Geomorphology

ADITYA PATEL
Assistant Director,
DRDO, Ministry of Defence

1. Introduction

Geomorphology, a science of landscape, deals with the form and processes involved to create it. The science helps to identify the topographical variation over the earth surface with a specific ordering of landforms and explain the geomorphic processes in temporal and spatial frameworks. In the beginning, the subjects were a description of topography by the travelers, which becoming quantitative during 1960s, and at present it becomes highly scientific and model building discipline to understand the dynamics of Earth's processes and predict for the future.

2. Learning Objectives

The module helps the student to understand the basic geomorphological processes happening around them.

1. To identify different relief feature over the Earth surface and can explain their basic causes of origin.
2. To know the processes of landscape evolution and role of different parameters on it.
3. To understand the interaction between intrinsic and extrinsic forces to developed and landform.
4. For detail understanding about the fluvial system of the Earth surface for further understanding of hydrology.
5. To understand the difference between glacial and periglacial environment.

3. Assessment of Prior Knowledge

- Real-life experience of river, desert, any cave in karst region, glaciated mountain could help to understand the theoretical knowledge of geomorphology very easily.
- Should have interest to observe and query about the physical landscape surrounding by trainees.

3. Examples and Illustrations

3.1 Fundamental Concepts in Geomorphology

The term geomorphology first used to describe the morphology of the Earth's surface in the 1870s and 1880s (e.g., de Margerie 1886, p. 315). However, the development of geomorphological thought comes through a long history. For example, Herodotus (484 – 420 B.C.) was conceptualized the formation of lower part of Egypt is the process of sedimentation by Nile River and was saying 'Egypt is a gift of Nile River'. The concept of geomorphology deals with the landforms on the earth surface and ongoing and historical processes behind their formation. The chief aspects of study in geomorphology are form, process, and time.

During the middle of the 20th century **W.D. Thornbury (1954)** has synthesized different aspect of geomorphology and presented ten fundamental concepts in geomorphology with the entitle of "Principal of Geomorphology", New York: Wiley.

1. "The same physical processes and laws that operate today, operated throughout geological time, although not necessarily always with the same intensity as now".
2. "Geological structure is a dominant control factor in the evolution of landforms and is reflected in them".

3. "To a large degree the Earth's surface processes relief because the geomorphic processes operate at different rates".
4. "Geomorphic processes leave their distinctive imprint upon landforms, and each geomorphic process develops its own characteristic assemblage of landforms".
5. "As the different erosional agents act upon the Earth's surface there is produced an orderly sequence of land forms".
6. "Complexity of geomorphic evolution is more common than simplicity".
7. "Little of the Earth's topography is older than Tertiary and most of it no older than Pleistocene".
8. "Proper interpretation of present-day landscapes is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene".
9. "An appreciation of world climates is necessary for a proper understanding of the varying importance of the different geomorphic processes".
10. "Geomorphology, although concerned primarily with present-day landscapes, attains its maximum usefulness by historical extension".

3.2 Fluvial Processes and Landforms

Except the frigid (dominated by ice) and dry regions, action of running water is present all around the world, which is geomorphologically known as fluvial action and the assemblage of landforms associated with these processes in called fluvial landscape. The term fluvial is derived from the Latin word 'fluvius', meaning river.

3.2.1 Major Drainage System and Pattern

Drainage system refers the origin and development of stream over a part of earth surface through time, however, Drainage Pattern means the spatial arrangement of the streams on that particular part of earth surface. The origin of drainage system and pattern is significantly influenced by nature of underlying geology, surface slope, rainfall, land use land cover etc. The major **drainage systems** are two types.

3.2.2.Sequent Drainage System

a.Consequent Streams: Streams following initial slope direction of a region
b.Subsequent Streams: Streams developed after the master consequent stream
c.Obsequent Streams: Streams flowing in the opposite direction of the master consequent stream
d.Resequent Streams: Streams developed in the last stage of fluvial landscape and flowing in the same direction with master consequent stream, while the bed height level is below the master consequent.

3.2.3 In-sequent Drainage System

1. Antecedent Drainage System: When a stream maintains its flow direction instead of upliftment of land across the channel path through deep vertical erosion.
2. Superimposed Drainage System: Not adjust the regional slope and overcome all problems related to topography to maintain its palaeo-path.

3.2.4 Major Drainage Patterns

1.Dendritic Pattern
2.Trellised Pattern
3.Rectangular Pattern
4.Radial Drainage Pattern
5.Centripetal Drainage Pattern
6.Annular Drainage Pattern
7.Barbed Drainage Pattern
8.Pinnate Drainage Pattern
9.Herringbone Drainage Pattern
10. Parallel Drainage Pattern

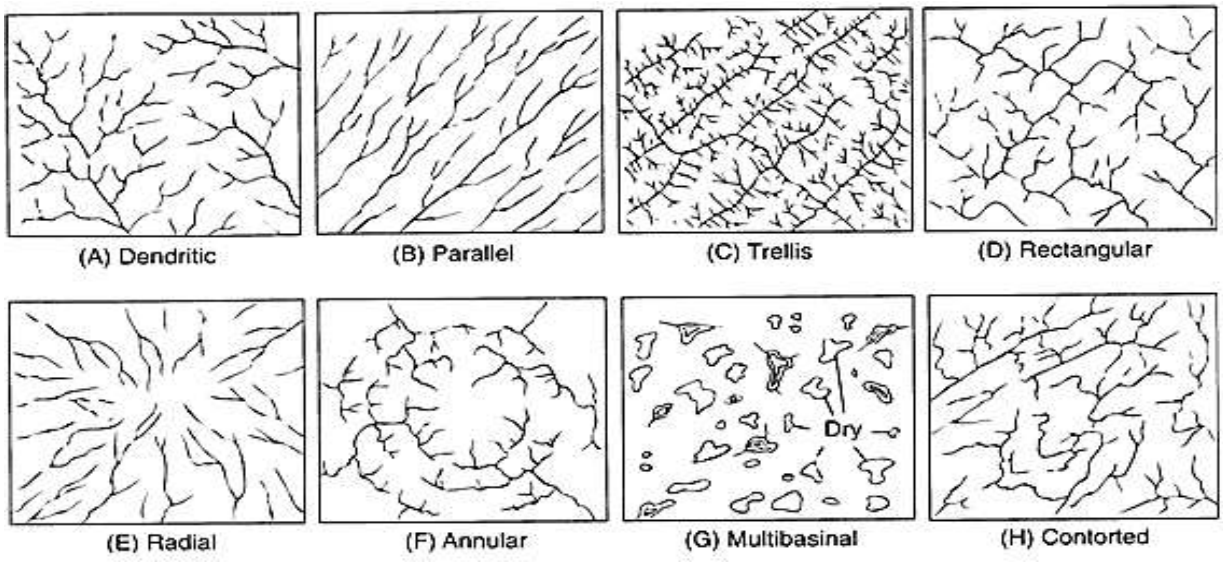


Fig. 1: Major drainage patterns (after Singh, 2010)

3.2.5 Major Erosional Processes

1. Abrasion or corrasion: This process means removing of loosened materials from the channel bed. The level of abrasion depends on the amount of erosional tool presence in the running water such as boulders, cobbles, pebbles, sands etc., which are working as drilling tools of river bed and bank.
2. Corrosion: This is a chemical process of erosion through the dissolution of soluble materials (carbonate rock mainly).
3. Hydraulic Action: It refers breakdown of channel materials due to the pressure created by water current.
4. Attrition: Tear and wear of erosional tools suffered by themselves.
5. Cavitation: Erosion produced by the water bubbles generated by the sudden dropping in flow.

3.2.6 Mode of Fluvial Sediment Transportation

Transportation of a river means the carrying of eroded materials from its catchment and channel through the flowing water in the name of sediments. The major sources of sediments are weathering and mass wasting over river basin, which are input in the river system through the sub-channels. In a channel sediment are transported in following ways.

1. Bed-load Transportation or Traction: sediment moves with the contact of channel bed.
2. Transportation through Saltation
3. Suspended Sediment Transportation,
4. In form of Solution

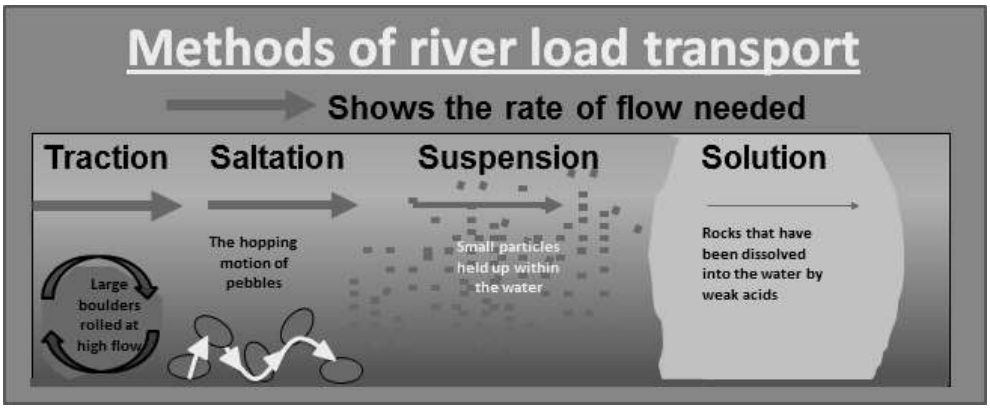


Fig. 2: Mode of sediment transport in fluvial system (Source: Wikipedia.org, 2018)

3.2.7 Major Fluvial Landforms

A variety of landforms developed within a fluvial system, which are classified as erosional, depositional or some are the combination of erosion and deposition (Table).

Erosional Landforms	Depositional Landforms
1.River Valley: Gorges and Canyons 2.Waterfall 3.Pot Holes 4.Structural Bench 5.River Terraces: Paired and Un-paired 6.River Meander 7.Ox-bow Lake 8.Peneplains	1.Alluvial Fans and Cones 2.Natural Levees 3.Delta 4.Floodplain 5.In-stream Bars

3.3 Processes and Landforms of Coast or Coastal Geomorphology

Coastal geomorphology means primarily the action of sea water through wave action, tidal current, tsunamis etc. The contact zone between land and water usually describe by two terms, e.g. shore and coast. Shore is the part of land-sea interaction zone delineated by extreme high and extreme low tide level. Coast denotes the adjacent land mass including the shore. The land mass is characterised with sea cliff and sand dunes. The zone of seashore has been classified into different section based on the tide level as in figure.

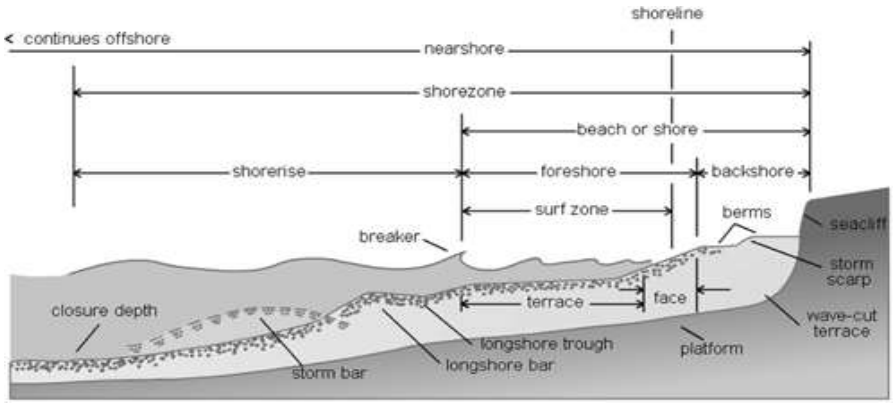


Fig. 3: Different terminology of coastal geomorphology (Source: http://www.coastalwiki.org/wiki/Definitions_of_coastal_terms)

3.3.1 Major Erosional Processes and Landforms

The erosional processes are active at the coastal zone and backshore region through the processes of hydraulic action, corration or abrasion, attrition, corrosion or solution and water pressure. The nature and magnitude of erosion depends on the wavelength, wave velocity, wave frequency, structure and composition of bedrocks of the coast land, longshore current, rip current, tides.

Erosional Landforms	Depositional Landforms
1.Sea Cliffs 2.Wave-cut Platform 3.Sea stacks 4.Sea Arches 5.Blow holes 6.Geo 7.Caves	1.Sea beaches 2.Offshore and Longshore bars 3.Spits 4.Hooks 5.Loops 6.Tombolo 7.Connecting Bars

3.4 Processes and Landforms of Arid Region or Aeolian Geomorphology

Arid region means a region with severally lack of water and usually characterised by desert area and the active geomorphic agent is wind. The geomorphic processes by wind action are known as aeolian activity. Although, wind action is not as much effective of river and sea waves, still a significant role played by wind with desert sand and create number of erosional and depositional landforms.

3.4.1 Erosional Work of Wind

The wind erosion depends on the wind velocity, nature and amount of sand, erosional tools present in the wind, nature of vegetation, and humidity, rainfall amount and temperature. Maximum wind erosion occurs at the short distance above the ground (20 - 25 cm) because wind velocity and sediment movement are high. The major erosional processes are (i) deflation (process of removing, lifting and blowing sand from the ground and to the long outward), (ii) abrasion or sandblasting, and (iii) attrition. The major transportation works are suspension, saltation, and traction.

3.4.2 Major Erosional Landforms

1. Deflation basin also known as buffalo wallows, pamg kiang for large depression
2. Mushroom rocks
3. Inselbergs or bornhardts
4. Demoisells
5. Zeugen
6. Yardangs
7. Dreikanter and Ventifacts
8. Stone latties
9. Wind bride and windows

3.4.3 Major Depositional Landforms

1.Formation of sand dunes

a.Longitudinal sand dunes
b.Transverse sand dune
c.Brachan
d.Parabolic
e.Other forms of sand dune: star dunes, reversing dunes, whalebacks

2.Loess: the accumulation of wind-blown silt, typically in the 20–50 micrometer size range, twenty percent or less clay and the balance equal parts sand and silt that are loosely cemented by calcium carbonate.

3.4.4 Fluvio-Aeolian Landforms

Some regions are characterised by the combine work of fluvial and aeolian and developed some typical landforms as follows:

1.Pediment
2.Bolsons and Playas
3.Bajada

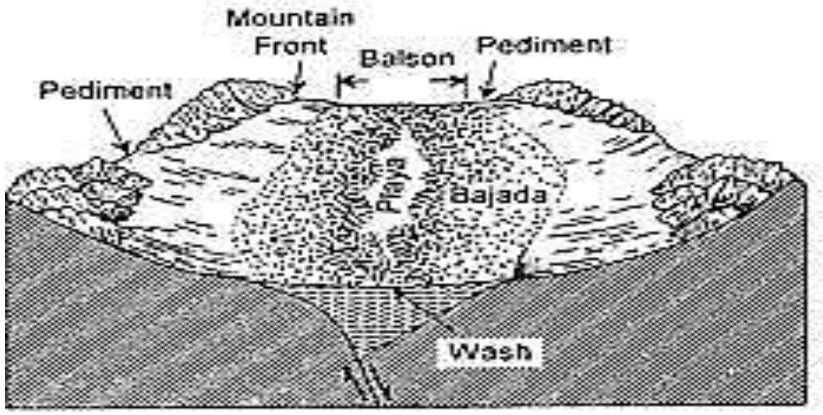


Fig. 4: Fluvio-aeolian landforms (after Singh, 2010)

Pediment is a bare rocky surface in the front in arid mountain, with a general gradient of 1˚ - 7˚, situated in between mountain and bajada. The term first coined by G.K. Gilbert (1882). A number of theories are developed to explain the process of its generation.

a.Lawson's Recession Theory (1915)
b.Sheet-flood Theory of McGee (1897)
c.Lateral Erosion Theory of Johnson (1932)
d.Composite Theory

3.5 Geomorphology of Karst Topography

A typical region, where the landforms are generated by the chemical weathering or by chemical erosion of carbonate rocks through the surface and subsurface water known as Karst Topography. The major dominated rock type is limestone; therefore, the alternative name of karst is Limestone Topography.

3.5.1 Favourable condition for Karst Topography

a. The limestone area must be well extended vertically as well as horizontally with a significant amount of thickness.
b. The limestone bed should be characterized with number joints and fracture, which support the good permeability of the bed and helps to the interaction between water and carbonate rock.
c. The area should be situated above the local ground water.
d. There must be enough rainfall to supply the required water for solution.

3.5.2 Distribution of Karst Topography

Yugoslavia: extended about 480 km in length and 80 km in width; Causes Region of southern France; Spanish Andalusia; Northern Puertorico; Western Cuba; Jamaica; Southern Indiana; Virginia; Tennessee; central Florida etc.

In India, especially at Guptadham Cave in Rohtas plateau; some patches in western and eastern Himalaya, Rovers Cave and Tapkeshwar temple near Dehra Dun; Pachmarhi (M.P.); Baster district (M.P.); coastal area near Visakhapatnam etc.
Major Erosional and Depositional Landforms

Erosional	**Depositional**
a.Lapies/Karren b.Terra rosa c.Solution holes: sink hole, swallow hole, dolines, Ovala d.Solution pan e.Karst Window f.Poljes g.Blind valley h.Caves i.Ponores j.Natural Bridge	a. Stalactite b.Stalagmite c. Cave pillars d.Helictite and helicmites e. Tufa

3.6 Concept of Cyclic and Non-Cyclic Theories in Geomorphology

Geomorphology, the discipline generally deals with the development of landscape over the Earth's Surface. A number of theories have been presented this concept. All these theories have been divided into two major categories: (a) Cyclic and (b) Non-cyclic.

William Morris Davis, an American geomorphologist, was first scholar to present the general theory of landscape development. His theory was published by three major research works in the name of 'complete cycle of river life' (1889), 'geographical cycle' (1899) and 'slope evolution'. Through these

research works, he was first presented the concept of cyclic nature of landscape evolution. According to him, the landscape is developed progressively through different geomorphological processes within a time-frame. He has divided the progressive time of landscape development into three stages e.g.

3.6.1 Youth, Mature and Old.

According to Davis, 'the geographical cycle is a period of time during which an uplifted landmass undergoes its transformation by the process of landsculpture ending into low featureless plain or peneplain'.

To define landscape, he said "Landscape is a function of structure, process and time". Structure means the lithological and structural characteristic of rocks, Process includes all the denudational processes e.g. weathering, mass wasting etc. and Time refers the temporal context as well as the progressive development.

Basic Characteristics of Landscape during the Stages of Youth, Mature, and Old

3.6.1.1 Youth

1. Erosion starts after complete of landmass upliftment.
2. The summits of the water divides are not affected.
3. Initiations of small consequent streams along the general slope.
4. Major channel processes are stream lengthening by headwater erosion and deep vertical erosion.
5. Channel gradient is very high and channel bank slope is very steep, some time >70˚.
6. The relative relief continues to increase and at the end of youth it reached maximum relief condition.
7. Erosional and Transportation work are high in river water with high flow velocity.

3.6.1.2 Mature

1. Reduced the width of river divides.
2. Lateral erosion is more active than vertical erosion.
3. Channel widening process is actively started.
4. Substantial decrease in channel gradient and bank slope, flow velocity, transporting capacity.
5. Old
6. Total absence of valley incision but lateral erosion and valley widening are still active.
7. Water divides are rapidly eroded and at the last stage they are vanished.
8. A period towards maximum entropy in fluvial system.
9. River started to deposit sediments within the channel due to over load than transport capacity.
10. At the end, the entire landscape is transformed into peneplain with number of monadnocks.

3.6.1.3 Some other theories on Landscape Development

1. Theory of W. Penck (1924): 'Morphological System' or 'Morphological Analysis'
2. Theory of L.C. King (1948): 'Cyclic model of Pediplanation'
3. Dynamic Equilibrium theory of J.T. Hack (1960).
4. Tectono-Geomorphic Model of M. Morisawa (1975)
5. Episodic Erosion model of S.A. Schumm (1965)
6. Non-Cyclic Theory by J.T. Hack (1960)

J.T. Hack, another American geomorphologist, have opposed the cyclic nature of landscape development and presented a new advanced concept of landscape development i.e., dynamic equilibrium model on 1960. According to him, it is not a model only this is a reality about landscape. The concept implies that landscape is result of energy balance between exogenic and endogenic forces.

The model was a serious attempt to fill the gap developed by Davis and Penck with no explanation about the poly-cyclic landscape. The basic views of this model are:

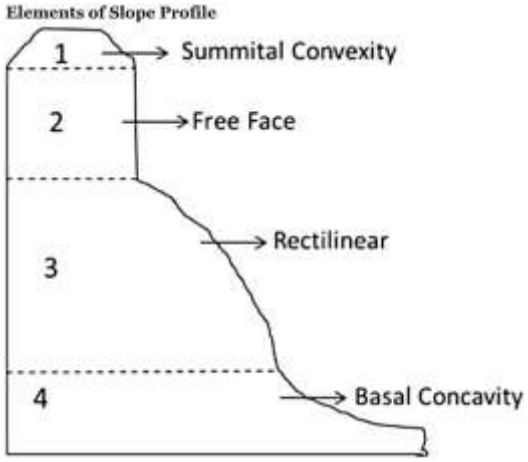
1. The landscape evolution is an open system and time independent process.
2. The processes are largely depending on the lithological adjustment to landforms.
3. The landscape is result of balance between erosion and deposition. iv.Base level of erosion plays significant role in the landscape development.

3.7 Slope

Slope is a key element to understand the geomorphology. Slope is basically the angular inclination of terrain between hill top to hill bottom. According to Singh (2010), 'slope is upward or downward inclination of surface between hills and valleys and form most significant aspect in landscape assemblages'.

3.7.1 Major Elements of Slope

In consideration of a longitudinal slope from the hill top to bottom, four major parts can be observed.



a. Summit Convexity: The convex segment at the top of the hill. The slope of this region also called 'waxing slope' or 'upper wash slope'.
b. Free Face: The wall-like vertical bare slope segment.
c. Rectilinear: The nearly straight or linear segment of a hillslope profile.
d. Basal Concavity: This part is also known as valley floor segment and slope is called waving slope.
e. Classification of Slope

A. Genetic Classification

a. Tectonic Slope: formed by tensional and compressional forces.
b. Erosional Slope: formed due to erosion by fluvial, aeolian, glacial, sea wave actions
c. Slope of Accumulation: formed by the deposition of eroded materials.

B.Quantitative Classification

a. Level to gentle slope (0˚ - 2˚)
b. Gentle Slope (2˚ - 5˚)
c. Moderate Slope (5˚ - 10˚)
d. Moderately Steep Slope (10˚ - 18˚)
e. Steep Slope (18˚ - 30˚)
f. Very Steep Slope (30˚ - 45˚)
g. Precipitous to Vertical Slope (>45˚)

3.7.2 Model of Slope Evolution

The study of slope evolution is done through three main approaches: (i) theoretically; (ii) experimentally, and (iii) empirically. There are a number of theories developed to study this geomorphological process, which is grouped into three main categories by A. Young (1972).

1.Slope Decline Theory by W.M. Davis
2.Slope Replacement Theory by W. Penck
3.Parallel Retreat Theory by L.C. King

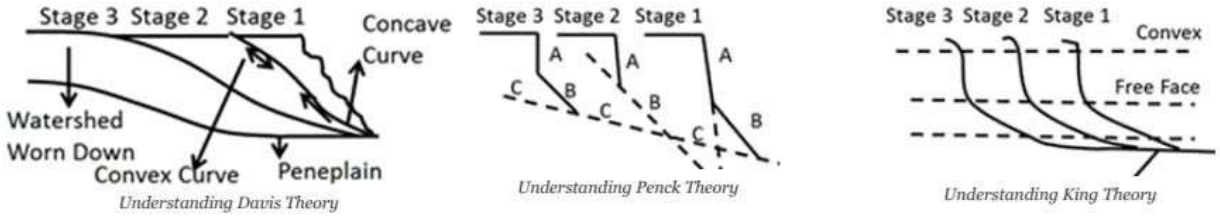


Fig. 5: Different Slope Models (Source: Singh, 2010)

3.8 Concept of Fluvial Morphometry – linear, areal and relief aspects

The concept of fluvial morphometry is a result of quantitative revolution during 1960s in the field of research, especially on the physical geography. The term 'morphometry' in geomorphology refers the quantitative measure and mathematical analysis the configuration of relief features of on the Erath surface. In particular, the fluvial morphometry includes the consideration of linear, areal, and relief aspects of fluvial originated drainage basin.

3.8.1 The Linear Aspects of the Basin

1. Stream Ordering
2. Bifurcation Ratio
3. Law of Stream Number
4. Stream Length Ratio and Law of Stream Number
5. Sinuosity Index: to study the shape geometry of a stream line with the help of ratio between original stream length and air length from source to confluence of that stream.
6. Meandering Pattern
7. Length of Overland Flow
8. Stream Junction Angles

3.8.2 The Areal Aspects of the Basin

1.Geometry of Basin's Shape
2.Area Ratio and law of basin area
3.Stream Frequency: to study the number of streams within a unit area
4.Drainage Density: the ration between total stream length and area of a unit of study
5.Drainage Texture

3.8.3 The Relief Aspects of the Basin

1.Hypsometric Curve: to know the distribution of area within a specific relief value
2.Average Slope of the Basin
3.Relative Reliefs
4.Dissection Index
5.Ruggedness Index
6.Law of Channel Slope and Profile Analysis

3.9 Periglacial Processes and Landforms

The term 'periglacial' defer from the term 'glacial' in terms of the nature of glaciations and climatic characteristic. The term periglacial was first used by Polish geomorphologist Walery von Lozinzki in 1909. The periglacial environments experienced with intense frost action during winter and snow-free ground during summer. The climate of these regions is characterised by mean annual temperature ranging between -1˚C to -15˚C, and mean annual precipitation mostly in form of snow is 120 mm to 1400 mm.

Permafrost is a most important feature of periglacial region. Permafrost means continuous and discontinuous zones of permanently frozen ground, currently 25% of the Erath comes under this type of land surface. In permafrost the soil or rocks have to remain frozen for at least two year or more consecutive years.

The fluvial activity is a main **process of periglacial** region in addition with the continuous 'freezing and thawing' of water. A verity of typical landforms has been observed over the periglacial regions, such as:

1.Ice and sand wedges
2.Frost mounds
3.Pingos
4.Bugors
5.Palsas, peat plateau, and string bogs
6.Thermokarst and oriented lakes
7.Pattern Ground

References

1. Charlton, R. (2008). Fundamental of Fluvial Geomorphology. Rutledge, London.
2. Huggett, R.J. (2007). Fundamental of Geomorphology. Rutledge, London.
3. Kale, V.S. and Gupta, A. (2001). Introduction to Geomorphology. Orient Longman, Hyderabad.
4. Knighton, A.D. (1984). Fluvial Forms and Processes. Edward Arnold Pub., London.
5. Singh, S. (2010): Geomorphology. Prayag Pustak Bhawan, Allahabad.
6. Thornbury, W.D. (1969). Principles of Geomorphology. Wiley.