AFFINITY OF PHYSICAL FEATURES South America and Africa seem to fit in with each other, especially, the bulge of Brazil fits into the Gulf of Guinea Ellesmere and Baffin islans. The east coast of India, Madagascar and Africa seem to have been joined. North and South America on one side and Africa and Europe on the other fit along the mid-Atlantic ridge. The Caledonian and Hercynian mountains of Europe and the Appalachians of USA seem to be one continuous series. Sierra de Tendill mountains (south America) and Cape Mountains of South Africa seem to exhibit a similar tendency.

Criticism Coastlines are a temporary feature and are liable to change due to erosional work of the sea, rivers etc. and are not, hence, reliable as a basis for attempting this type of analysis of landforms. Even drastic changes in the past in coastline profiles cannot be ruled out. Several other combinations of fitting in of landforms could be attempted. The Niger delta, for instance, on West Coast of Africa could not were one. For a delta to be formed there, the two continents must be separated by 200 kilometers and it would take 50 millon years for this purpose. Moreover, this line of thinking shifts India's position too much to the south, distorting its relating with Mediterranean Sea and the Alps. Finally, the mountains do not always exhibit geological affinity-a natural corollary which should have followed had the present landmasses been a result of the breakup of a larger landmass in the past.

2. CAUSES OF DRIFT Gravity of the earth, buoyancy of the seas and the tidal currents were given as the main factors causing the drift, by Wegener.

Criticism For these factors to be able to cause a drift of such a magnitude, they will have to be millions of times stronger.

3**. INTERPLAY OF SIMA AND SIAL** The lighter sial was carried by heavier sima, thus creating cordillera formation on western edges of North America. These formations are folded and warped.

Criticism If sima was so rigid, it could not have drifted away and if it was light and mobile, mountain building could not have occurred.

4. SHIFTING OF POLES Originally, the North Pole was positioned at 107° W, 3° N (south –west of California) and has now shifted in a North-westerly direction. The South Pole, on the other hand, was situated where present day South Africa (Natal coast) is, in the middle pf Pangaea. The drift of poles can be traced as given below

Time (Million Years)	Geological Period	Position of North Pole
600	Pre-Cambrian	30° N, 107° W
350	Silurian	14° N, 124° W
285	Carboniferous	16° N, 147° W
70	Tertiary	51° N, 153° W

Criticism Poles may have shifted, not necessarily the continents.

5. PRESENCE O ICE SHEETS Evidence of such ice cover dating back to the carboniferous period in the Falklands and other places in the southern hemisphere suggests that they were closer once.

Criticism Similar climatic conditions could prevail on different continents

6. BOTANICAL EVIDENCE Presence of glossopteris vegetation in carboniferous rocks of India, Australia, South Africa, Falkland Islands, Antarctica, etc. can be explained on the basis of the fact that these parts were linked in the past.

Criticism Such vegetation is also found in the northern parts like Afghanistan, Iran and Siberia.

7. PALAEOMAGMETISM The magnetic field of the earth has magnetised many iron-based rocks in the past. The study of the old magnetic rocks show different directions of magnetization. This study is known as Palaeomagnetism.

Criticism The evidence in this regard is not conclusive and is being further explored. Anyway, such magnetic aberrations may be due to local factors also.

WEGENER'S MAIN DRAWBACK Wegener ignored the time factor and took a two dimensional view of the subject, trying to solve the mystery like a zigsaw puzzle. He overlooked the fact that once separated, the edges of continents may have undergone considerable distortion. Going by Wegener's approach, even geologically untenable combinations like Australia and New Guinea are possible. Wegener failed to explain why this drift began only in the Mesozoic era and not in the period prior to it.

SEA FLOOR SPREADING (Hess, Dietz 1962)

The authors of the theory of sea floor spread recognised the existence of Pangaea, Tethys and Panthalassa, and tried to explain the apparent movement of sea floor at specific locations (submarine ridges)

According to this theory, the intense heat generated by radioactive substances in the mantle (100-2900 km below the earth surface) seeks a path to escape, and gives rise to the formation of convection currents in the mantle. Wherever rising limbs of these currents meet, oceanic ridges are formed on the sea floor and wherever the falling limbs meet, trenches are formed.

At the ridges, the eruption results in upwelling of the magmatic material. This causes movement of the crust. After upwelling, the hot magma cools down, solidifies and moves apart to make way for the material of successive eruptions. This results in effective sea floor spreading. Thus, discrete segments of earth's crust are formed by solidification of this erupted material at mid-oceanic ridges. The rate of movement is slow, perhaps 2.5 cm per year but it is measurable. The whole system resembles two giant conveyor belts positioned next to each other, slowly carrying their loads away form the middle – the mid-oceanic ridge.

It was on the basis of the continental drift theory, the discovery of mid-oceanic ridge system during the Second World War and the theory of sea floor spreading, that the theory of Plate Tectonics was formulated – first outlined by Morgan in 1968.

PLATE TECIONICS

According to this theory, the lithosphere (upper 100 km of the earth's crust) is broken into a number of plates or sections, each of which is capable of independent movement over the asthenosphere (100-250kn below surface, partially molten and capable of slow flow) carrying both continental and oceanic crust alike. The movement of these crustal plates causes the formation of various landforms and is the principal cause of all earth movements.

CRUSTAL PLATES There are six major plates and many minor ones. The major plates are American, Eurasian, African, Indo- Australian, Pacific and the Antarctic. The minor plates include North American, South American, Nazca, Turkish, Aegean, Arabian, Caribbean, Phillipine, Juan de Fuca and the Iranian plate. The average thickness of these plates is around 100 km and the entire thickness is involved in crustal spreading and downbending. The oceanic plates contain mainly the SIMATIC crust and are relatively thinner while, the continental plates contain SIALIC material and are relatively thicker.

INTERACTION OF PLATES AND THE RESULTS These crustal plates are borne along a worldwide system of oceanic ridges, oceanic trenches, great faults and active fold belts. The plates migrate away from ridges and inevitably collide. There are three ways in which the plates meet other.

1. **DIVERGENT EDGE** or the constructive edge can be seen along ridges. Here, the basaltic magma erupts and moves apart. Such edges are sites of earth crust formation (thus constructive) and volcanic earthforms are common along such edges. For example, Surtsey Island (south of Iceland) was "born" along mid-Atlantic ridge on November 14, 1968. Even earthquakes are common along divergent edges.

2. CON**VERGENT EDGE** or destructive edge is formed when two plates meet head on. The zone of collision may underago crumpling and folding and folded mountains may emerge. This is an orogenic collision. Himalayan Boundary Fault is one such example when one of the plates is an oceanic plate, it gets embedded in the softer asthenosphere of the continental plate and as a result, trenches are formed at the zone of subduction material gets heated up and is thrown out forming volcanic islands. The intrusive activity may result in the formation of batholiths.

3**. TRANSCURRENT EDGE** or a conservative is formed when two plates move past each other without directly interacting with each other. San Andreas Fault along the western coast of USA is an example.

Thus, all landforms are influenced directly or indirectly by tectogenesis which provides energy for formation of landforms. Because of interplay of the factors discussed above, the plate margins are areas of intense volcanic and earthquake activity.

EVIDENCE IN SUPPORT OF PLACE TECTIONICS

Older rocks form the continents while younger rocks are present on the ocean floor. On continents, rocks of upto 3.5 billion years old can be found on the ocean floor is not more than 75 million years old (western part of Pacific floor). As we move towards ridges, still younger rocks appear. This points to an-effective spread of sea floor along oceanic ridge which are also the plate margins.

The normal temperature gradient on the sea floor is 9.4^{o}C/300 m but near the ridge it becomes higher, indicating an upwelling of magmatic material from the mantle

In trenches, where subduction has taken place (convergent edge), the value of gravitational constant "geomorphology" is less. This indicates a loss of material. For instance, gravity measurements around the Indonesian islands have indicated that large gravity anomalies are associated with the oceanic trech bordering Indonesia. The mass deficiency which caused this negative gravity anomaly can be explained by the lighter earth's crust being pulled down into the mantle by sinking convection currents.

The orientation of iron grains on older rocks (for instance, investigations revelaing such an evidence on the ocean floor south west of Iceland in 1960s) shows an orientation which points to the existence of the South Pole, once upon time, somewhere between the present day Africa and Antarctica.

The fact that all plate boundary regions are area of earthquake and volcanic disturbances goes to prove the theory of plate disturbances goes to prove the theory of plate tectonics.

SIGNIFICANCE OF PLATE TECTONICS

For the earth scientists, it is a fundamental principle for study. For physical geographers …………………………………… Of landforms

New minerals are thrown up from the core with the magmatic eruptions. Economically valuable minerals like copper and uranium are found more frequently near the plate boundaries. Valuable mineral zone in one continent can thus be compared with its historical cousin continents.

On the basis of present knowledge of crustal plate movement, the shape of landmasses in future can be guessed. For instance, if the present trends continue, North and South Americas will separate. A piece of land will separate from western USA, and California will move northwards close to San Fransisco. A piece of land will separate from the east coast of Africa. Australia will move closer to Asia.

VOLCANISM

Volcanism refers to the activity of a volcano and the results of this activity. A volcano is essentially a vent or fissure in the earth's crust, communication with the earth's interior, from which flows of molten rock material (lava), fountains of red-hot spray or explosive bursts of gases and volcanic "ashes" are erupted at the surface. W.M.Davis (1905) treated volcanism as an "accident" that occurs so arbitrarily in time and place and is so disruptive in time and place and is so disruptive to the erosional development of landscapes that the landforms cannot be treated in a systematic manner.

On the basis of frequency of eruption, there are active, dormant and extinct or ancient volcanoes. The volcanoes which erupt fairly frequently as compared to others are active. Only a few volcanoes remain more or less continually in eruption for long periods, but intermittent activity is more common. The dormant (from Latin word dormir, meaning, 'to sleep') volcanoes are those in which eruption has not occurred regularly recently. These volcanoes undergo long intervals of repose during which all external signs of activity cease. Those volcanoes in which no eruption has been recorded in historic times are said to be extinct. Before a volcano becomes extinct, it passes through a waning stage during which steam and other hot as fumaroles or solfataras.

Sometimes, a volcano thought to have become extinct suddenly becomes active. The Barren Island in the Andaman and Nicobar Islands of India. Vesuvius (Italy) and Krakatao (Indonesia) are such examples. The Barren Island suddenly started fuming out hot gases and lava in recent years, while the Krakatao volcano became active in 1883, killing 36,000 people in West Java. It is reported that the sound of explosion was heard as far as Turkey in the west and Tokyo in the east. Today, Krakatao is no more than a low island with a caldera lake inside its crater.

CAUSES OF VOLCANIC ACTIVITY

The radioactive substances inside the earth keep generation a lot of heat through decomposition and chemical reactions. As a result the material in the earth's interior is in constant flux. This molten, semi-molten and sometimes gaseous material appears on earth at the first available opportunity. This opportunity is provided by weak zones along the earth's surface. The earthquake, for instance, may expose fault zones through which magma may escape. Because of high pressure in the earth's interior, the magma and gases escape with great velocity as the pressure is released through eruptions.

PRODUCTS OF VOLCANIC ACTIVITY

Basically, four types of volcanic activity can be identified.

EXHALATIVE This includes the discharge of material in gaseous form, such as steam, fumes and hydrochloric, acid, ammonium, chloride, sulphur dioxide, hydrogen, sulphide, hydrogen, carbon dioxide, nitrogen, carbon monoxide, etc. These gases may escape through vents which are in the form of hot springs. Geysers, fumaroles and solfataras-which are not generally considered volcanic eruption. Exhalative activity gives rise to landforms, such as sinter mounds, cones of precipitated minerals and mud volcanoes. The mud volcanoes of Capper River Basin of Alaska are between 45 and 95 m in height and discharge mineralised warm water and gas, including light hydrocarbons probably derived from the decay of buried peat beds or coal

EFFUSIVE This type of activity refers to the copious outpourings of lava from a vent or fissure. Lava is the name given to erupted molten rock and to the subsequently cooled, solid equivalent. While most lavas are molten silicates, silica-free lava is also common –as in eastern Africa. A sulpure-based lava has been commercially mined in Japan. Silica-rich (thus acidic) lava is more viscous (i.e dense) than silica-poor (thus basic) lave. The viscosity of lava is a crucial factor in landforms development. The two other factors, apart from silica, which determine the viscosity of lava are temperature and the dissolved gases.

Low silicate basaltic lavas are very mobile and flow freely for long distances. The Deccan traps, which are composed of such lavas today cover an area of 5,00,000 square km. Their present distribution, however, is no measure of their past extension because denudation has been at work for basalts and detaching & number of outliers which are separated from the main area by great distances. These outliers indicate that the original extent of the formation must have been at least 14 lakh square km. Acid lavas, on the other hand, being very viscous do not travel far. Columnar structure is sometimes developed in fine-grained plateau basalts of uniform texture. Very good columnar basalt are seen in the Deccan traps near Bombay.

EXPLOSIVE This type of activity results in fragmentation and ejection of solid material through vents. Volcanic ejects that settle out of air or water are sometimes called pyroclastic or volcaniclastic sediments or rocks. Tephra is a less cumbersome collective term for all fragmented ejecta from the volcanoes. The fragments classified under tephra can be of different grain sizes and shapes. The finest sand-sized tephra is called the ash. Larger cinders are called lapilli. These are gravel sizes and either molten or solid. The blocks are cobble or boulder-sized solid ejecta. The twisted, air-cooled ejecta are called bombs. Tephra under goes sorting during transport in air. Smaller particles like lapilli and ash travel through air for many kilometers and may remain suspended in the air for a long time. The heavier particles like bombs and blocks fall only as far from the vent or fissure as the explosive force is able to hurl them. Layers of volcanic dust and ashes are often compacted into a rock call tuff.

SUBAQUEOUS VOLCANISM This type of volcanic activity takes place below the surface of water. When lava flows over the deep ocean floor or is otherwise in contact with water, it consolidates to produce a structure like that of a jumbled heap of cushions, and is therefore described as pillow lava

Excellent examples of pillow lava of Pre Cambrian Age are to be seen in parts of Karnataka. More viscous lavas, and those erupted at lesser depths, develop shattered glassy margins on pillows and flow surfaces. The related volcanic product is hyaloclastite (literally, glassy fragment rock). Most hyaloclastites ………………….. hyaloclastites make up significant proportions of several volcanic peaks that protrude through the ice sheet.

CHARACTERISTIC ERUPTIVE TYPES

Based on the typical pattern or mode of eruptions of certain known volcanoes, four basic types of modes of eruption can be identified. None of the volcanoes, however, erupts with only one of the activities described.

- **HAWAIIAN ERUPTION** It involves the effusive outpouring of basalt lava rom craters, lava lakes or fissures. A single flow is roughly 10 m thick and either spreads widely over open slopes of flows down the valleys as lava rivers. Little gas or tephra is produced. Examples: The great basalt plateaus of Columbia and Iceland
- **STROMBOLIAN ERUPTION** In this case, more viscous lava is ejected upward in a fountainlike fashion from a lava lake in the crater at regular intervals of around 15 minutes. Stromboli lies in the Lipari Islands near Italy. It is called the 'lightouse of the Mediterranean'.
- **VULCANIAN ERUPTION** The eruption in this mode is explosive. The molten lava which fills the crater solidifies and is explosively ejected as a great cauliflower cloud of dark tephra, Bombs, blocks, lapilli shower the surrounding area. Only minor lava flows result. After each eruption cycle, the volcano is dormant for decades or for centuries.
- **PELEA ERUPTION** This type of eruption is the result of very viscous, gas-rich, acidic lava plugging the vent and either frothing violently over the crater rim or braking out laterally. An explosion of the Pelean type differs

from a vulcanian eruption in the very hot gas and lava mixture is not carried skyward by the updraft to become cold tephra but spreads downslope as a nuce ardente, continuing to evolve gas that cushions the flowing fragments.

EFFECTS OF VOLCANISM ON HUMAN ACTIVITY

DESTRUCTIVE EFFECTS Volcanic eruptions count among the earth;s great natural disasters. Wholesale loss of life and destruction of towns and cities are frequent in the history of peoples living near active volcanoes.

POSITIVE EFFECTS The volcanic ash and dust are very fertile for farms and orchards. Volcanic rocks yield very fertile soil upon weathering and decomposition. Although steep volcano slopes prevent extensive agriculture, forestry operations on them provide valuable timber resources. Volcanic activity adds extensive plateaus and volcanic mountains to our earth. Mineral resources, particularly metallic ores, are conspicuously lacking in volcanoes and lava flows unless later geological events have resulted in infusion of ore minerals into the volcanic rocks. Sometimes copper and other ores fill the gas-bubble cavities. The famed Kimberlite rock of South Africa, source of diamonds, is the pipe of an ancient volcano, waters in the depth are heated from contact with hot magma. The heat from the earth's interior in areas of volcanic activity is used to generate geothermal electricity. Countries producing geothermal power include U.S.A., U.S.S.R., Japan, Italy, New Zealand, Mexico. In India, 340oC have been identified. A pilot plant has been set up at Manikaran (Himachal Pradesh) producing 5 kilowatts of electricity, mainly for research purposes. The Puga valley in Ladakh region is another promising spot which has been identified. Geothermal potential can also be used for space heating.

As scenic features of great beauty, attracting a heavy tourist trade, few landforms, outrank volcanoes. At several places, national parks have been set up, centred around volcanoes. As a source of crushed rock for concrete aggregate or railroad ballast, and other engineering purposes, lava rock is often extensively used.

DISTRIBUTION OF VOLCANOES

Since the year 1500 AD, 486 volcanoes have been reported to be active. Of these, 403 are located in and around the Pacific Ocean and 83 are in the mid-world belt across the Mediterranean Sea, Alpine-Himalayan belt and in the Atlantic and Indian Oceans. Even within the high concentration Pacific belt, there are variations. The belts of highest concentration are Aleutian – Kurile Islands arc, Melanesia, New Zealand- Tonga belt. In the USA-Canada Pacific belt, only 7 volcanoes have been active in historic times.

If the more ancient known eruptions are taken into account, we get a total of 522 volcanoes, and over 1300 have probable erupted in Holocene time (last 10,000 years)

The pacific belt is known as the 'Ring of Fire' because of the coasts of the Americas and Asia on this ocean. The mid-world volcanic belt occupies a second place. Africa occupies the third place having one volcano on the west coast, an extinct one in the rift-valley lake belt passing through the Red Sea and extending upto Palestine in the north.

There are no volcanoes in Australia. Only 10 per cent to 20 per cent of all volcanic activity is above sea and terrestrial volcanic mountains are small when compared to their submarine counterparts. Of all the active submarine volcanoes, 62 per cent are in the subduction zone around Pacific basin (the Pacific Ring of Fire), 22 per cent around Indonesia, 10 per cent in the Atlantic Ocean (including the Caribbean Sea), while the rest are in Africa, Mediterranean-Middle East belt, Hawaiian island and mid-ocean islands.

Most known volcanic activity and the earthquakes occur along converging plate margins and mid-oceanic ridges where the rising limbs of convection currents within the earth's mantle between volcanic and earthquake zones of the earth which indicates that there is a definite relationship between these two groups of phenomena. The location of volcanoes on the steep continental borders near great ocean deeps and in or near youthful mountains correlates them definitely with zones of weakness in the earth's crust.

Volcanic landforms are constructed independently of any climatically controlled processes. Volcanic structure are built in or on the Antarctic ice cap, in the tropical forests of Melanesia and Indonesia, in deserts and on every other geomorphically significant climate. In each instance, the initial structure and form of the constructed landform are similar.

VOLCANOES IN INDIA There are not volcanoes in the Himalayan region or in the Indian peninsula. Barren Island, lying 135 km north-east of Port Blair was thought to be dormant since it last erupted in early nineteenth century. It suddenly became active again in March, 1991. A second phase of eruption started in January 1995. The island has its base 2000 metres above the level of the sea.

EARTHQUAKE

Earthquake is a phemomenon generally considered in the context of volcanic activity. An earthquake is the shaking or trembling of the earth, caused by the sudden movement of a part of the earth's crust.

Cause The chief cause of the earthquake shocks is the sudden slipping of rock formations along faults and fractures in the earth's crust. This happens due to constant change in volume and density of rocks due to intense temperature and pressure in the earth's interior. Some quakes originate at depths as great as several hundred kilometers and in such cases the tremors are too weak to reach the surface or cause the tremors are too weak to reach the surface or cause much damage. The actual shifting of the land at the time of an earthquake occurs only in a narrow zone on either side of the faultline. In such a case, the main zone of shock and consequent destruction is linear because the vibrations originate in the line of fracture. A sudden slipping of even five to fifteen meters along a line of fracture 80 to several hundred kilometers long can cause a very severe earthquake. Volcanic activity also can cause an earthquake but the earthquakes of volcanic origin are generally less severe and more limited in extent than those caused by fracturing of the earth's crust. Some minor earthquakes are caused by the collapse of roofs of cavities, mines or tunnels.

Focus The place of origin of an earthquake inside the earth is called its focus,

Epicenter The point on the earth's surface vertically above the focus is called epicentre. On the earth's surface, the maximum damage is caused at the epicentre.

Frequency There are annually 8,000 – 10,000 earthquakes in the world, which comes to about an earthquake every hour. Actually, there are many more undetected, because there are no stations to record them over the oceans covering a very large surface of our earth.

DURATION The vibrations of earthquakes which can be felt by human beings last from a few seconds to several minutes. Generally, the greater the intensity of the shocks, the longer they last. The average duration of shocks of sufficient intensity to produce much damage is perhaps from one to two minutes.

Wave Velocity Earthquake waves travel ordinarily at the rate of about 5 to 8 km per second through the outer part of the crust but travel faster with depth.

Isoseismic Line A line connecting all points on the surface of the earth where the intensity of shaking produced by earthquake waves is the same.

Effects of Earthquakes Earthquake cause landslides, damming of rivers, depressions which form lakes. Formation of cracks or fissures especially in the region of the epicentre is common. Water, mud and gases are ejected from beneath the fissure. The gases may ignite the air, and water and mud may flood the surrounding area. Larger areas also subside or sink during very severe earthquakes. An earthquake may also lead to change in surface drainage and underground circulation of water. More devastating features of earthquakes are fires and seismic waves (tsunamis)

Distribution of Earthquakes The Pacific Ring of Fire accounts for about 68 per cent of all earthquakes and these are closely linked with the phenomenon of plate tectonics. Chile, California, Alaska, Japan, Philippines, New Zealand and the mid-ocean areas have had many minor and major earthquakes in this belt. Mountains here run along the border of continents and nearly parallel to the depression in oceans. The sharpest break in relief in this belt is the cause of earthquakes.

The mid-world mountains belt extends parallel to the equator from Mexico across the Atlantic Oceans, the Mediterranean Sea from Alpine-Caucasus ranges to the Caspian, Himalayan mountains and the adjoining lands. This zone has folded mountains, large depressions and active volcanoes. The remaining 11 per cent of the shocks are recorded outside these two belts. Only a few occur along the fracture in African lakes, Red Sea and the Dead sea zone.

The other volcanic island in Indian territory is Narcondam, about 150 km north-east of Barren Island; it is probably extinct. Its crater wall has been completely destroyed

ROCKS

Rocks are the main constituent of the earth's crust. A rock may be defined as any mass of natural deposit present in the solid mass of the earth's crust. Most rocks are made of aggregates of mineral. These minerals are specifically referred to as the rock-forming minerals. A mineral is a naturally occurring inorganic (i.e have a non-living base) substance possessing certain physical properties, a definite chemical composition and a definite atomic structure. Many minerals have a tendency to form crystals which are bounded by plane surfaces arranged in a regular and symmetrical manner. Some physical properties like cleavage, hardness, specific gravity and colour are useful in the identification of minerals. Usually, minerls are composed of two or more than two elements, but some minerals have only one elements. For instance, sulphur, graphite, gold etc. are called one-element minerals

Most of the minerals are oxides, silicates and carbonates. The percentage of various elements present in the earth's crust is shown in

On the basis of their origin, the rocks can be classified as igneous, sedimentary and metamorphic rocks.

SOME ROCK- FORMING MINERALS

Feldspar half the crust is composed of feldspar. It has a light colour and its main constituents are silicon, oxygen, sodium, potassium, calcium, aluminum. It is of three types-orthoclase, plagioclase, microline.

Quartz It has two elements, silicon and oxygen. It has a hexagonal crystalline structure. It is uncleavaged, white or colourless. It cracks like glass and is present in sand and granite. It is used in manufacture of radio and radar.

Pyroxene It is a mineral with green or dull black lustre. Calcium, aluminium, magnesium, iron, silica are its main constiruents.

Amphibole A fibrous mineral with a hexagonal structure which has a green or blank glittering appearance. Its main constituents are calcium, magnesium, iron, aluminium, silica

Mica This is a layered, cleavaged, white, black or colourless mineral. It is used in electrical appliances. Its constituents are potassium, aluminium, magnesium, iron, silica

Olivine Its components are magnesium, iron, silica etc. It is a glassy, green or yellow mineral with crystalline structure.

Apatite A complex compound containing calcium phosphate. It is red, brown, yellow or green in colour. Phosphorus and fluorine are derived from it.

Barite It is barium sulphate and has a white or brown colour. It has a crystalline structure.

Bauxite A hydrous oxide of aluminium, it is the ore of aluminium. It is non-crystalline and occurs in small pellets.

Calcite An important ingredient of limestone, chalk and marble, it is calcium carbronte. It is white or colourless.

Chlorite It is hydrous magnesium, iron, aluminium silicate. It has a cleavaged structure.

Cinnabar It is mercury sulphide and mercury is derived from it. It has a brownish colour.

Corundum it is aluminium oxide and is present in form of ruby and sapphire. It has a hexagonal structure.

Dolomite A double carbonate of calcium and magnesium, it is used in cement and iron and steel industries. It is white in colour.

Galena It is lead sulphate and lead is derived from it.

Gypsum It is hydrous calcium sulphate and is used in cement, fertilizer and chemical industries.

Haematite It is a red ore of iron

Kaolinite China clay, it is basically aluminium silicate.

Magnesite It is magnesium carbonate and has a non-crystalline structure.

Magnetite it is the black ore (or iron oxide) of iron

Pyrite It is iron sulphide. Iron and sulphuric acid are obtained from it.

IGNEOUS ROCKS

Igneous rocks (ignis in Latin means fire) are the rocks formed through the solidification of molten material (magma) origination within the earth's crust. This happens when the molten matter either cools down on reaching the surface of the earth or within the fissures and cavities of the earth. Various classifications of igneous rocks are possible applying different criteria.

A. On the basis of the place and time taken in cooling of the molten matter, igneous rocks may be divided into three types.

1. PLUTONIC ROCKS (after Pluto, the Roman God of the underworld). Sometimes, the molten matter is not able to reach the surface and instead cools down very slowly at great depths. Slow cooling allows big-sized crystals to be formed. Granite is a typical example. These rocks appear on the surface only after being uplifted and denuded.

2. LAVA OR VOLCANIC ROCKS (after Vulcan, the Roman God of fire). These are formed by rapid cooling of the lava thrown out during volcanic eruptions. Rapid cooling prevents crystallization, as a result such rocks are fine-grained. Basalt is a typical example. The Deccan traps region in peninsular region is of basaltic origin.

3. HYPABYSSAL OR DYKE ROCKS These rocks occupy an intermediate position between the deep-seated plutonic bodies and the surface lava flows. Dyke rocks are semi-crystalline in structure.

B. Based on their chemical composition, the igneous rocks can be of four kinds:

BASALT, DIORITE AND TACHYLITE These crystalline, semi-crystalline and glassy forms of igneous rocks consist of lime, ferromajnesium silicates and reduced proportion of iron oxides

SILICON ROCKS These contain more of silica but less of iron, lime and magnesium. Tonalite, quartz an dacite are the crystalline, semi-crystalline and glassy variants of this type.

ALKALI ROCKS In these rocks, alkalis predominate and these rocks appear in various forms-diorite, porphyrite and andesite.

PERIDOTITE This is a crystalline rock consisting of ferro-magnesium, silicates and oxides.

The igneous rocks can be of two types, if the presence of acid forming radical, silicon, is taken as the basis.

ACID ROCKS These are characterised by high content of silica-upto 80 per cent, while the rest is divided among aluminuium, alkalis, magnesium, sodium, potassium, iron oxide, lime. These rocks constitute the sial portion of the crust. Due to the excess of silicon, acidic magma cools fast and, therefore, it does not flow and spread far away. High mountains are formed of this type of rock. These rocks have a lesser content of heavier minerals like iron and magnesium, hence they are of pale colour and normally contain quartz and feldspar. Acid rocks are hard, compact, massive and resistant to weathering. Granite is a typical example.

BASIC ROCKS These rocks are poor in silica (about 40 per cent). Magnesia content is upto 40 per cent and the remaining 40 per cent is spread over iron oxide, lime, aluminium, alkalis, potassium etc. due to low silica content, the parent material of such rocks cools slowly and thus, flows and spreads far away. This flow and cooling gives rise to plateaus. Presence of heavy elements imparts to these rocks a dark colour. Basalt is a typicl example, others being –gabbro and dolerite. Not being very hara, these rocks are weathered relatively easily.

On the basis of texture, igneous rocks could be divided into various types (the texture of a rock is shown by size, shape and arrangement of the constituent minerals)

COARSE-GRAINED ROCKS are the result of slow cooling of the magma, e.g. granite.

FINE GRAINED ROCKS are produced by rapid cooling e.g. basalt

GLASSY ROCKS are a result of extremely rapid cooling

PORPHYRITIC ROCKS have crystals of two different sizes –the big crystals are known as phenocrysts and they lie in a fine-grained or glassy groundmass

OPHITIC ROCKS have another characteristic texture called ophitic, which is common in dolerites.

E. Finally, based on the form the molten magma acquires after cooling, igneous rocks could be divided into several types.

BATHOLITHS when the molten magma spreads across a wide area cutting through various layers, it is known as batholith. At times batholiths are exposed on the ground.

LACOLOTHS When the acidic magma cools down fast, it gets hardened at ordinary temperatures. A further push from below gives it a domelike appearance. These are lacoliths.

LAPOLITH A concave variant of the batholith

PHACOLITH When the solidified magma acquires a wavelike form, it is called phacolith

SHEET When the molten magma cools down in thin horizontal layers parallel to the surface, it is called a sheet.

SILL If the sheet is thick, it is called a sill.

BOSS When the magma after cooling is not parallel to the layers around it and makes an angle with them, it is called boss.

DIKE If the above mentioned angle is 90^o, it is called dike

VOLCANIC NECK Solidified lava in the form of a cylinder is found as plug in the vents of volcanoes and is known as the volcanic neck.

GENERAL CHARACTERISTICS OF IGNEOUS ROCKS

All igneous rocks are of magmatic origin; each intrusive type has an extrusive counterpart

These rocks are made of crystals of various sizes and shapes.

These rocks are compact, massive, unlayered and have joints which are weak points open to the action of mechanical weathering.

Having their origin under conditions of high temperatures, the igneous rocks are unfossiliferous

Although basically impermeable, igneous rocks are weathered mechanically

ECONOMIC SIGNIFICANCE OF IGNEOUS ROCKS

Since magma is the chief source of metal ores, many of them are associated with igneous rocks. The minerals of great economic value found in igneous rocks are magnetic iron, nickel, copper, lead, zinc, chromate, manganese, gold, diamond, platinum. These metals are of great value in metallurgical industry of modern days. Amygdales are almond-shaped bubbles formed in basalt due to escape of gases and are filled with minerals. Many of the metals are derived from cyrstallised minerals usually filling the fissures in the rocks. The old rocks of the great Indian peninsula are rich in these crystallised minerals or metals. Many igneous rocks like granite are used as building material as they come in beautiful shades.

SEDIMENTARY ROCKS

Sedimentary rocks cover 75 per cent of the earth's surface but volumetrically occupy only 5 per cent of the earth's crust. This indicates that they are not as important as igneous rocks in the depth of the earth.

Sedimentary or detrital rocks are those formed by the deposition of the solid materials carried in suspension by transporting agents. As sedimentation by transporting agents. As Sedimentation is favoured by water, most of the Sedimentary rocks have been formed under water. Wind is another agent of transportation; loess is one example of fine sand carried by wind and deposited as wind-borne Sedimentary rocks, as in north-western China and the Indian subcontinent. An unassorted mixture of clay and boulders known as boulder clay or "till" is an example of ice-deposited Sedimentary rock as in the plains of northern Europe. The deposited material under the pressure of overlying layers is transformed into Sedimentary rocks with passage of time

Sedimentary rocks can be studied under various categories depending upon various criteria.

A. On the basis of the origin of sediments, Sedimentary rocks could be of six types.

MARINE ORIGIN These rocks have a shallow marine origin and include sandstones, clay, shales and limestones

CONTINENTAL ORIGIN These are the end products of eh erosional process taking place on the earth. These rocks are formed in the deserts or coastal regions through the agency of wind; as a result their particles are more rounded and polished. These rocks include sandstones, clay, shales etc.

ORGANIC ORIGIN Animals and plants suck dissolved matter in water and expel the water through processes like breathing, transpiration etc. In other words, the bodied of plants and animals are the transformations of the dissolved matter obtained by them from water. These rocks contain carbonates of magnesium, calcium, silica etc.

VOLANIC ORIGIN Material which comes out with volcanic eruptions contains pyroclasts, ash etc. and gets based on land as well as in seas. Such sediments contain sand mineral, coal etc.

METEORITIC ORIGIN Many meteors come so close to the earth that their fragments, after disintegration due to friction, get oxidised in the shape of fine ash and settle down on the earth's surface.

B. The commonest classification of sedimentary rocks is on the basis of the modus operandi of their formation. They may be formed through mechanical, chemical or organic processes.

MECHANICALLY FORMED SEDIMENTARY ROCKS These rocks are formed by mechanical agents like running water, wind, ocean currents, ice. Some of these rocks have more sand, big sized particles, and are hard. These are called arenaceous rocks e.g. sandstone. While some other mechanically formed rocks have more clay, are fine-grained, softer, impermeable and non-porous. These are called argillaceous rocks and are easily weathered and eroded e.g.shale

CHEMICALLY FORMED SEDEMENTARY ROCKS After coming in contact with running water (underground or surface), many minerals get dissolved in it. This chemically charged water often leaves layers of these chemicals after the water has been evaporated. Such deposits occur at the mouth of springs or salt lakes. Stalactities and stalagmites are the deposits of lime left over by the lime-mixed water as it evaporates in the underground caves and leaves the deposits rising from the ground or hanging down from the roof.

Oolite is the granular limestone which is found quite widely in North

Yorkshire in England. Gypsum is the sulphate of lime which is found commonly along with rock salt. Iron-stone is the iron carbonate which is usually found associated with the coal beds.

ORGANICALLY FORMED SEDEMENTARY ROCKS These rocks are formed from the remains of plants and animals. These plants and animals are buried under sediments and due to heat and pressure form overlying layers, their composition undergoes a change. Coal and limestone are well known examples. Plant remains give rise to coals of different grades depending upon the proportion of carbon and the degree of overlying pressure. The peat and lignite (brown coal) is the first stage of coal having below 45 per cent of carbon; the bituminous variety is the next stage with 60 percent – 70 per cent carbon. Limestone is composed of shells and skeletons of dead marine animals once living in shallow, warm and clear waters of a sea or lake. The lime shells of such organisms are cemented into limestones sedimentary rock of organic. The tiny organisms like coral and algae derive calcium carbonate from the sea water. Such are the reefs built from the skeletons of dead coral one living in tropical seas. Depending on the predominance of calcium content or the carbon content, sedimentary rocks may be calcareous (limestone, chalk, dolomite) or carbonaceous (coal)

CHIEF CHARACTERISTICS OF SEDIMENTARY ROCKS

These rocks consist of a number of layers or strata horizontally arranged one over the other.

The basic constituent of these rocks or sediments are derived from different sources and mineral groups

These rocks are characterised by marks left behind by water currents and waves and by sun cranks

These rocks have fossils of plants and animals. These fossils are in the form of prints of leaves, insects or soft bovine animal and piece of bones, shells or some hard parts of old living beings.

These rocks are generally porous and allow water to percolate through them.

Sedimentary rocks are weathered and eroded more rapidly than other types of rocks.

SPREAD OF SEDIMENTARY ROCKS IN INDIA The alluvial deposits in the Indo-Gangetic plain and in coastal plains is of sedimentary accumulation. These deposits contain loam and clay. Different varieties of sandstone are spread over Madhya Pradesh, eastern Rajasthan, parts of the Himalayas, Andhra Pradesh, Bihar and Orissa. The great Vindhyan highland in central India consists of sandstones, shales, limestones. Coal deposits occur in river basins of the Damodar, Mahanadi, and Godavari in the Gondwana sedimentary deposits.

ECONOMIC SIGNIFICANCE OF SEDIMENTARY ROCKS sedimentary rocks are not as rich inmenerals of economic value as the igneous rocks, but important minerals such as haematite iron ore, phosphates, building stones, coals, petroleum, and material used in cement industry are found is sedimentary rocks. The decay of tiny marine organisms yiels petroleum. Petroleum occurs in suitable structures only. One of such structure is the existence of a previous stratum like sandstone between tow strata of impervious rocks like shale. Its further movement is stopped by the impermeable rock, and pressure helps it to rise in the porous rocks. If the rocks are bent upwards as in an anticlinal fold, oil tends to rise to the top, being lighter than water. Important minerals like bauxite, manganese, tin are derived from other rocks but are found in gravels and sands carried by water. Sedimentary rocks also yield some of the richest soils.

METAMORPHIC ROCKS

Temperature, pressure and chemically active fluids changes in igneous and sedimentary rocks. Hence, rocks formed under the action of high pressure, high temperature, chemical reactions or by regrouping of the components of eroded rocks are called the metamorphic rocks and the process which produces metamorphic rocks is called metamorphism.

CAUSES OF METAMORPHISM Metamorphism may happen due to several causes.

OROGENIC (MOUNTAIN BUILDING) MOVEMENTS Such movements often take place with interplay of folding, warping, crumpling and high temperatures. These processes give existing rocks a new appearance.

LAVA INFLOW The molten magmatic material inside the earth's crust brings the surrounding rocks under the influence of intense temperature and pressure and causes changes and them.

GEODYNAMIC FORCES The omnipresent geodynamic forces such as plate tectonics also play an important role in metamorphism

ACTION OF UNDERGROUND WATER The chemical action of underground water caused changes in chemical composition and crystal structure of rocks an plays a role in metamorphism

fluorine and boric acid. These mineralisers act on the rocks to cause metamorphism.

MINERALISERS The fluid component of the magmatic material are mineralisers and include liquids and vapours, such as steam, chlorine.

SUPERIMPOSED AND ANTECEDENT DRAINAGE

A part of a river slope and the surrounding area gets uplifted and the river sticks to its original slope, cutting through the uplifted portion like a saw, and forming deep gorge: this type of drainage is called antecedent drainage. Examples: Indus, Satluji, Brahmaputra.

When a river flowing over a softer rock stratum reaches the harder basal rocks but continues to follow the initial slope, it seems to have no relation with the harder rock bed and seems unadjusted to the base. This type of drainage is called superimposed drainage. Example: rivers of eastern USA and southern France.

DRAINGE PATIERNS The typical shape of a river course as it completes its erosional cycle is referred to as the drainage pattern of a stream. A drainage pattern reflects the structure of basal rocks, resistance and strength, cracks or joints and tectonic irregularity, if any.

There **can be various types of drainage patterns.**

DENDRITIC OR PINNATE This is an irregular tree branch shaped pattern. Examples: Indus, Godavari, Mahanadi, Cauveri, Krishna.

TRELLIS In this type of pattern the short subsequent streams meet the main stream at right angles, and differential erosion through soft rocks paves the way for tributaries. Examples: Siene and its tributaries in Paris basin (France)

RECTANGULAR The main stream bends at right angles and the tributaries join at right angles creating rectangular patterns. This pattern has a subsequent origin. Example: Colorado river (USA)

ANGULAR The tributaries join the main stream at acute angles. This pattern is common in foothill regions

PARALLEL The tributaries seem to be running parallel to each other in a uniformly sloping region. Example: rivers of lesser Himalayas.

RADIAL The tributaries from a summit follow the slope downwards and drain down in all directions. Examples: streams of Saurashtra region and the Central French Plateau.

ANNULAR When the upland has an outer soft stratum, the radial streams develop subsequent tributaries which try to follow a circular drainage around the summit. Example: Black Hill streams of South Dakota.

CENTRIPETAL In a low lying basin the streams converge from all sides. Example: streams of Ladakh, Tibet, and the Baghmari and its tributaries in Nepal

A GENETIC CLASSIFICATION OF STREAMS

Consequent Stream Where course follows the slope, generally the main stream

Subsequent Stream generally a tributary, it adjusts its course by differential erosion through softer rocks

Insequent stream those developed by random headward erosion.

Resequent Stream follows the same direction as consequent stream, but it is a tributary.

FLUVIAL LANDFORMS

The landforms created by a stream can be studied under erosional and depositional categorise.

EROSIONAL LANDFORMS The erosional landforms are discussed below

RIVER VALLEYS The extended depression on ground through which a stream flows throughout its course is called a river valley at different stages of the erosinal cycle the valley acquires different profiles. At a young stage, the valley is deep, narrow with steep wall-like sides and a convex slope. The erosional action here is characterised by predominantly vertical downcutting nature. The profile of valley here is typically 'V' shaped. As the cycle attains maturity, the lateral erosion becomes prominent and the valley floor flattens out. The valley profile now becomes typically 'U' shaped with a broad base and a concave slope.

A deep and narrow 'V' shaped valley is also referred to as gorge and may result due to downcutting erosion and because of recession of a waterfall. Most Himalayan rivers pass through deep gores (at times more than 500 metres deep) before they descend to the plains. An extended from of gorge is called a canyon. The Grand Canyon of the Colorado river in Arizona (USA) runs for 483 km and has a depth of 2.88 km

A tributary valley lies above the main valley and is separated from it by a steep slope down which the stream may flow as a waterfall or a series of rapids.

WATERFALLS A waterfall is simply the fall of an enormous volume of water from a great height, because of a variety of factors such as variation in the relative resistance of rocks, relative difference in topographic reliefs, fall in the sea level and related rejuvenation, earth movements etc. For example, jog or Gersoppa falls on Sharavati (a tributary of Cauveri) has a fall of 260 metres.

A rapid on the other hand is a sudden change in gradient of a river and resultant fall of water.

POT HOLES The kettle-like small depressions in the rockly beds of the river valleys are called pot holes which are usually cylindrical in shape. Pot holes are generally formed in coarse-gained rocks such as sandstone and granites. Potholing or pothole-drilling is the mechanism through which the grinding tools (fragments or rocks, e.g. boulders and angular rock fragments) when caught in the water eddies or swirling water start dancing in a circular manner, and grind and drill the rock beds of the valleys like a drilling machine. They thus form small holes which are gradually enlarged by the repetition of the said mechanism. The potholes go on increasing in both diameter and depth.

TERRACES Stepped benches along the river courses in a flood plain are called terraces. Terraces represent the level of former valley floors and remnants of former (older) flood plains

GULLEYS/RILLS An incise water-worm channel, which is particularly common in semi-arid areas. It is formed when water from overland-flows down a slope, especially following heavy rainfall, is concentrated into rills, which merge and enlarge into a gulley, the ravines of Chambal Valley in Central India and the Chos of Hoshiarpur in Punjab are examples of gulleys.

MEANDERS A meander is defined as a pronounced curve or loop in the course of a river channel. The outer bend of the loop in a meander is characterised by deposition, a gentle convex slope, and is called the slip-off side.

Morphologically, the meanders may be wavy, horse-shoe type or ox-bow/bracelet type.

OX-BOW LAKE Sometimes, because of intensive erosion action, the outer curve of a meander gets accentuated to such an extent that the inner ends of the loop come close enough to get disconnected from the main channel and exist as converted into swamps in due course of time. In the Indo-Gangetic plains, southwards shifting of Ganga has left many ox-bow lakes to the north of the present course of the Ganga.

PENEPLANE (or peneplain) This refers to an undulating featureless plain punctuated with low-lying residual hills of resistant rocks. According to W.M.Davis, it is the end product of an erosional cycle.

DEPOSITIONAL LANDFORMS

The depositional action of a stream is influenced by stream velocity and the volume or river load. The decrease in stream velocity reduces the transporting power of the streams which are forced to leave additional load to settle down. Increase in river load is effected through (i) accelerated rate of erosion in the source catchment areas consequent upon deforestation and hence increase in the sediment load in the downstream sections of the rivers; (ii) supply of glacio-fluvial materials; (iii) supply of additional sediment load by tributary streamsl (iv) gradual increase in the sediment load of the streams due to rill and gully erosion.

ALLUVIAL FANS AND CONES When a stream leaves the mountains and comes down to the plains, its velocity decreases due to a lower gradient. As a result, it sheds a lot of material, which it had been carrying from the mountains, at the foothills. This deposited material acquires a conical shape and appears as a series of continuous fans. These are called alluvial fans. Such fans appear throughout the Himalayan foothills in the north Indian plains.

NATURAL LEVEES These are narrow, ridges of low height on both sides of a river, formed due to deposition action of the stream, appearing as natural embankments. These act as a natural protection against floods but a breach in a levee causes sudden floods in adjoining areas, as it happens in the case of the Hwang Ho river of China

DELTA A delta is a tract of alluvium, usually fan-shaped, at the mouth of a river where it deposits more material than can be carried away. The river gets divided into two or more channels (distributaries) which may further divide and rejoin to from a network of channels.

A delta is formed by a combination of two processes: (i) sediment is deposited when the load-bearing capacity of a river is reduced as a resulted of the check to its speed as it enters a sea or lake, and (ii) at the same time fine clay particles carried in suspension in the river coagulate in the presence of salt water and are deposited. The finest particles are carried farthest to accumulate as bottom-set bets, coarser material is deposited in a series of steeply sloping wedges forming the foreset beds; and the coarsest material is deposited in the braided surface of the delta as topset beds.

Depending on the conditions under which they are formed, deltas can be of many types

ARCUATE OF FAN-SHAPED This type of delta results when light depositions give rise to shallow, shifting distributaries and a general fan-shaped profile. Examples: Nile,Ganga, Indus

BIRD'S FOOT DELTA This type of delta emerges when limestone sediment deposits do not allow downward seepage of water. The distributaries seem to be flowing over projections of these deposits which appear as a bird's foot. The currents and tides are weak in such areas and the number of distributaries lesser as compared to an arcuate delta. Example: Mississippi river.

ESTUARIES Sometimes the mouth of the river appears to be submerged. This may be due to a drowned valley because of a rise in sea level. Here fresh water and the saline water get mixed. When the river starts 'filling its mouth' with sediments, mud bars, marshes and plains seem to be developing in it. These are ideal sites for fisheries, ports and industries because estuaries provide access to deep water, especially if protected from currents and tides. Example: Hudson

CUSPATE DELTA This is a pointed delta formed generally along straight coasts and is subjected to strong wave action. There are very few and no distributaries in a cuspate delta. It has curved sides because of an even deposition of material on either side of the mouth. Example: Tiber river on west coast of Italy

FLUVIAL CYCLE OF EROSION

Three distinct stages of youth, maturity and old age can be identified during the lifetime of a stream

YOUTH A few consequent steams exist and d few subsequent steams are trying to develop valleys by random headward erosion. These valleys may be 'V' shaped. The depth of these valleys depends on the height above sea levels. The inter-stream divides are broad, extensive, irregular and may have lakes. Rapids water-falls gorges, river capture are characteristic features. Floodplain is generally absent, but may exist along the trunk stream. Overall, a highly uneven relief exists

MATURITY This stage is marked by well integrated drainage system with a few streams trying to adjust through softer beds. Broad valleys result from continuous horizontal erosion. Meanders are a characteristic feature and velley floor width is more than the meander belt width. The inter-stream divides are sharp and the upland is reduced. Rapids and waterfalls are absent. Floodplain development is a prominent feature, maximum relief exits overall.

OLD AGE The streams are more numerous than in youth but less as compared to maturity. With increasing deposition valley broadening dominates. Menders are highly developed with ox-bow lakes, and floor width is more than the meander belt width. The interstream divides are highly reduced. Lakes and marshes may be present. The successive floodplains join to form a peneplain. Delta formation is characteristic of old age at the mouth of the river. Mass wasting is dominant and, overall, minimum relief is evident.

Glacial Landforms and Cycle of Erosion

A glacier is a moving mass of ice at speeds averaging between 30 to 40 cm and 15 to 18 metres per day. It originates at high altitudes due to low temperatures and high orographic precipitation.

Glaciers are o four types, viz. continental glaciers, ice caps, piedmont glaciers, velley glaciers. The continental glaciers are found in the Antarctica and the Greenland. The biggest continental ice sheet in Iceland, for example, has an area of 8,450 square kilometers, and the thickness of its ice is 1,000 metres. Ice caps are the covers of snow and ice on mountains from which the valley or mountain glaciers originate. The piedmont glaciers form a continuous ice sheet at the base of mountains as in southern Alaska.

The valley glaciers, also known as Alpine glaciers, are found in higher regions of the Himalayas in our country and on all such high mountain ranges of the world. While the contienetal ice masses covering thousands of square kilometers and thousands of matres thick move outward in all directions from their central portions, the valley glaciers move down the mountain slope towards lower regions. There is a great variation in their size. The largest of Indian glaciers occur in the Karakoram range, viz. Siachen (72 km), while Gangotri in Uttar Pradesh (Himalayas) is 25.5 km long and many others are as small as 5-10 km in different part of the range.

The conditions favouring the formation of snow fields above the snowline are (i) the gentle slopes from where it cannot easily be swept off by wind or break off the slope as an avalanche, and (ii) the hollows or localities sheltered from direct sun.

A glacier is charged with rock debris which range from highly pulverized rock flour to huge angular boulders of fresh rock, obtained by freeze-thaw and plucking and are used for erosional activity by moving ice. A glacier during its lifetime creates various landforms which may be classified into erosional and depositional landforms

EROSIONAL LANDFORMS

CIRQUE/CORRIE is an amphitheatreshaped hollow basin cut into a mountain ridge. It has steep sided slope on three sides, an open end on one side and a flat bottom. When the ice melts, the cirque may develop into a tarn lake.

GLACIAL TROUGH is an original stream-cut valley, further modified by glacial action. Step-formation takes place at maturity, otherwise it is an ungrated and irregular feature.

"U" SHAPED VALLEY is another typically glacial feature. Since glacial mass is heavy and slow moving, erosional activity is uniform – horizontally as well as vertically. A steep sided and flat bottom valley results, which has a "U" shaped profile.

HANGING VALLEY is formed when smaller tributaries are unable to cut as deeply as bigger ones and remain "hanging" at higher levels than the main valley as discordan tributaries. This may happen due to glacial tilting or faulting.

ARETE is a steep-sided, sharp-tipped summit with the glacial activity cutting into it from who sides.

HORN is a ridge that acquires a 'horn' shape when the piedmont glacier surrounds a summit

FJORD is formed as a steep-sided narrow entrane-like feature at the cost where the stream meets the coast. Fjords are common in Norway, Greenland and New Zealand.

MAMMILLATED FIELD

DEPOSITIONAL LANDFORMS

OUTWASH PLAIN When the glacier reaches its lowest point and melts, it leaves behind a stratified deposition material, consisting of rock debris, clay, sand, gravel etc. This layered surface is called till plain or an outwash plain and a downland extension of the deposited clay material is called valley train

ESKER is a winding ridge of unassorted depositions of rock, gravel, clay etc. running along a glacier in a till plain. The eskers resemble the features of an embankment and are often used for making roads. If the melting of glacier has been punctuated, it is reflected in a local widening of the esker and here it is called a beaded esker.

KAME TERRCES are the broken ridges or unassorted depositions looking like hummocks in a till plain.

DRUMLIN is an inverted boat-shaped deposition in a till plain caused by deposition. The ersional counterpart is called a roche moutonne.

KETTLE HOLES can be formed when the deposited material in a till plain gets depressed locally and forms a basin

MORAINE is a general term applied to rock fragments, gravel, sand etc. carried by a glacier. Depending on its position, the moraine can be ground, lateral, medial or terminal moraine. The material dropped at the end of valley glacial in the form of a ridge is call the terminal moraine. Each time a glaciertreats, a fresh terminal moraine is left at short distance behind the first one. The mater deposited at either of its sides is known lateral moraine. When two glaciers join, the lateral moraines also join near their confluer and are called medial moraine. Many Aplipastures in the Himalayas like the Marge Kashmir occupy the sites of morainic depos of old river valleys. The excessive load to cannot be carried forward by a glacier deposited on its own bed or at the base a appears as what is known as ground morair

GLACIAL CYCLE OR EROSIN

YOUTH

MATURITY

OLD AGE

Marine landforms and Cycle of Erosion

The sea performs the function of erosion and deposition through sea waves, aided by currents, tides and storms in coastal areas.

The erosive work of the sea depends upon (i) size and strength of waves, (ii) seaward slope, (iii) height of the shore between low and high tides (iv) composition of rocks (v) depth of water etc. The wave exerts a pressure to the magnitude of 3000 to 30,000 kilograms per squre kilometer. This wave pressure compresses the air trapped inside rock fissures, joints, faults, etc. forcing it to expand and rupture the rocks along weak points. This is how rocks get worn down under wave action. Waves also use rock debris as instruments of erosion. These rock fragments carried by waves themselves get worn down by striking against the coast or against one another. The solvent or chemical action or waves is another mode of erosion, but it is pronounced only in case of soluble rocks like limestone and chalk.

The marine landforms can be studied under reosional and depositional categories.

EROSIONAL LANDFORMS

CHASMS Thses are narrow, deep indentations carved out through vertical planes of weakness in the rocks by wave action. With time, further headward erosion is hindered by the chasm mouth, which itself keeps widening

WAVE-CUT PLATFORM When the sea waves strike against a cliff, the cliff gets eroded gradually and retreats. The waves level out the shore region to crave out a horizontal plane or a wave-cut platform. The bottom of the cliff suffers the maximum intensive erosion by waves and, as a result, a notch appears at this position.

SEA CLIFF It is the seaward limit of coast which is marked by a steep scarp

SEA CAVES Differential erosion by sea waves through a rock with varying resistances across its structure produces arched pockets in rocks. These are called sea caves.

SEA ARCHES When the waves attack a rock-form from two opposite sides, the differential erosion produces bridge-like structures or sea arches.

STACKS/SKARRIES/CHIMNEY ROCK When a portion of the sea arch collapses, the remaining column-like structure is called a stack, skarry or chimney rock.

HANGING VALLETS if the fluvial erosion by streams flowing down the coasts is not able to keep pace with the retreat of the cliff, the rivers appear to be hanging over the sea. These river valleys are called hanging valleys.

BLOW HOLES OR SPOUTING HORNS A narrow fissure through the roof of a sea arch is called a blow hole or a spouting horn because the wave action compresses and squeezes out the air from the sea caves through blow holes making a peculiar noise.

PLANE OF MARINE EROSION/PENEPLAIN The eroded plain left behind by marine action is called a plain of marine erosion, and if the level difference between this plain and the sea level is not much, the agents of weathering convert it into a peneplain.

DEPOSITIONAL FEATURES

BEACH This is the temporary veneer of rock debris on or long a wave-cut platform. It is by the sea waves that the deposition of rock flour is carried out.

BAR The longshore currents, tidal currents and the shore drift deposit rock debris and sand along the coast at a distance from the shoreline. The resultant landforms which remain submerged are called bars. The enclosed waterbody so created is called a lagoon

BARRIER It is the overwater counterpart of a bar.

SPIT AND HOOK A spit is a projected deposition joined at one end to the headland with the other end free in the sea. The mode of formation is similar to a bar or barrier. A shorter spit with one curved towards the land is called a hook

TOMBOLOS Sometimes, islands are connected to each other by a bar called tombolo. These islands are referred to as the tied islands.

COASTLINES

The boundary between the coast and the shore is known as the coastline; it marks the seaward limit of the coast. The outline of the coast may be modified by sea waves.

According to D.W.johnson, coastline can be divided into the following classess:

Coastline of Emergence

Coastline of Submergence

Neutral coastline

Compound coastline

Fault coastline

This classification has two bases: (a) the change of levels, i.e. if seal level rises the shores are submerged and if the sea level falls, the shores emerge, (b) the nature of shorelines, because it is necessary to know the nature of sea shore before emergence and submergence, whether the shore was upland or downland, for instance.

COASTLINE OF EMERGENCE These are formed either by an uplift of the land or by the lowering of the sea level. This type of coast has bars, spits, lagoons, salt marshes, beaches, sea cliffs and arches. The east coast of India, especially its south-eastern part, appears to be a coast of emergence. The coast has, however, been invaded by the sea a number of times during the past. The west coast of India, on the other hand, is both emergent and submergent. The northern portion of the coast is submerged as a result of faulting and the southern portion, that is the Kerala coast, is an example of an emergent coast.

COASTLINE OF SUBMERGENCE A submerged coast is produced either by subsidence of land or by a rise in sea level. The important types of such a coastline are ria, fjord, Dalmatian and drowned lowlands

When a region is dissected by streams into a system of valleys and divides, submergence produces a highly irregular, embayed shoreline called ria coastline. The coast of south-west Ireland is a typical example of ria coastline. Some coastal regions have been heavily eroded by glacial action and the valley glacier troughs have been excavated below sea level. After the glaciers have disappeared, a fjord coastline emerges. These coasts have long and narrow inlets with very steep sides. The fjord mouths are often dotted with small hilly islands which were once the outlying hills. The fjord coasts of Norway are a typical example. The Dalmatian coasts result by submergence of mountain ridges which run parallel to the sea coast. Therefore, there is a series of fold mountain ranges with alternating crests and troughs running parallel to the coast. The Dalmatian coast of Yugoslavia is a typical example. A drowned lowland coast is low and free from indentations, as it is formed by the submergence of a lowlying area. It is characterised by a series of bars running parallel to the coast, enclosing lagoons. The Baltic coasts of eastern Germany is an example of this type of coastline.

NEUTRAL COASTLINE These are coastline formed as a result of new materials being built out into the water. The word "neutral" implies that there need be no relative change between the level of sea and the coastral region of the continent. Neutral coastlines include the alluvial fan shaped coastline, delta coastline, volcano coastline and the coral reef coastline

COMPOUND COASTLINE Such coast lines show the forms of two of the previous classes combined, for example, submergence followed by emergence or vice versa. The coastlines of Norway and Sweden are examples of compound coatlines.

FAULT COASTLINE Such coastlines are unusual features and result from the submergence of a downthrown block along a fault, such that the uplifted block has its steep side (or the faulting) standing against the sea forming a fault coastline.

MARINE CYCLE EROSION

YOUTH The waves are very active. Sea cavas, arches and stacks begin to develop. Cliffundercutting is pronounced and wavecut. Platforms begins to emerge due to wave erosion. The height of cliff increases in the middle youth and cliffs retreat a lot. By the end of youth, an irregular coastline remains.

MATURITY The cliff and wave-cut platform are conspicuous. Stream deposition is taking place. These valleys may be normal or of the hanging type. Various landforms indicating continuous deposition are visible, such as bars, barriers and spits. A gradual straightening of the coastline heralds the arrival of old age.

OLD AGE Irregularities, such as caves and arches, have disappeared. The abrasion platform is so widened that all the wave energy is spent in friction and shifting of sand across the beach. Consequently, wave attack upon the cliff base is reduced. Finally, a straight, gently sloping coastline and a broad beach result with little bedrock appearing at the surface.

Karst Landforms and Cycle of Erosion

Karst is a terrain with characteristic relief and drainage arising mainly due to higher solubility of rock in natural water than is found elsewhere. It is a dry, upland landscape with underground drainage instead of surface streams. It is so named after a province of Yugoslavia on the Adriatic sea coast where such formations are most noticeable.

CONDITIONS ESSENTIAL FOR FULL DEVELOPMENT OF KARST TOPOGRAPHY

Presence of soluble rocks, preferably limestone at the surface or sub-surface level.

These rocks should be dense, highly jointed and thinly bedded.

Presence or entrenched valleys below the uplands underlain by soluble and well jointed rocks. This favours the ready downward movement of groundwater through the rocks.

The rainfall should be neither too high nor too low

There should be a perennial source of water.

KARST LANDFORMS

KARREN/LAPIES These are grooved, fluted features in an open limestone field

CAVERN This is an underground cave formed by water action by various methods in a limestone or chalk area. There are differing views on the mode of formation of these caverns. The Mechanical Action school represented by Penck, Weller and Dane considers mechanical action by rock debris and pebbles to be responsible for cavern excavation. This school argues that the water table is too low to have a solution effect. The Chemical Action school, on the other hand, considers the solution action of water to be mainly responsible for cavern excavation. This school is represented by Davis and Piper.

This largest cavern in Kentucky (USA) is 48 km long and 25 meters high. In India, such caves can be seen in Baster, Dehradun, Shillong plateau.

ARCH/NATURAL BRIDGE When a part of the cavern collapses the portion which keeps standing forms an arch

SINK HOLE/SWALLOW HOLE Sink holes are funnel shaped depressions having an average depth of three to nine metres and , in area, may vary from one square metre to more. These holes are developed by enlargement of the cracks found in such rocks, as a result of continuous solvent action of the rainwater. The swallow holes are cylindrical tunnel-like holes lying underneath the sink hole at some depth. The surface streams which sink disapper underground through swallow holes because these are linked with underground caves through vertical shafts.

KA**RST WINDOW** When a number of adjoining sink holes collapse, they form an open, broad area called a karst window

SINKING CREEKS/BOGAS In a valley, the water often gets lost through cracks an fissures in the bed. These are called sinking creeks, and if their tops are open, they are called bogas.

DOLINES These are small depressions dotting a karst landscape

UVALA A number of adjoining dolines may come together to form a large depression called uvala

POLJE/BLIND VALLEY A number of uvalas may coalesce to create a valley called polje which is actually a flat floored depression. If the streams lose themselves in these valleys, then these are called blind valleys. These **valleys may have surface streams and may be used for agriculture.**

DRY VALLEY/HANGING VALLEY Sometimes, a stream cuts through an impermeable layer to reach a limestone bed. It erodes so much that it goes very deep. The water table is also lowered. Now the tributaries start serving the subterranean drainage and get dried up. These are dry valleys or bournes. Lack adequate quantities of water and reduced erosion leaves them hanging at a height from the main valley. Thus, they are also referred to as hanging valleys.

HUMS These are curved relicts of limestone rocks after erosion

STALACTITE AND STALAGMITE The water containing limestone in solution seeps through the roof of caverns in the form of a continuous chain of drops. A portion of the roof hangs on the roof and on evaporation of water, a small deposit of limestone is left behind contributing to the formation of a stalactite, growing downwards from the roof. The remaining portion of the drop falls to the floor of the cavern. This also evaporates, leaving behind a small deposit of limestone siding the formation of a stalagmite, thicker and flatter, rising and stalagmite join together to form a complete pillar known as the column.

THE KARST CYCLE OF EROSION

YOUTH Youth begins with the surface drainage on either an initial limestone surface or one that has been laid bara and is marked by progressive expansion of underground drainage. Gradually, the upper impervious layer is eroded. Dolines, sink holes and swallow holes are particularly characteristic of this stage. No large caverns exist and underground drainage has not yet completed its course.

MATURITY Now, there is maximum underground drainage. Surface drainage is limited to short-sinking cracks ending in swallow holes or blind valleys. Cavern networks are characteristic of this stage. This is the time of maximum karst development. Late maturity marks the beginning of the decline of karst features. The portions of cavern streams are exposed through karst windows. These expand to form large uvalas, and detached areas of original limestone upland begin to stand out as hums.

OLD AGE Largescale removal of limestone mass leaves behind a karst plain. There is a reappearance of surface drainage with only a few isolated hums as remnants of the original limestone terrain.

Rejuvenated and Polycyclic Landforms

Landforms are generally created by complex geomorphological process, often involving a number of geographical cycles. We may notices, in a single landscape, a number of features representing different ages or stages, thus indicating a varity of incomplete geographical cycles which were interrupted (called "accidents" by Davis) for various reasons.

Dynamic reasons involving uplift or subsidence of land resulting in a change in base level. Such changes are mostly localized.

Eustatic reasons implying a worldwide change in sea level due to diastrophism or glaciation.

Static reasons e.g.a reduction in river load or an increase in volume (due to precipitation or deforestation) may alter the rate of erosion.

Climatic reasons such as audity, glaciations etc

INSTANCES OF POLYCYCLIC LANDFORMS

Older alluvium terraces, for instance Bhangar terraces in north Indian plains.

Existence of synclinal ridges and anticlinal valleys in successive cycles.

Rejuvenated landfrms

Scarped erosional surface of different ages. Examples – Appalachians and Western Ghats

Faultline scarp due to differential erosion

Uplifted peneplains.

Palaeomorphic landforms-i.e. those formed under conditions which do not exist now. These landforms include relict landforms (those based on earlier ones, e.g. drainage systems of north Sahara in Africa), buried landforms, e.g. by continental glaciers in USA, exhumed landforms (initially buried but now resurrected).

REJUVENATED LANDFORMS

If, because of eustatic, static, dynamic or climatic reasons, the erosional activity of a stream revives, it is said to have been rejuvenated. A stream may be rejuvenated when land is elevated near its headwaters or sea level sinks near its mouth. The stream's ability to erode is renewed and downward cutting begins. This results in the formation of river terraces and meanders get incised between steep sides. There is a slight break in slope and change in slope of the valley. If rejuvenation does not interrupt the cycle, the sea level rises or land submerges, the young stream becomes an old stream and lowering as well as extending of its basin continues. These changes may bring the completion of the cycle in sight, other things being equal.

The principle difference between a rejuvenated valley and a young valley, (although they show similarity of features) is that the "initial" surface in the former is an uplifted peneplane and in the latter, it is a former sea floor. The drainage on uplifted peneplane is already established, so the streams are merely rejuvenated and they cut deep 'Valley' shaped valley into their old shallow courses. When the maturity of the second cycle is reached, the former peneplane is completed consumed, but its influence is seen generally in the accordant summits of hilltops over the region as a whole

TREPPEN CONCEPT

The concept of Treppen refers to a steplike landcaps and is derived from a petrographic term 'trap' or 'traprock' for all dense, dark igneous rocks that look like basalt. Treppen landscape emerges out or erosional dissection of basalt plateaus. This process is strongly controlled by the sheetlike continuity and columnar jointing of the flows. In the landscape.

The basalt topography responsible for giving rise to Treppen landforms results from solidification of consecutive layers of basaltic material erupting on a fissure mode of volcanic activity. The largest flood basalt region is the Deccan region of peninsular India covering more than 5 lakh square kilometers. The Deccan flood basalts were emplaced within an interval of two million years between 65 millon and 69 million years age (Cretaceous Tertiary geologic boundary). The western margins of peninsular India are in the form of steplike terraces having undergone intense erosion to produce a rugged scarped relief a typically treppen feature.

Similar basalt plateaus are present in Columbia plateau (USA), southern Brazil, Manchuria (china), central Siberai and in fragments around the North Atlantic basin on Greenland, Iceland, Ireland, Faeroe Islands and Jan Mayen.

GEOMORPHOLOGY AND HYDROLOGY

Water used by human beings is available from different sources –streams, lakes ad rivers on the surface of the earth or groundwater. Different stratigraphic and lithological zones present different conditions of surface and ground water.

Limestone terrains vary widely and the ability to yield water depends on the type of rock. Permeability in limestones may be primary or secondary. Primary permeability depends upon the presence of intial interconnecting voids in the calcerous sediments from which the rock was formed. Secondary (or acquired) permeability occurs because of earth movements such as faulting, folding, warping, and due to solution or corrosion mechanism. This secondary permeability varies notably with respect to the topography of a region, being greatest beneath and adjacent to topographic lows or valleys. much of the groundwater in karst terrain is confined to solution channels.

In early stages of karst evolution conditions are not too different from those of other types of landscape with similar relief. But as the cycle advance, a large proportion of water is diverted to solutionally opened passageways, and surface water gets diminished. The main source of water in such regions then are karst springs. Such springs may supply water to meet moderate demands, but the quality of water may be affected by pollutants and bacteria. The sources of the spring water should be determined in such a case of pollution. The swallow holes and sinkholes feeding water to the underground drainage systems emerging as springs may be located. This can be done by putting some colouring material, such as flourescein, into the water entering nearby swallow holes (or sinkholes) and testing the various spring waters to find out their source. A knowledge of the structural grology of the region is of use in this context, as groundwater moves down rather than up the regional dip.

The ease with which water may be obtained in a limestone region depends on the geomorphology of the area. If the limestone have enough meability and are capped by sandstone layer, there may be no difficulty in obtaining wells of large yields. Moreover, the water would get naturally filtered as it passes through the sandstone beds. If, however, the limestone is dense and compact, with little mass permeability, movement of groundwater will be largely through secondary openings. In such circumstances, the yield of water may be low or, even if adequate, subject to contamination. Karst plains lack a filtering cover and sinkholes, swallow holes or karst valley within an area of clastic rocks should cast doubt on the purity of the water from springs nearby.

Groundwater potential in glaciated regions can be determined on the basis of understanding the geomorphic glacial deposits and landform. Outwash plains, valley trains and intertill gravels are likely to yield large volumes of water. Most tills are poor sources of water because of the clay in them, but they contain local strata of sand and gravel which may hold supply enough water for domestic needs.

Buried preglacial and interglacial valleys could be good sources of groundwater. Their presence (or absence) may be detected by studying the preglacial topography and geomorphic history of the area. Buried valleys are located by constructing bedrock topography maps of glaciated areas.

GEOMORPHOLOGY AND MINERAL EXPLORATION mineral deposits are are associated with geological structure. Landscape characteristics of the specific localities could indicate such geologicl structures.

SURFACE EXPRESSION OF ORE BODIES

Some ore bodies have obvious surface expressions as topographic forms, as outcrops of ore, gossan, or resieual minerals, or structural features such as faults, fractures and zones of breccia. Lead –zinc lodes could be marked by a conspicuous ridge as in the case of Broken Hill, Australia. Quartz veins could stand out prominently as they are much more resistant to erosion than the unsilicified surroundings, as in Chihuahua, Mexico. Some veins (calcite, for instance) and mineralised areas may be indicated by depressions or subsidence features.

WEATHERING RESIDUES many economically important minerals are the weathering residues of present or ancient geomorphic cycles and geomorphology can be of use in searching for such minerals. Iron orc, clay mineral, caliche, bauxite and some ores of manganese and nickel may be such weathering residues. Weathering and erosion are constantly at work on the rocks of earth’s surface, and the products of rock weathering may be economical value. The surfaces on which residual weathering products commonly form are pleneplain or near-pleneplain surface. Such minerals are more commonly to be found upon remnants of Tertiary erosional surface above present base levels of erosion. Bauxite, for instance, is either the residue of a small amount of insoluble aluminous material in dolomites and limestone or it is the direct product of the weathering of aluminous minerals.

PLACER DEPOSITS Placer deposits are mixtures of heavy metals which are aggregates of materials derived through chemical weathering or erosion of metallic formation. Placer concentration of minerals results from definite geomorphic processes, and found in specific topographical positions, and may have a distinctive topographic expression. The type of rock forming the bedrock floor may influence the deposition of placers.

Residual placers or "seam diggings" are residues from the weathering of quartz stringers or venis, are usually of limited amount, and grade down into lodes. Colluvial placers re produced by creep downslope of residual materials and are thus transitional between residual placers and alluvial placers. Gold placers of this type have been found in California, Australia, New Zealand, and elsewhere. Part of the tinplacers of Malaya are colluvial placers (the koelits) and part are alluvial placers (the kaksas).

About one-third of the world's platinum is obtained form alluvial placers in Russia, Colombia, and elsewhere. Gold, tin and diamonds are among the more important minerals obtained from alluvial placers. Diamonds in the Vaal and Orange river districts of South Africa, the Lichtenburg area of South Africa, the Belgian Congo, and minas Geraes, Brazil, are obtained from alluvial placers. About 20 per cent of the world's diamonds comes from placer deposits. Aeolian placers have yielded gold in Australia and Lower California, Mexico.

Bajada placers form in the gravel mantle of a pediment and in the confluent alluvial fans of a bajada. They are more likely to be found near a mountain base than out on the more gentle slopes of a basin fill. Beach placers have yielded gold in California and Alaska, diamonds in the Namaqualand district of South Africa, zircon in India, Brazil, and Australia, and ilmenite and monazite from Travancore, India,

"Location of placers may be aided by drilling and geophysical testing. A magnetic survey will usually be helpful because magnetite is likely to be associated with gold. If the bedrock is a basic type with a higher magnetic intensity than the placer gravels, areas of magnetic "lows" may reflect the positions of the filled channels.

"knowledge of eh bedrock geology, application of geophysical surveying, test drilling and aerial-photograph interpretation all contribute their parts to exploration for these buried placers, but most fundamental to this search is a thorough understanding of the geomorphic history of the region." Onserves W.D.Thornbury.

OIL EXPLORATION Many oil fields have been discovered because of their striking topographic expression. Mineral oil is considered to have been formed by the decay and decomposition of organic matter. After formation, this oil gets trapped in rocks under structural traps or stratigraphic traps. Sedimentary strata are folded into anticlines and synclines allowing the permeable and impermeable strata to get closer, and the mineral oil is well preserved within the upper permeable and the lower impermeable beds. Generally mineral oil is found in the porous and permeable rock structures with lower layers of impermeable rocks. Sandstone and limestone provide ideal locations of mineral oil as they are porous and permeable. The shale below acts as the impermeable bed. In regions of heavy tropical forests, tonal difference may indicate an anticlinal or domal structure.

More subtle evidence of geologic structures favourable to oil accumulations is being made use of today in the search for oil. Drainage analysis of a terrain shown on aerial photographs is one such technique. A sophisticated perception perception of drainage anomalies of an area is required, and a geomorphologist would most likely posses the requisite knowledge. Drainage analysis is particularly useful in regions where rocks have low dips and the topographic relief is slight.

According to Leverson, many oil and gas sources are associated with unconformities-ancient erosion surfaces; hence a petroleum geologist must deal with buried landscapes. where ancient erosion surfaces shorten permeable beds and are later sealed over by deposits, the erosion surfaces become stratigraphic traps, most of which are along unconformities.

GEOMORPHOLOGY AND ENGINEERING WORKS engineering works most often involve evaluation of geologic factors of one type or another; terrain characteristics are among the most common factors.

ROAD CONSTRUCTION The most feasible highway routes would be best determined by the topographic features of the area. Knowledge of the geologic structure, lithological and stratographic characteristics, strength of the surficial deposits, geomorphic history of the area, among other things, are of importance in road engineering.

A route over a karst plain necessitates repeated cut and fill, otherwise the road will be flooded after heavy rains as sinkholes fill with suface runoff. Bridge abutments in a karst region should be so designed that they will not be weakened by enlarged solutional cavities which are likely to be present.

Glacial terrains present many types of engineering problems. A flat till plain is topographically ideal for road construction, but in areas where end-moraines, eskers, kames or drumlins exist there is need for cut and fill to avoid circuitous routes. Muck areas, which mark sites of former lakes, are unsuited for roads which are to carry heavy traffic. If a road is built across them as they are, heavy traffic will cause the plastic materials beneath the lake floor to flow, and 'sinks' in the road bed will result. To avoid this, the lacustrine fill may have to be exvacated and replaced with material that will not flow under heavy load.

Areas with the considerable relief which characterises late youth and early maturity will necessitate much bridge construction any many cuts and fills. In such areas landslides, earth flows and slumping become serious problems.

In highway construction designed to carry heavy traffic, the nature of the soil beneath a road surface, or what is called the subgrade, has become increasingly significant because of its control over the drainage beneath a highway. The lifetime of a highway, under moderate loads, is determined largely by two factors: the quality of the aggregate, used in the highway and the soil texture and drainage of its subgrade. Thus an appreciation of the relationships of soils to varying topographic conditions and type of parent material becomes essential in modern highway consruction. A knowledge of soil profiles, which to a large degree reflect the influence of geomorphic conditions and history, is basic. Poor highway performance characterises silty-clay subgrades with a high water table, and best performance is found on granular materials with a low water table.

DAM SITE SELECTION Selecting sites for the construction of dams would be greatly helped by a synthesis of knowledge concerning geomorphology, lithology, and geologic structure of terrains. Five main requirement of good reservoir sites depend on geologic conditions, according to kirk Brayn: (1) a water-tight basin of adequate size; (2) a narrow outlet of the basin with a foundation that will permit economical construction of a dam; (3) opportunity to build an adequate and safe spillway to carry surplus waters; (4) availability of materials needed for dam construction (this is particularly true of earthen dams); and (5) assurance that the life of the reservior will not be too short as a result of excessive deposition of mud and silt.

Limestone terrain, for instance, may prove a difficult one for constructing a dam. The bedrock surface may be irregular because of differential solution and, unless a ture picture of the subsurface is understood, it could lead to avoidable expenditure.

A construction in a valley is desirable from the standpoint of eh size of the dam that will have to be built, but it may not always be a good dam site. In glaciated areas, where buried bedrock valleys containing sand and gravel fills are common, surficial topography may not give an adequate picture of sub-surface conditions.

On a superficial level, a dam could be situated at a constriction in a valley between a valley wall on one side and a spur end on the other. However, it is possible that the subsurface topography is not suitable; there may be a buried preglacial valley with sand and gravel in it. The dam, if build on such a site, would lead.

CONSTRUCTION OF AIR STRIPS While selecting sites for air strips, where aeroplanes may land and take off from, requires engineering skill, the engineer could well benefit from a geomorphologist's knowledge of landscope characteristics. The best sites for air strips would show an extensive flat surface with resistant geomaterials available: here a safe and suitable runway can be constructed. Furthermore, the ground surface should show an almost level slope, the area should be free of floods and marked by good visibility (may be free of frequent and intense for). These characteristics could be gathered from a morphological map of the region where the air strip is to he built.

LOCATING SAND AND GRAVEL PITS

Sand and gravel have many engineering as well as commercial and industrial uses. Selection of suitable sites for sand and gravel pits will entail evaluation of such geologic factors as variation in grade sizes, lithologic composition, degree of weathering, amount of overbueden and continuity of the deposits. Sand and gravel may be found as floodplain, river terrace, alluvial fan and cone, talus, wind-blow, residual and glacial deposits of various types. All have distinctive topographic relationships and expressions and varying inherent qualities and possibilities of development. A recognition of the type of deposit is essential to proper evaluations of its potentialities. Demand for gravel is generally greater than for sand, particularly in recent years with the decreased use of plaster in home construction, and thus a knowledge of he percentage of various grade sizes is important.

Floodplain deposits are likely to contain high proportions of silt and sand and show many veriable and heterogeneous lateral and vertical gradations. Alluvial fan and cone gravels are angular in shape as well as variable in size, especially near their apices. Talus material, in addition for most uses and are limited in extent Wind-blown sands may be satisfactory sources of sand but have no gravel in them. Residual deposits lack assortment and are likely to contain pebbles that are too deeply weathered to be suitable for use as aggeregate in cement work. A high percentage of iron-coated chert when used as aggregate usually has deleterious effects. Reisdual deposits are furthermore likely to be limited in extent.

Terraced valley trains and outwash plains are usually favourable sites for pits, for they do not have a thick overburden and are usually extensive.

GEOMORPHOLOGY AND MILITARY GEOLOGY

Thornbury points out the importance of geomorphology in the context of war.

"World War I was largely stabilised trench warfare, and the information that was most useful was more geologic than geomorphic in nature (Brooks, 1921). Information about the kind of rock that would be encountered in digging trenches, in mining and countermining and the possibilities of water supply and supplies of other geologic materials was most utilised. Topography did play a role in maneuvering and planning routes of attack, but it can hardly be said that the Allies utilised basic geomorphic knowledge to any great extent.

"With development of the blitzkrieg type of warface during World War II, topography became more important, because the effectiveness of a blitz depends to a large degree upon the trafficability of the terrain. As a comsequence, in more recent years terrain appreciation or terrain analysis have become semi-magic words with the milirary. A geomorphologist may lack knowledge as to how best to utilize terrains in military operations, but certainly his concepts of terrain conditions are far more adequate than those of the military specialist or other geologists for that matter. He appreciates that landforms are the result of an interaction of geomorphic and geologic processes through time; that landforms are not groups of unrelated and haphazard individual forms but have sustematic relatioships that reveal their origins and tell much about the underlaying bedrock geology and structure, as well as the soils and vegetation of a region. As Erdmann (1943) put it, the geomorphologist has 'an eye for the ground or an instinctive eye for configuration, the judgement of how distant ground, seen or unseen, is likely to lie when you come to it…. Terrain is the common denominator of geology and war.' Whether it is in connection with the interpretation o topographic maps or aerial photographs, this basic appreciation of different types of terrain is fundamental to a proper planning of military campaigns."

Regarding the use of aerial photographs in this connection, Hunt (1950) stated: "Even where geologic maps are lacking or are on such a small scale as to be pratically useless for tactical intelligence, geologic principles can be applied with advantage to interpreting the terrain from aerial photographs. Little training in reading vertical photographs is required to recognize mountains, hills, lakes, rivers,woods, plains or some kinds of swamps. But much more than that can and should be interpreted from the pictures for the purpose of acquiring completer terrain intelligence. It is essential to know the kind of hill, the kind of plain, the kind of river or lake, and so on, because by knowing this it is frequently possible to reconstruct the geology. The interpreter, with some confidence, can then make predictions as to water supply, the kind and depth of soil, trafficability, ground drainage and other construction problems, construction materials, movement and cover, and many of the other elements that are essential to an adequate estimate of the terrain situation. In brief, therefore, aerial photographs are useful to the preparation of terrain intelligence insofar as they provide information on the geology of the area. Identification of a hill or other terrain feature is but a small part of the story that can be read from a photograph; all important is the recognition of the significance of the particular landform, in terms of kind of ground and slope."

GEOMORPHOLOGY AND URBANISATION

Geomorphological knowledge applied to urban development has become important enough to grow into a separate branch, namely, urban geomorphology. This branch of geomorphology is concerned with “the study of landforms and their related processes, materials and hazards, ways that are beneficial to planning, development and management of urbanised areas where urban growth is expected,” according to R.U. Cooke.

A city or town depends for its stability, safety, basic needs and, later, its expansion on geomorphological features: lithologiacal and topographical features, hydrological conditions and geomorphic features. An urban geomorphologist begins work even before urban development through field survey, terrain classification, identification and selection of alternative sites for settlements. During and after urban development, an urban geomorphologist would be concerned with studying the impact of natural events on the urban community and that of urban development on the environment.

It has been pointed out by R.U. Cooke that “various geomorphological problems hitherto not understood by the planners and engineers lead to destruction and damage to urban settlements in varying environmental realms viz. settling of foundation materials in the dry lands of oil-rich states and in the periglacial regions; destruction of foundations by weathering processes; damage of highways; damage to buildings through inundation during floods in the subtropical humid regions etc. All these and many other problems arise in part from mismanagement or misunderstanding of geomorphological conditions.” Very little attention is paid to understanding the geomorphological conditions before the development of existing urban centres mainly in the developing countries. This results in uncontrolled growth, giving rise to squatter settlements or shanty towns. It commonly creates serious social and environmental problems.

GEOMORPHOLOGY AND HAZARD MANAGEMENT Event, natural or man-in-duced, exceeding a tolerable level or of an unexpected nature may be called hazards. A geomorphic hazard, says Chorley, may be defined as “any change, natural or man-made, that may affect the geomorphic stability of a landform to the adversity of living things". These hazards may arise from long-term factors such as faulting, folding, warping, uplifting, subsidence caused by earth movements, or changes in vegetation cover and hydrologic regime caused by climatic change. More immediate and sudden hazards are volcanic eruptions, earthquake, landslides, avalanches, floods, etc.

Geomorphic knowledge can be of use in identifying and predicting such hazards and in assessing their effects and proper management.

Regular measurement of seismic events and earth tremors by seismic methods; regular measurement of ground surface, mainly tilt measurement by tilt metres; constant measurement of temperature of crater lakes, hot springs, geysers, fumaroles; monitoring of gases coming out of craters, hot springs, geysers; monitoring of changes in the configuration of dormant or extinct volcanoes by lasers; measurement of local gravity and magnetic fields and their trents etc., help in making predictions of possible eruptions in the areas having past case histories of volcanism. The path of lava flow can be better predicted on the basis of detailed analysis of topography and identification of possible eruption points.

The geomorphic knowledge of the behaviour of a river system and its morphological characteristics viz. channel geometry, channel morphology and channel pattern, river metamorphosis, bank morphology etc., may help in controlling river floods through flood control measures. These include steps; (i) to delay the return of runoff resulting from torrential rainfall to the rivers; (ii) to hasten the discharge of water (by straightening the meandering channels); (iii) to divert the flow of water (through diversion channels); (iv) to reduce the impact of floods (through construction of protective embankments); and (v) to forewarn the occurrence of floods. Without the knowledge of the nature of erosion in the upper catchment area and sediment load characteristics of the rivers, the construction of levees to confine the flood water within the valley may prove disastrous: if the rate of erosion is very high in the upper catchment area, resulting in high sediment load, there would be more sedimentation in the valley causing a gradual rise in the river bed; this may lead to sudden flash floods whenever the levee is breached.

Earthquakes may be natural or man-in-duced geomorphic hazards. The geomorphic knowledge of the stability of terrain and probable impacts of man-made structures (such as dams and reservoirs) on crustal stability is of paramount importance in identifying weaker zones which are likely to be affected by seismic events. Similarly, the geomorphic study of the nature of Hill slopes and their associated lithologies enable us to known the stability or instability of the hill slopes. This knowledge would help in identifying and mapping unstable hillslopes unsuitable for human settlements and road construction.

Remote Sensing Survey enjoys the following advantages over ground surveys.

Synoptic view or wide coverage of a large area is possible.

Permanent record of ground conditions is subject to verification later at any time.

Interpretation of remote sensing date requires much less time than do cumbersome ground surveys.

Remote sensing technique is capable of accessing thermal and microwave regions not accessible to the naked eye.

Ground surveys involve more time, money and infrastructure in comparison to remote sensing surveys.

Ground surveys, if repeated, are highly uneconomical.

The same remote sensing date is useful for different purposes; for example, the name data may be used by soil scientists for soil surveys, by geohydrologiats for groundwater surveys or by agricultural scientists for crop surveys.

Remote sensing surveys are free from handicaps like bad weather conditions.

The major differences between aerial photographs and satellite imageries are as follows.

GEOMORPHOLOGY AND REGIONAL PLANNING

Applied geomorphology has a place in regional planning. A balanced growth of a country's economy requires a careful understanding of what each region offers in terms of resources, natural and human. Detailed information on topography, soils, hydrology, lithology and terrain characteristics are of obvious interest to enlightened regional planners who may then devise development projects best suited for the region.

OTHER APPLICATIONS

The applications of geomorphic principles are most striking in the fields discussed above. But there are several other areas in which applied geomorphology is of use. As thornubury points out soil maps are to a considerable degree topographic maps, and the differentiation of the various members of any soil series rests fundamentally upon the different topographic conditions under which each member of the soil series developed. Modern beach engineering (M.A., Mason, W.C.Krubein) to be successful, must be based upon an appreciation of the processes of shoreline development. The problem of soil erosion (C.B Brown, H.V Peterson) is essentially a problem involving recognition and proper control of such geomorphic processes as sheetwash erosion, The severity of erosion is not determined by the angle of slope alone. It may not be serious on steep slopes where those slopes are underlain by permeable materials, and it may be serious on slight slopes where they are on impermeable materials. The related problem of land classification also entails an appreciation of varying types of terrains and the best uses that may be made of them.

Application of geomorphology can be of immense use in controlling the adverse effects of human activities on geomorphic forms and processes. Indeed, this field has also developed into a separate branch, 'anthropogeomorphology' (A detailed discussion of human impact on geomorphic forms is given in the chapter, Environmental Geography)

SUPPLEMENTARY INFORMATION

On Earth Interior

To be read in conjunction with matter on P.11).

We consider rock density, pressure exerted by superincumbent load and increasing temperature with greater depth to understand the constitution of earth's interior. Studies conducted by satellite suggest that the average density of the core is 11 gms^{-3} whereas the average density of the core is 11 g cms^{-3} compared to the surface density of 2.6 to 3.3 g cms^{-3}

VARIOUS HYPOTHESES

HYPOTHESIS OF SUESS: CHEMICAL COMPOSTION OF THE EARTH suess identified three layers, sial, sima and nife.

Sial is located below the outer cover of sedimentary rocks made of granites. It is composed of silica and aluminium. The average density is 2.9.

Sima is found just below sial. It is made if basalt and the main chemical composition is of silica and magnesium. The average density is 2.9 to 4.7.

Nife is located below sima. The layer is composed of nickel and ferrum. The existence of iron suggests the magnetic property of the interior of the earth. The property also suggests the rigidity of earth.

DAL'YS HYPOTHESES

Daly identified three layers, viz (i) outer zone, density 3.0, thichness 1600km, (ii) Intermediate layer, density 4.5 to 9, thickness 1280 km, (iii) Central zone, density 11.6, thickness 7040 km.

HAROLD JEFFREY'S HYPOTHESIS

Jeffreys demarcated four layers, viz., (i) outer sedimentary rock layer; (ii) granite layer (iii) Thachylyte or diorite layer, (iv) dunite, peridotite or eclogite layer.

ARTHUR HOLMES HYPOTHESIS

Holmens inedited two major layers. Upper layer or crust composed of sialic layer followed by the upper part of sima. The lower layer is the substratum which coincides with the lower part of Suess' sima.

SIAL {Crust

SIMA {Upper

Lower Substratum

The thickness of sial is determined by various parameters:

Thermal conditions-20 km or less

Surface seismic waves (L waves) – 15km or more

Longitudinal waves (P waves) -20 to30 km

Subsidence of geosynclines having a depth beyond 20 km or more

HYPOTHESIS OF VAN DER GRACHT

Gracht odentifed four layers.

Outer sialic crust having a density of 2.75 to 2.9. The thickness of the crust is 60 km under continents and 20 km under the Atlanctic Ocean; it is absent under the Pacific Ocean.

Inner silicate mantle which has a density of 3.1 to 4.75. The thickness varies from 60 to 1140 km

Zone of mixed metals and silicates having a density of 4.75. The thickness varies from 1140 ti 2900 km

Zone of metallic nucleus having a density of 11.0. The thickness ranges from 2900 to 6371 km

The hypotheses discussed above were formed by early thinkers. Many of these views are now obsolete. By analysing the complex nature of seiscic waves of earthquakes, scientists have now been able to derive more authentic information on the interior of the earth. (These have been discussed in the chapter).

MOUNTAIN BUILDING (OROGENY)

The term 'orogeny' was coined by the American geologist, G.K.Gilbert, in 1890 to describe the process of mountain building. The term was originally used by Gilbert to describe the fold mountain belts of the Alps and the Rockies. According to the Oxford Dictionary of Geography, the term 'orogeny' may be defined as tectonic "Movements of the earth which involve the folding of sediments, faulting and metamorphism. Two major types of orogeny are recognised : a cordilleran type in which geosynclinal deposit are severely deformed and one created by a continental crust". The term can hardly be applied to mountains submerged in seas, because the submerged mountains originate through processes markedly distinct from those that created mountain systems like the Apls and the Rockies.

CLASSIFICATION OF MOUNTAINS

We may classify mountains along various criteria.

1.On the basis of height.

i. Low altitude mountains (700-1000 m)

ii. rough mountains (1000-1500 m)

iii. rugged mountains (1500-2000 m)

iv. high altitude mountains (above 2000 m)

2.On the basis of location

1. Continental mountains could be (a) coastal mountains; for example, the Rockies, the Appalachians, the Alpine mountain chains, the Western Ghats and the Eastern Ghats (India); or (b) inland mountains such as those found in the Vosges and the Black Forest (Europe), the Kunlum, Tienshan, Altai mountains of Asia, the Urals of Russia, the Aravallis, the Humalayas, the Satpura, and Maikal of India.

iii. Oceanic mountains are found on continental shelves and ocean floors. The height of the mountains is considered from the mean sea level. However, if considered from the ocean floor, some of the oceanic mountains will exceed the Himalayas in height. For example, Mauna Kea is about 9140 m from the sea bottom and thus is much higher than Mount Everest (8848 m).

3. On the basis of period of origin

i. Precambrian mountains belong to the geological time prior to the Cambrian period; a period that extended for more than 4000 million years. The rocks have been subjected to upheaval and metamorphosis. Traces of fossils are found in some unmetamorphosed rocks of Precambrian origin. Some of the examples are Laurentain mountains, Algoman mountains, Kilarnean mountains of Feno Scandinavia, North –west highlands and Angleysey of Europe.

ii. Caledonian mountains originated due to the great mountain-building movements and associated tectonic movements of the late Silurian and early Devonian periods. The mountains have a northeast-southwest alignment in the north-western part of Europe. Caledonian mountains came into existence between approximately 430 million years and mountains of Scotland Ireland and Taconic mountains of the Appalachians, Aravallis, Mahadeo etc.

iii. Hercynian mountains originated during the upper Carboniferous to Permian Period in Europe. Some authors use the term Hercynian for the whole mountain systems belonging to central Europe, whereas others use the terms Altaides, Variscan to identify the same into existence between approximately 340 million years and 225 million years ago. Some examples are the mountains of Iberian peninsula, Ireland, Spanish Messeta, Vosges and Black Forest, Variscan mountains of Europe and Altai, Sayan, Baikal Ards, Khingan and Tien Shan mountains of Asia.

iv. Alpine System had its origin in the Tertiary Period which consists of the Palaeocene, Eocene, Oligocene, Miocene, Pliocene epochs. The mountains were formed from about 65 million years to 7 million years ago. Examples are the Rockies of North America, the Alpine mountains of Europe, the Atlas mountains of north-western Africa, the Himalayas of the Indian sub-continent, mountains rediating from Pamir knot like Pauntic, Taurus, Elburz, Zagors and Kunlum etc.

4. On the basis of mode of origin

i. Original or Tectonic mountains are the product of tectonic forces. Ie., endogenetic forces originating from deep layers of the earth. The tectonic mountains may be categorised into fold mountains, block mountains and volcanic mountains.

ii. Circum –erosional or Relict or Residual mountains are the remnants of old fold mountains derived as a result of denudation.

BLOCK MOUNTAINS

Block mountains are also called fault block mountains since they are formed due to faulting as a result of tensile and compressive forces. Block mountains are surrounded by faults on either side of rift valleys or grabens. There are two basic types. (a) Titled block mountains have one steep side contrasted by a gentle slope on the other side. (b) Lifted block mountains have a flat top and extremely steep slopes.

THEORIES

Two theories explain the formation of block mountains.

Fault theory

A majority of geologists argue that block mountains are the product of faulting. Among those who advocated the fault theory are Clarence King, G.K.Gilbert, G.D.Louderback and W.M.Davis. According to this theory, block mountains are formed in the following ways.

i. Due to upward movement of the block in the middle between two normal faults. The summit of the block is flat.
ii. Sometimes, the surrounding blocks subside leaving the middle block stationary. Such cases are found in high plateau regions.
iii. Block mountains may originate when the middle moves downward and becomes a rift valley while the surrounding blocks stand higher as block mountains.

EROSION THEORY

J.F.Spurr on the basis of his study of the Great Basin Range of the USA said that the block mountains were formed as a result of differential erosion. The mountains, after their birth in the Mesozoic Era, were subjected to intense forces of erosion, and this led to the formation of the Great Basin Range. The theory is not accepted by most geologists since deformatory processes play a pivotal role in block mountain formation.

FOLD MOUNTAINS

Fold mountains are formed when sedimentary rock strata deposited in geosynclines are subjected to compressive forces produced as a result of endogenetic forces. Fold mountains are the loftiest mountains in the world and they are generally concentrated along continental margins.

Fold mountains can be divided into two broad types on the basis of the nature of folds: (i) simple fold mountains with open folds in which well-developed systems of synclines and anticlines are found and folds are of wavy pattern; (ii) complex fold mountains in which the rock strata are intensely compressed to produce a complex structure of folds. For example, in the Himalayas overfolds and recumbent folds are often found detached from their roots and carried few hundred kilometers away by the tectonic forces. These detached folds are called ‘nappe’.

On the basis of period of origin, fold mountains are divided into old fold mountains and Alpine fold mountains. Old fold mountains had their origin before the Tertiary period. For example, the fold mountain systems belonging to Caledonian and Hercynian mountain-building periods fall in this category. Some of the mountains like the Arvallis and Vindhyachal are among the oldest fold mountains in the world; now they are called relict the fold mountains. Alpine fold mountains belonging to the Tertiary period can be grouped under the new fold mountains category since they originated in the Tertiary period. Examples are the Rockies, the Andes, the Alps, the Himalayas, etc.

Characteristics of fold mountains

1. Fold mountains belong to the group of youngest mountains of the earth.
2. The presence of fossils in the rocks suggest that the sedimentary rocks of these folded mountains were formed after accumulation and consolidation of silts and sediments in a marine environment.
3. Fold mountains extend for great lengths whereas their width is considerably small. For example, the Himalayas have an east-west extension of 2400 km but the width hardly exceeds 40 km.

4. Generally, fold mountains have a concave slope on one side and a convex slope on the other.

5. Fold mountains are found continental margins facing oceans. For example, the Rockies and the Andes are located along the western margin of North and South America facing the Pacific Ocean.

6. The sedimentary rocks found in fold mountains have much greater thickness in comparison to other rocks belonging to the same period in adjacent regions.

7. Fold mountains are characterised by granite intrusions on a massive scale. Such intrusions of several kilometers length are found along the longitudinal profile of the mountain ranges.

8. Due to intense pressure large masses of rock break away from their roots and slump forward to be placed over younger rock groups. The process is called gravity sliding and the resultant features are known as nappe. Apart from nappe, recumbent folds and thrusts are commonly found.

9. Recurrent seismicity is a common feature in folded mountain belts which often finds expression in earthquakes.

10. High heat flow often finds expression in volcanic activity. Example are found in the folded mountains of the Zagros, the Makran, the Indonesion Arc, the Circum-Pacific Rockies, the Andes, the Japanese, Philippines and New Zealand mountain belts. This suggests that faults are deep enough to reach the bottom layer of earth crust capable of tapping heat and magma.

PLATE TECTONICS AND MOUNTAIN BUILDING PROCESSES

Four types of plate convergence are found in the process of mountain building

Collision of oceanic plates or ocean –ocean convergence.

Collision of continental and ocean plates or ocean-continent convergence.

Collision of continental plates or continent-continent convergence.

Collision of continent and arc or continent-arc convergence.

OCEAN –OCEAN CONVERGENCE OR THE ISLAND –ARC CONVERGENCE

The situation occurs when the oceanic plate is plunged into another oceanic plate away from the continent. The condition leads to the following consequences.

As a result of collision, the plate with greater density plunges beneath to form a trench.

As the ocean floor crust loaded with sediments subducts, the rocks on the continental side of the trench become metamorphosed under high pressure and temperature.

After reaching a depth of 100 km, plates melt causing an upward movement of magma.

A continuous piling of rocks raises them above the ocean crust and ultimately exposes them to form island arcs.

Japan is the largest island formed in this way. Orogenesis in island arcs is different from other types because of the deformed andesitic volcanic rocks and the sediments derived from them can be differentiated from oceanic basalt. Orogenesis sets in motion the process of building continental crust by replacing oceanic crust.

CONTINENT-OCEAN CONVERGENCE OR THE CORDILLERAN CONVERGENCE

In such cases a thick sequence of geoclinal sediments from the continents are found along continental margins. Moreover, silica-rich magma derived from the partial melting of the subducting plate is placed upon the continental crust, rather than the oceanic crust. The Cordilleran situation leads to the following consequences.

As a result of convergence, the buoyant granite of the continental crust overrides the oceanic crust.

The deep marine sediments found on the oceanic crust are crumpled and deformed.

Due to compression the geoclinal sediments are deformed followed by crustal thickening progressing landward. As a result the edge of the deformed continental margin is thrust above sea level.

With the formation of the orogenic belt, resistance builds up which effectively stops convergence. Thus, the subduction zone may progress seaward leading to the formation of an ocean to –ocean orogenic belt.

With the culmination of compression, erosion continues to denude mountains. This results in isostatic adjustment which causes ultimate exposure of the roots of mountains. Examples are found in the Rockies, deformed in late Mesozoic and early Tertiary period, and the Andes, where the deformation begun in the Tertiary Period is still going on.

CONTINENT –CONTINENT CONVERGENCE OR THE HIMALAYAN CONVERGENCE

The major events marking this phenomenon are listed below.

Geoclinal sediments are found along the continental margins.

As the continents converge, the ocean basin decreases in size before being finally squeezed between two approaching plates.

The subduction of the continental crust is not possible beyond 40 km because of the normal buoyancy of the continental crust. Thus, the fragments of oceanic crust are plastered against the plates causing welding of two plates known as suture zone. Example : The Indus-Tsangpo suture zone.

With the building up of resistance, convergence comes to an end. The mountain belt erodes and this is followed by isostatic adjustment.

As two massive continents weld, a single large continental mass joined by a mountain range is produced. Examples: The Himalayas, the Alps, the Urals and the Atlas mountains originated 100 million years ago due to the northward movement of the Deccan Shield colliding with the Eurasian Plate.

CONTINENT-ARC CONVERGENCE OR NEW GUINEA CONVERGENCE

New Guinea came into being about 20 million years ago as a result of continent-arc collision. This situation leads to the following consequences.

the oceanic plate plunges under the island arc.

A trench occurs on the ocean side of the island arc and, ultimately, the continental margin is firmly welded against the island arc.

IV. THE ARID CYCLE OF EROSION

William M.Davis considered the arid cycle as a modification imposed upon the humid cycle.

Davi's ideal arid cycle exists in a desert, especially in western USA. Davi's found a few significant differences between the cycle in arid regions and humid regions viz., differences in the manner of runoff, maximum relief in youth rather than in mature stage, relief decreasing as the cycle progresses, consequent drainage flowing into enclosed basins with few antecedent streams, highlands actively dissected in youth and basin aggradation, lack of continuous streams resulting in local base levels of erosion and continuous upliftment of local base levels mainly due to basin aggradation.

Of late, much emphasis has been laid on the formation and extension of pediments as the major geomorphic process as part of the arid cycle. L.C King has been the most ardent supporter of the pediplanation cycle. According to King, during youth, river incision takes place which causes valley development, increasing relief and beginning the process of formation of lateral pediments along both sides of the valley. In mature state the interstream hill tracts shrink through pediment extension by scrap retreat and the initial topography is almost destroyed to the original topography disappear as piedmont scraps are intersected from opposing sides of the uplands. Pediments coalesce leading to the formation of a multiconcave topography to which the term 'peneplain' is usually applied.

Lawson used the term panfan to designate the termination of the state of geomorphic development in an arid region in the same way the peneplain is found at the end stage of the general process of degradation in a humid region.

Savanna Cycle of Erosion is related to the landscape development in the semi-arid tracts of the African Savanna land. A wide range of opinions exists regarding the mode of origin of morphological evolution of landscapes in the Savanna region. Earlier the experts related the mode of landform development in this region to the dry geomorphic cycle but nowadays geomorphologists argue in favour of a separate cycle of erosion considering the typical landforms of Savanna land moulded by a typical climatic condition(dry and humid seasons characterized by mean annual high temperature) in the region.

Some gemorphologists applied the term desert peneplain to describe the erosinal topography of Africa produced by the action wind. J.H. Maxson and G.H.Anderson (1935) and A.D.Howard (1942) proposed the term pedeplain to describe coalescing pediments. A sudden break of slope exists at the contact zone of a pediment and its adjoining mountain front. L.C King attributes it to the change in the nature of water flow, i.e., extremely erosive turbulent linear flow as compared to less erosive laminar flow on the pediment zone. According to Kirk Bryan (1940), such knickpoints are the products of the change from unconcentrated rainwash in mountain scarplands to more efficient flow of ephemeral streams in the pediment zone. According to J.C.Pugh (1966), the sudden change of water flow from the mountain front to the pediment is the consequence, rather than the cause, of the change in slope. B.P.Buxton (1958) and C.R.Twidale (1964) attributed it to intense weathering at the foot of the mountain as a result of the accumulation of water flowing down from the mountain.

Bailey Wills (1936) coined the term bornhardt to refer to residual hills which rise above the denuded topography thought to be pediments and peneplains. In later decades, two more theories have been put forward regarding the origin of bornhards. The view of L.C.King (1948) that the denuded remnants of a pediment or pedeplain develop by parallel retreat of the mountain front slope as suggested by Penck have received wide acceptance from geomorphologists and geologists. The other view process that there are two cycles involved in borngardt formation, viz.,

(i) deep weathering occurs in the subsurface and (ii) the weathered materials are washed away leaving the unweatherd mass as bornhardt. However, King opposes this view by arguing that bornhardrs are 1000 to 1500 feet high in extreme cases which belies any possibility of subsurface weathering. So he thought that pre-weathering may be involved in tors and core stone formations but he thought of bornhardts as belonging to a different set of landforms. Despite all the differences, it is obvious that bornhards are made of resistant, massive and monolithic rocks. M.F.Thomas (1966) opposed the pedeplanation ideas of L.C King. Thomas viewed that the pediments of Nigerian Savanna are neither basal slops, nor have they been formed by the twin processes of pedeplanation, i.e., scarp retreat and pedeplanation as proposed by King. According to him these are concave wash slopes which came into existence due to the removal of weathered materials. Thomas viewed that Savanna landscapes are the product etching and removal of etched products by streams and surface wash, which leads to the formation of etchplain, not pedeplain.

Differences of opinion also exist regarding the origin of inselberlandschaft of tropical Africa. Wind which was thought to be the principal agent of erosion in early years is now believed to be less important in inselberglandschaft formation. R.F.Peel (1960, 1966) viewed that the inselberges in the humid climate condition prevalent during the Quarternary period when rivers were common and lateral erosion was dominant.

EROSIONAL WORKS OF WIND

The wind or Aeolian erosion takes place in the following three ways, viz., (1) deflation, (2) abrasion or sandblasting, and (3) attrition. Deflation refers to the process of removing, lifting and carrying away dry, unsorted dust particles by winds. It causes depressions known as blow outs. When wind loaded with sand grains erodes the rock through mechanisms like abrasion, fluting, grooving, pitting and polishing, the combined impact of these mechanisms is called abrasion or sandblasting. Afftrition refers to wear and tear of the sand particles while they are being transported by wind mainly by processes like saltation (sands and gravels moving through bouncing, jumping and hopping) and surface creep (involving movement of comparatively larger particles along the surface).

EROSOPNAL LANDFORMS

Following are the major landforms produced by wind erosion.

DEFLATION BASINS

They are also known as blow-outs and desert hollows varying in size from the very small ('buffalo wallows' of the American Great Plains) to the extremely large depressions like 'Pang Kiang' of the Mongolian desert. In areas where deflation has been active and the desert surface is filled with loose fragments, lag deposits are found. Thus desert pavements are formed as the pebbles roll and jostle together.

MUSHROOM ROCKS

The rocks have broad upper portion in contrast to their narrow base and thus resemble an umbrella or mushroom. Mushroom rocks are also called pedestal rocks of pilzfelsen (J.Walther). They are the products of abrasion from all sides caused by variable directions of wind. Such features are called gara in the Sahara and pilzfelsen in Germany.

INSELBERGS

The term was first used by Passarge in 1904 to delineate relict hills of South Africa. There has been a debate regarding the origin of these inselberges of bornhardts. It has been dealt in detail elsewhere in this chapter.

DEMOISELLES

These are rock pillars which stand as resistant rocks above soft rocks as a result of differential erosion of hard and soft rocks.

ZEUGEN

Flat-topped rock masses resembling a capped inkpot, zeugens stand on softer rock pedestals like mudstone, shale, etc, Zeugens are formed in desert areas characterized by a high range of temperature. The alternate freeze and thaw of moisture results in expansion and contraction which ultimately disintergrates rocks along the joints.

YARDANGS

These steep-walled rock ridges are segregated from one another by grooves, corridors or passageways found on less resistant rocks in desert. The yardangs have an average height of eight metres although yardangs of 60 m height are found in the Lutt desert of Iron. Yardangs are formed where hard and soft rocks are placed vertically in alternate bands parallel to each other. Yardangs have been named 'cock scomb' by A. Holmes.

VENTIFACTS AND DREIKANTER

Ventifacts are formed when faceted rock boulders, cobbles and pebbles are subjected to abrasion by prolonged wind erosion. Dreikanters are formed when a ventifact is abraded on as many as three sides. Boulders having two abraded facets are known as zweikanter.

Stone lattice

In deserts, rocks made of varying compositions and resistance are converted into pitted and fluted surfaces as powerful winds charged with rock particles remove weaker sections of the rocks.

WIND BRIDGES AND WINDOWS

Powerful wind continuously abrades stone lattices, creating holes. Sometimes the holes are gradually widened to reach the other end of the rocks to create the effect of a window-thus forming a wind window. Window bridges are formed when the holes are further winded to form and arch like feature.

DEPOSITIONAL LANDFORMS

Land forms are also created by the depositional force of wind. These are as follows.

SAND DUNES

Sand dunes are heaps or mounds of sand found in deserts. Generally their heights vary from a few meters to 20 meters but in some cases dunes are several hundred meters high and 5 to 6 Km long. The formation of sand dunes requires (i) abundant sand, (ii) wind of high velocity, 9iii) obstacles such as trees, bushes, forests, rock outcrops, walls boulders against which dunes may settle, and (iv) ideal places i.e., dune complex, dune chain or dune colony. Dunes formed due to obstacles like bushes, walls etc., are called nebkhas where dunes formed in the leeside of desert depressions are called lunettes.

Dunes are categorised on the basis of morphology, structure, orientation, ground pattern, location, internal structure and number of slip faces.

R.A.Bagnold (1953) divided dunes into two types : (i) barchans or crescent dunes and (ii) seifs or longitudinal dunes.

J.T.Hack (1941) categorized dunes of the western Navajo Country of the USA as follows : (i) transverse dunes (ii) parabolic dunes, and (iii) longitudinal dunes.

Melton (1940) classified dunes as : (i)simple dunes formed by unidirectional wind, (ii) dunes formed as a result of conflict with vegetation, and (iii) complex dunes deposited by variable wind.

E.D.Mckee (1979) categorised dunes as (i) dome dune, (ii) barchan, (iii) barchanoid, (iv) transverse dune, (v) parabolic dune, (vi) linear dune, (vii) reversing dune with two slip faces, and (viii) star dune.

Some of the forms are discussed below :

Longitudinal dunes are formed parallel to the wind movement. The windward slope of the dune is gentle whereas the leeward side is steep. These dunes are commonly found at the heart of trade-wind deserts like the Sahara, Australia, Libyan, South Africa and Thar deserts. Longitudinal dunes are sparated by regor hammada-sand-free bare surfaces. The corridors so formed are called caravans.

Transverse dunes are dunes deposited transverse to the prevailing wind direction. They are formed due to ineffective winds blowing along the coast and margins of deserts.

Barchans have a crescent shape with two horns. The windward side is convex whereas the leeward side is concave and steep.

Parabolic dunes are generally developed in partially stable sandy deserts. They are U-shaped and are much longer and narrower than barchans.

Star dunes have a high central peak, radically extending three or more arms. Reversing dunes are formed when winds blow from opposite directions and are balanced in strength and duration. These dunes have two slipfaces opposing each other. When longitudinal dunes migrate, the coarser sands are left behind to form whaleback dunes. Very large whalebacks are known as draas.

LOESS Loess is loose, unstratified, non-industrated, buff-coloured fine sediments which are deposited at places far from their source of origin. Loess is of two types: (i) desert loess and (ii) glacial loess. The most extensive loess deposits occur in North China where it spreads over 7,74,000 sq.km. The loess terrain has been converted into badland topography as a result of erosion. Loess is known as limon is France and Belgium. In North America it is called adobe.

V.GROUNDWATER

Groundwater or phreatic water is subsurface water which absolutely saturates the pore spaces above an impermeable layer. Water found in the pore spaces, cracks, tubes, crevices beneath the surface has been termed as under ground water, groundwater, subsurface water and subterranean water.

SOURCES OF GROUNDWATER

There are four sources of groundwater.

(i) CONNATE WATER

At the time of rock formation water is trapped in the interstices of sedimentary rocks.

(ii) METEORIC WATER

It originates in the atmosphere, falls as rain and ultimately becomes groundwater by infiltration. It forms the major part of groundwater.

(iii) JUVENILE WATER

It originates in the earth's interior and reaches the upper layers of the earth surface as magmatic water.

(iv) CONDENSATIONAL WATER

It is the prime source which replenishes water in deserts and semi-desert areas. During summer land becomes warmer than the air trapped in the soil, which leads to a huge difference of pressure between the water vapour penetrates the rocks and gets converted into water due to falling temperature of the water vapour below.

All the four sources get mixed along complex water-migration routes.

Occurrence of groundwater

More than half of all groundwater is available within 750 m of the earth's surface. However, evidences of the presence of groundwater are also found at a depth of more than 11000 m for instance in the Kola Peninsula of Russia. Water below the ground is available in four zones, viz., soil zone, intermediate zone where water is available is called the zone of aeration. There are two forces which actively prevent groundwater from moving downward, viz., (a) the molecular attraction between water and the rock and earth materials and (b) the molecular attraction between water particles.

The zone of aeration is further sub-divided into three layers-siol moisture zone, intermediate zone and capaillary zone, collectively called Vadose Zone. Some amount of water in this zone is used by plants. At the bottom of the intermedicate zone lies the capillary fringe (a thin layer of 2 to 3 cm) from where water moves upward. The capillary condition is temporarily destroyed when heavy rain takes place. In such cases the groundwater body is replenished by recharge.

The zone of saturation lies below the zone of aeration and is also called the phreatic zone. The water available in this zone is known as groundwater. The groundwater table or water table segregates the zone of aeration and the zone of saturation. The maximum elevation of water in a well which penetrates the groundwater zone is known as piezometric water table. Generally, the water table follows the irregularities of the earth's surface; for example, the water table is highest beneath hills and lowest beneath valleys. A geological structure fully saturated by water, capable of producing sufficient quantities of water that can be economically use and development, is known as aquifer (Latin, to bear water). Example include sandstone layer, unconsolidated sand and gravel, limestone, franctured plutonic and metamorphic rocks which act as aquifer can be broadly divided into (a) unconfirmed and (b) confined aquifers. In the former lateral groundwater flow or from upward movement of water. The latter (also known as artesian or pressure aquifers) have an impermeable stratum that maintains hydrostatic pressure sufficient enough to raise water higher than the surface of the aquifer. Confining layers of the aquifer can be categorised into aquicludes, aquitards and aquifuges. Aqicludes form small saturated layers above the impermeable layers; examples are clay, shale and most of the igneous and metamorphic rocks. Aquitards form confining layers but cannot completely check water flow to or from an adjacent auifer. An aquifuge consists of a rock layer which has no interconnected opening or interstices. So it neither stores nor transmits water; for example, quartzite, obsidian. Water penetrates an aquifer through a recharge area which is exposed or is covered by a permeable zone of aeration. Water rises to the level of water table if digging can be done through the zone of aeration into the saturation zone.

CONTROLLING FACTORS OF THE OCCURRENCE OF GROUNDWATER

The occurrence of groundwater is influenced by the following factors:

CLIMATE

Groundwater is easily available at great depths in arid regions while it exists at shallow depth in humid regions. Water table rises during rainy season and sinks in dry season.

TOPOGRAPHY

The water table tends to be higher near the hilltops and lower near the valleys, because near the valleys water seepages into streams, swamps and laks cause descending water table.

TYPES OF MATERIALS

Porosity and permeability of the underground materials have an impact on the storage and movement of groundwater. The variability in porosity exists as the underground materials are heterogeneous in nature.

Porosity refers to the percentage of the total volume of rock with voids. Porosity determines the volume of water a rock body can retain. Four types of pore spaces are found-(i) Pore space between mineral grains, (ii) Fractures, (iii) Solution cavities, and (iv) Vesicles.

Premeability refers to the capacity of a rock body to transmit water. Sandstone and conglomerate are highly permeable because of the presence of relatively large interconnected pore space between the grains.

NATURE AND MOVEMENT OF GROUNDWATER

The groundwater movement takes place through pore spaces at extremely slow velocity. The flow velocity of groundwater is expressed in metres^{-1} day. Water percolates from areas of high water table to the areas where water table is lowest i.e., towards laks and surface streams. Such differences of water table are known as hydraulic head. Groundwater percolates through the soil layers after being activated by gravity. Since the bottom layers of a soil are compact due to tremendous weight exerted by the overlying soil, permeability decreases downward. So, the vertical infiltration of water decreases and if the soil is situated on a slope groundwater deflects downslope as through flow.

The nature of groundwater at shallow depth reveals that it acts both as reservoir as well as conduit. Groundwater at shallow level forms a small but integral part of the hydrological cycle.

Precipitation falls on recharge areas where water adds up to the saturated zone. It moves ultimately to discharge areas. i.e., areas where subsurface water is discharged to river or other water bodies. The areal extent of discharge areas is smaller than recharge areas are found everywhere except streams and adjacent floodplains whereas in arid regions recharge areas encompass only the mountains and bordering alluvial fans and also the major streams underlain by porous alluvium through which water percolates and recharges groundwater.

The fluctuation of water table is evident from the fact that in regions like the Indian subcontinent which experiences monsoon climate, the water table flattens and gradually high water table beneath hills decreases to the level of valleys particularly during dry periods.

If the permeability of the ground remains uniform, the velocity of groundwater flows in creases with an increasing gradient of slope of the water table (hydraulic gradient).