GEOG-501

GEOG-501: FUNDAMENTALS OF GEOMORPHOLOGY

M.A./M.Sc. 1st Semester

DEPARTMENT OF GEOGRAPHY AND NATURAL RESOURCE MANAGEMENT

SCHOOL OF EARTH AND ENVIRONMENT SCIENCE

UTTARAKHAND OPEN UNIVERSITY

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BLOCK- 1 CONCEPTUAL BASE

UNIT -1 NATURE, SCOPE, TRENDS AND DEVELOPMENT OF GEOMORPHOLOGY

1.1 OBJECTIVES

After reading this unit you will be able to understand:

- To introduce the concept of geomorphology and provide an overview of its scope and importance in the broader field of physical geography.
- To describe the historical development of geomorphology, including important theories and concepts that have shaped the discipline.
- To discuss the various subfields of geomorphology, such as fluvial, glacial, coastal, and tectonic geomorphology, and their respective research questions and methodologies.
- To examine current trends and new directions in geomorphology research, including the integration of interdisciplinary approaches and the application of new technologies.
- To provide examples of key geomorphologists and their contributions to the discipline, and to encourage readers to explore further research in this field.

1.2 INTRODUCTION

Geomorphology is the branch of Earth science that focuses on the study of landforms, their formation, evolution, and their spatial distribution. Geomorphology is an interdisciplinary field that combines aspects of geology, geography, physics, and ecology to understand the processes that shape the Earth's surface. Geomorphology is crucial in understanding how landscapes change over time and in predicting the effects of natural and human-induced changes.

Geomorphology has a long history, with early theories of landform development proposed by prominent scientists such as Charles Darwin and James Hutton. However, the modern field of geomorphology emerged in the early 20th century, with the pioneering work of scientists such as William Morris Davis, who developed the cycle of erosion model to explain how landscapes evolve. Since then, geomorphology has advanced significantly, with the development of new technologies, such as remote sensing and computer modelling, allowing for more detailed and accurate analysis of landforms.

The study of geomorphology involves a range of methods and techniques, including field observations, laboratory experiments, and computer modelling. Geomorphologists also use a variety of tools, including GPS, LIDAR, and satellite imagery, to collect data and analyze landscapes. This data is used to develop models and theories to explain landform evolution and to identify patterns in landscape change over time.

Geomorphology has many applications, including in natural resource management, land-use planning, and hazard mitigation. For example, geomorphology can help predict the location and magnitude of landslides, floods, and other natural hazards, allowing for the development of effective mitigation strategies. Geomorphology can also inform land-use planning decisions by identifying areas that are prone to erosion or other forms of landscape change.

Geomorphology is a scientific discipline that is concerned with the study of landforms, the processes that shape and modify them, and the interactions between landforms and other aspects of the Earth system. Geomorphologists study a wide range of phenomena, including mountains, valleys, plateaus, plains, coastlines, rivers, glaciers, and permafrost.

Geomorphology is a multidisciplinary field that draws on principles and techniques from a wide range of disciplines, including geology, geography, physics, ecology, and engineering. Geomorphologists use a variety of observational and analytical tools to collect data on landforms and the processes that shape them, including field observations, remote sensing, laboratory experiments, and numerical modelling.

One of the key principles of geomorphology is that landforms are the result of the interaction between different processes acting on the Earth's surface. These processes include weathering, erosion, deposition, tectonic activity, climate change, and human activity. Geomorphologists seek to understand the mechanisms and rates of these processes, and how they interact to produce the diverse range of landforms observed on Earth.

Another important aspect of geomorphology is the study of landscape evolution. Geomorphologists seek to understand how landscapes change over time, including the effects of long-term tectonic activity, climate change, and human impacts. They use a variety of approaches, including geochronology, landscape modelling, and spatial analysis, to reconstruct the history of landscape evolution and predict future changes.

Geomorphology also has important practical applications, including natural hazard management, environmental planning, resource management, and landscape design. Geomorphologists work with a range of stakeholders, including policymakers, engineers, and the general public, to develop strategies for managing and protecting the Earth's surface.

1.2.1 Definition of Geomorphology:

Geomorphology is the branch of Earth science that deals with the study of landforms, their origin, evolution, and spatial distribution. Throughout history, several ancient and modern geographers have contributed to the development of geomorphology as a scientific discipline. Here are some of the definitions of geomorphology given by ancient to modern geographers:

- **Strabo (64 BCE - 24 CE):** Strabo was a Greek geographer and historian who wrote extensively about the geography of the ancient world. In his book, "Geographica," he defined geomorphology as the study of the physical features of the earth's surface, including mountains, rivers, and valleys.
- **Leonardo da Vinci (1452-1519):** Da Vinci was a renowned Italian artist, inventor, and scientist. He was one of the first to recognize the importance of water in shaping the Earth's surface. He defined geomorphology as the study of the effects of water on the Earth's surface, including erosion and sedimentation.
- **William Morris Davis (1850-1934):** Davis was an American geographer who is often referred to as the father of modern geomorphology. He defined geomorphology as the study of the processes that shape the Earth's surface and the landforms that result from these processes. Davis emphasized the concept of a "cycle of erosion," which describes the process by which landscapes evolve.
- **Walther Penck (1888-1923):** Penck was a German geographer who developed a quantitative approach to geomorphology. He defined geomorphology as the study of the Earth's surface in terms of its relief, which is the three-dimensional shape of the land surface. Penck believed that the Earth's surface could be described using mathematical models.
- **Richard Chorley (1927-2002):** Chorley was a British geographer who made significant contributions to the study of geomorphology. He defined geomorphology as the study of the Earth's surface in terms of its form, function, and history. Chorley emphasized the

importance of understanding the processes that shape landscapes and how these processes vary across different spatial and temporal scales.

- **Robert W. Young (born 1942):** Young is an American geomorphologist who has made significant contributions to the study of geomorphology. He defines geomorphology as the study of the Earth's surface in terms of its physical and biological processes, and how these processes interact to produce landscapes. Young emphasizes the importance of interdisciplinary approaches to understanding geomorphic processes.

1.3 NATURE OF GEOMORPHOLOGY

The nature of geomorphology is complex and multifaceted, drawing on principles from a wide range of disciplines and involving the study of a wide range of phenomena. Geomorphology is fundamentally concerned with understanding the form, processes, and evolution of the Earth's surface, and with developing a conceptual framework for interpreting and explaining these phenomena.

At its core, geomorphology is a scientific discipline that is driven by a commitment to empirical observation, hypothesis testing, and the development of conceptual models. Geomorphologists use a range of observational and analytical tools to collect data on the Earth's surface and to develop and test hypotheses about the processes that shape it.

One of the key characteristics of geomorphology is its interdisciplinary nature. Geomorphology draws on principles and techniques from a range of fields, including geology, geography, physics, ecology, and engineering, among others. This interdisciplinary approach is critical to understanding the complex interactions between physical and biological processes that shape the Earth's surface. Geomorphology is a branch of physical geography that deals with the study of landforms and the processes that shape them. It is a multidisciplinary field that draws on the principles and techniques of geology, hydrology, meteorology, and ecology to understand the evolution of the Earth's surface.

The nature of geomorphology can be described in terms of its key concepts, principles, and methods:

- ***Landforms:*** Geomorphology focuses on the study of landforms, which are the physical features of the Earth's surface. Landforms include mountains, valleys, plateaus, canyons, beaches, and other features that result from geologic processes such as erosion, weathering, and tectonic activity.
- ***Processes:*** Geomorphology seeks to understand the processes that shape landforms. These include erosion, weathering, mass wasting, deposition, and tectonic activity. By studying these processes, geomorphologists can reconstruct the history of the Earth's surface and predict how it will change in the future.
- ***Spatial and temporal scales:*** Geomorphology operates on a range of spatial and temporal scales, from the microscopic level of individual minerals to the global scale of tectonic plate movements. Geomorphologists use a variety of methods and tools to study landforms and processes at different scales, including field observations, remote sensing, and numerical modelling.
- ***Interdisciplinary approach:*** Geomorphology is an interdisciplinary field that draws on the principles and techniques of geology, hydrology, meteorology, and ecology to understand the Earth's surface. Geomorphologists often work in collaboration with scientists from other disciplines to address complex research questions.
- ***Human impact:*** Geomorphology also considers the impact of human activities on the Earth's surface, such as land use change, deforestation, and climate change. Human activities can alter natural processes and lead to changes in landforms over time.

The nature of geomorphology is to understand the physical and environmental processes that shape the Earth's surface and the landforms that result from those processes. By studying landforms and their evolution over time, geomorphologists can improve our understanding of the natural world and inform decision-making related to land use, environmental management, and natural hazard mitigation.

1.4 SCOPE OF GEOMORPHOLOGY

The scope of geomorphology is broad and encompasses a wide range of phenomena related to the Earth's surface. Geomorphology is concerned with the study of landforms, including mountains, valleys, plateaus, plains, and coastlines, as well as the processes that shape and modify these landforms, such as weathering, erosion, deposition, tectonic activity, and climate change.

One of the primary areas of focus in geomorphology is the study of fluvial systems, which include rivers, streams, and other forms of running water. Geomorphologists study the behaviour of fluvial systems, including their erosion and sediment transport processes, and their interactions with human activities such as dam construction and channelization.

Another area of focus in geomorphology is the study of glacial and periglacial systems, including glaciers, ice sheets, and frozen ground. Geomorphologists study the formation and movement of glaciers and their interactions with the landscape, as well as the impacts of climate change on these systems.

Geomorphology also encompasses the study of coastal and marine systems, including beaches, cliffs, and estuaries. Geomorphologists study the dynamics of coastal and marine systems, including erosion, sediment transport, and sea level change, and their interactions with human activities such as coastal development and sea level rise.

Geomorphology is a highly interdisciplinary field of study that encompasses a wide range of topics related to the Earth's surface and its evolution over time. Here are some of the key aspects that fall within the scope of geomorphology:

1.4.1 Landforms: Geomorphology studies the various landforms that exist on the Earth's surface, including mountains, valleys, canyons, plateaus, and coastal features such as beaches and cliffs.

1.4.2 Processes: The study of the Earth's surface requires an understanding of the various physical and chemical processes that shape it, such as erosion, weathering, tectonics, and sediment transport. These processes are studied at different spatial and temporal scales, from local to global and from seconds to millions of years.

1.4.3 Geological history: Geomorphology seeks to understand the Earth's geological history and how it has influenced the evolution of its landforms. This involves studying the rock types, structures, and stratigraphy of the Earth's surface.

1.4.4 Environmental change: Geomorphology is concerned with understanding how environmental change, both natural and human-induced, affects the Earth's surface. This includes studying the impacts of climate change, land use changes, and natural disasters such as floods, earthquakes, and landslides.

1.4.5 Interdisciplinary approach: Geomorphology is an interdisciplinary field that involves collaboration between geologists, geographers, hydrologists, ecologists, and other scientists. The integration of multiple disciplines allows for a more holistic understanding of the Earth's surface and its evolution over time.

1.4.6 Practical applications: Geomorphology has many practical applications, including the management of natural resources such as water and soil, the mitigation of natural hazards, and the development of sustainable land use practices.

The scope of geomorphology is broad and encompasses many different aspects related to the Earth's surface and its evolution. The interdisciplinary nature of the field allows for a more comprehensive understanding of the processes that shape the Earth's surface and the impacts of environmental change on the landscape.

1.5 TRENDS IN GEOMORPHOLOGY

Several emerging trends in geomorphology reflect recent advances in technology and changes in research priorities. These trends are discussed below:

1.5.1 Interdisciplinary approaches: There is a growing trend towards interdisciplinary research in geomorphology, with an increasing number of collaborations between geomorphologists and researchers from other fields such as ecology, hydrology, and engineering. This approach has led to a more comprehensive understanding of landscape processes and their interactions with other Earth systems.

1.5.2 Technological advancements: The development of new technologies such as LiDAR, drones, and high-resolution remote sensing has revolutionized the study of geomorphology, allowing researchers to collect large amounts of data quickly and accurately.

This has enabled more detailed and precise measurements of topography and landforms, as well as improved modelling of landscape processes.

1.5.3 Quantitative analysis: There is a growing emphasis on quantitative analysis in geomorphology, with the development of new statistical and modelling approaches. This has led to a more rigorous understanding of landscape processes and a greater ability to make predictions about future landscape change.

1.5.4 Human impacts: There is increasing recognition of the role of human activities in shaping landscapes, and the need to integrate social and economic factors into geomorphological research. This includes the study of land use change, urbanization, and mining.

1.5.5 Climate change: There is a growing emphasis on the study of climate change and its impacts on the Earth's surface. This includes the study of glacial and periglacial systems, sea level rise, and changes in weathering and erosion rates.

1.5.6 Landscape evolution modelling: Landscape evolution models (LEMs) have become an important tool in geomorphology, allowing researchers to simulate the evolution of landscapes over long periods. Advances in computing power and modelling techniques have made it possible to create increasingly realistic and complex models of landscape evolution.

1.5.7 Geomorphology and society: There is a growing trend towards applying geomorphological research to address societal challenges, such as natural hazard mitigation, ecosystem restoration, and sustainable land use planning. This includes the development of decision support systems that integrate geomorphological data into policy-making and planning processes.

1.5.8 Integration of multiple data sources: With advances in technology, there is an increasing amount of data available on the Earth's surface, including remote sensing data, digital elevation models, and geophysical measurements. Geomorphologists are integrating these different data sources to gain a more comprehensive understanding of the Earth's surface and the processes that shape it.

1.5.9 Coupling of process-based models: Process-based models, such as numerical models of landscape evolution, have become increasingly important in geomorphology. These models simulate the physical processes that shape the Earth's surface, such as erosion, sediment transport, and tectonic activity. There is a trend towards coupling these models with other models that simulate biotic processes, such as vegetation growth and ecological interactions.

1.5.10 Emphasis on multi-scale analysis: Geomorphologists are increasingly interested in understanding processes and landforms at multiple scales, from the local to the regional and global. This involves using different methods and techniques at each scale and integrating the results to gain a more comprehensive understanding of the Earth's surface.

1.5.11 Focus on human impacts: As human populations continue to grow and expand, the impacts of human activities on the Earth's surface are becoming more pronounced. Geomorphologists are studying how human activities, such as land use changes and infrastructure development, are affecting the Earth's surface and the processes that shape it.

1.5.12 Interdisciplinary collaborations: As geomorphology is an interdisciplinary field, there is an increasing trend towards collaborations with researchers from other disciplines, such as ecology, hydrology, and engineering. This allows for a more comprehensive understanding of the Earth's surface and the processes that shape it.

1.5.13 Application of new technologies: New technologies, such as drones and LiDAR (Light Detection and Ranging), are transforming the way geomorphologists collect data on the Earth's surface. These technologies allow for high-resolution mapping and monitoring of landforms and processes and are leading to new insights into the evolution of the Earth's surface.

1.6 DEVELOPMENT OF GEOMORPHOLOGY

Geomorphology, the study of Earth's landforms and the processes that shape them has a long history that spans from ancient times to the present day. This field has evolved through the contributions of many scholars and researchers from different disciplines. In this response, I will provide a brief overview of the development of geomorphology from ancient to modern periods, along with some key references.

1.6.1 Ancient Period:

Geomorphology has roots in the works of ancient Greek philosophers like Aristotle and Eratosthenes, who made early attempts to explain the formation of Earth's landforms. However, it was not until the 19th century that geomorphology emerged as a distinct field of study.

Geomorphology is the study of the physical and spatial aspects of the Earth's surface and the processes that shape them. Ancient Europeans have made significant contributions to the development of geomorphology. In this answer, we will discuss some of the key contributions made by ancient European scholars in this field.

Aristotle: Aristotle was a Greek philosopher who lived in the fourth century BCE. He is considered one of the earliest contributors to the study of geomorphology. Aristotle observed the gradual changes in the Earth's surface and concluded that these changes were caused by natural processes such as erosion and sedimentation. He also recognized the importance of studying rocks and soils to understand the underlying geological processes.

Strabo: Strabo was a Greek geographer who lived in the first century BCE. He is known for his work "Geography," in which he described the physical features of the Earth, including its mountains, rivers, and seas. Strabo was one of the first scholars to recognize the role of climate in shaping the Earth's surface. He also observed the relationship between landforms and the underlying geology.

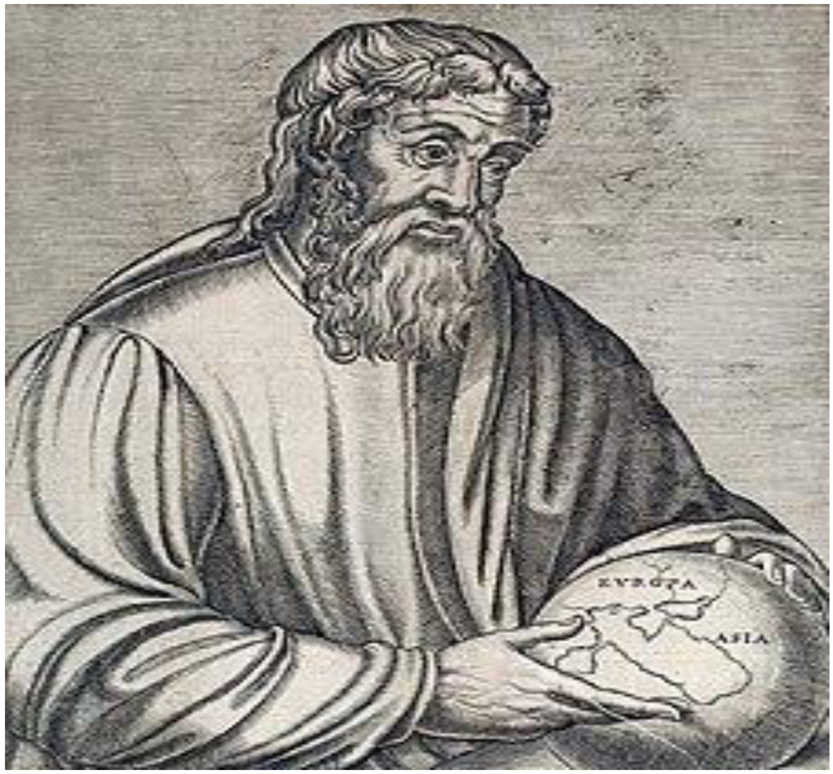

Fig. 1.1 Strabo, Source Google Image

Leonardo da Vinci: Leonardo da Vinci was an Italian artist, scientist, and inventor who lived in the fifteenth and sixteenth centuries. He is known for his sketches and drawings of the Earth's surface, including mountains, rivers, and coastlines. Leonardo was one of the first scholars to recognize the importance of studying the Earth's surface to understand its underlying geological processes.

Fig. 1.2 Leonardo da Vinci, Source Google Image

James Hutton: James Hutton was a Scottish geologist who lived in the eighteenth century. He is considered the father of modern geology and made significant contributions to the field of geomorphology. Hutton observed the processes of erosion and deposition and recognized the role of water and wind in shaping the Earth's surface. He also proposed the idea of uniformitarianism, which suggests that the same geological processes that occur today have been occurring throughout Earth's history.

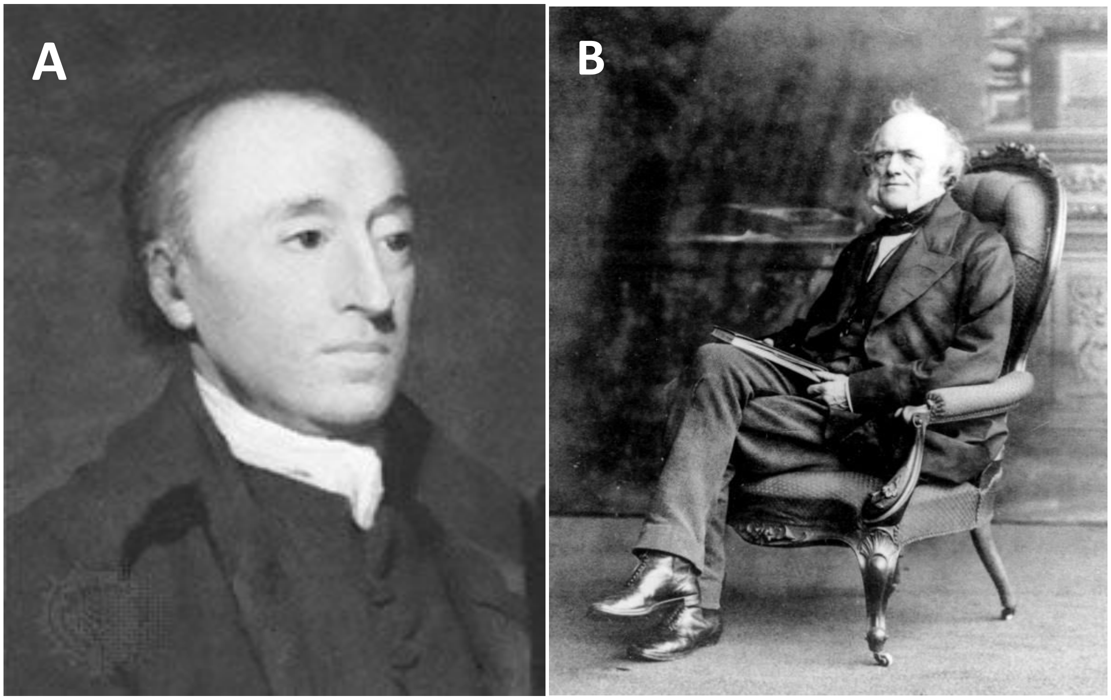

Fig.1.3 (A) James Hutton & (B) Charles Lyell, Source Google Image

Charles Lyell: Charles Lyell was an English geologist who lived in the nineteenth century. He is known for his work "Principles of Geology," in which he developed the concept of uniformitarianism further. Lyell proposed that the Earth's surface is shaped by slow and gradual processes that occur over long periods, rather than sudden catastrophic events. He also recognized the role of climate in shaping the Earth's surface.

These are just a few examples of the contributions made by ancient Europeans to the field of geomorphology. Their observations and theories have laid the foundation for modern studies of the Earth's surface and have helped us to understand the complex processes that shape our planet.

1.5.2 Catastrophism:

Catastrophism is a geological theory that was popular in the late 18th and early 19th centuries. It proposed that the Earth's surface had been shaped primarily by sudden and catastrophic events, such as floods, earthquakes, and volcanic eruptions. Catastrophism was eventually superseded by uniformitarianism, which proposed that the Earth's surface was shaped primarily by slow and gradual processes, such as erosion and sedimentation.

One of the key proponents of catastrophism was Georges Cuvier, a French naturalist who lived in the late 18th and early 19th centuries. Cuvier studied the fossils of extinct animals and used them to reconstruct the history of the Earth's surface. He proposed that the Earth had undergone a series of catastrophic events, such as floods and ice ages, which had wiped out entire species of animals and created new landforms.

Another important figure in the development of catastrophism was James Hutton, a Scottish geologist who lived in the 18th century. Hutton proposed that the Earth's surface had been shaped over long periods by a series of slow and gradual processes. However, he also recognized the possibility of catastrophic events, such as earthquakes and volcanic eruptions, which could have a significant impact on the Earth's surface.

Today, catastrophism is not widely accepted as a geological theory. However, some modern researchers have proposed that certain catastrophic events, such as asteroid impacts, may have played a significant role in shaping the Earth's surface at certain points in history.

1.5.3 Uniformitarianism:

Uniformitarianism is a geological theory that proposes that the processes that shape the Earth's surface today are the same processes that have shaped the Earth's surface throughout its history. This theory suggests that the Earth's surface has been shaped over long periods by slow and gradual processes such as erosion and sedimentation, rather than sudden and catastrophic events such as floods and volcanic eruptions.

The concept of uniformitarianism was first proposed by James Hutton, a Scottish geologist who lived in the 18th century. Hutton argued that the Earth's surface had been shaped over long periods by a series of slow and gradual processes that were still operating today. He believed that these processes could account for the features of the Earth's surface that we see today and that there was no need to invoke sudden and catastrophic events to explain them.

The ideas of Hutton were further developed by Charles Lyell, an English geologist who lived in the 19th century. Lyell argued that the Earth's surface had been shaped over long periods by slow and gradual processes that could be observed and measured today. He believed that these processes had been operating throughout the history of the Earth and that they could account for all of the features of the Earth's surface.

Today, uniformitarianism is widely accepted as a geological theory, and it forms the basis for much of the research that is conducted in the field of geomorphology. This theory is supported by a wide range of evidence, including the study of sedimentary rocks, the analysis of landforms and their formation processes, and the use of isotopic dating techniques to determine the ages of rocks and other geological features.

1.5.4 Contribution of German Geographers in the Field of Geomorphology

German geographers have made significant contributions to the field of geomorphology over the years. Here are some of the key German geographers and their contributions:

Alexander von Humboldt: Alexander von Humboldt (1769-1859) was a German naturalist and explorer who made significant contributions to the field of geomorphology. He is considered one of the pioneers of the modern study of physical geography, which includes geomorphology, climatology, and biogeography.

Fig. 1.4 Alexander von Humboldt, Source Google Image

Humboldt's contributions to geomorphology include:

Concept of landscape: Humboldt introduced the concept of landscape, which refers to the physical and visible characteristics of a region, including landforms, water bodies, vegetation, and human-made features. He emphasized the importance of studying landscapes as a whole, rather than focusing on individual features.

Geographical regions: Humboldt also developed the concept of geographical regions, which are defined by their physical and environmental characteristics. He recognized that different regions have different landscapes, climates, and ecosystems and that these factors are interrelated.

Relief maps: Humboldt was one of the first scientists to use relief maps, which are three-dimensional models of the Earth's surface, to study and visualize landforms. He believed that relief maps were a powerful tool for understanding the relationship between landforms and geologic processes.

River systems: Humboldt conducted extensive studies of river systems, including the Amazon River and its tributaries. He recognized the importance of studying the entire river system, from its source to its mouth, to understand the processes that shape it and the relationships between the river and the surrounding landscape.

Environmental determinism: Humboldt rejected the idea of environmental determinism, which suggests that physical and environmental factors determine human behaviour and culture. He argued that human culture and society are influenced by a complex interplay of environmental, historical, and social factors.

Humboldt's contributions to geomorphology laid the foundation for the modern study of physical geography and influenced generations of scientists who followed in his footsteps. His emphasis on studying landscapes as a whole and his recognition of the interrelationships between physical and environmental factors are still relevant today.

Walther Penck: Walther Penck was a German geographer who lived in the late 19th and early 20th centuries. He is known for his work on landscape evolution and his theory of cyclic geomorphology. Penck proposed that the Earth's surface undergoes cycles of uplift, erosion, and deposition over long periods. He developed a method of mapping landforms called the Penck map, which showed the relative ages and stages of development of different landforms. He also developed a classification system for different types of landscapes based on their origin and evolution.

Alfred Hettner: Alfred Hettner was a German geographer who lived in the late 19th and early 20th centuries. He is known for his work on the relationship between landforms and the underlying geology. Hettner proposed the concept of the geochore, which refers to a region with a distinct combination of landforms, soils, and vegetation. He recognized the importance of studying the cultural and historical context of the Earth's surface, and he developed a method of regional geography that emphasized the interdependence of physical, biological, and human factors.

Hans Cloos: Hans Cloos was a German geologist and geographer who lived in the early 20th century. He is known for his work on tectonic geomorphology and his studies of the Rhine River Valley. Cloos proposed that the Earth's surface is shaped by the interplay between tectonic forces and erosional processes. He developed a model of rock deformation called the Cloos shear model, which showed how rock layers can be folded and faulted by compressional stresses. He also applied his theories to the study of the formation of mountain ranges and the evolution of landscapes over time.

Carl Troll: Carl Troll was a German geographer who lived in the 20th century. He is known for his work on landscape ecology and his studies of the impact of human activity on the Earth's surface. Troll recognized the importance of studying the interactions between human society and the natural environment, and he developed a method of mapping ecosystems called the Troll map. This map showed how different types of vegetation corresponded to different soil and climate conditions, and it highlighted the importance of preserving natural ecosystems in the face of human development.

1.5.5 Contribution of French Geographers in the Field of Geomorphology

French geographers have made significant contributions to the field of geomorphology, which is the study of the Earth's surface and the processes that shape it. Some of the most notable French geographers who have contributed to the field include Jean Tricart, Marcel Dubois, and Claude Allègre.

Jean Tricart was a French geographer who lived from 1924 to 2003. He is known for his work on mountain geomorphology, particularly in the Himalayas. Tricart conducted extensive fieldwork in the Himalayas, where he studied the processes that shape mountain landscapes, including glacial erosion and tectonic uplift. He also proposed the concept of "geomorphological regions," which refers to large areas of the Earth's surface that are characterized by similar geomorphological features.

Marcel Dubois was another French geographer who made significant contributions to geomorphology. He lived from 1920 to 1996 and is known for his work on karst landscapes, which are characterized by sinkholes, underground rivers, and other features that are formed by the dissolution of limestone rocks. Dubois conducted fieldwork in many different parts of the world, including France, China, and North Africa, where he studied the processes that shape karst landscapes.

Claude Allègre is a French geophysicist who has also made important contributions to geomorphology. He is known for his work on the evolution of the Earth's crust and the processes that shape it. Allègre has conducted extensive research on the movement of tectonic plates, which are responsible for the formation of many of the Earth's major landforms, including mountains, valleys, and ocean basins. He has also studied the chemical composition of rocks and minerals, which has provided important insights into the processes that shape the Earth's surface.

1.5.6 Contribution of British Geographers in the Field of Geomorphology

British geographers have made significant contributions to the field of geomorphology, which is the study of the Earth's surface and the processes that shape it. Some of the most notable British geographers who have contributed to the field include William Morris Davis, Charles Lyell, and John Wesley Powell.

William Morris Davis was an American-born geographer who spent much of his career at Harvard University in the United States and was heavily influenced by British geographers. He is known as the father of modern geomorphology and is famous for his concept of the cycle of erosion, which describes how landscapes evolve through the processes of erosion, transport, and deposition. Davis also developed the concept of geomorphic systems, which are defined by their inputs, processes, and outputs, and he emphasized the importance of studying the interactions between these different components.

Charles Lyell was a British geologist who lived from 1797 to 1875 and is known for his theory of uniformitarianism, which proposed that the same geological processes that operate today have been operating throughout Earth's history. This theory had a profound impact on the development of modern geomorphology, as it emphasized the importance of studying the present-day processes that shape the Earth's surface to understand past geological events. Lyell's work also laid the foundation for the field of stratigraphy, which is the study of the layers of rocks that make up the Earth's crust.

John Wesley Powell was an American geologist and explorer who lived from 1834 to 1902 and is known for his pioneering work on the geomorphology of the American West. Powell led expeditions down the Colorado River and through the Grand Canyon, where he conducted extensive fieldwork and collected data on the geological features of the region. He also developed the concept of the graded stream, which refers to a river that has achieved a state of equilibrium between the volume of water it carries and the amount of sediment it can transport.

1.5.7 Contribution of American Geographers in the Field of Geomorphology

American geographers have made significant contributions to the field of geomorphology, which is the study of the Earth's surface and the processes that shape it. Some of the most notable American geographers who have contributed to the field include John Wesley Powell, William Morris Davis, and Grove Karl Gilbert.

John Wesley Powell was an American geologist and explorer who lived from 1834 to 1902 and is known for his pioneering work on the geomorphology of the American West. Powell led expeditions down the Colorado River and through the Grand Canyon, where he conducted extensive fieldwork and collected data on the geological features of the region. He also developed the concept of the graded stream, which refers to a river that has achieved a state of equilibrium between the volume of water it carries and the amount of sediment it can transport.

William Morris Davis was an American-born geographer who spent much of his career at Harvard University and is known as the father of modern geomorphology. Davis developed the concept of geomorphic systems, which are defined by their inputs, processes, and outputs, and he emphasized the importance of studying the interactions between these different components. He also proposed the concept of the cycle of erosion, which describes how landscapes evolve through the processes of erosion, transport, and deposition.

Grove Karl Gilbert was an American geologist who lived from 1843 to 1918 and is known for his work on the geomorphology of the American West. Gilbert conducted extensive fieldwork in the region and proposed the concept of the "peneplain," which refers to a gently sloping surface that has been eroded to a nearly flat condition. He also developed the concept of stream piracy, which describes how one stream can capture the drainage of another stream through headward erosion.

Other notable American geographers who have contributed to the field of geomorphology include Luna Leopold, who conducted groundbreaking research on river systems and developed the concept of the geomorphic threshold; and Arthur Strahler, who developed a widely used system for classifying rivers based on their morphological characteristics.

1.5.8 Contribution of Indian Geographers in the Field of Geomorphology

Indian geographers have made significant contributions to the field of geomorphology, which is the study of the Earth's surface and the processes that shape it. Some of the most notable Indian geographers who have contributed to the field include Rakesh Kumar, Amita Bhaduri, and K. S. Valdiya.

Rakesh Kumar is a well-known Indian geomorphologist who has made significant contributions to the field of fluvial geomorphology. He has worked extensively on rivers and has studied the geomorphology of the Himalayan region. Kumar has also researched the impact of climate change on river systems and has developed models to predict the impact of climate change on river runoff.

Amita Bhaduri is another prominent Indian geographer who has made important contributions to the field of geomorphology. Her research has focused on the impact of human activities on geomorphic processes, particularly in the context of land-use change and urbanization. Bhaduri has also studied the geomorphology of river systems and has developed models to predict the impact of climate change on river morphology.

K. S. Valdiya is a leading Indian geomorphologist who has made significant contributions to the study of the Himalayan region. His research has focused on the tectonic processes that have shaped the Himalayan landscape and have shed light on the geological history of the region. Valdiya has also conducted extensive fieldwork on the geomorphology of the Deccan Plateau and has contributed to our understanding of the processes that have shaped this region.

Other notable Indian geographers who have contributed to the field of geomorphology include D. M. Maurya, who has studied the impact of tectonic processes on river morphology; S. K. Tandon, who has worked on the geomorphology of the Indian subcontinent; and S. C. Gupta, who has studied the geomorphology of arid regions.

1.5.9 Modern Period:

In the 20th century, geomorphology emerged as a distinct subfield within the broader discipline of geology. This period saw the development of new techniques for studying Earth's landforms, including aerial photography, topographic mapping, and remote sensing. Notable contributors from this period include William Morris Davis, who is widely considered the founder of modern geomorphology, and John Wesley Powell, who conducted extensive studies of the geomorphology of the American West.

In recent years, geomorphology has continued to evolve and expand, with new advances in technology and interdisciplinary research. Today, geomorphologists are studying a wide range of topics, including climate change, human impacts on landscapes, and the evolution of planetary surfaces beyond Earth.

Methods and Approaches of Landform

Geomorphologists use a variety of methods and approaches to study landforms, which are the features on the Earth's surface that have been created by various geological processes. Some of the most common methods and approaches used in geomorphology include fieldwork, remote sensing, GIS, and numerical modelling.

Subjective description

Subjective description in geomorphology involves the interpretation of landforms and geological processes based on the observer's personal experience, perception, and judgment. It involves the use of qualitative data, such as field notes, photographs, and sketches, to describe and analyze the characteristics of landforms and the processes that have shaped them.

A subjective description is an important tool in geomorphology because it allows scientists to capture the complexity and variability of landforms that cannot be easily quantified. It also allows for the integration of multiple sources of data, including remote sensing and numerical modelling, to create a more comprehensive understanding of landforms and geological processes.

However, subjective description can also be a source of bias and inconsistency, as different observers may perceive and interpret landforms differently. To mitigate these issues, scientists often use standardized methods of data collection and analysis and compare their observations with those of other observers.

Some examples of subjective description in geomorphology include the classification and interpretation of rock weathering patterns, the analysis of soil profiles, and the identification of erosional features on hillslopes and river channels. Subjective descriptions can also be used to analyze the cultural and historical significance of landforms, such as the role of mountains and rivers in shaping human settlement patterns.

Genetic description

Genetic description in geomorphology refers to the analysis and interpretation of landforms and geological processes based on their origin or genesis. It involves the use of quantitative data, such as geological maps, cross-sections, and chronologies, to reconstruct the history of landforms and the processes that have shaped them over time.

Genetic description is an essential tool in geomorphology as it allows scientists to understand how landforms were formed and how they have evolved. It also provides insights into the underlying physical, chemical, and biological processes that have shaped the landscape, which can be used to make predictions about future landscape change.

There are several methods and approaches used in genetic description in geomorphology, including:

Chronological analysis: This involves using dating methods such as radiocarbon dating, luminescence dating, and cosmogenic nuclide dating to determine the age of landforms and the timing of landscape change.

Geomorphological mapping: This involves the identification and mapping of landforms and the relationships between them. It can be used to understand the spatial distribution and evolution of landforms and the processes that have shaped them.

Stratigraphic analysis: This involves the analysis of the sedimentary layers or strata in a landscape. It can be used to reconstruct the depositional history of a landscape and to identify the processes that have shaped the sediments.

Geophysical surveying: This involves the use of techniques such as ground-penetrating radar, electrical resistivity tomography, and seismic reflection to image the subsurface structure of a landscape. It can be used to understand the underlying geology and to identify buried landforms and features.

Numerical modelling: This involves the use of computer models to simulate the physical, chemical, and biological processes that have shaped a landscape. It can be used to test hypotheses about landscape evolution and to make predictions about future landscape change.

The genetic description has been used to study a wide range of landforms and processes, including river erosion and sediment transport, glacial erosion and deposition, karst landscape formation, and tectonic landscape evolution.

Objective description

Objective description in geomorphology refers to the factual and measurable characteristics of landforms and geological processes. It involves the use of quantitative data, such as topographic maps, aerial photographs, and field measurements, to describe landforms and the processes that have shaped them. This approach aims to provide an accurate and unbiased representation of the landscape.

Objective description is an essential tool in geomorphology as it allows scientists to measure and quantify the physical properties of landforms and to make comparisons between different landscapes. It also provides a basis for understanding the underlying physical, chemical, and biological processes that have shaped the landscape, which can be used to make predictions about future landscape change.

There are several methods and approaches used in objective description in geomorphology, including:

Topographic analysis: This involves the use of topographic maps and digital elevation models (DEMs) to measure the elevation, slope, aspect, and other topographic properties of a landscape. It can be used to identify landforms such as mountains, valleys, and ridges, and to measure their dimensions and morphometric properties.

Remote sensing: This involves the use of aerial photographs, satellite images, and LiDAR data to measure and map the physical properties of a landscape. It can be used to identify and map landforms and to measure their dimensions, surface characteristics, and vegetation cover.

Field measurements: This involves the use of field instruments such as clinometers, tape measures, and GPS receivers to measure the physical properties of landforms and the processes that have shaped them. It can be used to measure the dimensions, orientation, and sediment properties of landforms, as well as the discharge and sediment transport rates of rivers.

Laboratory analysis: This involves the use of laboratory techniques such as grain size analysis, mineralogical analysis, and chemical analysis to characterize the physical and chemical properties of sediments and rocks. It can be used to identify the processes that have shaped a landscape and to reconstruct the history of landscape change.

The objective description has been used to study a wide range of landforms and processes, including river erosion and sediment transport, glacial erosion and deposition, coastal erosion and sedimentation, and tectonic landscape evolution.

1.5.10 Classification of Landform

Landforms are the physical features of the Earth's surface, created by natural processes such as erosion, weathering, and tectonic activity. They can be classified in various ways, depending on their size, shape, origin, and the processes that have shaped them. In this response, we will discuss the main ways in which landforms are classified.

BASED ON THE PROCESSES THAT SHAPE THEM:

a. Fluvial landforms: These are landforms created by the action of rivers, such as valleys, floodplains, meanders, and deltas.

b. Glacial landforms: These are landforms created by the movement of glaciers, such as cirques, horns, aretes, and U-shaped valleys.

c. Coastal landforms: These are landforms created by the action of waves and currents along coastlines, such as cliffs, beaches, spits, and barrier islands.

d. Karst landforms: These are landforms created by the dissolution of soluble rocks such as limestone and dolomite, such as sinkholes, caves, and disappearing streams.

e. Tectonic landforms: These are landforms created by the movement of the Earth's crust, such as mountains, plateaus, rift valleys, and fault scarps.

BASED ON THEIR SHAPE AND SIZE:

a. Mountains: These are landforms with a peak or summit that rises significantly above its surroundings, typically with steep slopes and rugged terrain.

b. Plateaus: These are large, flat-topped areas that are elevated above their surroundings, typically with cliffs or escarpments around their edges.

c. Hills: These are landforms that are smaller and less steep than mountains, with rounded or conical summits.

d. Valleys: These are low-lying areas between hills or mountains, typically with a river or stream running through them.

e. Plains: These are large, flat areas that are generally low-lying and often covered with sedimentary deposits.

BASED ON THEIR ORIGIN:

a. Structural landforms: These are landforms created by the internal forces of the Earth, such as mountains and rift valleys.

b. Depositional landforms: These are landforms created by the deposition of sediment, such as dunes, river deltas, and alluvial fans.

c. Erosional landforms: These are landforms created by the erosion of rock or sediment, such as canyons, cliffs, and waterfalls.

d. Volcanic landforms: These are landforms created by volcanic activity, such as lava flows, cinder cones, and volcanic calderas.

The classification of landforms is important in understanding the processes that shape the Earth's surface and in predicting the impact of natural disasters such as earthquakes, landslides, and floods. It is also useful in planning and managing land use, as different landforms have different characteristics and vulnerabilities.

APPROACHES OF GEOMORPHOLOGY STUDY

Geomorphology is the study of landforms, their evolution, and the processes that shape them. It employs various approaches and methods to understand the natural processes that create and shape the Earth's surface. In this response, we will discuss some of the main approaches used in geomorphology studies.

Process-based approach: This approach focuses on understanding the physical and chemical processes that shape landforms. It involves observing and measuring the movement of water, wind, ice, and sediment, and their interaction with the Earth's surface. This approach is often used in conjunction with field studies and laboratory experiments to identify and quantify the processes that create landforms. The process-based approach to geomorphology focuses on identifying the different types of geomorphic processes and understanding how they operate to shape the landscape. In detail, the process-based approach of geomorphology involves the following steps:

- **Identifying geomorphic processes:** The first step in the process-based approach is to identify the different types of geomorphic processes that operate on the Earth's surface. These can include processes such as weathering, erosion, mass wasting, fluvial processes, aeolian processes, and glacial processes.

- **Understanding process interactions:** Once the geomorphic processes have been identified, the next step is to understand how they interact with each other. For example, fluvial processes can erode the land, leading to mass wasting and deposition of sediment in rivers and deltas.
- **Analyzing process rates:** The third step is to analyze the rates at which different geomorphic processes occur. This can involve measuring erosion rates, sediment transport rates, and deposition rates.
- **Examining the role of external factors:** External factors such as climate, tectonic activity, and human activities can also influence geomorphic processes. The process-based approach involves examining the role of these external factors in shaping the landscape.
- **Mapping geomorphic features:** The process-based approach also involves mapping geomorphic features to better understand how they have been shaped by different geomorphic processes. For example, mapping river channels and floodplains can provide insights into how fluvial processes operate.
- **Using models to predict future changes:** Finally, the process-based approach can also involve using models to predict how the landscape may change in the future. For example, models can be used to predict how erosion rates may change in response to changes in climate or land use.

Historical approach: This approach seeks to understand the evolution of landforms over time by examining their history and development. It involves the study of the geological, climatic, and environmental factors that have influenced the formation and modification of landforms. This approach is often used in conjunction with field studies, geochronological methods, and paleo-environmental reconstructions. The historical approach in geomorphology focuses on understanding the long-term evolution of the Earth's surface features, based on the principle of uniformitarianism, which states that the present is the key to the past. The approach involves studying the history of landscapes and their formation, identifying the forces that have shaped them, and determining how these forces have operated over time. In detail, the historical approach in geomorphology involves the following steps:

- **Studying landscape history:** The first step in the historical approach is to study the history of a landscape. This can involve analyzing the formation of landforms and the changes that have occurred over time, such as erosion, sedimentation, and tectonic activity.
- **Identifying key forces:** The next step is to identify the key forces that have shaped the landscape over time. These can include climatic, tectonic, and biotic forces, as well as anthropogenic factors such as human land use.
- **Reconstructing past environments:** The historical approach involves reconstructing past environments to understand how they have contributed to the formation of the landscape. This can involve analyzing sedimentary deposits, fossils, and other indicators of past environments.
- **Determining rates of change:** The historical approach also involves determining the rates at which geomorphic processes have occurred over time. This can involve analyzing the sedimentary record, dating techniques, and other methods.
- **Analyzing spatial patterns:** The historical approach involves analyzing the spatial patterns of landscape features to understand how they have been shaped by different forces over time. For example, analyzing the distribution of glacial landforms can provide insights into the history of past glaciation.
- **Comparing landscapes:** Finally, the historical approach involves comparing landscapes to understand how different forces have operated in different regions. This can involve comparing landscapes that have been shaped by similar processes but under different conditions, such as deserts in different regions of the world.

Systems approach: This approach treats landforms as part of a larger system, and seeks to understand the interrelationships between landforms, their processes, and their environments. It involves the study of feedback and interactions between landforms, ecosystems, and human activities. This approach is often used in conjunction with modelling and simulation techniques to understand the behaviour of complex systems. The systems approach in geomorphology views the Earth's surface as a complex system made up of interconnected components that interact with each other to shape the landscape. It focuses on the inputs, outputs, and feedback between these components, and seeks to understand how changes in one component can impact the entire system. In detail, the systems approach in geomorphology involves the following steps:

- **Identifying system components:** The first step in the systems approach is to identify the different components of the geomorphic system, such as landforms, vegetation, climate, water, and humans.
- **Understanding component interactions:** The next step is to understand how these components interact with each other to shape the landscape. For example, vegetation can influence erosion rates, while tectonic activity can create new landforms.
- **Analyzing system inputs:** The systems approach involves analyzing the inputs into the geomorphic system, such as water and sediment, as well as the external factors that impact the system, such as climate change or human land use.
- **Examining system outputs:** The approach also involves examining the outputs of the geomorphic system, such as sediment transport and deposition, as well as how these outputs impact other systems, such as aquatic ecosystems.
- **Using models to predict system behaviour:** Finally, the systems approach can involve using models to predict how the geomorphic system may respond to changes in input or feedback. For example, models can be used to predict how climate change may impact erosion rates or sediment transport.

Spatial analysis approach: This approach focuses on the spatial distribution of landforms and their characteristics, and seeks to identify patterns and relationships between different landforms. It involves the use of geographic information systems (GIS) and remote sensing techniques to collect and analyze data on landforms and their attributes. This approach is often used in conjunction with statistical methods and modelling to understand the spatial variability of landforms. The spatial analysis approach in geomorphology focuses on analyzing the distribution, arrangement, and pattern of landforms and other landscape features. It involves the use of geographic information systems (GIS) and other spatial analysis tools to examine spatial relationships between different components of the landscape. In detail, the spatial analysis approach in geomorphology involves the following steps:

- **Collecting spatial data:** The first step in the spatial analysis approach is to collect spatial data on landforms, soils, vegetation, and other landscape features. This can involve using remote sensing techniques, such as satellite imagery or LiDAR, as well as field surveys and other data collection methods.

- **Creating spatial databases:** The approach involves creating spatial databases to organize and manage spatial data. These databases can be used to store information on the location, attributes, and relationships of different landscape features.
- **Analyzing spatial relationships:** The spatial analysis approach involves analyzing spatial relationships between different landscape features, such as proximity, connectivity, and spatial autocorrelation. This can involve using GIS tools to create maps and perform statistical analysis on spatial data.
- **Identifying spatial patterns:** The approach also involves identifying spatial patterns in the distribution and arrangement of landscape features. This can involve using statistical techniques, such as cluster analysis or principal component analysis, to identify patterns in the data.
- **Exploring spatial processes:** The spatial analysis approach involves exploring the processes that have shaped the spatial patterns observed in the landscape. This can involve using models and simulations to explore how different processes, such as erosion or tectonic activity, may have influenced the distribution and arrangement of landforms.
- **Using spatial analysis for management:** Finally, the spatial analysis approach can be used to inform management decisions related to the landscape. For example, it can be used to identify areas at risk of erosion or to optimize the placement of conservation measures.

Geomorphic mapping approach: This approach involves the identification, description, and mapping of landforms and their attributes. It seeks to develop a detailed inventory of landforms at various scales and to analyze their spatial distribution and relationships. This approach is often used in conjunction with field surveys, aerial photography, and GIS techniques to create detailed maps of landforms. Geomorphology is the study of landforms and their evolution over time. One important aspect of geomorphology is mapping, which involves creating detailed maps of the Earth's surface and its features. Geomorphic mapping is an approach in geomorphology that focuses on the identification and classification of landforms based on their characteristics and processes.

The process of geomorphic mapping typically involves the following steps:

- **Data acquisition:** This involves gathering data about the area of interest, such as topographic maps, aerial photographs, and satellite imagery.
- **Fieldwork:** Once the data has been acquired, fieldwork is conducted to verify the accuracy of the data and to collect additional information about the landforms and their characteristics.
- **Interpretation:** The data and field observations are then analyzed and interpreted to identify and classify the different landforms in the area.
- **Mapping:** The identified landforms are then mapped using a variety of techniques, such as topographic mapping, GIS (geographic information system) mapping, and remote sensing.

The resulting geomorphic map can be used for a variety of purposes, such as understanding the geological history of an area, identifying areas prone to natural hazards, and planning land use and development.

There are several approaches to geomorphic mapping, including:

- **Morphological mapping:** This approach focuses on the shape and form of landforms, and how they relate to underlying geologic processes.
- **Process-based mapping:** This approach focuses on the processes that shape the landforms, such as erosion, weathering, and deposition.
- **Quantitative mapping:** This approach uses mathematical models and analysis to identify and classify landforms based on their physical characteristics, such as slope, aspect, and curvature.
- **Ecological mapping:** This approach focuses on the interactions between landforms and the surrounding ecosystems, and how they influence each other.

These approaches are not mutually exclusive and are often used in combination to provide a comprehensive understanding of landforms and their processes. The choice of approach depends on the research questions, the availability of data and resources, and the objectives of the study.

1.6 SUMMARY

Geomorphology is a field of study that focuses on the processes that shape the Earth's surface, including landforms and landscapes. The field emerged in the early 20th century and has since become an interdisciplinary field that combines aspects of geology, geography, physics, and ecology.

Geomorphologists use a range of methods and techniques, including field observations, laboratory experiments, and computer modelling, to study landforms and landscapes. They also use a variety of tools, such as GPS, LIDAR, and satellite imagery, to collect data and analyze landscapes.

The study of geomorphology has many applications, including in natural resource management, land-use planning, and hazard mitigation. Geomorphology can help predict the location and magnitude of natural hazards, such as landslides and floods, allowing for the development of effective mitigation strategies. Geomorphology can also inform land-use planning decisions by identifying areas that are prone to erosion or other forms of landscape change.

1.7 GLOSSARY

- **Anthropogenic:** Refers to human activities or impacts on the environment, often used to describe the human influence on geomorphic processes and landforms.
- **Applied geomorphology:** The application of geomorphic knowledge and methods to address practical problems, such as natural hazard management, environmental planning, or resource management.
- **Dynamics:** The study of the processes that shape the Earth's surface and the interactions between those processes.
- **Evolution:** The process of change over time, often used to describe the development of landscapes and landforms.
- **Geomorphic systems:** The Earth's surface and the interconnected processes that shape it, including tectonics, weathering, erosion, sediment transport, and landscape evolution.

- **Geomorphic thresholds:** The points at which a geomorphic system undergoes a significant change in behaviour or state, often as a result of a feedback mechanism.
- **Geomorphological mapping:** The production of maps that depict the distribution and characteristics of landforms, often using field observations or remote sensing data.
- **Geomorphology:** The study of the Earth's surface and the processes that shape it.
- **Landform evolution:** The study of how landforms change over time due to geomorphic processes and external drivers, such as climate change or human activities.
- **Landforms:** The physical features that make up the Earth's surface, such as mountains, valleys, and coastlines.
- **Morphology:** The study of landforms and their characteristics, such as shape, size, and spatial distribution.
- **Paleogeomorphology:** The study of ancient landforms and geomorphic processes, often using methods such as sediment analysis or paleoclimate reconstruction.
- **Processes:** The physical and chemical forces that shape the Earth's surface, including erosion, weathering, tectonics, and sediment transport.
- **Spatial analysis:** The study of the spatial distribution of landforms, processes, and environmental variables, often using geographic information systems (GIS) or remote sensing.
- **Sustainability:** The ability of a system to persist over time without degrading the natural resources or ecological functions that support it.
- **Temporal analysis:** The study of how geomorphic processes and landforms change over time, often using methods such as dendrochronology, radiocarbon dating, or stratigraphy.
- **Threshold:** The point at which a system undergoes a significant change in behaviour or state, often as a result of a feedback mechanism.

1.8 ANSWER TO CHECK YOUR PROGRESS

1. Which of the following best describes the nature of geomorphology?

A. The study of the processes that shape the Earth's surface.

B. The study of the internal structure of the Earth.

C. The study of the Earth's climate and weather patterns.

D. The study of the Earth's natural resources.

2. What is the scope of geomorphology?

A. The study of the Earth's physical features.

B. The study of the Earth's chemical composition.

C. The study of the Earth's biological systems.

D. The study of the Earth's political boundaries.

3. Which of the following is a current trend in geomorphology?

A. Increased focus on fluvial geomorphology.

B. Decreased use of remote sensing technology.

C. Reduced interest in glacial geomorphology.

D. Limited application of GIS software.

4. Which of the following is an important development in the history of geomorphology?

A. The introduction of the concept of uniformitarianism.

B. The discovery of the internal structure of the Earth.

C. The development of plate tectonics theory.

D. The creation of the International Geomorphology Association.

5. What is the main goal of geomorphology?

A. To understand the processes that shape the Earth's surface.

B. To extract natural resources from the Earth's surface.

C. To predict the occurrence of natural disasters.

D. To study the impacts of human activities on the Earth's surface.

Answers: A, A, A, A, A

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1.10 TERMINAL QUESTIONS

1. Here are some terminal questions related to the nature of geomorphology:
2. How do natural processes such as weathering, erosion, and tectonic uplift shape the Earth's surface over time?
3. What are the major types of landforms and landscapes, and what processes are responsible for their formation?
4. How do human activities such as land use change and climate change impact geomorphic processes and landforms?

5. What methods and tools do geomorphologists use to study the Earth's surface, including field observations, remote sensing, and numerical modeling?
6. What are the major theories and concepts in geomorphology, including the concept of the geomorphic cycle and the role of thresholds in landscape evolution?
7. How do geomorphic processes and landforms interact with other Earth systems, including the biosphere, hydrosphere, and atmosphere?
8. How can geomorphological research inform our understanding of natural hazards such as landslides, floods, and volcanic eruptions, and help us to mitigate their impacts on human communities?
9. How has the field of geomorphology evolved over time, and what are some of the major trends in current research?
10. What are some of the emerging subfields and interdisciplinary areas of research within geomorphology, such as fluvial geomorphology, hillslope hydrology, and landscape ecology?

UNIT- 2 CONCEPTS OF GEOMORPHOLOGY

2.1 OBJECTIVES

After reading this unit you will be able to understand:

- Understanding the concepts of uniformitarianism.
- Learning the Rocks in detail like Igneous rocks, Sedimentary rocks, and Metamorphosis rocks.
- Gaining knowledge of terrestrial structure concepts.
- Discussing the deep weathering theory, periglacial theory and work of erosion.
- Understanding the concept of Geomorphic Scale.
- Learning the geological history of the earth's topography.

2.2 INTRODUCTION

Geomorphology as a scientific discipline has a long and complex history that spans many centuries. Here is a brief overview of the key historical developments in geomorphology:

2.2.1 Ancient times: The earliest recorded observations of landforms and geological processes date back to ancient civilizations such as the Greeks, Romans, and Chinese. For example, Aristotle (384-322 BCE) observed the formation of deltas at the mouths of rivers, while the Chinese philosopher Zhuangzi (369-286 BCE) noted the erosive power of rivers and the formation of mountains.

2.2.2 17th-18th centuries: The birth of modern scientific thought in the 17th and 18th centuries led to increased interest in the study of landforms and the processes that shape them. Scholars such as Johannes Kepler, René Descartes, and Nicolas Steno made important contributions to the understanding of geological processes.

2.2.3 19th century: The 19th century saw the development of the concept of uniformitarianism, which held that the processes that shape the Earth's surface have operated in the same way throughout geologic time. This idea was championed by the Scottish geologist

James Hutton (1726-1797) and popularized by Charles Lyell (1797-1875) in his influential book "Principles of Geology" (1830-1833).

2.2.4 20th century: The 20th century saw the development of quantitative methods in geomorphology, which allowed scientists to measure and analyze landforms and the processes that shape them more rigorously and systematically. The development of aerial photography, remote sensing, and GIS technology also greatly expanded the ability to study landforms and their distribution over large areas.

2.2.5 Contemporary geomorphology: In recent decades, geomorphology has become an increasingly interdisciplinary field, drawing on methods and theories from physics, chemistry, biology, and other disciplines. The study of geomorphology has also become more focused on understanding the role of human activity in shaping the Earth's surface, and on developing solutions to environmental problems caused by human impacts.

Today, geomorphology is a thriving field of study that encompasses a wide range of topics and approaches. Its insights are used in many areas of environmental management, from land use planning and natural hazard mitigation to restoration ecology and sustainable development.

2.3 UNIFORMITARIANISM

Uniformitarianism is a foundational concept in the study of geomorphology that holds that the processes that shape the Earth's surface have operated in the same way throughout geologic time. This principle suggests that the present is the key to the past and that the same geological processes that are observable today were also at work in the past.

Uniformitarianism was first proposed in the late 18th century by the Scottish geologist James Hutton, who argued that the Earth's geological features could be explained by gradual processes such as erosion, deposition, and uplift, rather than by catastrophic events like floods or earthquakes. Hutton famously wrote in his 1788 paper, "The history of our globe must be explained by what can be seen to be happening now."

This idea was later popularized by the English geologist Charles Lyell, who developed the concept of "deep time" and applied uniformitarianism to his studies of rock formations and geological processes. Lyell's influential book "Principles of Geology," published in three volumes from 1830 to 1833, argued that the Earth's features were the result of long-term, slow-moving processes that could be observed and measured in the present.

In the context of geomorphology, uniformitarianism means that the same processes that shape the Earth's surface today, such as erosion, weathering, and sedimentation, have been at work throughout geologic time. For example, a river valley that is actively eroding today can be interpreted as the result of long-term erosion over millions of years. Similarly, the formation of a dune can be understood as the result of wind erosion and sedimentation, processes that have operated throughout the Earth's history.

Uniformitarianism has been a controversial concept in the history of geology, with some scientists arguing that it does not take into account the possibility of rare catastrophic events, such as meteorite impacts or large volcanic eruptions, that could dramatically alter the Earth's surface. However, most modern geomorphologists agree that uniformitarianism is a useful principle for understanding the processes that shape the Earth's surface, while also acknowledging the importance of rare catastrophic events in shaping the planet's history.

“The same physical processes and laws that operate today, operated throughout geologic time, although not necessarily always with the same intensity as now.”- Thornbury

The principle of uniformitarianism states that the same physical processes and laws that operate today to shape the Earth's surface have also operated throughout geologic time. However, this does not mean that these processes and laws have always operated with the same intensity as they do today.

Physical processes such as erosion, weathering, and sedimentation are influenced by a range of factors, including climate, geology, and tectonic activity, that can vary over time. For example, the amount of rainfall in a given area can fluctuate over centuries or millennia, leading to changes in the rate of erosion and sedimentation. Similarly, tectonic activity, such as mountain building, can lead to changes in the intensity and distribution of erosion and sedimentation.

Moreover, physical laws such as gravity, thermodynamics, and fluid mechanics are universal and apply throughout the universe. However, the intensity and frequency of these processes may vary over time due to changes in external factors. For example, the force of gravity that pulls sediment down a slope is constant, but the amount of sediment transported by a river can vary depending on factors such as the slope of the river bed, the amount of rainfall in the river's catchment area, and the vegetation cover of the surrounding land.

Therefore, the principle of uniformitarianism does not suggest that the physical processes and laws that shape the Earth's surface have always operated at the same intensity or frequency as they do today. Instead, it suggests that the same processes and laws have been at work throughout geologic time, but that their intensity and frequency have varied in response to changes in environmental conditions.

2.3.1 History of Uniformitarianism

Uniformitarianism is a foundational concept in the study of geomorphology, which suggests that the same physical processes and laws that shape the Earth's surface today have been at work throughout geologic time. This idea was first proposed by the Scottish geologist James Hutton in the late 18th century, who argued that the Earth's geological features could be explained by gradual processes such as erosion, deposition, and uplift, rather than by catastrophic events like floods or earthquakes.

Hutton famously wrote in his 1788 paper, "The history of our globe must be explained by what can be seen to be happening now." This concept of gradualism was further developed by the English geologist Charles Lyell, who applied uniformitarianism to his studies of rock formations and geological processes. Lyell's influential book "Principles of Geology," published in three volumes from 1830 to 1833, argued that the Earth's features were the result of long-term, slow-moving processes that could be observed and measured in the present.

Lyell's ideas had a profound impact on the development of geology and geomorphology and helped to establish the field as a scientific discipline. Uniformitarianism has since become a central concept in the study of the Earth's surface processes, guiding research on topics such as landscape evolution, climate change, and natural hazards.

Despite its widespread acceptance in the scientific community, uniformitarianism has been subject to criticism and debate over the years. Some geologists have argued that it does not take into account the possibility of rare catastrophic events, such as meteorite impacts or large volcanic eruptions, that could dramatically alter the Earth's surface. Others have questioned the assumption that the same physical laws and processes that operate today have always operated in the same way over geologic time.

Despite these criticisms, uniformitarianism remains a powerful and useful concept in the study of geomorphology. It has allowed scientists to develop a deep understanding of the Earth's surface processes, and to make accurate predictions about how landscapes will respond to changing environmental conditions.

2.3.2 Uniformitarianism and Hutton

Hutton was one of the first geologists to propose that the Earth's surface features were the result of slow, gradual processes that could be observed in the present. He believed that the Earth was much older than previously thought and that its features could be explained by the cumulative effects of natural processes like erosion, sedimentation, and uplift over long periods.

Hutton's ideas were revolutionary for their time, as they challenged the prevailing belief in the Biblical account of creation and the idea of catastrophism, which held that the Earth's features were the result of sudden, violent events like floods or earthquakes. Hutton argued that the processes that shaped the Earth were slow and continuous and that they could be observed and measured in the present.

Hutton's concept of gradualism was further developed by the English geologist Charles Lyell, who applied it to his studies of rock formations and geological processes. Lyell's influential book "Principles of Geology," published in three volumes from 1830 to 1833, argued that the Earth's features were the result of long-term, slow-moving processes that could be observed and measured in the present. Lyell also emphasized the importance of uniformitarianism, stating that "the present is the key to the past."

Hutton's and Lyell's ideas had a profound impact on the development of geology and geomorphology, and they helped to establish the field as a scientific discipline.

Uniformitarianism has since become a central concept in the study of the Earth's surface processes, guiding research on topics such as landscape evolution, climate change, and natural hazards.

However, uniformitarianism has also been subject to criticism and debate over the years. Some geologists have argued that it does not take into account the possibility of rare catastrophic events, such as meteorite impacts or large volcanic eruptions, that could dramatically alter the Earth's surface. Others have questioned the assumption that the same physical laws and processes that operate today have always operated in the same way over geologic time.

Despite these criticisms, uniformitarianism remains a powerful and useful concept in the study of geomorphology. It has allowed scientists to develop a deep understanding of the Earth's surface processes, and to make accurate predictions about how landscapes will respond to changing environmental conditions.

“No vestige of a beginning, no prospect of an end.”

The concept of "no vestige of a beginning, no prospect of an end" refers to the idea that the Earth's surface and the processes that shape it have been operating for an infinitely long time in the past and will continue to do so for an infinitely long time in the future. This concept is often associated with the principles of uniformitarianism and deep time, which emphasize the continuity and gradualism of natural processes over vast timescales.

The phrase "no vestige of the beginning" was first used by James Hutton, the Scottish geologist who is considered the father of modern geology, in his book "Theory of the Earth" published in 1785. Hutton argued that the Earth's surface had undergone a series of cyclical changes over an immensely long period, with no discernible beginning or end. He observed that rocks and sediments in the Earth's crust showed evidence of erosion, deposition, and deformation, indicating that natural processes had been operating for millions of years.

The concept of "no prospect of an end" was later articulated by Charles Lyell, another influential geologist who expanded on Hutton's ideas in his book "Principles of Geology" published in 1830. Lyell argued that the same processes that were shaping the Earth's surface in the present day had been operating in the past and would continue to do so in the future, with no clear endpoint or outcome. He emphasized the importance of studying the slow and gradual processes that shape the Earth's surface, rather than catastrophic events such as floods and earthquakes.

The idea of an infinitely long past and future has since become a cornerstone of modern geology and earth science, with the principles of uniformitarianism and deep time providing a framework for understanding the complex history of the Earth's surface. By studying the patterns and processes that have shaped the Earth over millions of years, scientists can gain insights into how the planet will continue to evolve in the future, and how human activities may impact its natural systems.

2.4 CONCEPT OF ROCKS

In geomorphology, rocks play a crucial role in shaping the Earth's surface features. Understanding the properties and characteristics of different types of rocks is essential for studying the processes that create landforms, such as mountains, valleys, and coastlines. Here are some of the key concepts related to rocks in geomorphology:

Rock types: Rocks can be classified into three main categories based on their origin and composition: igneous, sedimentary, and metamorphic rocks. Igneous rocks are formed from the solidification of magma or lava, while sedimentary rocks are formed from the accumulation of sediment over time, and metamorphic rocks are formed from the transformation of preexisting rocks under high pressure and temperature.

Rock properties: Rocks have various physical and chemical properties that influence their behaviour and response to external forces. These properties include hardness, density, porosity, permeability, and chemical composition.

Weathering and erosion: Rocks are subject to weathering and erosion processes that break down and remove material from their surface. Weathering can occur through physical, chemical, or biological processes, while erosion is the transport of weathered material by wind, water, or ice.

Rock cycle: The rock cycle describes the continuous process of rock formation, transformation, and destruction that occurs over geological time scales. It involves the transformation of one rock type into another through processes such as melting, crystallization, weathering, erosion, and metamorphism.

Landforms: Different types of rocks and their properties influence the formation of various landforms. For example, sedimentary rocks are commonly associated with flat and layered landscapes, while igneous and metamorphic rocks are often associated with more rugged and irregular terrain.

Understanding these concepts is crucial for interpreting the origin and evolution of the Earth's surface features. Geomorphologists use various techniques to study rocks, including field observations, laboratory analysis, and remote sensing methods. By examining the properties and behaviour of rocks, they can gain insights into the complex processes that shape our planet.

“Rocks are the books of earth history and fossils are the pages.”

The statement "Rocks are the books of Earth's history, and fossils are the pages" suggests that rocks provide a long-term record of the geological processes that have shaped the Earth over millions of years and that fossils offer a snapshot of life forms that existed during particular points in geological history.

Rocks can be thought of as a kind of geological library, containing information about the history of the Earth's formation and the processes that have shaped its surface features. The characteristics of rocks, such as their mineral composition, texture, and structure, can provide clues about the environment in which they formed, the types of geological events that have affected them, and the length of time they have been exposed to different geological conditions. For example, sedimentary rocks are formed from layers of sediment deposited over time, which can contain information about ancient climates, sea levels, and the types of organisms that existed in the past.

Fossils, on the other hand, provide evidence of past life forms that have been preserved in the rock record. Fossils can be used to study the evolution of different species, the relationships between different groups of organisms, and the environments in which they lived.

Fossil evidence can also provide insights into how different organisms have responded to environmental changes over time.

Together, rocks and fossils offer a comprehensive record of the Earth's geological and biological history. By studying these materials, geologists and palaeontologists can reconstruct the past and gain a deeper understanding of the processes that have shaped the Earth and the life forms that have inhabited it.

“No vestige of a beginning, no prospect of an end" -Hutton 1785.

The statement "No vestige of a beginning, no prospect of an end" is attributed to James Hutton, a Scottish geologist who is often referred to as the "father of modern geology." Hutton made this statement in his book "Theory of the Earth," which was published in 1785.

The statement refers to Hutton's view of the Earth as a self-sustaining system that has no discernible beginning or end. Hutton believed that the processes that shape the Earth's surface, such as erosion and sedimentation, have been occurring continuously for millions of years and will continue to occur in the future. He argued that the Earth's features and landscapes are the result of these long-term processes and not the product of a catastrophic event or a short-term process.

Hutton's view of the Earth as a system that is constantly changing and evolving was a departure from the prevailing view in the 18th century, which held that the Earth was created in its present form by a divine act of creation. Hutton's ideas were revolutionary and laid the foundation for the development of modern geology.

Today, Hutton's statement is often interpreted as a recognition of the deep time scale of geological processes. The Earth is estimated to be around 4.5 billion years old, and its history is marked by a series of geological events that have occurred over vast periods. Hutton's statement highlights the idea that the Earth's history is so vast that it is difficult for humans to comprehend and that the processes that shape the Earth are ongoing and will continue long into the future.

2.5 TERRESTRIAL STRUCTURE CONCEPT

Terrestrial structure refers to the physical and geological features that make up the Earth's surface and subsurface, including the different layers of the Earth's crust, mantle, and core. Understanding the structure of the Earth is important for studying the processes that shape the Earth's surface, including erosion, plate tectonics, and volcanism. In this answer, we will discuss the concepts of terrestrial structure in geomorphology in detail with references.

The Earth's crust is the outermost layer of the Earth, and it is composed of different types of rocks, including sedimentary, metamorphic, and igneous rocks. The thickness of the crust varies from about 5-70 km, depending on the location on Earth. The Earth's crust is divided into several tectonic plates, which move slowly and interact with each other at plate boundaries. These interactions can cause earthquakes, volcanic eruptions, and the formation of mountains.

Beneath the crust is the Earth's mantle, which is a thick layer of hot, dense rock that extends to a depth of about 2,900 km. The mantle is composed of several layers with different physical and chemical properties, and it plays a critical role in driving the movement of the tectonic plates. The mantle is also responsible for the formation of magma, which can rise to the surface and form volcanoes.

The Earth's core is located beneath the mantle, and it is composed of a liquid outer core and a solid inner core. The outer core is made of molten iron and nickel, while the inner core is a solid ball of iron and nickel. The core generates the Earth's magnetic field and plays a critical role in regulating the Earth's climate.

Studying the structure of the Earth is essential for understanding the processes that shape the Earth's surface and for predicting natural hazards such as earthquakes and volcanic eruptions. Geomorphologists use a range of techniques to study the structure of the Earth, including seismic imaging, satellite remote sensing, and geological mapping.

"Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them" W. D. Thornbury

The statement "Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them" by Thornbury means that the geological features and processes that shape the Earth's crust have a significant influence on the formation and evolution of landforms. The geologic structure of an area, including the rock types, faults, folds, and other features, can affect the way the landscape erodes and changes over time.

Geological structures such as folds and faults can influence the formation of landforms by affecting the way that rocks respond to stresses and strains. For example, a fold in the rock layers can create a ridge or a valley, while a fault can cause the land to move and create a series of steps or terraces. Different types of rocks, such as sedimentary or igneous, can also have different properties that affect how they weather and erode, and this can create distinctive landforms.

The geological structure of an area is also reflected in the landforms that are present. For example, a mountain range may indicate the presence of uplift and folding, while a flat plain may indicate the presence of a stable, relatively un-deformed area. The different types of landforms, such as valleys, canyons, and cliffs, are a result of the interaction between geologic structure, erosion, and other environmental factors.

2.5.1 The Lithology of Nature of Rocks

Lithology refers to the physical and chemical properties of rocks, including their mineralogy, texture, and structure. The nature of rocks is an important aspect of geomorphology because it influences the way that landscapes form and evolve.

Different types of rocks have varying properties that affect their resistance to weathering and erosion, as well as their ability to hold water, support vegetation, and provide habitat for animals. For example, sedimentary rocks such as sandstone and shale are often more susceptible to erosion than igneous rocks like granite or basalt. This is because sedimentary rocks are typically composed of loose sediment that can be easily broken apart, whereas igneous rocks are more solid and resistant to weathering.

The texture and structure of rocks also play a significant role in geomorphology. For instance, jointing and fracturing of rocks can create lines of weakness that can be exploited by erosion, leading to the formation of canyons or valleys. Similarly, layering in sedimentary rocks can create distinct bands or patterns in the landscape that can be used to interpret past environmental conditions.

Geologists use a variety of techniques to study the nature of rocks, including field observations, laboratory analyses, and remote sensing. Fieldwork involves examining rock outcrops, collecting samples, and mapping the distribution of different rock types. In the laboratory, scientists can study the mineralogy and chemistry of rocks using a range of techniques such as X-ray diffraction and electron microscopy. Remote sensing methods, such as satellite imagery and LiDAR (light detection and ranging), can also provide detailed information on the surface characteristics of rocks and the landforms they create.

2.5.2 Igneous rocks and its landform

Igneous rocks are formed through the solidification and crystallization of molten magma. They are classified into two main types: intrusive (plutonic) igneous rocks, which cool and solidify beneath the Earth's surface, and extrusive (volcanic) igneous rocks, which form from lava that erupts onto the Earth's surface. The landforms associated with igneous rocks are diverse and varied. Here are some examples:

Fig. 2.1 Igneous Rocks, Source Google Image

Volcanoes: Volcanoes are prominent landforms formed by the eruption of molten lava, ash, and gases from the Earth's interior. They can have different shapes and sizes, ranging from shield volcanoes with broad, gently sloping profiles (e.g., Mauna Loa in Hawaii) to stratovolcanoes with steep slopes and a conical shape (e.g., Mount Fuji in Japan).

Lava Plateaus: Lava plateaus are extensive flat or gently rolling landforms composed of vast accumulations of basaltic lava flows. They form when lava erupts from long fissures and covers large areas. Examples include the Columbia River Plateau in the United States and the Deccan Plateau in India.

Fig. 2.2 An example of Lava Plateaus, Source Google Image

Dikes and Sills: Dikes are tabular intrusions of igneous rock that cut across existing rock layers, forming vertical or near-vertical walls. Sills, on the other hand, are horizontal or near-horizontal intrusions that occur between layers of pre-existing rock. Dikes and sills can create distinctive linear or sheet-like landforms in various landscapes.

Batholiths: Batholiths are large, intrusive igneous bodies that form deep beneath the Earth's surface. They are often composed of granite or granitic rocks. Over time, erosion may expose batholiths, creating landforms such as rounded granite domes or mountains, such as the Sierra Nevada Batholith in California.

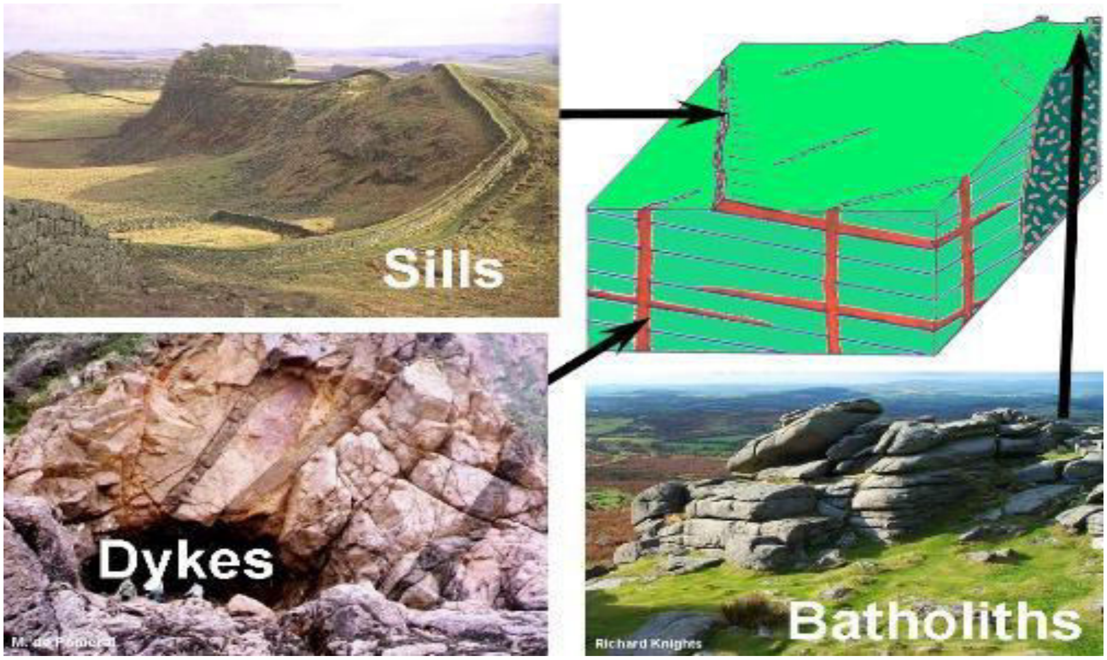

Fig. 2.3 Sills, Dykes and Batholiths, Source Google Image

Volcanic Neck: A volcanic neck is formed when the hardened magma inside a volcano's pipe remains after the softer surrounding rock erodes. It creates a prominent landform characterized by a steep-sided, often cylindrical mass of igneous rock, such as Shiprock in New Mexico, USA.

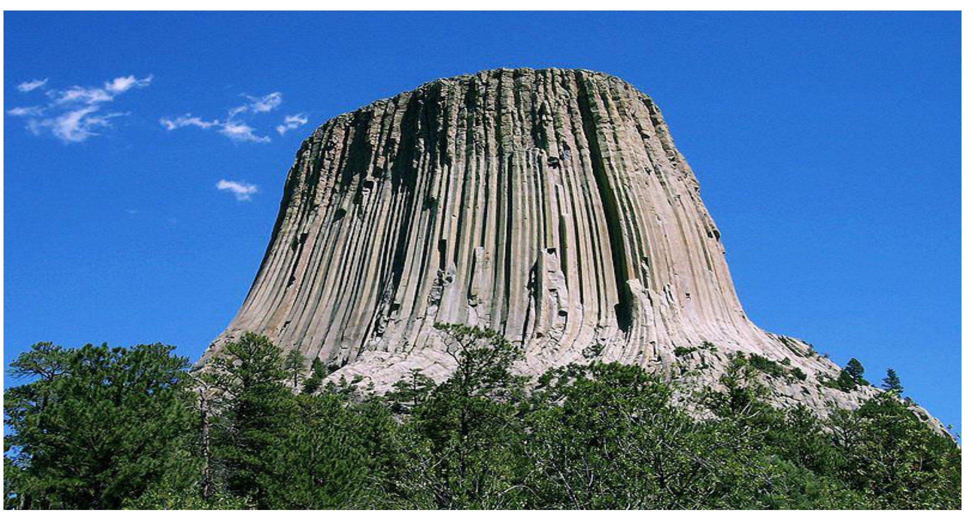

Fig. 2.4 An example of Volcanic Neck, Google Image

Tuff Rings and Cones: Tuff rings and cones are landforms formed by explosive volcanic eruptions that eject volcanic ash and fragmented rock material into the air. As the material falls back to the ground, it forms a circular or cone-shaped deposit. Examples include Sunset Crater in Arizona, USA.

Calderas: Calderas are large, basin-shaped depressions that form when a volcano collapses following a massive eruption or the emptying of magma chambers. They can be several kilometres in diameter and are often associated with explosive eruptions. The caldera at Yellowstone National Park in the United States is a well-known example.

Fig. 2.5 An example of Calderas, Source Google Image

2.5.3 Pedeplanation Theory

The pedeplanation theory, also known as the geomorphic erosion-surface theory, is a concept in geomorphology that explains the formation of large, nearly level or gently sloping erosional surfaces. These surfaces, known as pediplains or peneplains, are thought to represent extensive erosion of uplifted regions over long periods. The pedeplanation theory was first proposed by American geologist William Morris Davis in the late 19th century.

According to the pedeplanation theory, the formation of pediplains occurs through a series of geomorphic processes. The theory suggests that uplift and tectonic forces elevate regions above base level (the lowest point to which erosion can occur). Subsequently, the uplifted areas are subjected to prolonged erosion by various agents such as rivers, weathering, and mass wasting.

As erosion continues, the relief of the uplifted region gradually diminishes, and the landscape becomes more subdued. Steep slopes are eroded more rapidly than gentle slopes, resulting in the levelling of the land surface. Over time, the erosional processes remove irregularities and unevenness, creating a nearly flat or gently sloping peneplain.

The pedeplanation theory posits that the formation of pediplains is a result of long-term, steady-state erosion processes. It suggests that the development of a peneplain requires sufficient time for erosion to wear down the landscape to a near-equilibrium state. The theory also emphasizes the role of continuous or intermittent base-level changes and the importance of a prolonged period of erosion to achieve significant landscape levelling.

While the pedeplanation theory has been influential in geomorphological studies, it has also faced criticism and alternative explanations. Some geologists argue that factors such as climate change, tectonic uplift rates, variations in lithology and resistance to erosion play significant roles in landscape development. Additionally, recent research has highlighted the complexity of landscape evolution and the presence of multiple erosion processes acting simultaneously.

Nonetheless, the pedeplanation theory provides a foundational concept for understanding the formation of large-scale, relatively flat erosional surfaces. It contributes to our understanding of long-term landscape evolution and the interactions between tectonic forces and erosional processes.

2.5.4 Deep Weathering Theory

Deep weathering theory, also known as the theory of deep weathering or weathering front theory, is an explanation in geomorphology that describes the process of chemical weathering and its impact on the formation of deep weathering profiles in tropical and subtropical regions.

The theory of deep weathering proposes that in areas with a warm and humid climate, extensive chemical weathering occurs over long periods, resulting in the development of deep weathering profiles. These profiles consist of distinct layers or zones of altered and weathered rock materials, extending several meters below the Earth's surface.

According to the theory, the deep weathering process begins with the infiltration of water into the subsurface. The water carries dissolved carbon dioxide, organic acids, and other chemical agents derived from organic matter and plant roots. These agents promote the dissolution and alteration of minerals within the rocks.

Over time, the chemical weathering process leads to the decomposition and breakdown of primary minerals in the rocks, such as feldspars and micas, into secondary minerals like clays and iron oxides. This transformation is often accompanied by an increase in porosity and the development of extensive networks of fractures and fissures in the rock.

The weathering front, which represents the boundary between unweathered bedrock and the altered weathering profile, gradually moves downward through the rock mass as the chemical weathering process continues. The rate of weathering is influenced by factors such as temperature, moisture, the presence of vegetation, and the composition of the rocks.

As deep weathering progresses, distinct zones can be observed within the weathering profile. The upper zone, known as the saprolite or rotten rock, consists of highly weathered and fragmented material with a high clay content. Below the saprolite, the unweathered bedrock may be encountered.

Deep weathering profiles have important geomorphic implications. They contribute to the development of specific landforms, such as rounded hillslopes, inselbergs (isolated rock outcrops), and residual landscapes characterized by low relief and subdued topography. The deep weathering process also influences soil formation and fertility, as the weathered material provides a source of nutrients for plant growth.

The deep weathering theory has been particularly influential in understanding landscape evolution in tropical and subtropical regions with deep weathering profiles. It helps explain the unique characteristics of these landscapes and their associated soil and vegetation patterns. However, it is important to note that the theory is specific to certain climatic and environmental conditions and may not apply universally to all regions.

2.5.5 Periglacial Theory

The periglacial theory is a concept in geomorphology that focuses on the processes and landforms associated with cold, non-glacial environments. It examines the effects of freeze-thaw cycles, frost action, and ground ice on the shaping of landscapes in regions near and beyond the margins of past and present glaciers.

The periglacial environment refers to areas that experience freezing temperatures for a significant portion of the year but without the presence of a continuous ice cover. These environments are characterized by freeze-thaw processes, intense frost action, and the presence of ground ice.

Periglacial theory suggests that the repeated freezing and thawing of water within the soil and rock materials plays a significant role in landform development. The freeze-thaw cycles cause the expansion of water upon freezing, exerting pressure on the surrounding materials.

5.5.6 Sedimentary Rocks and its landform

Sedimentary rocks are one of the three major types of rocks found on Earth, alongside igneous and metamorphic rocks. They are formed through the accumulation, transportation, and subsequent lithification (hardening) of sediments. Sediments are small particles derived from the weathering and erosion of pre-existing rocks, organic remains, or chemical precipitates.

Fig. 2.6 Example of Sedimentary Rocks, Source Google Image

The process of sedimentary rock formation typically involves several steps:

Weathering and Erosion: Weathering is the breakdown and alteration of rocks at or near the Earth's surface, caused by physical, chemical, and biological processes. Erosion refers to the removal and transport of weathered materials by agents such as wind, water, ice, or gravity.

Transportation: Once sediments are weathered and eroded, they are transported by various agents. Water is the most common transport medium, with sediments being carried by rivers, streams, and ocean currents. Wind can transport finer particles, while glaciers can move sediments over long distances.

Deposition: When the transporting medium loses energy or encounters an obstacle, it deposits the sediments. Deposition occurs in areas such as river deltas, lakes, oceans, and alluvial fans. As sediments settle, they undergo sorting, with larger and heavier particles depositing first, followed by finer particles.

Compaction: Over time, the weight of overlying sediments compresses the deposited layers, reducing the pore spaces between particles. Compaction is facilitated by the pressure from subsequent sediment deposition above and the expulsion of water from the sediments.

Cementation: Cementation is the process by which dissolved minerals precipitate and fill the remaining pore spaces between sediment particles, binding them together. Common cementing minerals incl ude calcite, silica, and iron oxide. The cementation process solidifies the sediment into a coherent rock mass.

Sedimentary rocks exhibit various characteristics and can be classified into three main categories based on their origin:

Clastic Sedimentary Rocks: These rocks are composed of clasts, which are fragments of pre-existing rocks or minerals. Clastic sedimentary rocks are classified based on the size of the clasts present. Examples include conglomerate (coarse-grained with rounded clasts), sandstone (medium-grained with sand-sized clasts), and shale (fine-grained with clay-sized particles).

Chemical Sedimentary Rocks: These rocks form from the precipitation of minerals dissolved in water. Chemical sedimentary rocks can include limestone (formed from the accumulation of calcium carbonate), evaporites (such as rock salt and gypsum, formed by the evaporation of saline water), and chert (formed from the accumulation of microcrystalline quartz).

Organic Sedimentary Rocks: These rocks are derived from the accumulation of organic remains, such as plant and animal debris. Examples include coal (formed from the compressed remains of plant material) and petroleum-rich rocks (such as oil shale and bituminous sands).

Sedimentary rocks preserve a wealth of information about Earth's history, including past environments, climate changes, and the evolution of life forms. They often contain fossils, providing valuable insights into past ecosystems. The study of sedimentary rocks, known as sedimentology, is crucial for understanding Earth's geologic past and the processes that have shaped our planet over millions of years.

2.5.6 Metamorphosis rocks and their Landform

Metamorphic rocks are one of the three major types of rocks found on Earth, alongside igneous and sedimentary rocks. They are formed from pre-existing rocks, called protoliths, through the process of metamorphism. Metamorphism occurs when protoliths experience changes in their mineralogy, texture, and sometimes chemical composition due to high temperatures, pressures, and/or chemical reactions.

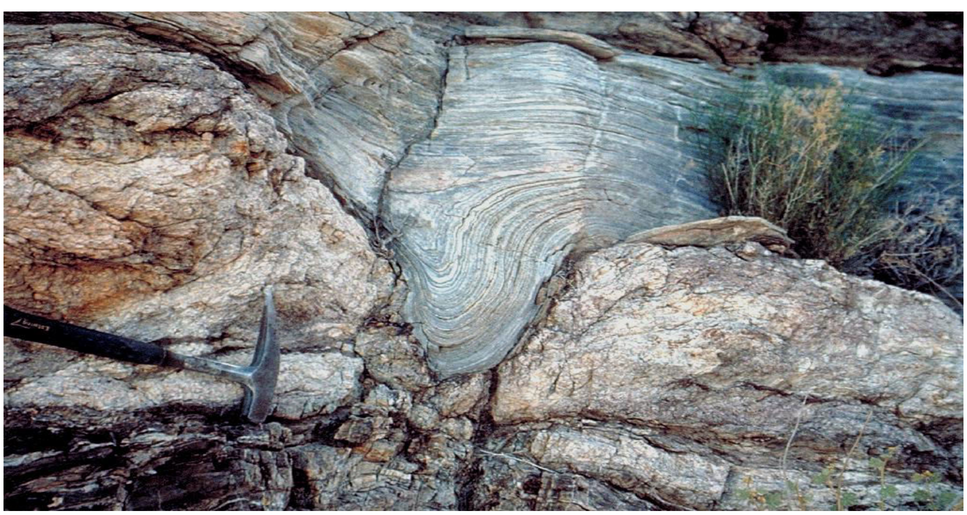

Fig. 2.7 Example of Metamorphic rocks, Source Google Image

Metamorphism can take place within the Earth's crust under conditions of increased temperature and pressure or in the presence of chemically active fluids. The process typically occurs deep within the Earth's crust, often in tectonically active regions such as convergent plate boundaries or areas where rocks are subjected to intense heat and pressure.

There are two main types of metamorphism:

Regional Metamorphism: This type of metamorphism occurs over large areas and is associated with mountain-building processes, such as during the formation of mountain ranges. Regional metamorphism is characterized by high pressures and temperatures, as well as the deformation of rocks due to tectonic forces. The intense heat and pressure cause changes in the mineralogy and texture of the rocks. Examples of regional metamorphic rocks include gneiss, schist, and slate.

Contact Metamorphism: Contact metamorphism occurs when rocks come into contact with a heat source, typically an intrusive igneous body such as a magma chamber. The heat from the magma causes localized metamorphism in the surrounding rocks. Contact metamorphism is characterized by high temperatures but relatively low pressures. The metamorphic changes are most pronounced near the contact zone and decrease in intensity further away. Examples of contact metamorphic rocks include hornfels and skarn.

Metamorphic rocks exhibit various textures and mineral assemblages that reflect the conditions under which they formed. Some common textures and structures found in metamorphic rocks include:

Foliation: Foliation refers to the parallel alignment of minerals or the presence of the preferred orientation of mineral grains. It is often a characteristic feature of metamorphic rocks and can be observed as distinct layers or banding. Foliation develops as a result of directed pressure during metamorphism and can be seen in rocks like gneiss and schist.

Non-Foliated Texture: Some metamorphic rocks do not exhibit foliation and have a non-foliated texture. These rocks have equidimensional mineral grains that are randomly oriented. Examples include marble and quartzite.

Index Minerals: Certain minerals are indicative of specific metamorphic conditions. These minerals, known as index minerals, form under specific temperature and pressure conditions and can be used to determine the degree of metamorphism. Examples of index minerals include garnet, staurolite, and kyanite.

Metamorphic rocks are important in understanding Earth's history and the processes that have shaped the planet. They often provide clues about the temperature, pressure, and deformation experienced by rocks during their formation. The study of metamorphic rocks, known as metamorphic petrology, is crucial for understanding the dynamic processes occurring within the Earth's crust and the effects of tectonic forces over geologic time.

2.5.7 Arrangement and Disposition of Rockbeds

The arrangement and disposition of rock beds refer to the patterns and characteristics of how rock layers or beds are positioned and organized within the Earth's crust. This arrangement can provide valuable information about the geological processes that have shaped the rock formations. Here is a detailed explanation of the arrangement and disposition of rock beds:

Horizontal or Tabular Bedding: Horizontal bedding refers to the arrangement of sedimentary rock layers in nearly parallel, horizontal planes. It occurs when sediments are deposited in a relatively calm environment, such as a lake or ocean floor. The rock layers retain their original horizontal orientation, and the beds appear as distinct, flat layers. This type of bedding is commonly observed in sedimentary rocks like sandstone, shale, and limestone.

Inclined or Cross-Bedded Bedding: Inclined or cross-bedded bedding occurs when sedimentary rocks display layers that are inclined or tilted relative to the horizontal plane. This type of bedding is common in environments with flowing water or wind, where sediment is deposited in inclined or cross-bedded layers. Cross-bedding is often seen in dunes, river channels, and deltaic deposits. It provides evidence of the direction and intensity of ancient currents or wind patterns.

Fig. 2.8 Cross Bedding, Source Google Images

Folded Bedding: Folded bedding refers to the bending or deformation of rock layers due to tectonic forces. It occurs when rocks are subjected to compressional forces, resulting in the folding and curving of the rock beds. Folds can vary in size and shape, ranging from gentle, broad folds to tight, overturned folds. Folded bedding is a characteristic feature of folded mountain ranges, such as the Appalachian Mountains in North America or the Himalayas in Asia.

Fig. 2.9 Folded Bedding, Source Google Image

Faulted Bedding: Faulted bedding occurs when rock layers are displaced along a fault plane. A fault is a fracture or break in the Earth's crust where movement has occurred. When rocks on one side of a fault move relative to those on the other side, the continuity of the rock beds is disrupted. This displacement can be vertical, horizontal, or oblique, and it creates distinctive patterns in the arrangement of the rock layers. Faulted bedding is common in areas of active tectonic activity, such as along transform plate boundaries or in regions of significant crustal deformation.

Fig. 2.10 Faulted Bedding, Source Google Image

Unconformities: Unconformities are gaps or breaks in the sequence of rock layers, representing periods of missing geological time. They occur when there is erosion, non-deposition, or removal of previously deposited rocks before the deposition of subsequent layers. Unconformities can result from various geological processes, such as uplift and erosion, sea-level changes, or tectonic activity. They are significant because they indicate gaps in the geological record and can provide clues about past geological events.

Understanding the arrangement and disposition of rock beds is crucial for deciphering Earth's geologic history, reconstructing past environments, and studying tectonic processes. Geologists analyze the orientation, relationships, and characteristics of rock beds through field observations, mapping, and stratigraphic studies to unravel the complex geological history of an area.

2.5.8 Work of Erosion

Erosion refers to the natural process of wearing away, displacement, and removal of materials such as soil, rock, or sediment from the Earth's surface. It is primarily driven by the actions of various agents, including water, wind, ice, and gravity. Erosion plays a crucial role in shaping the Earth's landforms and altering landscapes over long periods.

The process of erosion involves the detachment of particles or fragments from the Earth's surface and their subsequent transportation to other locations. Erosion can occur in different forms and at varying rates, depending on the geological and environmental conditions present in a particular area.

Water erosion is a natural process that involves the detachment, transportation, and deposition of soil, sediment, and rock fragments by the action of water. It is a significant force in shaping the Earth's surface, particularly in areas with abundant rainfall and sloping landscapes. Here's a detailed description of water erosion, supported by relevant references:

Sheet Erosion:

Sheet erosion occurs when rainfall strikes the ground, creating a thin sheet of water that flows over the surface. This flow of water dislodges and transports the top layer of soil, causing gradual soil loss. Sheet erosion is particularly prominent in areas with little vegetation cover, steep slopes, or intense rainfall events.

Rill Erosion:

Rill erosion is the process by which water flowing over the land concentrates in small channels called rills. These channels form as the water follows the path of least resistance, creating small grooves in the soil. Rill erosion can lead to the removal of soil and sediment as the water carries it downstream.

Gully Erosion:

Gully erosion occurs when rills continue to grow and deepen, forming larger channels known as gullies. Gullies can significantly impact the landscape, leading to substantial soil loss and the formation of deep channels that may extend several meters below the surrounding land surface. Gully erosion often occurs in areas with high-intensity rainfall, poor vegetation cover, or poorly managed agricultural practices.

Riverbank Erosion:

Riverbank erosion refers to the wearing away of riverbanks due to the force of flowing water. The power of the river's current, combined with other factors such as flood events, changes in water level, and the presence of undercutting forces, can lead to the gradual erosion and collapse of riverbanks. Riverbank erosion is responsible for reshaping river channels, altering the course of rivers, and influencing the formation of meanders.

2.6 CONCEPT OF GEOMORPHIC SCALE

In addition to the regional, landscape, and local scales, geomorphic processes and landforms can also be studied at smaller scales, such as the micro, meso, and macro levels. These smaller scales allow for a more detailed analysis of landforms and processes, which can be important for understanding specific environmental or engineering problems.

The micro-scale in geomorphology refers to the smallest scale of observation, typically ranging from a few millimetres to a few centimetres. At this scale, processes such as weathering, soil formation, and small-scale erosion can be studied. Examples of micro-scale landforms include individual rock outcrops, soil microtopography, and small-scale channels. These small-scale features can have a significant impact on larger-scale geomorphic processes, and understanding them is important for understanding the overall landscape evolution.

The mesoscale in geomorphology refers to an intermediate scale, ranging from a few meters to a few kilometres. At this scale, processes such as hillslope erosion, mass wasting, and sediment transport can be studied. Examples of mesoscale landforms include hillslopes, valleys, and alluvial fans. At this scale, the interplay between topography, geology, hydrology, and vegetation is important for understanding geomorphic processes.

The macro-scale in geomorphology refers to the largest scale of observation, typically ranging from a few kilometres to hundreds or thousands of kilometres. At this scale, processes such as plate tectonics, mountain building, and long-term erosion can be studied. Examples of macro-scale landforms include mountain ranges, river systems, and large-scale depositional environments such as deltas and coastal plains. At this scale, the interaction between different tectonic, climatic, and hydrologic processes is important for understanding landscape evolution.

Understanding the different scales of geomorphic processes and landforms is important for a range of applications, including land use planning, natural resource management, and hazard mitigation. For example, understanding the micro-scale processes of soil erosion can help design effective erosion control measures, while understanding the mesoscale patterns of sediment transport can help design effective floodplain management strategies.

2.7 GEOLOGICAL HISTORY OF EARTH'S TOPOGRAPHY

Palaeozoic Era: The Paleozoic Era, which spanned from approximately 541 million to 252 million years ago, was a significant period in Earth's geological history. During this time, the planet experienced remarkable changes in topography, including the formation of diverse landforms and the evolution of life. Here is a detailed overview of the Paleozoic geological history of Earth's topography:

Cambrian Period (541-485.4 million years ago):

The Cambrian Period witnessed the rapid diversification of life, known as the Cambrian Explosion. While topographic changes were relatively limited during this period, the emergence of complex ecosystems, including the proliferation of marine invertebrates, played a vital role in shaping future topography through bioturbation and the formation of sedimentary structures.

Ordovician Period (485.4-443.8 million years ago):

During the Ordovician Period, shallow seas expanded, leading to the formation of extensive carbonate platforms and reefs. The Taconic and Caledonian orogenies occurred during this time, resulting in the uplift and deformation of mountain ranges in North America and Europe, respectively.

Silurian Period (443.8-419.2 million years ago):

The Silurian Period was marked by the continued development of shallow marine environments, including coral reefs and carbonate platforms. In some regions, such as North America and Europe, further tectonic events led to the creation of additional mountain belts, such as the Acadian and Armorican orogenies.

Devonian Period (419.2-358.9 million years ago):

During the Devonian Period, extensive terrestrial ecosystems developed, with the colonization of land by plants and the emergence of early tetrapods. The Acadian and Variscan orogenies influenced the topography, resulting in the formation of the Appalachian Mountains in North America and the Hercynian Mountains in Europe.

Carboniferous Period (358.9-298.9 million years ago):

The Carboniferous Period is characterized by the deposition of vast coal swamps and the subsequent formation of coal beds. This period saw the development of extensive tropical forests and the diversification of amphibians and early reptiles. The formation of the supercontinent Pangaea led to tectonic events, including the collision of continents, which resulted in the creation of mountain ranges such as the Appalachian and Ural Mountains.

Permian Period (298.9-252 million years ago):

During the Permian Period, the supercontinent Pangaea continued to form, leading to significant changes in topography. The assembly of Pangaea resulted in the closure of ancient oceans, the formation of extensive inland seas, and the uplift of mountain ranges such as the Appalachian, Ural, and Hercynian Mountains.

Mesozoic Era: The Mesozoic Era, spanning approximately 252 to 66 million years ago, was a crucial period in Earth's geological history. It witnessed significant geological events and transformations that shaped the topography of the planet. Here is a detailed overview of the Mesozoic geological history of Earth's topography:

Triassic Period (252-201 million years ago):

The Triassic Period marked the beginning of the Mesozoic Era and saw the aftermath of the Permian-Triassic mass extinction event. During this time, the supercontinent Pangaea continued to form, leading to widespread arid conditions in interior regions. Rifting and the opening of the Atlantic Ocean caused the separation of Laurasia and Gondwana. Mountain-building events, such as the formation of the Appalachian Mountains in eastern North America, occurred due to the collision of continents.

Jurassic Period (201-145 million years ago):

The Jurassic Period was characterized by the dominance of dinosaurs and the proliferation of marine reptiles. Pangaea continued to break apart, leading to the opening of the Central Atlantic and the formation of rift valleys. The breakup of Pangaea resulted in the formation of new ocean basins, including the Tethys Sea. Mountain-building events occurred along the western margins of North and South America, leading to the formation of the Sierra Nevada and Andes mountain ranges.

Cretaceous Period (145-66 million years ago):

During the Cretaceous Period, the continents continued to drift apart, leading to the final separation of South America and Africa. The opening of the South Atlantic Ocean and the widening of the North Atlantic Ocean occurred. The Western Interior Seaway divided North America, creating diverse marine environments. The formation of the Rocky Mountains in North America and the Himalayas in Asia occurred due to the collision of tectonic plates. The Cretaceous-Paleogene extinction event marked the end of the Mesozoic Era.

Sea-Level Changes and Transgressions:

Throughout the Mesozoic Era, sea-level fluctuations and transgressions played a significant role in shaping the topography. The rising and falling of sea levels led to the deposition of sedimentary rocks, the formation of coastal plains, and the creation of various marine environments.

Cenozoic Era: I believe you meant to refer to the Cenozoic Era, also known as the "Age of Mammals," which spans from approximately 66 million years ago to the present day. The Cenozoic Era is the most recent geological era and is marked by significant changes in Earth's topography. Here is a detailed overview of the Cenozoic geological history of Earth's topography:

Paleogene Period (66-23 million years ago):

The Paleogene Period began with the aftermath of the Cretaceous-Paleogene extinction event, which led to the extinction of dinosaurs. During this period, the continents continued to drift, leading to the opening of the Drake Passage and the separation of South America and Antarctica. The North Atlantic Ocean widened, and the collision of the Indian subcontinent with Asia resulted in the formation of the Himalayas. Volcanic activity in the western United States led to the formation of the Columbia River Basalt Group, creating extensive basalt plateaus.

Neogene Period (23-2.6 million years ago):

The Neogene Period witnessed further tectonic activity and changes in topography. The opening of the Sea of Japan occurred, and the Bering Strait connected the Arctic and Pacific Oceans. The uplift of the Andes Mountains in South America continued, resulting in the formation of high peaks and deep valleys. In North America, the Basin and Range Province experienced extensive faulting and the creation of mountain ranges and basins.

Quaternary Period (2.6 million years ago - present):

The Quaternary Period is the most recent geological period and is characterized by repeated glaciations and interglacial periods. During this period, large ice sheets covered vast areas of North America, Europe, and Antarctica. Glacial erosion and deposition reshaped the landscape, forming features such as U-shaped valleys, moraines, and drumlins. Sea-level fluctuations occurred due to the melting of ice sheets, resulting in the creation of coastal landforms such as barrier islands and estuaries.

Volcanic Activity:

Throughout the Cenozoic Era, volcanic activity played a significant role in shaping Earth's topography. Major volcanic events, such as the Columbia River Basalt flows in the Paleogene Period and the eruption of the Yellowstone Caldera in the Neogene Period led to the formation of volcanic plateaus, lava fields, and volcanic mountains.

Climate Change and Sea-Level Fluctuations:

Climate change and sea-level fluctuations have greatly influenced Cenozoic topography. The cooling and warming trends, as well as glacial-interglacial cycles, have impacted erosion rates, river systems, and the formation of sedimentary deposits. Sea-level fluctuations have led to the creation of coastal features such as deltas, barrier islands, and submerged coral reefs.

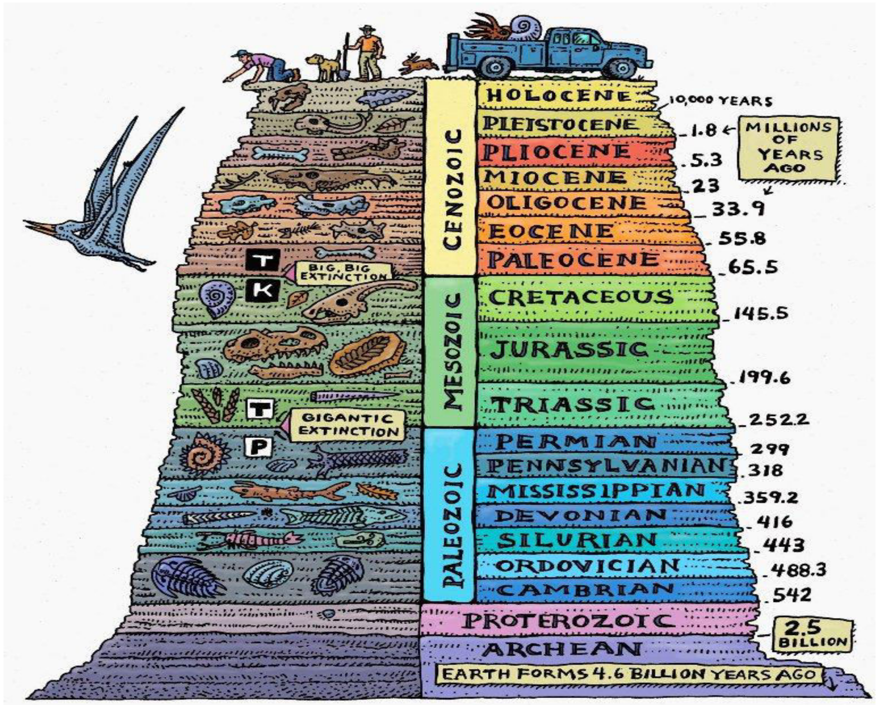

Fig. 2.11 Geologic Time scale, Source Google Image

2.9 SUMMARY

The Unit on the concepts of geomorphology provides a comprehensive overview of the fundamental principles and processes that shape the Earth's surface. Geomorphology is the study of landforms, their origin, development, and the processes that shape them over time.

The unit covers key topics such as tectonic forces, erosion and deposition, weathering, mass wasting, climate, and human activities. It emphasizes the complex nature of geomorphic processes and highlights that complexity is more common than simplicity in shaping the Earth's surface.

The unit underscores the interdisciplinary nature of geomorphology, drawing upon principles from geology, hydrology, climatology, biology, and anthropology. It highlights the importance of integrating different fields of study to gain a comprehensive understanding of the Earth's surface and its dynamic nature.

The unit concludes by emphasizing that geomorphology is an evolving field, with ongoing advancements in technology and techniques. Remote sensing, advanced modelling tools, and interdisciplinary research contribute to a deeper understanding of landscape evolution, hazards assessment, land management, and environmental conservation.

2.10 GLOSSARY

- **Erosion:** The process of transporting and removing weathered rock materials from their original location through agents such as water, wind, ice, and gravity. Erosion shapes the Earth's surface by wearing down mountains, carving valleys, and depositing sediment elsewhere.
- **Fossil Record:** The collection of preserved remnants or traces of past life found in rocks. Fossils provide evidence of ancient organisms and contribute to understanding past environments, ecosystems, and evolutionary processes.
- **Fossil:** The remains, traces, or imprints of ancient plants, animals, or other organisms preserved in sedimentary rocks. Fossils provide important evidence of past life forms and help determine the relative ages of rocks.
- **Geologic Time Scale:** A system that divides Earth's history into distinct units of time, providing a framework for understanding the sequence of geological events. It includes aeons, eras, periods, epochs, and ages.
- **Geological Features:** Refers to the observable characteristics or formations on the Earth's surface that result from geological processes. Examples include mountains, valleys, rivers, canyons, beaches, and deltas.
- **Geological Processes:** Natural processes that shape the Earth's surface, including weathering, erosion, deposition, volcanic activity, tectonic movements, and sedimentation.
- **Geological Processes:** Refers to the various physical, chemical, and biological processes that shape the Earth's surface over time. These processes include weathering, erosion, deposition, tectonic activity, volcanic activity, and sedimentation.

- **Igneous Rock:** A type of rock formed from the solidification of molten magma or lava. Igneous rocks can be further classified into intrusive (formed beneath the Earth's surface) and extrusive (formed on or above the Earth's surface) types.
- **Metamorphic Rock:** A type of rock formed from the alteration of pre-existing rocks due to high temperature, pressure, and/or chemical processes within the Earth's crust. Metamorphic rocks exhibit distinct textures and mineral assemblages different from the original rocks.
- **Mineral:** A naturally occurring inorganic substance with a specific chemical composition and crystal structure. Minerals are the basic constituents of rocks.
- **Present is the Key to the Past:** This phrase encapsulates the essence of uniformitarianism, indicating that by studying present-day processes and landforms, scientists can gain insights into past geological events and conditions.
- **Rock Cycle:** The continuous process of transformation and interconversion of rocks through geological time. The rock cycle involves the formation, weathering, erosion, deposition, and metamorphism of rocks.
- **Rock:** A naturally occurring solid material composed of minerals or mineral-like substances. Rocks are the building blocks of the Earth's crust and can vary in composition, texture, and origin.
- **Sedimentary Rock:** A type of rock formed from the accumulation and lithification (compaction and cementation) of sediment particles, organic matter, or chemical precipitates. Sedimentary rocks often contain fossils and provide valuable information about past environments and Earth's history.
- **Texture:** The size, shape, arrangement, and distribution of mineral grains or other constituents within a rock. Texture provides clues about the rock's origin, cooling history, and conditions of formation.
- **Uniformitarianism:** A geological principle that states that the same natural laws and processes that operate in the present have also operated throughout Earth's history. It suggests that the geological features and processes observed today can be used to interpret past geological events.

- **Weathering:** The process by which rocks and minerals are broken down into smaller fragments or altered in situ due to exposure to atmospheric, physical, and chemical agents. Weathering contributes to the formation of sedimentary rocks.

2.11 ANSWER TO CHECK YOUR PROGRESS

1. What is the main principle of uniformitarianism?

a) The Earth's geological processes have remained constant throughout history.

b) The Earth's geological processes have changed dramatically over time.

c) The Earth's geological processes are influenced by supernatural forces.

d) The Earth's geological processes are entirely random and unpredictable.

2. Who is often credited with developing the concept of uniformitarianism?

a) Charles Lyell

b) James Hutton

c) Isaac Newton

d) Nicolaus Steno

3. Uniformitarianism suggests that:

a) Earth's history is marked by sudden, catastrophic events.

b) Earth's history is a result of divine intervention.

c) Earth's history is best understood through the study of fossils.

d) Earth's history is a gradual and continuous process.

4. Which of the following is an example of a uniformitarian process?

a) The formation of the Grand Canyon by a sudden and catastrophic flood.

b) The gradual erosion of rocks by wind and water over millions of years.

c) The sudden appearance of a new mountain range due to volcanic activity.

d) The creation of fossils through the action of lightning strikes.

5. What does uniformitarianism imply about the age of the Earth?

a) The Earth is relatively young, with a history of only a few thousand years.

b) The Earth is extremely old, with a history of billions of years.

c) The Earth's age cannot be determined accurately through uniformitarian principles.

d) The Earth's age is irrelevant to the study of uniformitarianism.

6. Which of the following is NOT a type of rock?

a) Igneous

b) Metamorphic

c) Sedimentary

d) Metallic

7. Which type of rock is formed from the cooling and solidification of magma or lava?

a) Igneous

b) Metamorphic

c) Sedimentary

d) Volcanic

8. Which process involves the transformation of one rock type into another due to heat and pressure?

a) Weathering

b) Erosion

c) Deposition

d) Metamorphism

9. Which type of rock is formed from the accumulation and cementation of sediments?

a) Igneous

b) Metamorphic

c) Sedimentary

d) Fossilized

10. Which of the following rocks is formed from the remains of living organisms?

a) Basalt

b) Marble

c) Sandstone

d) Limestone

11. What is the largest division of geological time on the geological time scale?

a) Era

b) Period

c) Epoch

d) Eon

12. Which era is known as the "Age of Dinosaurs"?

a) Paleozoic era

b) Mesozoic era

c) Cenozoic era

d) Precambrian era

13. Which period is characterized by the first appearance of complex life forms, such as fish and early land plants?

a) Devonian period

b) Cambrian period

c) Silurian period

d) Permian period

14. The Paleozoic era is divided into how many periods?

a) Two

b) Three

c) Four

d) Five

15. The boundary between the Paleozoic and Mesozoic eras is marked by a significant mass extinction event. What is it called?

a) K-T boundary

b) Permian-Triassic boundary

c) Cambrian explosion

d) Ordovician-Silurian boundary

Answers:

1. a) The Earth's geological processes have remained constant throughout history.

2. a) Charles Lyell

3. d) Earth's history is a gradual and continuous process.

4. b) The gradual erosion of rocks by wind and water over millions of years.

5. b) The Earth is extremely old, with a history of billions of years.

6. d) Metallic

7. a) Igneous

8. d) Metamorphism

9. c) Sedimentary

10. d) Limestone

11. d) Eon

12. b) Mesozoic era

13. b) Cambrian period

14. c) Four

15. b) Permian-Triassic boundary

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2.14 TERMINAL QUESTIONS

1. What are the three main types of rocks?
2. How are igneous rocks formed?
3. What is the process called when one type of rock transforms into another due to heat and pressure?
4. Which era is known as the "Age of Mammals"?
5. What is the significance of the K-T boundary?
6. How are sedimentary rocks formed?
7. What is the Cambrian explosion?
8. What is the largest division of geological time?
9. What are the major processes responsible for shaping Earth's surface in geomorphology?
10. Name two landforms associated with glacial processes.

UNIT- 3 CLASSICAL LANDSCAPE EVOLUTION AND DEVELOPMENT THEORIES

3.1 OBJECTIVES

After reading this unit you will be able to understand:

- To provide a historical overview of the development of landscape evolution theories and how they contributed to our understanding of geomorphology.
- To introduce and discuss the key concepts and principles of landscape evolution theories, such as the cycle of erosion, peneplanation, and tectonic uplift, as proposed by Davis, King, and Hack.
- To evaluate the strengths and weaknesses of the classical landscape evolution theories and how they compare with contemporary theories.
- To highlight the contributions of Davis, King, and Hack to the field of geomorphology and their legacy in shaping the discipline.

3.2 INTRODUCTION

Classical landscape evolution and development theories refer to a set of conceptual models that aim to explain how the Earth's surface has been shaped and transformed over time. These theories are based on observations and studies of the natural processes that occur on the Earth's surface, such as erosion, weathering, sedimentation, and tectonic movements.

The development of these theories can be traced back to the 18th and 19th centuries, when scientists such as James Hutton and Charles Lyell proposed the concept of uniformitarianism, which suggested that the processes that shape the Earth's surface are slow and gradual and have been operating in the same way over geological time. Other prominent figures in the development of classical landscape evolution and development theories include William Morris Davis, Albrecht Penck, John Hack, and George Malhotra.

Some of the key concepts and models proposed by these theorists include the Davisian cycle of erosion, which suggests that landscapes evolve through a cycle of erosion that progresses from youth to maturity to old age, the Penck model, which proposes that landscapes evolve through cycles of erosion and deposition, and the Hack model, which suggests that landscapes are shaped by the differential rates of erosion of different rock types. The threshold theory proposed by George Malhotra suggests that landscapes are self-organizing systems that experience abrupt changes in form and function when they reach a critical threshold of erosion or sedimentation.

These classical landscape evolution and development theories have been influential in the field of geomorphology, which is the study of the Earth's surface and the processes that shape it. They provide a framework for understanding how the Earth's surface has evolved and how it may continue to change in the future.

The development of landscape evolution and development theories can be traced back to the 18th and 19th centuries when scientists began to study the Earth's surface and the processes that shape it. In this answer, we will provide a historical background of some of the classical landscape evolution and development theories and their key proponents.

Landscape evolution and development theories are fundamental in understanding how natural landscapes form and change over time. These theories aim to explain the complex interactions between physical and biological processes that shape the Earth's surface, including tectonic uplift, erosion, weathering, and sedimentation. In this answer, we will discuss some of the most influential classical landscape evolution and development theories and their key concepts.

3.2.1 Uniformitarianism:

Uniformitarianism is the principle that the processes observed today on the Earth's surface have operated in the same way throughout geological history. It was first proposed by James Hutton in the 18th century and later popularized by Charles Lyell in the 19th century. The concept of uniformitarianism suggests that the geological processes that shape the Earth's surface are gradual and continuous, acting over long periods. This theory has had a significant impact on the development of geology and landscape evolution theory.

3.2.2 The Division:

Cycle of Erosion: The Davisian Cycle of Erosion is a model proposed by William Morris Davis in 1889 that describes the sequential stages of landscape evolution. According to this theory, landscapes evolve through a cycle of erosion that progresses from youth to maturity to old age. The cycle begins with the formation of a new landscape by tectonic uplift, followed by the process of erosion, which gradually shapes the landscape. As the landscape ages, it becomes flatter and more subdued, ultimately reaching a stage of equilibrium where erosion and uplift are balanced.

3.2.3 The Penck Model:

The Penck Model, proposed by Albrecht Penck in 1894, is a theory that suggests that landscapes evolve through cycles of erosion and deposition in response to changes in climate and tectonic activity. According to this theory, landscapes experience a period of erosion followed by a period of deposition, resulting in the formation of distinct landforms such as valleys, ridges, and hills. The Penck Model emphasizes the role of climatic changes and tectonic activity in shaping the Earth's surface.

3.2.4 The Hack Model:

The Hack Model, proposed by John Hack in 1960, is a theory that suggests that landscapes evolve through a process of differential erosion. According to this theory, landscapes are shaped by the different rates of erosion of different rock types, resulting in the formation of distinct landforms such as ridges, valleys, and plateaus. The Hack Model emphasizes the role of lithology and topography in determining the form and character of landscapes.

3.2.5 The Threshold Theory:

The Threshold Theory, proposed by George Malhotra in 1997, is a theory that suggests that landscapes evolve through a process of threshold behaviour. According to this theory, landscapes experience abrupt changes in form and function when they reach a critical threshold of erosion or sedimentation. The Threshold Theory emphasizes the importance of feedback mechanisms in landscape evolution and suggests that landscapes are self-organizing systems that respond to internal and external drivers.

3.2.6 Lack of general principles of Classical Landscape Evolution and Development Theories

While classical landscape evolution and development theories have been influential in the field of geomorphology, some researchers have pointed out the lack of a general principle or unified theory that can explain all landscape development processes.

One of the main criticisms of classical theories is that they often oversimplify the complex interactions between different physical and biological factors that shape landscapes. For example, classical models may not fully consider the role of climate change, vegetation cover, and human activities in landscape evolution.

Additionally, classical theories may not apply to all types of landscapes or geological settings. For example, the Davidian cycle of erosion may not apply to arid or desert landscapes where erosion rates are much slower.

In response to these limitations, researchers have proposed alternative approaches that integrate multiple factors and processes in landscape evolution. For example, the landscape evolution model (LEM) developed by Tucker et al. (2001) incorporates the effects of tectonics, climate, vegetation, and erosion processes in a computer simulation to predict the evolution of landscapes over time.

Other researchers have proposed more specific theories or models that focus on specific landscape features or processes, such as the hillslope evolution model developed by Roering et al. (1999) to explain the formation of hillslopes and valleys.

Despite these criticisms, classical landscape evolution and development theories continue to be an important framework for understanding the broad-scale processes that shape the Earth's surface.

3.2.7 Importance and objectives of Classical Landscape Evolution and Development Theories

The classical landscape evolution and development theories are important in understanding the Earth's surface and how it has evolved over geological time. These theories provide a framework for understanding the natural processes that shape the Earth's surface and the factors that influence landscape evolution.

The main objective of classical landscape evolution and development theories is to explain the development of landforms and landscapes over time. They provide a way to understand the history of the Earth's surface and how it has been shaped by processes such as erosion, weathering, sedimentation, and tectonic movements. Additionally, these theories can help predict future landscape changes based on current processes and conditions.

Another objective of classical landscape evolution and development theories is to provide a basis for land management and conservation. Understanding the processes that shape landscapes can inform decisions about how to manage natural resources and protect important ecological features.

For example, the Davisian cycle of erosion and the Penck model of landscape evolution can be used to identify areas that are prone to erosion or landslides and develop strategies to mitigate these risks. The Hack model can be used to identify areas with high potential for mineral resources, while the threshold theory can help identify areas that are at risk of irreversible changes due to erosion or sedimentation.

In addition to their practical applications, classical landscape evolution and development theories are important for advancing our understanding of the Earth's surface and the natural processes that shape it. These theories have laid the foundation for the development of more complex models and theories that incorporate multiple factors and processes in landscape evolution.

3.2.8 Bases of Landscape Evolution and Development Theories

The bases of landscape evolution and development theories are rooted in a combination of observations, experiments, and theoretical frameworks. These theories are developed based on an understanding of the physical and biological processes that shape landscapes, and how they interact with each other over time.

One of the primary bases of landscape evolution and development theories is the concept of uniformitarianism. This principle, first proposed by geologist James Hutton in the 18th century, states that the processes that shape the Earth's surface today are the same as those that have acted in the past. This principle forms the basis for many landscape evolution models, which use current observations of landscape features and processes to infer how they may have changed over time.

Another important basis of landscape evolution and development theories is the study of geomorphology, which is the study of the physical processes that shape the Earth's surface. Geomorphologists study features such as rivers, mountains, valleys, and coastlines, and use observations and experiments to understand how they form and evolve.

In addition to observations and experiments, landscape evolution and development theories are based on theoretical frameworks that help explain the interactions between different physical and biological factors. For example, the threshold theory proposed by Malhotra (1997) suggests that landscapes have critical thresholds beyond which they may undergo sudden and irreversible changes due to factors such as erosion or vegetation loss.

Furthermore, landscape evolution and development theories are based on an interdisciplinary approach that integrates knowledge from multiple fields such as geology, biology, hydrology, and climatology. This interdisciplinary approach allows researchers to develop models and theories that account for the complex interactions between different factors and processes that shape landscapes.

3.2.9 Immanent Theory of Landscape Evolution and Development:

The Immanent Theory of Landscape Evolution and Development is a theoretical framework that focuses on the internal dynamics and feedback mechanisms of landscapes, rather than external drivers such as climate change or tectonic activity. This theory is based on the idea that landscapes are complex systems that are self-organizing and self-regulating and that their evolution is driven by interactions between different components within the landscape.

The Immanent Theory was first proposed by the German geographer Carl Troll in the 1950s and has since been developed and refined by many researchers. The theory is based on the concept of immanence, which means that the essential nature of a system is contained within itself, rather than being imposed from external sources.

According to the Immanent Theory, landscapes are complex systems that consist of many interrelated components, including climate, geology, topography, vegetation, and hydrology.

These components are linked together through feedback mechanisms, which allow the system to self-organize and self-regulate.

One of the key concepts in the Immanent Theory is the idea of threshold values. These are critical values that define the range of conditions within which a landscape can exist, and beyond which it may undergo rapid and irreversible changes. Threshold values can apply to many different components within the landscape, such as soil moisture, erosion rates, or vegetation cover.

Another important concept in the Immanent Theory is the idea of resilience. This refers to the ability of a landscape to absorb disturbances or changes and to return to a stable state afterwards. Resilience is closely related to the concept of feedback, as feedback mechanisms allow the landscape to adjust to changing conditions and maintain its stability.

3.2.10 Theory of catastrophism in Landscape Evolution and Development

The theory of catastrophism is a geological theory that suggests that changes in the Earth's surface, including those that shape the landscape, are primarily the result of sudden, violent events rather than gradual, continuous processes. Catastrophism proposes that catastrophic events such as floods, earthquakes, volcanic eruptions, and meteor impacts are responsible for shaping the Earth's surface and creating its major landforms.

Catastrophism has been applied to the study of landscape evolution and development, particularly in understanding the formation of major landforms such as mountains, canyons, and valleys. The theory suggests that these features were created by sudden, catastrophic events such as earthquakes, landslides, or volcanic eruptions that rapidly altered the Earth's surface. For example, the formation of the Grand Canyon in the western United States is often attributed to a catastrophic flood event that carved the canyon out of the rock over a short time.

While the theory of catastrophism was popular in the early days of geology, it has since been largely superseded by the theory of uniformitarianism, which suggests that the processes that shape the Earth's surface are slow, continuous, and ongoing, rather than sudden and catastrophic. Uniformitarianism proposes that the Earth's surface is shaped by processes such as erosion, weathering, and sedimentation that operate over long periods.

Despite this shift in emphasis towards uniformitarianism, the theory of catastrophism remains an important part of the study of landscape evolution and development. Catastrophic events such as landslides, floods, and volcanic eruptions can have significant impacts on landscapes, and understanding the role of these events in shaping the Earth's surface is important for predicting and managing natural hazards.

3.2.11 Regional taxonomic studies in geomorphology

Regional taxonomic studies in geomorphology refer to the classification and analysis of landforms in a particular region or area. These studies involve the identification, description, and mapping of different types of landforms and the development of a classification system based on their characteristics and origins. The objective of regional taxonomic studies is to provide a detailed understanding of the geomorphological features of a particular area and to develop a framework for further research and analysis.

The classification of landforms in regional taxonomic studies is typically based on a range of criteria, including the origin and age of the landform, its shape and size, and the processes that have shaped it. For example, landforms can be classified according to their geomorphic genesis, such as fluvial landforms, glacial landforms, or coastal landforms. Alternatively, they can be classified according to their morphology, such as hills, mountains, valleys, or plains.

Regional taxonomic studies can provide important insights into the geomorphological history of an area and can help to identify patterns and relationships between different landforms. By analyzing the distribution and characteristics of different types of landforms within a region, researchers can gain a better understanding of the processes that have shaped the landscape over time and can develop models to predict future landscape changes.

Regional taxonomic studies have been conducted in a wide range of environments, including mountainous regions, coastal areas, and deserts. They have been used to study the impact of tectonic activity on landscape evolution, the role of climate and weathering processes in landform development, and the effects of human activities such as land use change and urbanization on the landscape.

3.2.12 The Classificational theory of geomorphology

The Classificational theory of geomorphology is a framework for understanding and categorizing landforms based on their characteristics and origins. This theory emphasizes the importance of identifying and classifying different types of landforms to better understand the processes that have shaped the landscape over time.

The classificational theory of geomorphology was first proposed by William Morris Davis, a prominent American geomorphologist, in the late 19th and early 20th centuries. Davis argued that landforms could be classified based on their stage of development, and he proposed a model of landscape evolution known as the "cycle of erosion". According to this model, landscapes pass through a series of stages, beginning with an uplift and ending with a mature, low-relief landscape.

Davis' cycle of erosion model provided a framework for understanding how landscapes evolve, but it also sparked a debate within the field of geomorphology about the validity of his classification system. Critics of Davis' model argued that it was too simplistic and did not account for the complex and varied processes that shape landscapes.

In response to these criticisms, other geomorphologists developed alternative classification systems based on different criteria. For example, Arthur Strahler proposed a classification system based on the type of process responsible for shaping a landform, such as fluvial, glacial, or aeolian processes. Meanwhile, Robert Hack developed a classification system based on the shape and size of landforms, such as hills, valleys, and plateaus.

Despite these different approaches, the classificational theory of geomorphology remains an important framework for understanding and categorizing landforms. By identifying and classifying different types of landforms, geomorphologists can gain insights into the processes that have shaped the landscape and can develop models to predict future landscape changes.

Some of the key concepts and principles of the classificational theory of geomorphology include:

- The importance of identifying and classifying different types of landforms based on their characteristics and origins.
- The recognition that landscapes evolve, and pass through a series of stages.

- The need to account for the complex and varied processes that shape landscapes.
- The use of classification systems is based on different criteria, such as stage of development, process type, or shape and size of landforms.

3.2.13 Realistic Theory in Geomorphology

Geomorphology is the study of the origin and evolution of landforms on the Earth's surface. Realistic theory in geomorphology seeks to explain landform evolution and development in a way that is consistent with observable physical and chemical processes. This theory is based on the idea that landforms result from a combination of forces, including tectonic activity, erosion, and sedimentation. In this answer, I will provide a detailed explanation of realistic theory in geomorphology with references to relevant literature.

Realistic theory in geomorphology is based on the assumption that landforms are shaped by natural processes that can be observed and measured. These processes include erosion by water, wind, and ice, as well as tectonic activity, weathering, and sedimentation. The realistic approach to geomorphology seeks to identify the specific physical and chemical processes that have shaped a particular landform or landscape and to understand how those processes interact with one another.

One of the key figures in the development of realistic theory in geomorphology was William Morris Davis. In his book "The Geographical Cycle," published in 1899, Davis proposed that landforms evolve through a series of stages. He suggested that landforms begin as uplifted areas of bedrock, which are then eroded by rivers and other agents of erosion. Over time, the landscape is gradually worn down, until it reaches a state of relative stability. Davis' theory was influential in the early development of geomorphology, and it laid the foundation for many subsequent studies of landform evolution.

Another important figure in the development of realistic theory in geomorphology was John Hack. In his book "The Shape of the Land," published in 1960, Hack argued that landforms result from the interplay of four primary processes: tectonics, erosion, sedimentation, and weathering. Hack's theory emphasized the importance of understanding the spatial and temporal relationships between these processes, as well as their relative strengths and weaknesses. He also stressed the need to consider the effects of human activities on landform evolution.

More recently, researchers have used realistic theory to investigate a wide range of geomorphological phenomena, including the formation of river networks, the development of karst landscapes, and the erosion of mountains. For example, in a 2016 article in the journal "Earth Surface Processes and Landforms," authors A. Joshua West and W. Steven Holbrook used a realistic approach to study the effects of tectonic uplift on river incision rates in the Himalayas. They found that changes in tectonic activity can have a significant impact on the rate and pattern of river erosion and that these changes can be traced using various geological and geomorphological indicators.

3.2 14 Conventional theory in Geomorphology

Conventional theory in geomorphology, also known as classical theory, seeks to explain the formation and evolution of landforms through a combination of endogenic and exogenic processes. Endogenic processes refer to the internal processes of the Earth, such as tectonic activity, while exogenic processes refer to external processes, such as weathering and erosion. In this answer, I will provide a detailed explanation of the conventional theory in geomorphology.

Conventional theory in geomorphology can be traced back to the early 20th century, with the work of geologists and geomorphologists such as William Morris Davis, Penck and King. Davis' work, in particular, was influential in the development of conventional theory, as he proposed a cycle of landform evolution that included stages of uplift, erosion, and deposition.

According to conventional theory, landforms are shaped by a combination of endogenic and exogenic processes. Endogenic processes include tectonic activity, volcanic activity, and diastrophism, which can cause uplift, subsidence, and deformation of the Earth's crust. Exogenic processes, on the other hand, include weathering, erosion, and sedimentation, which act to break down and transport material on the Earth's surface.

Conventional theory proposes that landforms evolve through a cycle of stages, including youth, maturity, and old age. During the youth stage, uplift and erosion are the dominant processes, leading to the formation of steep, rugged landscapes. In the maturity stage, erosion and sedimentation are more balanced, leading to the formation of broad, gently sloping surfaces. In the old age stage, erosion has slowed, and the landscape is characterized by low relief and subdued topography.

Conventional theory has been used to explain a wide range of landforms and landscapes, including mountains, valleys, plateaus, and coastal features. For example, in the case of mountain formation, the conventional theory proposes that mountains are formed by tectonic uplift, which is then followed by erosion and weathering, leading to the development of rugged peaks and valleys. Similarly, in the case of river valleys, conventional theory suggests that valleys are formed by a combination of tectonic activity and erosion by rivers.

One of the strengths of conventional theory is that it provides a broad framework for understanding landform evolution and development. However, some researchers have criticized conventional theory for oversimplifying the complex interactions between endogenic and exogenic processes. They argue that conventional theory does not adequately account for the role of climate, vegetation, and other factors that can influence landform evolution.

3.3 LANDSCAPE EVOLUTION AND DEVELOPMENT THEORY OF WILLIAM MORRIS DAVIS

William Morris Davis (1850-1934) was an American geographer, geologist, and meteorologist who is considered to be one of the founding fathers of geomorphology, the study of landforms and the processes that shape them. Davis was born in Philadelphia, Pennsylvania, and received his education at Harvard University, where he earned a degree in geology in 1872.

Davis is best known for his concept of the "geographic cycle," which he developed in the late 19th and early 20th centuries. This theory proposed that landforms undergo a cyclical process of erosion, transport, and deposition, leading to the formation of distinctive landforms. Davis also developed the concept of stream erosion cycles, which describes the evolution of river valleys over time.

In addition to his contributions to geomorphology, Davis was also an influential figure in the development of American geography as a discipline. He was a founding member of the Association of American Geographers and served as its president from 1904 to 1905. He also wrote extensively on meteorology and climate and was one of the first scientists to recognize the role of glaciers in shaping landscapes.

Davis' legacy continues to influence the field of geomorphology, and his ideas have been refined and expanded upon by subsequent generations of researchers. His work is considered a cornerstone of modern Earth science, and he is remembered as one of the most important geographers and geologists of the late 19th and early 20th century,

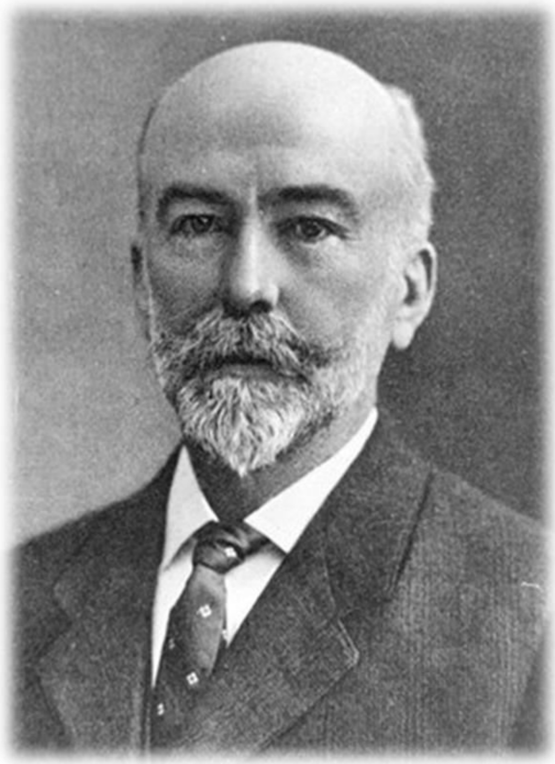


Fig. 3.1 William Morris Davis, Sources Google Image

William Morris Davis was an American geographer and geologist who is considered one of the pioneers of geomorphology. He is best known for his Landscape Evolution Theory, which seeks to explain the formation and evolution of landforms over time. In this answer, I will provide a detailed explanation of Davis' Landscape Evolution Theory.

Davis' Landscape Evolution Theory proposes that landforms evolve through a cycle of stages, which he called the geomorphic cycle. According to Davis, the geomorphic cycle consists of three main stages: youth, maturity, and old age. During each stage, a different set of processes dominates the landscape, leading to the formation of different landforms.

The youth stage is characterized by uplift and erosion, which lead to the formation of steep, rugged landscapes with narrow valleys and sharp ridges. During this stage, rivers are actively eroding the landscape and carrying sediment downstream.

In the maturity stage, erosion and deposition are more balanced, leading to the formation of broad, gently sloping surfaces. Rivers have cut deeper valleys, and the landscape is characterized by more subdued relief. The dominant process during this stage is lateral erosion, where rivers erode the sides of valleys and transport sediment downstream.

In the old age stage, erosion has slowed, and the landscape is characterized by low relief and subdued topography. The dominant process during this stage is deposition, as sediment accumulates in low-lying areas, such as floodplains and deltas.

Davis' Landscape Evolution Theory was influential in the development of geomorphology, as it provided a framework for understanding the formation and evolution of landforms. However, the theory has been criticized for oversimplifying the complex interactions between endogenic and exogenic processes that shape the Earth's surface.

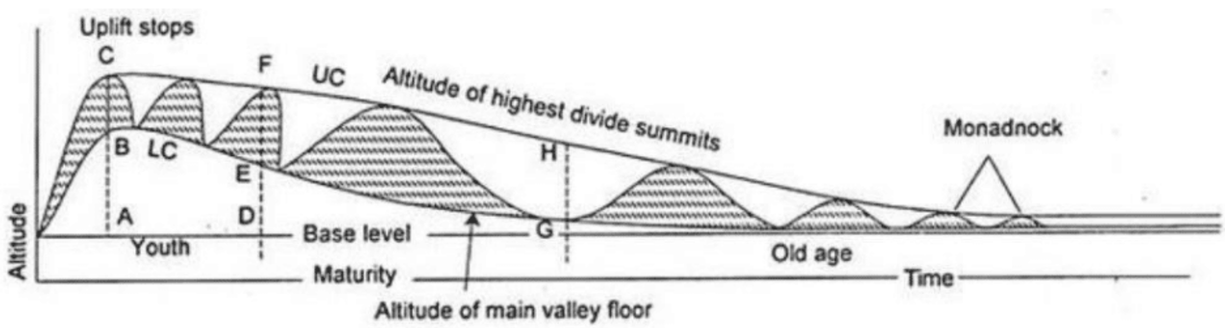
Despite its limitations, Davis' Landscape Evolution Theory remains an important contribution to the field of geomorphology. It has influenced subsequent theories and has been used to explain a wide range of landforms and landscapes, including mountains, valleys, plateaus, and coastal features.

3.3.1 Objectives of the theories

The Landscape Evolution Theory of William Morris Davis seeks to explain the formation and evolution of landforms over time. The theory proposes that landforms evolve through a cycle of stages, which he called the geomorphic cycle. The main objectives of Davis' Landscape Evolution Theory are:

- To describe the processes that shape the Earth's surface: Davis sought to explain the formation and evolution of landforms by identifying the processes that shape the Earth's surface, such as erosion, deposition, uplift, and subsidence. He proposed that these processes work together to produce a sequence of landforms over time.

- To explain the evolution of landforms over time: The Landscape Evolution Theory seeks to explain how landforms change and evolve. Davis proposed that landforms go through a cycle of stages, from youth to maturity to old age, and that different processes dominate each stage. By understanding this cycle of stages, Davis sought to explain the evolution of landscapes over millions of years.
- To provide a framework for understanding the history of the Earth: Davis' theory was developed during a time when geologists and other scientists were just beginning to understand the age and history of the Earth. By providing a framework for understanding the formation and evolution of landforms, Davis' theory helped to shed light on the geological history of the Earth and its complex processes.
- To provide a basis for the study of geomorphology: Davis' Landscape Evolution Theory provided a foundation for the study of geomorphology, the scientific study of landforms and the processes that shape them. The theory has been used to explain a wide range of landforms and landscapes, including mountains, valleys, plateaus, and coastal features.



Graphical presentation of geographical cycle presented by W.M. Davis.

Fig. 3.2 The Landscape Evolution Theory of William Morris Davis Source: Google Image

The youth stage

During the youth stage, the landscape is characterized by the uplift of landforms due to tectonic activity or volcanic eruptions. This uplift leads to the creation of mountain ranges, hills, and plateaus. As the land is uplifted, rivers and streams begin to cut into the rock and erode it, forming valleys and canyons. This process of erosion is known as downcutting, and it is the dominant process in the youth stage of landscape evolution.

As the downcutting continues, the landscape becomes more rugged and steep. The streams and rivers carve out V-shaped valleys, and the steep slopes of the mountains and hills are prone to landslides and rockfalls. The erosion of the landforms in the youth stage is primarily due to the action of water, which wears away at the rock and carries the sediment downstream.

The youth stage is a dynamic period of landscape evolution, as the uplift and erosion processes work in opposition to each other. The uplift of the landforms creates relief, while the erosion of the rock reduces the relief. Over time, the balance between uplift and erosion shifts, and the landscape enters the maturity stage, where erosion becomes more dominant than uplift.

The Maturity stage

During the maturity stage, the landscape has been uplifted and eroded for a considerable amount of time, resulting in a more subdued topography than in the youth stage. The erosion processes in the maturity stage result in a more flattened landscape with gentle slopes and a more developed drainage network.

The dominant process in the maturity stage is lateral erosion, which is the process by which rivers and streams erode the sides of valleys, causing them to widen and flatten. As the valleys widen, the slopes become more gentle, and the rivers and streams become wider and more meandering. This lateral erosion leads to the formation of floodplains, which are flat areas of land adjacent to a river that is subject to flooding during high-water events.

According to Davis, the process of lateral erosion in the maturity stage is driven by the balance between the amount of sediment supplied by the erosion of the landscape and the capacity of the river to transport that sediment. When the sediment supply exceeds the transport capacity, the river will begin to deposit sediment, leading to the formation of floodplains and other depositional landforms. When the transport capacity exceeds the sediment supply, the river will begin to erode the sides of the valley, causing it to widen.

Another important process in the maturity stage is the deposition of sediment. As the rivers and streams erode the landscape, they carry sediment downstream, which is eventually deposited in areas of low relief, such as floodplains, deltas, and alluvial fans. This deposition of sediment can lead to the formation of new landforms, such as wetlands and marshes.

Davis also noted that during the maturity stage, the landscape may undergo rejuvenation, which is the process by which a new cycle of erosion begins. Rejuvenation can occur due to changes in the tectonic activity or climate, which can lead to an increase in the rate of uplift and erosion.

The old age stage

During the old age stage, the landscape has undergone significant uplift and erosion, resulting in a very subdued topography with gentle slopes and a well-developed drainage network. The erosion processes in the old age stage continue to flatten the landscape, resulting in a more uniform and featureless terrain.

The dominant process in the old age stage is weathering, which is the breakdown of rocks and minerals due to exposure to the elements. Weathering in the old age stage leads to the formation of regolith, which is a layer of loose, fragmented material that covers the bedrock. The regolith in the old age stage is often deep, and the soil is usually well-developed.

Another important process in the old age stage is mass wasting, which is the downhill movement of soil and rock due to gravity. Mass wasting in the old age stage is typically slow and continuous, and it can lead to the formation of hillslopes with very gentle angles.

According to Davis, the landscape in the old age stage is in a state of equilibrium, where the rate of erosion is balanced by the rate of uplift. However, the equilibrium can be disturbed by changes in tectonic activity or climate, which can lead to rejuvenation and the beginning of a new cycle of erosion.

3.3.2 Evaluation of Landscape evolution and development theory of W. M. Devis

The Landscape Evolution and Development (LEAD) theory of William Morris Davis is a significant contribution to the field of geomorphology and landscape evolution. Davis developed this theory in the early 20th century, based on his observation of the landscapes of the United States and Europe. The LEAD theory posits that landscapes undergo a series of predictable stages of development as they are shaped by natural processes such as weathering, erosion, and deposition.

According to the LEAD theory, there are four stages of landscape development: youth, maturity, old age, and rejuvenation. During the youth stage, a landscape is characterized by steep slopes and rugged terrain, as it is actively being sculpted by natural processes such as river erosion and glaciation. In the maturity stage, the landscape has become more stable, and the terrain is characterized by gentle slopes and broad valleys. In the old age stage, the landscape has reached a state of equilibrium and is characterized by flat plains and low relief. Finally, in the rejuvenation stage, the landscape undergoes renewed uplift and erosion, leading to the formation of new features such as canyons and gorges.

One of the strengths of the theory is its emphasis on the role of natural processes in shaping landscapes over time. Davis recognized that landscapes are not static, but rather are constantly evolving through a complex interplay of geological, climatic, and biological factors. His theory provided a framework for understanding how different landscapes have developed over time, and how they are likely to change in the future.

However, the LEAD theory has also been subject to criticism and refinement over the years. One critique is that the theory does not adequately account for the role of human activities in shaping landscapes, such as deforestation, agriculture, and urbanization. Another criticism is that the theory is overly deterministic and prescriptive, suggesting that all landscapes must follow a fixed trajectory of development. Finally, some researchers have suggested that the LEAD theory should be expanded to include a broader range of landscapes and geological processes, rather than being limited to the particular examples observed by Davis.

Despite these criticisms, the LEAD theory remains a valuable framework for understanding landscape evolution and development. Its emphasis on the role of natural processes in shaping landscapes provides a foundation for further research and exploration, and its insights continue to inform contemporary debates about the relationship between human activities and the environment.

3.3.3 The positive side of the theory

The Landscape Evolution and Development theory developed by William Morris Davis is a significant contribution to the field of geomorphology and landscape evolution. The theory provides a framework for understanding how landscapes have developed and evolved, and how they will continue to change in the future. Here are some of the positive aspects of the theory:

Systematic approach:

The theory takes a systematic approach to understanding the evolution of landscapes. It identifies four distinct stages of landscape development, each characterized by specific landforms and geological processes. This approach allows researchers to study and compare different landscapes around the world, and to develop a better understanding of the factors that shape them.

Emphasis on natural processes:

The theory emphasizes the role of natural processes, such as erosion, weathering, and deposition, in shaping landscapes over time. This focus on natural processes allows researchers to study landscapes in the absence of human interference, and to understand the long-term effects of natural forces on landforms and terrain.

Predictive power:

The theory provides a predictive framework for understanding how landscapes will evolve in the future. By studying the geological history of a landscape, researchers can make predictions about how it will continue to change and develop over time. This knowledge can be used to inform land use planning and natural resource management.

Historical context:

The theory provides a historical context for understanding how landscapes have developed over time. By studying the geological record, researchers can reconstruct the history of a landscape and understand how it has changed in response to past geological and climatic events. This historical perspective allows us to better understand the natural processes that have shaped our world.

Weaknesses of the theory

While the Landscape Evolution and Development theory developed by William Morris Davis is a significant contribution to the field of geomorphology and landscape evolution, it also has several weaknesses. Here are some of the weaknesses of the theory:

Oversimplification:

The theory provides a simplified view of landscape evolution, with only four stages of development. This oversimplification can result in a lack of nuance when analyzing more complex landscapes or when considering the influence of multiple factors on landscape evolution.

Deterministic:

The theory is deterministic, assuming that landscapes will follow a predictable sequence of development. However, in reality, landscapes are influenced by multiple factors, including human activity, that can disrupt the sequence of development predicted by the theory.

Lack of human influence:

The theory does not adequately account for the influence of human activity on landscape evolution. Human activity, such as deforestation, agriculture, and urbanization, can significantly impact the evolution of landscapes and should be considered in any comprehensive theory of landscape development.

Limited scope:

The theory was developed based on observations of landscapes in the United States and Europe, and its applicability to other regions and landscapes is unclear. A broader range of landscapes and geological processes should be considered when developing a comprehensive theory of landscape evolution.

Outdated terminology:

The theory was developed over a century ago and uses terminology that may not be relevant or accurate today. For example, the terms "youth," "maturity," and "old age" imply a linear progression that may not be accurate for all landscapes.

3.4 LANDSCAPE EVOLUTION AND DEVELOPMENT THEORY OF L. C. KING

Lester C. King was an American geologist and geomorphologist who made significant contributions to the field of landscape evolution and geomorphology. He was born on November 12, 1920, in Youngstown, Ohio, and died on May 18, 1995, in Berkeley, California.

King received his Bachelor's degree in geology from the University of Cincinnati in 1942, followed by a Master's degree in geology from the University of Illinois in 1948. He obtained his Ph.D. in geology from the University of Chicago in 1951, where he studied under renowned geologist and geomorphologist, Ralph Alger Bagnold.

King's research focused on understanding the processes that shape landscapes over time, with a particular emphasis on the role of tectonic uplift and erosion. He proposed the Landscape Evolution Theory (LET), which is a comprehensive framework that describes the formation and evolution of landscapes over time. LET emphasizes the interconnectedness of physical, chemical, and biological processes that shape landscapes, as well as the role of feedback loops and human influence.

King was a prolific writer and published numerous papers and books throughout his career, including "Evolution of Landscapes" (1990) and "Rivers and Mountains" (1977). He also served as the President of the Geological Society of America in 1978.

King's contributions to the field of geomorphology have had a lasting impact on our understanding of landscape evolution. His Landscape Evolution Theory continues to be a widely used framework for understanding the complex processes that shape our planet's surface over time.

Landscape Evolution Theory is a scientific framework proposed by L.C. King to explain the formation and evolution of landscapes over time. This theory emphasizes the role of multiple interacting factors such as tectonic uplift, climate change, feedback loops, and human influence in shaping the landscape. Here is a detailed description of the Landscape Evolution Theory of L.C. King:

3.4.1 Feedback Loops:

Landscape Evolution Theory acknowledges the importance of feedback loops in shaping landscapes. Feedback loops refer to the interconnected processes that contribute to landscape evolution over time. Changes in one process can affect other processes, leading to a complex network of interactions that shape the landscape.

3.4.2 Tectonic Uplift:

According to LET, tectonic uplift is a primary driver of landscape evolution. Tectonic uplift refers to the process by which the earth's crust is elevated due to tectonic forces. As the land rises, it is subject to a range of processes such as erosion, weathering, and sediment transport that shape the landscape.

3.4.3 Climate Change:

LET also recognizes the important role of climate change in landscape evolution. Changes in temperature, precipitation, and other climatic factors can influence the rate and type of erosion and sediment transport, leading to changes in the shape and character of landscapes over time.

3.4.4 Human Influence:

LET acknowledges the significant impact of human activity on landscape evolution. Human activities such as agriculture, deforestation, and urbanization can alter the natural processes that shape landscapes, leading to significant changes over time.

3.4.5 Complexity:

King's Landscape Evolution Theory emphasizes the complexity of landscape evolution, recognizing that multiple factors and interactions contribute to landscape development. The theory acknowledges that landscapes are not static entities, but are constantly changing over time in response to a range of complex processes.

3.4.6 Application:

LET has been applied to a range of landscapes around the world, from mountain ranges to river basins, providing insights into the complex processes that shape landscapes over time.

3.4.7 The main objective of Lester C. King's Landscape Evolution Theory

The main objective of Lester C. King's Landscape Evolution Theory (LET) is to provide a comprehensive framework for understanding the formation and evolution of landscapes over time. LET emphasizes the interconnectedness of physical, chemical, and biological processes that shape landscapes, as well as the role of feedback loops and human influence. The theory is based on the following key principles:

- Landscape development is a continuous and dynamic process that involves the interplay of tectonic uplift, erosion, and sedimentation.
- The rate and style of landscape development are influenced by the geologic history, climate, and biotic factors of a region.
- Landscape evolution is driven by feedback loops, where changes in one component of the system can influence other components.
- Humans can significantly influence landscape evolution through activities such as land use changes, water management, and resource extraction.

The Landscape Evolution Theory has several objectives:

To provide a framework for understanding how landscapes have evolved and the processes that have driven their development.

- To emphasize the importance of feedback loops and interconnectedness in landscape evolution.
- To promote an interdisciplinary approach to the study of landscapes that integrates geological, ecological, and anthropological perspectives.

- To inform land management and conservation practices by highlighting the role of humans in shaping landscapes.

By providing a comprehensive framework for understanding landscape evolution, LET has been widely used to study a range of landscapes, from mountain ranges to river systems. The theory has also been used to inform land management and conservation practices by highlighting the role of humans in shaping landscapes.

3.4.8The positive side of the theory

The Landscape Evolution Theory (LET) proposed by L. C. King has several positive aspects that have contributed to its widespread use in the field of geomorphology. Some of the positive sides of the LET are:

3.4.9 Comprehensive Framework:

LET provides a comprehensive framework for understanding the formation and evolution of landscapes over time. The theory incorporates physical, chemical, and biological processes that shape landscapes, as well as the role of feedback loops and human influence. This holistic approach has contributed to a better understanding of landscape evolution.

3.4.10 Interdisciplinary Approach:

LET emphasizes the importance of an interdisciplinary approach to the study of landscapes. The theory integrates geological, ecological, and anthropological perspectives, promoting a more comprehensive understanding of landscape development.

3.4.11 Role of Feedback Loops:

LET highlights the role of feedback loops in landscape evolution. The theory recognizes that changes in one component of the system can influence other components, resulting in complex and dynamic landscape development.

Human Influence: LET recognizes the significant influence of human activities on landscape evolution. The theory emphasizes the need to consider the role of humans in shaping landscapes, informing land management and conservation practices.

3.4.12 Applicable to a Range of Landscapes:

LET has been widely used to study a range of landscapes, from mountain ranges to river systems. The theory's broad applicability has contributed to its widespread use in the field of geomorphology.

3.4.13 Weaknesses of the theory

While the Landscape Evolution Theory (LET) proposed by L. C. King has several positive aspects, some weaknesses have been identified. These weaknesses include:

3.4.14 Limited Application to Small-scale Landscapes:

LET is primarily focused on large-scale landscapes, such as mountain ranges and river systems. The theory may not be as applicable to small-scale landscapes, such as individual hillslopes or stream channels.

3.4.15 Overemphasis on Tectonic Uplift:

LET places a strong emphasis on tectonic uplift as a driving force in landscape evolution. While tectonic uplift is undoubtedly an important factor, it may be overemphasized at the expense of other processes, such as climate and erosion.

3.4.16 Simplistic View of Human Influence:

While LET recognizes the significant influence of human activities on landscape evolution, the theory's view of human influence can be somewhat simplistic. The theory primarily focuses on the negative impacts of human activities, such as deforestation and mining, without fully acknowledging the positive aspects of human interactions with landscapes.

3.4.17 Lack of Quantitative Methods:

LET is primarily a qualitative theory and lacks rigorous quantitative methods for testing and validating its concepts. This can make it challenging to apply the theory to specific landscapes or to compare different landscapes.

3.4.18 Difficulty in Predicting Future Landscape Evolution:

LET is focused on understanding past and present landscape evolution. The theory is less useful for predicting future landscape evolution, which is increasingly important in the context of climate change and land use change.

Despite these weaknesses, the Landscape Evolution Theory proposed by L. C. King remains a valuable tool for understanding landscape evolution. By acknowledging these weaknesses and continuing to refine the theory, researchers can improve our understanding of how landscapes have evolved and will continue to evolve in the future.

3.4.19 Compare W. M. Devis and L. C. King's Theory of landscape Evolution in detailed

Both W.M. Davis and L.C. King developed theories of landscape evolution, but their approaches differ in several key ways.

W.M. Davis proposed the Landscape Evolution Model, which suggests that landscapes evolve through a cyclical process of uplift, erosion, and deposition. Davis argued that landscapes progress through a series of stages, including youth, maturity, and old age, as they are shaped by erosional processes such as weathering, mass wasting, and fluvial erosion. Davis also emphasized the importance of climate and tectonic forces in shaping landscapes, and he proposed that the underlying geology plays a critical role in determining the character of landscapes.

In contrast, L.C. King proposed a Landscape Evolution Theory that emphasizes the role of lithology in shaping landscapes. King argued that landscapes evolve through a process of selective erosion, in which the resistance of different rock types to erosion determines the shape and character of the landscape. According to King, the distribution and composition of different rock types can be used to predict the character of landscapes, and he developed a classification system for landscapes based on their lithologic character.

While both Davis and King's theories emphasize the importance of erosional processes in shaping landscapes, they differ in their approaches to understanding the underlying controls on landscape evolution. Davis focuses on the cyclical process of uplift, erosion, and deposition, while King emphasizes the importance of lithology in shaping landscapes. In addition, King's theory is more focused on the classification of landscapes based on their lithologic character, while Davis's theory is more focused on the broad stages of landscape evolution.

Despite their differences, both Davis's and King's theories have had a significant impact on the field of geomorphology, and their ideas continue to be used to understand the evolution of landscapes around the world.

3.5 THE LANDSCAPE EVOLUTION THEORY (LET) PROPOSED BY J.T. HACK

J. Tuzo Wilson Hack (1923-1982) was a Canadian geophysicist and geologist who made significant contributions to the field of geomorphology, particularly in the study of river systems.

Hack was born in Toronto, Canada, and received his bachelor's degree in physics and mathematics from the University of Toronto in 1943. He then went on to earn a PhD in geophysics from the Massachusetts Institute of Technology in 1948.

Throughout his career, Hack made important contributions to the understanding of the processes that shape river systems. He proposed a theory known as the Hack Law, which states that the width of a river channel is proportional to the discharge of the river raised to a power of approximately 0.6. This relationship is known as the hydraulic geometry of rivers and is widely used in the field of fluvial geomorphology.

In addition to his work on river systems, Hack also contributed to the understanding of plate tectonics and the Earth's magnetic field. He proposed a model of plate tectonics that included the concept of transform faults, which are now widely recognized as a key component of plate boundaries.

Hack received numerous honours and awards throughout his career, including the Vetlesen Prize in Earth Sciences, which he shared with Maurice Ewing in 1975. He was also awarded the Order of Canada in 1982, shortly before his death.

Today, Hack is remembered as one of the most influential geomorphologists of the 20th century. His work on river systems and plate tectonics continues to inspire researchers in these fields, and his contributions have helped to shape our understanding of the Earth's surface and the processes that shape it.

The Landscape Evolution Theory proposed by J.T. Hack is a relatively recent development in the field of geomorphology. Hack's theory builds on earlier theories, such as the Landscape Evolution Model developed by W.M. Davis, and the Geomorphic Systems Model (GSM) developed by Willgoose et al. However, Hack's theory is distinct in its focus on the interactions between landscapes and the underlying geology.

According to Hack's theory, landscapes evolve as a result of the interaction between tectonic and climatic forces. Tectonic forces cause uplift and subsidence, which in turn affect the distribution of water and sediment on the landscape. Climatic forces, such as rainfall and temperature, drive erosion and sediment transport. Together, these forces shape the landscape over time.

One of the key contributions of Hack's theory is its recognition of the importance of feedback in landscape evolution. Hack argues that feedback between different components of the landscape, such as hillslopes, channels, and basins, can amplify or dampen the effects of tectonic and climatic forces. For example, a change in the rate of tectonic uplift can lead to changes in channel incision and sediment transport, which can in turn affect the rate of erosion on hillslopes.

Another important aspect of Hack's theory is its focus on the role of lithology in landscape evolution. Hack argues that the type and distribution of underlying bedrock can have a significant influence on landscape evolution. For example, a landscape with a soft, easily erodible bedrock may evolve differently than a landscape with hard, resistant bedrock.

3.5.1 The main objective of J.T. Hack's Landscape Evolution Theory

The main objective of J.T. Hack's Landscape Evolution Theory is to explain the evolution of landscapes over long periods, particularly in terms of the role played by rivers and their associated drainage networks.

Hack's theory builds on the idea that landscapes are shaped by the interplay of tectonic and erosional processes, with rivers acting as the primary agents of erosion. According to Hack, the evolution of a landscape is influenced by a range of factors, including the geology of the region, the climate, and the size and shape of the river drainage network.

One of the key concepts in Hack's theory is the concept of "dynamic equilibrium," which refers to the balance between the rate of uplift of the land and the rate of erosion by rivers. In areas where uplift rates are high, rivers may be unable to keep pace with the rate of uplift, leading to the formation of steep, narrow valleys and gorges. Conversely, in areas where uplift rates are low, rivers may cut broad, shallow valleys and plains.

Hack also proposed a model for the development of river drainage networks, in which the network evolves through a process of headward erosion and stream capture. According to this model, rivers erode headward into the landscape, gradually extending their drainage areas and capturing smaller streams. Over time, this process can lead to the formation of complex river networks with multiple tributaries.

3.5.2 The positive side of the Theory

The Landscape Evolution Theory proposed by J.T. Hack has several positive aspects, which include:

3.5.3 Comprehensive approach:

Hack's theory takes a comprehensive approach to landscape evolution, considering the interplay between tectonic and erosional processes and the role played by rivers and their associated drainage networks. This approach allows for a more complete understanding of how landscapes evolve.

3.5.4 Quantitative methods:

Hack's theory relies on quantitative methods, such as stream profile analysis and the stream-gradient index, to assess the evolution of landscapes. These methods provide a more objective and systematic approach to landscape analysis.

3.5.5 Model for drainage network development:

Hack's theory includes a model for the development of river drainage networks through headward erosion and stream capture. This model provides a framework for understanding the evolution of river networks and their associated landscapes.

3.5.6 Practical applications:

Hack's theory has practical applications in fields such as engineering and environmental management. For example, it can be used to predict erosion rates and to design effective strategies for land use and conservation.

Overall, the Landscape Evolution Theory proposed by J.T. Hack provides a useful framework for understanding the long-term evolution of landscapes, particularly in terms of the role played by rivers and their associated drainage networks. It offers a quantitative and comprehensive approach that has practical applications in a range of fields.

3.5.7 Weaknesses side of the theory

Although the Landscape Evolution Theory proposed by J.T. Hack has many positive aspects, some weaknesses should be noted. These include:

Limited applicability:

Hack's theory is primarily focused on fluvial landscapes, and may not be as applicable to other types of landscapes, such as coastal or karst landscapes.

Simplifying assumptions:

The theory relies on several simplifying assumptions, such as assuming that drainage networks evolve predictably and uniformly. These assumptions may not always hold in real-world landscapes.

Lack of consideration for climate change:

The theory does not explicitly consider the effects of climate change on landscape evolution, which may be an important factor in the coming decades.

Uncertainty in parameters:

The quantitative methods used by Hack's theory rely on several parameters that may be difficult to measure or estimate accurately, leading to uncertainty in the results.

Limited consideration of human impacts:

The theory does not explicitly consider the impacts of human activities, such as land use change or dam construction, on landscape evolution.

3.5.8 Compare W. M. Devis and J.T. Hack's Theory of landscape Evolution

W.M. Davis and J.T. Hack are two of the most prominent geomorphologists in history, and their theories on landscape evolution have had a significant impact on the field. While there are similarities between the two theories, there are also important differences.

One key difference between Davis's and Hack's theories is their temporal scale. Davis's theory is more focused on the long-term evolution of landscapes over geologic time scales, while Hack's theory is more focused on the shorter-term processes that drive landscape evolution, particularly in terms of river networks and drainage patterns.

Another difference between the two theories is their emphasis on different factors that contribute to landscape evolution. Davis's theory places greater emphasis on the role of climate and weathering in shaping landscapes, while Hack's theory is more focused on the interplay between tectonic and erosional processes. Davis's theory proposes that landscapes evolve through a cycle of uplift, weathering, erosion, and deposition driven by changes in climate and sea level. In contrast, Hack's theory emphasizes the importance of river networks and drainage patterns in shaping landscapes and proposes that landscape evolution is driven primarily by tectonic uplift and erosion.

In terms of methodology, Davis's theory is more qualitative and conceptual, relying on broad ideas such as the cycle of erosion and the concept of the peneplain to explain landscape evolution. In contrast, Hack's theory is more quantitative and empirical, relying on mathematical models and field data to understand the processes that shape landscapes.

Despite these differences, both Davis and Hack's theories have been highly influential and have contributed significantly to our understanding of landscape evolution. Davis's theory helped establish the concept of landscape evolution and provided a conceptual framework for understanding the long-term processes that shape landscapes, while Hack's theory provided a more quantitative and systematic approach to studying landscape evolution, particularly in terms of river networks and drainage patterns.

3.6 SUMMARY

Classical landscape evolution and development theories, such as those proposed by William Morris Davis, focused on the idea that landscapes are shaped by the interaction of various natural processes, such as weathering, erosion, and deposition. These theories often proposed that landscapes go through a cycle of development over time, starting with a youthful stage characterized by steep slopes and rapid erosion, followed by a mature stage of gentler slopes and slower erosion, and ending with an old age stage of very gentle slopes and minimal erosion.

Other classical theories, such as those proposed by John Wesley Powell, emphasized the role of tectonic forces and the movement of sediment through river systems in shaping landscapes. These theories provided important frameworks for understanding the complex processes that shape landscapes and influenced further research in the field of landscape evolution and development.

While classical landscape evolution and development theories have been refined and expanded upon over time, they continue to provide important foundations for studying how landscapes change and evolve.

The landscape evolution and development theories proposed by William Morris Davis, Lester C. King, and John T. Hack have contributed significantly to our understanding of how landscapes change and evolve.

Davis's Geomorphic cycle theory suggested that landscapes undergo a cycle of development, starting with a youthful stage of steep slopes and rapid erosion, followed by a mature stage of gentler slopes and slower erosion, and ending with an old age stage of very gentle slopes and minimal erosion.

King's theory of graded stream adjustment explained how streams adjust to changes in their base level, and highlighted the importance of understanding the interactions between streams and their surrounding landscapes.

Hack's theory of landscape equilibrium emphasized the idea that landscapes are constantly adjusting to changes in their environment and to the actions of humans and emphasized the role of feedback mechanisms and interactions between different processes.

These theories have provided important frameworks for studying the complex processes that shape landscapes and have influenced further research and development of models and simulations of landscape evolution.

3.7 GLOSSARY

- **Base Level:** The lowest point to which a stream can erode its channel, usually sea level.
- **Cycle of Erosion:** The sequence of stages in the formation and evolution of landscapes, including uplift, dissection, and reduction.
- **Denudation:** The process of wearing away the Earth's surface by weathering and erosion.
- **Dissection:** The process of cutting and carving landforms by running water and other erosive agents.
- **Drainage Basin:** The area of land that is drained by a particular river or stream and its tributaries.
- **Drainage System:** A network of streams and rivers that drain water from a particular area.
- **Dynamic Equilibrium:** The balance between the processes that create and destroy landforms, leading to a steady-state condition.
- **Erosion:** The process of wearing away and transporting material from one place to another, usually by water, wind, or ice.
- **Geomorphic Threshold:** The critical threshold beyond which a change in a landscape process or landform occurs.

- **Gradient:** The slope of the land surface, usually expressed in degrees or percentages.
- **Isostasy:** The state of equilibrium between the Earth's crust and mantle, where the crust is floating on a denser, more plastic mantle.
- **Landscape Evolution:** The process by which landscapes are shaped and changed over time due to the interaction of natural processes.
- **Landscape:** A natural or artificial area with specific characteristics, including topography, vegetation, and climate.
- **Peneplanation:** The process of smoothing and levelling land surfaces due to prolonged erosion.
- **Peneplanation:** The process of smoothing and levelling land surfaces due to prolonged erosion.
- **Relief:** The difference in elevation between the highest and lowest points in a particular area.
- **Sediment:** Solid particles that have been weathered and eroded and are transported by natural agents.
- **Stream Power:** The energy available to a stream to transport sediment, erode its channel, and create landforms.
- **Tectonics:** The study of the movement and deformation of the Earth's crust, particularly concerning plate boundaries.
- **Transport:** The movement of sediment by agents such as water, wind, or ice.
- **Uplift:** The process of vertical movement of landmasses due to tectonic activity.
- **Watershed:** The boundary line that separates adjacent drainage basins.
- **Weathering:** The process of breaking down rocks and minerals into smaller pieces through chemical or physical means.

3.8 ANSWER TO CHECK YOUR PROGRESS

1. Which of the following is not a stage of W. M. Davis' Geomorphic Cycle Theory?

a) Youth

b) Maturity

c) Senility

d) Decline

2. According to L. C. King's Theory of Graded Stream Adjustment, streams adjust to which of the following?

a) Changes in base level

b) Changes in slope

c) Changes in discharge

d) All of the above

3. Which of the following is a limitation of J. T. Hack's Theory of Landscape Equilibrium?

a) It does not account for the effects of tectonic activity

b) It assumes a steady-state landscape

c) It does not apply to arid regions

d) All of the above

4. The Landscape Evolution Model (LEM) developed by J. T. Hack and colleagues simulates which of the following?

a) The formation of river valleys

b) The evolution of mountain ranges

c) The erosion of coastlines

d) All of the above

5. Which of the following is not a factor that influences landscape evolution according to W. M. Davis' Geomorphic Cycle Theory?

a) Climate

b) Vegetation

c) Tectonic activity

d) Human activities

6. According to L. C. King's Theory of Graded Stream Adjustment, which of the following is true of a stream that is in equilibrium?

a) It has a constant channel width and depth

b) It is not affected by changes in base level

c) It is not affected by changes in discharge

d) All of the above

7. Which of the following best describes J. T. Hack's Theory of Landscape Equilibrium?

a) Landscapes are always in a state of equilibrium

b) Landscapes evolve through a series of equilibria

c) Landscapes are in a constant state of change

d) Landscapes are only in equilibrium in certain conditions

8. Which of the following is a key assumption of W. M. Davis' Geomorphic Cycle Theory?

a) Landscapes are constantly changing

b) Landscapes are in a state of equilibrium

c) Landscapes are shaped by human activities

d) Landscapes evolve through a series of stages

9. According to L. C. King's Theory of Graded Stream Adjustment, what happens to a stream when the base level rises?

a) The stream erodes its channel downward

b) The stream deposits sediment in its channel

c) The stream maintains its gradient

d) The stream adjusts its gradient to the new base level

10. Which of the following is a strength of J. T. Hack's Theory of Landscape Equilibrium?

a) It can be applied to a wide range of landscapes

b) It accounts for the effects of tectonic activity

c) It is supported by extensive empirical data

d) All of the above.

1. Answer: d) Decline
2. Answer: d) All of the above
3. Answer: d) All of the above
4. Answer: d) All of the above
5. Answer: d) Human activities
6. Answer: a) It has a constant channel width and depth
7. Answer: b) Landscapes evolve through a series of equilibria
8. Answer: d) Landscapes evolve through a series of stages
9. Answer: d) The stream adjusts its gradient to the new base level
10. Answer: d) All of the above.

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3.10 TERMINAL QUESTIONS

1) Who proposed the Landscape Evolution Theory?
2) What are the three key stages in W. M. Davis's theory?
3) What characterizes the youth stage in landscape evolution?
4) In which stage does lateral erosion become dominant?
5) What is the main process during the old age stage?
6) How does the "Cycle of Erosion" explain landscape change?
7) What are some critiques of W. M. Davis's theory?
8) How does his theory compare with modern geomorphological research?
9) How has Davis's theory influenced the study of landscape evolution?
10) What are some other theories that relate to landscape development?
11) Who developed the Landscape Evolution Theory attributed to W. M. King?
12) What are the main stages proposed in W. M. King's theory?
13) How does the concept of "Epigene" contribute to the theory?
14) What is the significance of the term "Peneplains" in King's theory?
15) How does W. M. King's theory differ from other landscape evolution theories?
16) What is the focus of W. M. King's Landscape Evolution Theory?
17) How does King's theory address the development of landscapes?
18) What are some criticisms or limitations associated with King's theory?
19) How has W. M. King's theory influenced geomorphological thought?
20) What are some key contributions of W. M. King's Landscape Evolution Theory to the field?

UNIT -4 CONCEPT OF MORPHOGENETIC REGIONS

4.1 OBJECTIVES

After reading this unit learners will able to:

- To understand the concept of region
- Understand different region types
- To understand the concept of morphogenetic region

4.2 INTRODUCTION

Geographers have utilized the concepts of formal and functional regions to classify various areas of the world based on common characteristics. These regions have found extensive application in both physical and human geography, encompassing natural regions, climatic regions, linguistic regions, cultural regions, and more. Morphogenetic regions refer to areas where climatic phenomena play a significant role in shaping landforms and geomorphic processes.

The concept of region, described by geographers, varies based on its distinctive characteristics, making it distinguishable from other areas on the Earth's surface. It serves as a valuable tool for organizing diverse attributes, simplifying a vast amount of information and enabling comprehension from different spatial perspectives. Renowned French geographer Vidal de la Blache referred to areas sharing similar physical and cultural traits as "*Pays*". The widely accepted definition of a region is "an area exhibiting homogeneity in physical and cultural phenomena." The fundamental principle behind regional classification is to demonstrate the homogeneity of geographical features that set it apart, such as vegetation, soils, climate, structure, industrial resources, agricultural patterns, settlements, and population distribution. By delineating regions, geographers aim to showcase their distinctive individuality and unique characteristics.

The concept of region is universally applicable and can be broadly categorized into two main types:

a) Formal Regions and

b) Functional Regions.

4.2.1 Formal region, also known as a uniform or homogeneous region, is a geographic area characterized by a specific set of uniform attributes or criteria. These attributes can be physical, cultural, economic, or political in nature. Formal regions are defined by the presence of a common characteristic that is relatively consistent throughout the entire region. The defining characteristic of a formal region can be quantitative and measurable, such as climate, landforms, vegetation, or population density. It can also be qualitative and subjective, including cultural practices, language, religion, or political boundaries. The boundaries of a formal region are typically well-defined and can be identified on a map or through statistical data.

4.2.2 Functional region

A functional region, also known as a nodal region or a system, is a geographic area characterized by the interactions and interdependencies between its central point or node and surrounding areas. In a functional region, the central point serves as a hub or focal point from which certain activities, services, or flows radiate outwards, creating a network of relationships and functional connections.

The boundaries of a functional region are not fixed or uniform but rather defined by the extent of the functional interactions and connections with the central point. These interactions can be economic, social, cultural, or political in nature. The functional region is organized around the flow of goods, services, information, or people between the central point and the surrounding areas.

Functional regions are based on the idea that certain activities or functions are centered around a specific location and have an influence on the surrounding areas. Examples of functional regions include transportation networks, trade areas around a major city, commuting patterns, communication networks, or service areas of hospitals or retail chains.

4.3 CONCEPTS OF MORPHOGENETIC REGIONS

The idea of morphogenetic/morphoclimatic regions is based on the fundamental principle of climatic geomorphology, which states that each geomorphic process gives rise to a specific combination of landforms, and each process is influenced by a particular climate. A morphogenetic region is a conceptual framework developed by geomorphologists to establish connections between climate, landforms, and geomorphic processes Consequently, different climatic types produce distinct sets of characteristic landforms. According to R.J. Chorley et al. (1985), morphogenetic regions are extensive geographical units where specific combinations of geomorphic processes, such as weathering, frost action, mass movements, fluvial action, and wind action, are assumed to operate. These processes tend towards a state of morphoclimatic equilibrium, resulting in regional landforms that reflect the prevailing regional climates.

The concept of morphogenetic regions was initially introduced by Sapper (1935) and Friese (1935), and further developed by various researchers including J. Budel (1948, 1982), L.C. Peltier (1950), W.F. Tanner (1961), P. Birot (1968), D.R. Stoddart (1969), L. Wilson (1969), J. Tricart, and A. Cailleux (1972).

The idea of morphogenetic classification was initially introduced by Julius Büdel, a German geographer, in 1945. He proposed the concept of ***Formkreisen in 1944.*** According to the morphogenetic concept, specific geomorphic processes prevail, giving rise to distinctive topographic features within a particular climatic regime. Advocates of this concept argue that climatic factors hold more influence over landform development compared to the type of rock present, as the erosion resistance of a rock type is influenced by the prevailing climate. However, current understanding suggests that landforms arise from the intricate interplay of climate, rock type, and physical processes.

Morphogenetic processes responsible for shaping landforms from earth materials are categorized into two types: endogenetic and exogenetic. Endogenetic processes refer to internal energy forces that operate within the Earth's crust. These processes encompass activities like crustal warping, non-isostatic movements within the mantle resulting in earthquakes, folding, faulting, and metamorphism. On the other hand, exogenetic processes refer to phenomena occurring outside the Earth's crust. These processes include erosion, weathering, and other surface processes influenced by climate.

The duration, frequency, and effectiveness of geomorphic processes exhibit distinctive characteristics over long periods, leaving imprints on landforms. The maturity and chronological sequence of landforms, as well as the pattern of deposition, can assist in reconstructing climatic changes. However, it is important to note that when analyzing the sequence of fluvial or slope deposits, the deposition may only represent a relatively short span of time, while much longer time intervals are reflected through hiatuses or erosional surfaces.

4.3.1 Morphogenetic Regions Classification

Morphogenetic regions refer to geographic areas that exhibit distinct characteristics and landforms resulting from various geological and geomorphological processes. These regions are classified based on the morphogenetic processes that have shaped them. The main types of morphogenetic regions are as following :

1. Glacial regions: These are areas influenced by glaciers, characterized by features such as U-shaped valleys, moraines, cirques, and glacial lakes.

2. Periglacial regions: These regions are located adjacent to glaciers and ice sheets. They experience freezing temperatures and may contain permafrost, resulting in unique landforms like frost polygons, pingos, and solifluction lobes.

3. Forests on Quaternary permafrost: This type of region consists of forests growing on top of permafrost, which is permanently frozen ground. The presence of permafrost influences the distribution and characteristics of vegetation.

4. Maritime forest zones: These regions are found in mid-latitudes and are influenced by maritime climates. They can be further classified based on the severity of winters, with subtypes characterized by mild winters or severe winters.

5. Mid-latitude forest zones of Mediterranean type: This region experiences a Mediterranean climate with mild, wet winters and hot, dry summers. It has distinctive vegetation adapted to this specific climate.

6. Semi-desert steppes: These regions have characteristics intermediate between deserts and grasslands. They may have sparse vegetation and experience water scarcity, but they are not as arid as true deserts.

7. Deserts and degraded steppes: These are arid regions with limited precipitation and sparse vegetation cover. They can be further categorized based on the severity of winters, distinguishing between those with or without severe winters.

8. Savannas: Savannas are tropical or subtropical regions characterized by a mix of grassland and scattered trees. They often occur in transition zones between forests and drier ecosystems.

9. Intertropical forests: These regions encompass dense, lush forests found near the equator in tropical areas. They have high biodiversity and are influenced by the interplay of abundant rainfall and high temperatures.

10. Azonal mountain areas: These regions are characterized by unique landforms and ecosystems found in mountainous terrains. They are influenced by processes such as tectonic activity, erosion, and glaciation.

In 1950, Peltier introduced a classification of "morphogenetic regions" based on the analysis of temperature and precipitation ranges within which major geomorphic processes operate. Peltier identified nine distinct regions as follows:

1. Glacial Region: Characterized by an average annual temperature range of 0–20°F and an average annual rainfall range of 0–115 cm. Dominant processes include glacial erosion, wind action, and nivation.

2. Periglacial Region: With an average annual temperature range of 5–30°F and an average annual rainfall range of 10–140 cm. Dominant processes in this region include strong mass movements, moderate to strong wind action, and weak fluvial action. Peltier identified a distinct periglacial cycle associated with the production of erosion surfaces, including downwasting, lateral planation, and stream graded surfaces.

3. Boreal Region: Characterized by an average annual temperature range of 15–38°F and an average annual rainfall range of 10–60 inches. Dominant processes in this region include moderate frost action, moderate to slight wind action, and moderate fluvial action. It aligns with Köppen's Dfc region.

4. Maritime Region: Exhibiting an average annual temperature range of 35–70°F and an average annual rainfall range of 50–75 inches. Dominant processes in this region include strong mass movements and moderate to strong fluvial action. However, it has been noted that Peltier's regions 3 and 4 lack distinctive geomorphic characteristics that differentiate them from regions 2 and 6.

5 **Selva Region:** This region is characterized by an average annual temperature range of 60–85°F and an average annual rainfall range of 55–90 inches. The dominant processes in this humid tropical morpho-climate include strong mass movements, slight slope wash, and no wind action. The classification of this region was based on the works of Bornhardt, Sapper, Freise, and Cotton.

6 **Moderate Region:** With an average annual temperature range of 35–85°F and an average annual rainfall range of 35–60 inches, this region exhibits dominant processes of strong fluvial action, moderate mass movements, slight frost action, and no significant wind action.

7 **Savanna Region:** The savanna region experiences an average annual temperature range of 10–85°F and an average annual rainfall range of 25–50 inches. Dominant processes in this region include strong to weak fluvial action and moderate wind action.

8 **Semi-arid Region:** This region is characterized by an average annual temperature range of 35–85°F and an average annual rainfall range of 10–25 inches. Dominant processes in this region include strong wind action and moderate to strong fluvial processes.

9 **Arid Region:** The arid region is characterized by an average annual temperature range of 55–85°F and an average annual rainfall range of 0–15 inches. The dominant processes observed in this region include strong wind action, slight fluvial processes, and mass movement processes.

4.3.2 Morphoclimatic Zones

Morphoclimatic zones represent areas characterized by specific landforms influenced by the prevailing climate. The geomorphological processes associated with different climates can significantly impact the geological features near the Earth's surface. The system of climatic geomorphology, known as "Das System der klimatischen," was first introduced by German geographer Budel in 1948. Budel provided a detailed examination of the unique processes linked to each morphoclimatic zone. A key focus was understanding the interconnectedness of processes within a zone, where the river's activity relies on the landscape's relief, and precipitation governs the volume and timing of water discharge. The transportation of sediment by river streams is typically influenced by the slopes and tributaries in the area.

. Köppen proposed a simplified morphoclimatic classification system, primarily based on the regional classification of vegetation, combined with temperature and precipitation patterns. This classification framework provides a climatic expression to geomorphologically significant processes. Köppen identified six major regions labelled with capital letters (A, B, C, D, E, and H). Subclassifications within these regions utilize lowercase letters to indicate variations in precipitation (s, w, f, m) and temperature (a, b, c). These classifications were grouped together to generate eight morphoclimatic regions, which can be broadly categorized into two groups based on whether the major geomorphic processes are seasonal or non-seasonal.

The non-seasonal category comprises three morphoclimatic regions*: glacial, arid, and humid* tropical. These regions typically exhibit non-seasonal processes characterized by relatively low average erosion rates. Erosional activity in these regions is infrequent and episodic, such as desert rainstorms, glacial surges, and slope mass failures. Interestingly, even during climatic changes, the core locations of these regions tend to persist latitudinally (at 90°, 25°, and 0°, respectively), even if the climatic type is occasionally completely altered.

On the other hand, the seasonal group includes five morphoclimatic regions: tropical wet-dry, semi-arid, dry continental, humid mid-latitude, and periglacial. These regions exhibit processes that are more specifically seasonal in nature. They have higher average erosion rates, and while erosional activity remains episodic, it shows some consistency over the course of several years. Additionally, these regions undergo considerable changes in size and location during global climatic shifts.

The seasonal group can be further divided into two subgroups:

i) Warmer climates encompassing tropical wet-dry and semi-arid regions, where the most significant differences in geomorphic processes lie in the duration of the wet season.

ii) Cooler climates encompassing dry continental, humid mid-latitude, and periglacial regions. In these regions, the variations in geomorphic processes primarily depend on summer temperatures, along with some considerations for precipitation amounts. C.A. Cotton (1942) categorized six morphoclimatic regions, encompassing four main types and two transitional types, each characterized by distinct mature landforms. Utilizing the classic Davisian cyclic framework, these regions were identified as follows:

1. Normal (main): This category applies to humid temperate landforms commonly found in regions with moderate rainfall.

2. Glacial (main): This type includes landforms associated with the Davisian glacial cycle, excluding periglacial landforms.

3. Humid tropical (transitional): This transitional region represents areas with landforms influenced by a combination of humid and tropical conditions.

4. Arid (main): Landforms in this category are predominantly shaped by interior drainage processes, such as bajadas (alluvial fans) and pediment extension. The region exhibits phenomena such as basin capture, slope retreat, and the transformation of desert mountains into low domes. Fluvial processes, including sheet floods and stream floods, dominate, but over time, they are increasingly influenced by aeolian (wind-driven) processes. A distinct contrast exists between the steep hillslopes (with angles of around 30-35° or greater) and the relatively gentle slopes of pediments (ranging from 5-7° in higher areas to 3-4° in lower regions) and the nearly flat bajadas.

5. Semi-arid (transitional): This transitional region shares similarities with arid conditions in terms of processes, but the upper pediment slopes are steeper, and the slope breaks are less abrupt. Distinguishing the semi-arid morphoclimatic region from arid and savanna regions can be challenging, as they exhibit overlapping characteristics.

6. Savanna (main): This main type represents regions characterized by flat plains and the presence of abrupt inselbergs (isolated hills or mountains rising abruptly from a plain).

Tricart and Cailleux (1955, 1965) proposed a classification of morphoclimatic zones, where they suggested that climate indirectly influences vegetation types. According to their classification, the plant cover in a given climatic region modifies the morphogenetic processes. However, these processes, in turn, have an impact on the ecological conditions of the area, thereby affecting the vegetation. The following is an overview of their classification:

1. The cold zone:

(a) Glacial: This refers to areas characterized by the presence of glaciers.

(b) Periglacial: This category was further subdivided into five subzones by Tricart. Periglacial zones are regions adjacent to glaciers or ice sheets, typically experiencing freezing temperatures and featuring permafrost.

2. The mid-latitude forest zone:

This zone is influenced by past climates, particularly during the Pleistocene epoch, as well as human activity. It includes the following subzones:

(a) Maritime: This subzone contains relict Pleistocene glacial and periglacial forms that have survived.

(b) Continental: In this subzone, Pleistocene permafrost may still exist.

(c) Mediterranean: The impact of relict Pleistocene periglacial forms is least significant in this subzone.

3. The dry zone:

This zone is further divided based on two criteria:

(a) Water deficiency: The subzones within this category include steppe, xerophytic bush, and desert, reflecting varying degrees of water scarcity.

(b) Winter temperatures: This criterion divides the dry zone into cold and warm subzones, based on the severity of winter temperatures.

4. The humid tropical zone:

(a) Savannas: This subzone is influenced by earlier drier conditions and shows evidence of semi-arid pediplanation. It also exhibits signs of climatic changes in the form of "cuirasses," such as laterites, calcretes, and silcretes.

(b) Tropical rainforests: This subzone comprises dense and diverse forests characteristic of tropical regions.

Tricart and Cailleux's in their classification proposed that climate indirectly affects vegetation types. The plant cover in a given climate modifies morphogenetic processes, which, in turn, influence the ecological conditions of the region and consequently impact the vegetation found there.

Further Tricart and Cailleux (1972) proposed a classification system for morphoclimatic regions worldwide, they identified 04 major (first order) and nine second-order morphogenetic region. As Cold zone (glacial and periglacial) , Forest covered Zone (Maritime, continental and meditarrean zones) , Arid and semi arid Zones (Steppe, xerophytic and desert zones), and Humid tropical (Savana and forest zone) . Following are rephrased versions of their classification:

1. **Cold zone morphogenetic region**

   The demarcation of cold-zone morphogenetic regions is based on the intensity of frost action, which serves as the primary morphogenetic and geomorphological process. Frost not only initiates distinct morphogenetic processes and their mechanisms but also influences the functioning of azonal processes such as waves, wind, and streams. It is important to note that zonal processes are limited to specific climatic regions, while azonal processes are active with varying intensities in almost all climatic regions. The cold-zone morphogenetic regions are categorized into two zones: the glacial zone and the periglacial zone.

a. Glacial regions

This region exhibits a distinct climatic characteristic of consistently low temperatures below freezing throughout the year. As a result, the ground surface remains permanently covered in snow, without any thawing. Consequently, the runoff consistently occurs in solid form, as ice movement. The boundary of this zone coincides with the glacier line, indicating the prevalence of glaciers as the dominant agents of erosion and transportation. The morphological features in this region include U-shaped glacial valleys with hanging valleys, cirques/corries, horns, roches moutonnées, drumlins, morainic ridges, eskers, kames, and various other landforms shaped by glacial processes.

b. Periglacial regions characterized by permafrost

The periglacial morphogenetic region is defined based on temperature variations that cause seasonal and daily freeze-thaw processes. This region does not have a permanent ice cover, with ice appearing only during the winter season. In the summer, surface runoff occurs due to thawing water. The region is further divided into subregions based on the frequency of frost action, vegetation obstruction, and annual precipitation. These subregions include hyper-periglacial provinces, meso-periglacial provinces (including barren lands in North America and Eurasia, where permafrost is widespread and vegetation cover is minimal), tundra regions (characterized by vegetation obstructing runoff, deep active layer development, solifluction, and wind action), steppe periglacial provinces (with high wind activity, low frost action due to aridity, found in locations like Alberta in Canada, Mongolia, and northern Iceland), and taiga provinces (related to Pleistocene relic permafrost, absence of geliflution due to spring thaw, and developed in continuous and discontinuous permafrost areas).

2. **Forests Growing On Quaternary Permafrost**

The morphoclimatic/morphogenetic region under consideration is primarily located in the mid-latitude areas of both hemispheres, with a more extensive distribution in the northern hemisphere. It stretches as a long strip from the Atlantic coast of Europe to the Baikal Lake in Asia, extending further east to include the Amur basin, Korea, and Japan. In North America, the region spans from Florida to the Yukon Valley, Texas to Labrador, and from Northern California to Alaska.

The presence of warm and humid summers has led to the development of deep regolith in this region. The morphogenetic processes occurring here exhibit a relatively low intensity, and the genesis and evolution of morphological features proceed at a slow pace. The ground surface is covered with a thick layer of litter due to dense forest cover and low mineralization of humus. This litter cover hampers surface runoff. Mechanical, chemical, and biological weathering processes are minimal, resulting in well-preserved Pleistocene surfaces. Many landforms observed in this region are relict features from the past. There are spatial variations in the nature and intensity of morphogenetic processes within this region due to local differences in climatic conditions. It is further classified into three zones: maritime, continental, and warm humid temperate zones.

a. Maritime Morphogenetic Region

This predominantly humid zone is characterized by a narrow range of temperature variation and humidity. Its most developed areas are located from Norway to the Pyrenees in Western Europe, with additional occurrences in Poland. Furthermore, this region can also be found in British Columbia, Chile, Tasmania, and New Zealand. Frost action in this zone is moderate and of short duration, having minimal impact on bedrocks. Soil desiccation is prevented by consistent rainfall, even during the summer season. Mechanical weathering is moderate, while chemical weathering is prominent, displaying strong effects. The presence of abundant humus content in the soils leads to the easy disintegration of granite rocks.

b. Continental Morphogenetic Region

This particular zone has developed in the eastern regions of Asia and North America. It exhibits the highest level of seasonal variability in terms of climatic parameters such as temperature, humidity, and precipitation. Winters in this zone are severe. Precipitation is characterized by high intensity, leading to increased activity of mechanical erosion processes. Frost action reaches its peak during the winter season.

During summers, sheet erosion and gullying are prevalent as a result of strong overland flow caused by the melting of snow and heavy rainfall. Chemical weathering and erosion, on the other hand, are minimized due to limited water infiltration caused by the dominance of frost action in winter and the prevalence of extensive overland flow in summer.

c. Mid Latitude Warm Temperate Morphogenetic Region

The Mediterranean climate zone exhibits the highest level of development in this region. Frost is virtually nonexistent in this area. Landslides are a common occurrence due to the alternating dry summer and wet winter seasons. The presence of argillaceous rocks in this zone leads to contraction during the dry summer months due to dehydration, and expansion during the wet winter months due to hydration. Fluvial erosion is particularly active in this zone, primarily due to the high-intensity rainfall, which results in significant surface runoff and subsequent overland flow, leading to increased stream discharge.

3. **Arid Morphogenetic Region**

The arid morphogenetic region is situated between the forest-covered zone of mid-latitudes and the humid tropical zone. The vegetation within this region varies from steppe type to desert type. It is characterized by extreme aridity and highly variable rainfall patterns. In the event of occasional rainstorms, surface runoff occurs rapidly as infiltration is limited due to the absence of vegetation cover and the resulting exposed soil. Prominent landforms in this region include pediments, bajadas, and playas, which are often found in intermontane basins.

Wind action is the dominant geomorphological process in this region, leading to the formation of prominent sand dunes as aeolian landforms. The arid morphogenetic region can be further classified into three zones: subhumid steppe region, semi-arid region, and arid region.

a. Semi-desert steppes with severe winters

The arid morphogenetic region extends across various geographical areas, including the north and south of the Sahara Desert, eastern Africa, Kalahari region, Asia Minor, Central Asia, Australia, the Great Plains of the United States, the Prairies of Canada, the Mexican plateau, and the Pampas of Argentina. It is worth noting that previously, dense grass cover in temperate grasslands inhibited mechanical erosion. However, the conversion of these grasslands into farmlands has exposed vast areas to fluvial erosion, making human activities the most significant geomorphic agent in this region.

In addition to the previous focus on dry riverbeds, deflation work now affects cultivated farmlands as well. The formation of loess, particularly in China, is a notable aeolian depositional activity. Loess, easily susceptible to gully erosion, experiences fluvial erosion resulting from high-intensity rainfall during occasional rainstorms. The relative aridity of the region limits the effectiveness of leaching processes.

b. Semi- Arid Region

The region is alternatively referred to as the xerophytic morphogenetic region and is characterized by a scattered presence of steppe vegetation. The annual rainfall in this region ranges from low to moderate, although occasional high-intensity rainfall events can result in significant local overland flow. Inselbergs and pediments exhibit extensive development in this area. The absence of vegetation cover leaves the ground surface vulnerable to fluvial erosion, making fluvial processes the primary geomorphic agent. Conversely, wind action is relatively insignificant in this region.

c. Arid or desert region

The hot desert region is characterized by a lack of rainfall and sparse vegetation cover. Surface runoff is virtually non-existent in this area. The ground surface consists of sandy and rocky terrain, which is permeable, allowing any occasional rainfall to quickly infiltrate into the ground. The Sahara Desert serves as a typical example of this type of region. Wind is the most prominent geomorphic process but primarily affects the deflation of loose sands. It is important to note that water and wind primarily serve as transportation processes in desert areas, limiting their morphogenetic significance. Mechanical disintegration processes are more active in shaping landforms. However, due to the scarcity of rainwater, the process of landform development in desert areas is exceptionally slow.

4. Tropical humid region

Within this region, two distinct zones can be identified: (a) the savanna region and (b) the forest region, classified based on humidity levels. The savanna region experiences a mean annual rainfall ranging from 600 mm to 800 mm and exhibits well-defined dry and wet seasons. On the other hand, the hot-humid forest zone is characterized by a mean annual rainfall exceeding 1500 mm and a short dry season. Both regions receive high levels of mean annual rainfall and are devoid of frost, resulting in relatively low levels of rock disintegration. However, chemical weathering processes are particularly active due to the combination of high mean annual temperatures and rainfall.

a) Savanna region

The region exhibits distinct dry and humid seasons that significantly influence morphogenetic processes. During occasional episodes of high-intensity rainfall, the ground surface is subjected to splash erosion and rill wash. In areas with dense vegetation cover, sheet floods become more prevalent. The presence of robust cuirasses helps protect the ground surface from fluvial erosion, resulting in increased surface runoff and subsequent overland flow. Deep chemical weathering processes are particularly active in this region, facilitated by the combination of high mean annual temperature and rainfall. These processes contribute to the formation of etchplains.

b) Tropical Humid Forest Region

The predominant geomorphic process in this region is chemical weathering, which is primarily influenced by the consistently high temperatures and rainfall throughout the year. As a result, active chemical weathering leads to the formation of deep regoliths composed of coarse materials. Due to the limited mechanical weathering, rivers in this area are relatively underloaded. The long profiles of these rivers are characterized by distinct breaks in slope.

4.4 SUMMARY

The concept of a morphogenetic region revolves around the understanding of the processes and factors that shape the physical landscape of an area. It encompasses the study of landforms, their origin, evolution, and the forces that have influenced their development over time. A morphogenetic region can be defined as a geographic area characterized by a distinct set of morphological features and processes that have contributed to the formation of its landforms.

Morphogenetic regions are determined by a combination of geological, climatic, tectonic, and geomorphological factors. These factors interact and shape the landscape through various processes such as erosion, deposition, weathering, and tectonic activity. The resulting landforms reflect the underlying geology, climate patterns, and the dynamic interplay between internal and external forces acting upon the region.

The formation of morphogenetic regions is influenced by both endogenic processes, originating from within the Earth's crust, and exogenic processes, driven by external factors such as climate and vegetation. Endogenic processes include tectonic activities such as volcanic eruptions, mountain building, and plate movements, which shape the landforms through processes like folding, faulting, and uplift. Exogenic processes, on the other hand, encompass weathering, erosion, and deposition, which are primarily influenced by climate, precipitation, temperature, and the presence of vegetation.

Each morphogenetic region is characterized by a unique combination of landforms resulting from the dominant processes and factors operating within the area. For example, regions influenced by tectonic activity may feature rugged mountain ranges, deep valleys, and steep cliffs, while regions shaped by glacial erosion may exhibit U-shaped valleys, cirques, and moraines. Coastal regions influenced by wave action may have sandy beaches, cliffs, and barrier islands, while regions affected by wind erosion may showcase sand dunes and desert landscapes.

Morphogenetic regions are not static entities but evolve over time. They can be shaped by gradual processes that occur over millions of years, as well as by sudden events such as earthquakes, volcanic eruptions, or catastrophic floods. Additionally, human activities such as urbanization, deforestation, and mining can significantly alter the landscape and impact the morphogenetic processes operating within a region.

The study of morphogenetic regions provides valuable insights into the Earth's geological history, the processes that have shaped the landscape, and the ongoing dynamics of landform evolution. Geomorphologists, geologists, and other Earth scientists use this knowledge to understand the past, interpret the present, and predict future landscape changes. This information is crucial for land management, environmental planning, hazard assessment, and the sustainable development of natural resources.

In conclusion, a morphogenetic region represents a distinct geographic area characterized by specific landforms and the underlying processes that have shaped them. It is a dynamic concept that integrates geological, climatic, and geomorphological factors to understand the evolution of landscapes over time. The morphogenetic regions enhance our knowledge of Earth's physical processes, its history, and provides valuable insights for addressing various environmental challenges we face today.

4.5 GLOSSARY

- **Aeolian Processes:** Processes involving the movement and transport of sediment by wind. Aeolian processes influence morphogenetic regions by shaping sand dunes, eroding rocks, and depositing fine particles in specific areas.
- **Climate:** The long-term atmospheric conditions of a region, including temperature, precipitation, wind patterns, and seasonal variations. Climate plays a significant role in shaping morphogenetic regions by influencing erosion rates, weathering processes, and the distribution of water resources.
- **Deposition:** The process of depositing or laying down eroded materials, such as sediment or soil, in a new location. Deposition occurs as a result of erosional forces losing their energy, leading to the accumulation and formation of new landforms.
- **Erosion:** The process by which materials and landforms are worn away and transported by natural agents such as water, wind, ice, or gravity. Erosion plays a significant role in the morphogenetic processes and the formation of different landforms.
- **Fluvial Processes:** Processes related to the movement, erosion, and deposition of water, primarily in rivers and streams. Fluvial processes are essential in shaping morphogenetic regions, particularly in areas where water plays a dominant role in landform development.
- **Geological Structure:** The arrangement and composition of rock layers, faults, and folds within the Earth's crust. Geological structures can influence morphogenetic processes by affecting the resistance to erosion and the formation of distinctive landforms.
- **Glacial Processes:** Processes associated with the movement, erosion, and deposition of ice and snow in glaciers. Glacial processes have a significant impact on

morphogenetic regions, especially in high-altitude or high-latitude areas, where glaciation can carve valleys, create moraines, and reshape the landscape.

- **Karst Processes:** Processes related to the dissolution of soluble rocks, such as limestone and gypsum, by water. Karst processes contribute to the formation of distinctive landforms, including sinkholes, caves, and underground drainage systems, in morphogenetic regions with soluble bedrock.
- **Landform:** A natural feature or shape on the Earth's surface, such as mountains, valleys, plateaus, plains, or canyons. Landforms are the result of ongoing morphogenetic processes shaping the Earth's surface over time.
- **Morphogenetic Region:** A geographical area characterized by specific morphogenetic processes, which refer to the formation and shaping of landforms and landscapes. Morphogenetic regions are influenced by various factors such as geology, climate, tectonic activity, and erosion.
- **Tectonic Activity:** The movement and deformation of the Earth's crust due to the forces acting within the planet. Tectonic activity, such as plate tectonics and volcanic eruptions, can lead to the creation of new landforms and influence morphogenetic regions.
- **Tidal Processes:** Processes influenced by the rise and fall of tide.
- **Topography:** The arrangement and variation of the physical features on the Earth's surface, including elevation, slope, and relief. Topography is influenced by morphogenetic processes and helps define the characteristic landforms of a region.
- **Volcanic Processes:** Processes associated with volcanic activity, including eruptions, lava flows, and the deposition of volcanic ash and tephra. Volcanic processes can create new landforms, such as volcanic mountains, calderas, and lava plateaus, influencing morphogenetic regions in volcanic areas.
- **Weathering:** The breakdown and alteration of rocks and minerals at or near the Earth's surface through physical, chemical, and biological processes. Weathering contributes to the morphogenetic processes by gradually changing the characteristics of landforms.

4.6 ANSWER TO CHECK YOUR PROGRESS

1. Which term refers to a geographical area characterized by specific morphogenetic processes?

a) Morphoclimatic region

b) Morphogenetic region

c) Geological region

d) Climatic region

2. What are the factors that influence morphogenetic regions?

a) Geology and climate

b) Climate and vegetation

c) Vegetation and tectonic activity

d) Tectonic activity and erosion

3. What process contributes to the formation of different landforms in morphogenetic regions?

a) Erosion

b) Weathering

c) Deposition

d) All of the above

4. Which of the following is NOT an example of morphogenetic process?

a) Tectonic activity

b) Erosion

c) Vegetation growth

d) Weathering

5. How does climate influence morphogenetic regions?

a) By affecting erosion rates

b) By determining vegetation patterns

c) By influencing weathering processes

d) All of the above

6. Which process is associated with the movement and erosion of ice in morphogenetic regions?

a) Fluvial processes

b) Aeolian processes

c) Glacial processes

d) Karst processes

7. What is the role of topography in morphogenetic regions?

a) It defines the characteristic landforms

b) It determines the climate

c) It influences the vegetation type

d) It affects the erosion rates

8. What type of processes are related to the dissolution of soluble rocks in morphogenetic regions?

a) Glacial processes

b) Karst processes

c) Volcanic processes

d) Tidal processes

9. How do geological structures influence morphogenetic processes?

a) By affecting resistance to erosion

b) By determining climate patterns

c) By influencing deposition rates

d) By shaping vegetation patterns

10. Which process involves the movement and transport of sediment by wind in morphogenetic regions?

a) Glacial processes

b) Tectonic processes

c) Aeolian processes

d) Karst processes

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4.8 TERMINAL QUESTIONS

1. Explain the concept of morphogenetic regions and discuss the key factors that contribute to their formation and characteristics.

2. Describe the role of climate in shaping morphogenetic regions. Provide examples of how different climatic conditions influence the morphogenetic processes and resultant landforms in specific regions.

3. Discuss the significance of geological structures in the formation and evolution of morphogenetic regions. Explain how different types of geological structures, such as rock layers, faults, and folds, interact with morphogenetic processes and influence landform development.

4. Compare and contrast the processes and landforms associated with fluvial and glacial activity in morphogenetic regions.

5. Explore the impact of human activities on morphogenetic regions. Discuss how human interventions, such as deforestation, urbanization, and infrastructure development, can alter natural morphogenetic processes and lead to changes in landforms and landscapes.

UNIT-5 RECENT TRENDS IN GEOMORPHOLOGY

5.1 OBJECTIVES

After reading this unit, you will be able to:

- Introduce to recent trends of geomorphology
- Able to understand geomorphic development in the Anthropocene era

5.2 INTRODUCTION

Geomorphology encompasses the study of landforms, employing both descriptive and quantitative approaches to investigate morphology, geomorphological processes, landform origins, and ages. The primary objectives of geomorphology are to comprehend the mechanisms behind landform formation and to document their evolution over time. The geomorphology of any given area or site results from the interplay of three fundamental factors: process, structure, and time. All surfaces of the Earth are subject to diverse physical, chemical, and biological processes that operate at varying rates. There are no static landscapes, as all landscapes undergo continuous modification, ranging from slow changes to rapid and instantaneous events like volcanic eruptions or asteroid impacts. Active processes also undergo temporal variations, ensuring that landscapes are in a constant state of evolution.

Internal processes are linked to plate tectonics and the surface manifestations of plate movements, as well as other forces originating from the Earth's interior. External processes, on the other hand, occur at or above the Earth's surface within the atmosphere, hydrosphere, cryosphere, or biosphere. These processes involve wind, water, ice, mass movements, and the activities of living organisms, all of which shape and modify landforms. Additionally, impacts and the accumulation of extraterrestrial materials also contribute to external processes.

The combination of internal and external processes, along with geologic structure and time, gives rise to the observed landforms on the Earth's surface. Most landforms consist of substantial amounts of material, including bedrock and sediment, making them slow to adapt to environmental changes. Therefore, the geomorphology of a region represents the long-term integration of environmental conditions and trends. It reflects both past and present environments, serving as a testament to the complex interactions between the Earth's processes and its landforms.

Geomorphology experienced significant advancements and transformations during the 1960s, leading to changes in techniques, concepts, and objectives. The most notable transformation was the introduction of quantitative methods, particularly those relying on computer-based data processing. This shift, which began around 1945, prompted an in-depth exploration of the significance of drainage network topology.

Research on stream channels, primarily pioneered by the U.S. Geological Survey, expanded to encompass the study of minimum variance and the establishment of thermodynamic analogs to understand fluvial behavior. The growing application of stochastic methods emphasized the importance of random variations in geomorphological processes. Climatic geomorphology, although facing challenges from certain quarters, continued to find robust support through extensive field records documenting clima-morphogenetic shifts.

Slope research, which had long been a focal point in geomorphic studies, took a new direction with the establishment of the Virgil Network. This network played a central role in investigating the speed of contemporary geomorphic processes in general. Given the rapidly evolving nature of modern geomorphology, making predictions about its future direction is precarious, even in the near term.

5.3 RECENT TRENDS IN GEOMORPHOLOGY

5.3.1 Early Stage Geomorphology

The exploration of landforms and the Earth's surface evolution can be traced back to ancient scholars of Classical Greece. During the 5th century BC, the Greek historian Herodotus made observations of soils and argued that the Nile delta was actively expanding into the Mediterranean Sea. Based on these observations, he estimated the age of the delta. In the 4th century BC, the Greek philosopher Aristotle speculated that the seas would eventually fill up due to sediment transport, leading to a swap between land and water, resulting in an endless cycle.

During the 10th century, the Encyclopedia of the Brethren of Purity, published in Arabic at Basra, discussed the cyclical interchange of land and sea, with rocks breaking down and being washed into the sea, eventually forming new continents. The Persian Muslim scholar Abū Rayhān al-Bīrūnī, in the medieval period, hypothesized that the Indian Ocean once covered the entire Indian subcontinent based on his observations of rock formations at the mouths of rivers. In 1546, the German metallurgist and mineralogist Georgius Agricola wrote about erosion and natural weathering in his work De Natura Fossilium.

Another early theory of geomorphology was put forth by the Song dynasty Chinese scientist and statesman Shen Kuo. He observed marine fossil shells in a geological stratum of a mountain far from the Pacific Ocean and inferred that the cliff had once been a seashore that had shifted over time due to soil erosion and silt deposition. Shen Kuo also noticed natural erosions of the Taihang Mountains and the Yandang Mountain, leading him to propose the reshaping of landforms through erosion and deposition. He also highlighted the theory of gradual climate change based on the preservation of ancient petrified bamboos in the dry northern climate zone.

Another Chinese authors, Du Yu and Ge Hong, presented ideas about changing landforms. Du Yu predicted the shifting positions of monuments and the transformation of hills and valleys over time. Ge Hong, in a fictional dialogue, described the territory of the East China Sea as a land filled with mulberry trees.

5.3.2 Modern Stage Geomorphology

The term "geomorphology" is believed to have been first used by Laumann in an 1858 work written in German. It gained widespread usage in English, German, and French following its use by John Wesley Powell and W. J. McGee during the International Geological Conference of 1891. John Edward Marr considered his book, "*The Scientific Study of Scenery,*" as an introductory treatise on geomorphology, a subject that emerged from the intersection of geology and geography.

Early model in geomorphology was William Morris Davis's *Geographical Cycle Or Cycle Of Erosion Model*, developed between 1884 and 1899. It expanded upon the concept of uniformitarianism proposed by James Hutton. The model described a sequence of valley formation, where a river gradually carved a deep valley through flat terrain, followed by the erosion of side valleys that resulted in a flattened terrain at a lower elevation. It was believed that tectonic uplift could initiate the cycle anew. This framework, known as "Davisian Cycle of Erosion " .

During the 1920s, Walther Penck introduced an alternative model to Davis's. Penck proposed that landform evolution involves a cyclical interplay of uplift and denudation processes, contrasting Davis's single uplift followed by decay. He emphasized the significance of back wearing of rocks in slope evolution, challenging Davisian-style surface lowering. Penck's approach focused more on surface processes rather than detailed understanding of specific locality histories.

In the early 1900s, the study of regional-scale geomorphology was referred to as "*Physiography*." The term later became associated with physical. Some geomorphologists aligned physiography with geology and emphasized physiographic regions, while some geographers sought to separate it from its geological origins, equating physiography with "pure morphology." Following World War II, the rise of process-oriented, climatic, and quantitative studies led to a preference for the term "geomorphology" among earth scientists, suggesting an analytical approach to landscapes rather than a purely descriptive one.

5.3.3 Climate Geomorphology

Climatic geomorphology emerged as a subfield within geomorphology, focusing on the intricate relationship between climate and landforms. Its primary objective is to understand how climatic processes shape and transform the Earth's surface. The study of climatic geomorphology acknowledges the significant role of climate in influencing the creation, distribution, and evolution of landforms across different scales of time and space.

The roots of climatic geomorphology can be traced back to the late 19th century when European explorers and scientists embarked on voyages of discovery during the era of New Imperialism. As geographical knowledge expanded, researchers began organizing their findings to identify patterns in landscape and landform distributions, with climate emerging as a pivotal factor in explaining these patterns.

Renowned figures such as Wladimir Köppen, Vasily Dokuchaev, Andreas Schimper, and William Morris Davis played instrumental roles in establishing the groundwork for climatic geomorphology. They recognized the profound influence of climate on landforms and incorporated climatic processes into their theories and classifications of geomorphic phenomena.

Notable figures such as Wladimir Köppen, Vasily Dokuchaev, Andreas Schimper, and William Morris Davis made significant contributions to the field of climatic geomorphology. There works is as following :

1. *Wladimir Köppen*: Köppen was a German-Russian climatologist and geographer who developed the Köppen climate classification system, which categorizes climates based on temperature, precipitation, and vegetation patterns. This classification system has been widely used in climatic geomorphology to understand the relationships between climate and landforms.

2. ***Vasily Dokuchaev*****:** Dokuchaev was a Russian geologist and soil scientist who is often regarded as the founder of soil science. His research emphasized the role of climate in soil formation processes and the influence of soil on landforms. His work highlighted the importance of studying the interaction between climate, soils, and landforms in understanding landscape development.

3. ***Andreas Schimper*****:** Schimper was a German botanist and geographer who conducted extensive research on plant ecology and the effects of climate on vegetation patterns. His studies contributed to the understanding of how climate influences plant distributions and the impact of vegetation on landforms. Schimper's work provided insights into the relationships between climate, vegetation, and geomorphic processes.

4. ***William Morris Davis*****:** Davis was an American geographer and geomorphologist known as the father of American geomorphology. While Davis focused more on the processes and evolution of landforms in general, he recognized the influence of climate on landscape development. He incorporated the effects of arid and glacial cycles of erosion into his geomorphic cycle theory, alongside the "normal" temperate climate cycle. Davis's recognition of climatic processes laid the groundwork for later developments in climatic geomorphology.

There pivotal roles in recognizing and incorporating the influence of climate on landforms, laying the foundations for the study of climatic geomorphology. Their works contributed to the understanding of the interactions between climate, vegetation, soils, and landforms, and provided a basis for further advancements in the field.

Not until the mid-20th century that climatic geomorphology gained widespread recognition as an independent field of study. Criticisms of Davisian geomorphology, which was deemed stagnant and questionable, prompted the development of new approaches that placed greater emphasis on climate as a driving force in shaping landforms.

The advancement of climatic geomorphology was primarily centered in continental Europe, where scholars from countries like Germany, France, and Russia made significant contributions. In the English-speaking world, explicit emphasis on climatic geomorphology took longer to materialize, with the publication of L.C. Peltier's work on periglacial erosion cycles in 1950 representing a notable milestone in this regard.

Some major significant work and progress contributed in 20 th century in the field of climate geomorphology , is as following :

1. *Carl Troll's Regional Climatology*: German geographer Carl Troll made substantial contributions to the study of climatic geomorphology through his work on regional climatology. He emphasized the influence of climate on landforms and landscape development, particularly in relation to vegetation patterns and fluvial processes. Troll's regional climatology approach provided insights into the interactions between climate, landforms, and ecosystems.

2. *L.C. Peltier's Periglacial Erosion Cycles*: L.C. Peltier's publication on periglacial erosion cycles in 1950 represented a significant milestone in climatic geomorphology. Peltier studied the effects of cold climate conditions on landforms, focusing on periglacial environments. His work highlighted the distinctive erosional processes associated with freezing and thawing, as well as the formation of periglacial landforms such as patterned ground and solifluction lobes.

3. *Geomorphic Response to Climate Change*: Throughout the 20th century, numerous studies investigated the impacts of climate change on landforms. Researchers examined how variations in temperature, precipitation, and other climatic factors influenced erosion rates, glacier dynamics, river systems, and coastal processes. These studies provided valuable insights into the geomorphic response to ongoing and historical climate changes.

4. *Climatic Controls on Desert Landforms*: The study of desert landforms and the role of climate in their formation and evolution advanced significantly in the 20th century. Researchers examined processes such as wind erosion, dune formation, and the development of desert pavement. They investigated the relationships between climate parameters, including aridity, temperature, and wind patterns, and their impact on desert geomorphology.

5. *Advances in Paleoclimatology and Geochronology*: In the latter half of the 20th century, advances in paleoclimatology and geochronology provided valuable tools for studying past climatic conditions and their influence on landforms. Techniques such as dendrochronology, isotopic analysis, and sediment dating allowed researchers to reconstruct climate histories and investigate the links between climate change and landform development over longer timescales.

5.3.4 Quantitative Revolution and Geomorphology

The emergence of the quantitative revolution can be attributed to a general dissatisfaction with regional geographic studies, leading to a shift in focus towards more systematic and specialized approaches. According to Stoddart (1997), the quantitative techniques taught in physical geography during the 1960s were primarily centered around statistical concepts introduced by Strahler, rather than the thermodynamic principles he advocated . The emphasis on statistics linked to the philosophical foundations of the quantitative revolution. As Van Bemmelen (1961) suggests, geology is also an exact science capable of measuring and grouping various factors of geological phenomena into correlation structures, allowing for mathematical treatment of certain aspects.

In the mid-20th century, geomorphology underwent a significant transformation, moving towards a more solid quantitative foundation. Building upon the early work of Grove Karl Gilbert in the late 19th and early 20th centuries, a group of primarily American scientists, including geologists, hydraulic engineers, and natural scientists such as William Walden Rubey, Ralph Alger Bagnold, Hans Albert Einstein, Frank Ahnert, John Hack, Luna Leopold, A. Shields, Thomas Maddock, Arthur Strahler, Stanley Schumm, and Ronald Shreve, began conducting systematic and direct measurements of landscape elements like rivers and hillslopes. Their research focused on quantifying various aspects of these features.

By these quantitative methods, researchers were able to make predictions about the past and future behavior of landscapes based on present observations. This marked the emergence of a highly quantitative approach to studying geomorphic problems. Quantitative geomorphology encompasses a range of disciplines, including fluid dynamics and solid mechanics, geomorphometry, laboratory studies, field measurements, theoretical work, and comprehensive landscape evolution modeling. These approaches contribute to the understanding of processes such as weathering, soil formation, sediment transport, landscape change, and the complex interactions among climate, tectonics, erosion, and deposition.

scientists who contributed to the quantitative revolution in geomorphology:

1. William D. Thornbury: Thornbury, an American geologist, made important contributions to quantitative geomorphology through his work on river systems. In his book "Principles of Geomorphology" published in 1954, Thornbury emphasized the importance of quantitative analysis in understanding fluvial processes and landform evolution. He developed mathematical models to study channel patterns, streamflow, sediment transport, and erosion rates, promoting the application of quantitative techniques in geomorphological research.

2. Richard Chorley: Chorley, a British geographer, played a significant role in promoting quantitative approaches in geomorphology. His book "Introduction to Physical Hydrology" co-authored with Robert P. Beckinsale in 1964, presented a systematic framework for studying hydrological processes in landscapes. Chorley emphasized the use of statistical analysis, mathematical modeling, and field measurements to quantify runoff, erosion, and sedimentation processes. His work contributed to the integration of hydrological principles into the study of landform development.

3. Richard J. Chorley, Stanley A. Schumm, and David E. Sugden: In their influential book "Geomorphology" published in 1973, Chorley, Schumm, and Sugden presented a comprehensive overview of quantitative methods in geomorphology. The book emphasized the use of quantitative techniques such as flow duration curves, sediment rating curves, and digital terrain analysis for analyzing landforms and processes. They define concepts such as threshold, system, and feedback to describe the dynamic nature of geomorphic systems. The work played a significant role in establishing quantitative geomorphology as a distinct field of study.

4. John C. Doornkamp: Doornkamp, a British geographer, made significant contributions to quantitative approaches in urban geomorphology. There research focused on analyzing the spatial patterns and processes of urban landforms, particularly in relation to human-induced modifications. Doornkamp developed quantitative models and techniques to assess the impact of urbanization on landform evolution and to understand the interactions between natural and anthropogenic processes. The work highlighted the importance of integrating quantitative methods with social and economic factors in urban geomorphological studies.

5. Robert Hack: Hack, an American geographer, made notable contributions to the quantitative analysis of fluvial geomorphology. He developed the Hack Index, a quantitative measure of stream channel sinuosity, which provided insights into the relationships between channel form and discharge characteristics. Hack's work demonstrated the utility of quantitative indices in characterizing river behavior and assessing the influence of various factors on channel morphology.

5.3.5 Contemporary Geomorphology

Geomorphology encompasses a broad range of approaches and interests, reflecting the diverse nature of the field. Contemporary researchers in geomorphology strive to uncover quantitative "laws" that govern the processes shaping the Earth's surface. They also acknowledge the distinctiveness of each landscape and environment in which these processes occur. Several significant realizations have emerged in modern geomorphology:

1) The understanding that landscapes cannot be simply classified as either "stable" or "perturbed," where perturbation represents a temporary deviation from an idealized form. Instead, it is recognized that dynamic changes are inherent to the nature of landscapes.

2) The recognition that many geomorphic systems are best comprehended in terms of the stochastic nature of the processes operating within them. This involves understanding the probability distributions of event magnitudes and recurrence intervals. Consequently, the significance of chaotic determinism in shaping landscapes has been acknowledged, and landscape properties are better understood through statistical considerations. It is evident that identical processes in the same landscapes do not consistently yield identical outcomes.

Recent Contemporary geomorphology encompasses a wide range of research topics and areas of study. Here are a few examples of current studies conducted by geomorphologists:

1. Fluvial Processes and River Dynamics: In this Scientists investigate the behavior of rivers and their response to changes in sediment supply, flow regime, and channel morphology. Example include , research work done by Gary Parker at the University of Illinois , he examined the dynamics of river channels, including the formation and evolution of meandering patterns and the interaction between flow and sediment transport.

2. Coastal Geomorphology and Shoreline Change: Coastal geomorphologists study the processes shaping coastlines, including erosion, sediment transport, and coastal hazards. Work of Karen L. F. Holman at Oregon State University focuses on the morphodynamics of sandy beaches, investigating how waves, tides, and sediment interactions influence coastal landforms.

3. Glacial and Periglacial Environments: Geomorphologists study the dynamics of glaciers and the landforms created by them. Researcher such as Richard J. Chiverrell at the University of Liverpool analyze glacial retreat and the formation of glacial landforms such as moraines, drumlins, and eskers. There study include periglacial environments, the processes and landforms associated with freezing and thawing in cold regions.

4. Hillslope Processes and Landslides: Scientists investigate the mechanisms and triggers of landslides, as well as the factors influencing slope stability. For example, Jean-Philippe Malet at the University of Strasbourg studies the geomorphological processes leading to landslides, employing remote sensing techniques and numerical modeling to understand their occurrence and behavior.

5. Geomorphic Responses to Climate Change: The impacts of climate change on landforms and landscapes are studied . scientists like Anne K. Leibman at the University of Alaska Fairbanks study how permafrost thaw affects the formation of thermokarst landforms, such as sinkholes and patterned ground, in Arctic environments.

5.3.6 Current Geomorphology And Natural Hazards In Anthropogenic Environment

Since the late 19th century, there has been a significant increase in human impact on landforms and underlying substrates, leading to a greater influence on morpholitho systems. In certain countries, the volume of technogenically displaced material has exceeded natural denudation by several times. In the latter half of the 20th century, the number of processed rocks surpassed the annual runoff of all rivers by a factor of two orders of magnitude. This human-induced activity has resulted in a rise in natural disasters such as floods, landslides, mudflows, and erosion. The anthropogenic impact extends beyond triggering events and introduces additional factors contributing to disasters, including artificial substrates, matter and energy flows, and physical fields. The global scale of human impact has marked the beginning of a new geological era known as the *Anthropocene*, with traces of nuclear tests serving as geological indicators. The emergence of this era is characterized by various criteria, including the formation of anthropogenic geomorphology as a new direction in the study of landforms. According to this new paradigm, relief formation is a result of the interaction between natural factors and human activities. Modern geomorphology primarily focuses on the evolutionary development of landforms, their anthropogenic transformations, and geomorphological systems. Geomorphology continues to advance its theory, applies its knowledge in practical applications, and collaborates with other disciplines. While new branches and directions in geomorphology are emerging, there are still unresolved issues within traditional fields such as structural and climatic, dynamic, and historical geomorphology.

5.3.7 New Approaches in Geomorphology

At present, a significant aspect of the advancement of geomorphological methods lies in the ability to acquire data that enables quantitative assessments and comprehensive reconstructions across the entire spatiotemporal range relevant to geomorphological research. This includes reconstructing relief formation based on global and regional relief models, as well as studying nanoforms. The development of methods in this field shows promise, particularly in two main areas:

a) Firstly , the collection of data on relief and substrate, which are encompassed by the concept of "morpholithosystems." There are new opportunities to obtain detailed information about surface morphology through rapidly advancing remote sensing techniques utilizing high-resolution satellite imagery, laser, scanner, radar, acoustic, and ultrasonic sensors. These advancements have enabled the construction of 3D models of terrains that were previously inaccessible due to dense vegetation or water coverage, spanning a wide range of scales.
b) Secondly, there is a growing focus on studying the properties of relief-forming rocks and deposits using innovative remote geophysical technologies and contact methods

that examine substrate properties, including isotopic analysis. These approaches facilitate the estimation of sedimentation rates, denudation processes, and the age, volume, and rate of relief formation itself.

5.3.8 Satellite imageries

Satellite images, traditionally used in remote sensing and various stages of geomorphological research, hold significant importance. A notable advancement in this field is the emergence of radar interferometry (InSAR, IfSAR) technology, which has gained momentum since the launch of Sentinel-1 satellites in 2014. Radar interferometry enables the construction of digital elevation models based on the phase shift of radio waves reflected from the Earth's surface. This method allows for the monitoring of elevation changes over large areas using multi-temporal radar images with high temporal resolution. Geomorphologists find this technology particularly valuable as it aids in the detection and tracking of various phenomena, such as landslides, subsidence events, and the assessment of earthquake and volcanic eruption impacts. The precision in measuring height changes can reach subcentimeter values, with accuracy potentially reaching half the length of the radio wave. By processing long-term series of Sentinel-1 images, along with earlier and lower-resolution images like Alos Palsar, a new level of exomorphodynamic mapping can be achieved, resulting in a significant enhancement of geomorphological analysis and understanding.

5.3.9 Digital Elevation Models (DEMs)

The utilization of digital elevation models (DEMs) plays a significant role in contemporary geomorphological research. This approach gained momentum with the introduction of freely accessible global products, starting with SRTM (Shuttle Radar Topographic Mission), followed by Aster GDEM and Alos World 3D. The ArcticDEM height model, with a remarkable resolution of 2 m/px, further expanded research possibilities in the Arctic region. The availability of DEMs enables morphometric analysis of the terrain, facilitating the extraction of standard characteristics such as height ranges, their spatial distribution, hypsographic curves, slope distribution by steepness and orientation, and more. Moreover, these models enable researchers to address specific issues like simulating water and sediment runoff, denudation, and accumulation. DEMs are also utilized for automated engineering assessments of the relief, as well as for identifying optimal routes for linear structures based on geological and geomorphological criteria.

5.3.10 Unmanned Aerial Vehicle

The utilization of unmanned aerial vehicles (UAVs) has brought about significant transformations in the methodologies employed in field geomorphological studies. For geomorphologists, the primary objective of using UAVs is to acquire high-resolution digital terrain models and orthophoto maps, which can achieve remarkable detail down to the millimeter scale when captured from low altitudes. These maps primarily serve the purpose of deciphering the contours that manifest exogenous processes, while digital terrain models (DTMs) are specifically designed for conducting morphometric analysis of micro- and nanoscale relief features. By ensuring precise referencing, it becomes possible to compare DTMs from different time periods, calculate volumes of denudation and accumulation, and interpret alterations in the Earth's surface morphology resulting from various geomorphological processes.

5.3.11 Mathematical Modelling

Presently, there is a renewed surge of interest in the application of mathematical methods and modeling within the field of geomorphology. Three primary domains of mathematical modeling in the study of landforms can be distinguished. Automated recognition of individual forms and complex relief features, modeling the temporal evolution of Earth's surface (both in two dimensions along profiles and in three dimensions across the entire area), and mathematical modeling of the underlying mechanisms driving geomorphological processes. The first area focuses on identifying mathematical indicators and signatures associated with distinct landforms and genetic types of relief using Digital Elevation Models (DEMs). The goal is to partially automate geomorphological mapping by clustering the Earth's surface based on various indicators and implementing classification with training. This approach involves training statistical models to delineate boundaries using pre-existing geomorphological maps, raster models representing morphometric characteristics of the relief, vector boundaries representing geological variations, and data from airborne geophysical surveys, among other relevant sources.

5.4 SUMMARY

In recent years, geomorphology, the study of the Earth's surface and the processes that shape it, has witnessed significant advancements and evolving trends. One prominent trend in modern geomorphology is the increasing use of mathematical methods and modeling techniques to understand and analyze landforms. This trend has opened up new avenues for quantitative assessments and comprehensive investigations in the field.

Mathematical modeling in geomorphology encompasses three main areas of focus. The first area involves the automated recognition of individual forms and complexes of relief. Geomorphologists employ mathematical indicators and signatures derived from digital elevation models (DEMs) to partially automate the process of geomorphological mapping. By clustering the Earth's surface based on various indicators, such as exodynamic regimes, researchers can identify and classify different landform types. This approach has facilitated the generation of geomorphological maps and raster models that capture the morphometric characteristics of the relief.

The second area of mathematical modeling in geomorphology pertains to the temporal development of the Earth's surface. In this context, researchers utilize mathematical techniques to model and simulate the changes that occur over time. Two-dimensional and three-dimensional modeling techniques enable geomorphologists to analyze the evolution of landforms and understand the underlying processes driving their development. By comparing digital terrain models (DTMs) of different times, scientists can quantify denudation and accumulation volumes, and interpret the morphological changes on the Earth's surface resulting from various geomorphological processes.

The third area of mathematical modeling focuses on understanding the mechanisms of geomorphological processes. By employing mathematical models, researchers can simulate and analyze the complex interactions between various factors influencing landform development. This approach allows for a deeper understanding of the underlying processes driving geomorphological changes, including erosion, deposition, and tectonic activity. Through these models, scientists can explore the spatial and temporal dynamics of landforms and gain insights into the intricate relationships between different geomorphological factors.

Advancements in technology have also played a crucial role in shaping recent trends in geomorphology. High-resolution satellite images have revolutionized remote sensing techniques, enabling geomorphologists to obtain detailed and accurate data for their studies. Satellite-based radar interferometry, such as InSAR (Interferometric Synthetic Aperture

Radar) and IfSAR (Interferometric Synthetic Aperture Radar), allows for the construction of digital elevation models based on the phase shift of radio waves. This technology provides precise measurements of elevation changes over vast areas and facilitates the monitoring of landforms and the assessment of geomorphic hazards such as landslides, subsidence, and volcanic activity.

Furthermore, the advent of unmanned aerial vehicles (UAVs) has significantly impacted field geomorphological studies. Geomorphologists now utilize UAVs to capture high-resolution digital terrain models and orthophotomaps. These detailed maps are instrumental in deciphering the contours of exogenous processes and analyzing micro- and nanorelief features. With accurate referencing and comparison of DTMs from different time periods, scientists can quantify changes in landforms and interpret the implications of geomorphological processes.

The availability of freely distributed global products, such as SRTM (Shuttle Radar Topographic Mission), Aster GDEM, Alos World 3D, and ArcticDEM, has further enhanced the capabilities of geomorphologists. These digital elevation models provide researchers with comprehensive datasets for morphometric analysis, simulation of runoff, denudation, and accumulation, and automated engineering assessments of the relief. Geomorphologists can now analyze the distribution of slopes, study hypsographic curves, and evaluate the geomorphological characteristics of specific regions with unprecedented precision.

Hence recent trends in geomorphology highlight the growing prominence of mathematical methods and modeling techniques in understanding landforms and the processes that shape them. The integration of mathematical modeling, advanced remote sensing technologies, and the availability of high-resolution datasets have revolutionized the field, enabling geomorphologists to undertake quantitative assessments, simulate landform development, and gain deeper insights into the complex interactions between various geomorphological factors. These advancements has contribute to the advancement of geomorphological knowledge also have practical implications in areas such as hazard assessment, land management, and engineering projects that interact with the Earth's surface.

5.5 GLOSSARY

- **Automated Recognition:** The use of mathematical indicators and signatures derived from DEMs to partially automate the process of geomorphological mapping.

- **Digital Elevation Model (DEM):** A digital representation of the Earth's surface that provides detailed elevation data.
- **Exogenous Processes:** External processes that shape the Earth's surface, such as erosion, deposition, and tectonic activity.
- **Freely Distributed Global Products:** Datasets such as SRTM, Aster GDEM, Alos World 3D, and ArcticDEM, providing comprehensive information for geomorphological analysis.
- **Geomorphology:** The study of the Earth's surface and the processes that shape it.
- **Hazard Assessment:** The evaluation and prediction of potential risks associated with geomorphological processes, including landslides, subsidence, and volcanic activity.
- **High-Resolution Satellite Images:** Detailed images captured by satellites, revolutionizing remote sensing techniques in geomorphology.
- **Hypsographic Curves:** Graphs that depict the distribution of land surface area at various elevations.
- **Land Management:** The application of geomorphological knowledge in the planning and sustainable use of land resources.
- **Mathematical Modeling:** The use of mathematical methods and techniques to understand and analyze landforms.
- **Mechanisms of Geomorphological Processes:** The use of mathematical models to simulate and analyze the interactions between factors driving landform development.
- **Morphometric Analysis:** The quantitative analysis of landform characteristics, such as slope distribution and hypsographic curves.
- **Orthophotomaps:** Geometrically corrected aerial photographs or satellite images that provide accurate representation of the Earth's surface.
- **Radar Interferometry:** The use of radar technology to construct digital elevation models and monitor elevation changes over large areas.
- **Remote Sensing Technologies:** Technologies, including satellite imagery and UAVs, used to collect data about the Earth's surface from a distance.
- **Runoff Simulation:** The modeling of water and sediment flow over the Earth's surface.
- **Temporal Development:** The study of how landforms change over time, analyzed through two-dimensional and three-dimensional modeling techniques.

- **Unmanned Aerial Vehicles (UAVs):** Aerial vehicles used to capture high-resolution digital terrain models and orthophotomaps.

5.6 ANSWER TO CHECK YOUR PROGRESS

1. Which area of mathematical modeling in geomorphology focuses on automated recognition of individual forms and complexes of relief?

a) Modeling the development of the earth's surface in time

b) Mathematical modeling of the mechanisms of geomorphological processes

c) Automated geomorphological mapping

d) Statistical analysis of landform characteristics

Answer: c) Automated geomorphological mapping

2. What is the primary purpose of digital terrain models (DTMs) in geomorphology?

a) Analysis of the micro- and nanorelief

b) Identification of exodynamic regimes

c) Mapping the distribution of slopes by steepness and exposure

d) Interpretation of changes in the earth's surface morphology

Answer: a) Analysis of the micro- and nanorelief

3. Which aspect of geomorphological studies is influenced by the widespread use of unmanned aerial vehicles (UAVs)?

a) Morphometric analysis of landforms

b) Automated recognition of relief features

c) Mathematical modeling of exogenous processes

d) Acquisition of high-resolution digital terrain models and orthophotomaps

Answer: d) Acquisition of high-resolution digital terrain models and orthophotomaps

4. What is the main objective of mathematical modeling in geomorphology regarding the development of the earth's surface in time?

a) Identification of genetic types of relief

b) Automation of geomorphological mapping

c) Analysis of temporal changes in landforms

d) Modeling the mechanisms of geomorphological processes

Answer: c) Analysis of temporal changes in landforms

5. Which mathematical modeling approach in geomorphology involves the clustering of the earth's surface based on various indicators?

a) Automated recognition of relief features

b) Modeling the development of the earth's surface in time

c) Mathematical modeling of exogenous processes

d) Statistical analysis of landform characteristics

Answer: a) Automated recognition of relief features

6. What is the primary focus of mathematical modeling in geomorphology regarding the mechanisms of geomorphological processes?

a) Automation of geomorphological mapping

b) Modeling the development of the earth's surface in time

c) Analysis of temporal changes in landforms

d) Understanding the underlying mechanisms driving geomorphological processes

Answer: d) Understanding the underlying mechanisms driving geomorphological processes

7. Which data source has significantly impacted field geomorphological studies through the use of unmanned aerial vehicles (UAVs)?

a) Remote sensing satellite images

b) Topographic maps

c) Digital elevation models (DEMs)

d) Aerial photographs

Answer: c) Digital elevation models (DEMs)

8. What is the key advantage of using radar interferometry (InSAR, IfSAR) in geomorphology?

a) Construction of orthophotomaps

b) Tracking the dynamics of elevation marks

c) Automated recognition of individual forms of relief

d) Analysis of temporal changes in landforms

Answer: b) Tracking the dynamics of elevation marks

9. Which technique allows for the comparison of digital terrain models (DTMs) of different times to estimate denudation and accumulation volumes?

a) Automated recognition of relief features

b) Modeling the development of the earth's surface in time

c) Mathematical modeling of exogenous processes

d) Statistical analysis of landform characteristics

Answer: b) Modeling the development of the earth's surface in time

10. How do digital elevation models (DEMs) contribute to geomorphological research?

a) They facilitate the identification of genetic types of relief.

b) They enable the analysis of temporal changes in landforms.

c) They support the automation of geomorphological mapping.

d) They provide data for morphometric analysis of the relief.

Answer: d) They provide data for morphometric analysis of the relief.

5.7 REFERENCES

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5.8 *TERMINAL QUESTIONS*

1. Discuss the role of mathematical methods and modeling techniques in modern geomorphology. How have these approaches contributed to quantitative assessments and comprehensive investigations in the field?
2. Describe the advancements in technology that have influenced recent trends in geomorphology. How have high-resolution satellite images and radar interferometry techniques contributed to the study of landforms and the assessment of geomorphic hazards?
3. Analyze the impact of unmanned aerial vehicles (UAVs) on field geomorphological studies. How do UAVs contribute to the collection of high-resolution data and the generation of digital terrain models and orthophotomaps?
4. Discuss the practical implications of recent trends in geomorphology. How can the integration of mathematical modeling, advanced remote sensing technologies, and high-resolution datasets contribute to hazard assessment, land management, and engineering projects that interact with the Earth's surface?
5. Explore the concept of temporal development in geomorphology. How can mathematical techniques be employed to model and simulate the changes that occur over time? Provide

examples of studies or applications that demonstrate the use of two-dimensional and three-dimensional modeling in understanding landform evolution.

BLOCK-2 LANDFORM AND PROCESSES (WATER, WIND AND KARST)

UNIT- 6 DRAINAGE PATTERN AND SYSTEM

6.1 OBJECTIVES

After reading this unit, you will be able to:

- Evaluating the role of river drainage systems in shaping physical and biological landscapes, including their impact on soil erosion, sediment transport, and habitat formation.
- To understand the structure and functioning of river drainage systems, including the main components and their interactions.
- To identify and classify different types of river drainage patterns, and to explain the factors that influence their formation.
- Understanding the concept of river drainage patterns, including their types and characteristics.
- Identifying the factors that influence the formation of river drainage patterns, such as geology, topography, and climate.

6.2 INTRODUCTION

A river drainage system is a network of interconnected rivers and streams that drain water from a particular watershed, or drainage basin, into a larger body of water, such as an ocean or a lake. The term "river drainage system" is often used interchangeably with "river basin" or "watershed."

A watershed is an area of land that is defined by its topography and hydrology, meaning the way that water flows over and through the land. The boundary of a watershed is typically defined by the highest points of elevation that surround it, known as the watershed divide. All water that falls within the watershed eventually drains into a common outlet, such as a river, lake, or estuary.

River drainage systems play a critical role in the water cycle, as they transport water and nutrients from one area to another. They also provide important habitats for fish and other aquatic life and support a variety of human activities, including agriculture, recreation, and industry.

The structure and function of a river drainage system can vary widely depending on the characteristics of the watershed it serves. Factors such as climate, geology, and land use can all influence the amount and quality of water that flows through a system, as well as the types of plants and animals that inhabit it.

In recent years, river drainage systems have faced increasing pressures from human activities such as urbanization, agriculture, and industrial development. These pressures can result in water pollution, habitat destruction, and changes in the flow and quality of water. As a result, there has been growing recognition of the importance of protecting and restoring river drainage systems to ensure their continued function and ecological health.

A river drainage system, also known as a river basin or watershed, refers to a network of interconnected rivers and streams that drain water from a particular geographical area into a larger body of water, such as an ocean or a lake. The term "drainage system" refers to the natural and artificial channels, as well as other features such as wetlands, that collect and transport water from the land to the larger water body.

The concept of a river drainage system is based on the hydrological cycle, which is the continuous movement of water between the Earth's surface and the atmosphere. When precipitation falls onto the land, it evaporates, infiltrates into the soil, or flows over the surface into nearby water bodies. The water that flows over the surface collects in streams and rivers, which eventually converge into larger bodies of water.

A river drainage system can range in size from small streams and tributaries to large river basins that cover thousands of square miles. The size and complexity of a drainage system depend on various factors, such as the topography, climate, and geology of the area.

Understanding the structure and function of a river drainage system is essential for managing and conserving water resources. Proper management of a drainage system involves minimizing human impacts, such as pollution and development, and maintaining natural habitats for aquatic plants and animals.

Here are some definitions of river drainage systems by famous geographers, geologists, and scientists:

- John Wesley Powell, a geologist and explorer, defined a river drainage system as "the territory of a river and its tributaries, bounded by watersheds, the area within which all the surface water drains into the river system."
- Gilbert White, an American geographer, described a river basin as "a spatial unit within which all surface runoff drains through a sequence of streams to a single outlet."
- Luna Leopold, a hydrologist, defined a watershed as "a unit of land within which all the water flows to a single outlet."
- Ian McHarg, a Scottish landscape architect and planner, described a watershed as "a landform that is defined by its topography and hydrology, which influences the way water moves across the land and through the soils."
- All of these definitions emphasize the interconnectedness of the rivers, streams, and other features that make up a river drainage system, and the importance of the watershed or drainage basin as the unit of analysis.

6.3 MAIN RIVER DRAINAGE SYSTEM

Sequent Steams

In sequent Steams

6.3.1 Sequent Steams:

Sequent streams is a concept in fluvial geomorphology that describes the natural sequence of stream types and sizes in a river drainage system. The concept was first introduced by Luna Leopold, an American hydrologist, in the 1960s. Sequent streams are typically found in mountainous regions, where the landscape is characterized by steep gradients and diverse geology.

The sequence of streams in a sequent stream system is determined by a variety of factors, including topography, geology, climate, and vegetation. At the headwaters of the system, small streams and tributaries with steep gradients and high velocities erode and transport sediment downstream. As these streams converge and the gradient decreases, they begin to deposit sediment and form larger, meandering streams. These larger streams may then be joined by additional tributaries, forming a complex network of channels and floodplains.

The sequent stream concept is useful for understanding the natural processes that shape river drainage systems and for predicting the response of these systems to changes in land use, climate, or other factors. By identifying the different types of streams within a system and the processes that control their behaviour, scientists and land managers can develop more effective strategies for managing water resources, protecting aquatic habitats, and reducing the risk of floods and erosion.

One example of a sequent stream river drainage system can be found in the Appalachian Mountains of the eastern United States. The Appalachian Mountains are characterized by a complex network of streams and rivers that flow through a variety of geological formations, including sedimentary rocks, metamorphic rocks, and igneous rocks. The streams and rivers in this region are classified according to their position in the natural sequence of stream types and sizes, as described by the concept of sequent streams.

At the headwaters of the Appalachian river drainage system, small, first-order streams are common. These streams are characterized by steep gradients, high velocities, and a tendency to erode and transport sediment downstream. As these streams converge and the gradient decreases, they form larger, second-order streams, which begin to deposit sediment and form pools and riffles. Third-order streams are formed when two or more second-order streams converge, and they are characterized by meanders, floodplains, and oxbow lakes. Fourth-order streams are even larger and may be joined by additional tributaries, forming a complex network of channels and floodplains.

An example of a fifth-order stream in the Appalachian Mountains is the New River, which flows through Virginia, West Virginia, and North Carolina. The New River has a drainage area of more than 6,000 square miles and is characterized by a meandering channel, extensive floodplains, and deltaic deposits.

Understanding the different types of sequent streams in the Appalachian river drainage system is important for predicting the behaviour of these systems and for developing effective strategies for managing water resources, protecting aquatic habitats, and reducing the risk of floods and erosion.

.6.3.2 In sequent Steams

Insequent streams refer to a concept in river geomorphology that describes streams that do not conform to the sequent stream concept. Instead of following a natural sequence of stream types and sizes, insequent streams are formed by a variety of factors, including geology, topography, and climate. In other words, insequent streams do not fit neatly into the hierarchical framework of the sequent stream concept.

Insequent streams are often found in areas with complex geology or topography, such as mountainous regions or regions with karst topography. They may be formed by a variety of processes, including faulting, landslides, or underground drainage systems. In some cases, insequent streams may also be created by human activities, such as the construction of dams or other water management infrastructure.

Unlike sequent streams, which are organized by their size and position in the drainage network, insequent streams are characterized by their irregularity and unpredictability. They may have a variety of channel shapes and sizes, and their behaviour may be influenced by a variety of factors, including precipitation, snowmelt, and other hydrologic processes.

Understanding the behaviour of insequent streams is important for predicting the behaviour of river drainage systems in areas with complex geology or topography. In these areas, the presence of insequent streams can complicate water management and conservation efforts and may pose challenges for the protection of aquatic habitats.

Insequent streams are commonly found in areas with complex topography or geology, where the drainage network is not organized in a predictable, hierarchical manner. Some examples of insequent streams include:

- **Karst landscapes:** In karst landscapes, the geology is dominated by soluble rocks such as limestone or gypsum. These rocks can be dissolved by groundwater, leading to the formation of sinkholes, caves, and underground drainage systems. The resulting streams in these areas are often highly variable and unpredictable, with sudden changes in flow and channel morphology.

- **Mountainous regions:** In mountainous regions, the topography is highly irregular, with steep slopes and deep valleys. This can lead to the formation of insequent streams that follow the contours of the land, rather than conforming to a hierarchical drainage network. In some cases, these streams may be formed by landslides or other mass movements that disrupt the natural drainage network.
- **Urban areas:** In urban areas, the natural drainage network is often modified by human activities such as road construction and development. This can lead to the formation of insequent streams that follow the path of least resistance, rather than conforming to a natural hierarchy. These streams may be highly variable in flow and channel morphology and may pose challenges for stormwater management and flood control.

Understanding the behaviour of insequent streams is important for managing and conserving water resources in these areas. In many cases, these streams play a critical role in maintaining aquatic habitats and supporting biodiversity, and efforts to protect them must take into account their complex and unpredictable nature.

6.3.3 Types of Sequent Steams

- **Consequent streams**
- **Subsequent stream**
- **subsequent streams**
- **Resequent streams**

Consequent streams:

Consequent streams refer to a type of river drainage system that follows the slope of the land, with smaller streams merging to form larger ones as they flow downstream. These streams are organized hierarchically, with smaller tributaries feeding into larger rivers, which eventually flow into the ocean or other large bodies of water.

Consequent streams are formed through a process known as "headward erosion." This occurs when a stream erodes its way upstream, cutting into the surrounding landscape and creating a channel that follows the slope of the land. As the stream flows downstream, it gathers water from smaller tributaries, which join the main channel and contribute to its size and flow.

A consequent stream river system is a type of river drainage system where the streams flow in the same direction as the main river channel. This happens when the river follows the path of least resistance along a slope or terrain, and the tributaries that join the main channel also flow in the same direction.

Consequent streams are typically found in areas where the landscape is relatively uniform, with no major geological barriers or changes in elevation. They tend to have a dendritic or branching pattern, with the tributaries joining the main channel at acute angles.

An example of a consequent stream river system is the Mississippi River in the United States. The Mississippi River is one of the longest rivers in the world, flowing from its source in northern Minnesota through several states before emptying into the Gulf of Mexico. The river system includes numerous tributaries that flow in the same direction as the main channel, such as the Missouri River, the Ohio River, and the Arkansas River.

Consequent stream river systems are important for supporting a wide range of human and ecological communities. They provide water for irrigation, transportation, and other uses, and they support diverse aquatic habitats, including wetlands, floodplains, and estuaries. However, they are also vulnerable to a range of environmental challenges, such as pollution, climate change, and habitat loss, which can impact their sustainability and resilience over time.

An example of a consequent stream system is the Mississippi River system in the United States. The Mississippi River is formed by the convergence of two smaller rivers, Missouri and the Ohio, and is joined by numerous other tributaries as it flows southward toward the Gulf of Mexico. The river system includes hundreds of smaller streams and rivers, all flowing in a hierarchical pattern that follows the slope of the land.

Consequent streams are common in areas with gentle slopes and relatively uniform geology. They are often found in low-lying areas such as river valleys and coastal plains, where the landscape is shaped by the flow of water over long periods. Understanding the behaviour of consequent streams is important for managing and conserving water resources in these areas, as well as for predicting the effects of climate change and other environmental factors on river systems.

An example of a consequent stream river drainage system in India is the Narmada River. The Narmada River is one of the most important rivers in central India, flowing through the states of Madhya Pradesh, Maharashtra, and Gujarat before emptying into the Arabian Sea. The river system includes numerous tributaries, many of which are consequent streams that follow the slope of the land and flow into the main channel.

The Narmada River system is characterized by its complex geology, which includes extensive basaltic lava flows that have created a unique landscape of deep gorges and cliffs. The consequent streams in the region have eroded the landscape over millions of years, creating a spectacular canyon system known as the Marble Rocks.

The Narmada River system is important for agriculture, providing water for irrigation and supporting the livelihoods of millions of people who depend on the river for their daily needs. However, the river system is facing a range of environmental challenges, including pollution, deforestation, and dam construction. Understanding the behaviour of consequent streams is therefore important for managing and protecting these important resources and ensuring their sustainability for future generations.

In addition to the Narmada River, other examples of consequent stream river drainage systems in India include the Tapti River in western India and the Mahanadi River in eastern India. These river systems are characterized by their extensive networks of tributaries that follow the slope of the land and flow into the main channel, shaping the landscape and supporting human and ecological communities.

Subsequent stream:

Subsequent streams are a type of river drainage system that develops after the initial formation of the landscape. They are characterized by their relationship to existing topography and the patterns of erosion that shape the landscape. Unlike consequent streams, which follow the slope of the land, subsequent streams are often perpendicular or oblique to the main axis of the drainage network.

Subsequent streams typically form when the underlying geology or topography is complex, such as in areas with folded or faulted rock formations. In these areas, streams may be diverted by ridges or other features, leading to the development of new channels that intersect the main drainage network at an angle.

A subsequent stream river drainage system is a type of river drainage system where the streams flow perpendicular to the main river channel. Subsequent streams are formed after the main river channel has been established, and they cut across the existing topography. These streams are typically found in areas where the landscape has undergone significant changes, such as through uplift or erosion, which have caused the main river channel to deviate from its original path.

Subsequent streams are characterized by a trellis-like pattern, with the tributaries joining the main channel at right angles. They are typically found in areas with alternating layers of hard and soft rock, where the soft rock erodes more quickly than the hard rock, creating valleys and ridges. The subsequent streams cut across the ridges and flow into the valleys, creating a pattern that resembles a ladder.

An example of a subsequent stream river drainage system is the Ganga River in India. The Ganga River is one of the largest rivers in India, flowing through several states before emptying into the Bay of Bengal. The river system includes numerous tributaries, many of which are subsequent streams that have been formed as a result of geological changes over millions of years.

Subsequent streams are important for supporting a wide range of human and ecological communities. They provide water for irrigation, transportation, and other uses, and they support diverse aquatic habitats, including wetlands, floodplains, and estuaries. However, they are also vulnerable to a range of environmental challenges, such as pollution, climate change, and habitat loss, which can impact their sustainability and resilience over time.

An example of a subsequent stream system is the Susquehanna River in the northeastern United States. The Susquehanna River flows from New York State into Pennsylvania and Maryland, where it eventually empties into the Chesapeake Bay. The river is characterized by its numerous tributaries, many of which are subsequent streams that intersect the main channel at an angle. These streams were formed by the complex geology of the region, which includes folded and faulted rock formations.

Subsequent streams can be important for managing and conserving water resources in areas with complex topography or geology. They may play a key role in maintaining aquatic habitats and supporting biodiversity, and can also have significant cultural and historical value. Understanding the behaviour of subsequent streams is therefore important for predicting the effects of climate change and other environmental factors on river systems, as well as for managing and protecting these important resources.

An example of a subsequent stream river drainage system in India is the Godavari River system. The Godavari River is one of the largest rivers in India, flowing through the states of Maharashtra, Telangana, Andhra Pradesh, and Odisha before emptying into the Bay of Bengal. The river system includes numerous tributaries, many of which are subsequent streams that intersect the main channel at an angle.

The Godavari River system is characterized by its complex geology, which includes folded and faulted rock formations. These features have led to the development of numerous subsequent streams that intersect the main channel at various points along its length. One notable example is the Pranhita River, which flows into the Godavari River at an angle of nearly 90 degrees. The Pranhita River is formed by the convergence of two smaller rivers, the Wardha and Wainganga, which flow from opposite directions and intersect at a right angle to form the Pranhita River.

The subsequent streams in the Godavari River system are important for maintaining aquatic habitats and supporting biodiversity in the region. They also play a key role in agriculture, providing water for irrigation and supporting the livelihoods of millions of people who depend on the river for their daily needs. However, the river system is facing a range of environmental challenges, including pollution, dam construction, and climate change.

Understanding the behaviour of subsequent streams is therefore important for managing and protecting these important resources and ensuring their sustainability for future generations.

Subsequent streams

A subsequent stream river drainage system is a type of river system where the streams flow parallel to the main river channel, indicating that they were formed after the main channel was established. These streams form in areas where the landscape has been uplifted or tilted, and the main river channel is already established before the tributaries begin to form.

A subsequent stream river drainage system is a type of river drainage system where the streams flow parallel to the main river channel. This happens when the main river channel follows the path of least resistance along a slope or terrain, and the tributaries that join the main channel also flow parallel to it.

Obsequent streams are typically found in areas where the landscape is relatively uniform, with no major geological barriers or changes in elevation. They tend to have a parallel pattern, with the tributaries joining the main channel at acute angles.

An example of a subsequent stream river system is the Tapti River in India. The Tapti River is a major river in central India, flowing from its source in the Satpura Range through several states before emptying into the Arabian Sea. The river system includes numerous tributaries that flow parallel to the main channel, such as the Purna River, the Girna River, and the Panzara River.

Obsequent stream river systems are important for supporting a wide range of human and ecological communities. They provide water for irrigation, transportation, and other uses, and they support diverse aquatic habitats, including wetlands, floodplains, and estuaries. However, they are also vulnerable to a range of environmental challenges, such as pollution, climate change, and habitat loss, which can impact their sustainability and resilience over time.

One example of a subsequent stream river drainage system is the Tungabhadra River in southern India. The Tungabhadra River is formed by the confluence of the Tunga and Bhadra Rivers in the Western Ghats and flows eastward through the states of Karnataka and Andhra Pradesh before joining the Krishna River.

The Tungabhadra River system includes numerous tributaries that are subsequent streams, flowing parallel to the main river channel. These streams are believed to have been formed after the main river channel was established, as a result of tectonic uplift in the region. The tributaries include the Vedavathi, Chitravathi, Penna, and Musi Rivers, among others.

The subsequent streams in the Tungabhadra River system are important for supporting agriculture and biodiversity in the region. They provide water for irrigation and support a wide range of aquatic habitats, including wetlands, marshes, and floodplains. However, the river system is facing a range of environmental challenges, including pollution, dam construction, and climate change. Understanding the behaviour of subsequent streams is therefore important for managing and protecting these important resources and ensuring their sustainability for future generations.

Resequent streams

Resequent streams are a type of river drainage system that form when a river system is modified by tectonic or geomorphic processes, leading to the formation of new channels that have different characteristics from the original channel. These new channels are known as resequence streams, and they flow parallel to the main river channel.

A request streams river drainage system is a type of river drainage system where the streams flow parallel to the main river channel but in the opposite direction. Unlike subsequent streams, which flow parallel to the main channel in the same direction, resequence streams flow parallel to the main channel in the opposite direction.

Resequent streams are typically formed in areas where the landscape has been uplifted or tilted, causing the river channel to flow in one direction, while the tributaries flow in the opposite direction. This creates a river system with a dendritic or trellis-like pattern, where the tributaries join the main channel at acute or obtuse angles.

An example of a resequent stream river drainage system is the Brahmaputra River in northeastern India. The Brahmaputra River is one of the largest rivers in the world, flowing through Tibet, India, and Bangladesh before emptying into the Bay of Bengal. The river system includes numerous tributaries, many of which are resequent streams that have been formed as a result of tectonic uplift and other geological processes.

One example of a resequent stream in the Brahmaputra River system is the Subansiri River. The Subansiri River is a major tributary of the Brahmaputra River, flowing through the states of Arunachal Pradesh and Assam in northeastern India. The river system includes several channels, with the main channel flowing southwards and the resequent channel flowing northwards.

The Subansiri River is an important resource for the people living in the region, supporting agriculture and fishing activities. However, the river system is facing a range of environmental challenges, including pollution, deforestation, and dam construction. Understanding the behaviour of resequent streams is therefore important for managing and protecting these important resources and ensuring their sustainability for future generations.

In addition to the Brahmaputra River, other examples of resequent stream river drainage systems in India include the Ganga and Indus River systems. These river systems have been modified by a range of tectonic and geomorphic processes over millions of years, leading to the formation of new channels and tributaries that shape the landscape and support human and ecological communities.

6.3.4 Types of insequent Drainage Systems

- **Antecedent Drainage System**
- **Superimposed Drainage System**

Antecedent Drainage System

An antecedent river drainage system is a type of river system that maintains its original course and direction despite the geological changes in the surrounding landscape. In other words, the river channel existed before the landscape around it was formed, and it continues to flow in the same direction as it did before the landscape was uplifted, folded, or faulted.

Antecedent rivers are typically found in regions with complex geological structures, such as mountainous areas or areas with underlying rock strata that are folded or faulted. As the landscape is uplifted or deformed, the river channel remains in place and continues to cut through the uplifted terrain, creating a steep and narrow river valley. Antecedent rivers are those that maintain their original course and direction despite the geological changes in the surrounding landscape. They are typically found in regions with complex geological structures, such as mountainous areas or areas with underlying rock strata that are folded or faulted. Here are some examples of antecedent river drainage systems around the world and in India:

- **Indus River:** The Indus River in Pakistan is one of the longest rivers in Asia, originating in the Himalayas and flowing through Pakistan before emptying into the Arabian Sea. The Indus River is an example of an antecedent river drainage system, as it maintains its original course and direction despite the tectonic uplift that created the Himalayas.
- **Mekong River:** The Mekong River is a transboundary river that flows through China, Myanmar, Laos, Thailand, Cambodia, and Vietnam. It is an example of an antecedent river drainage system, as it cuts through the uplifted terrain of the Southeast Asian mountains.
- **Yangtze River:** The Yangtze River is the longest river in China and the third-longest river in the world. It is an example of an antecedent river drainage system, as it has maintained its course through the tectonic uplift that created the Tibetan Plateau.

- **Narmada River:** The Narmada River in India is one of the seven holy rivers of India and is the fifth-longest river in the country. It is an example of an antecedent river drainage system, as it has maintained its course through the tectonic uplift that created the Satpura and Vindhya mountain ranges.
- **Godavari River:** The Godavari River is the second-longest river in India and flows through the states of Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh, and Odisha. It is an example of an antecedent river drainage system, as it has maintained its course through the tectonic uplift that created the Eastern Ghats.

Antecedent river drainage systems are important for supporting a wide range of ecological and economic activities, and their sustainability and resilience can be impacted by environmental challenges such as pollution, climate change, and habitat loss.

Antecedent river drainage systems are important for supporting a wide range of ecological and economic activities. They provide water for irrigation, transportation, and other uses, and they support diverse aquatic habitats, including wetlands, floodplains, and estuaries. However, they can also be vulnerable to environmental challenges such as pollution, climate change, and habitat loss, which can impact their sustainability and resilience over time.

Superimposed Drainage System

A superimposed river drainage system is one where the river's course is determined by a previously established drainage pattern, such as a structural or geological feature. This means that the river does not follow the existing topography of the area, but rather cuts through it, eroding the underlying rock and creating its path.

This type of drainage system typically occurs in regions where there has been significant tectonic uplift or where there are contrasting layers of rock. The river's path is determined by the underlying structural features, rather than by the existing topography.

One example of a superimposed river drainage system is the Amazon River in South America. The Amazon River cuts through the South American Plateau, which was formed by tectonic uplift and has created its path through the underlying rock. The Amazon River's course is determined by the underlying rock layers, rather than by the topography of the plateau.

Another example of a superimposed river drainage system is the Colorado River in the United States. The Colorado River cuts through the Colorado Plateau, which was formed by tectonic uplift and has created its path through the underlying rock. The Colorado River's course is determined by the underlying rock layers, rather than by the topography of the plateau.

Superimposed river drainage systems can have important environmental and economic impacts, as they can create unique ecosystems and provide important water resources for human populations. However, they can also be vulnerable to environmental stressors such as climate change, pollution, and habitat loss.

The geomorphology of a superimposed river drainage system is characterized by the interaction between the river's erosional forces and the underlying geological structure of the region. In this type of drainage system, the river's course is not determined by the pre-existing topography, but rather by the underlying rock structure. The river erodes through the overlying layers of rock, creating a path that is largely independent of the topography.

The process by which a superimposed river drainage system is formed is complex and can take millions of years. It typically begins with tectonic activity, which causes the uplift of the land. The river is then superimposed on the newly uplifted landscape and begins to erode through the underlying rock layers, creating a new path.

The erosion of the rock layers can result in the formation of various landforms such as canyons, gorges, and waterfalls. These landforms can be quite spectacular and attract tourists from around the world. However, they can also pose challenges to human populations living in the region, particularly if the area is prone to flooding or landslides.

Superimposed river drainage systems can be found all around the world, in areas where the landscape has been shaped by tectonic activity and the underlying rock structure is resistant to erosion. Here are some examples of superimposed river drainage systems from around the world:

Grand Canyon, United States: The Colorado River has created a deep and winding gorge that is over 1.6 kilometres (1 mile) deep in places. The rocks exposed in the canyon walls are some of the oldest on the planet, dating back billions of years.

Tsangpo Gorge, Tibet: The Yarlung Tsangpo River flows through a deep gorge in the Himalayas that is over 5,000 meters (16,000 feet) deep in places. The gorge was formed by the collision of the Indian and Eurasian tectonic plates.

Victoria Falls, Zambia and Zimbabwe: The Zambezi River flows over a large basalt plateau, creating the world-famous Victoria Falls. The falls are over 100 meters (328 feet) tall and are one of the largest waterfalls in the world.

In India, the Deccan Plateau is an example of a region with a superimposed river drainage system. The plateau was formed by volcanic activity millions of years ago and is now home to several major rivers, including the Godavari, Krishna, and Cauvery. These rivers have carved deep gorges through the plateau, creating spectacular waterfalls and canyons.

Another example of a superimposed river drainage system in India is the Brahmaputra River. The river flows through the Himalayas and has created a deep gorge known as the Brahmaputra Canyon. The canyon is over 500 kilometres (310 miles) long and is one of the largest in the world.

6.4 DRAINAGE PATTERNS

A river drainage pattern is the network of interconnected streams and rivers that make up a river system. It is the arrangement of rivers and streams within a given drainage basin. Drainage patterns are formed by a combination of geological, hydrological, and topographical factors. These patterns can be classified into several types based on their appearance and formation, like Dendritic pattern, Radial pattern, Rectangular pattern, Trellis pattern, Parallel pattern, Deranged pattern

The type of river drainage pattern found in a particular area is determined by a variety of factors, including the geology of the area, the topography, and the climate. Understanding the different types of drainage patterns can help geologists and hydrologists better understand how rivers and streams behave, and how they interact with the landscape around them.

6.4.1 Trellis Pattern

The trellis pattern is a type of river drainage pattern that is characterized by a network of parallel streams that are tributaries to a single, main-stem river. These parallel streams typically run perpendicular to the main stem river and are separated by ridges of harder rock that are more resistant to erosion. The ridges are often formed by anticlines or synclines in folded sedimentary rocks.

The trellis pattern is commonly found in areas with alternating bands of resistant and less-resistant rock, such as the Appalachian Mountains in the eastern United States. The pattern is also common in regions that have undergone tectonic uplift or that have been glaciated, as these processes can create alternating bands of hard and soft rock.

One of the most well-known examples of the trellis pattern is the Susquehanna River system in the northeastern United States. The main stem of the Susquehanna River flows southward through Pennsylvania and Maryland, while a series of parallel streams flow into it from the east and west. These parallel streams are separated by ridges of harder rock that form the Appalachian Mountains.

The trellis pattern is also found in other parts of the world, such as the drainage systems of the Tigris and Euphrates rivers in the Middle East, and the Chambal River system in India. In these regions, the trellis pattern is influenced by the underlying geology and topography of the area.

Overall, the trellis pattern is an important example of how geological and topographical factors can shape the patterns of river drainage systems. Its distinctive parallel streams and ridges can provide insights into the complex history and evolution of a particular landscape.

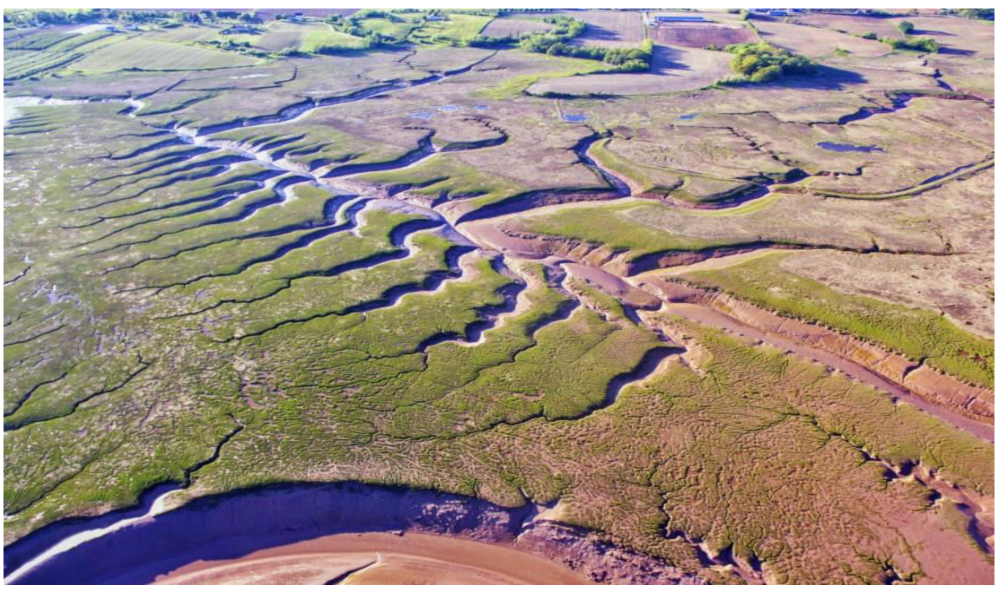


Fig. 6.1 Trellis Drainage patten, Bay of fundy NS Canada Source- Google Image

6.4.2 Dendritic Drainage Pattern

The dendritic river drainage pattern is the most common and widely spread pattern in the world. It is characterized by a network of tributaries that branch out like the branching of a tree or the veins of a leaf. The main river channel is in the centre of the drainage basin, and the tributaries flow into it at acute angles. The dendritic pattern is formed when rivers flow over a relatively uniform surface, such as sedimentary rocks, and the channels erode through the rock at similar rates.

The dendritic pattern is most commonly found in regions with horizontal or gently sloping terrain, and it is often associated with areas of sedimentary rock that have been uplifted or eroded. This pattern can be seen in many parts of the world, including the Appalachian Mountains, the Great Plains of North America, and parts of Europe, Africa, and Asia.

One of the most well-known examples of a dendritic river drainage pattern is the Mississippi River system in the United States. The main stem of the Mississippi River flows southward from its headwaters in Minnesota to the Gulf of Mexico, and it is fed by a vast network of tributaries that branch out in all directions across the Midwest and the Southeastern United States.

The dendritic pattern is also found in many Indian rivers such as the Ganges, the Brahmaputra, and the Godavari. These rivers originate from the Himalayas and flow across the plains of India, branching out into a complex network of tributaries that drain into the Bay of Bengal.

Overall, the dendritic river drainage pattern is an important example of how geological and topographical factors can shape the patterns of river drainage systems. Its distinctive branching structure can provide insights into the complex history and evolution of a particular landscape.

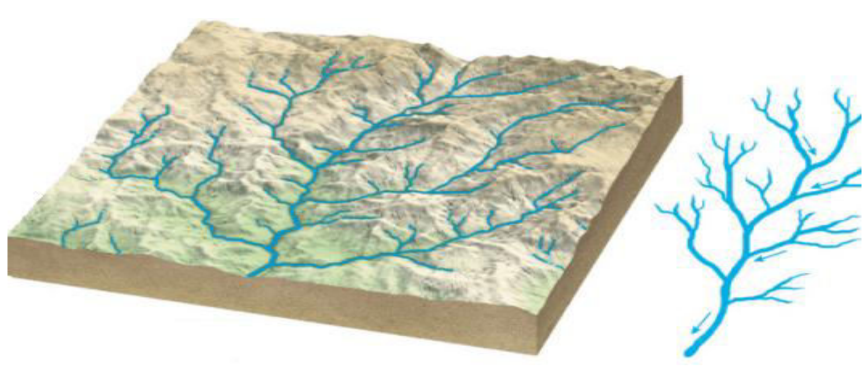


Fig. 6.2 Dendritic Drainage Pattern, Source Google Image

6.4.3 Rectangular Drainage pattern

The rectangular river drainage pattern is a less common pattern of river drainage that is characterized by a network of streams that form right-angle turns, resembling a rectangular grid pattern. This pattern is formed when rivers flow across alternating bands of hard and soft rock or a highly jointed or faulted bedrock surface. The streams follow the lines of weakness in the rock, resulting in a pattern of right-angle turns.

The rectangular pattern is most commonly found in regions with highly jointed or faulted bedrock, such as the Colorado Plateau in the southwestern United States, the Deccan Plateau in India, and the Kimberley Plateau in Australia. These regions are characterized by flat-lying sedimentary rock formations that have been uplifted and subjected to extensive tectonic activity.

One example of a rectangular river drainage pattern is the San Juan River in southeastern Utah, which flows through a region of highly jointed sandstone formations. The river follows the joints in the rock, resulting in a series of right-angle turns and rectangular blocks of rock.

In India, one example of a rectangular drainage pattern can be seen in the Subarnarekha River that flows through the states of Jharkhand, Odisha, and West Bengal. The river flows over a region of highly jointed and faulted Precambrian rocks, resulting in a network of streams that form right-angle turns.

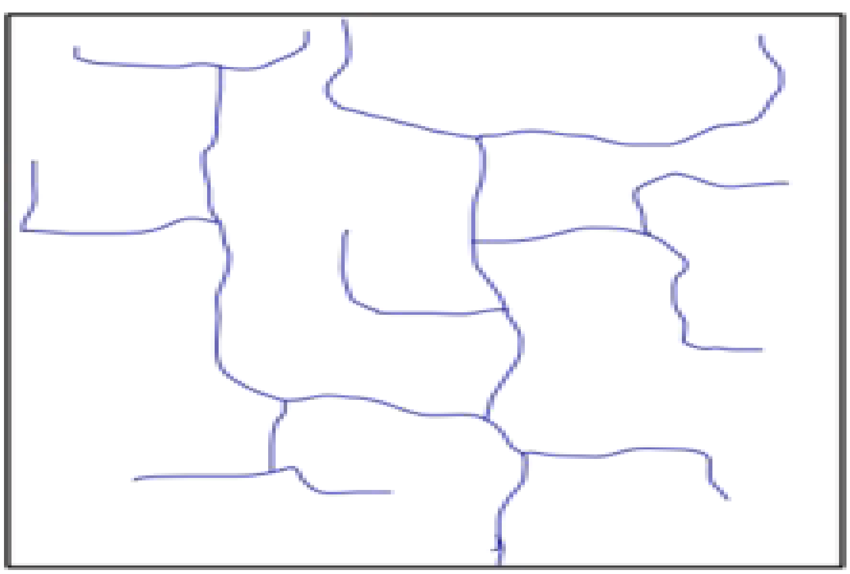


Fig. 6.3 Rectangular Drainage Pattern source Google Image

6.4.4 Redial or Centrifugal Drainage Pattern

The radial or centrifugal river drainage pattern is a type of river drainage pattern that is characterized by streams that flow outward from a central high point in a radial or spoke-like pattern. This pattern is commonly found in areas of volcanic or dome-shaped uplifts, where the rivers flow outwards from the centre of the uplift in a radial pattern.

The radial drainage pattern is typically found in volcanic areas, such as the Hawaiian Islands, where lava flows have created a dome-shaped uplift in the centre of the island. The rivers on these islands flow outward from the central high point in a spoke-like pattern, with the lower portions of the streams converging to form larger rivers that flow to the ocean.

One example of a radial river drainage pattern can be seen in the Radial Lake District in Chile. This region is characterized by a series of dome-shaped volcanoes that have created a radial pattern of rivers flowing outward from the centre of the region.

In contrast to the dendritic drainage pattern, the radial pattern is relatively rare and is typically only found in areas with specific geological characteristics, such as volcanic uplifts.

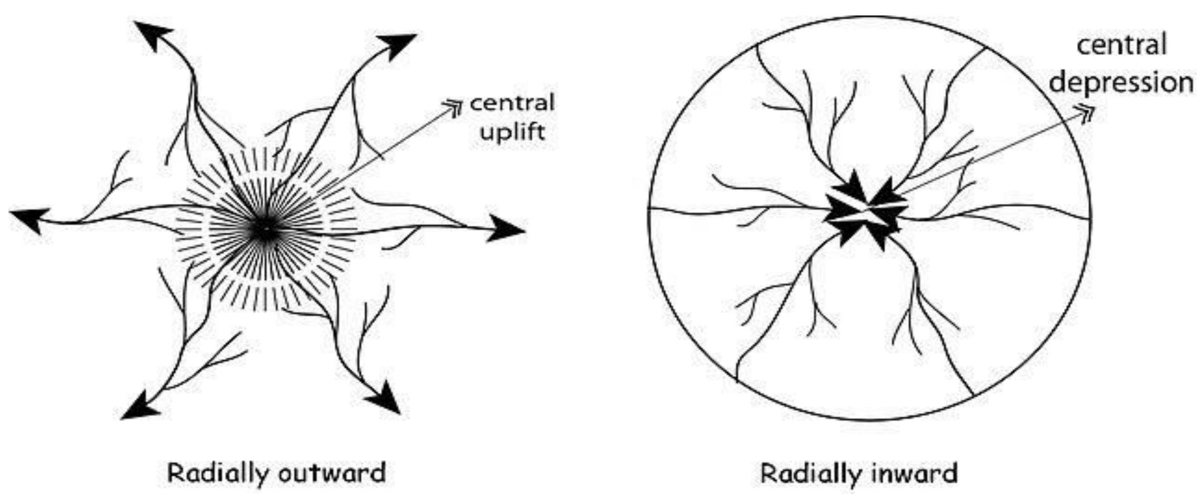


Fig. 6.4 Redial or Centrifugal Drainage Pattern, Source Google Image

6.4.5 Centripetal or Inland Drainage Pattern

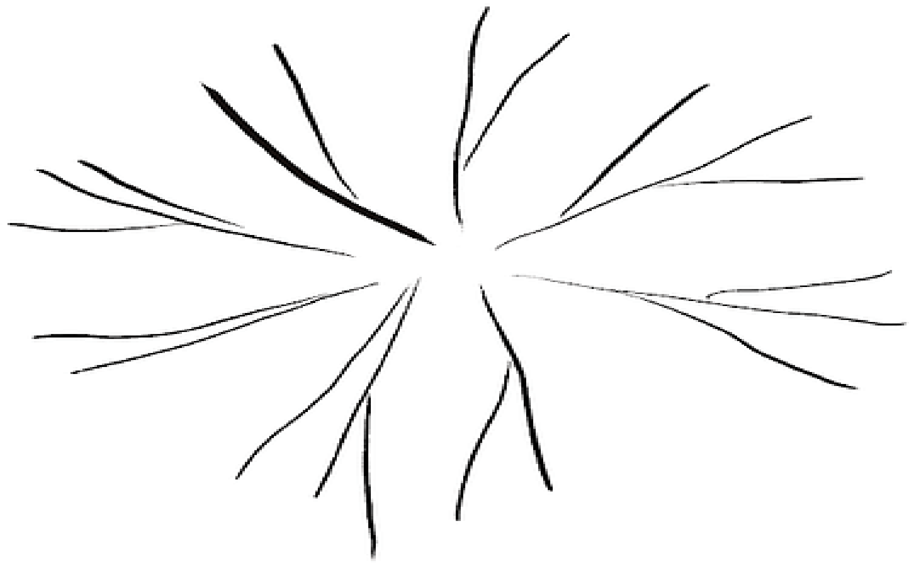
A centripetal or inland river drainage pattern is a type of drainage pattern where a river system flows towards a central depression or basin. This pattern is commonly found in regions where the land is relatively flat or gently sloping, and the rivers do not have a significant gradient to flow towards the ocean. Instead, they flow towards a central point, such as a lake or an inland sea, and form a dendritic or radial pattern of tributaries.

The formation of a centripetal drainage pattern is often the result of tectonic activity or glaciation, which can create a basin or depression in the centre of a region. The surrounding land then drains into this central point, forming a dendritic pattern of streams and rivers that converge towards the centre.

One example of a centripetal drainage pattern is the Mississippi River system in the United States. The Mississippi River and its tributaries flow towards the Gulf of Mexico, but the system also includes several large lakes, including Lake Superior, which serve as a central point for the drainage of surrounding areas.

Another example of a centripetal drainage pattern is the Ob River system in Russia. The Ob River flows towards the Arctic Ocean, but the system also includes several large lakes, including Lake Baikal, which serves as a central point for the drainage of surrounding areas.

Finally, a centripetal or inland river drainage pattern is a type of drainage pattern where a river system flows towards a central depression or basin, forming a dendritic or radial pattern of tributaries. This pattern is commonly found in regions where the land is relatively flat or gently sloping and can be the result of tectonic activity or glaciation.



Centripetal Drainage

Fig. 6.5 Centripetal or Inland Drainage Pattern, Source Google Image

6.4.6 Annular Drainage Pattern

An annular river drainage pattern is a type of drainage pattern where the rivers follow concentric paths around a highland or dome-shaped structure. The pattern resembles a series of concentric rings or circles, with the rivers flowing along the contours of the land, forming circular loops or arcs.

This pattern is commonly found in regions where there is a dome-shaped geological feature, such as a volcanic peak, a mountain range, or a plateau. The rivers follow the contours of the land, flowing around the central highland, and forming a series of circular loops. The rivers may eventually flow outwards and join other river systems, or they may form lakes or wetlands in the central region.

An example of an annular drainage pattern can be found in the Scottish Highlands, where the rivers follow circular paths around the Cairngorm Mountains. The rivers flow around the central highland, forming circular loops that eventually join larger river systems, such as the River Spey and the River Dee.

Another example of an annular drainage pattern can be found in the Deccan Plateau in India. The rivers in this region follow concentric paths around the highland, forming circular loops and eventually joining larger river systems such as the Godavari and the Krishna rivers.

An annular river drainage pattern is a type of drainage pattern where the rivers follow concentric paths around a highland or dome-shaped structure, forming circular loops or arcs. This pattern is commonly found in regions where there is a central highland or plateau, and the rivers follow the contours of the land. The rivers may eventually flow outwards and join other river systems or form lakes or wetlands in the central region.

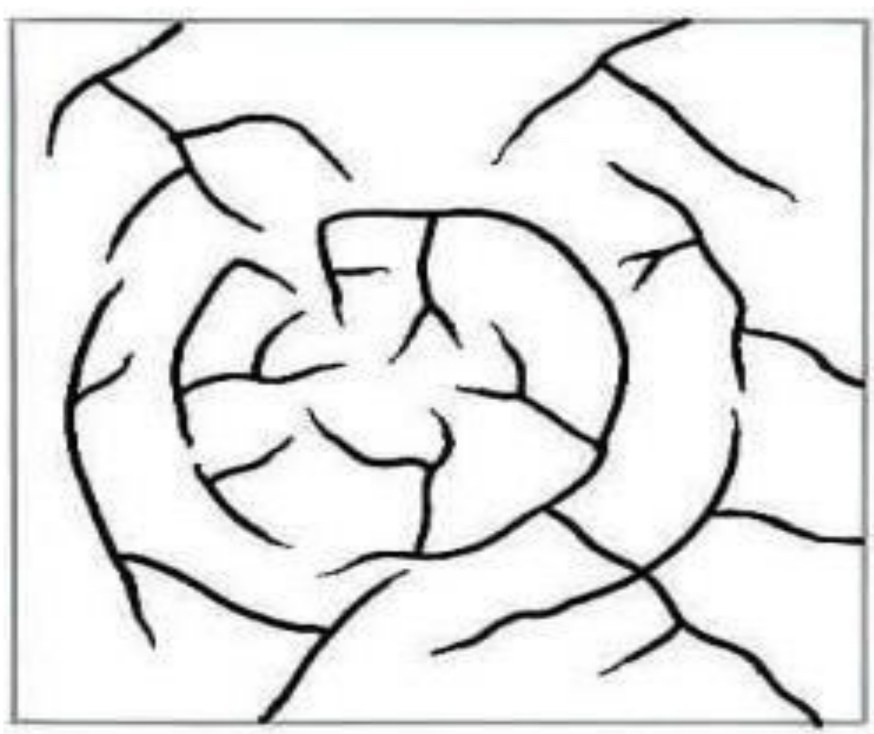


Fig. 6.6 Annular Drainage Pattern, Source Google Image

6.4.7 Barbed Drainage Pattern

A barbed river drainage pattern, also known as a trellis drainage pattern, is a type of drainage pattern where the rivers flow in a parallel direction and join each other at acute angles. The pattern resembles a series of tree branches or a garden trellis, with the main river flowing in a straight line, while its tributaries join at sharp angles, forming a series of V-shaped valleys.

This pattern is commonly found in regions with alternating layers of hard and soft rock or sediment, where the rivers follow the path of least resistance, eroding through the soft rock and following the harder rock layers in a parallel direction. The tributaries then join the main river at sharp angles, following the path of least resistance through the softer layers.

An example of a barbed drainage pattern can be found in the Appalachian Mountains in the eastern United States. The rivers in this region flow in a parallel direction, following the alternating layers of hard and soft rock, and form a series of V-shaped valleys that join the main river at sharp angles.

Another example of a barbed drainage pattern can be found in the Narmada River basin in India. The rivers in this region flow in a parallel direction, following the alternating layers of hard and soft sediment, and form a series of V-shaped valleys that join the main river at sharp angles.

A barbed river drainage pattern is a type of drainage pattern where the rivers flow in a parallel direction and join each other at acute angles, resembling a series of tree branches or a garden trellis. This pattern is commonly found in regions with alternating layers of hard and soft rock or sediment, where the rivers follow the path of least resistance and erode through the soft layers, with tributaries joining at sharp angles.

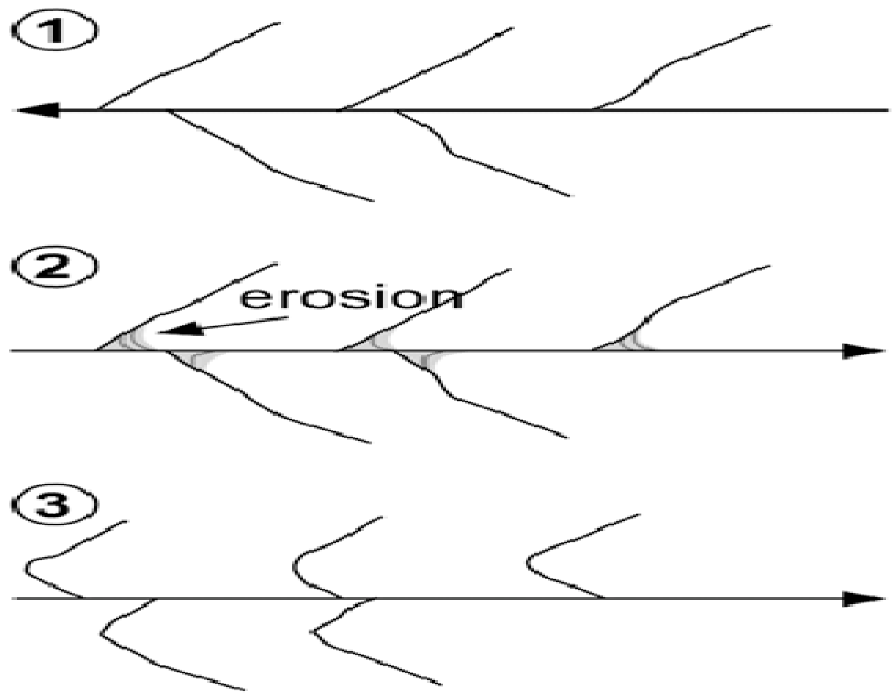


Fig. 6.7 Barbed Drainage Pattern, Source Google Image

6.4.8 Herringbone Drainage Pattern

A herringbone river drainage pattern is a type of drainage pattern where the rivers flow in a parallel zig-zag pattern, resembling the bones of a herring. The pattern consists of a main river that flows in a straight line, with its tributaries flowing at acute angles and then reversing direction to flow in a parallel direction to the main river.

This pattern is commonly found in regions with alternating layers of hard and soft rock or sediment, where the rivers follow the path of least resistance, eroding through the soft rock and following the harder rock layers in a parallel zig-zag pattern. The tributaries then join the main river at acute angles and reverse directions, flowing in a parallel direction to the main river.

An example of a herringbone drainage pattern can be found in the Western Ghats in India. The rivers in this region flow in a parallel zig-zag pattern, following the alternating layers of hard and soft rock, and form a series of V-shaped valleys that join the main river at acute angles.

Another example of a herringbone drainage pattern can be found in the Catskill Mountains in the eastern United States. The rivers in this region flow in a parallel zig-zag pattern, following the alternating layers of hard and soft rock, and form a series of V-shaped valleys that join the main river at acute angles.

A herringbone river drainage pattern is a type of drainage pattern where the rivers flow in a parallel zig-zag pattern, resembling the bones of a herring. This pattern is commonly found in regions with alternating layers of hard and soft rock or sediment, where the rivers follow the path of least resistance, eroding through the soft layers, with tributaries joining at acute angles and reversing direction to flow in a parallel direction to the main river.

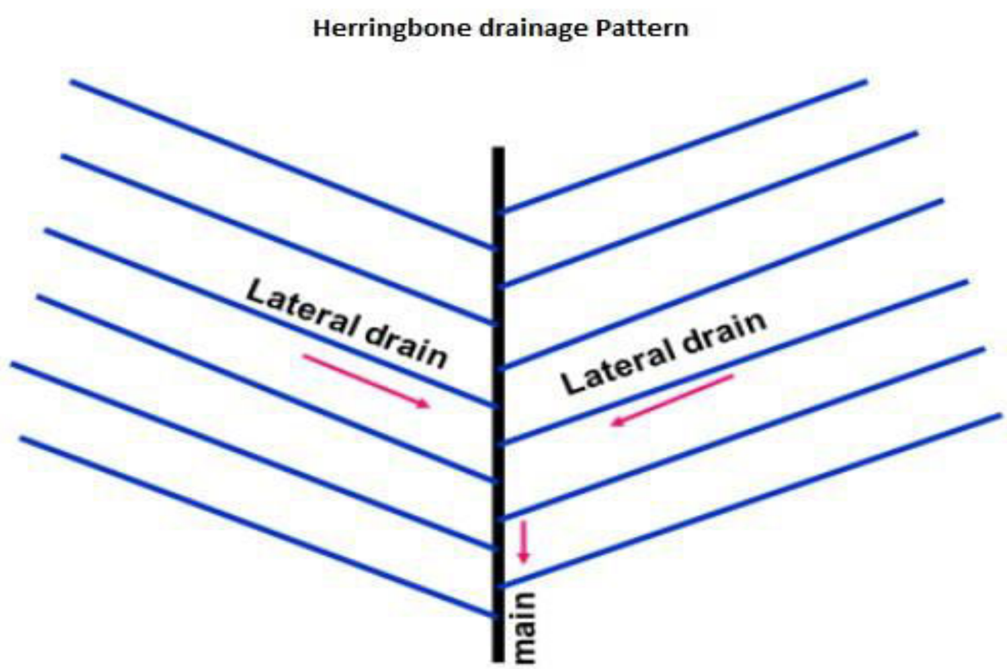


Fig. 6.8 Herringbone Drainage Pattern, Source Google Image

6.4.9 Pinnate Drainage Pattern

A pinnate river drainage pattern, also known as a dendritic drainage pattern, is a type of drainage pattern where the rivers flow in a branching or tree-like pattern, with smaller tributaries joining larger rivers at acute angles. The pattern resembles the veins of a leaf or the branches of a tree.

This pattern is common in regions with uniform geology and topography, where the rivers follow the path of least resistance, eroding the landscape evenly and forming a network of branching channels. The tributaries join the main river at acute angles and gradually increase in size as they flow downstream.

The formation of this pattern is often the result of uniform geology and topography, where the rivers are not influenced by major faulting, folding, or differential erosion. Instead, the drainage system follows the path of least resistance, carving out a network of branching channels as it erodes the landscape.

An example of a pinnate river drainage pattern can be found in the Mississippi River basin in the United States. The rivers in this region flow in a branching or tree-like pattern, with smaller tributaries joining larger rivers at acute angles. The main river, the Mississippi River, is fed by numerous tributaries, including the Ohio River, the Missouri River, and the Arkansas River.

Another example of a pinnate river drainage pattern can be found in the Amazon River basin in South America. The rivers in this region flow in a branching or tree-like pattern, with smaller tributaries joining larger rivers at acute angles. The main river, the Amazon River, is fed by numerous tributaries, including the Rio Negro, the Madeira River, and the Xingu River.

A pinnate river drainage pattern is a type of drainage pattern where the rivers flow in a branching or tree-like pattern, with smaller tributaries joining larger rivers at acute angles. This pattern is commonly found in regions with uniform geology and topography, where the rivers follow the path of least resistance and form a network of branching channels.

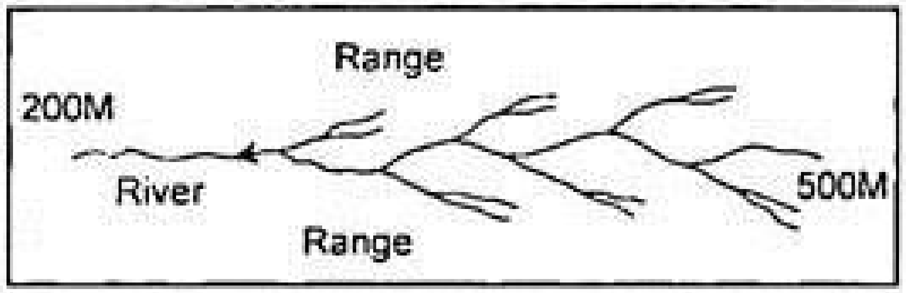


Fig. 6.9 Pinnate River Drainage Pattern, Source Google Image

6.4.10 Parallel Drainage Pattern

A parallel drainage pattern is a type of drainage pattern in which the main river channel and its tributaries run parallel to each other. This pattern is commonly found in areas with steep slopes and parallel ridges or valleys. Here are some key characteristics of parallel drainage patterns:

- **Parallel streams:** The main river channel and its tributaries run parallel to each other, with very little variation in their direction. This gives the appearance of a set of parallel lines on a map.
- **Steep slopes:** Parallel drainage patterns are usually found in areas with steep slopes, such as mountainous regions or areas with deep valleys. Parallel ridges and valleys often form as a result of the erosion of the surrounding terrain by water or glaciers.
- **Little dendritic branching:** Unlike dendritic drainage patterns, which have many small tributaries branching off of the main river channel, parallel drainage patterns have very little dendritic branching. Instead, the tributaries are often short and merge quickly with the main channel.
- **V-shaped valleys:** The valleys that form between the parallel ridges are usually V-shaped, with steep sides and a narrow bottom. This is because the water erodes the rock or soil more quickly at the bottom of the valley than at the top, leading to a sharper V-shape.
- **Common in arid regions:** Parallel drainage patterns are often found in arid regions, where there is little vegetation to hold the soil in place and a lot of erosion takes place.

The lack of vegetation also means that there is less water available to form dendritic patterns.

6.4.11 Appalachian Mountains, Eastern United States:

The Appalachian Mountains are a range of mountains in eastern North America that stretch from Canada to Alabama. The mountains are known for their parallel ridges and valleys, which have been eroded by water over millions of years. The rivers and streams in this region flow parallel to each other, forming a parallel drainage pattern.

Andes Mountains, South America:

The Andes Mountains are the longest mountain range in the world, stretching over 7,000 kilometres along the western coast of South America. The mountains are characterized by their steep slopes and parallel ridges and valleys, which have been formed by erosion over millions of years. The rivers and streams in this region flow parallel to each other, forming a parallel drainage pattern.

Himalayan Mountains, Asia:

The Himalayan Mountains are a range of mountains in Asia that stretch over 2,400 kilometres through India, Nepal, Bhutan, and China. The mountains are known for their steep slopes and parallel ridges and valleys, which have been eroded by water over millions of years. The rivers and streams in this region flow parallel to each other, forming a parallel drainage pattern.

Karoo Basin, South Africa:

The Karoo Basin is a sedimentary basin located in South Africa, known for its parallel drainage pattern. The basin is characterized by its flat topography and steep sides, which have been eroded by water over millions of years. The rivers and streams in this region flow parallel to each other, forming a parallel drainage pattern.

Valleys of Southern California, United States:

The valleys of Southern California, including the San Fernando Valley and San Gabriel Valley, are known for their parallel drainage patterns. These valleys were formed by the movement of tectonic plates, which caused the land to uplift and form parallel ridges and valleys. The rivers and streams in this region flow parallel to each other, forming a parallel drainage pattern.

6.4.12 Indeterminate Drainage Pattern

An indeterminate drainage pattern is a type of drainage pattern in which the rivers and streams do not follow a specific pattern or direction. This type of pattern is usually found in areas with a flat topography or areas with irregular landforms. Here are some key characteristics of indeterminate drainage patterns:

- **No clear direction:** Unlike other drainage patterns, indeterminate drainage patterns do not follow a clear direction or flow. Instead, the rivers and streams meander and twist in different directions, often forming loops and curves.
- **Flat topography:** Indeterminate drainage patterns are usually found in areas with flat topography, such as plains or plateaus. The lack of steep slopes or valleys means that the water has no clear direction in which to flow.
- **Irregular landforms:** Indeterminate drainage patterns can also be found in areas with irregular landforms, such as areas with karst topography or areas with volcanic activity. These areas often have unpredictable water flow due to the unique features of the land.
- **Common in humid regions:** Indeterminate drainage patterns are often found in humid regions, where there is a lot of rainfall and a high water table. The abundance of water can cause the rivers and streams to meander and twist in different directions.
- **Lack of tributaries:** Indeterminate drainage patterns do not have many tributaries or smaller streams branching off of the main river channel. Instead, the rivers and streams often merge and split in unpredictable ways.

Amazon Basin, South America:

The Amazon Basin is a vast area of low-lying land in South America that is home to the Amazon River, the largest river by discharge volume in the world. The rivers and streams in this region do not follow a clear direction or pattern, instead meandering and twisting in different directions. This is due to the flat topography of the area and the high amount of rainfall and water table.

Florida Everglades, United States:

The Florida Everglades is a wetland area located in southern Florida, known for its unique ecosystem and indeterminate drainage pattern. The area is characterized by a flat landscape and a high water table, which has led to the formation of numerous rivers and streams that meander in different directions.

The Okavango Delta, Botswana:

The Okavango Delta is a large inland delta in Botswana, Africa, formed by the Okavango River. The delta is known for its unique ecosystem and indeterminate drainage pattern, with the river and its tributaries flowing in different directions due to the flat topography and irregular landforms of the area.

The Mekong Delta, Vietnam:

The Mekong Delta is a vast area of low-lying land in southern Vietnam, formed by the Mekong River. The area is known for its indeterminate drainage pattern, with the river and its tributaries meandering in different directions due to the flat topography and irregular landforms of the area.

The Nile River Delta, Egypt:

The Nile River Delta is a vast area of low-lying land in Egypt, formed by the Nile River. The delta is known for its unique ecosystem and indeterminate drainage pattern, with the river and its tributaries meandering in different directions due to the flat topography and irregular landforms of the area.

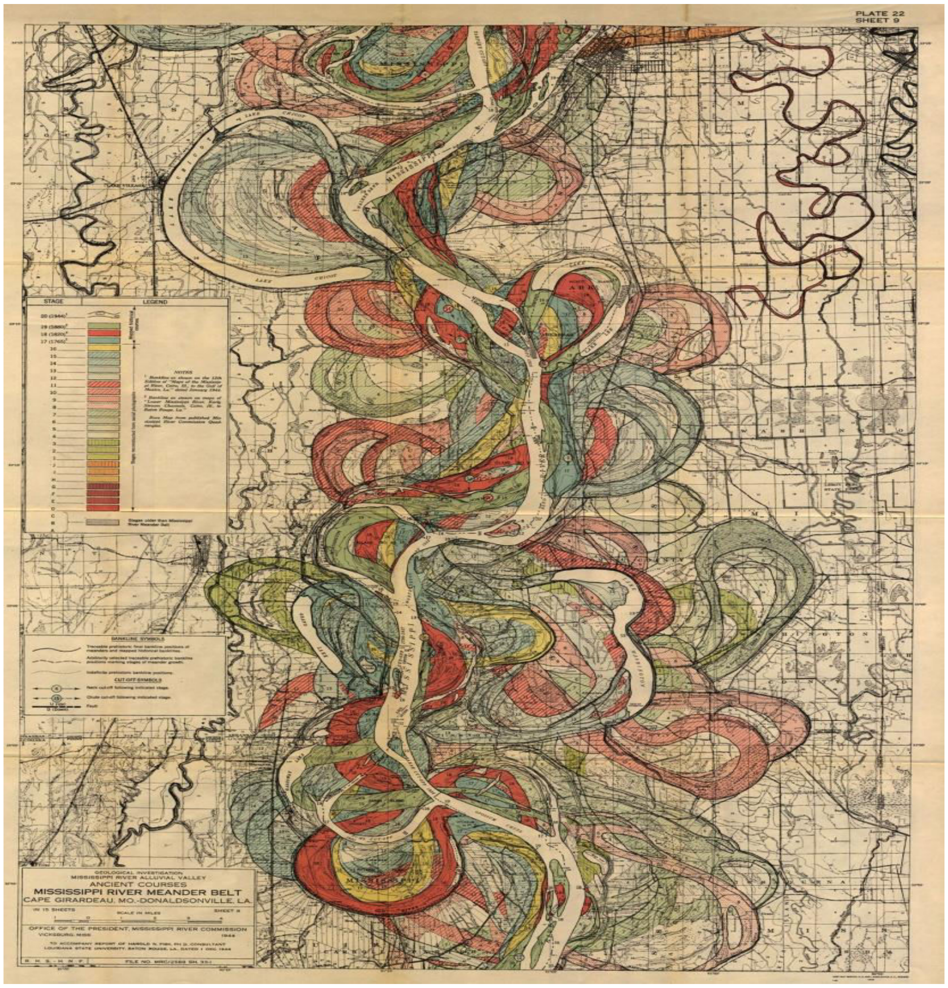


Fig. 6.10 Indeterminate Drainage Pattern, Source Google Image

6.4.13Intermittent Drainage Pattern

An intermittent drainage pattern is a type of drainage pattern in which the rivers and streams flow only during certain times of the year or in response to specific events such as rainfall or snowmelt. This type of drainage pattern is often found in arid or semi-arid regions, where there is not enough water to maintain a continuous flow throughout the year. Here are some key characteristics of intermittent drainage patterns:

- **Flow only during certain times:** Intermittent rivers and streams flow only during specific times of the year, such as during the rainy season or snowmelt. The rest of the time, they may be dry or have only a small amount of water flowing through them.

- **Arid or semi-arid regions:** Intermittent drainage patterns are most commonly found in arid or semi-arid regions, where there is not enough water to maintain a continuous flow throughout the year. These regions typically have low precipitation rates and high evaporation rates.
- **Flash floods:** Intermittent rivers and streams can experience sudden and intense floods during periods of heavy rainfall or snowmelt. These flash floods can cause significant damage and are a major hazard for people living in the region.
- **Ephemeral pools:** Intermittent drainage patterns can lead to the formation of ephemeral pools or ponds, which are temporary bodies of water that are filled by rainwater or snowmelt. These pools can provide important habitats for wildlife and can be a source of water for people and livestock during dry periods.
- **Human impact:** Intermittent drainage patterns are often impacted by human activities such as irrigation, mining, and damming. These activities can alter the natural flow of the rivers and streams, leading to changes in the ecosystem and water availability.

Examples of areas with intermittent drainage patterns include the Sonoran Desert in the southwestern United States, the Sahara Desert in Africa, and the Nullarbor Plain in Australia. These areas are characterized by a lack of rainfall and a high evaporation rate, leading to the formation of intermittent rivers and streams.

A few examples of intermittent river drainage patterns:

Wadi Rum, Jordan - This desert valley has an intermittent river that flows during the rainy season and creates a stunning landscape of sandstone cliffs and rock formations.

Sonoran Desert, United States - The Sonoran Desert is home to several intermittent rivers, including the Santa Cruz River, which flows seasonally through Arizona and northern Mexico.

Nullarbor Plain, Australia - The Nullarbor Plain is a vast, arid region in southern Australia that is crisscrossed by intermittent rivers, known locally as "creeks."

Sahara Desert, North Africa - The Sahara Desert is the largest hot desert in the world, and it is home to several intermittent rivers, including the Kufra Oasis and the Ubari Oasis.

The Atacama Desert, Chile - The Atacama Desert is one of the driest places on Earth, but it is also home to several intermittent rivers, such as the Loa River and the Copiapó River, which flow during the rainy season.

Fig. 6.11 Intermittent Drainage Pattern, Source Google Image

6.4.14 Underground Drainage Pattern

An underground river drainage pattern is a type of drainage system in which water flows through underground channels and caverns. This type of drainage system is found in areas where soluble rock such as limestone or gypsum is present, and the water has eroded the rock over time to form underground channels. Here are some details about underground river drainage patterns:

- **Characteristics:** Underground rivers can be found in a variety of shapes and sizes. They can be wide and shallow or narrow and deep, depending on the type of rock and the amount of water flow. Underground rivers can also be quite long, with some rivers flowing for many miles.
- **Formation:** Underground rivers are formed over a long time through the process of erosion. Rainwater or other surface water dissolves the soluble rock, creating

underground channels and caverns. Over time, these channels can grow larger and deeper, forming underground rivers.

- **Importance:** Underground rivers are important sources of freshwater in areas where surface water may be scarce or polluted. They also play a crucial role in the formation of cave systems, which are important for scientific research and tourism.
- **Threats:** Underground rivers are vulnerable to pollution from human activities, such as industrial waste or agricultural runoff. They are also susceptible to over-extraction, which can lead to the collapse of underground channels and the loss of important water resources. Therefore, it is essential to protect these unique and valuable ecosystems.

Underground river drainage patterns are found in many parts of the world, particularly in areas where soluble rock such as limestone or gypsum is present. Here are some examples of underground river drainage patterns:

Puerto Princesa Subterranean River, Philippines - This is the world's largest underground river, with a length of over 8 kilometres. It flows through a series of underground chambers before emerging into the ocean. The river is located in the Puerto Princesa Subterranean River National Park and is a UNESCO World Heritage Site.

Caves Branch River, Belize - The Caves Branch River is a subterranean river that flows through the Nohoch Che'en Caves Branch Archaeological Reserve in Belize. Visitors can explore the river and the surrounding cave system on guided tours.

Sistema Sac Actun, Mexico - This is the longest-known underground river system in the world, with a length of over 347 kilometres. It is located in the Yucatan Peninsula and is known for its extensive cave system and unique geological features.

Waitomo Caves, New Zealand - The Waitomo Caves are a popular tourist destination known for their stunning underground river system and glowworms. Visitors can take guided tours through the caves to see the underground river and the thousands of glowworms that live there.

Mammoth Cave, United States - Mammoth Cave is located in Kentucky and is the world's longest-known cave system, with over 650 kilometres of underground passages. It includes an underground river, the Echo River, which visitors can explore by boat.

6.4.15 River Capture

River capture, also known as river piracy or stream piracy, is a geological phenomenon in which one river or stream captures the flow of another river or stream. This occurs when the headwaters of one river erode into a nearby drainage basin, causing the water to flow in a different direction. Here are some details about river capture:

- **Causes:** River capture can occur due to several factors, including changes in land elevation, tectonic movements, and erosion caused by glaciers or other natural forces. In some cases, river capture can also be caused by human activities, such as the construction of dams or other structures.
- **Process:** River capture occurs when a river erodes into the drainage basin of another river. As the river's channel grows deeper, it may eventually intersect with the other river's channel, causing the water to flow in a new direction. Over time, the captured river may become completely diverted, with all of its flow being directed into the new channel.
- **Consequences:** River capture can have significant impacts on the surrounding landscape and ecosystems. The river that is captured may lose its source of water, leading to reduced flow and lower water levels downstream. The river that captures the flow may experience increased flow and erosion, leading to changes in the river's course and the surrounding landforms.
- **Importance:** River capture is an important process in the evolution of landscapes and the formation of river networks. It can also have significant impacts on human societies, particularly in areas where water resources are scarce or highly valued. Therefore, understanding the causes and consequences of river capture is essential for managing water resources and protecting the environment.

Some examples of river capture:

River Rhine and River Rhone: The River Rhine used to flow into the North Sea via the River Meuse. However, due to tectonic uplift and erosion, the Rhine gradually eroded into the drainage basin of the River Rhone. Today, the Rhine flows into the Mediterranean Sea via the Rhone River, while the Meuse flows into the North Sea.

River Colorado and Rio Grande: The Colorado River in the United States used to flow into the Gulf of California. However, due to tectonic movements and erosion, the river gradually changed its course and was captured by the Rio Grande, which now flows into the Gulf of Mexico.

River Arkavathi and River Kaveri: In India, the River Arkavathi used to flow into the Bay of Bengal via the River Kaveri. However, due to erosion and changes in land elevation, the Arkavathi was captured by the River Pennar, which now flows into the Bay of Bengal.

River Danube and River Morava: The Danube River in Europe used to flow into the Black Sea via the River Morava. However, due to erosion and tectonic uplift, the Danube gradually eroded into the drainage basin of the River Sava. Today, the Danube flows into the Black Sea via the River Sava, while the Morava flows into the Danube.

River Yellowstone and River Missouri: In the United States, the River Yellowstone used to flow into the Pacific Ocean. However, due to tectonic movements and erosion, the river gradually changed course and was captured by the Missouri River, which now flows into the Gulf of Mexico.

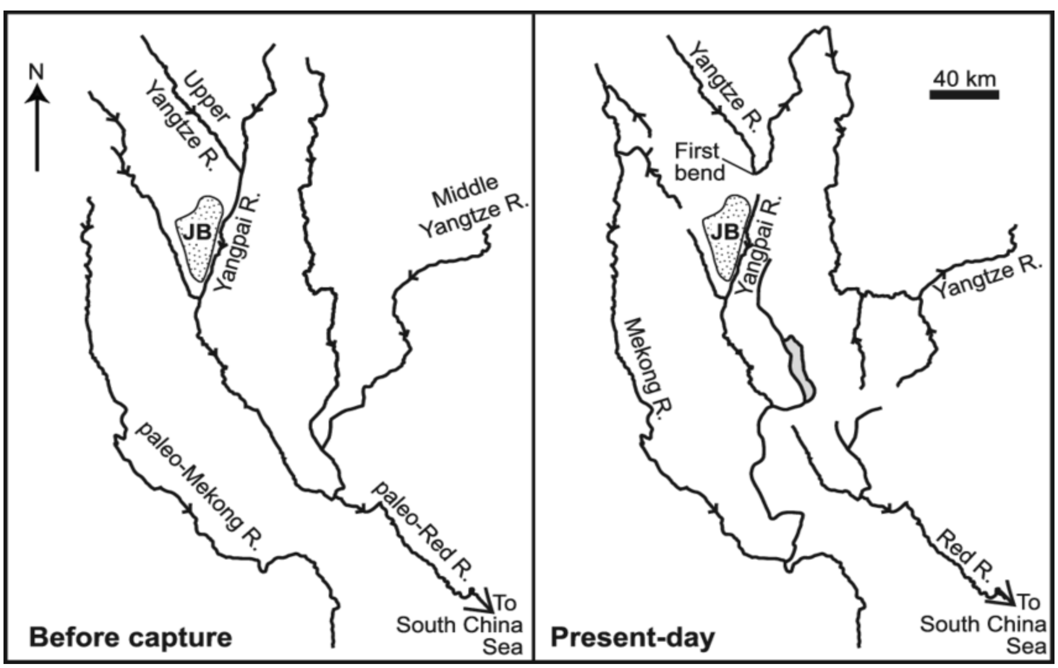


Fig. 6.12 River Capture, Source Google Image

6.4.16 Forms of River Capturing

There are different forms of river capturing, and here are some of them:

Headward erosion capture: This form of river capturing occurs when a river or stream erodes upstream and captures the headwaters of another river or stream. This can happen when the erosion rate of one river is higher than that of another river, leading to the capture of the latter's headwaters. The captured stream can either be diverted into the capturing stream or disappear entirely.

Elbow capture: In an elbow capture, a river or stream erodes around a bend and captures the flow of another river or stream. This typically happens when two rivers or streams flow parallel to each other, and one river erodes faster than the other, causing it to capture the flow of the other river or stream around a bend.

Fluvial capture: Fluvial capture occurs when two rivers or streams flow towards each other and meet at a confluence. If one river has a higher discharge than the other, it can capture the flow of the other river or stream, leading to a change in the drainage pattern.

Diversion capture: Diversion capture occurs when human activities, such as building dams or canals, divert the flow of a river or stream, leading to the capture of another river or stream. This form of river capturing is not natural and is usually done for water management purposes.

Continental divide capture: Continental divide capture occurs when a river or stream changes its course and flows across a continental divide, capturing the flow of another river or stream that was previously on the other side of the divide. This can happen due to tectonic movements or changes in land elevation.

6.5 SUMMARY

The Unit on river drainage patterns and systems provides a detailed overview of the natural network of rivers, streams, and other water bodies that collect and convey surface water and groundwater from high elevations to lower elevations and eventually to the oceans.

The Unit covers the various types of drainage patterns, including dendritic, trellis, rectangular, radial, and parallel drainage patterns. It explains that the type of drainage pattern that forms depends on factors such as the type of rock and soil in the area, the slope of the land, and the climate.

The Unit also covers the three main types of drainage systems, including dendritic, trellis, and rectangular drainage systems. It explains that the type of drainage system that forms depends on the geological and tectonic processes that shape the landscape, such as uplift, faulting, and erosion.

The Unit highlights the importance of understanding river drainage patterns and systems for managing water resources, environmental conservation, and scientific research. Proper management and conservation of these systems are critical for the sustainable development of human societies and the protection of the planet's ecosystems.

6.6 GLOSSARY

- **Antecedent drainage:** A drainage pattern that predates the uplift of a mountain range and continues to flow across the uplifted terrain.
- **Dendritic drainage pattern:** A drainage pattern characterized by a network of branching and converging streams that resemble the branches of a tree.
- **Dendritic drainage system:** A drainage system characterized by a network of small streams that join together to form larger streams.
- **Drainage basin/watershed:** The area of land drained by a river and its tributaries.
- **Drainage divide:** The boundary between two adjacent drainage basins/watersheds.
- **Drainage network:** The interconnected system of rivers, streams, and other water bodies that collect and convey surface water and groundwater from high elevations to lower elevations and eventually to the oceans.
- **Drainage pattern:** The spatial arrangement of rivers and streams within a drainage basin/watershed.
- **Drainage system:** The hierarchical arrangement of rivers and streams within a drainage basin/watershed.

- **Parallel drainage pattern:** A drainage pattern characterized by a network of parallel streams that follow a uniform slope.
- **Piracy:** A form of river capture where one stream diverts the drainage of another stream through headward erosion.
- **Radial drainage pattern:** A drainage pattern characterized by streams that radiate outwards from a central high point or peak.
- **Rectangular drainage pattern:** A drainage pattern characterized by a network of streams that follow a rectangular grid-like pattern, caused by tectonic or structural controls.
- **Rectangular drainage system:** A drainage system characterized by a network of streams that follow a rectangular grid-like pattern.
- **River capture:** The process by which a river or stream captures the drainage of another river or stream, usually due to erosion and changes in the landscape.
- **Trellis drainage pattern:** A drainage pattern characterized by parallel main streams with tributaries perpendicular to them.
- **Trellis drainage system:** A drainage system characterized by parallel main streams with tributaries perpendicular to them.

6.7 ANSWER TO CHECK YOUR PROGRESS

1. What is a drainage pattern?

a. The area of land drained by a river and its tributaries.

b. The boundary between two adjacent drainage basins/watersheds.

c. The spatial arrangement of rivers and streams within a drainage basin/watershed.

d. The interconnected system of rivers, streams, and other water bodies that collect and convey surface water and groundwater from high elevations to lower elevations and eventually to the oceans.

2. Which type of drainage pattern resembles the branches of a tree?

a. Dendritic

b. Trellis

c. Rectangular

d. Radial

3. Which type of drainage system is characterized by parallel main streams with tributaries perpendicular to them?

a. Dendritic

b. Trellis

c. Rectangular

d. Radial

4. What is river capture?

a. The process by which a river or stream captures the drainage of another river or stream, usually due to erosion and changes in the landscape.

b. The interconnected system of rivers, streams, and other water bodies that collect and convey surface water and groundwater from high elevations to lower elevations and eventually to the oceans.

c. The area of land drained by a river and its tributaries.

d. The boundary between two adjacent drainage basins/watersheds.

5. Which type of drainage system is characterized by a network of streams that follow a rectangular grid-like pattern?

a. Dendritic

b. Trellis

c. Rectangular

d. Radial

6. Which of the following is NOT a condition necessary for river capturing to occur?

a. The presence of a drainage divide.

b. A difference in elevation between the two rivers or streams.

c. The presence of a resistant rock formation.

d. A steep gradient along the channel of the river or stream is captured.

7. What is a drainage divide?

a. The area of land drained by a river and its tributaries.

b. The boundary between two adjacent drainage basins/watersheds.

c. The interconnected system of rivers, streams, and other water bodies that collect and convey surface water and groundwater from high elevations to lower elevations and eventually to the oceans.

d. The spatial arrangement of rivers and streams within a drainage basin/watershed.

Answers:1. c. 2. a. 3. b. 4. A 5. c. 6. d. .7. b

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6.9 TERMINAL QUESTIONS

1) What is a river drainage system and how is it formed?
2) What are the different types of river drainage patterns, and how do they differ from one another?
3) How do geologic, climatic, and topographic factors influence the formation of river drainage patterns?
4) What are the main components of a river drainage system, and how do they interact with one another?
5) What is the role of river drainage systems in shaping the physical and biological landscapes of an area?

6) How do river drainage systems impact human societies, and what are some examples of this impact throughout history?
7) What are some of the key challenges associated with managing river drainage systems, and how are these challenges typically addressed?
8) What are some of the ecological and environmental issues that can arise from changes to river drainage systems, and how can these issues be mitigated?
9) What role do river drainage patterns and systems play in hydrological processes, such as water cycling and groundwater recharge?
10) How might changes in climate and land use affect river drainage patterns and systems, and what are some potential consequences of these changes?

UNIT- 7 PERIGLACIAL PROCESSES AND LANDFORM

7.1 OBJECTIVES

After reading this unit, you will be able to:

- To provide an overview of periglacial processes and mechanism .
- To identify the different types of periglacial landforms and their characteristics
- To understand the historic and present-day periglacial areas relationship

7.2 INTRODUCTION

The term periglacial means ice or peripheral to the margins of a glacier. It is derived from the combination of two words: "peri-" meaning "near" or "around," and "glacial" referring to glaciers. Periglacial environments are characterized by the presence of frozen ground, known as permafrost, which remains below the freezing point for extended speriods, typically two or more consecutive years. These environments are influenced by the freezing and thawing of water and the processes associated with it. The term periglacial was first introduced by W. Lozinski in 1906, although earliest scientist had addressed subglacial process by the different terms *Nivation* process by F. E . Matthes in 1900 , *Subglacial Climate* process by J. G.Anderson in 1906 and later by DD Cairnes as *Equiplanation* , and by H.M .Eakin as *Altiplanation.*

Periglacial areas can be divided into two parts viz, a) Present day b) the Fossil zones (other part of the past Ice age). Previous part include the Arctic Region Of Alaska, Canada , Greenland And Siberia and Antarctica. Later division include ice of Pleistocene and the Ice age period. The cold climate in periglacial areas leads to unique landforms and processes. Freeze-thaw cycles play a significant role, where water freezes during colder periods and expands, exerting pressure on the surrounding materials. This process can cause rock fragmentation, soil erosion, and the formation of characteristic landforms such as frost polygons and ice wedges. Solifluction is another common periglacial process, characterized by the slow movement of water-saturated soil or sediment downhill due to the thawing of the upper layer while the underlying frozen layers remain impermeable. This process can result in the formation of terracettes and lobes on slopes. Periglacial regions can also exhibit patterned ground, such as stone circles or sorted patterns of stones, formed due to the repeated freezing and thawing of the ground. These patterns arise from the contraction and expansion of the ground materials as they freeze and thaw, causing the movement and redistribution of particles.

Defining periglacial climate is challenging due to significant variations in conditions between different periglacial areas and even within periglacial zones. L.C. Peltier established the *Periglacial Morphogenetic Region* based on criteria such as mean annual temperature ranging from -15°C to 1°C, mean annual precipitation between 120 to 1400 mm (mostly in solid form), high wind velocity, and minimal fluvial activity. Periglacial climate can be broadly categorized into two subtypes: the Iceland type (maritime arctic) and the Siberia type (continental arctic). The Iceland type exhibits low mean annual temperatures above 0°C, high precipitation (mostly as snowfall in winter), while the Siberia type experiences extremely low mean annual temperatures, dropping to -60°C, with moderate precipitation and summer rainfall. Overall, periglacial climate is characterized by long, cold winters with subzero temperatures, freezing of surface and subsurface water, limited weathering and erosion, short and relatively warm summers without night frost, thawing of surface ice, brief periods of active fluvial action and solifluction.

Periglacial areas exhibit a dynamic nature, as they are not permanently fixed in their locations. Instead, they undergo shifts or can even disappear due to climatic changes that alter the temperature patterns. Even today, many periglacial areas from the Pleistocene period have not transitioned out of their periglacial environment. Roughly 20 percent of the Earth's surface is classified as periglacial, with the majority of these areas located in the northern hemisphere. Notable periglacial regions in the northern hemisphere include the Tundra Regions Of Alaska (USA) and Canada, Northern Europe, And Much Of Siberia. A substantial portion of the former USSR is also characterized by periglacial climate. Periglacial areas can also be found in high mountainous regions at lower latitudes. In India, periglacial areas are primarily found in the Himalayas, particularly in the eastern Himalayas. One of the most significant and defining features of periglacial areas is the presence of permafrost, which refers to permanently frozen ground.

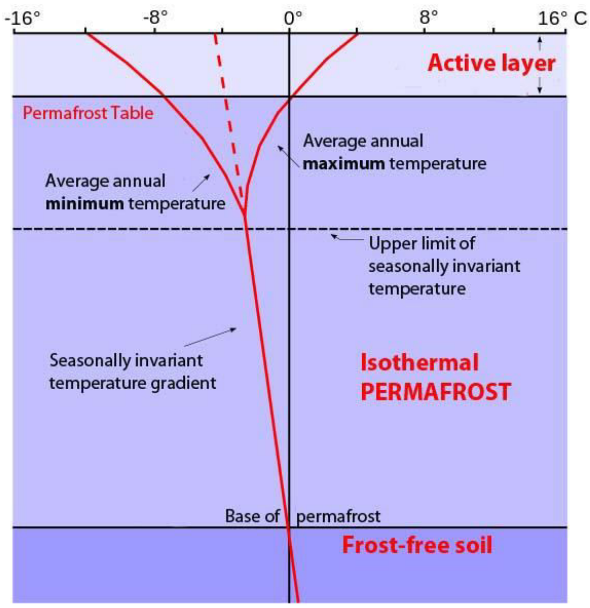
7.2.1 Permafrost

The most notable feature of periglacial areas is the presence of permanently frozen ground known as Permafrost, which exists without a permanent ice cover. The term "permafrost" was first introduced by S.W. Muller, while K. Bryan used the term "Pergelisol" (pergelisol = per, meaning permanently + gelare, meaning to freeze + solum, meaning soil) to describe the permanently frozen soil. The depth of permafrost varies from one location to another. The greatest depth, reaching 600 meters, has been discovered near Nordvik in northern Siberia. In other regions, depths of permafrost have been observed as 500 meters in the Tamyr Peninsula of Siberia, 314 meters near Cape Simpson in Alaska, and 450 meters in northern Canada.

Permafrost zones, classified based on the extent of permafrost coverage, provide a representation of the distribution of permanently frozen ground. These zones include continuous (90%–100%), discontinuous (50%–90%), sporadic (10%–50%), and isolated patches (10% or less). Together, these zones encompass approximately 22% of the Northern Hemisphere. The continuous permafrost zone accounts for slightly over half of this area, while the discontinuous permafrost zone covers around 20%, and the sporadic permafrost zone, along with isolated patches, makes up just under 30%.

Permafrost refers to the permanently frozen ground that remains at or below 0°C for two or more consecutive years. It is important to note that these permafrost zones do not entirely consist of permafrost; rather, they represent the areas underlain by permafrost within those zones. Thus, only about 15% of the ice-free area in the Northern Hemisphere is actually underlain by permafrost. The majority of this permafrost-covered area is predominantly found in regions such as Siberia, northern Canada, Alaska, and Greenland.

As we move deeper beneath the active layer, the amplitude of annual temperature fluctuations within the permafrost decreases. The deepest extent of permafrost occurs in areas where geothermal heat maintains temperatures above freezing. Above this lower limit, there may exist permafrost with a consistent annual temperature, known as "*isothermal permafrost*."



Permafrost is classified into three categories: *Continuous Permafrost, Discontinuous Permafrost, And Sporadic Permafrost*. Approximately 50 percent of Alaska and Canada's areas are covered by continuous or discontinuous permafrost, while the USSR (formerly) also has a significant coverage. Roughly 20 to 25 per cent of the Earth's geographical area is encompassed by permafrost.

It can be classified into three categories based on its spatial distribution: continuous permafrost, discontinuous permafrost, and sporadic permafrost.

Fig. 7.1 Source: https://de.wikipedia.org/wiki/Datei:Vertikale_gliederung_Permafrost.svg

1. Continuous Permafrost: Continuous permafrost is found in regions where the ground remains permanently frozen without any significant breaks. It covers vast areas and is typically observed in polar regions and high mountain ranges. In these areas, the ground remains frozen throughout, creating a continuous layer of permafrost. Examples of continuous permafrost can be found in northern Siberia, Alaska's North Slope, and most of the Canadian Arctic Archipelago.

2. Discontinuous Permafrost: Discontinuous permafrost refers to areas where the permafrost cover is interrupted by non-permafrost patches. It consists of isolated pockets or patches of frozen ground within a predominantly non-permafrost terrain. These patches of permafrost are usually smaller in size and can be found in regions with a milder climate or where local conditions create variations in ground temperatures. Discontinuous permafrost can be seen in areas such as the boreal forest zone of Canada, parts of Alaska, and some high-altitude regions in the Rocky Mountains.

3. Sporadic Permafrost: Sporadic permafrost is characterized by widely scattered or isolated patches of permafrost. These patches are typically small and occur within predominantly non-permafrost areas. Sporadic permafrost is influenced by localized factors such as topography, local climate variations, or specific ground conditions. It can be found in regions with a warmer climate and is often associated with colder microenvironments, such as depressions or shadowed areas. Examples of sporadic permafrost can be found in certain parts of Scandinavia, the Alps, and high-altitude areas in Central Asia.

7.2.2. Active Layer

The uppermost layer of permanently frozen ground in periglacial areas is referred to as the *Active Layer*. This layer is subject to daily freeze-thaw cycles during the intervening periods of summer and winter seasons. It is completely frozen in winter and thaws in the summer. The active layer's depth varies from a few centimeters to three meters. All periglacial processes such as frost heave, nivation, congelifraction, and congelifluction operate in the active layer. The main driving force behind periglacial processes is thermal conditions, such as seasonal and diurnal temperature changes. During the summer, the active layer thaws during the day and freezes at night when temperatures drop below 0°C, remaining completely thawed in late summer. With the onset of winter, this layer again freezes during the night and thaws during the day and becomes completely frozen during the winter season. The active layer's name is derived from its alternate freeze-thaw mechanism. In contrast, the permafrost beneath the active layer is inactive since it remains permanently frozen throughout the year. Kirk Bryan introduced the term *"Molisol"* to describe the active layer, with "*Moller*" meaning to make soft and "*Solum*" meaning soil.

Soil formation in active layer

Cryoturbation, which refers to the mixing and churning of soil materials by frost action, is the dominant process occurring within the active layer of permafrost regions. Through cryoturbation, the composition of the active layer tends to become relatively uniform throughout. In permafrost regions, the composition of soils can still exhibit significant variations due to differences in the parent rock. This is primarily attributed to the slow rate of weathering in the extremely cold climate characteristic of these areas.

The slow decomposition of organic matter further contributes to the unique nature of *Gelisols, Or Permafrost Soils*. These gelisols serve as significant carbon dioxide sinks due to the prolonged preservation of organic material. Over time, the excess organic matter in most gelisols decomposes at a sluggish pace, resulting in the gradual release of carbon dioxide and other greenhouse gases, notably methane. During relatively warmer periods, this decomposition process occurs predominantly within the upper layer, known as the *Pereletok Layer*, while in warmer periods that took place around 5000 to 6000 years ago, it extended below this layer. This prolonged storage of carbon dioxide in permafrost soils has significant implications, as the thawing of permafrost has the potential to accelerate global warming. Climate experts suggest that this impact could be important , especially if the carbon dioxide has been sequestered since before the most recent glacial maximum.

Therefore, the intricate dynamics of cryoturbation, organic decomposition, and carbon storage in permafrost regions have important implications for the understanding of climate change. Thawing permafrost has the potential to release stored carbon, contributing to a feedback loop that may amplify global warming.

Pereletok Layer

The term "pereletok layer" refers to a specific layer within the active layer of permafrost. It is a zone of the soil that undergoes seasonal freeze-thaw cycles in permafrost regions. The pereletok layer is located above the permanently frozen permafrost layer and experiences the most significant temperature fluctuations throughout the year. During the summer season, when temperatures rise above freezing, the pereletok layer thaws and becomes temporarily unfrozen. This allows for increased biological activity and the decomposition of organic matter within this layer. Which result in , releasing of nutrients , important for plant growth.

During the winter season, when temperatures drop below freezing, the pereletok layer freezes again. This freezing process temporarily halts the biological activity within the soil.

\ The thickness of the pereletok layer can vary depending on climatic conditions and the specific characteristics of the permafrost region. In areas with more pronounced seasonal temperature fluctuations, the pereletok layer may be thicker, while in milder climates, it can be relatively thin.

7.3 PERIGLACIAL PROCESSES AND LANDFORMS

Periglacial processes are a set of geomorphological phenomena and landform development that occur in regions influenced by cold climates and the presence of permafrost. These processes are primarily driven by the freezing and thawing of water and the movement of materials within the frozen ground. They play a crucial role in shaping the landscape and landforms in periglacial areas. One of the key periglacial processes is frost action, which includes frost shattering, frost wedging, and frost heaving. Freeze-thaw cycles cause the expansion of water within rocks and soils, leading to the fragmentation of rock surfaces and the dislodging of particles. This process is particularly significant in cold climates with fluctuating temperatures. Another important periglacial process is solifluction, which involves the downslope movement of soil and sediment due to the gradual thawing and refreezing of the active layer. The saturated soil flows slowly downhill, creating lobes or terraces. Thermal contraction and expansion also contribute to periglacial processes. The repeated freezing and thawing of the ground result in the formation of patterned ground, such as polygonal or hummocky terrains. These patterns arise due to the differential contraction and expansion of the ground surface. Other periglacial processes include nivation, which involves erosion caused by snow accumulation and melting, and the development of ice-cored moraines, ice-wedge polygons, pingos (ice-cored hills), and rock glaciers.

7.3.1 .Periglacial Mechanism

F.E. Matthes in 1900 provided an explanation of the *Nivation Process*, which becomes active in climates characterized by alternating freeze and thaw cycles due to temperature changes, but without complete glaciation. J.G. Anderson (1906) described the process of *solifluction*, which operates in subglacial climates. various scientists described different periglacial processes such as *"Planation By Frost Action*" (described by Write in 1910), *equiplanatio*n (a process of down wasting responsible for land planation, described by D.D. Caim in 1912), *Altiplanation* (a specific process occurring on hilltops and hillslopes, described by H.M. Eakin in 1916), *Frost Heaving* (described by B. Hogbom in 1914), *Cryoplanation* (described by K. Bryan in 1946), among others.

The primary periglacial processes include congelifraction (also known as frost weathering), congelifluction (or solifluction, which refers to soil creep), frost heave, nivation (erosion caused by snow accumulation and melting), cryoturbation (also known as cryoplanation, involving the rearrangement of materials due to freeze-thaw cycles), and the influence of wind (aeolian processes) and water (fluvial processes).

These various periglacial processes play significant roles in shaping the landforms and landscapes of cold climate regions with the presence of permafrost. Understanding these processes is crucial for comprehending the dynamic nature of periglacial environments and their influence on land surface evolution.

7.3.2 Congelifraction

Congelifraction, also known as frost weathering or frost shattering, is a periglacial process that involves the mechanical breakdown and fragmentation of rocks and other geological materials due to the freezing and expansion of water.

The process of congelifraction begins when water enters cracks, joints, or pore spaces within rocks or sediments. During periods of freezing temperatures, the water in these spaces freezes and expands, exerting pressure on the surrounding material. As the water expands, it can generate tremendous force, leading to the mechanical disruption and fracturing of the rock or sediment. The repeated cycles of freezing and thawing further contribute to the process. Each time the water freezes and expands, it widens existing cracks or creates new fractures, gradually breaking down the material into smaller fragments. Over time, this continuous freeze-thaw action can lead to the disintegration and dislodging of rocks. The extent of congelifraction is influenced by several factors, including the frequency and intensity of freeze-thaw cycles, the availability of water, the type and composition of the rock or sediment, and the presence of other contributing processes such as frost wedging or ice segregation.

Congelifraction form various landforms, such as blockfields, talus slopes, and scree deposits. It is particularly prominent in regions with cold climates and significant temperature fluctuations, where the freeze-thaw action is frequent and intense.

7.3.3 Frost heaving

Frost heaving is a periglacial process that occurs when the freezing and expansion of water within the ground causes upward movement or displacement of the soil or sediment. It occurs in regions with freezing temperatures and the presence of moisture in the ground, particularly in areas with seasonally frozen ground or permafrost. The process of frost heaving begins when moisture in the soil or sediment freezes during cold periods. As water freezes, it expands, exerting pressure on the surrounding material. This expansion creates upward forces that lift and displace the overlying layers of soil or sediment. The extent of frost heaving depends on several factors, including the freezing temperature, the amount and distribution of moisture in the ground, the composition and structure of the soil, and the presence of vegetation or other obstacles that may impede the movement. Frost heaving can lead to the formation of distinctive landforms and features. Small-scale frost heaving can create frost boils or frost mounds, which are rounded mounds of soil pushed up by the freezing and expansion of water. In some cases, frost heaving can also result in the formation of patterned ground, characterized by polygonal or hummocky patterns on the surface. The upward movement of the ground can disrupt foundations, crack pavements, and affect the stability of structures.

7.3.4 Congelifluction

Congelifluction, also known as solifluction or soil creep, is a periglacial process that involves the gradual downhill movement of soil or regolith due to the freeze-thaw cycle. This process occurs in areas with a permanently frozen ground layer (permafrost) and an active layer that experiences seasonal freezing and thawing. During the summer months, the top layer of soil thaws and becomes saturated with water. As temperatures drop, the water in the soil freezes and expands, causing the soil particles to lift and loosen. When the soil thaws again, it becomes unstable and begins to move downhill due to gravity. The process is repeated each year, causing the soil to slowly creep or flow downhill.

Solifluction typically occurs in areas with gentle slopes, such as hillsides and valleys. The movement of soil can be slow, usually a few centimeters per year, but can have significant long-term effects on the landscape. Solifluction can lead to the formation of distinctive landforms, such as lobes, terraces, and stripes, as well as the downslope displacement of vegetation, boulders, and other debris.

7.3.5 Nivation

Nivation is a periglacial process that refers to the combined erosional and depositional actions of snow and ice in cold environments. It primarily occurs in areas where snow accumulation and freeze-thaw cycles play a significant role in shaping the landscape.

Nivation typically takes place in hollows or depressions on hillslopes, often called nivation hollows. The process involves several interrelated mechanisms:

1. Snow Accumulation: Snow accumulates in depressions, especially during the winter season, forming a snowpack. The snowpack acts as an insulating layer, protecting the ground beneath it from extreme temperatures.

2. Frost Weathering: The freeze-thaw cycles associated with the presence of snow contribute to frost weathering. Water infiltrates the ground and freezes, causing expansion and fracturing of rocks and sediments.

3. Nivation Erosion: The combined action of freeze-thaw cycles, gravity, and meltwater leads to erosion within the nivation hollow. Meltwater flows through the snowpack and infiltrates the ground, enhancing weathering and transporting loose materials downslope.

4. Plucking: As meltwater freezes and thaws, it can freeze onto rocks or sediments. When the ice re-freezes, it can "pluck" or detach rock fragments, which are then transported downslope by gravity.

5. Solifluction: In areas with permafrost, solifluction can occur within nivation hollows. The thawed active layer becomes saturated with water, making the soil or sediment above the frozen ground layer (permafrost) flow slowly downslope.

6. **Nivation Deposition**: As the nivation process continues, material eroded from the hollow is transported and deposited downslope. This can lead to the formation of depositional features such as rock slopes, debris cones, or terraces.

7.3.6 periglacial landforms

Periglacial landforms are the result of various geomorphological processes that occur in cold environments, typically in regions surrounding glaciers or areas influenced by permafrost. These landforms are shaped by the unique combination of freeze-thaw cycles, frost weathering, solifluction, and other periglacial processes. Following are the several prominent periglacial landforms:

1. Patterned Ground: Patterned ground refers to the distinctive arrangement of polygonal or hummocky patterns on the ground surface. These patterns are formed as a result of freeze-thaw cycles and the movement of water and ice within the active layer of permafrost. The two common types of patterned ground are sorted and nonsorted circles, with the latter exhibiting raised rims and depressed centers.

2. Frost Wedges: Frost wedges are vertical cracks or fissures in the ground that develop as a result of repeated freezing and thawing of the active layer. During the freezing process, water in the soil expands and exerts pressure, causing the ground to crack. Over time, these cracks deepen and widen, forming distinct wedge-shaped features.

3. Pingos: Pingos are unique landforms that occur in periglacial regions, characterized by a conical or dome-shaped mound with a core of ice. They are result of freezing and expansion of groundwater within the permafrost. The formation of pingos is closely associated with the presence of an underground ice lens, which acts as a hydraulic head, pushing the overlying sediment upward and forming the distinctive mound shape.

Pingos are dome-shaped landforms that form when groundwater freezes and expands beneath the permafrost. As the freezing process continues, the ice core expands and pushes the overlying sediments upward, forming a hill or mound. Pingos are commonly found in areas with an abundance of groundwater and are often associated with lakes or wetland environments.

Based on their formation process pingos can be divided into following types :

1. Closed System Pingos: These pingos develop in areas where groundwater is trapped in a confined basin, such as a depression or a lake. Freezing of the groundwater creates a pressure build-up, causing the overlying sediments to uplift and form a closed, circular or elliptical mound. Closed-system pingos are typically small in size and often found in groups.

2. Open System Pingos: These pingos form in areas where groundwater is not confined and can freely flow through the sediments. They are usually associated with artesian springs or seepage zones. The upward movement of groundwater due to freezing creates a mound with a central depression or crater-like feature. Open system pingos are often larger than closed system pingos and can reach considerable heights.

3. Subaquatic Pingos: These pingos form beneath lakes or shallow seas. They occur when pressurized groundwater freezes and expands beneath the water body, causing the sediments and water above to uplift and create a mound. Subaquatic pingos are usually identified by their circular or elliptical shape and may become exposed when the lake or sea level drops.

Pingos can vary in size, with some reaching heights of several tens of meters and diameters of hundreds of meters. The common area of permafrost regions are the Arctic and subarctic areas.

4. Rock Glaciers: A rock glacier is a type of landform found in mountainous regions, typically in areas with permafrost. It is formed by a combination of rock debris, ice, and permafrost. Unlike traditional glaciers composed of ice, rock glaciers consist of a mixture of rock fragments, soil, and ice that move downslope due to the influence of gravity.

The formation of a rock glacier begins with the accumulation of debris, such as rockfall, weathered material, and sediment, on a slope. This debris becomes intermixed with ice, either from groundwater or frozen precipitation, creating a frozen mass. Over time, the ice within the rock glacier acts as a lubricant, allowing the mass to slowly move downslope.

The movement of rock glaciers is generally very slow, with rates ranging from a few centimeters to a few meters per year. The movement is governed by the downslope pull of gravity and the presence of ice acting as a lubricant. The downslope movement causes characteristic features, such as lobes, ridges, and furrows, to develop on the surface of the rock glacier. Rock glaciers can vary in size and shape, ranging from a few meters to several kilometers in length. They are commonly found in high-altitude and high-latitude regions, where permafrost is present. The presence of a rock glacier indicates the presence of subsurface ice and permafrost.

5. Solifluction Lobes: Solifluction lobes are elongated landforms formed by the downslope movement of saturated soil or sediment in the active layer. As the top layer thaws, the waterlogged material becomes fluid-like and flows downslope, resulting in lobate features. Solifluction lobes commonly occur on hillsides and valley bottoms.

6. Palsas: Palsas are elevated mounds or hummocks found in peatlands or wetland areas of permafrost regions. They form as a result of the accumulation of frozen peat or organic material, which becomes elevated above the surrounding terrain. Palsas typically have a conical or dome-shaped appearance and are formed by the freezing of groundwater and subsequent expansion.

7. Hummocks: Hummocks are small upstanding wrinkles on surface of permafrost. They are characterized by their irregular, rounded, or hilly shape and are typically composed of soil, peat, or other unconsolidated materials. Hummocks can vary in size from small mounds to larger hills or ridges. Hummocks in periglacial regions can form through several processes, including frost heave, solifluction, and patterned ground formation. Hummocks exhibit several characteristic features that distinguish them from surrounding terrain:

1. ***Shape and Size*****:** Hummocks typically have irregular shapes and vary in size, ranging from a few centimeters to several meters in height and width. They can have a rounded or hilly appearance and may occur individually or in clusters.

2. ***Vegetation*****:** Hummocks often support unique vegetation patterns due to variations in soil moisture, nutrient availability, and microclimate conditions. They can provide different habitats for plant species, leading to diverse plant communities.

3. ***Stability*****:** Hummocks can be relatively stable features in periglacial landscapes, persisting for long periods of time. However, their stability can vary depending on factors such as the nature of the materials, the intensity of freeze-thaw processes, and the presence of vegetation cover.

4. ***Spatial Distribution*****:** Hummocks can occur in various periglacial environments, including tundra regions, peatlands, and areas influenced by permafrost. They are often found in association with other periglacial landforms such as patterned ground, solifluction lobes, or pingos.

Hummocks can be divided into two types based on presence and absence of vegetation i.e, (i) Turf hummocks that are with small vegetation and (ii) Earth hummocks without vegetation.

8. Involutions: Involutions are twisted shapes observed in layered deposits of unconsolidated materials just beneath the surface of permafrost regions. They are the result of compression and bending of these layered materials. Sometimes, the intense squeezing causes such intricate intermingling of deposits that their original forms become unidentifiable. In terms of shape, involutions can be categorized into three types: fold involutions, pillar involutions, and amorphous involutions.

9. Thermokarst : While resembling carbonate rock karst topography in appearance, thermokarsts differ substantially from karstic landforms. The formation of karst landforms is primarily attributed to chemical reactions between water and the dissolution of carbonate rocks such as limestones and dolomites. In contrast, Thermokarsts are formed as a result of thawing frozen ground in permafrost regions due to changes in thermal conditions. Thermokarst pertains to landforms characterized by depressions and sinkholes that develop when the ground surface collapses due to the thawing of ice within the active layer of permafrost, caused by increased temperatures. Unlike karstic landforms, which are influenced by the composition of rocks, Thermokarst landforms are primarily shaped by thermal factors.

Thermokarst landforms encompass various features such as surface pits, sinks (including funnel sinks and sinkholes), hollows, ravines, dry valleys, caves, thaw lakes, and subsidence cauldrons. These landforms emerge as a consequence of the upper surface collapsing as a result of ice melting within the active layer, prompted by rising temperatures. Changes in rock temperature can be attributed to factors such as the removal of vegetation cover, land ploughing, construction of reservoirs and lakes, as well as climate change.

10. Altiplanation Terraces :Flattened summits and bench-like formations that develop at higher elevations on spurs and hill sides in periglacial areas are referred to as altiplanation terraces. These terraces are characterized by distinct scarps, ranging in height from 2m to 12m. They can stretch between 10 and 90 meters in length and span up to 800 meters in width. The angle of the scarps varies from 15° to 22°, and the base of the scarps may exhibit frost-weathered cliffs. These terraces are the outcome of altiplanation processes, including frost sapping, congelifraction, and congelifluction (solifluction). Terraces that contain stones are known as stone-banked terraces.s

11. Tors : Tors, which, consist of accumulations of fragmented and exposed masses of durable rocks. They typically feature a crown of differently-sized rock blocks on top, as well as scattered clusters of rocks along the sides. The rock blocks, which constitute the main components of tors, can exhibit various shapes such as cuboidal, rounded, angular, or elongated. These tors can be situated at the summits of hills, on the slopes of hillsides, or on flat platforms with heights ranging from 6m to 30m. They can be found in diverse climates, ranging from cold to hot, and from dry to humid conditions. While tors can develop on various types of rocks, they are commonly observed in regions characterized by granite formations.

7.4 SUMMARY

Periglacial processes and landforms refer to the unique geological features and phenomena that occur in regions adjacent to glaciers and ice sheets, where freezing and thawing of ground materials play a significant role. These areas experience extreme cold temperatures and exhibit distinct landforms shaped by the actions of freeze-thaw cycles, frost heaving, and other periglacial processes.

One prominent periglacial process is frost weathering, which involves the breakdown of rock and sediment due to repeated freezing and thawing. This process leads to the formation of blockfields, where angular rock fragments accumulate on the surface. Another important process is solifluction, which occurs when saturated soil and sediment move downslope due to the expansion and contraction of frozen ground. This results in the formation of terracettes and lobes on hillslopes.

Periglacial landforms encompass a wide range of features. Hummocks are small, rounded mounds formed by frost heaving and are commonly found in tundra regions. Patterned ground consists of intricate arrangements of polygons, stripes, or circles on the ground surface, formed by the segregation and movement of ice and sediment. Pingos are ice-cored hills that develop from the freezing and expansion of groundwater.

Other periglacial landforms include thermokarsts, which are depressions formed by the thawing of ice-rich permafrost, and involutions, contorted layers of unconsolidated material resulting from squeezing and buckling. Altiplanation terraces are flattened summits and bench-like features found at higher elevations in periglacial areas.

This summarize that , periglacial processes and landforms are shaped by the freezing and thawing of ground materials, leading to the formation of distinctive features such as blockfields, patterned ground, hummocks, pingos, thermokarsts, involutions, and altiplanation terraces. These landforms provide valuable insights into past and present periglacial environments and contribute to our understanding of Earth's dynamic processes.

7.5 *GLOSSARY*

- **Altiplanation terraces**: Flattened summits or bench-like features at higher elevations in periglacial areas.
- **Blockfields:** Accumulations of angular rock fragments on the surface, resulting from frost weathering.
- **Cryoturbation**: Mixing and displacement of soil and sediment due to freeze-thaw processes.
- **Freeze-thaw cycles**: Repeated cycles of freezing and thawing of ground materials, leading to various periglacial processes.
- **Frost weathering**: The breakdown of rock and sediment due to the expansion of water upon freezing.
- **Hummocks**: Small, rounded mounds created by frost heaving in tundra regions.
- **Involutions**: Contorted layers of stratified, unconsolidated material caused by squeezing and buckling.
- **Nivation**: The combined processes of frost weathering, solifluction, and snow accumulation shaping hollows and valleys.
- **Patterned ground**: Complex arrangements of polygons, stripes, or circles on the ground surface, formed by the segregation and movement of ice and sediment.
- **Periglacia**l: Referring to the areas adjacent to glaciers and ice sheets, characterized by freezing and thawing processes.
- **Permafrost**: Permanently frozen ground that remains below the freezing point for at least two consecutive years.
- **Pingos**: Ice-cored hills formed by the freezing and expansion of groundwater.
- **Solifluction:** The movement of saturated soil and sediment downslope due to the expansion and contraction of frozen ground.
- **Terracette**s: Small, elongated mounds or lobes formed by solifluction on hillslopes.
- **Thermokarsts**: Depressions or sinks resulting from the thawing of ice-rich permafrost.

7.5 ANSWER TO CHECK YOUR PROGRESS

1. What is solifluction?

a) Movement of glaciers

b) Movement of saturated soil and sediment

c) Frost weathering of rocks

d) Formation of ice-cored hills

Answer: b) Movement of saturated soil and sediment

2. What are hummocks in periglacial environments?

a) Small, rounded mounds caused by frost heaving

b) Ice-cored hills formed by freezing groundwater

c) Flattened summits at higher elevations

d) Complex arrangements of polygons on the ground surface

Answer: a) Small, rounded mounds caused by frost heaving

3. Which landform results from the thawing of ice-rich permafrost?

a) Blockfields

b) Terracettes

c) Pingos

d) Involutions

Answer: c) Pingos

4. What is the main characteristic of permafrost?

a) Seasonal freezing and thawing

b) Continuous movement downslope

c) Permanently frozen ground

d) Development of ice-cored hills

Answer: c) Permanently frozen ground

5. Which process involves the contortion of stratified, unconsolidated materials?

a) Cryoturbation

b) Frost heaving

c) Congelifraction

d) Nivation

Answer: c) Congelifraction

6. What are altiplanation terraces?

a) Flattened summits at higher altitudes

b) Ice-cored hills formed by freezing groundwater

c) Small mounds caused by frost heaving

d) Elongated lobes formed by solifluction

Answer: a) Flattened summits at higher altitudes

7. What term refers to the breakdown of rock and sediment due to freezing water?

a) Solifluction

b) Cryoturbation

c) Frost weathering

d) Nivation

Answer: c) Frost weathering

8. Which landform results from the freezing and expansion of groundwater?

a) Terracettes

b) Blockfields

c) Pingos

d) Involutions

Answer: c) Pingos

9. What process involves the mixing and displacement of soil and sediment due to freeze-thaw cycles?

a) Frost heaving

b) Cryoturbation

c) Congelifraction

d) Nivation

Answer: b) Cryoturbation

10. What is the main characteristic of thermokarst landforms?

a) Lithological control

b) Formation by chemical reactions of water

c) Formation due to thawing of frozen ground

d) Presence of ice-cored hills

Answer: c) Formation due to thawing of frozen ground

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7.8 TERMINAL QUESTIONS

1) Describe the concept of periglacial processes and their significance in shaping landforms in cold environments. Provide examples of periglacial landforms.
2) Discuss the formation and characteristics of permafrost. Explain how permafrost influences the development of landforms in periglacial regions.
3) Compare and contrast the processes of nivation and solifluction. How do these processes contribute to the formation of specific landforms in periglacial areas?
4) Explain the formation and characteristics of thermokarst landforms. How do they differ from karstic landforms formed by chemical reactions in carbonate rocks?
5) Discuss the formation and significance of hummocks in periglacial regions. Explain the processes that contribute to the development of hummocks and their role in shaping the landscape.

UNIT-8 GLACIAL PROCESSES AND LANDFORMS

8.1 OBJECTIVES

After reading this unit learners will able to:

- Introduction to the glacier
- Understand the process of glaciers and different types of glacier
- Understand erosional landforms
- Learn depositional landforms

8.2 INTRODUCTION

Ice and snow cover the major part of the earth's surface. This ratio accounts for about 15 million km^2 , restricted primarily to higher altitudes and latitudes. Therefore it is more or less a permanent feature in high mountain ranges. Region like tropical latitudes shares the same feature as evident in Uganda which is located in tropical Africa. Earth's entire ice reserve exists in the form of ice filed or solidified snow; almost 95 % which is about 14 million km2 is confined to Green land and Antarctica, rest 5% exists in the mountains of Europe, Asia and America. A glacier is a thick mass of ice that moves continuously due to its own weight. It develops over many years from the accumulation of snow exceeding its melting or erosion. As it progresses, it takes on unique characteristics like crevasses and seracs and shapes landforms such as fjords, cirques, and moraines by scraping off debris and rock from the earth's surface. Unlike sea ice or lake ice that forms on bodies of water, glaciers exist exclusively on land and may extend into bodies of water.

The term "glacier" originates from French and has been borrowed from the Franco-Provençal language. It can be traced back to the Vulgar Latin word "glaciārium", which is derived from "glacia" in Late Latin and "glaciēs" in Latin, both of which mean "ice". The features and phenomena resulting from or associated with glaciers are described as "glacial", while the process of glacier formation, enlargement, and movement is known as "glaciation". The field of study concerning glaciers is referred to as "glaciology". Glaciers are significant elements of the global cryosphere.

During the Quaternary Ice Age, it is believed that the collective area occupied by the glacier in the northern hemisphere was three times much greater than the present glacier coverage. Furthermore in northern hemisphere the accumulated volume of Ice, in the form of glaciers was twice the size of than southern hemisphere, as the northern hemisphere glaciers had ample land space to spread in comparison to the southern hemisphere which had a high percentage of ocean causing glacier calving.

Large parts of the globe, including almost all of Canada, the northern third of the United States, most of Europe, Scandinavia, and significant areas of northern Siberia, were covered by ice during the major glacial stages. During the Pleistocene Epoch (from 2.6 million to 11,700 years ago), glacial ice covered up to 30 percent of the world's land surface, but at other times, the ice cover was much smaller than it is today. Therefore, it could be argued that the world is still in an ice age. As the term "glacial" usually refers to ice-age events or the Pleistocene period, the word "glacier" is used as an adjective in this discussion when referring to ice that exists in the present day. Glaciers exist in all regions of the world, spanning nearly all latitudes. Even in places like Ecuador, Kenya, Uganda, and Irian Jaya (New Guinea), glaciers can be found at or close to the Equator, albeit at high elevations.

8.2.1 Classification of Glaciers

There are different types of glaciers found on the Earth’s surface but they can be classified into the following broad classes. As a glacier is a moving river of ice descending from a higher position to a lower one. The movement in a glacier is slow under the influence of gravity. based on size and nature glaciers can be classified as Following : -

- **Continental Glaciers**
- **Alpine / Mountian Glaciers**

Continental Glacier

Continental glaciers, which are primarily located in Antarctica, are enormous ice sheets that cover extensive land areas. These glaciers flow over unconfined terrains, causing the underlying landscapes to become buried. As the glaciers deposit more ice, the accumulation process intensifies and the force exerted on the snow is evenly distributed, resulting in a flattened terrain. The ice sheets can extend over great distances and are over 3000 meters thick. Antarctica and Greenland are the primary locations where massive continental glaciers are located. These glaciers are about 3,500 meters thick. Ice caps that are circular and dome-shaped are larger than ice fields but smaller than ice sheets. Smaller ice caps may flow from the outlets of ice shields. Even in the Arctic Circle, continental glaciers can be found.

Type of Continental Glaciers

Continental glaciers are massive bodies of ice that cover large stretches of land. They are categorized into three types based on their morphology: ice caps, ice sheets, and outlets.

- **Ice sheets** are the largest type of continental glacier, covering vast areas of land. Greenland and Antarctica are two of the most prominent locations where ice sheets are found. The ice sheet in Greenland is almost 1,710,000 square kilometers in size, covering about 80 percent of the island. It has a thickness of around 3 kilometers. Antarctica has the world's largest single ice sheet, covering nearly 98 percent of its land area, with a thickness of 4.98 kilometers.

- **Ice Caps** are dome-shaped and circular continental glaciers that are smaller than ice sheets but larger than ice fields. They have an area less than 50,000 square kilometres and are found in the Arctic Circle, as well as in other parts of the world. Ice caps can also have smaller ice outlets that flow from the main body. While they are commonly found in mountainous regions, they can also be considered continental glaciers since they are not confined to smaller areas only. As these glaciers move, they erode the landscape, creating green lakes and coastal waters from the fine sediments they leave behind.

- **Outlet glaciers**, on the other hand, are similar to valley glaciers and are confined to topographical features, but they originate from ice caps. These glaciers appear like protruding tongues as they reach the valley. Outlets are smaller ice formations that flow from the ice shields. They can be found in regions such as Greenland and Antarctica. While they are smaller than ice caps and ice sheets, they still have a significant impact on the landscape and local ecosystems.

Continental glaciers have a significant impact on the world's climate and geography. They are important sources of freshwater and can have a major effect on sea levels if they melt. Understanding the behaviour and characteristics of continental glaciers is crucial for predicting their impact on the environment and planning for their conservation.

Alpine / Mountain Glaciers

Alpine or mountain glaciers are found in high-altitude regions of the world, typically above the snow line where snow persists throughout the year. These glaciers are found in many mountain ranges, including the Alps, the Rocky Mountains, the Himalayas, and the Andes.

The morphology of mountain glaciers varies depending on the size and shape of the mountain range. In general, mountain glaciers are long and narrow, and they flow downhill from their accumulation zone, where snow and ice accumulate, to their ablation zone, where ice melts and evaporates. Some mountain glaciers may also have tributaries, which are smaller glaciers that merge with the main glacier. They are often termed Valley Glaciers. They have well-developed cirques, flowing in linear along narrow troughs or valleys.

Valley glaciers can be further divided based on regional topography , as follow –

a) **Longitudinal glacier**

b) **Transverse**

Longitudinal & Transverse Glaciers

The term longitudinal refers to glaciers that occupy the head of the main valley. Longitudinal glaciers are large masses of ice that flow along the length of a valley or depression. They form in high-altitude areas where snow accumulates over time and compresses into ice. As the glacier moves, it erodes the surrounding rock, creating distinctive U-shaped valleys. Longitudinal glaciers can range in size from just a few meters to several kilometres wide and can extend for many kilometers down a valley. They are also subject to seasonal and long-term variations in their movement and mass, which can affect the overall health of the glacier and surrounding ecosystems. Himalayas are featured in such type of glaciers, they are fed by a number of tributaries during their long course from cirque to snout. These tributaries are invariably transverse along the longitudinal outline of the main glacier hence called **Transverse glaciers**.

8.2.2 Classification Based On Surface Characteristic Of A Glacier

Classification based on surface characteristics of a glacier is a method used to categorize glaciers based on their visible physical features. This classification method focuses on the surface properties of glaciers and helps researchers better understand their behaviour and dynamics. Based on the surface characteristic of a glacier it can be classified as following :-

a) **Debris-free or clean glacier**

b) **Debris-covered or dark glacier**

Debris free glacier

Debris-free glaciers are glaciers that have little to no surface debris or rock cover on their ice surface. Technically meant by debris-free glaciers are defined as glaciers that have less than 10% of their surface covered by rock or other debris. Debris-free glaciers are often found in high-altitude, cold environments where the rate of debris accumulation is low due to the lack of vegetation, soil, and erosion. In contrast, glaciers in more temperate regions tend to have more surface debris due to higher rates of rockfall, landslides, and erosion. Debris-free glaciers are of particular interest to glaciologists and climatologists because they are more sensitive to changes in temperature and precipitation than debris-covered glaciers. Their relatively clean ice surface allows for easier monitoring of glacier mass balance and ice dynamics, and they are important indicators of climate change. However, debris-free glaciers are also more vulnerable to melting and retreat due to their lack of insulating debris cover.

Dark or Debris covered Glaciers

Debris-covered glaciers are glaciers that have a significant amount of rock, sediment, and debris covering their ice surface. Scientifically speaking, debris-covered glaciers are defined as glaciers that have more than 10% of their surface area covered by debris. Debris-covered glaciers are often found in more temperate regions where the rate of debris accumulation is high due to the presence of vegetation, soil, and erosion. The debris cover on the glacier surface can range from a thin layer to several meters thick and can consist of rock, boulders, sand, and silt. The debris cover on a glacier's surface has a significant impact on its behaviour and dynamics. The insulating effect of the debris cover reduces the rate of melting, which can help to preserve the glacier's mass balance and slow its retreat. However, the debris cover also increases the friction between the glacier and its underlying bedrock, which can slow its flow and cause the glacier to become stagnant.

8.2.3 Classification Based on the Temperature of Ice

Classification based on the temperature of ice is a method used to categorize glaciers based on the temperature of the ice within them. This classification method helps researchers better understand the internal characteristics and dynamics of glaciers. Glaciers can be classified into two main types based on the temperature of the ice within them:

a) Cold glaciers

b) Warm glacier

Cold Glacier

The term is suggested for the glaciers that are cold enough to form ice in the glacier displaying a temperature gradient that is below the pressure-melting point. In such a situation glaciers are bound to the bedrock underneath; therefore the movement within the glacier are result due to deformation of ice. It is believed that the base of the glacier is dry hence the motion is extremely slow, for this reason, it does not exhibit any characteristic features like striations on the underlying rock floor. The terminology is specifically assigned to glaciers existing only in Polar regions.

Warm Glacier

A warm glacier is a type of glacier in which the temperature of the ice is at or near the pressure melting point. Ice that forms these glaciers are more stable at pressure melting point hence melting and sliding is caused by small changes. This means that the ice is essentially at the melting point, even though it is still in a solid state. As a result, warm glaciers tend to have a high rate of ice flow, as the ice is able to deform and flow more easily. Warm glaciers are also typically characterized by extensive meltwater production, which can contribute to the erosion and transport of sediment. In contrast, cold glaciers have ice that is below the pressure melting point, meaning that they flow more slowly and produce less meltwater.

Warm glaciers are typically found in regions where the climate is relatively warm, such as at lower elevations or in areas with a maritime climate. These glaciers can be found in a variety of locations around the world, including parts of the Alps, the Himalayas, and the Andes. They are also found in areas with high precipitation, which can contribute to the formation and maintenance of glaciers. However, it's important to note that even in relatively warm regions, not all glaciers are warm - some may still be cold, depending on factors such as altitude, shading, and other local conditions.

8.2.4 Classification Based On Geomorphic Factors

Glaciers can be classified based on geomorphic factors, which refer to the shape and characteristics of the landscape where the glacier is located. This classification system is based on the idea that different types of glaciers tend to form in different types of landscapes, and can provide insight into the behavior and dynamics of the glacier.

These categories provide a framework for understanding the different types of glaciers that can be found in different landscapes around the world. By understanding the characteristics of these different types of glaciers, scientists can better predict how they will respond to changes in climate and other environmental factors.

1. **Valley glaciers**: These are glaciers that form in valleys or canyons and flow down the valley under the force of gravity. Valley glaciers are typically long and narrow, with steep sides and a U-shaped cross-section.
2. **Niche glacier**: These are small remnant glaciers that can be seen occupying hollows and throughs in high-altitude mountains. They are the degenerated remanent of valley glacier that had existed in past.
3. **Piedmont glaciers**: These are glaciers that form at the base of mountains and spread out onto a flat plain or valley. Piedmont glaciers are often wide and shallow, with a characteristic bulb-like shape.
4. **Hanging glaciers**: These are small glacier . These are glaciers that form in cirques, which are bowl-shaped depressions on the side of a mountain. Hanging glaciers can be found on steep slopes and often have a tongue that extends down the valley.

5. **Icefield**s: These are large, flat expanses of ice that cover a broad area, often at high elevations. Icefields are typically fed by multiple glaciers and can be several kilometers wide.

8.3 GLACIER PROCESS AND LANDFORMS

Glacier processes refer to the various ways in which glaciers move and evolve over time. All activities of glaciers creating an impact on the bedrock or walls of valleys directly or indirectly. Other processes include Depositional and accumulation of glacier ice in solid estate. These processes are driven by a combination of factors, including the properties of the ice itself, the slope and topography of the underlying terrain, and the climate and weather conditions in the surrounding region. It not only effect the ground temperature but also initiates the geomorphic process which later has a major impact on the landscape. One of the key processes that drives glacier movement is internal deformation, which refers to the way in which the ice deforms and flows under the influence of its own weight. This process occurs because the ice in a glacier is constantly being compressed, causing it to flow like a viscous fluid. Over time, this deformation can cause the glacier to move downslope, carving out valleys and shaping the surrounding landscape.

Another important glacier process is basal sliding, which occurs when the ice at the base of the glacier is able to slide over the underlying terrain. This can occur when meltwater accumulates at the base of the glacier, reducing friction between the ice and the ground. Basal sliding can contribute significantly to glacier movement and can lead to the formation of distinctive features such as crevasses and moulins. Erosion is also an important process in glacier evolution, as glaciers are able to transport vast quantities of rock and sediment as they move downslope. As glaciers move, they can erode the underlying rock, creating valleys and other landforms. They can also transport large amounts of sediment, which can be deposited in the form of moraines and other features. Meltwater is another important factor in glacier processes, as it can affect the rate of glacier movement and the way in which glaciers erode and deposit sediment. As glaciers melt, they can produce large amounts of meltwater, which can carve out channels and transport sediment. This can lead to the formation of distinctive landforms such as eskers, kames, and outwash plains.

8.3.1 Glacier Erosional Landforms

- **Cirque**

A cirque, also known as a "circle", is a basin with steep walls that has an amphitheatre-like shape. This landform is typically found at the head of a glacial valley and is formed as a result of erosion beneath the bergschrund of a glacier. A bergschrund is a large crevasse that lies near the exposed rock walls and separates the stationary from the moving ice. During early summer, the bergschrund opens and exposes the rock at its base to changes in temperature. This results in frost action, which rapidly disintegrates the lower rock and causes the upper rock to avalanche, producing an almost vertical headwall. The resulting rock material becomes embedded in the glacier and scours a concave floor, which may contain a small lake (known as a tarn) if the glacier disappears. Expansion of neighbouring cirques can lead to the formation of sharp arêtes, cols, and horns.

Cirque can be classified as follows: -

Simple cirque : A simple cirque is a small, bowl-shaped depression that forms at the head of a mountain valley due to glacial erosion. It is typically less than 1 kilometer in diameter and has steep walls that form a concave shape. Simple cirques are often the starting point for the formation of larger glacial landforms such as arêtes, cols, and horns. Simple cirques are usually found in mountainous areas where glaciers have been present in the past, but they can also be formed by other erosive processes such as weathering and mass wasting. These landforms are often used by geologists and glaciologists as indicators of past glacial activity and to understand the history of glaciation in a region.

Compound Cirque : A compound cirque is a larger and more complex version of a simple cirque. It is a depression that forms at the head of a valley, with steep walls that form a concave shape. However, unlike a simple cirque, a compound cirque has several tributary valleys that lead into it, each with its own glacier. These tributary glaciers erode the walls of the cirque, creating ridges or spurs that separate them from each other. These ridges or spurs are called arêtes or cols, depending on their shape.

Complex Cirque : when more than two cirque collapse together into one large cirque

Staircase Cirque : when cirques occur in the same longitudinal profile one above other.

- **Col**

In glaciology and geomorphology, a col is a narrow, low point on a ridge or mountain crest that forms as a result of glacial erosion. It is essentially a saddle-shaped depression between two peaks, which allows passage from one valley or cirque to another. A col can form when two adjacent glaciers erode the mountainside from opposite sides, eventually meeting at a central point and carving out a low point or pass.

- **Aretes**

An arête is a narrow, sharp-edged ridge that separates two adjacent valleys or cirques in a mountainous area. Arêtes are a common glacial landform that are created through the process of erosion by glaciers. As glaciers flow down a valley, they erode the surrounding rock, creating a U-shaped valley with steep walls. If two glaciers erode parallel valleys on either side of a narrow ridge, they can erode the ridge to form an arête. Arêtes range in size from small ridges to larger formations that stretch for several kilometers. They are steep, with near-vertical walls on either side. Arêtes are typically composed of hard, resistant rock that is able to withstand the erosive power of glaciers, such as granite or quartzite.

- **Glacier Horn**

A glacial horn, also known as a pyramidal peak, is a distinctive mountain landform that is created by the erosion of cirque glaciers. It is a pointed peak with three or more arêtes radiating outwards from the summit, giving it a pyramidal shape. Glacial horns are typically composed of very hard, resistant rock, such as granite or quartzite, which is able to withstand the erosive power of glaciers. The formation of a glacial horn begins with the creation of a cirque by glacial erosion. As the cirque glacier moves downhill, it erodes the surrounding rock and creates steep, narrow ridges called arêtes. Over time, the glacier erodes the rock at the head of each arête, creating a concave depression that deepens into a cirque. If multiple cirques are eroded into the same mountain peak, the erosion can create a glacial horn. Glacial horns are found in many mountainous regions around the world that have experienced significant glaciation, including the European Alps, the Rocky Mountains, and the Andes.

- **Glacier Pavement**

Glacier pavement, also known as glacial polish, is a type of glacial landform that is characterized by a smooth, polished surface on exposed bedrock. It is created by the abrasive action of rock debris that is carried along by glaciers as they move downhill.Glacier pavement is typically found in areas where glaciers have receded, leaving behind a bare, rocky landscape. The rock surface appears polished and smooth due to the constant grinding of rocks and debris against the bedrock as the glacier moves over it. The size and shape of the rocks carried by the glacier can also contribute to the appearance of the glacier pavement, with larger rocks producing deeper grooves and scratches in the bedrock.

- **Roche Moutonnee**

A glacier moutonnee is a type of glacial landform that is formed by the erosive action of a glacier. It is characterized by a smooth, gently sloping side on the upstream side of the glacier, and a steep, jagged slope on the downstream side. The upstream side is typically smoothed and polished by the glacier as it moves over it, while the downstream side is eroded by the glacier's abrasive action. Glacier moutonnees are formed in areas where the underlying bedrock is relatively hard and resistant to erosion, and the glacier is able to exert significant pressure on the rock surface. The process of glacier erosion is known as plucking, and it occurs when the glacier freezes onto rock surfaces and then pulls pieces of the rock away as it moves. As the glacier moves over the landscape, it creates a smooth, polished surface on the upstream side of the moutonnee, and a rough, jagged surface on the downstream side. This asymmetrical shape is the result of the different types of erosion that occur on each side of the landform.

- **Whaleback Form**

The distinct features of the Roche Moutonnee landform are attributed to the extensive polishing and striations that it undergoes. Its polished, oval-shaped surface is longer than it is wide, giving it the appearance of a whaleback hump.

- **Hanging Valley**

A hanging valley is a unique glacial landform that occurs when a smaller glacial tributary valley is eroded into the side of a larger main valley. The term "hanging" refers to the fact that the floor of the smaller valley is situated at a higher elevation than the floor of the larger valley, causing it to appear to "hang" above the main valley.

Hanging valleys are typically formed when a smaller glacier flowing into a larger valley is unable to erode the bedrock at the same rate as the larger glacier. As a result, when the larger glacier recedes, the smaller glacier is left perched high above the main valley, with a steep drop-off at the lip of the valley. Hanging valleys are often marked by waterfalls or cascades, as the smaller tributary stream drops down to the floor of the larger valley. These waterfalls can be quite spectacular, and are popular destinations for hiking and sightseeing.

- **Glacier Tarns**

A glacier tarn is a small mountain lake that is formed by a glacier. It is typically located in a cirque or a glacial valley, and is usually characterized by its clear blue or green water, surrounded by steep rocky walls. Glacier tarns are formed as a result of glacial erosion. As a glacier moves downhill, it erodes the rock beneath it, creating a depression in the landscape. This depression can fill with meltwater from the glacier, forming a small lake. The water in the tarn is often fed by snowmelt and glacial meltwater, which gives it a distinctive turquoise color.

- **Rock-Cut Terrace**

A rock cut terrace is a glacial landform that is created by the erosion of glaciers. It is a flat, bench-like surface that is cut into the bedrock on the sides of glacial valleys. Rock cut terraces are typically found at the base of steep valley walls, and they can be several meters to tens of meters wide.

In glaciated regions, one may often come across a valley slope that takes the form of a flat, barren surface with little to no supra-glacial material covering it. This type of landform is known as a rock cut terrace, and it is formed through the process of lateral cutting and erosion by a glacier. As the glacier moves through the valley, it erodes the bedrock at the base of the valley, creating a flat, bench-like surface that is characteristic of rock cut terraces.

Depositional Land Forms

Glaciers can cause depositional work as they move and erode the land beneath them. As glaciers move, they carry rocks, sediment, and other debris along with them. When the glacier begins to melt, this material is deposited on the ground or in bodies of water. This process is known as *glacial deposition*. Glaciers carry rock debris on, in and beneath, eroded from valley walls and from bedrock under frost action by scrapping and scooping. These deposition are termed *moraines.* Moraines are landforms composed mostly of till that form on or within a glacier or are left behind when it melts.

Glacial deposition can create a variety of landforms, such as moraines, drumlins, eskers, and kames. Moraines are ridges of sediment that form along the edges of glaciers or at their terminus. Drumlins are elongated hills of sediment that are streamlined in the direction of glacier movement. Eskers are long, narrow ridges of sediment that were deposited by streams that flowed under glaciers. Kames are small, cone-shaped hills of sediment that form when sediment is deposited at the melting front of a glacier.

Lateral Moraine

Lateral moraines are long, narrow ridges of sediment that form along the sides of glaciers. As glaciers move down slopes, they erode the surrounding rock and soil and collect this material on their surfaces. Some of this material is carried along the sides of the glacier and deposited as a lateral moraine. Lateral moraines are typically made up of weathered material that has fallen from the valley sides above the glacier.

A glacier's lateral moraine is formed by the accumulation of rock and soil on both sides of its path as it scrapes along. This material is deposited as a ridge at the top of the glacier's edges, often in matching formations on each side. When a glacier melts, it deposits all the moraine it was carrying at its front, forming a terminal moraine. The sediment that makes up a lateral moraine can range in size from small particles to large boulders. This material is usually unsorted, meaning that it contains a mixture of different sizes and types of rocks. Lateral moraines can also contain debris from the surrounding rock, such as soil and vegetation. Glaciers can transport large amounts of material including rocks, stones, and particles.

Lateral moraines can be found along the edges of both valley glaciers and continental glaciers. In some cases, lateral moraines can merge with other moraines to form a medial moraine that runs down the centre of the glacier.

Terminal moraine

A terminal moraine is a type of glacial deposit that forms at the leading edge or terminus of a glacier. It is created by a ridgelike accumulation of glacial debris that is pushed forward by the advancing glacier and deposited at the outermost edge of its reach. The terminal moraine typically curves down the valley in a convex shape and may also extend up the sides as lateral moraines. As a glacier moves, it erodes the land beneath it, carrying rocks, soil, and other debris along with it. As the glacier melts, it deposits this material at its front, creating a ridge or mound known as a terminal moraine. Glacier front degeneration and retreat leave behind large mounds and moraines. Mounds in crescent form along the valley floor are vacated by ice and are referred to as Terminal or End moraines. These moraines can cover thousands of kilometres and are naturally restricted.This glacial deposit can appear as a belt of hilly ground with knobs and kettles, creating distinctive landforms in the landscape.

Medial Moraine

A medial moraine is a type of glacial deposit that forms as a long and narrow line or zone of debris. It is created when lateral moraines, which form along the sides of glaciers, merge at the intersection of two ice streams. This results in a moraine that is located in the middle of the combined glacier. The medial moraine is deposited as a ridge that is roughly parallel to the direction of ice movement.

Recessional Moraine

A recessional moraine is a type of glacial deposit that forms as a secondary terminal moraine during a temporary halt in glacial retreat. These deposits can reveal the history of glacial retreats along a valley. In some cases, 10 or more recessional moraines may be present in a given valley. Scientists can develop a chronology of glacial movements over time by analyzing the ages of growing trees or other sources of dates found within the recessional moraines.

Glaciated Till

Glacial till is the sediment that is deposited by glaciers and is found extensively throughout glacial environments. It overlaps the glacier forefields and can be arranged to form a range of landforms, including moraines. The composition of glacial till is unique and distinct. This is because glaciers not only grind rocks into fine, small pieces, but they also remove large chunks of rock. This means that glaciers transport everything from big boulders to small grains smaller than sand. Essentially, till is any substance that is deposited directly by a glacier or has been reworked by it. It is made up of rock fragments and gibber stones in a fine-grained matrix of mud or sand. The specific composition of any till depends on a variety of factors, such as the content of clay, the size of boulders, and their mixture. In glacial landforms, the type of deposition that forms till is called lodgement till.

Outwash Deposits

Outwash refers to the sediment consisting of sand and gravel that is transported by flowing water resulting from the melting ice of a glacier. These sediments are typically laid down in stratified deposits. The thickness of an outwash can reach up to 100 meters (328 feet) at the edge of a glacier, but it is usually much thinner. Outwashes can extend over many kilometers in length, as is evident in the outwash deposits from the Wisconsin Glaciation, which can be traced to the mouth of the Mississippi River, a distance of 1,120 km (700 miles) from the nearest glacial terminus.

Outwash deposits may be characterized by pitted undrained kettles or dissected by streams that have formed post-glaciation. They are usually cross-bedded with alternating grain sizes, with larger materials being dropped nearest the glacier due to the gentle slope, while smaller grain sizes are spread over greater distances. Striated pebbles are not commonly found as the transportation process wears away the striations. Outwashes are the largest of the fluvioglacial deposits and provide a significant source of windblown material. When the outwash is confined within valley walls, it is referred to as a valley train.

Permafrost

Permafrost is a type of ground that remains frozen all year round. In regions with permafrost, the layer of soil closest to the surface, called the "active layer," undergoes seasonal and daily freeze-thaw cycles. This constant fluctuation in water volume causes larger particles in the soil to rise to the surface. As the soil continues to freeze and thaw, frost heaving occurs, which arranges stones and rocks based on their size, resulting in the patterned ground. Larger rocks may form circular arrangements called stone rings, which can coalesce with neighbouring rings to form polygonal stone nets. When the active layer of permafrost moves due to gravity, the process is called gelifluction. The soft, flowing layer may be folded and draped on hillsides and at the slopes' base, forming solifluction or gelifluction lobes.

Pingos

These land features are associated with permafrost. These are low profile domes covering a large area. these dome shaped are called pingos . These conical mounds, or pingos, may be several tens of metres high and hundreds of metres in diameter. They result due to uplifting of frozen ground by thawing and freezing process of underground water layer into ice ,immediately below soil.

Esker

An esker is a long, winding ridge of gravel and coarse sediment that was deposited by meltwater streams that flowed within and under glaciers during the last Ice Age. Eskers are often several kilometers long and up to tens of meters high.

Drumlin

A drumlin is a smooth, elongated hill composed of glacial till that was deposited and shaped by the movement of a glacier. Drumlins are typically elongated in the direction of ice flow and have a steep, tapered end and a more gentle slope on the upstream side. They are often found in groups or swarms and can be several kilometers long and up to 50 meters high.

U shaped valley

A U-shaped valley is a geological landform formed by the erosive action of a glacier. It has a characteristic shape of a deep and wide valley with steep sides and a flat bottom, resembling the letter "U". The glacial erosion process begins when a valley glacier moves through an existing V-shaped valley, widening and deepening it through the processes of plucking and abrasion. The glacier scours the valley floor and removes the softer rock and soil, leaving behind a broad, flat-bottomed valley with steep sides. U-shaped valleys are commonly found in mountainous regions that have undergone glaciation, and they may contain lakes, waterfalls, and hanging valleys.

8.4 SUMMARY

Glaciers are large masses of ice that flow under the influence of gravity, eroding and depositing sediment as they move. Glacial erosion can create a variety of landforms, including U-shaped valleys, cirques, and horns. Glacial deposition can create moraines, outwash plains, and drumlins. Glaciers can also create distinctive features such as glacial till, which is a mixture of rock fragments and gibber stones, and outwash, which is sand and gravel carried by running water from the melting ice of a glacier. Additionally, permafrost is ground that remains perennially frozen and covers about 20-25% of the Earth's land surface. Permafrost processes can create patterned ground, ice wedges, and pingos. These features provide important clues about the past and present climate of the Earth, and are also important for understanding natural hazards, such as landslides and floods.

8.5 GLOSSARY

- **Arete:** A narrow, sharp ridge separating two adjacent cirques.

- **Cirque:** A bowl-shaped depression at the head of a glacial valley, typically formed by erosion.
- **Drumlin:** A streamlined hill of glacial till, usually composed of clay, that is aligned in the direction of ice flow.
- **Esker:** A winding ridge of sand and gravel deposited by a subglacial stream.
- **Glacial erratic:** A large boulder that was transported and deposited by a glacier.
- **Glacier:** A slowly moving mass or river of ice formed by the accumulation and compaction of snow.
- **Hanging valley:** A tributary valley that enters a U-shaped valley from a higher elevation, often resulting in a waterfall.
- **Horn:** A sharp peak formed by the erosion of several cirques around a single mountain summit.
- **Ice cap:** A smaller, dome-shaped glacier that covers a mountain peak or plateau.
- **Ice sheet:** A very large, continental-scale glacier that covers a vast area of land.
- **Moraine:** A ridge or mound of glacial till (unsorted mixture of sediment) deposited by a glacier.
- **Outwash:** Sediment (sand and gravel) deposited by meltwater streams flowing from a glacier.
- **Permafrost:** Ground that remains perennially frozen, covering about 20-25% of the Earth’s land surface.
- **Pingo:** A conical mound of ice formed by the expansion of groundwater within a confined area of permafrost
- **Solifluction:** The slow, downhill movement of soil and sediment due to the freeze-thaw cycles of the active layer of permafrost.
- **U-shaped valley:** A valley with steep, straight sides and a flat bottom, formed by the erosion of a glacier.

8.6 ANSWER TO CHECK YOUR PROGRESS

1. Which of the following is not a type of glacier?

a) Alpine glacier

b) Continental glacier

c) Ice sheet

d) Volcanic glacier

2. Which process involves the breaking off of large chunks of ice from a glacier?

a) Plucking

b) Abrasion

c) Melting

d) Sublimation

3. Which landform is created when two lateral moraines join at the end of a glacier?

a) Medial moraine

b) Terminal moraine

c) Recessional moraine

d) Ground moraine

4. The process of glacial retreat is also known as:

a) Deglaciation

b) Glacial surge

c) Ice advance

d) Ice accumulation

5. Which of the following landforms is not created by glacial erosion?

a) U-shaped valley

b) Cirque

c) Arete

d) Drumlin

6. Which type of glacier moves faster, the center or the edges?

a) Center

b) Edges

c) Both move at the same speed

d) Glaciers do not move

7. What is the term for a glacier-fed river?

a) Ephemeral stream

b) Braided stream

c) Meandering stream

d) Perennial stream

8. What is the term for the process of melting at the base of a glacier due to friction?

a) Calving

b) Sublimation

c) Basal sliding

d) Plucking

9. Which landform is created by the accumulation of sediment deposited by a glacier?

a) Esker

b) Cirque

c) Arete

d) Horn

10. What is the term for the ridge of sediment deposited at the end of a glacier?

a) Lateral moraine

b) Medial moraine

c) Terminal moraine

d) Recessional moraine

Answers:

1. d) Volcanic glacier

2. a) Plucking

3. b) Terminal moraine

4. a) Deglaciation

5. d) Drumlin

6. b) Edges

7. d) Perennial stream

8. c) Basal sliding

9. a) Esker

10. c) Terminal moraine

8.7 REFERENCES

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8.8 TERMINAL QUESTIONS

1) Describe the process of glacial erosion and its role in shaping the landscape. Include examples of landforms created by glacial erosion.

2) Explain the concept of glacial deposition and the formation of landforms such as moraines, drumlins, and eskers. How do these landforms differ from those created by erosion?

3) Discuss the impact of climate change on glaciers and glacial landforms. what are the potential long-term consequences of these changes?

4) Describe the different types of glaciers and their characteristics. How do glaciers form, grow, and move, and what factors affect their behaviour and size?

5) Explain the concept of permafrost and its role in shaping the landscape. what are the potential consequences of permafrost thaw due to climate change?

UNIT- 9 ARID PROCESSES AND LANDFORMS

9.1 OBJECTIVES:

After studying this lesson, you will be able to:

- Know about different types of deserts and arid regions in the world
- Describe, with the help of diagrams, different types of erosional and depositional landforms produced in arid topography
- To understand the Geographical cycle in an Arid Region

9.2 INTRODUCTION

You have learned how different erosion and deposition agents work on the Earth's surface in the previous chapters. You have already learned about landforms formed by periglacial and glacial processes. In this unit, we will study the aeolian topography. Here we will learn about the aeolian or arid landscape found across the world. Different landforms have formed because of the erosion and deposition processes in such a landscape. We will be discussing these landforms in this chapter, along with the Arid Cycle of erosion.

9.3 ARID REGIONS OF THE WORLD

First, one should know that aridity is often regarded as a climatic accident (Cotton,1966). Such a condition sometimes interrupts and other times modify the course of the normal cycle. A landscape at any stage of erosion that is young, mature, or old can be the initial base for such a formation as an arid cycle is usually the result of the upheaval, disinformation, or dislocation of a former landscape.

Scholars have used several definitions based on different criteria to define arid regions; the term is used synonymously with deserts or dry lands. The basic premise is the same – moisture deficiency. In this section, you will first know the different types of deserts and their location in various parts of the world.

9.3.1 Types of Deserts and Desert Landscapes

One-fifth of the world is made up of deserts, though they may have different characteristics as some are rocky, some are stony, while others are sandy. Barren deserts where nothing grows are rare. Some deserts may have perennial rivers like the River Nile flowing through Egypt and Sudan's driest parts. In such regions, winds and waterworks have given rise to 5 distinct kinds of deserts or desert landscapes.

These are –

<u>Rocky Desert</u> – These are usually known as *"Hamada."* The word *Hamada* in Arabic means '*a rocky plane surface*' (Fairbridge, 1997). A distinctive feature of this type of desert is the presence of large stretches of rocks, usually bare ones, which have been swept clear of dust and sand due to the action of wind – deflation (lifting and blowing away loose materials from the ground). The result is the presence of thoroughly polished and smoothed exposed rocks in the form of plateaus or desert pavements. Such a region is generally sterile and bare. Gautier (1935) defines such a desert landscape as a sand-scoured bedrock surface with or without a veneer of boulders or pebbles (Figure 1). One of the best examples of such a rocky desert is found in the Sahara Desert in Africa in Libya, known as *Hamada el Homra* (approximately 20000 square miles) (Leong, 1974). Another example has been cited by Mabbutt (1977) as *hamadas* of Dra and in the Guir, North-Western Sahara. The *Hamadas* of Sahara rests on surfaces of varied ages, starting from the Cretaceous, Oligocene, Miocene, and Pliocene to Quaternary periods (Conrad, 1969).


Figure 9.1: Rocky Desert or *Hamada* in the Sahara Desert, Source Google Image

<u>Stony Desert</u> – This type of desert is commonly known as "*Reg."* It is formed of extensive sheets of angular gravels and pebbles left by the wind as it could not blow these off. These types of deserts are typically formed by wind deflation. These stony deserts are more accessible and approachable as compared to the sandy deserts. They are also called *gibber plains* or desert pavement as they resemble a thin and continuous sheet-like veneer of pebbles and gravels that protect the finer materials underneath (Edgell, 2006). Such deserts are also called *Serir* (eastern Sahara) or *Sai* (Central Asia).

Figure 9.2: Stony Desert or *Reg* in the Sahara Desert, Source Google Image

<u>Sandy Desert</u> – This type of desert is commonly known as the '*Sea of Sand*' or *Erg* (Leong, 1974) as it represents an area of a large accumulation of sand. These are regions of active sand – dunes that symbolize the typical desert landscape. Here the sand is generally loose, making it difficult to traverse. One can easily identify the wind direction in such a landscape as it leaves distinguishing marks as ripples on the sand. In Turkestan, sandy deserts are called *Koum*. Example – Calanscio Sand Sea in Libya.

Figure 9.3: Sandy Desert or *Erg* in Libya, Source Google Image

Badlands – The term 'Badlands' was first given to an arid area in U.S.A (South Dakota). The region was severely eroded by rain-storms resulting in the formation of gullies and ravines. Thus badlands represent extremely dissected landscapes dotted with steep slopes and narrow valleys without vegetation cover. Some of the best-known badlands are those in the semi-arid Great Plains of North America and *Ghor* in the Jordan Rift Valley (Mabbutt, 1977).


Figure 9.4: Badlands of North America and Jordan, Source Google Image

Mountain Deserts – Some deserts are found in the mountainous regions or even on high plateaus. Here, frost's action is dominant, which results in the formation of sharp, irregular edges. The Ahaggar Mountains and the Tibesti Mountains in the Sahara Desert are good examples of such desert types.

Figure 9.5: Mountain Desert of the Tibesti Mountains, Source Google Image

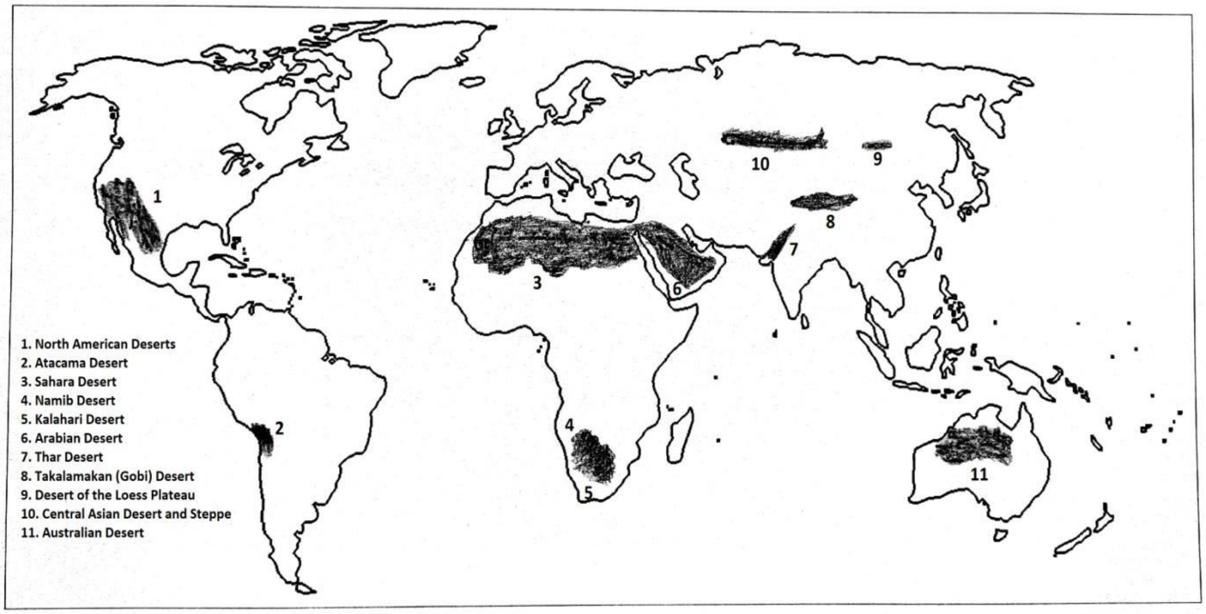

Figure 9.6: Major Deserts of the World, Source Prepared by Author

Major Deserts of the world

The deserts in the world are not restricted by longitude, latitude, or even elevation. They are found anywhere on the Earth, from regions close to the Equator to areas near the Poles. But most deserts are areas of aridity or with water-shortage. One can easily say that the location of deserts is dependent on the following factors –

i. **Subtropical zones of high atmospheric pressure**

ii. **Continentality (Distance from the Sea)**

iii. **Rain-shadow effects**

These result in the presence of a definite pattern to the location of deserts. The deserts are confined within the latitudes of 15 to 30 degrees North and South of the Equator in the Trade Wind belt on the continents' western parts (Figure 9.6). In this section, some of the significant deserts are discussed.

The Sahara and its Margins – The Sahara is the largest desert in the world, covering approximately 9,150,000 square km (Tucker and Nicholson, 1999). This desert nearly covers the entire northern part of the African continent. It extends from the Red Sea in the East to the Atlantic Ocean in the West. And from the Mediterranean Sea in the North to the Sahel Region in the south. The desert covers all or parts of the following ten countries: Egypt, Sudan, Libya, Chad, Tunisia, Algeria, Morocco, Mali, Mauritania, and Niger (Hereher, 2011). Most regions are devoid of surface water, vegetation, high temperatures, and rainfall less than 400 mm. The desert is flat and associated with great sandstone plateaus with broad and closed basins (example. Chad Basin). The entire region is dotted with wind-molded landscapes with *regs*, yardangs, and *ergs*. One of the salient features is that it is the prime source of atmospheric dust in the world as it produces the most considerable quantity of aeolian dust (Goudie and Middleton, 2001).

Southern Africa – The Namib Desert, the Kalahari Desert, and the Great Karoo semi-desert are the major deserts in southern Africa.

The Namib Desert: this desert extends along the coastal plains of the western part of Namibia. It extends from the River Unlab (in the North) to Luderitz in the South. The desert forms a narrow strip (80 – 200 km) as the Great Escarpment bounds it on the Eastern side. One of the striking features

i) From the Orange River valley to the Klinghardt and Aurus Mountains:

- **Partially vegetated**
- **Linear and reticulate dunes**
- **Obib Dune Field**

ii) From the Namib coast to the Namib sand sea:

- **Sand transport corridors**
- **Barchans up to 30 m high**

of this desert is the presence of two main areas of dune fields –

Namib Sand Sea extends from the Luderitz to the Kuiseb River, for approximately 300 km. Simple and compound crescentic dunes are predominant here (Lancaster, 2014). Some of the significant dune fields are the Skeleton Coast Dune Field, the Cuneen Dune Filed, and the Baia dos Tigres Dune Field. Inselberg-studded gravel plains usually separate these fields.

The Kalahari Desert: the word Kalahari is derived from the Setswana word "*Kgalagale,"* meaning "*always dry."* The Kalahari Desert covers about 930,000 square km. It covers most of Botswana, the eastern third of Namibia, and the Northern Cape Province of South Africa (Trappe, Claridge, and Kagan-Zur, 2014). The desert is characterized by a gentle undulating sandplain covered with sand sheets (red, commonly known as the Kalahari Truffle), claypans (three types: white/calcareous, pink/slightly calcareous, and red/non-calcareous), and longitudinal dunes (north-south oriented, 2.5 km, 7-70 m tall and 100 m or more broad; these are separated from one-another by broad parallel depressions known as *straat).* The southern part of the desert has no perennial surface water; scattered water holes dominate the desert –scape. The entire desert can be divided into three regions:

- The Kalahari dune desert in Botswana and adjoining parts of South Africa and Namibia
- The Kalahari Thirstland Region between the Orange-Limpopo Rivers and the Okavango Swamps
- The Mega-Kalahari between the Congo River and the Orange River (Malloy, Brock, Floyd, Livingstone, and Webb, 2013).

The Great Karoo Semi-Desert**:** it is a sizeable landlocked plateau in the western part of South Africa extending up to Southeastern Namibia. It extends to nearly 248284 square km (Trelitzia, 2006). The name derives from the Khoi Sun word '*Kuru*,' meaning dry.

The Great Indian Desert or Thar – The Thar Desert, also known as the Great Indian Desert, is situated in the western part of India. It spreads in the state of Rajasthan and the adjoining sandy terrain in Pakistan, covering an area of approximately 285,000 square km (Kar, 2014). The primary sequence of landforms in this desert is hills and uplands – rocky or gravelly pediments/ pavements – older and young alluvial plains – river beds. The desert is dotted with sand dunes, interdune plains, low sandy hummocks, and sand sheets. The dunes here are stable, both old and new. Parabolic, star, traverse, linear, and obstacle dunes are the various types of old dunes found here. In the new dunes, the forms predominant are barchans, sand streaks, or *nebkhas*.

Arabia and the Middle East - The deserts in Arabia and the Middle East have been formed by cyclic aridity and climatic fluctuations over the period. The deserts here are one of the most extensive unbroken stretches of sand, the predominant one being the Ar Rub al Khali, which covers nearly 660000 square km (Edgell, 2006). These deserts are sandy, just like the Sahara Desert. But there are exceptions, like the classic saline coastal and continental Sabkhah, Hamadas, or the presence of black lave fields. The dunes are linear and one of the largest in the world.

9.4 ARID LANDFORMS

In this section, we would be learning about landforms formed in the arid regions. Before that, we will also try to understand the mechanism of arid erosion (Figure 9.7).

9.4.1 Mechanism of Arid Erosion, Transportation and Deposition

As already mentioned above, the arid-scape results from a combination of factors that act on one another. Some of these factors are insufficient rainfall, high temperatures, continentality, and evaporation. The processes of weathering, aeolian, and water action produce this distinctive and varied landscape. These processes have been discussed here –

Arid Erosion

Weathering – weathering is one of the essential processes in the deserts as it reduces rocks to sand. Mechanical weathering, especially exfoliation or *onion-peeling* (Figure 9.8), is predominant. Drastic diurnal range of temperatures causes stress in the rocks due to continuous contraction and expansion. This stress speeds up the process of exfoliation as the rocks are weathered at relatively faster rates than other regions. Another potent process here is the *Freeze and Thaw* (Figure 9.9) in the rocks and fragments of rocks.

Action of Winds in Deserts- in arid regions, the wind is the most effective agent of erosion, transportation, and deposition (Figure 9.10). Wind erosion is carried out in the following ways

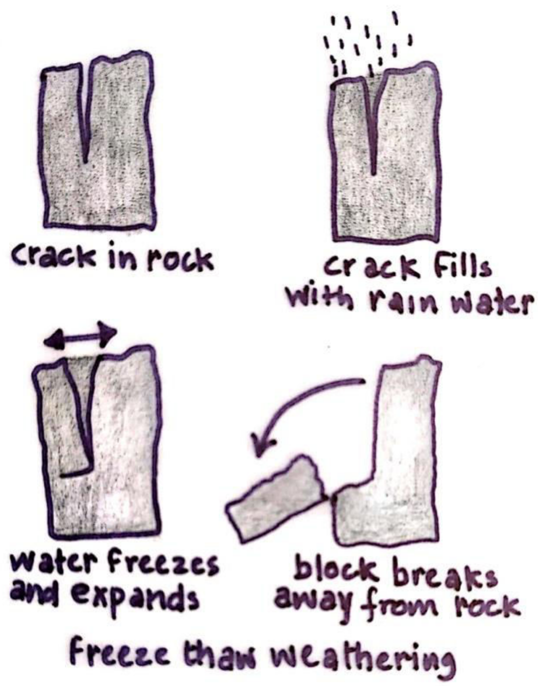

Figure 9.9: Freeze and Thaw, Source Prepared by Author

- *Deflation:* it is the process by which the wind removes fine materials from the desert surface. It leads to the formation of stone pavements as the coarse-grained sand and rocks are left behind. In regions of sparse vegetation, deflation usually leads to dust storms resulting in the formation of landforms like pans and yardangs.
- *Abrasion*: it is the physical process that involves rubbing, scraping, or scouring, whereby rock particles are eroded by friction (Fairbridge, 1968). This process is most effective at or near the base of the rocks.
- *Attrition*: it occurs when hard objects hit against each other and are eroded as a result. In other words, it is an act of rubbing things together and, in the process, wearing them down.

Transportation by Wind - once the wind picks the loose particles in the deserts, they are transported to different locations through the following processes (Figure 9.10) discussed here

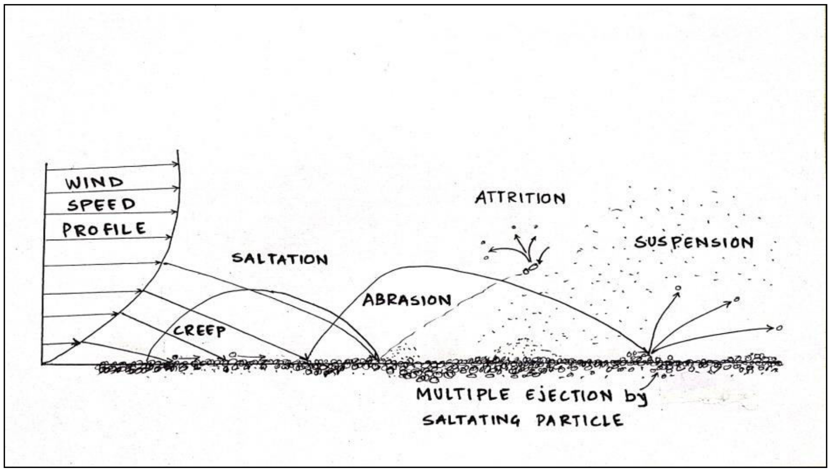

Figure 9.10: Transportation by Wind, Source Prepared by Author

Rolling: When the wind moves in a straight direction, it rolls the sand grains along the surface. As a result, ripple marks are formed on the surface. The result of this process is the formation of shallow depressions and low ridges alternately.

Suspension: In this process, the finer sand particles are transported by the wind. They are suspended high in the air and can travel thousands of kilometers before they land on the surface.

Saltation: This is the most common form of transportation of sand in the arid regions. The wind velocity causes turbulence in the sand particles when the wind hits the ground. The result is the movement of these particles, initially along the surface and hitting other particles on their way, causing them to bounce in the air. Eventually, the wind picks up these air laden particles and transports them to other locations. The process usually occurs in a chain reaction.

Creep: the larger and bigger particles of gravels and rocks are heavier to be carried away by the wind. They move along the ground and also collide with each other. The eroded particles are now smaller in size and are transported or moved by saltation or suspension.

Deposition of Wind – Like water, when wind also slows down, it leaves the particles it has carried. It often happens when there is an obstruction in the movement of the wind. The larger particles are deposited first. Several landforms are formed depending on the size of the deposited particles.

9.4.2 Erosional Landforms

Deflation Hollows – These surface depressions are the work of deflation in the desert landscapes accompanied by chemical weathering. Some of them in the Sahara are as wide as that they stretch for hundreds of kilometers.

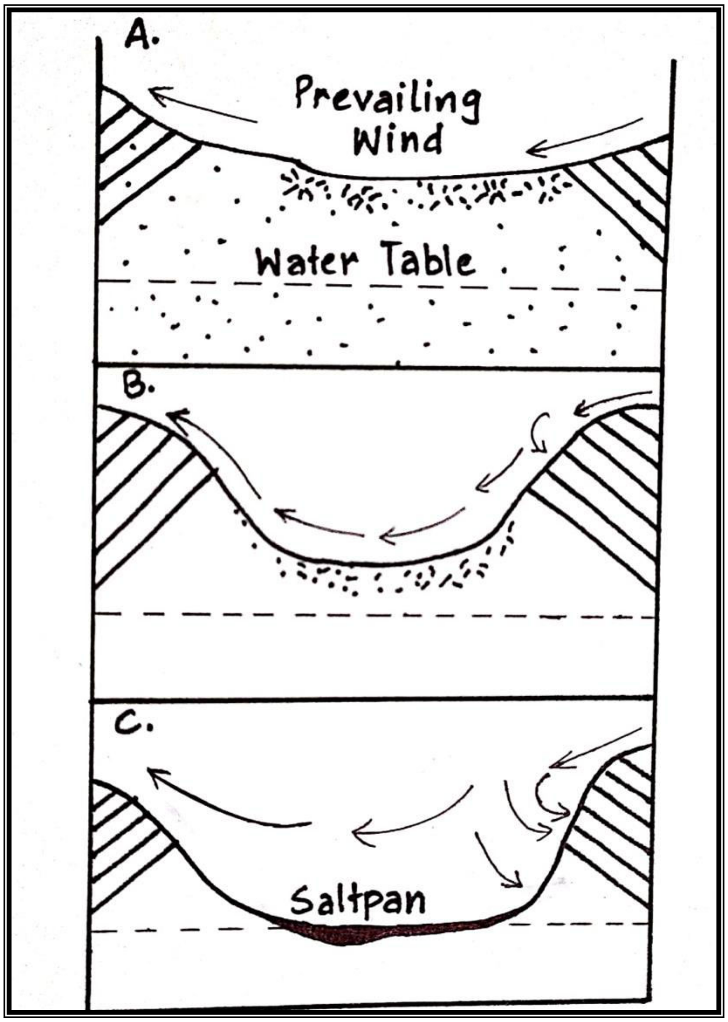

Figure 9.11: Formation of Deflation Hollows, Source Prepared by Author

Desert Pavements – The pavements are also known as *regs* and usually resemble a cobbled street. These are flat stony surfaces formed of particles of varied sizes that have been blown and transported by the wind (Figure 9.12).

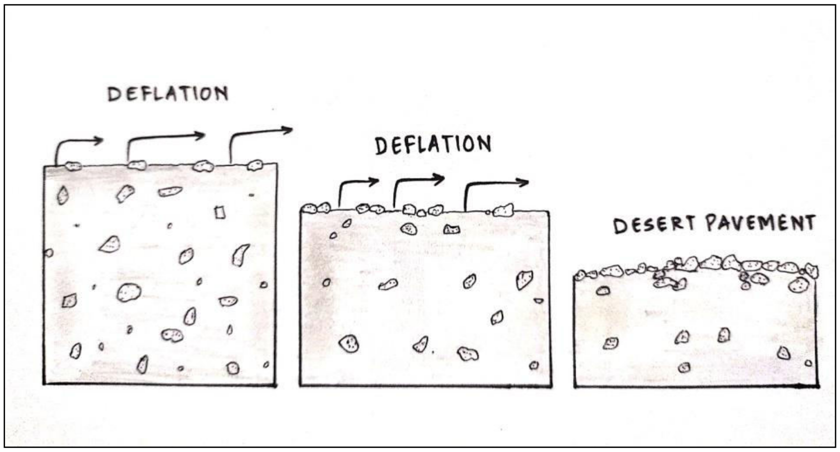

Figure 9.12: Desert Pavements, Source Prepared by Author

Ventifacts and Driekenters – The term Ventifact was introduced by Evans (1911) to define and describe pebbles and stone faceted by the sandblasting action of the wind. These also include the Dreikanters (a ventifact with three wind-faceted surfaces), which are in the shape of Brazil-nut (Figures 9.13 and 9.14). These landforms are usually formed in areas where the following three conditions are met –

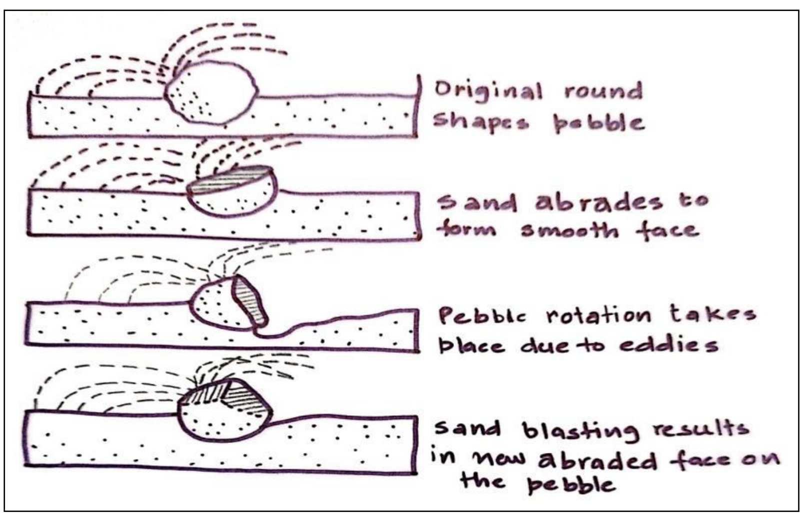

Figure 9.13 Ventifacts, Source Prepared by Author

- strong uni-directional winds
- the presence of loose materials in the form of sand, dust, etc

- the presence of bigger and larger particles like pebbles, boulders, and rock outcrops as an obstruction in the wind direction.

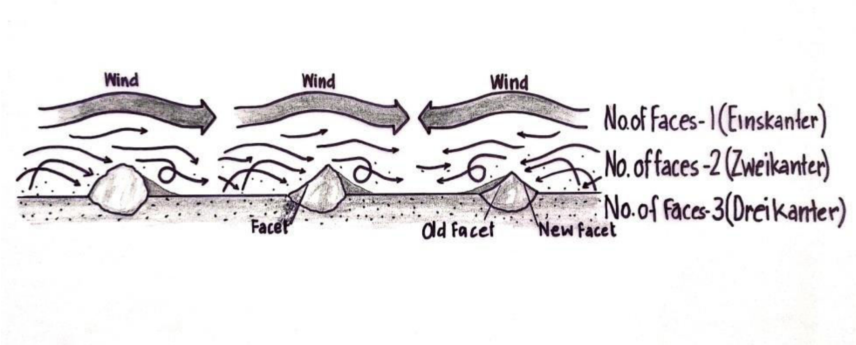

Figure 9.14: Driekenters, Source Prepared by Author

<u>Yardangs –</u> A Turkmen word coined by Hedin in 1903 to describe an erosional landform formed in an arid region. These are abraded ridges of cohesive materials, which range in size from few centimeters to some kilometers. The steep-sided yardangs form a landscape that is quite similar to the 'ridges and furrow.' They are formed in vertical bands that are aligned to the wind direction (Figure 9.15). Aeolian abrasion and deflation in such landscapes result in the formation of long narrow corridors of softer rocks, separated by the steep-sided overhanging ridges of hard rocks in the form of Yardangs. These landforms are common in the Atacama Desert and the central part of the Sahara.

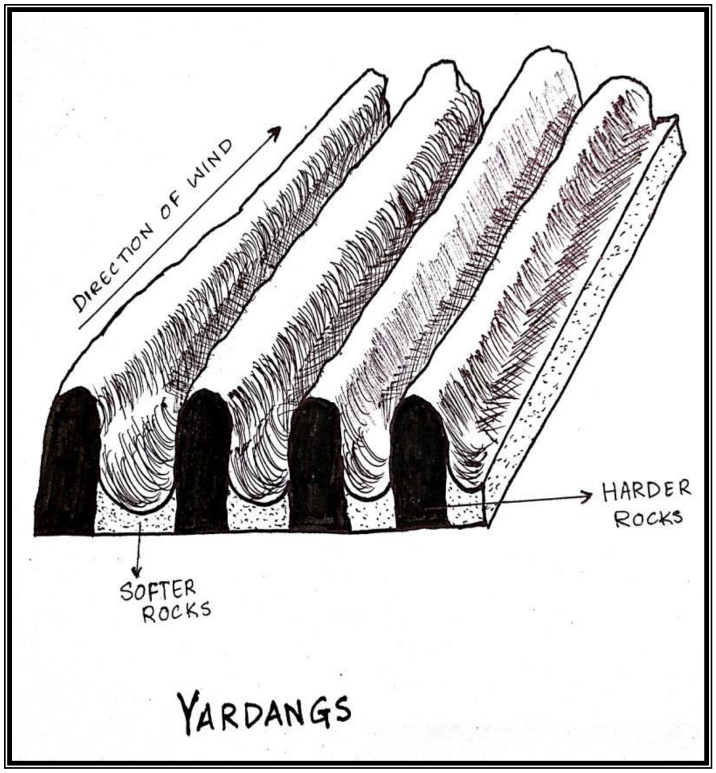

Figure 9.15: Yardangs, Source Prepared by Author

Zeugen – Zeugen is tabular masses of resistant rocks that lie above the softer rocks. The word is derived from a German word meaning 'witness.' Mechanical weathering initiates their formation, further completed by aeolian abrasion. It is a result of differential erosion by sand-laden wind. These hard rocked ridges can range from 10 to 100 feet above the sunken furrow, representing the 'ridge and furrow' landscape (Figure 9.16).

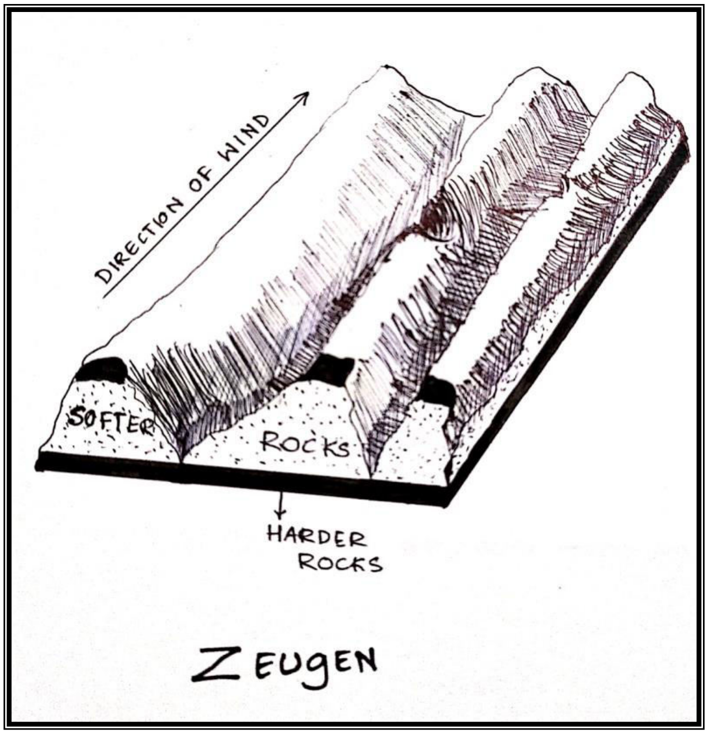

Figure 9.16: Zeugen, Source Prepared by Author

Rock Pedestals or Pedestal Rock-It is an isolated rock mass with a slender stem, neck, or column supporting a wider cap (Figure 9.17). It is also known as Mushroom Rock or Perched Rock. These landforms develop especially well in sandstone, granite, and limestone. Differential weathering and sandblasting are the reasons for their formation. Locally they are knowns as *Gour* in the Sahara, *Loganstones* in south-west England, and *Hoodoo rocks* in North America.

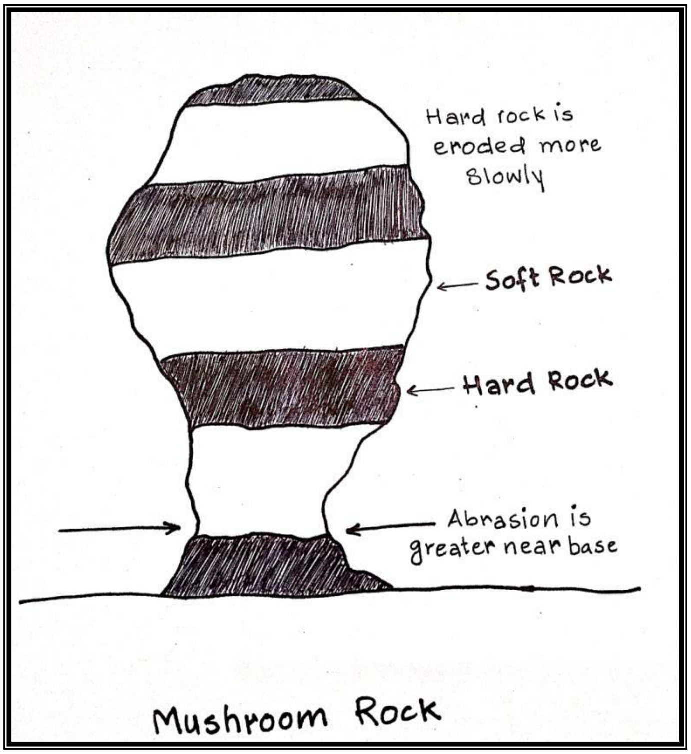

Figure 9.17: Rock Pedestal or Mushroom Rock, Source Prepared by Author

<u>Mesas and Buttes</u> – the word Mesa is of Spanish origin used to describe a steep-sided and flat-topped ridge or hill. These ridges are formed of flat and soft sedimentary rocks capped by harder ones. They develop due to the unequal retreat of the scarp. Due to continuous denudation, the Mesas are reduced, forming an isolated flat-topped hill commonly referred to as the buttes in some regions (Figure 9.18).

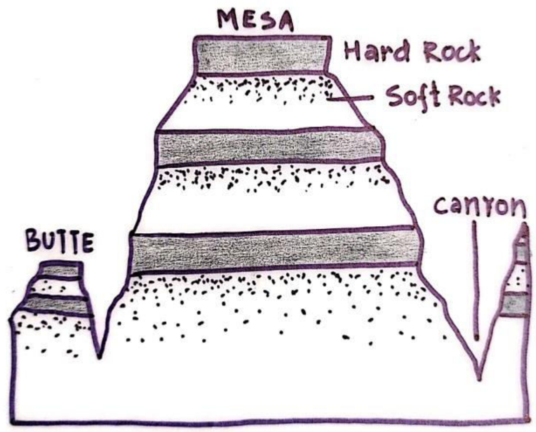

Figure 9.18: Mesa and Butte, Source Prepared by Author

Demoiselles – A French word meaning ‘young lady’ used to define a needle-shaped pillar where the hard rocks cap the softer rocks. They are usually formed of eroded rock that is capped with a boulder (Figure 9.19).

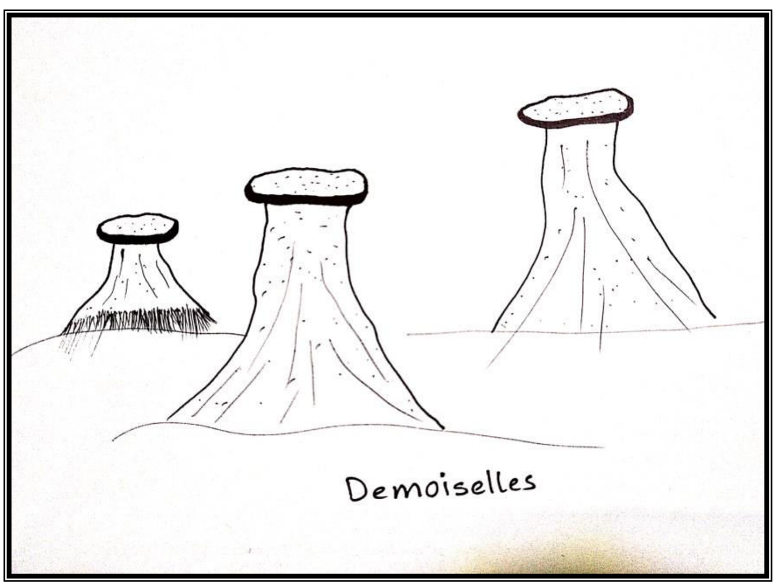

Figure 9.19: Demoiselles, Source Prepared by Author

9.4.3 Depositional Landforms

Dunes – The dunes are created through the accumulation of windblown sand. The dunes are found in most climatic regions in the world, especially in the arid areas. The following conditions are essential for the formation of dunes:

i) Abundant supply of sand

ii) Strong sand-moving wind

iii) Direction and velocity of the wind

iv) An obstacle for the dune to form against

v) Suitable particle size

These are commonly known as *hills of sand*. In the following paragraphs, we will learn about different types of dunes.

The most common typology of dunes is based on their shape, and on this basis, there are five types of dunes. These are:

a) Parabolic –

- U-shaped mounds of sand with convex noses trailed by elongated arms
- also called U-shaped, blowout, or hairpin dune
- common in coastal deserts
- their crests point upwind
- they are fixed by vegetation
- the dune points in the leeward direction
- the longest known parabolic dune has a trailing arm 12 kilometers long (Figure 9.20).

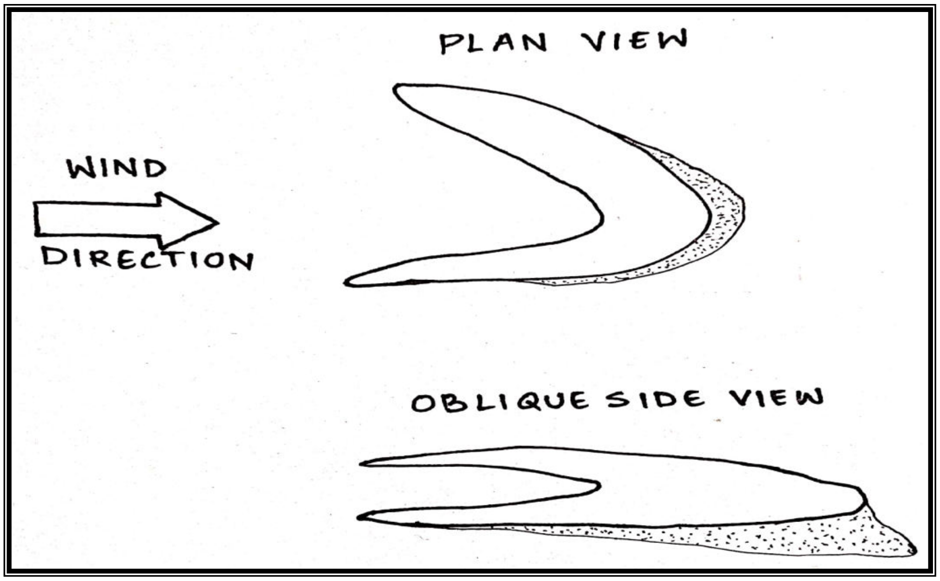

Figure 9.20: Parabolic Dunes, Source Prepared by Author

b) Star –

- rare dunes that are radially symmetrical
- look like a pyramidal sand mound with slip faces on three or more arms that radiate from the mound's high center
- tend to accumulate in areas with multidirectional wind regimes
- grow upward rather than laterally
- makeup to 8.5 % of all dunes on the planet (Kollegger and Grunert, 2017)
- common in the Sahara and Badain Jaran Desert of China (Figure 9.21).

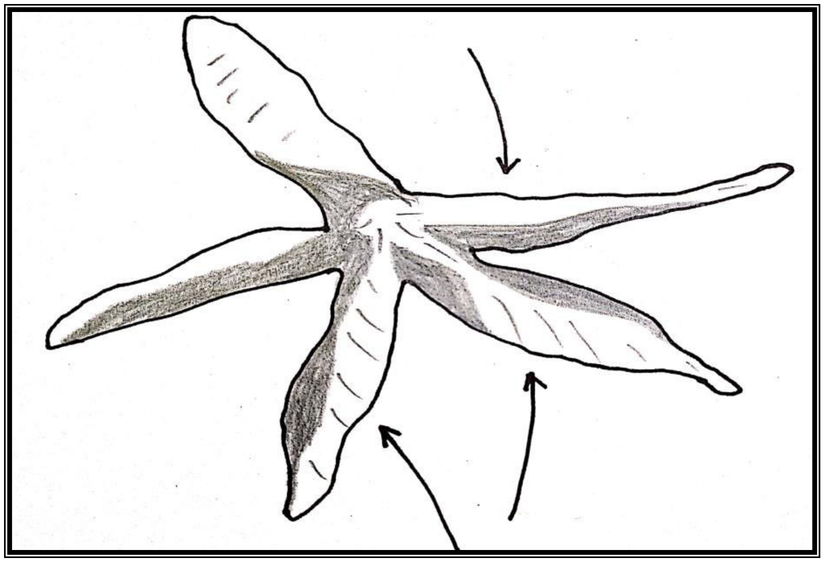

Figure 9.21: Star Dune, Source Prepared by Author

c) **Barchan or Crescentic –**

- are crescent or half-moon shaped
- They form where conditions are ideal.
    i. a flat landscape,
    ii. winds from only one direction, and
    iii. limited sand
- found in all types of deserts
- they point against the wind
- their faces are steep, but their trailing sides are not. They will often join up with other barchans to form barchanoid ridges.
- Common in the Sahara and the Turkestan deserts (Figure 9.22)

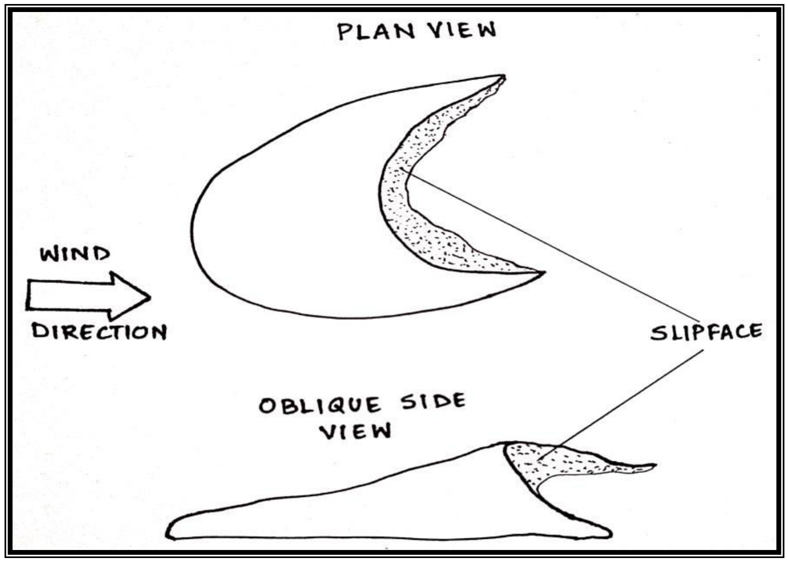

Figure 9.22: Barchans, Source Prepared by Author

d) **Longitudinal or Seifs –**

- Seif an *Arabic* word meaning '*sword.'*
- look like large, parallel needle-esque features on the desert landscape
- are straight and long, unlike the typical dune that one can imagine
- forms when sand is not in excess and the wind blows in one constant direction
- over an extended period, the dunes tend to migrate in the direction the wind is blowing.
- Common in the Sahara, the Namib, the Thar, and the West Australian deserts (Figure 9.23)

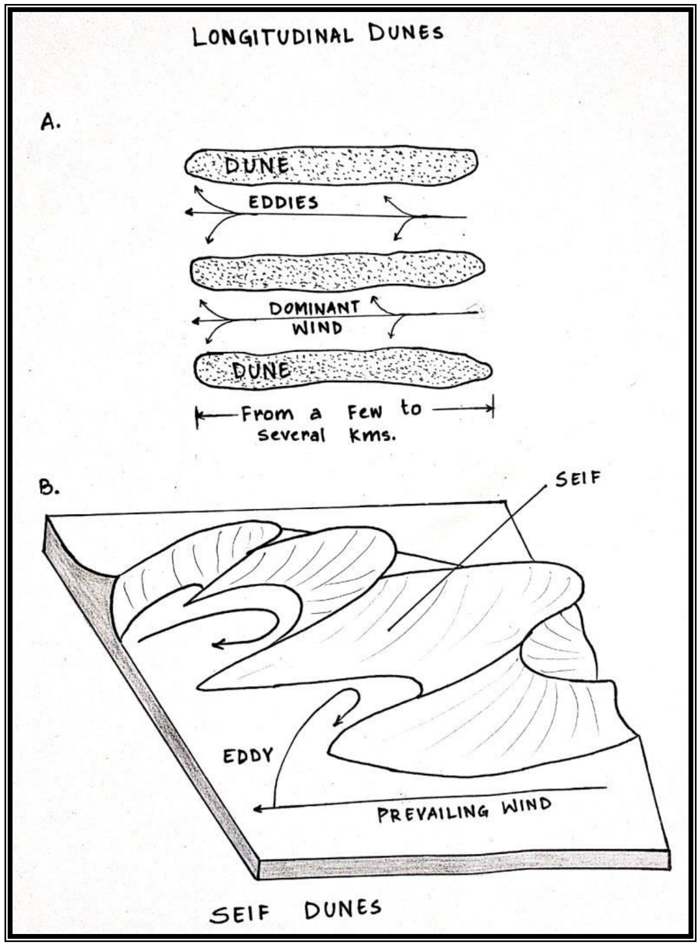

Figure 9.23: Longitudinal dunes or Seifs, Source Prepared by Author

e) **Linear –**

- Straight or slightly sinuous ones that are typically longer than they are wide
- maybe more than 160 kilometers long
- may occur as an isolated ridge.
- sometimes form sets of parallel ridges separated by kilometers of sand, gravel, or rocky inter-dune corridors.
- some may also merge to form Y-shaped compound dunes.

Concerning the mobility of dunes, they can be classified into three types –

a) inactive or stable dunes – fixed dunes rooted with vegetation

b) partly active dunes

c) fully active dunes – constantly on the move

Based on forms, there are three types –

a) Simple – these are basic dunes that have a minimum number of slip faces. Such dunes also suggest that the intensity or direction of the wind has not changed since its formation.

b) Compound – these are large dunes where both smaller dunes and slip faces are superimposed

c) Complex – these are a combination of two or more types of dunes. This type includes a great variety of pyramidal, peaked, ridged, pitted, branching, radiating, and intersecting assemblages. Example – crescent dune with a star dune on its crest.

There is always a change in the wind's direction or intensity in both compound and complex dunes.

Loess –

Loess is fine dust blown beyond the limits of the desert. It has the following characteristics-

- yellow in colour, a sedimentary deposit draped over the landscape
- windblown silt thus aeolian in nature
- friable that is easily crumbled
- unstratified calcareous silt thus very fertile
- with a modal grain size in the range of 0.02 – 0.5 mm (Mabbutt, 1977)
- most extensive deposits are found in north-west China in the Loess Plateau of the Hwang-Ho basin – the region is also known as Yellow Earth
- similar deposits are located in Germany, France, and Belgium and are locally called *Limon*
- in North America, it is termed *Adobe*

Sand Ripples –

- small-scale aeolian features
- regular, wave-like ridges

- are 1 to 30 centimeters high,
- few centimeters to some meters apart
- develop perpendicular to the wind direction
- shape changes very quickly.

Sand Ridges –

- long, undulating aeolian features parallel to the wind direction
- forms because of saltation.
- in the beginning, there are windward and slip-face activities, just like the dunes
- particles on the leeward side are protected from the wind's impact.
- large grains are pushed up along the windward slope to the crest; the crest receives grains faster than it loses them.
- depressions lose grains more quickly than they receive and therefore are hollow (Figure 9.24)

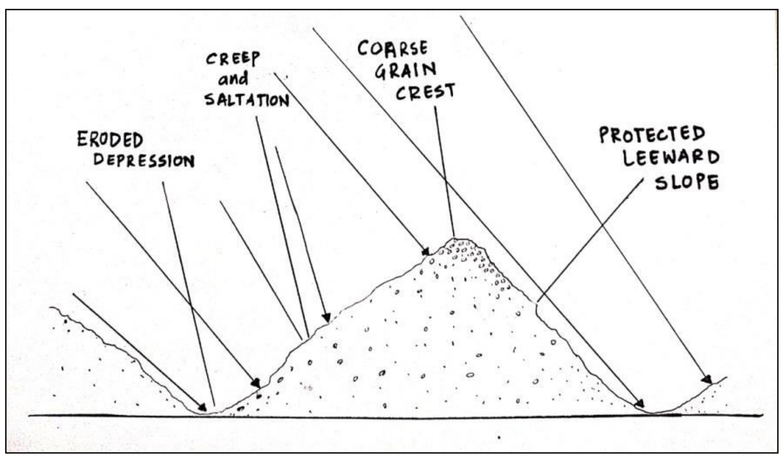

Figure 9.24: Sand Ridges, Source Prepared by Author

9.4.4 Landforms due to Water Action in deserts

In desert landscapes, rainfall is usually rare, but sometimes torrential rains occur. It is extremely erosive and therefore alters the entire landscape drastically. In this section, the landforms formed due to water action in deserts have been discussed.

Erosional Landforms –

Inselbergs**:** the word Inselberg is derived from a German word meaning 'Island Hill.' Bornhardt first coined the term. These are typical isolated steep-sided hills that are remnants of erosional processes that occurred in the arid region. They often tend to occur in groups and form a distinct inselberg landscape. Uluru (Ayers Rock) in Australia, Sptizkoppe in the Namib Desert are examples of Inselbergs (Figure 9.25).

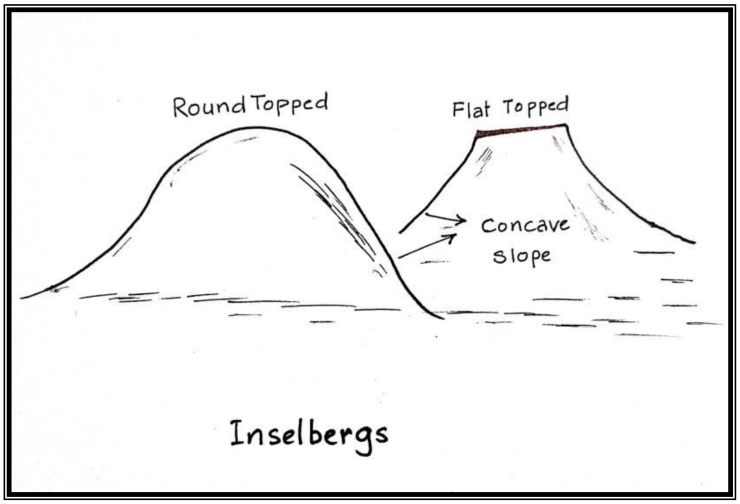

Figure 9.25: Inselbergs, Source Prepared by Author

Wadis**:** A *Wadi* is a fluvial valley in an arid region. The most spectacular feature of these valleys is that they are dry for most of the year and are only filled with water when torrential rains occur. Sometimes when they are repeatedly eroded by water, they develop deep ravines and gorges. In the Sahara, some of these valleys have enormous paleo drainage systems.

Depositional Landforms –

Pediments**:** These are gently sloping terrain found at the foot of the mountains over a solid rock base formed due to abrasion. They are the junction that occurs between the zone of a steep erosional slope and the depositional lowlands.

Alluvial fans**:** These are delta-like depositional features formed at the foot of the mountains. Alluvial fans are usually cone in shape that radiates away from the apex (Figures 9.26 and 9.27).

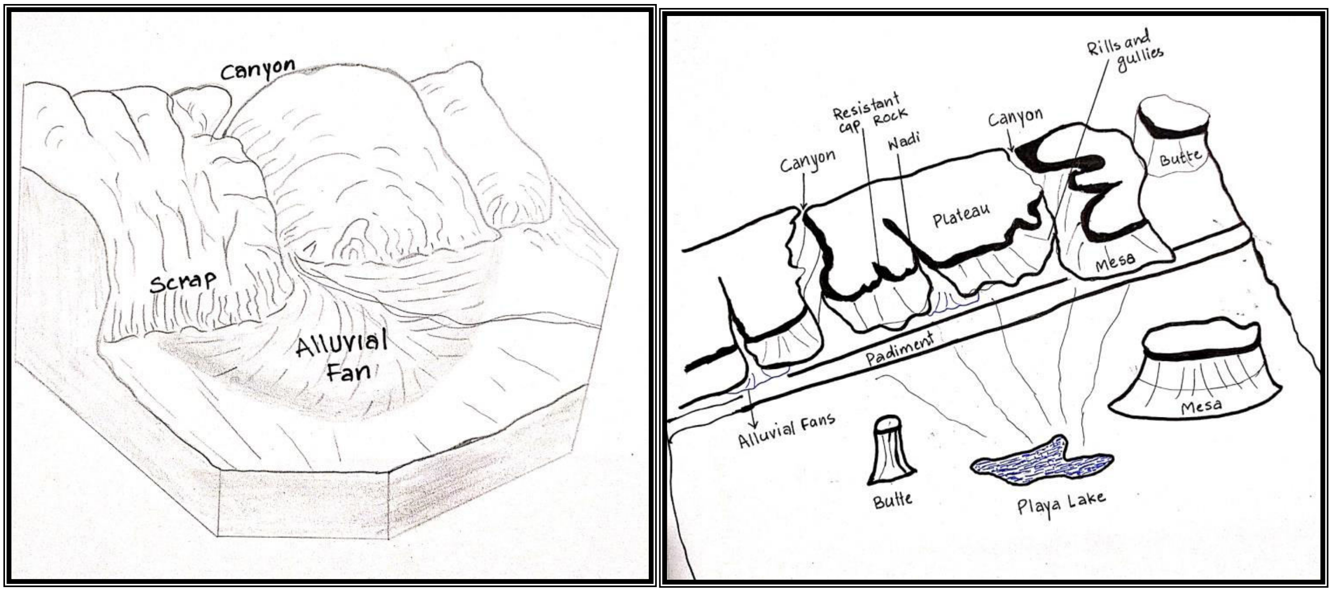

Figure 9.26: Alluvial fans, Source Prepared by Author

Bajadas**:** the term is derived from a Spanish word meaning 'slope.' It was first coined by Tolman (1909). When several *Wadis* that are parallel to each other converge at a mountain front nearby, resulting in the coalescence of alluvial fans, a *bajada* is formed. These landforms can be found on a pediment or foot of the mountains where the gradient is almost flat.

Sabkhas**:** The word comes from an Arabic word meaning 'salt-pan.' Locally, they are known as *Playas* (North America), *Chotts* (Africa), *Pans* (Australia). These are common in desert landscapes and have typical characteristics which can be summed as – i) shallow-inconsistent or temporary salt lakes, ii) found at the lowest points in the arid regions, iii) flat with dry lake beds, and iv) evaporation leads to the formation of these salt-pans (Figure 9.27).

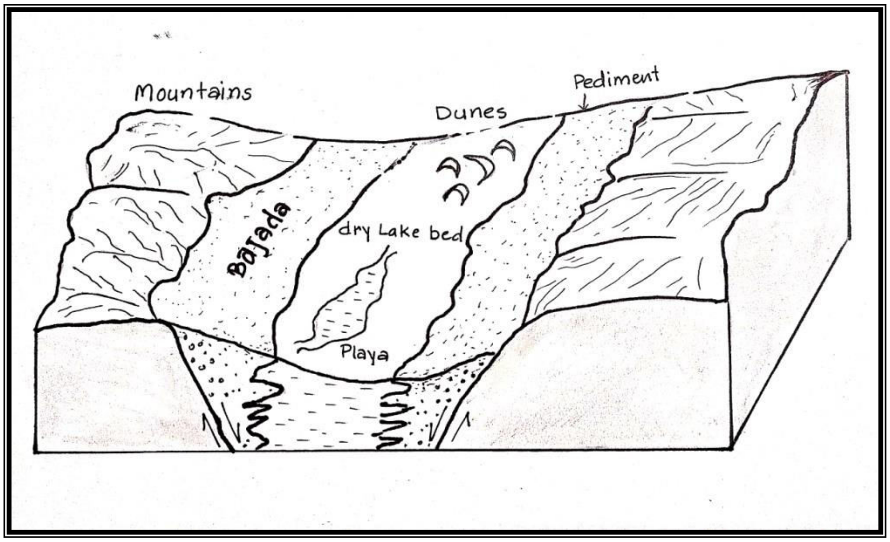

Figure 9.27: Sabkhas, Source Prepared by Author

Bolsons**:** the word is derived from a Spanish word that means 'purse.' The Bolsons are depressions with centripetal drainage systems with a center of a saline playa or a salt-pan. They are part of the semi-arid ridge and basin topography and contain alluvial fans, pediments, and Bajadas (Figure 9.28).

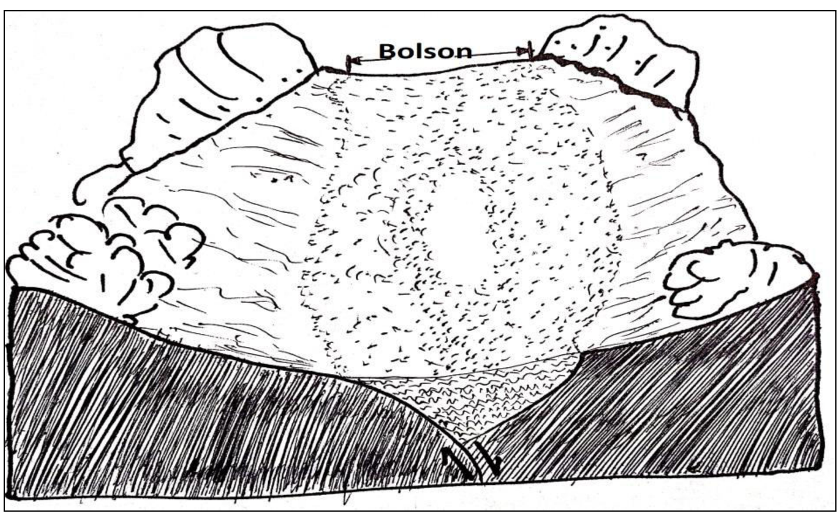

Figure 9.28: Bolson, Source Prepared by Author

9.4.5 Other Landforms

<u>Dune fields and Sand Sea –</u>

- collection of dunes is called dune fields (could be two dunes), and larger ones are called sand sea (from about 32 000 square km to up to 200,000 square km)
- occur mainly in basins or lowlands where sand sea nearly fills the basins
- sand seas, unlike dune fields, is composed of a variety of dunes
- have some non-aeolian features - the blockage of the pre-existing and marginal drainage by the dunes resulting in the formation of lakes; common in the Taklamakan in China and the Nebraska Sand sea

Sand Shadow –

- the material deposited when an obstacle checks the wind velocity
- accumulates in the shelter of or immediately behind the obstacle
- also called wake dune
- formation and morphology depend upon the morphology of the obstacle, shape of the pass, and wind regime
- the following conditions are necessary for the formation of sand shadow:
  - strong winds, sufficient sand, suitable obstacles, and a dry climate;
  - one or both sides of the obstacle have a hill pass, which allows the passage of wind and sand; and
  - the windward side of the obstacle has a wide, flat area, which provides adequate spacing for the wind flow and transport of sand material,
  - the leeward side also has a sufficiently broad, flat area to allow the release of the wind and blown sand (Figure 9.29)

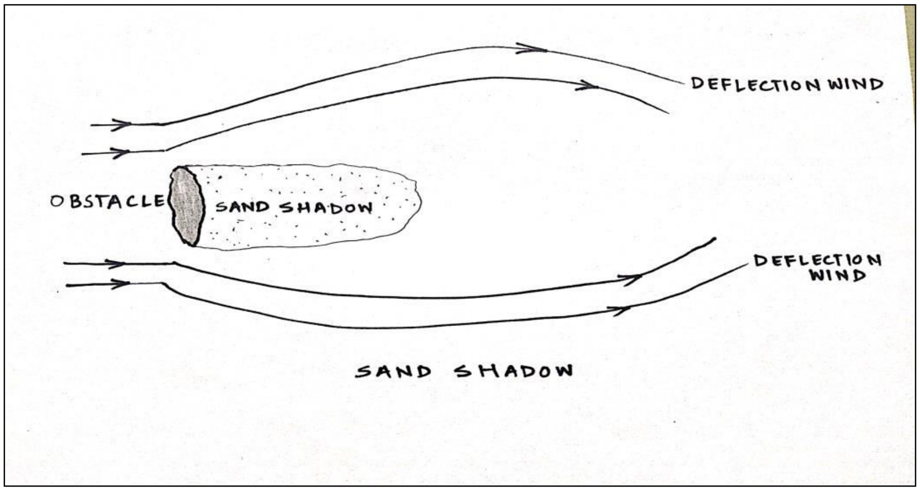

Figure 9.29: Sand Shadow, Source Prepared by Author

9.5 THE GEOGRAPHICAL CYCLE

The geographical cycle needs a special adaptation in an arid climate. In the following section, the geographical cycle in the arid environment has been discussed (Figure 9.30).

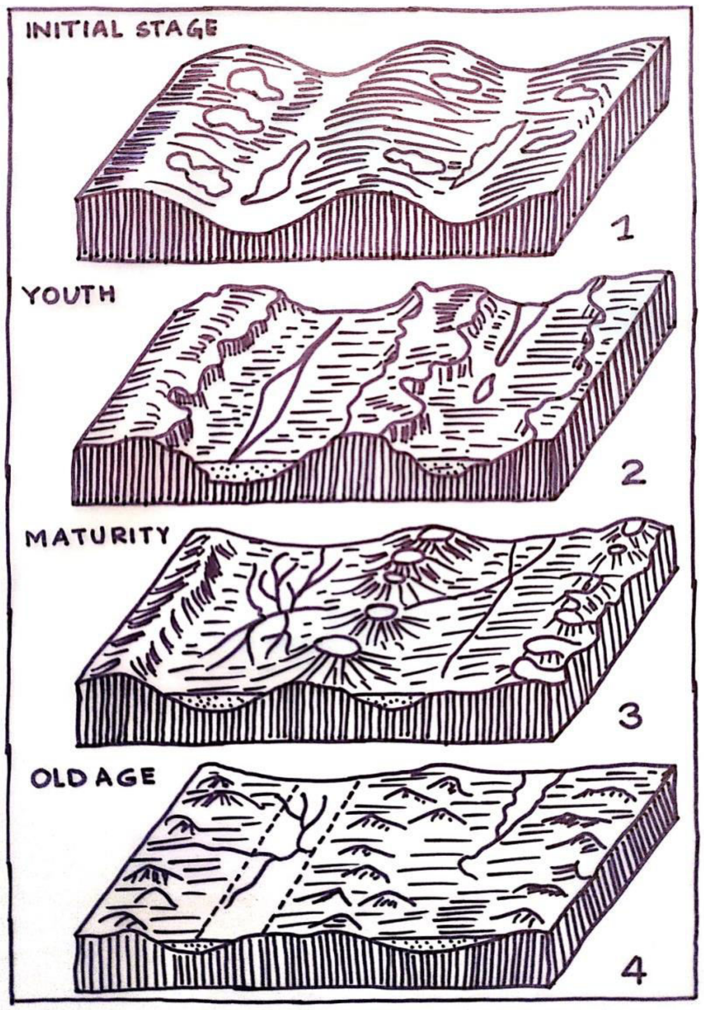

Figure 9.30: The Geographical Cycle, Source Prepared by Author

9.5.1 Initial Stage

- Presence of an uplifted region over a large extent where arid climate prevails
- Consequent drainage
- Presence of many separate streams
- Formation of Playas

9.5.2 Youthful Stage

- Erosion and deposition go hand in hand

- the relief is slowly diminished by the removal of waste from the highlands,
- deposition on the lower gentler slopes and the basin beds of all the separate centripetal drainage systems occurs
- local base-level rises
- Inter-montane basins may contain saline lakes
- Wind erosion is active, resulting in the formation of shallow depressions
- Subsequent streams do not develop
- Playa lake, some sand dunes are formed

9.5.3 Mature Stage

- Intermittent drainage is established
- three different kinds of surface are found –
  - dissected high-lands or mountains,
  - graded piedmont slopes of rock or waste, and
  - aggraded central plains with playas, salinas, or lakes
- Deflation is the most active
- maturity is reached when the drainage becomes integrated into a single aggraded basin-base-level. The slopes should lead from all parts of the surface to a single area where there is a deposition
- Bolsons and desert pavements form

9.5.4 The Old Age

- Deflation is the most active
- Windblown hollows are common
- the process of drainage disintegration begins to predominate
- plain is lowered, and rock masses that could resist weathering remain in the form of *Inselbergs*
- several pediments coalesce and form extensive pediplains.

9.6 SUMMARY

To start with, you have learned about the types of deserts and their distribution. In the second section, you came to know about erosion, transportation, and deposition mechanism in the arid landscape. Further, you have learned about the various landforms associated with this landscape. Different erosional and depositional landforms have been discussed in detail with special reference to dunes and their types. The entire landscape can be divided into four stages of erosion put forward by Davis and Passarge. According to them, there are four stages – initial, youthful, mature, and old. Each stage has its distinctive characteristics and landforms, which distinguish them from each other.

9.7 GLOSSARY

- ***Bajadas*** - the term is derived from a Spanish word meaning 'slope.' It was first coined by Tolman (1909). When several *Wadis* that are parallel to each other converge at a mountain front nearby, resulting in the coalescence of alluvial fans, a *bajada* is formed.
- ***Bolsons -*** the word is derived from a Spanish word that means 'purse.' These are depressions with centripetal drainage systems with a center of a saline playa or a salt-pan.
- **Deflation - The** process by which the wind removes fine materials from the desert surface. It leads to the formation of stone pavements as the coarse-grained sand and rocks are left behind.
- **Desert Pavements** – The pavements are also known as *regs* and usually resemble a cobbled street. These are flat stony surfaces formed of particles of varied sizes that have been blown and transported by the wind.
- ***Erg*** - Also known as *Sea of sand*, it represents an area of a large accumulation of sand. These are regions of active sand – dunes that symbolize the typical desert landscape. Here the sand is generally loose, making it difficult to traverse.
- ***Hamada*** - The word *Hamada* in Arabic means '*a rocky plane surface*'. In this type of desert, large stretches of rocks, usually bare ones, are present, which have been swept clear of dust and sand due to the action of wind – deflation.

- ***Reg*** - It is formed of extensive sheets of angular gravels and pebbles left by the wind as it could not blow these off. These types of deserts are typically formed by wind deflation. These stony deserts are more accessible and approachable as compared to the sandy deserts. They are also called *gibber plains*
- ***Sabkhas*** **-** The word comes from an Arabic word meaning 'salt-pan.' Locally, they are known as *Playas* (North America), *Chotts* (Africa), *Pans* (Australia). These are common in desert landscapes and have typical characteristics like shallow-inconsistent or temporary salt lakes, flat with dry lake beds, and salt-pans.
- **Ventifacts and Driekenters** – The term Ventifact was introduced by Evans (1911) to define and describe pebbles and stone faceted by the wind's sandblasting action. These also include the Dreikanters (a ventifact with three wind-faceted surfaces), which are in the shape of Brazil-nut.
- ***Wadis*** **-** A *Wadi* is a fluvial valley in an arid region. The most spectacular feature of these valleys is that they are dry for most of the year and are only filled with water when torrential rains occur.
- **Yardangs** – A Turkmen word coined by Hedin in 1903 to describe an erosional landform formed in an arid region. These are abraded ridges of cohesive materials, which range in size from few centimeters to some kilometers. The steep-sided yardangs form a landscape that is quite similar to the 'ridges and furrow.'
- **Zeugen** – Zeugen is tabular masses of resistant rocks that lie above the softer rocks. The word is derived from a German word meaning 'witness.' Mechanical weathering initiates their formation, further completed by aeolian abrasion. It is a result of differential erosion by sand-laden wind. These hard rocked ridges can range from 10 to 100 feet above the sunken furrow, representing the 'ridge and furrow' landscape.

9.8 ANSWER TO CHECK YOUR PROGRESS

1. The Sahara and its Margins; Southern Africa; The Great Indian Desert or Thar and Arabia and the Middle East (figure 9.6)

2. Arid erosion, Transportation by wind, Deposition by Wind
3. Yardangs –_A Turkmen word coined by Hedin in 1903 to describe an erosional landform formed in an arid region (Figure 9.15).
4. .Zeugen –_Zeugen is tabular masses of resistant rocks that lie above the softer rocks. It is a result of differential erosion by sand-laden wind. These hard rocked ridges can range from 10 to 100 feet above the sunken furrow, representing the 'ridge and furrow' landscape (Figure 9.16).
5. The most common typology of dunes is based on their shape, and on this basis, there are five types of dunes. These are Parabolic, Star, Barchan, Seifs, and Linear.
6. **6.** Four Stages – Initial, Youthful, Mature, and Old

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9.10 TERMINAL QUESTIONS

1. How do wind erosion and deposition contribute to the formation of specific arid landforms, such as sand dunes and yardangs?
2. What role do temperature variations and the availability of water play in shaping arid landscapes?
3. What are the primary geomorphic processes that shape arid landscapes, and how do these processes lead to the formation of characteristic landforms such as plateaus, mesas, and buttes?
4. How do desert pavement and desert varnish contribute to the development of arid landforms, and what are the underlying mechanisms behind their formation?
5. Explore the role of wind erosion in shaping arid landscapes, with a focus on the formation and types of sand dunes found in desert regions.

UNIT- 10 WATER PROCESSES AND LANDFORMS

10.1 OBJECTIVES

After reading this unit, you will be able to:

- Explain the importance of water as an agent of erosion, transportation, and deposition.
- Identify and describe the different types of water-related processes, such as weathering, mass wasting, and fluvial processes.
- Analyze the impact of water processes on the formation of various landforms, including valleys, canyons, deltas, and caves.
- Illustrate the influence of water in shaping coastal features like beaches, cliffs, and sea stacks.

10.2 INTRODUCTION

Water is a powerful force that shapes the Earth's surface in a variety of ways. From the erosion of rock and soil to the formation of new landforms through deposition, water processes are constantly at work shaping the landscape around us. In this introduction to water processes, we will explore the various ways in which water interacts with the Earth's surface, including erosion, weathering, transportation, and deposition.

Water processes and landforms refer to how water interacts with the Earth's surface and the resulting features that are created as a result. Water processes include erosion, weathering, transportation, and deposition, while landforms can range from small features such as potholes and dunes to large features such as valleys, canyons, and deltas.

Erosion is the process by which water wears away the surface of the Earth, carrying away soil and rock particles. This can occur in many forms, including sheet erosion, rill erosion, and gully erosion. Sheet erosion occurs when water flows over a large area and removes a thin layer of soil, while rill erosion occurs when small channels are formed in the soil by flowing water. Gully erosion occurs when larger channels are formed that can cut through the soil and into the bedrock. These erosional processes create a variety of landforms, including valleys, canyons, and gorges.

Weathering is another process by which water interacts with the Earth's surface. Weathering is the breakdown of rocks and other materials through physical, chemical, or biological means. Water can contribute to weathering through processes such as freeze-thaw weathering and chemical weathering. Freeze-thaw weathering occurs when water seeps into cracks in rocks and then freezes, causing the rock to expand and potentially break apart. Chemical weathering can occur when water reacts with certain types of rock, such as limestone or granite, to break them down over time. These weathering processes can create unique rock formations, such as arches, hoodoos, and spires.

Transportation is the process by which sediment and other materials are moved from one location to another by flowing water. This can occur in a variety of ways, including bed load, suspended load, and dissolved load. Bed load occurs when sediment is transported along the bottom of a river or stream, while suspended load occurs when sediment is carried in the water column. Dissolved load occurs when minerals and other materials are dissolved in the water and carried downstream. These transportation processes create landforms such as alluvial fans and floodplains.

10.3 CHANNEL MORPHOLOGY

Channel morphology refers to the shape, size, and structure of a river channel. The following is a detailed explanation of channel morphology:

1.3.1 Channel Shape: The channel shape of a river can vary depending on a variety of factors, including the type of rock and sediment in the river bed, the amount and velocity of water flowing through the channel, and the surrounding landscape. The following is a detailed explanation of channel shape in river morphology:

Straight Channels: Straight channels are typically found in areas with gentle slopes and low water velocities. They are characterized by a single, straight channel that does not meander or change course. Straight channels can occur in both natural and man-made environments, such as irrigation channels and canals.

Sinuous Channels: Sinuous channels are characterized by a meandering or winding pattern. These channels are common in areas with moderate water velocities and gentle to moderate slopes. The meandering pattern of sinuous channels is created by a combination of bank erosion and deposition, as well as changes in water velocity and direction.

Braided Channels: Braided channels are characterized by a complex network of channels that split and rejoin multiple times. These channels typically occur in areas with high water velocities and steep slopes, such as mountainous regions or areas with glacial meltwater. Braided channels are created by the rapid erosion and deposition of sediment, which causes the river to split into multiple channels.

Anabranching Channels: Anabranching channels are similar to braided channels in that they have multiple channels, but they are characterized by a slower water velocity and a more stable channel network. Anabranching channels occur in low-gradient areas, such as floodplains, and are created by a combination of lateral erosion and sediment deposition.

Bedrock Channels: Bedrock channels are characterized by a channel that is carved directly into the bedrock, with little to no sediment in the channel. These channels typically occur in areas with hard, resistant bedrock, and are created by the slow erosion of the rock by water over time.

10.3.2 Cross-Sectional Shape: The cross-sectional shape of a river can vary depending on a variety of factors, including the amount and velocity of water flowing through the channel, the type and size of sediment in the river bed, and the surrounding landscape. The following is a detailed explanation of cross-sectional shape in river morphology:

Narrow and Deep Channels: Narrow and deep channels are characterized by a deep channel with steep banks. These channels typically occur in areas with high water velocities and rocky or hard riverbeds. The narrow and deep shape of the channel allows for water to flow quickly and efficiently through the channel, reducing the risk of flooding and sediment deposition.

Wide and Shallow Channels: Wide and shallow channels are characterized by a shallow channel with gently sloping banks. These channels typically occur in areas with low water velocities and sandy or soft riverbeds. The wide and shallow shape of the channel allows for more sediment deposition, which can create a habitat for aquatic plants and animals.

Stepped Channels: Stepped channels are characterized by a series of shallow pools and rapids. These channels typically occur in areas with high water velocities and a steep slope. The stepped shape of the channel allows for water to flow in a controlled manner, reducing the risk of erosion and sediment deposition.

Concave-Upward Channels: Concave-upward channels are characterized by a U-shaped cross-section, with a wide channel bottom and gently sloping banks. These channels typically occur in areas with low to moderate water velocities and a mix of sediment types. The concave-upward shape of the channel allows for sediment deposition and habitat creation.

Flat Channels: Flat channels are characterized by a flat channel bottom and low banks. These channels typically occur in areas with low water velocities and fine sediment. The flat shape of the channel allows for sediment deposition, creating a habitat for aquatic plants and animals.

10.3.3 Bedrock and Sediment: Bedrock and sediment play important roles in determining the shape of the channel, the rate of erosion and deposition, and the types of habitats that are created in the river.

Bedrock: Bedrock is the solid rock that underlies the river bed and banks. The type of bedrock can influence the shape of the channel, the rate of erosion and deposition, and the types of habitats that are created in the river. Bedrock can be classified as either hard or soft, depending on its strength and resistance to erosion.

Hard bedrock, such as granite, basalt, or sandstone, is generally more resistant to erosion than soft bedrock, such as shale or limestone. As a result, rivers that flow over hard bedrock tend to have more narrow and steep channels, with less sediment deposition and a greater potential for erosion. In contrast, rivers that flow over soft bedrock tend to have wider and shallower channels, with more sediment deposition and a greater potential for habitat creation.

Sediment: Sediment refers to the particles of rock, sand, silt, and clay that are carried by the river and deposited in the channel. The type and size of sediment can influence the shape of the channel, the rate of erosion and deposition, and the types of habitats that are created in the river.

Coarse sediment, such as gravel or boulders, is generally more resistant to erosion than fine sediment, such as sand or silt. As a result, rivers that carry coarse sediment tend to have more narrow and steep channels, with less sediment deposition and a greater potential for erosion. In contrast, rivers that carry fine sediment tend to have wider and shallower channels, with more sediment deposition and a greater potential for habitat creation.

The characteristics of bedrock and sediment in river morphology are complex and can vary widely depending on the specific river system. For example, some rivers may have a mix of hard and soft bedrock or a mix of coarse and fine sediment. The characteristics of bedrock and sediment can also change over time due to natural processes such as erosion and deposition, or due to human activities such as dam construction or land use changes.

10.3.4 Bank Erosion and Deposition: Bank erosion and deposition are important components of river morphology. The banks of a river are constantly changing as the river flows and erodes sediment from one bank and deposits it on the other. This process is influenced by various factors, including the type of sediment, the velocity and volume of water, and the slope and composition of the banks. The following is a detailed explanation of bank erosion and deposition in river morphology:

Bank Erosion: Bank erosion occurs when the river water flows faster than the bank can withstand, resulting in the removal of sediment from the bank. This can happen due to various factors such as high water velocity, increased volume of water during floods, or weak and unstable banks. Bank erosion can result in the formation of steep and unstable slopes, undercutting of the bank, and loss of vegetation and wildlife habitat.

The rate of bank erosion depends on various factors, such as the slope and composition of the bank, the type and size of sediment, and the volume and velocity of the water. Erosion can be either gradual or sudden and can result in channel migration or channel widening. In some cases, bank erosion can lead to landslides and large-scale movement of soil and rock, causing damage to infrastructure and property.

Bank Deposition: Bank deposition occurs when sediment is deposited on the banks of the river. This can happen when the velocity of the river water decreases, allowing sediment to settle on the banks. Bank deposition can lead to the formation of stable banks, an increase in vegetation cover, and the creation of new wildlife habitats.

The rate of bank deposition depends on various factors such as the velocity and volume of water, the size and type of sediment, and the slope and composition of the banks. Deposition can be either gradual or sudden and can result in the formation of point bars or islands in the river.

The interaction between bank erosion and deposition is a natural process that shapes the morphology of the river channel over time. The balance between these two processes determines the shape, size, and stability of the river banks. Human activities such as land use changes and the construction of dams and levees can alter the balance between bank erosion and deposition and affect the morphology of the river channel.

Vegetation: The presence or absence of vegetation along the banks of a river can also influence channel morphology. Trees and other vegetation can stabilize banks, preventing erosion and creating a more sinuous channel shape. However, excessive vegetation can also impede the flow of water and create areas of stagnant water.

10.4 FORMS OF RIVER EROSION

River erosion occurs in several forms due to the impact of flowing water, and they are often classed depending on the type of erosion mechanism that is responsible for their development. Here are some of the most prevalent types of river erosion:

1.4.1 Hydraulic action erosion: This occurs when the force of the water flowing in a river wears away the bed and banks of the river. This can cause the river to widen or deepen over time, and can also lead to the formation of features such as river cliffs, caves, and waterfalls.

Hydraulic action erosion occurs when rushing water puts pressure on rocks and other objects in its path, causing them to break apart and be transported away by the current.The power of the water can dislodge the particles, which can then be taken downstream by the river. The kinetic energy of the water drives the hydraulic action erosion process, which rises as the flow speed increases.

The process of hydraulic action erosion can create a range of features in river landscapes, including waterfalls, rapids, and canyons. The force of the water can also create potholes and other erosional features in the bedrock of the river channel. Over time, the effects of hydraulic action erosion can reshape the river channel, altering its course and creating a variety of different habitats for aquatic species.

Hydraulic action erosion is one of the primary processes responsible for shaping river landscapes around the world, and it plays an important role in the movement of sediment and nutrients through river systems. Understanding the process of hydraulic action erosion can help scientists and environmental managers better predict and manage the impacts of natural and human-induced changes to river ecosystems.

10.4.2 Abrasion erosion: This occurs when sediment carried by the river scrapes against the bed and banks of the river, causing them to wear away over time. This process can create features such as potholes and grooves in the river bed, as well as smooth rock surfaces along the river banks.

Abrasion erosion is a type of erosion that occurs when rocks and sediment carried by a moving fluid, such as a river or wind, scrape against the surface of another rock or sediment, wearing it away. The process of abrasion erosion is driven by the kinetic energy of the fluid, which causes the particles carried by the fluid to collide with the surface being eroded.

Abrasion erosion can occur in a variety of environments, including in rivers, where the force of moving water can cause sediment and rocks to collide with the river bed and banks, gradually wearing them down over time. The process of abrasion erosion is particularly effective when the particles being carried by the fluid are hard and angular, as they can cause more damage to the surface they are colliding with.

In addition to rivers, abrasion erosion can also occur in coastal environments, where the force of waves can cause sediment and rocks to collide with the shore, gradually wearing it away. Abrasion erosion can also occur in deserts, where wind-blown sand can cause rocks to erode through a similar process of abrasion.

The effects of abrasion erosion can be seen in a range of features in natural landscapes, including canyons, gorges, and valleys, where the movement of water or wind has carved away at the surrounding rock over time. Understanding the process of abrasion erosion is important for scientists and environmental managers who are studying and managing natural landscapes, as it can help them predict and manage the impacts of erosion on ecosystems and human infrastructure.

10.4.3 Corrosion erosion: This occurs when the chemical composition of the rock or soil is altered by the water in the river. For example, if the water is acidic, it can dissolve certain minerals in the rock, causing it to weaken and break down over time. This process can create features such as underground caves and sinkholes.

Corrosion erosion, also known as chemical erosion, is a type of erosion that occurs when chemical reactions between rock or soil and a fluid, such as water or acid rain, gradually dissolve and wear away the material. Corrosion erosion can be caused by a range of factors, including the presence of minerals in the rock or soil that are susceptible to chemical reactions, as well as changes in the acidity or salinity of the fluid in contact with the material.

The process of corrosion erosion is particularly effective in environments where the fluid is highly acidic or alkaline, as these conditions can increase the rate of chemical reactions between the fluid and the material. In addition to natural processes, corrosion erosion can also be caused by human activities, such as the release of chemicals into waterways or the burning of fossil fuels, which can contribute to the formation of acid rain.

The effects of corrosion erosion can be seen in a range of landscapes, including caves and karst landscapes, where the dissolution of limestone and other soluble rock types has created a range of unique landforms, such as stalactites and sinkholes. Corrosion erosion can also be a major factor in the degradation of human infrastructure, such as bridges and pipelines, particularly in environments where the fluid in contact with the structure is highly corrosive.

Understanding the process of corrosion erosion is important for scientists and environmental managers who are studying and managing natural landscapes and human infrastructure, as it can help them predict and manage the impacts of erosion on ecosystems and infrastructure. Additionally, strategies for mitigating the impacts of corrosion erosion may include measures such as controlling the release of chemicals into waterways or using protective coatings on infrastructure exposed to corrosive fluids.

10.4.4 Attrition erosion: This occurs when sediment carried by the river collides with other particles, causing them to break down into smaller pieces. As the particles become smaller, they can be carried more easily by the river and contribute to the overall erosion process.

Attrition erosion is a type of erosion that occurs when particles carried by a fluid, such as a river or wind, collide with each other, causing them to break down into smaller and more rounded fragments over time. The process of attrition erosion is driven by the kinetic energy of the fluid, which causes the particles to collide with each other and wear down through repeated impacts.

Attrition erosion is particularly effective when the particles being carried by the fluid are hard and angular, as they are more likely to collide with each other and break down into smaller fragments. The process of attrition erosion can result in the creation of sediment with a range of different sizes and shapes, depending on the composition and properties of the particles being eroded.

The effects of attrition erosion can be seen in a range of natural landscapes, including riverbeds, where the movement of water and sediment causes particles to collide with each other and wear down over time. Attrition erosion can also occur in coastal environments, where the movement of waves can cause sediment to collide with each other and wear down into smaller fragments.

Understanding the process of attrition erosion is important for scientists and environmental managers who are studying and managing natural landscapes, as it can help them predict and manage the impacts of erosion on ecosystems and human infrastructure. Additionally, strategies for mitigating the impacts of erosion may include measures such as the use of erosion-resistant materials or the construction of barriers to protect vulnerable areas.

These different forms of river erosion can have a significant impact on the landscape and can create a variety of unique and interesting features over time. However, they can also pose a threat to nearby infrastructure and communities, which is why it is important to understand and manage the impacts of river erosion.

10.4.5 Base level

In Geomorphology, the term "river base level" refers to the lowest elevation point to which a river can erode its bed. There are two types of base levels: ultimate base level and local base level.

The ultimate base level is the lowest point that a river can erode its bed to, and it is typically the level of the sea or an inland lake. Once a river reaches its ultimate base level, it can no longer erode its bed any further. This means that the river's gradient will decrease, and its speed will slow down, causing sediment to be deposited on the riverbed.

Local base level, on the other hand, is a temporary or local constraint on a river's ability to erode. This can be caused by geological structures, such as dams, waterfalls, or resistant rock formations. When a river encounters a local base level, it will erode its bed upstream until it reaches the base level, and then deposit sediment downstream. Over time, the river will adjust its channel shape and gradient to accommodate the local base level.

The concept of base level is important because it influences how a river erodes and shapes the landscape. A river's gradient, or slope, is determined by the difference in elevation between its source and its base level. If the base level is low, the river will have a steep gradient and will erode its bed quickly, creating a deep V-shaped valley. If the base level is high, the river will have a shallow gradient and will erode its bed more slowly, creating a wider, U-shaped valley.

In addition to influencing erosion, the base level also plays a role in sediment transport and deposition. When a river encounters a local base level, sediment will be deposited downstream, creating features such as alluvial fans or deltas. When a river reaches its ultimate base level, sediment will be deposited on the riverbed, creating features such as floodplains or terraces.

10.4.6 General or ultimate or permanent base level

The ultimate base level is the lowest point to which a river can erode its bed, and it is typically the level of the sea or an inland lake that is stable and unlikely to change in elevation. Once a river reaches its ultimate base level, it can no longer erode its bed any further, and its gradient flattens out. This causes sediment to be deposited on the riverbed, creating features such as floodplains or terraces.

10.4.7 The ultimate base level includes the following:

The ocean: The ultimate base level for many rivers is the ocean. Rivers that flow into the ocean will eventually reach sea level, which is the lowest possible elevation on Earth. The Nile River in Egypt, for example, flows into the Mediterranean Sea, which serves as its ultimate base level.

Inland lakes: Inland lakes can also serve as ultimate base levels for rivers. The Great Lakes in North America, for example, serve as the ultimate base level for many rivers in the region. As the rivers flow into the lakes, they deposit sediment and create features such as deltas.

Closed basins: In some cases, rivers may flow into closed basins that have no outlet to the sea. These closed basins can also serve as ultimate base levels for the rivers that flow into them. The Great Salt Lake in Utah, for example, is a closed basin that serves as the ultimate base level for several rivers in the region.

Understanding the ultimate base level is important for understanding how rivers erode and shape the landscape over time. By identifying the ultimate base level for a river, geologists and geomorphologists can make predictions about how the river will behave and how it will shape the landscape in the future.

10.4.8 Temporary base level

A temporary base level is a local constraint on a river's ability to erode that is caused by geological structures such as dams, waterfalls, or resistant rock formations. When a river encounters a temporary base level, it will erode its bed upstream until it reaches the base level, and then deposit sediment downstream. Over time, the river will adjust its channel shape and gradient to accommodate the temporary base level.

10.4.9 The temporary base level includes the following:

Dams: Dams can serve as temporary base levels for rivers that flow into them. As water accumulates behind a dam, the river that feeds it may encounter a temporary base level, causing sediment to be deposited upstream and creating a lake or reservoir. As water is released from the dam, the river will adjust its channel shape and gradient to accommodate the new base level.

Waterfalls: Waterfalls can also serve as temporary base levels for rivers. As water cascades over a waterfall, it erodes the rock below, creating a step in the river's profile. Upstream of the waterfall, the river may encounter a temporary base level, causing sediment to be deposited and creating a pool or plunge pool. Downstream of the waterfall, the river will continue to erode its bed until it reaches the new base level.

Resistant rock formations: Resistant rock formations can also serve as temporary base levels for rivers. When a river encounters a layer of resistant rock, it may erode its bed more slowly, causing sediment to be deposited upstream. Downstream of the resistant rock, the river will continue to erode its bed until it reaches the new base level.

10.4.10 Local Base Level

Local base level refers to a temporary or permanent constraint on a river's ability to erode that is specific to a particular segment of the river. Local base levels can be caused by geological structures, such as dams, waterfalls, or resistant rock formations, or by anthropogenic factors, such as bridges or culverts. Understanding the local base level is important for understanding how rivers shape their surrounding landscapes and how human activities can impact river processes.

10.4.11 Examples of local base level include the following:

Culverts and bridges: Culverts and bridges can serve as local base levels for rivers, particularly in urban areas where the natural channel has been altered by human development. As water flows through a culvert or under a bridge, it encounters a local base level, causing sediment to be deposited upstream and altering the flow of the river. Downstream of the culvert or bridge, the river will continue to erode its bed until it reaches the new base level.

Waterfalls and rapids: Waterfalls and rapids can also serve as local base levels for rivers. As water flows over a waterfall or through a rapid, it erodes the rock below, creating a step in the river's profile. Upstream of the waterfall or rapid, the river may encounter a local base level, causing sediment to be deposited and altering the flow of the river. Downstream of the waterfall or rapid, the river will continue to erode its bed until it reaches the new base level.

Faults and folds: Faults and folds in the rock can also serve as local base levels for rivers. As a river flows through a region with faulted or folded rock, it may encounter segments of the riverbed that are elevated or depressed relative to the surrounding area. These local variations in elevation can act as temporary base levels, causing sediment to be deposited upstream and altering the flow of the river.

10.4.12 River Transportation Work

River transportation work refers to the movement of sediment by the flow of water in a river. This process involves the erosion, transport, and deposition of sediment, and plays an important role in shaping the morphology of rivers and their surrounding landscapes.

The transportation of sediment by rivers is driven by a combination of factors, including the flow velocity of the water, the size and characteristics of the sediment particles, and the gradient and roughness of the riverbed. As water flows over the riverbed, it exerts a force on the sediment particles, which can cause them to become dislodged and transported downstream. Over time, this process can lead to the formation of features such as river channels, bars, and floodplains.

The transportation of sediment by rivers has important environmental and economic implications. For example, it can affect water quality by introducing sediment and other pollutants into the river system and can impact the stability and safety of river infrastructure such as bridges and dams. In addition, river transportation work can play a key role in the formation and maintenance of aquatic habitats and can have significant impacts on the movement of nutrients and organic matter within river ecosystems.

Researchers have developed several models and theories to describe and quantify the process of river transportation work, including the Stream-Power Law (also known as Gilbert's Sixth Power Law), which relates the rate of energy expenditure by a river to the rate of erosion and sediment transport. These models are used by scientists and engineers to better understand

and predict the behaviour of rivers and to design and manage infrastructure projects such as river restoration and flood control measures.

River Transportation Work by traction: River transportation work by traction refers to the movement of sediment along the bed of a river as a result of the force of flowing water. This process involves sediment particles rolling, sliding, or bouncing along the riverbed and is most commonly observed in the lower reaches of a river. The amount of sediment transported by traction depends on factors such as flow velocity, sediment size and shape, and riverbed roughness. Sediment transport by traction has important environmental and economic implications, including impacts on water quality, aquatic habitats, and infrastructure. Researchers use models and theories to understand and predict the behaviour of sediment transport by traction in rivers and to design and manage infrastructure projects such as river restoration and flood control measures.

10.4.13 River Transportation Work by Saltation: River transportation work by saltation refers to the movement of sediment in a river by bouncing along the riverbed. This process occurs when sediment particles are lifted from the riverbed by the force of flowing water and then fall back down, causing other particles to be lifted and carried along in a chain reaction. Saltation is most commonly observed in rivers with moderate flow velocities and is an important process in the transport of sand-sized sediment. The amount of sediment that can be transported by saltation depends on factors such as flow velocity, sediment size and shape, and riverbed roughness. Sediment transport by saltation has important environmental and economic implications, including impacts on water quality, aquatic habitats, and infrastructure. Researchers use models and theories to understand and predict the behaviour of sediment transport by saltation in rivers and to design and manage infrastructure projects such as river restoration and flood control measures.

10.4.14 River Transportation Work by Suspension: River transportation work by suspension refers to the movement of sediment in a river by being carried along in the water column. This process occurs when the force of flowing water is strong enough to suspend sediment particles in the water, allowing them to be transported downstream. Suspension is most commonly observed in rivers with high flow velocities and fine sediment particles such as silt and clay. The amount of sediment that can be transported by suspension depends on factors such as flow velocity, sediment size and shape, and water turbulence. Sediment transport by suspension has important environmental and economic implications, including impacts on water quality, aquatic habitats, and infrastructure. Researchers use models and theories to understand and predict the behaviour of sediment transport by suspension in rivers and to design and manage infrastructure projects such as river restoration and flood control measures.

10.4.15 River Transportation Work by Solution: River transportation work by solution refers to the movement of sediment in a river by being dissolved in the water. This process occurs when water with dissolved minerals, such as calcium or carbon dioxide, comes into contact with rocks or sediment containing minerals that can dissolve. The dissolved minerals are then carried downstream in the water column. This process is most commonly observed in limestone or other carbonate-rich rivers. The amount of sediment that can be transported by solution depends on factors such as the water chemistry, the mineral content of the sediment, and the river flow rate. Sediment transport by solution has important environmental and economic implications, including impacts on water quality and soil fertility. Researchers use models and theories to understand and predict the behaviour of sediment transport by solution in rivers and to design and manage infrastructure projects such as river restoration and flood control measures.

10.4.16 Gilbert's Sixth Power Law

Gilbert's Sixth Power Law, often known as the Stream-Power Law, is a key idea in river geomorphology that outlines the link between a river's rate of erosion and its rate of energy consumption. Grove Karl Gilbert, a pioneering American geologist who suggested it in 1877, is the name given to this law.

According to Gilbert's Sixth Power Law, the rate of energy expenditure by a river is proportional to the sixth power of its flow velocity ($E \propto V^6$). This means that small changes in flow velocity can have a large impact on the rate of energy expenditure and erosion in a river.

The Stream-Power Law has important implications for understanding the behaviour of rivers and their impact on the surrounding landscape. For example, it helps to explain why erosion is often concentrated in areas of high flow velocity, such as the outside bend of a meandering river or the base of a waterfall. It also highlights the importance of factors that influence flow velocity, such as channel gradient, discharge, and sediment load.

The Stream-Power Law can be expressed mathematically as:

$E = KQ^m S^n$

Where E is the rate of energy expenditure, Q is the discharge, S is the channel gradient, and K, m, and n are constants that vary depending on the specific characteristics of the river and its surrounding landscape.

The constant K is known as the erodibility coefficient and reflects the ease with which sediment can be eroded from the riverbed and banks. The exponent m reflects the degree to which discharge influences erosion, while the exponent n reflects the degree to which channel gradient influences erosion.

The Stream-Power Law has been the subject of extensive research and testing over the past century and has been shown to hold across a wide range of river systems and environmental conditions. However, some studies have suggested that the relationship between energy expenditure and erosion may be more complex than Gilbert's original formulation suggests, and may vary depending on the specific characteristics of the river and its surrounding landscape.

10.5 RIVER TOPOGRAPHY

River topography refers to the physical features of a river and its surrounding landscape. These features can vary depending on the type of river, its age, the climate, and the geology of the area.

10.5.1 Development of River Valley:

Valleys are common landforms created by the erosive power of rivers and glaciers. The development of valleys can take millions of years and can be influenced by a variety of factors, including tectonic activity, climate, and topography. Here are some examples of valley development and i10ts causes:

V-shaped valleys: These are the most common type of valley, and are created by the erosive power of rivers. Over time, rivers can erode the surrounding rock and soil, creating a steep-sided channel with a flat bottom. V-shaped valleys are often characterized by waterfalls, rapids, and meandering channels. Examples of v-shaped valleys include Yosemite Valley in California, USA, and the Valleys of the Seven Castles in Bulgaria.

fig. 10.1 V-shaped valleys, Source Google Image

Examples of V-shaped valleys can be found all over the world. One famous example is the Grand Canyon in the United States. The Grand Canyon is a massive V-shaped valley that was carved by the Colorado River over millions of years. Another example is the Rhine Gorge in Europe. The Rhine River has carved a deep V-shaped valley through the mountains of Germany and Switzerland, creating a dramatic landscape.

V-shaped valleys are important because they provide a window into the geological history of an area. By studying the rocks and sediments in the sides and bottom of a V-shaped valley, geologists can learn about the processes that formed the valley and the history of the landscape.

Gorge: A gorge is a narrow, deep valley with steep sides that is typically formed by the erosion of rock by a river or stream. The process of gorge formation involves the gradual erosion of the rock and soil in an area by a river or stream, which causes the sides of the valley to become steeper and the channel to become deeper over time. Gorges can also be formed by tectonic activity, glacial movement, or lava flows. Gorges are important geological features that provide insight into the history of the landscape and the processes that shaped it. Some examples of famous gorges include the Grand Canyon in the United States and the Samaria Gorge in Greece.

Fig. 10.2 Gorge, Source Google Image

India has several beautiful gorges that have been formed by the erosion of rock by rivers or streams over millions of years. Here are some examples:

Gandikota Gorge: Located in Andhra Pradesh, Gandikota Gorge is also known as the Grand Canyon of India. It has been formed by the Penna River and is known for its scenic beauty.

Patalpani Gorge: Situated near Indore in Madhya Pradesh, Patalpani Gorge has been formed by the Choral River. It is a popular destination for trekking and rock climbing.

Kolli Hills Gorge: Located in Tamil Nadu, Kolli Hills Gorge has been formed by the Aiyaru River. It is known for its beautiful waterfalls and is a popular destination for hiking and trekking.

Khasi Hills Gorge: Situated in Meghalaya, the Khasi Hills Gorge has been formed by the Umiam River. It is known for its breathtaking views and is a popular tourist destination.

Chambal Gorge: Located in Madhya Pradesh and Rajasthan, the Chambal Gorge has been formed by the Chambal River. It is home to a variety of wildlife and is a popular destination for river rafting and boating.

Canyon: A canyon is a deep, narrow valley with steep sides that is typically formed by the erosion of rock by a river or stream. The formation of a canyon begins with the gradual erosion of the surface of the earth by water, wind, or ice. Over time, a river or stream may begin to cut a path through the eroded rock, gradually deepening and widening the valley. As the river or stream continues to erode the rock, the sides of the valley become steeper, and the channel becomes deeper.

Fig. 10.3 Canyon, Source Google Image

Canyons can also be formed by tectonic activity, such as the uplift of mountains, or by volcanic activity, such as the formation of lava flows. Some of the most famous canyons in the world include the Grand Canyon in the United States, the Fish River Canyon in Namibia, and the Copper Canyon in Mexico.

Canyons are important geological features that provide insight into the history of the earth and the processes that have shaped it. They also provide habitats for a wide variety of plants and animals, making them important ecosystems. Canyons are also popular tourist destinations, attracting visitors from around the world who come to admire their beauty and explore their natural wonders.

There are several examples of canyons in India, but they are not as well-known or as large as some of the famous canyons in other parts of the world. Here are a few examples:

Gandikota Canyon: Also known as the Grand Canyon of India, this canyon is located in the state of Andhra Pradesh and has been formed by the Penna River.

Barabar Canyon: Located in the state of Bihar, this canyon has been formed by the Barabar River.

Bhor Ghat Canyon: Located in Maharashtra, this canyon has been formed by the Ulhas River.

Talakaveri Canyon: Located in the Western Ghats, this canyon has been formed by the Kaveri River.

Rapids: Rapids are sections of a river where the water flows rapidly and becomes turbulent due to the presence of rocks, boulders, or other obstacles. These obstacles create a disturbance in the water flow, causing it to move faster and with more force, which leads to the formation of rapids.

The formation of rapids is a natural process that occurs in rivers and streams all over the world. The speed and intensity of the rapids depend on the volume of water, the slope of the river bed, and the nature of the obstacles in the river. Rapids are commonly found in mountainous regions, where rivers flow down steep slopes and encounter numerous obstacles in their path.

One example of rapids formation in India is the Rishikesh rapids, located on the river Ganges in the state of Uttarakhand. These rapids are formed as the river flows through the narrow channels between the mountains, creating a series of swift and turbulent water flows.

Another example is the Teesta river rapids, located in the state of Sikkim in northeast India. The Teesta river flows down the steep slopes of the Himalayas, creating a series of rapids and waterfalls along its course.

In other parts of the world, notable examples of rapids include the Colorado River rapids in the Grand Canyon, USA, and the Victoria Falls rapids on the Zambezi River in Africa.

Waterfalls: Waterfalls are formed when a river or stream flows over a cliff or a steep slope, causing the water to fall freely and create a spectacular display of cascading water. The formation of waterfalls is a natural process that occurs over millions of years as a result of erosion and the movement of the earth's crust.

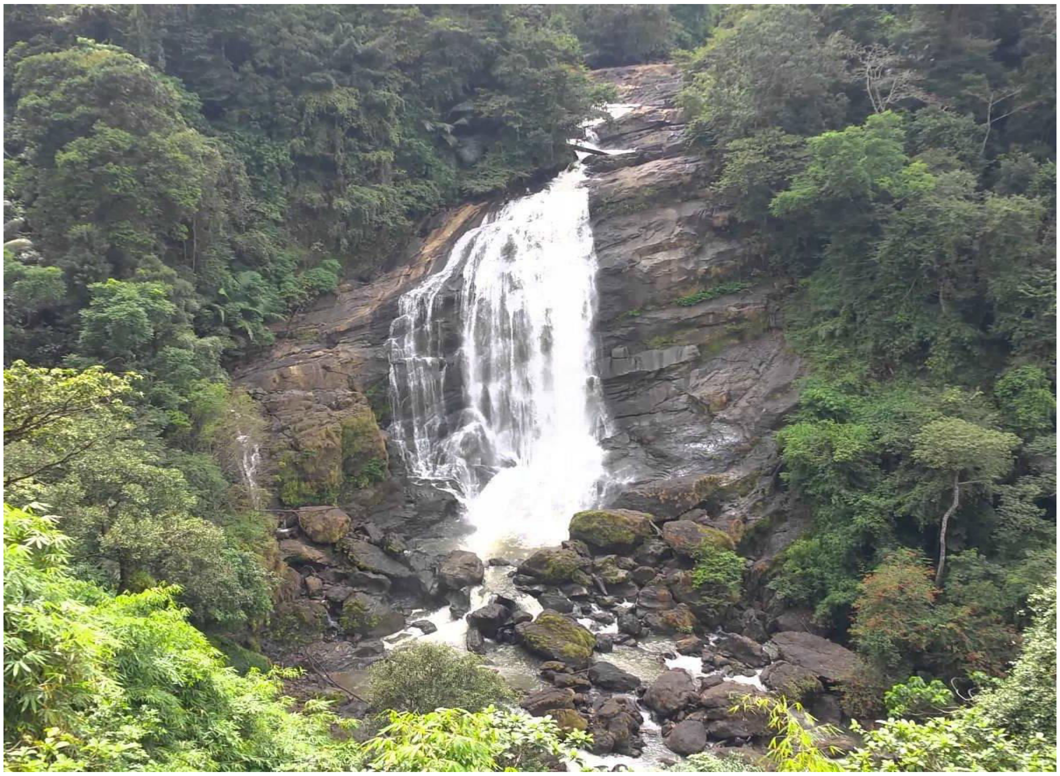

Fig. 10.4 Waterfall, Source Google Image

The basic process of waterfall formation involves the gradual erosion of rock and soil by the flowing water of a river or stream. Over time, the water erodes the softer rocks, leaving behind harder rocks and creating a cliff or a steep slope. As the water flows over the cliff or steep slope, it falls freely and creates a waterfall.

The speed and volume of the water flowing over a waterfall depend on several factors, including the height of the waterfall, the volume of water in the river, and the shape and angle of the rock face over which the water falls.

One of the most famous waterfalls in the world is Niagara Falls, located on the Niagara River on the border of the United States and Canada. Niagara Falls is formed by the erosion of soft rocks such as shale and sandstone, which have been worn away by the water flowing over the falls for millions of years.

In India, some of the most famous waterfalls are:

Jog Falls - located in the state of Karnataka, Jog Falls is one of the highest waterfalls in India, with a height of 830 feet. The waterfall is formed by the Sharavathi River, which flows over a cliff and creates a spectacular display of cascading water.

Dudhsagar Falls - located in the state of Goa, Dudhsagar Falls is a four-tiered waterfall that is formed by the Mandovi River. The waterfall gets its name from the milky white foam that is created by the water falling from a height of over 1000 feet.

Athirappilly Falls - located in the state of Kerala, Athirappilly Falls is a popular tourist destination that is formed by the Chalakudy River. The waterfall is surrounded by lush green forests and is famous for its scenic beauty and the variety of flora and fauna found in the area.

Other famous waterfalls in the world include Victoria Falls on the Zambezi River in Africa, Iguazu Falls on the border of Brazil and Argentina, and Angel Falls in Venezuela.

10.5.2 Types of Waterfalls:

Ladder Waterfalls: Ladder waterfalls, also known as staircase waterfalls, are a type of waterfall that is characterized by a series of small drops that are arranged in descending order, resembling a ladder or a staircase. The water cascades down the steps or levels, creating a beautiful display of falling water.

Ladder waterfalls occur in the same manner as other types of waterfalls do, through erosion. Water progressively wears away the softer materials as it passes over rocks and dirt, forming a sequence of steps or levels. The tougher rocks and dirt are left behind and constitute the foundation of each stage.

Over time, the water continues to erode the softer materials, causing the steps to become more defined and deeper. As the water cascades down each step, it creates a beautiful display of falling water.

Ladder waterfalls can be found in various parts of the world, including the United States, Canada, Europe, and Asia. One example of a ladder waterfall is the Bridal Veil Falls in Yosemite National Park, California, USA. The falls have a series of steps that create a beautiful staircase effect as the water cascades down. Another example is the Gavarnie Falls in France, which is also known for its staircase-like appearance.

In India, one example of a ladder waterfall is the Hundru Falls, located in the state of Jharkhand. The falls are formed by the Subarnarekha River, which cascades down a series of steps, creating a beautiful display of falling water.

Ladder waterfalls are a unique and beautiful natural wonder that provides a breathtaking sight for visitors. The steps or levels create a fascinating pattern that adds to the beauty of the waterfall, making it a popular tourist attraction in many parts of the world.

Barrier waterfalls: Barrier waterfalls, also known as block waterfalls, are a type of waterfall that is formed by the accumulation of hard rock, which acts as a barrier to the flow of water. As the water flows over the barrier, it drops down a steep slope, creating a spectacular display of falling water.

Ladder waterfalls occur similarly to other forms of waterfalls through the process of erosion. Water progressively wears away the softer materials as it rushes over rocks and dirt, forming a sequence of steps or levels. The harder rocks and dirt are left behind, providing the foundation of each stage.

As the water continues to flow, it will gradually carve out a path around the barrier, cutting into the softer rock on either side. This creates a channel for the water to flow through, while the hard rock barrier remains in place. Over time, the water will wear away at the barrier, causing it to become thinner and eventually creating a drop or waterfall.

One famous example of a barrier waterfall is Niagara Falls, located on the border of Canada and the United States. The falls are formed by a layer of hard limestone that has eroded more slowly than the surrounding rock, creating a natural barrier that the water flows over. The drop at Niagara Falls is around 50 meters high and is one of the most popular tourist attractions in the world.

In India, one example of a barrier waterfall is the Jog Falls, located in the state of Karnataka. The falls are formed by a layer of hard rock known as the Deccan Traps, which is over 1,000 meters thick in some areas. The water cascades down a series of steps, creating a beautiful display of falling water that attracts thousands of visitors each year.

Barrier waterfalls are a unique and fascinating natural wonder, created by the powerful forces of nature over thousands of years. They provide a stunning display of falling water and are a popular tourist attraction in many parts of the world.

Plateau Waterfall: Plateau waterfalls, also known as cataracts, are a type of waterfall that is formed on the edge of a plateau or a flat-topped landform. As the water flows over the edge of the plateau, it drops down a steep slope, creating a spectacular display of falling water.

The formation of plateau waterfalls begins with the geological process of erosion. Over time, the force of water flowing over a flat-topped landform can cause the rock to erode and break down. As the water continues to flow over the edge of the plateau, it cuts into the softer rock below, creating a steep slope that the water can cascade down.

Plateau waterfalls can vary in size and shape depending on the size and shape of the plateau. Some plateau waterfalls can be hundreds of meters high, while others can be relatively small. The size and shape of the waterfall can also be influenced by the amount of water flowing over the plateau, with larger volumes of water creating more dramatic waterfalls.

One famous example of a plateau waterfall is Victoria Falls, located on the border of Zambia and Zimbabwe in Africa. The falls are formed on the Zambezi River, which flows over a flat-topped plateau before dropping down a steep slope to create a spectacular waterfall over 100 meters high. Victoria Falls is one of the largest waterfalls in the world and is a popular tourist attraction.

In India, one example of a plateau waterfall is the Chitrakoot Falls, located in the state of Chhattisgarh. The falls are formed on the Indravati River, which flows over a flat-topped plateau before dropping down a series of steps to create a beautiful waterfall that is over 30 meters high.

Plateau waterfalls are a unique and impressive natural wonder, created by the powerful forces of nature over thousands of years. They provide a stunning display of falling water and are a popular tourist attraction in many parts of the world.

Fault Falls: A fault waterfall, also known as a fault scarp waterfall, is a type of waterfall that is formed along a fault line. Fault lines are areas where the Earth's crust has been fractured and shifted, often due to tectonic activity. As water flows along the fault line, it may encounter an area where the land has been uplifted or dropped down, creating a steep drop or cliff that the water can flow over.

The formation of fault waterfalls begins with the geological process of tectonic activity. When the Earth's crust is subject to forces that cause it to shift or break, it can create a fault line. As water flows along the fault line, it can encounter an area where the land has been uplifted or dropped down, creating a steep slope or cliff.

When the water encounters a steep slope or cliff, it may begin to flow over the edge, creating a waterfall. Over time, the waterfall may erode the rock beneath it, causing the waterfall to retreat upstream. This can create a canyon or gorge as the water continues to erode the rock.

One famous example of a fault waterfall is the Yosemite Falls, located in Yosemite National Park in California, USA. The falls are formed on the Merced River, which flows over a series of cliffs that were created by tectonic activity along a fault line. Yosemite Falls is one of the tallest waterfalls in North America, with a total drop of over 700 meters.

In India, one example of a fault waterfall is the Kunchikal Falls, located in the state of Karnataka. The falls are formed on the Varahi River, which flows over a series of steep cliffs that were created by tectonic activity along a fault line. Kunchikal Falls is one of the tallest waterfalls in India, with a total drop of over 450 meters.

Fault waterfalls are a unique and fascinating natural wonder, created by the powerful forces of tectonic activity and erosion. They provide a stunning display of falling water and are a popular tourist attraction in many parts of the world.

Step Falls: Step falls, also known as cascades or tiered waterfalls, are a type of waterfall that is formed by a series of drops or steps. The water flows down a series of inclined rock formations, creating a cascade of water that can be quite dramatic.

The formation of step falls begins with the geological process of erosion. As water flows over the surface of the land, it can erode the rock and soil, creating channels and pathways. Over time, these channels can deepen, creating a steep slope or cascade.

Step falls can vary in size and shape depending on the topography of the land. Some step falls can be relatively small, with only a few drops or steps, while others can be quite large, with dozens of drops or steps.

One famous example of step falls is the Huangguoshu Waterfall, located in Guizhou Province, China. The waterfall is formed by a series of steps, with a total height of over 77 meters. Huangguoshu Waterfall is one of the largest waterfalls in China and is a popular tourist attraction.

In India, one example of step falls is the Athirappilly Falls, located in the state of Kerala. The falls are formed by a series of steps, with a total height of over 24 meters. Athirappilly Falls is located in the middle of a forest and is a popular tourist attraction.

Nick point falls: A nick point waterfall, also known as a knick point waterfall, is a type of waterfall that is formed by a sudden change in the gradient of a river or stream. This sudden change in gradient creates a vertical drop or waterfall, as the water flows over a resistant rock layer.

The formation of a nick point waterfall begins with the geological process of erosion. As water flows over the surface of the land, it can erode the rock and soil, creating channels and pathways. Over time, these channels can deepen, creating a river or stream. As the river or stream flows, it may encounter an area where the rock is more resistant to erosion. This resistant rock layer may create a sudden change in gradient, causing the water to flow over a vertical drop or waterfall.

Nick point waterfalls are typically formed in areas where the underlying rock layers are composed of different types of rock with varying degrees of resistance to erosion. The more resistant rock layers create a sudden change in gradient, which causes the water to flow over a waterfall.

One famous example of a nick point waterfall is Niagara Falls, located on the Niagara River on the border between Canada and the United States. The falls are formed by a sudden change in gradient as the river flows over a layer of resistant rock. Niagara Falls is one of the most famous waterfalls in the world and is a popular tourist attraction.

In India, one example of a nick point waterfall is the Dudhsagar Falls, located in the state of Goa. The falls are formed by a sudden change in gradient as the Mandovi River flows over a layer of resistant rock. Dudhsagar Falls is one of the tallest waterfalls in India, with a total height of over 310 meters.

Nick point waterfalls are a unique and fascinating natural wonder, created by the powerful forces of erosion and water flow. They provide a stunning display of falling water and are a popular tourist attraction in many parts of the world.

Disappearance of waterfalls: The disappearance of waterfalls can be attributed to geological causes such as erosion and changes in the underlying rock formations. As waterfalls are formed by the erosion of rock layers, changes to these layers can have a significant impact on the stability and existence of the waterfall.

For example, the Agawa Canyon Falls in Canada disappeared due to a landslide that occurred upstream, which changed the course of the river and caused the waterfall to dry up. Similarly, the Horse Tail Falls in California disappeared in 1968 due to a change in the riverbed caused by an earthquake, which altered the flow of water over the falls.

Human activities such as damming and mining can also impact the underlying rock formations and lead to the disappearance of waterfalls. For example, the Marmore Falls in Italy was once a natural waterfall but was transformed into an artificial waterfall to power a hydroelectric plant. The construction of dams can also alter the natural flow of rivers, which can lead to the disappearance of waterfalls.

Water Pot holes: Water potholes, also known as plunge pools or erosional potholes, are geological formations that are created by the erosive action of water. These formations are typically found at the base of waterfalls or rapids, where the force of the falling water erodes the rock and creates depressions in the riverbed.

The formation of water potholes begins with the hydraulic action of the falling water, which creates eddies and swirls that erode the softer rock at the base of the waterfall. Over time, the erosive action of the water causes these depressions to deepen and widen, creating potholes that can be several meters deep and wide.

Water potholes can be found in a variety of rock formations, but are most commonly found in sedimentary rocks such as sandstone and limestone. These rocks are particularly susceptible to erosion due to their porous nature and the presence of weak planes of rock that can be easily eroded.

Water potholes can also be found in glacial valleys, where the melting ice creates rivers and waterfalls that erode the rock and create these formations. Some famous examples of water potholes include Devil's Kettle Falls in Minnesota and Horseshoe Falls in Niagara Falls.

Structural benches: Structural benches are geological formations that are created by the uplift and erosion of mountain ranges. They are also known as "terraces" or "benches", and are flat or gently sloping surfaces that are located on the sides of mountains or valleys.

The formation of structural benches begins with the uplift of a mountain range due to tectonic activity. As the mountain range rises, erosion begins to wear away the rock at the surface, which exposes older layers of rock beneath. Over time, these older layers of rock are also eroded, which creates a flat or gently sloping surface known as a structural bench.

Structural benches are often found in areas with steep topography and can be used to determine the history of the uplift and erosion of a mountain range. By studying the layers of rock exposed on a structural bench, geologists can gain insights into the geological history of the area and the processes that have shaped the landscape over time.

Structural benches can also be used as a way to access and explore the geology of a mountain range. For example, in the Grand Canyon, structural benches have been used to construct trails and campsites, as well as to study the geology of the area.

River Terraces: River terraces are flat or gently sloping surfaces that are located alongside a river or stream, and are formed by the erosion and deposition of sediment over time. These terraces are often located above the current level of the river or stream and are remnants of older floodplain surfaces.

The formation of river terraces begins with the erosion of the surrounding landscape by the river or stream. As the river cuts deeper into the bedrock, it also erodes sediment and carries it downstream. During times of high flow, the river may deposit this sediment along its banks, creating a new floodplain surface.

Over time, the river may cut down through this new floodplain surface, creating a new terrace. This process can repeat itself multiple times, resulting in a series of river terraces at different elevations above the current level of the river or stream.

The formation of river terraces can also be influenced by tectonic activity, climate change, and sea level fluctuations. For example, uplift and tectonic activity can cause the river to erode more rapidly, creating terraces at higher elevations. Conversely, periods of climate change or sea level fluctuations can cause the river to deposit more sediment along its banks, creating new floodplain surfaces and terraces.

River Meander: A river meander is a bend or curve in a river channel. They are formed by the erosive power of water, which wears away the outer banks of a river bend and deposits sediment on the inner banks. Over time, this process causes the river to migrate back and forth across its floodplain, creating a sinuous, meandering path.

The formation of a river meander begins with a relatively straight river channel. As the river flows, it erodes the outer banks of any bends in the channel, causing the channel to become more sinuous. At the same time, sediment is deposited on the inner banks of the bends, which causes them to become more stable and resistant to erosion.

As the river continues to erode the outer banks and deposit sediment on the inner banks, the bends in the channel become more pronounced, and the river begins to migrate back and forth across its floodplain. This process is known as lateral migration, and it is the primary mechanism by which meandering rivers create their characteristic sinuous patterns.

Over time, the meandering path of a river can become quite complex, with multiple bends and curves in the channel. Meandering rivers can also create features such as oxbow lakes, point bars, and cut banks, which are all shaped by the erosive and depositional forces of the river.

The formation of meanders is influenced by a variety of factors, including the shape of the valley floor, the size and velocity of the river, and the sediment load of the river. Meanders are also influenced by external factors such as tectonic activity and climate change, which can alter the shape of the river valley and affect the way that the river erodes and deposits sediment.

There are several types of river meanders, each with its own distinct characteristics and formation processes. Some of the most common types of river meanders include:

Point bar meanders: These meanders form on the inside of river bends and are characterized by a buildup of sediment on the inside bank. Point bar meanders are often associated with low-energy rivers with a relatively small sediment load.

Cut bank meanders: Cut bank meanders form on the outside of river bends and is characterized by erosion of the outside bank. Cut bank meanders are often associated with high-energy rivers with a large sediment load.

Compound meanders: Compound meanders are complex systems of interconnected river bends that are formed when the river channel is highly sinuous. Compound meanders are often associated with meandering rivers in low-gradient environments.

Pool-riffle meanders: These meanders are characterized by alternating sequences of shallow riffles and deep pools. They are often found in high-gradient environments and are formed by the erosive and depositional forces of the river.

Braided meanders: Braided meanders are formed when a meandering river channel becomes unstable and begins to braid, creating multiple channels that are separated by islands or bars of sediment.

The formation of different types of river meanders is influenced by a variety of factors, including the velocity and sediment load of the river, the shape of the river valley, and external factors such as tectonic activity and climate change.

Peneplain: Peneplain is a nearly flat land surface that has been eroded to a low elevation by prolonged denudation and is often covered by a veneer of sediment. The formation of peneplains is a gradual and long-term process that involves several stages of erosion and sedimentation.

The process of peneplain formation begins with tectonic uplift that exposes a land surface to erosion. The process of erosion gradually wears down the land surface, and over time, it develops into a nearly flat surface. Once the base level stabilizes, the river continues to erode the land surface and transports sediment downstream. However, the rate of erosion is slow, and the sediment load is low, resulting in the formation of a nearly flat surface.

As the erosion rate slows down, vegetation begins to colonize the surface, and sedimentation becomes the dominant process. Over time, the sedimentation process creates a thin layer of sediment on top of the nearly flat land surface. The final stage in the formation of a peneplain is further tectonic uplift and erosion, which exposes the peneplain surface once again to erosion and starts the process all over again.

Peneplains are often found in regions of ancient mountain ranges and are important indicators of the long-term tectonic history of a region. The formation of peneplains is a slow and long-term process that can take millions of years to complete.

Depositional work of river: Deposition is the geological process by which sediments, soil, and rocks are added to a landform or landmass. Rivers are one of the most important agents of deposition on the Earth's surface.

As a river flows, it carries sediment and other materials, such as sand, silt, and clay, downstream. When the river reaches a flat area, such as a floodplain or a delta, the flow velocity slows down, and the sediment is deposited.

The sediment is deposited in layers and builds up over time, eventually forming a flat, fertile plain. The deposition of sediment by a river is responsible for the formation of many important landforms, such as deltas, floodplains, alluvial fans, and terraces.

The deposition process also plays a critical role in soil formation, as the sediment deposited by rivers is rich in minerals and nutrients that are essential for plant growth. In addition, deposition helps to prevent erosion by stabilizing the riverbanks and shorelines.

Causes of depositional work: The depositional work of a river is a result of several factors that influence the transport and deposition of sediment. These factors include the sediment supply, the water velocity, the river gradient, and the nature of the riverbed.

Sediment supply: The amount and type of sediment available for transport is a critical factor that influences the depositional work of a river. The sediment supply is affected by factors such as climate, geology, and human activities. For example, heavy rainfall and erosion from deforestation can increase the sediment supply, leading to increased deposition.

Water velocity: The velocity of the water in a river is another important factor that influences the deposition of sediment. When the water velocity decreases, sediment settles out of the water column and is deposited. This often occurs when a river enters a larger body of water, such as a lake or an ocean, or when the river flows over a relatively flat area, such as a floodplain.

River gradient: The gradient of a river, or the slope of the riverbed, also affects the depositional work of the river. When the gradient of the river decreases, the velocity of the water also decreases, allowing sediment to settle out and be deposited.

Nature of the riverbed: The nature of the riverbed, including the type of sediment and the presence of vegetation or other obstacles, can also influence the deposition of sediment. For example, if the riverbed is covered in vegetation, such as trees and shrubs, the roots can stabilize the sediment and promote deposition.

10.5.3 River Deposition Landforms:

River deposition can create various types of landforms, each with unique characteristics and processes of formation. Some of the most common river depositional landforms are described below:

Alluvial Fans: Alluvial fans are fan-shaped landforms that are created when a river or stream emerges from a narrow canyon or mountainous area and flows into a broader valley. As the river or stream spreads out, its velocity decreases, causing sediment to be deposited in a fan-like shape. Alluvial fans are typically composed of gravel, sand, and silt, and are often found at the base of mountains or hills.

Fig. 10.5 Alluvial Fans, Source Google Image

The formation of alluvial fans is a complex process that involves both erosion and deposition. According to a study published in the journal Geology, the formation of alluvial fans can be broken down into three main stages: initiation, expansion, and abandonment.

Initiation occurs when a river or stream emerges from a narrow canyon or mountainous area and enters a broader valley. The decrease in velocity causes sediment to be deposited at the mouth of the canyon or mountain, creating a small, steep-sided alluvial cone.

Expansion occurs as the river or stream continues to deposit sediment at the base of the alluvial cone. As sediment accumulates, the cone becomes larger and more fan-shaped, with a gentler slope.

Abandonment occurs when the river or stream changes course and begins to deposit sediment elsewhere. This can result in the formation of multiple alluvial fans in a single valley, each with its distinct characteristics and history of formation.

Alluvial fans can also be influenced by other factors, such as climate, tectonic activity, and vegetation cover. For example, a study published in the journal Earth Surface Processes and Landforms found that vegetation cover can influence the size and shape of alluvial fans by affecting sediment transport and deposition rates.

In addition to their scientific significance, alluvial fans also have important economic and cultural significance. They are often important sources of water, minerals, and other resources, and have played a significant role in the development of human societies throughout history.

Levees: Levees are raised landforms that parallel a river or other body of water and are designed to prevent flooding. They are typically composed of sediment deposited by the river during periods of high flow, such as floods. The formation of levees is a natural process that occurs as part of the overall cycle of erosion and deposition in river systems.

During a flood event, the velocity of the water in a river increases, allowing it to carry larger sediment particles. As the water spreads out onto the floodplain, it loses velocity and deposits the sediment it is carrying. Over time, these sediment deposits build up, creating a natural levee along the banks of the river.

As the river continues to flood over time, it will deposit additional sediment on top of the existing levee, gradually raising its height. The levee can also be reinforced by vegetation, which stabilizes the sediment and prevents erosion. In some cases, humans may also build artificial levees to protect against flooding, but these structures can have negative environmental impacts if they are not carefully designed and maintained.

Levees can have both positive and negative effects on the surrounding environment. On the one hand, they can protect human populations and infrastructure from the destructive effects of floods, allowing communities to live and work in flood-prone areas. On the other hand, levees can alter the natural flow of the river and reduce the amount of sediment that is deposited on the floodplain, leading to decreased fertility and other ecological effects.

Examples of levees include the Mississippi River levees in the United States, which were built to protect communities along the river from catastrophic flooding; the Nile River levees in Egypt, which were built in ancient times to prevent flooding and irrigate crops; and the Yellow River levees in China, which were built to prevent flooding and irrigate crops.

The importance of levees cannot be overstated, particularly in areas prone to flooding. Here are some points about the significance of levees

In the United States, levees have been instrumental in protecting communities and infrastructure from the devastating effects of river flooding, particularly along the Mississippi River and its tributaries.

In Europe, levees have been used to protect low-lying areas along major rivers such as the Rhine and the Danube from floods.

In China, levees have been used for centuries to protect communities and agriculture in the flood-prone areas of the Yellow River and the Yangtze River.

In Egypt, the Nile River levees have been used for thousands of years to irrigate crops and protect communities from floods.

The Kosi River in northern India has a long history of catastrophic flooding, and a system of levees has been built along the river to prevent future flooding.

However, there have been concerns about the effectiveness and maintenance of levees in India, particularly in the aftermath of major flood events.

In recent years, there has been a growing recognition of the need to improve flood management in India, with an emphasis on developing more comprehensive and sustainable approaches that incorporate a range of measures, including levees, as part of a broader flood management strategy.

10.5.4 Delta:

A delta is a landform that is formed at the mouth of a river where it meets a standing body of water, such as a lake, sea, or ocean. It is characterized by the accumulation of sediment carried by the river and deposited at its mouth. The sediment, which can be sand, silt, or clay, is deposited in a fan-like shape, forming a triangular or bird-foot-shaped landform.

Deltas are dynamic and constantly changing environments. They can be influenced by tides, waves, and other factors that can erode or deposit sediment. Vegetation, such as mangroves, can also play a role in delta formation and stabilization.

Fig. 10.6 Delta, Source Google Image

Deltas are important habitats for a variety of wildlife, including birds, fish, and other aquatic species. They also serve as important agricultural areas, providing fertile land for crop cultivation. However, they can also be prone to flooding and other natural hazards.

Conditions Necessary for the Formation of a Delta:

Sufficient sediment supply: Deltas are formed by the deposition of sediment carried by a river, so a sufficient supply of sediment is necessary for delta formation. This can be influenced by factors such as the size of the river, the slope of the riverbed, and the amount of sediment carried by the river.

Low wave energy: Deltas are typically formed at the mouth of a river where it meets a standing body of water, such as a lake, sea, or ocean. To prevent the sediment from being eroded by waves, the standing body of water should have relatively low wave energy.

Minimal tidal influence: Deltas can also be influenced by tides, which can affect sediment deposition and erosion. To promote delta formation, minimal tidal influence is desirable.

Reduced river velocity: As a river flows into a standing body of water, its velocity decreases, which can cause sediment to settle out and form a delta. Therefore, reduced river velocity is necessary for delta formation.

Subsidence: In some cases, subsidence of the land can also contribute to delta formation. This occurs when the land sinks, causing the river to deposit sediment at a faster rate and leading to the formation of a larger delta.

Formation of Delta:

Deltas are formed by the deposition of sediment carried by a river as it flows into a standing body of water, such as a lake, sea, or ocean. The formation of a delta typically involves several stages, each of which can be influenced by a range of environmental factors.

The first stage in delta formation is the production of sediment. Sediment can be derived from a variety of sources, including erosion of rocks and soils, weathering of minerals, and deposition of organic matter. Once sediment is produced, it is transported by the river downstream towards the standing body of water.

As the river approaches the standing body of water, its velocity decreases, causing it to deposit some of the sediment it is carrying. This causes the riverbed to rise, creating a natural levee on either side of the river. Over time, the sediment accumulates and begins to form a delta.

The second stage in delta formation is the construction of distributary channels. These are channels that branch off from the main river channel and carry sediment towards the standing body of water. As the river deposits sediment at its mouth, it begins to form a fan-like shape, with the distributary channels spreading out and branching further downstream.

The third stage in delta formation is the building of a platform. This is an area of relatively flat land that is formed by the deposition of sediment. The platform may be above or below the water level, depending on the relative rates of sediment deposition and sea level rise.

The final stage in delta formation is the development of vegetation. As the platform becomes more stable, vegetation can take root and begin to grow. This can help to stabilize the sediment and prevent erosion, as well as provide habitat for a range of species.

The formation of a delta can be influenced by a range of environmental factors, including sediment supply, river discharge, wave energy, and sea level rise. Human activities such as dam construction, river channelization, and land use change can also affect delta formation.

Classifications of Delta:

Deltas are classified based on a range of factors, including their morphology, sedimentology, and the dominant processes that shape them. Some common classifications of delta include:

Arcuate deltas: These are fan-shaped deltas that form when a river flows into a standing body of water at an oblique angle. They are characterized by a single prominent distributary channel that carries most of the sediment, and they often have a curved or crescent-shaped shoreline.

Arcuate deltas form when a river flows into a standing body of water at an oblique angle, causing the sediment to be deposited in a fan-shaped pattern. The formation of an arcuate delta is influenced by a range of factors, including the volume of water and sediment discharged by the river, the wave and tidal energy of the standing body of water, and the rate of subsidence or uplift of the land beneath the delta.

The formation of an arcuate delta typically follows a cyclical pattern of avulsion, where the river channel shifts its course and creates new distributary channels that extend the delta outward. As sediment continues to be deposited in these new channels, they may become dominant and the old channels may become abandoned. This process creates a series of lobes or tongues that extend the delta outward into the standing body of water, forming the characteristic fan shape of an arcuate delta.

The shape of an arcuate delta is also influenced by the direction and strength of ocean currents and waves, which can cause the sediment to be redistributed and eroded. This can result in the formation of spits or barrier islands that extend parallel to the shoreline, further shaping the morphology of the delta.

Some examples of arcuate deltas include the Nile Delta in Egypt, the Ganges-Brahmaputra Delta in Bangladesh and India, and the Mississippi River Delta in the United States.

Birdfoot deltas: These are named for their resemblance to a bird's foot, with several distributary channels that spread out and extend into the standing body of water. They are typically found in areas with low wave energy and high sediment supply.

Birdfoot deltas are a type of delta that forms when a river flows into a standing body of water and deposits sediment in a fan shape with several distributary channels that spread out and extend into the standing body of water. These deltas are named for their resemblance to a bird's foot.

The formation of a bird foot delta is influenced by several factors, including the volume of water and sediment discharged by the river, the wave and tidal energy of the standing body of water, and the rate of subsidence or uplift of the land beneath the delta. In the case of birdsfoot deltas, the river channel divides into several smaller distributary channels that spread out and deposit sediment in a fan shape.

The morphology of birdfoot deltas is also influenced by the direction and strength of ocean currents and waves. In areas with low wave energy and high sediment supply, the delta may continue to extend outward, creating long, narrow protrusions of land that resemble a bird's foot. However, in areas with high wave energy, the sediment may be eroded and redistributed, causing the delta to become more rounded or flattened.

Some examples of birdfoot deltas include the Mississippi River Delta in the United States and the Po River Delta in Italy. These deltas are important ecosystems and support a range of wildlife, including birds, fish, and other aquatic species. However, they are also vulnerable to human impacts such as land use changes, dam construction, and sea level rise, which can alter their morphology and threaten their ecological integrity.

Cuspate deltas: These are triangular-shaped deltas that form when a river flows into a standing body of water at a sharp angle. They have a distinctive cusp shape, with a narrow, pointed apex and broad, curved sides.

Cuspate deltas are a type of delta that forms when a river flows into a standing body of water at an acute angle, causing the sediment to be deposited in a triangular shape with a pronounced point at the river mouth. These deltas are characterized by their sharp, angular morphology and can extend several kilometres into the standing body of water.

The formation of cuspate deltas is influenced by a range of factors, including the volume of water and sediment discharged by the river, the wave and tidal energy of the standing body of water, and the rate of subsidence or uplift of the land beneath the delta. In the case of cuspate deltas, the sediment is deposited in a triangular shape with a pronounced point at the river mouth, creating a series of ridges and troughs that extend outward into the standing body of water.

The morphology of cuspate deltas is also influenced by the direction and strength of ocean currents and waves, which can cause the sediment to be redistributed and eroded. This can result in the formation of spits or barrier islands that extend parallel to the shoreline, further shaping the morphology of the delta.

Some examples of cuspate deltas include the Tiber River Delta in Italy, the Ebro River Delta in Spain, and the St. Augustine Beach Cuspate Foreland in Florida, USA. These deltas are important ecological systems that support a variety of plant and animal life, but they can also be vulnerable to human impacts such as development, dredging, and sea level rise.

Estuarine deltas: These form at the mouths of estuaries, where a river flows into a partially enclosed body of water that is affected by tides. They are characterized by a complex network of distributary channels and are often dominated by tidal processes.

Estuarine deltas are a type of delta that forms where a river flows into a narrow, elongated inlet or bay that is partially enclosed by land. These deltas are characterized by a relatively smooth, gently sloping morphology and are typically composed of fine-grained sediment.

The formation of estuarine deltas is influenced by a range of factors, including the volume of water and sediment discharged by the river, the shape and size of the inlet or bay, and the wave and tidal energy of the surrounding water. In the case of estuarine deltas, the sediment is deposited in a relatively smooth, gently sloping shape, which is influenced by the movement of the tidal currents within the inlet or bay.

The morphology of estuarine deltas is also influenced by the rate of subsidence or uplift of the land beneath the delta, as well as the amount of sediment delivered to the delta by the river. In areas where the rate of subsidence is higher than the rate of sediment delivery, the delta may become submerged and eventually disappear below the water surface.

Some examples of estuarine deltas include the Ganges-Brahmaputra Delta in Bangladesh and India, the Nile Delta in Egypt, and the Yangtze River Delta in China. These deltas are important ecological systems that support a variety of plant and animal life, as well as human populations that rely on the resources provided by these systems. However, they can also be vulnerable to human impacts such as pollution, land use changes, and sea level rise, which can threaten their ecological and socio-economic function.

Tidal deltas: These form in areas with high tidal energy, such as inlets or lagoons. They are typically characterized by elongated sand spits or barrier islands that extend parallel to the shore.

Tidal deltas are a type of delta that forms where a river flows into a large body of water that experiences significant tidal energy, such as a bay or an ocean. These deltas are characterized by their elongated, lobate morphology, and are typically composed of coarse-grained sediment.

The formation of tidal deltas is influenced by a range of factors, including the volume of water and sediment discharged by the river, the wave and tidal energy of the surrounding water, and the shape and size of the basin into which the river flows. In the case of tidal deltas, the sediment is deposited in an elongated, lobate shape, which is influenced by the movement of the tidal currents within the basin.

The morphology of tidal deltas is also influenced by the rate of sediment delivery to the delta by the river, as well as the rate of subsidence or uplift of the land beneath the delta. In areas where the rate of subsidence is higher than the rate of sediment delivery, the delta may become submerged and eventually disappear below the water surface.

Some examples of tidal deltas include the Mississippi River Delta in the Gulf of Mexico, the Amazon River Delta in Brazil, and the Gironde Estuary in France. These deltas are important ecological systems that support a variety of plant and animal life, as well as human populations that rely on the resources provided by these systems. However, they can also be vulnerable to human impacts such as pollution, coastal erosion, and sea level rise, which can threaten their ecological and socio-economic function.

River-dominated deltas: These are deltas that are dominated by fluvial processes, with the river being the primary source of sediment and controlling the morphology of the delta. They often have a single large distributary channel and are typically found in areas with high sediment supply.

River-dominated deltas are a type of delta that forms where a river flows into a large body of water, such as an ocean, and delivers a large volume of sediment. These deltas are characterized by their broad, fan-shaped morphology and are typically composed of coarse-grained sediment.

The formation of river-dominated deltas is influenced by a range of factors, including the volume of water and sediment discharged by the river, the wave and tidal energy of the surrounding water, and the shape and size of the basin into which the river flows. In the case of river-dominated deltas, the sediment is deposited in a broad, fan-shaped shape, which is influenced by the river's discharge and the way the sediment is transported and deposited by the river.

The morphology of river-dominated deltas is also influenced by the rate of subsidence or uplift of the land beneath the delta, as well as the rate of sediment delivery to the delta by the river. In areas where the rate of subsidence is higher than the rate of sediment delivery, the delta may become submerged and eventually disappear below the water surface.

Some examples of river-dominated deltas include the Nile River Delta in Egypt, the Irrawaddy River Delta in Myanmar, and the Mekong River Delta in Vietnam. These deltas are important ecological systems that support a variety of plant and animal life, as well as human populations that rely on the resources provided by these systems. However, they can also be vulnerable to human impacts such as pollution, coastal erosion, and sea level rise, which can threaten their ecological and socio-economic function.

Wave-dominated deltas: These are deltas that are dominated by wave processes, with wave energy shaping the morphology of the delta. They often have multiple smaller distributary channels and are typically found in areas with low sediment supply and high wave energy.

Wave-dominated deltas are a type of delta that form when waves play a dominant role in shaping the morphology of the delta. They typically occur in areas where the river discharge is low relative to wave energy and the supply of sediment to the coast is high. In such areas, the waves play a significant role in transporting and redistributing sediment along the coast, resulting in a landform that is shaped more by wave action than by the river.

The formation of wave-dominated deltas is influenced by a range of factors, including the wave energy and direction, the size and shape of the sediment particles, and the depth and slope of the ocean floor. The waves can transport sediment along the shore and distribute it over a large area, leading to the formation of a low-gradient, triangular or fan-shaped delta. The sediment is typically fine-grained and well-sorted due to the reworking of sediment by waves.

Wave-dominated deltas often have a smooth, gently sloping shoreline with shallow water extending far out to sea. The sediment at the delta front is often reworked and redistributed by waves, leading to the formation of sand spits, barrier islands, and other coastal landforms. These features can protect the delta from further erosion and provide a habitat for a variety of coastal plants and animals.

Examples of wave-dominated deltas include the Ganges-Brahmaputra Delta in Bangladesh and the Mekong River Delta in Vietnam. These deltas are important ecological systems that support a variety of plant and animal life, as well as human populations that rely on the resources provided by these systems. However, they can also be vulnerable to human impacts such as pollution, coastal erosion, and sea level rise, which can threaten their ecological and socio-economic function.

10.6 SUMMARY

The unit on Water Processes and Landforms provides an in-depth look at the various ways in which water interacts with the Earth's surface and shapes the landscape. The following is a summary of the key points covered in this chapter:

Water erosion: Water is one of the most significant agents of erosion, creating valleys, canyons, and other landforms. The amount and speed of water flow, the type of sediment being transported, and the slope of the land all influence the shape of these landforms.

Water deposition: Sediments carried by water can be deposited in a variety of ways, creating landforms such as alluvial fans, deltas, and levees. These landforms are shaped by the amount and type of sediment, the speed and volume of water flow, and the geological characteristics of the area.

River landforms: Rivers create a variety of landforms, including meanders, oxbow lakes, braided channels, and waterfalls. These landforms are shaped by the flow of water, the type of sediment, and the geology of the area.

Deltas: Deltas are landforms created when sediment-rich rivers meet the ocean or a lake. They are classified based on the dominant geological and hydrological processes that shape their morphology, such as river-dominated, wave-dominated, estuarine, birdfoot, cuspate, and arcuate deltas.

10.7 GLOSSARY

- **Alluvial fan:** A fan-shaped deposit of sediment that forms where a stream or river flows out of a mountainous area and onto a flat plain.
- **Arcuate delta:** A delta that has a curved or arched shape, resembling a bow or crescent moon.s
- **Barrier island:** A long, narrow island that runs parallel to the mainland and provides protection from ocean waves and storms.
- **Birdfoot delta:** A delta that has a branching network of distributaries that resemble the toes of a bird's foot.
- **Braided channel:** A type of river channel that is divided into numerous smaller channels separated by small, often temporary islands of sediment.
- **Cuspate delta:** A delta that has a triangular shape with a pointed apex.
- **Delta:** A landform that forms where a river or stream flows into a body of water and deposits sediment to form a triangular or fan-shaped deposit.
- **Deposition:** The process of sediment and other materials being deposited onto a surface by wind, water, or ice.
- **Erosion:** The process of wearing away rocks and other geological materials by the action of water, wind, or other natural agents.

- **Estuarine delta:** A delta formed in an estuary where freshwater from a river mixes with saltwater from the ocean or a bay.
- **Estuary:** The tidal mouth of a river, where freshwater and saltwater mix to form an area of transition.
- **Levee:** A raised bank of sediment along the edge of a river or stream that forms when sediment is deposited during floods.
- **Meander:** A winding curve or bend in a river or stream.
- **Oxbow lake:** A crescent-shaped lake that forms when a meander in a river or stream is cut off from the main channel and becomes isolated.
- **River-dominated delta:** A delta formed when sediment is deposited by a river at its mouth, often in a triangular or fan-shaped pattern.
- **Waterfall:** A steep drop in the course of a river, stream or other waterway.
- **Wave-dominated delta:** A delta formed when sediment is deposited along a shoreline by waves and long-shore currents.

10.8 ANSWER TO CHECK YOUR PROGRESS

1. What is the name of the process by which water soaks into the ground and becomes groundwater?

A) Runoff

B) Infiltration

C) Evaporation

D) Condensation

2. Which of the following landforms is created by the erosion of a river?

A) Delta

B) Canyon

C) Volcano

D) Glacier

3. Which of the following landforms is created by a glacier?

A) Beach

B) Mesa

C) Moraine

D) Arch

4. What is the name of the process by which water vapour turns into liquid water?

A) Evaporation

B) Transpiration

C) Precipitation

D) Condensation

5. What is the name of the landform created by the deposition of sediment at the mouth of a river?

A) Estuary

B) Delta

C) Mesa

D) Butte

6. Which of the following landforms is created by the erosion of wind-blown sand?

A) Glacier

B) Mesa

C) Dune

D) Arch

7. Which of the following processes involves the movement of water through a plant and its subsequent release into the atmosphere?

A) Transpiration

B) Infiltration

C) Runoff

D) Precipitation

8. What is the name of the process by which water flows downhill over the surface of the land?

A) Runoff

B) Infiltration

C) Evaporation

D) Condensation

9. Which of the following landforms is created by the erosion of a coastline by waves?

A) Delta

B) Canyon

C) Beach

D) Arch

10. Which of the following landforms is created by the movement of a glacier over an area of land?

A) Delta

B) Canyon

C) Moraine

D) Arch

Answers: B, B, C, D, B, C, A, A, C, C

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10.10 TERMINAL QUESTIONS

1) What are the main processes involved in the development of valleys?
2) How does fluvial erosion contribute to the formation of different landforms within river valleys?
3) What are the different forms of river erosion, and how do they shape the landscape?
4) How do meanders form in river channels, and what factors influence their development?
5) What are the characteristics and formation processes of river terraces?
6) How do waterfalls and rapids form in river systems, and what role do they play in erosion and landscape development?
7) What are the key factors that determine river topography and the arrangement of channels within a river network?
8) How do rivers interact with and shape their floodplains?
9) What are the various landforms associated with river deltas, and how do they form?
10) How does human activity, such as channelization and dam construction, affect river topography and erosion processes?

UNIT-11 KARST TOPOGRAPHY

11.1 OBJECTIVES:

After studying this lesson, you will be able to:

- Explain the conditions required for the formation of karst topography
- Describe, with the help of diagrams, different types of erosional and depositional landforms produced in such a landscape
- Understand the Karst cycle of erosion

11.2 INTRODUCTION

You have learned how different erosion and deposition agents work on the Earth's surface in the previous chapters. You have already learned about landforms formed by periglacial, glacial, arid, and water processes. In this unit, we will study about the karst topography. Here we will learn about the conditions essential for the development of the Karst landscape found across the world. Different landforms have formed because of the erosion and deposition processes in such a landscape. We will be discussing these landforms in this chapter, along with the Karst Cycle of erosion.

11.3 CONDITIONS ESSENTIAL FOR THE DEVELOPMENT OF KARST TOPOGRAPHY AND PROCESSES INVOLVED

Karst is a term usually given to limestone areas that are characterized by typical topographical features. Dolomite, Gypsum, and chalk also give rise to distinctive karst scenery. In such regions, the dominant process is the erosional process of the solution. Another significant feature here is the lack of surface water and a well-defined cave system. The process of formation of such a landscape is known as ***karstification***. This process is abundant in humid regions where carbonate rocks are present, and sometimes it is also found in temperate, alpine, and tropical climates. Several ***conditions*** are mandatory for the formation of the karst region. These are –

1. The presence of thick massive soluble rocks, preferably limestone, dolomite, or chalk at the surface or sub-surface level
2. These rocks should be dense, highly jointed, mechanically strong, and thinly bedded.
3. Rocks should not be porous but should be permeable.
4. The presence of entrenched valleys below the upland is favourable as it helps in the downward movement of groundwater through the rocks.
5. Considerable relief should be present so that the circulation of water is facilitated to cause typical karst topography.
6. Moderate to heavy rainfall to cause the solution of rocks.
7. There should be a perennial source of water.

The ***process of Solution*** (Figure 11.1) that occurs in the Karst landscape is -

- Main reaction: $CaCO_3 + H_2O + CO_2 \Rightarrow Ca^{+2} + 2HCO_3^-$
- calcite + water + carbon dioxide => calcium ion + carbonic acid

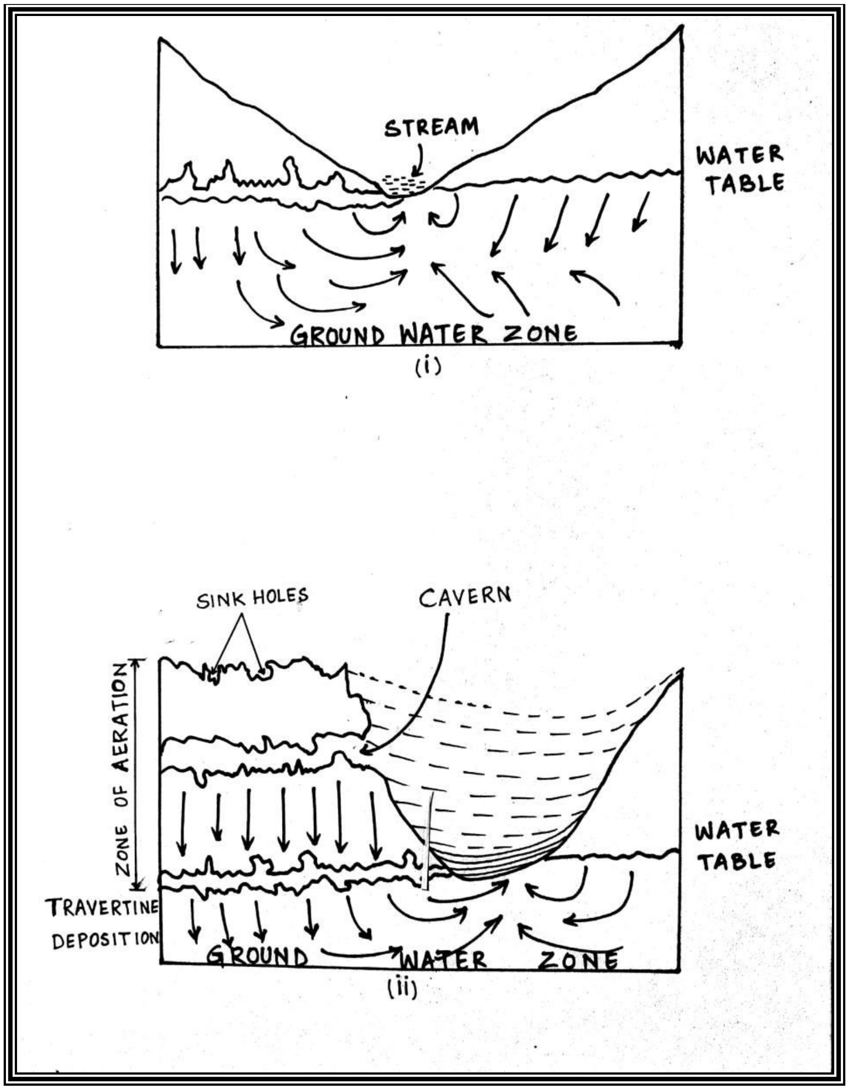

Figure 11.1: The Process of Solution in a Limestone Region, Source Prepared by Author

Several factors control this process of solution, which are –

a) amount of dissolved CO_2
b) the concentration of calcium (Ca) in solution
c) climate – temperature and moisture
d) pH content of water

- Solution is the main process that occurs in the Karst landscape.

11.3.1 THE MAJOR KARST REGIONS OF THE WORLD

In this section, you will be learning about the major karst regions of the world. But at first, one must know how Karst's word came to be used for limestone or other carbonate rocks. Karst is a general term being used universally to describe landforms, hydrology, and environment found in the areas where there is limestone, dolomite, or other carbonate rocks in abundance. Moreover, the region is characterized by high – rock solubility and well-developed subterranean drainage.

Karst is a Germanized form of a carbonate plateau situated above the Adriatic Sea, immediately to the east of Trieste, Italy (Figure 11.2). This region's regional name is *Kras,* where Ka(r) means stone or rock (Gams, 1973, 1993, 2003). In folk language, *Karst* means 'barren stony land,' which could denote an entire landscape.

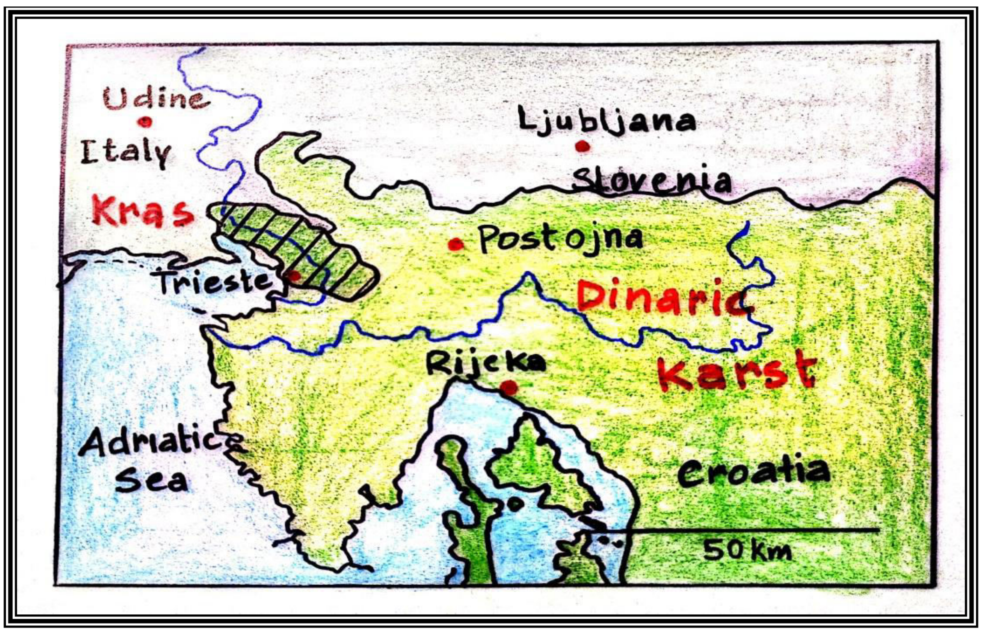

Figure 11.2: The Kras and the Dinaric Karst (after Baroody after Petric, 2005)

Source Prepared by Author

In present times the term 'Karst' is associated with a region depicting specific relief on water-soluble rocks like limestone and dolomite with subsurface features that have formed over a long geological period. The '*classic Karst'* is a region called Kras plateau. This plateau is situated in Italy and Slovenia, covering nearly 750 square km. Some scholars have extended this classical karst region's limits from Trieste to Postojna and south of Rijeka (Croatia). The extended area is famous in the name of *Dinaric Karst*. The latitudinal extent of the *Dinaric Karst* is between 42° and 46° N at the Mediterranean Sea's northeastern edge. The region falls within the temperate climatic zone, where mid-latitude westerlies blow throughout the year. The area gained popularity after Jovan Cvijic (1893, 1901, 1918) investigated this area and published his work on international platforms.

Figure 11.3 shows the major Karst regions of the world. The distribution shown here is the one given by Hollingsworth (2009). Various scholars like White (1988), Veni. et al. (2001) and Ford and Williams (2007) state that the karst regions cover 12 to 25 percent of the Earth's surface. Table 11.1 depicts the names of the countries where major karst regions are located. It also provides information on the percent cover of the karst regions in each region. Table 11.2 shows the parts within each region, which depict Karst topography.

Table 11.1

Distribution of the Karst Regions of the World (KROW)

Region	**Countries**	**Percentage of Karst Cover**
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Congo the democratic, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South	10.5

	Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia, Zimbabwe	
Australia and Oceania	American Samoa, Australia, Christmas Island, Cook Islands, Fiji, French Polynesia, Micronesia, New Caledonia, New Zealand, Niue, Norfolk Island, Northern Mariana Islands, Palau, New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu, West Iran, Western Samoa.	6.8
Central and Middle East Asia	Afghanistan, Bangladesh, Bhutan, Cyprus, India, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Maldives, Nepal, Oman, Pakistan, Palestine, Qatar, Saudi Arabia, Sri Lanka, Syria, Tajikistan, Turkey, United Arab Emirates, Uzbekistan, Yemen	20.9
East and Southeast Asia	Brunei Darussalam, Cambodia, China, East Timor, Indonesia (excluding Papua), Japan, Korea (north and south), Lao, Malaysia, Mongolia, Myanmar, Philippines, Singapore, Taiwan, Thailand, Vietnam	18.3
Europe (excluding Russia and Iceland)	Albania, Andorra, Austria Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Macedonia, Malta, Moldova, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, Vatican City, Yugoslavia	23.5
North America (excluding Greenland)	Anguilla, Antigua and Barbuda, Bahamas, Barbados, Belize, Bermuda, Canada, Cayman Islands, Costa Rica, Cuba, Dominica, Dominica Republic, El Salvador, Guadeloupe, Guatemala, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Nicaragua, Panama,	16.3

	Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Turks and Caicos Islands, United States, Virgin Islands (US)	
Russian Federation	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Russia, Turkmenistan, Uzbekistan	17.9
South America	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Falkland Islands, French Guiana, Guyana, Paraguay, Peru, South Georgia and the South Sandwich Island, Surinam Uruguay, Venezuela	4.3
WORLD		**14.1**

Source: Hollingsworth, 2009

Table 11.2

Karst Topography within each Region

Region	**Karst Areas**
Africa	• Atlas Mountains • Madagascar Island (Tsingy de Bemaraha Strict Nature Reserve)
Australia and Oceania	• Nullarbor Plains • North Queensland • Western Victoria • Heard Island
Central, Middle East, and South Asia	• Meteora in Greece • HierapolisPamukkale in Turkey • Lebanon • Israel

	• Arabian Peninsula • India • Zagros Mountains of Iran • Band-E-Amir in Afghanistan
East and Southeast Asia	• China (Kweichow, Kwangsi, Yunnan, and Hunan provinces) • Indonesian archipelago (Lorentz National Park) • Jeju Volcanic Island in South Korea • Gunung Mulu in Malaysia • Ha Long Bay and Phong Nha-Ke Bang National Park in Vietnam
Europe (excluding Russia and Iceland)	• Dinaric Alps • HallstattDachstein Salzkammergut Cultural Landscape in Austria • Škocjan Caves in Slovenia • Central and Southern Italy • Southern Spain • The Pyrenees • Henderson Island in the United Kingdom • Romania, Moldovia, Bulgaria, and former Yugoslavia • Southern Poland • Slovakia • Velebit Mountains in Croatia
North America (excluding Greenland)	• Nahanni National Park in Canada • Mammoth Cave area of Central Kentucky • Jewel and Wind Caves in South Dakota

	• the American Cordillera in the states of Florida, Alabama, and Georgia • the Ozark Dome in Missouri and northern Arkansas • Oklahoma and eastern Texas • Snake River area of Idaho, • Columbia Basalt Plateau in Washington and Oregon, • Lava fields of northeastern California • The Yucatan Peninsula in Mexico • Cockpit Country of Jamaica • Desembarco del Granma National Park in Cuba
Russian Federation	• Caucasus Mountains • Ural Mountains • Optimistychna in Ukraine
South America	• Peruvian Andes • Canaima in Venezuela • Columbia

Source: Hollingsworth, 2009 and www.iucn.org, 2008

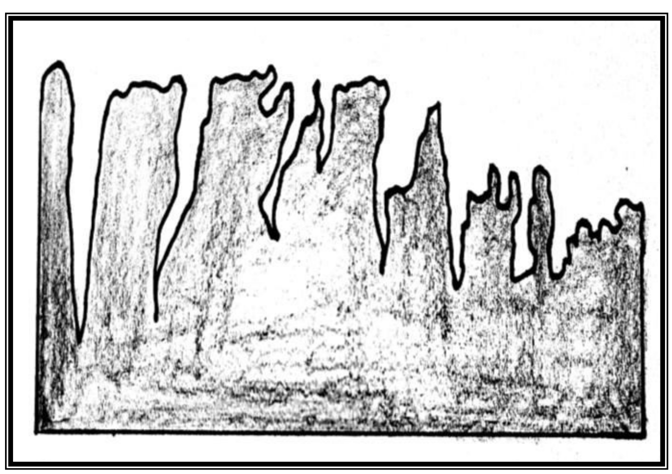

Figure 11.4: Lapies/Karren, Source Prepared by Author

The karst regions occur in all climatic zones, but their distribution is uneven. The highest percentage is in the temperate zone, where 19.1% of the land surface consists of carbonate rocks, followed by cold (16.8%) and arid (14.8%) climates. In contrast, the proportion of carbonate rocks is much lower in tropical (8.8%) and polar (7.7%) climatic regions.

Topographically, also the distribution of Karst is uneven. Most of these regions are in the mountains (40.8 %), followed by the plains (31.3 %) and hills (28.1 %).

- The term *'Karst'* is associated with a region depicting specific relief on water-soluble rocks like limestone and dolomite with subsurface features that have formed over a long geological period.

11.4 KARST LANDFORMS

Karst landforms usually develop in the limestone region produced by groundwater action through the solution and deposition processes. Both erosional and depositional landforms have been discussed in the next section.

11.4.1 EROSIONAL LANDFORMS

The landforms in the Karst region can be seen to develop at three levels:

i) a scale of less than 10 m – known as *Karren* (solution pits, pans, or grooves)

ii) intermediate scale ranging between 1 to 1000 m (dolines, sinkholes)

iii) large scale, where the landforms are greater than 1 km in length (poljes, dry valleys)

All these together form the karst landscapes, which sometimes can extend for thousands of kilometers. But as already stated, each one of the landforms is unique, so they have been discussed separately for your better understanding.

a) **Lapies/Karren** – Lapies, a *French* word, is usually used to denote a highly corrugated rough surface in the Karst landscape. This is marked by small rills and gullies, minor ridges, and deep clefts (Figure 11.1). In Germany, they are known as *Karren*, while in the Northern part of England, they are termes as *Clints*. This landform results from limestone corrosion in areas where limestone is highly exposed to the ground surface (Figure 11.4).

b) **Terra Rosa -** It means '*red residual soils*' or '*red earth*.' They result from weathering processes and can extend for kilometers across the Earth's surface and may be up to several meters thick.

c) **Limestone Pavement -** This is flat land in a natural karst landscape where limestone is exposed to resemble an artificial pavement. These are the result of the solvent action of underground water.

d) **Grikes** – Grikes are vertical or near-vertical fissures or joints in the limestone pavement. Initially, they are microscopic, but as water seeps in, their size increases (Figure 11.5).

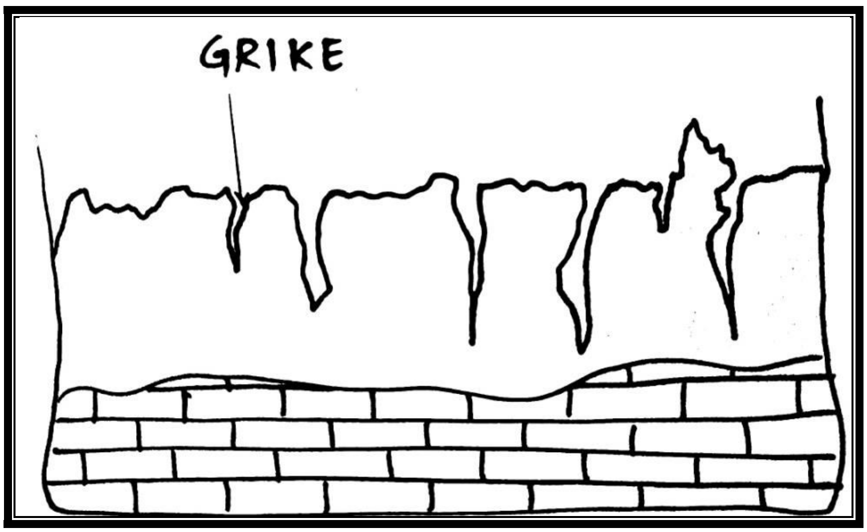

Figure 11.5: Grikes, Source Prepared by Author

e) **Solution Holes** – These are formed because of the dissolution of limestone and other carbonate rocks by the chemically active groundwater. They are usually 5 to 30 cms wide shallow, and flat-bottomed depressions.

f) **Sink Holes**– These are depressions with an average depth of 3 to 9 m, which develops due to the cracks' enlargement. These are generally of two types – funnel-shaped and cylindrical sink holes (Figure 11.6).

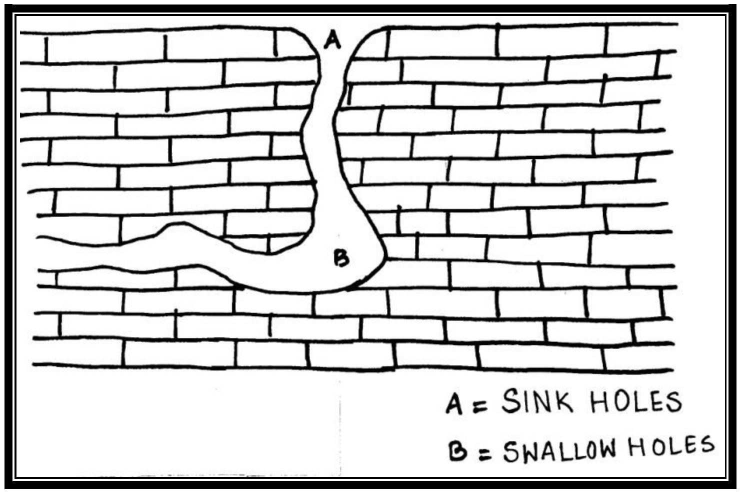

Figure 11.6: Sink holes/ Swallow holes, Source Prepared by Author

g) **Swallow Holes** – The continuous dissolution of carbonate rocks leads to gradual enlargement of sink holes, resulting in swallow holes. We can say that the swallow holes form because of the coalescence of closely spaced sink holes into one large hole (Figure 11.6).

h) **Dolines -** Dolines are saucer-shaped depressions formed when swallow holes enlarge due to the continuous process of solution. Their diameter ranges from a few meters to thousands of meters, while the depth varies from a few meters to 300 meters (Figure 11.7). The formation of Dolines can be associated with four distinct processes, namely,

a. Solution

b. Mechanical collapse

c. Subsidence

d. Seepage erosion

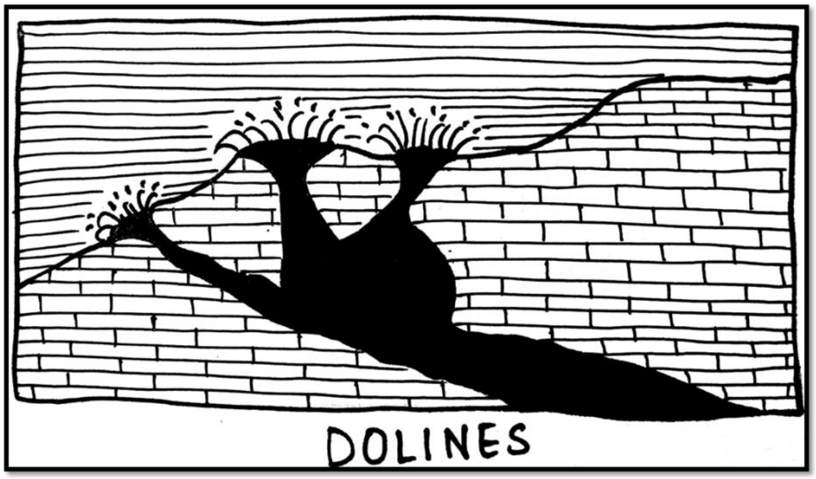

Figure 11.7: Dolines, Source Prepared by Author

Solution Pan – These are similar in appearance to dolines but have shallow depth and larger areal extent.

i) **Karst lakes –** Sometimes, the floor of dolines is filled with water, and these are called karst lakes (Figure 11.8).

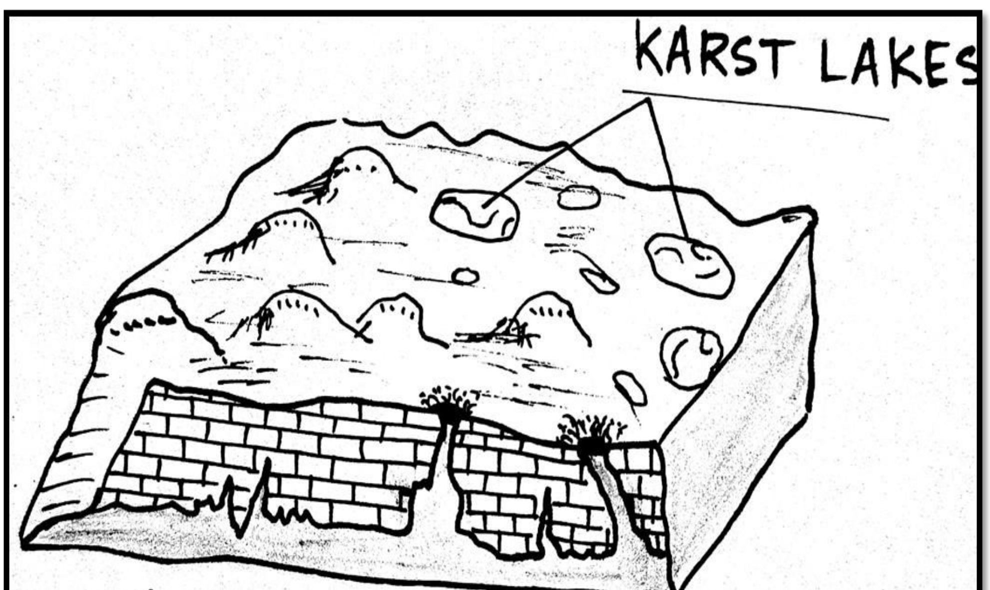

Figure 11.8: Karst Lakes, Source Prepared by Author

j) **Karst Window –** When the upper surface of sink holes or dolines collapse, it leads to karst windows. This landform's exciting feature is that you can observe sub-surface drainage and other landforms below the ground surface from them (Figure 11.9).

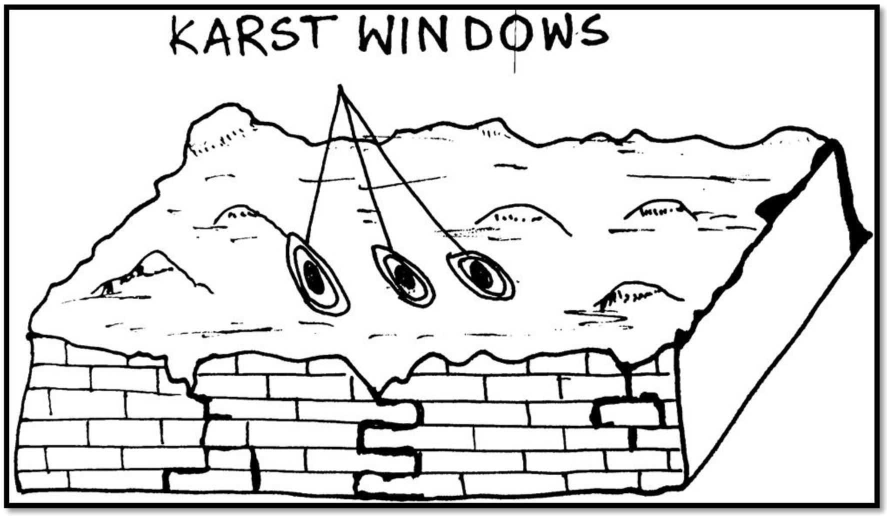

Figure 11.9: Karst Windows, Source Prepared by Author

k) **Uvalas -** are also depressions but extensive, extending up to one kilometer across (Figure 11.10). They are also called compound sinks. The formation of uvalas can be associated with the following processes,

a. coalescence of several dolines
b. continuous solution and enlargement of dolines,
c. the collapse of the upper roof of large cavities formed underground, and
d. coalescence of various sink holes

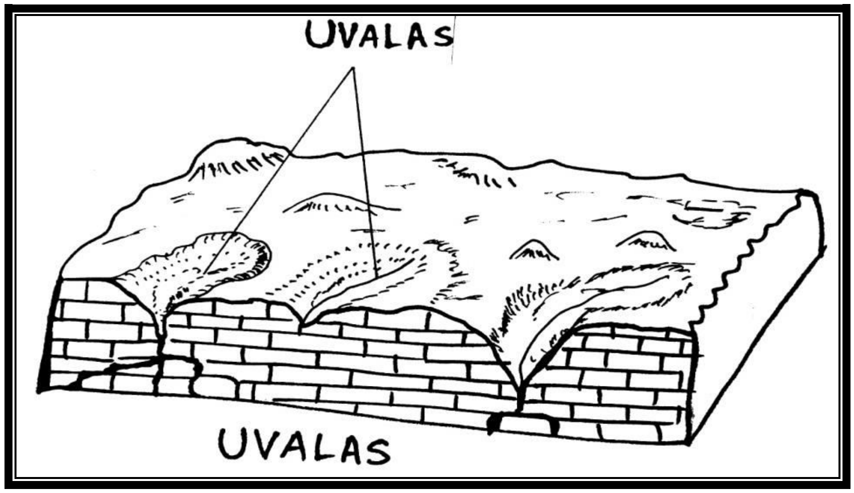

Figure 11.10: Uvalas, Source Prepared by Author

l) **Poljes** – They are the most extensive depressions in the karst landscape. Vertical sidewalls, flat alluvial floors, a lake at the center, surface drainage at their bases are some of the unique characteristics of this landform (Figure 11.11).

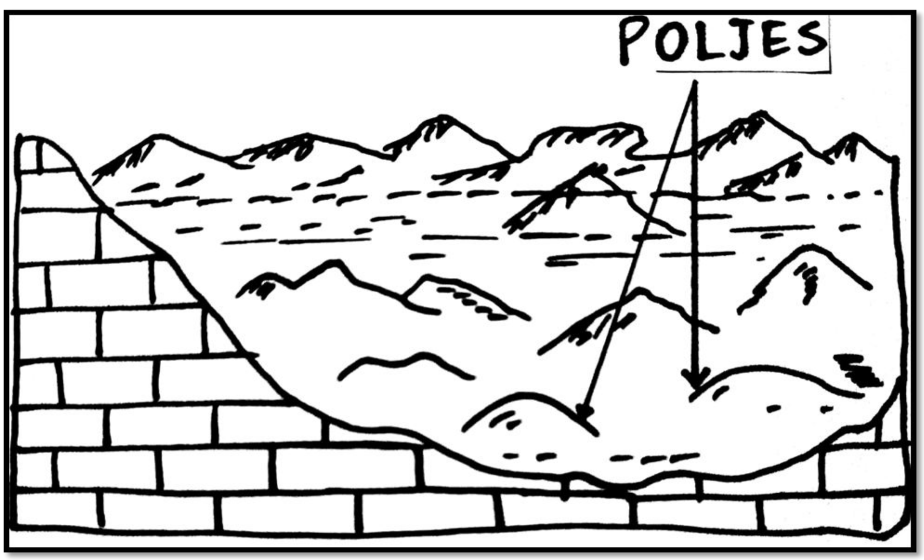

Figure 11.11: Poljes, Source Prepared by Author

m) Karst Plain – The plain surface at the ground, characterized by several sink holes, having inclined to horizontal beds are known as karst plains. These have independent surface drainage dotted with various types of valleys and other landforms (Figure 11.12).

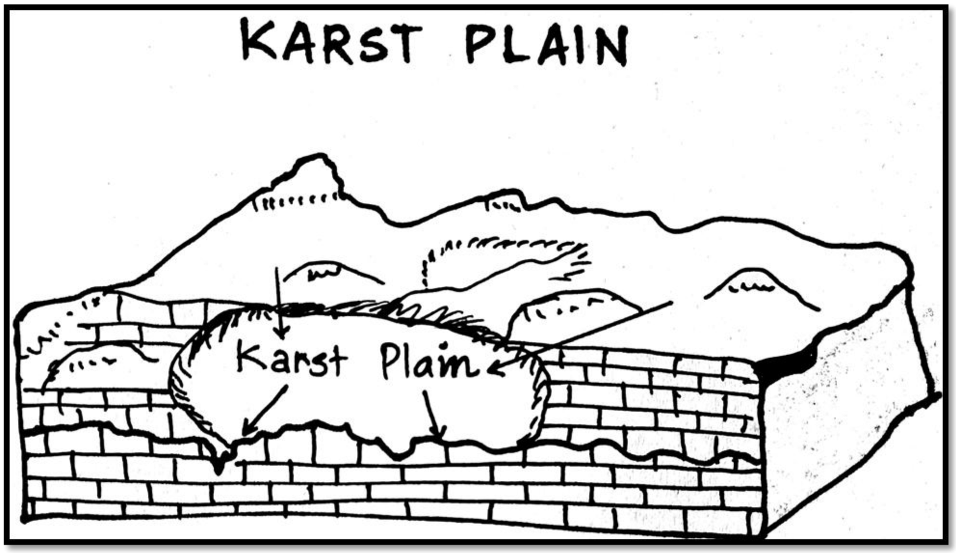

Figure 11.12: Karst Plain, Source Prepared by Author

n) Sinking Creek – when numerous sink holes are located in a line, a sinking creek is formed. If their tops are exposed, then they are called *bogas*.

o) Blind Valleys – When the surface stream disappears in the carbonate rock formation through either a sink hole or a swallow hole, it is known as a blind valley (Figure 11.13).

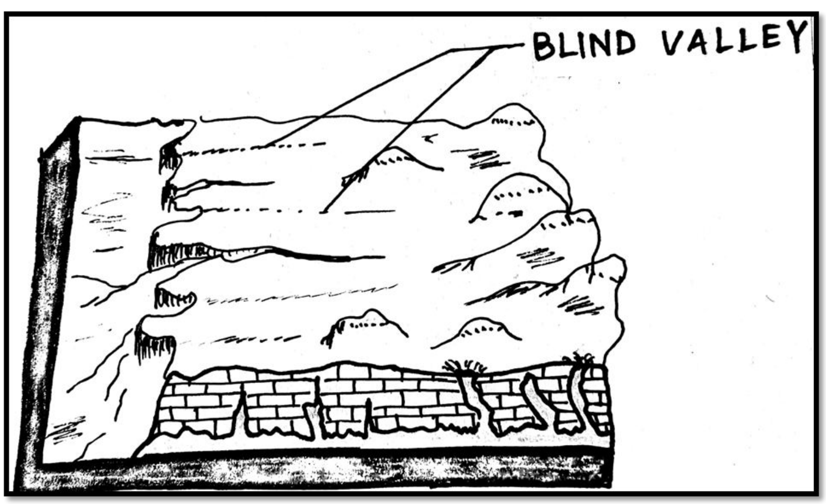

Figure 11.13: Blind Valleys, Source Prepared by Author

p) Dry Valley/ Bourne/ Hanging Valley – In a karst landscape, the surface streams form a U-shaped valley, usually temporary, leaving the valleys dry. They are termed as dry valley or *bourne* or hanging valley (Figure 11.14).

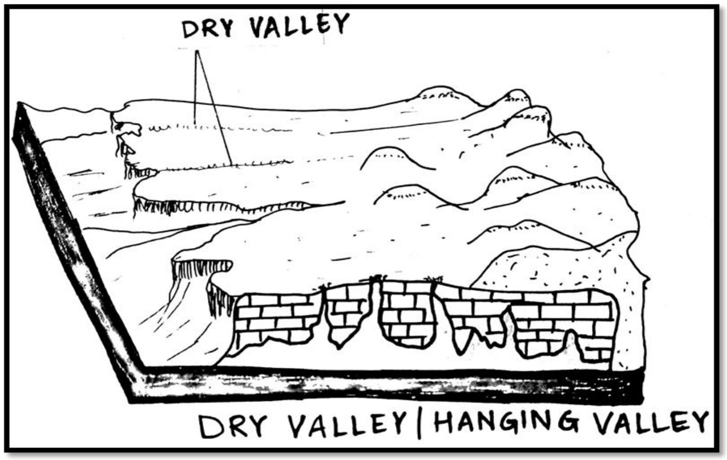

Figure 11.14: Dry Valley, Source Prepared by Author

q) Cavern – Caverns or caves are the most spectacular erosional landform in the karst region dominated by limestone. They vary in sizes and shapes. Numerous theories have been put forward by various scholars about the formation of caves (Figure 11.15).

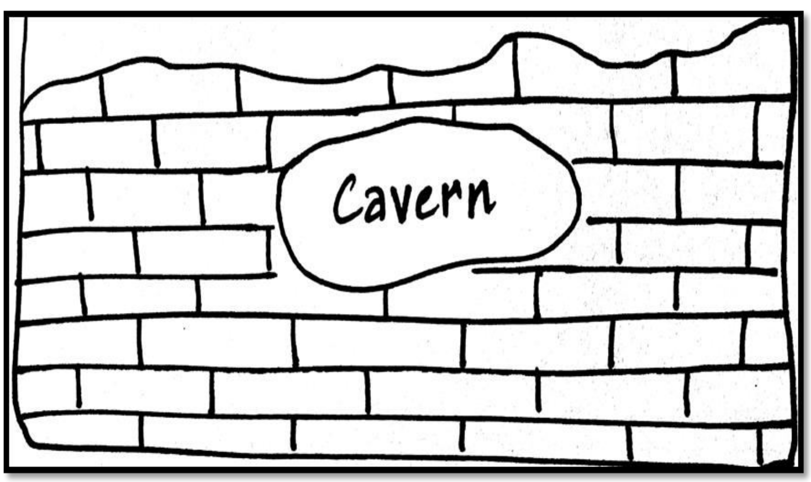

Figure 11.15: Cavern, Source Prepared by Author

r) **Arch/Natural bridge** – When the roofs of the caves collapse or surface streams disappear, the arch or natural bridge is formed (Figure 11.16 and 11.17.

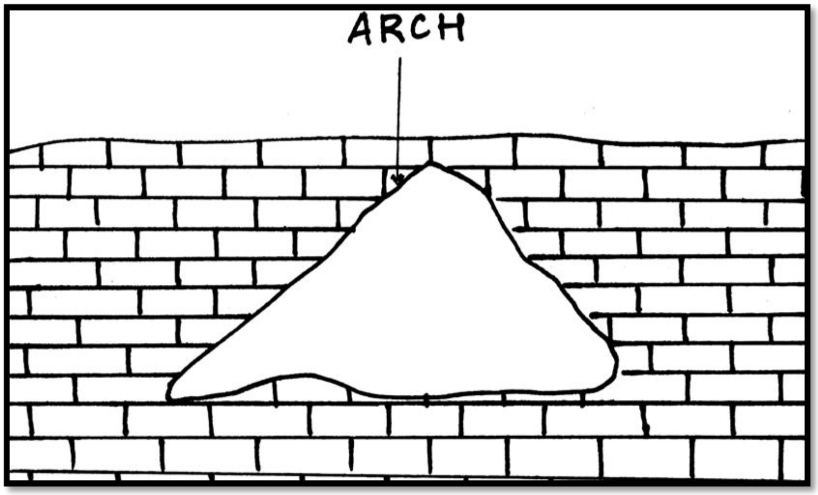

Figure 11.16: Arch, Source Prepared by Author

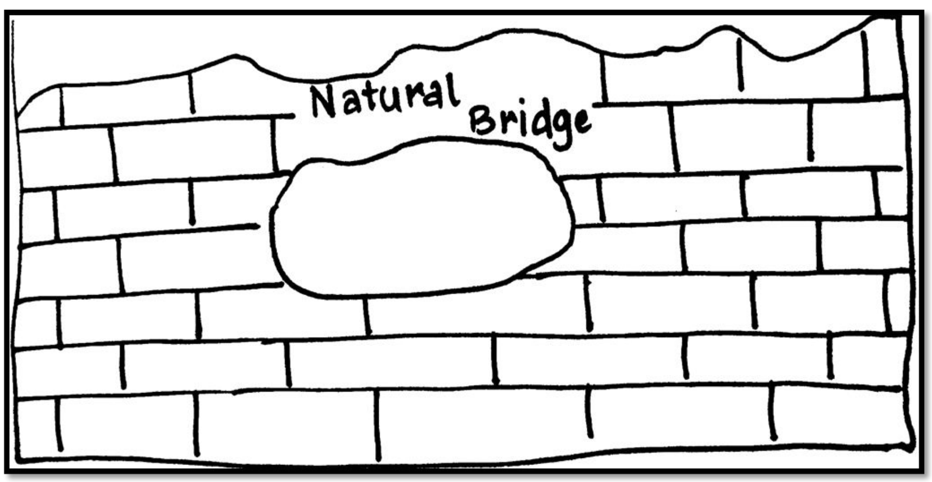

Figure 11.17: Natural Bridge, Source Prepared by Author

s) **Ponors –** These are vertical pipe-like passages that connect the caves with the swallow

- Some of the theories put forward for the origin and development of limestone caves viz.:
    - Corrasion theory of Lapparent, Martonne, Martel, Weller and C. A. Malott,
    - Two-cycle theory of W.M. Davis and supported by J.H. Bretz,
    - Water table theory of A.C. Swinnerton,
    - Static water zone theory of J.H. Gardner,
    - Invasion theory of C.A. Malott
- Various theories have been put forth to account for the origin of natural bridges in limestone regions. These are –
    - Solution theory of F.W. Gilmer,
    - Subterranean stream piracy theory of H.P. Woodward, and
    - Subterranean stream cut off theory of C.A. Malott and R.R. Shrock

holes.

11.4.2 DEPOSITIONAL LANDFORMS

Depositional landforms in a karst region are usually the result of the deposition of calcium carbonate. These have been discussed in this section.

a) **Travertines –** These are banded calcareous deposits. When these are formed at the mouth of the caverns, they are known as *tufa* or *calc-tufa*. The latter one is usually softer in texture (Figure 11.18).

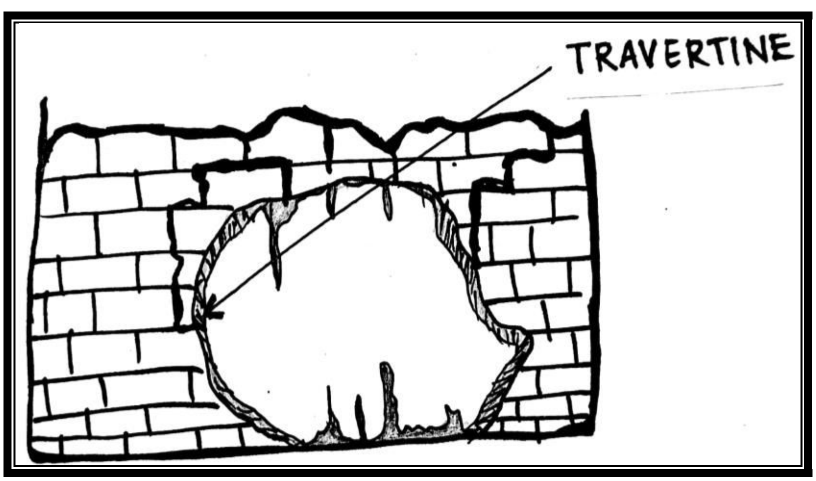

Figure 11.18: Travertines, Source Prepared by Author

b) Dripstones – These are calcareous deposits that form as a result of water dripping in a dry valley. They are found in regions where the cavern is at or above the water table level so that water can quickly evaporate. Drapes, curtains, stalagmites, stalactites, helictites, heligmites, globulites, flowstones, and cave pillars are different formations of the dripstones that form in a karst cave (Figure 11.19).

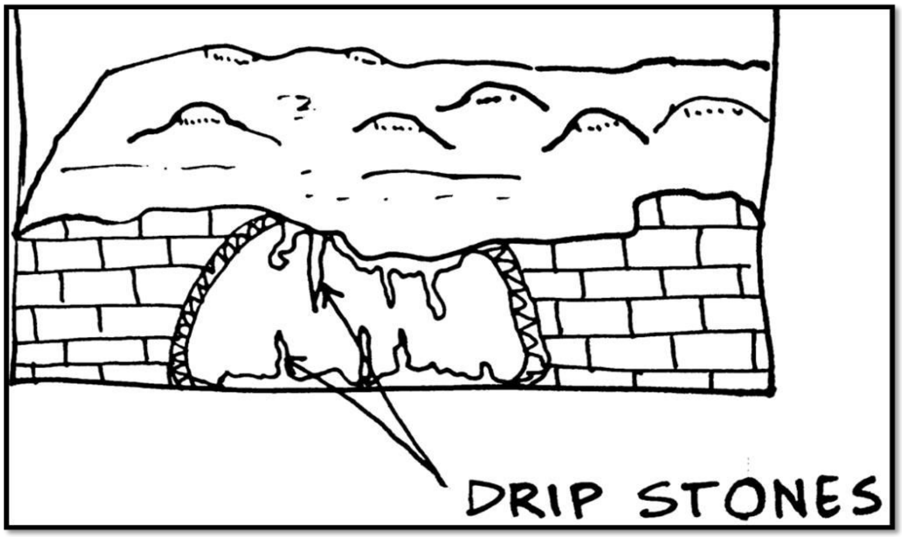

Figure 11.19: Dripstones, Source Prepared by Author

c) Drapes or Curtains – These are needle-shaped, found hanging from the cave (Figure 11.20).

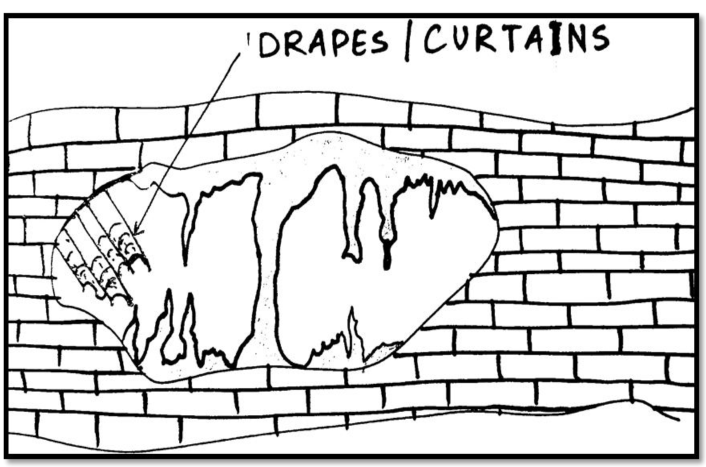

Figure 11.20: Drapes or Curtains, Source Prepared by Author

d) **Stalactites -** Are sharp, slender, downward growing icicles that hang from the caves' roofs. They are of various forms, but their bases are usually broader than the entire structure (Figure 11.21).

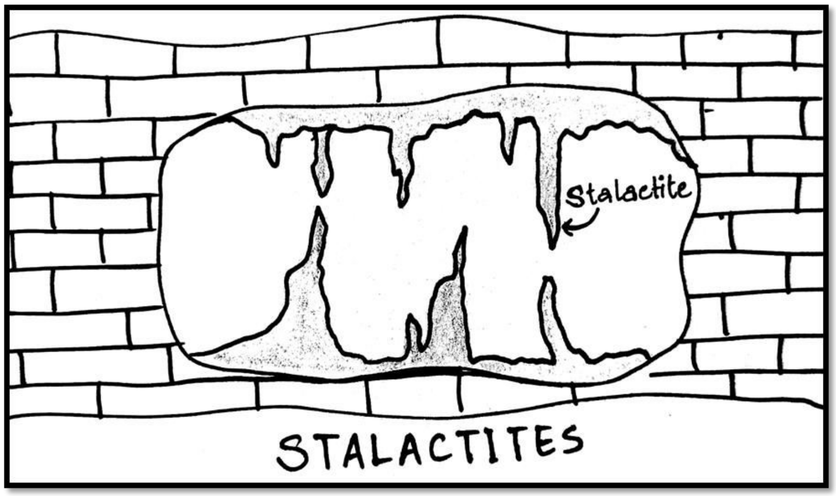

Figure 11.21: Stalactites, Source Prepared by Author

e) **Helictites and Helgmites** – the dripstones that form due to the sideward expansion of stalactites and stalagmites are known as helictites and helgmites, respectively.

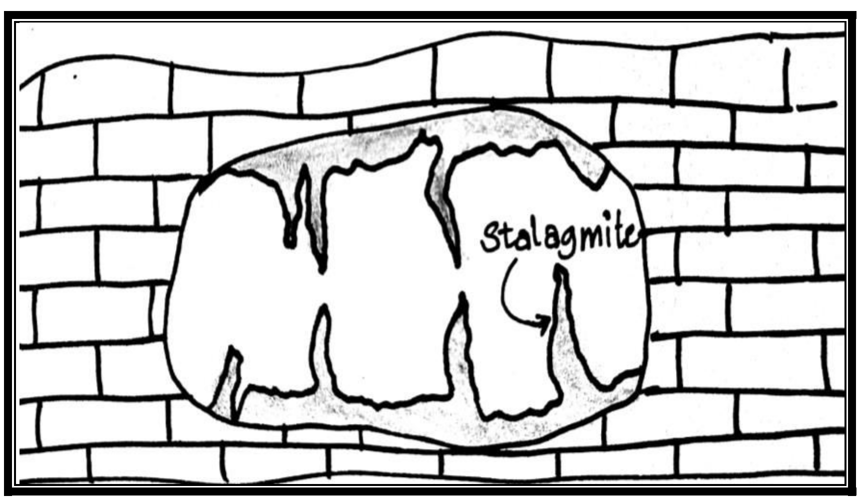

Figure 11.22: Stalagmites, Source Prepared by Author

f) **Globulites and Flowstones –** Globulites are helictites having globular structure, while flowstones are floor deposits formed because of seepage from stalagmites.

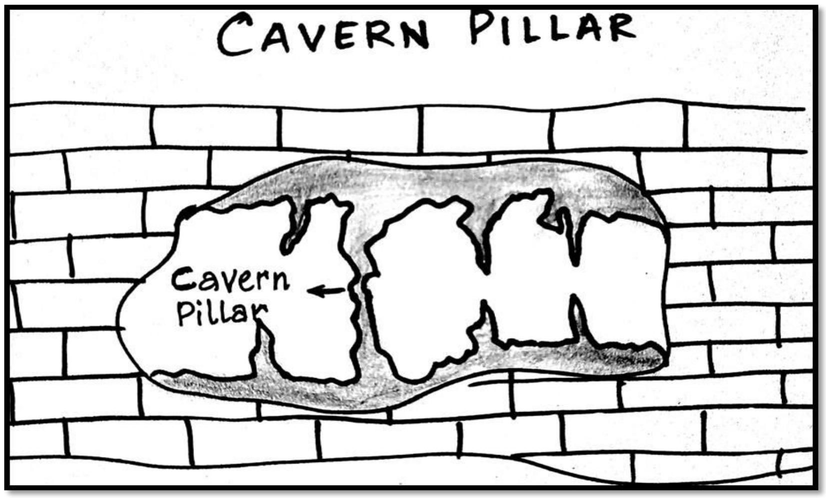

Figure 11.23: Cave Pillars, Source Prepared by Author

g) **Cave Pillars –** Pillars are formed when stalactites merge with stalagmites. These are also of different diameters and are in the form of pillars or columns (Figure 11.23).

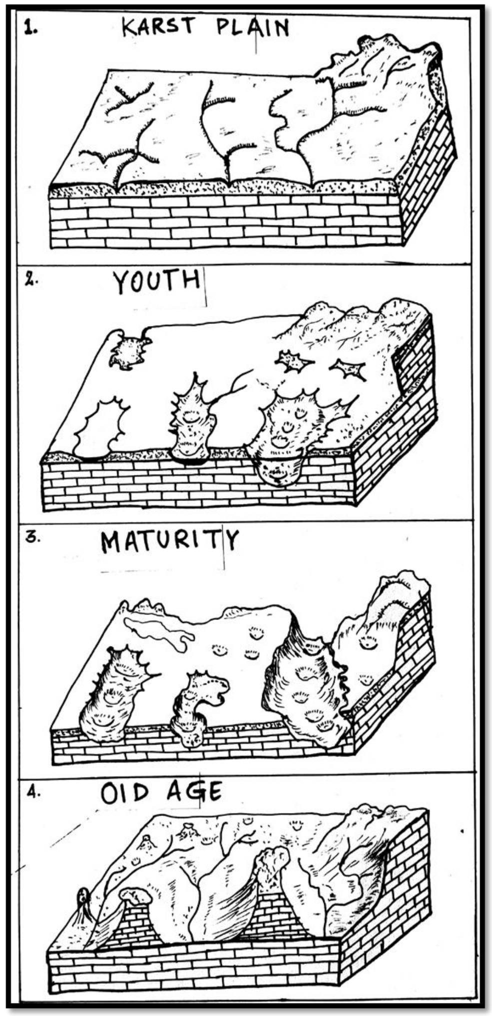

Figure 11.24: Cvijic's Karst Cycle of Erosion, Source Prepared by Author

All these landforms are collectively called speleothems (Figure 11.24).

11.5 KARST CYCLE OF EROSION

The concept of Karst Cycle of Erosion was first put forward by Beede in 1911 and later by Cvijic in 1918. According to Davis (1930), this cycle is a peculiar phase as it is characterized by the appearance and disappearance of surface drainage. He identifies the following four stages –

i. Development of surface drainage

ii. The disappearance of surface drainage underground

iii. Formation of subterranean drainage

iv. The reappearance of subterranean drainage as surface drainage

Beede put forward a three-stage cycle – youth, maturity, and old while, Cvijic's cycle of erosion has four stages. These are youth, maturity, late maturity, and old. In this section, you will study Cvijic's Karst Cycle of Erosion, as shown in Figure 11.24.

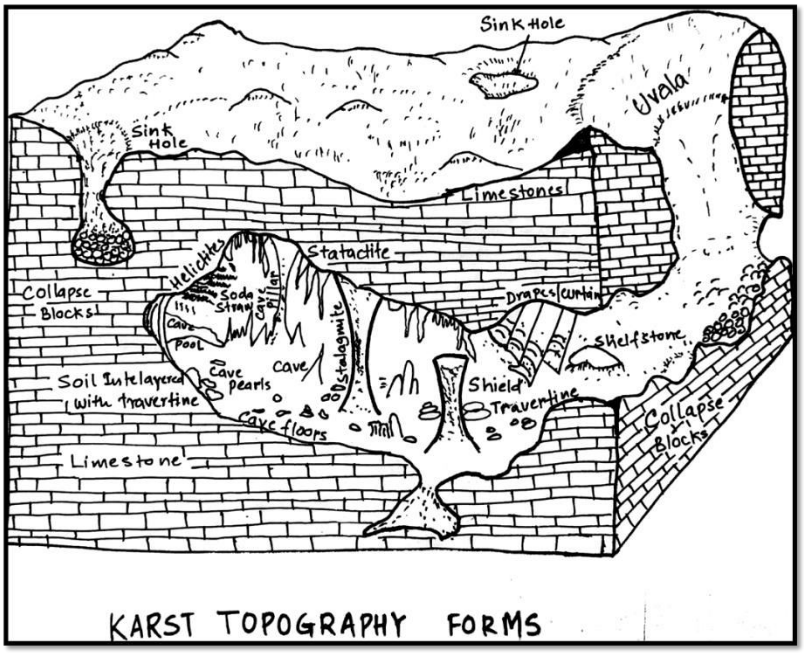

Figure 11.25: Karst Landforms, Source Prepared by Author

Karst topography develops mainly in limestone and dolomite regions because of their differing response to weathering. The two assumptions for the evolution of all the four stages are –

i. a mass of pure limestone, which is soluble and is formed of strata inclined at a great angle but without disruptions from crushing or faulting

ii. the thickness of the limestone mass

The characteristic features of different stages of the Karst cycle of erosion are summarized in the next few sections.

11.5.1 THE YOUTHFUL STAGE

- Initiation of the surface drainage.
- The process of solution leads to the formation of sink holes and swallow holes.

- Development of Lapies or Karren
- The total disappearance of surface drainage marks the end of this stage
- Landforms formed in this stage are –
    - *Sink holes*
    - *Swallow holes*
    - *Sinking creeks*
    - *Lapies or Karren*
    - *Bogas*
    - *Blind valleys*
    - *Caves of smaller dimension*
    - Found in Tennessee, Kentucky, and Virginia in the United States.

11.5.2 THE MATURE STAGE

- Maximum development of underground drainage, therefore, karst topography
- The ground surface had a dry waterless condition
- Development of *caves* and *caverns; swallow holes* and *dolines*
- Developed in the Dinaric coastal strip of the Adriatic Sea.

11.5.3. THE LATE MATURITY STAGE

- The decay of Karst topography
- Formation of *Uvalas, Poljes*, and *Hums*, which are visible on the surface
- The fall of caverns leads to the formation of gorges all over the Karst landscape
- Destruction of most of the solutional landforms

11.5.4 THE OLD AGE

- The reappearance of surface drainage
- Un-roofing of caves occurs

- Formation of Hums in the form of isolated knolls
- It may occur in Natural Bridge County, Virginia, and the Cause of Central France.

11.6 SUMMARY

You have learned about the Karst Region and the various landforms associated with this region. You have understood why this region is unique and what are the essential conditions required for the formation of such a landscape. The karst regions of the world have been explained in detail with the help of tables and maps to show their accurate location.

Solution is the dominant process responsible for such formations in an area which usually has a thick landmass of limestone or any other carboneous rocks. Various landforms form in this region which can easily be distinguished as erosional and depositional landforms. In the depositional landforms the formation of caves or cavern with associated dripstone formations is peculiar of this region.

The entire landscape can be divided into four stages of erosion put forward by Beede and subsequently by Cvijic. According to them there are four stages – youthful, maturity, late maturity and old. Each stage has its distinctive characteristics and landforms which distinguish them from each other.

11.7 GLOSSARY

- **Carbonate karst** – A terrain with typical hydrology and landforms usually result from high-rock solubility and well-developed porosity but at the secondary level. Dissolution is the primary process.
- **Carbonate rocks** - Sedimentary rocks composed mainly of calcium carbonate.
- **Cave system** - A cave or caves are a complex network of interconnected chambers and passages that constitute an underground drainage system.
- **Disappearing streams** - In karst areas, streams often disappear into the ground, usually at a sinkhole.
- **Evaporate Karst -** Here, dissolution is the primary process, but the result is different as the entire process leads to highly mineralized groundwater.

- **Flowstone** - A general term referring to a deposit formed from thin films or trickles of water, the minerals are usually calcium carbonate and encrust floors or walls.
- **Fluvial** - About a river or rivers
- **Groundwater** - Water below the level at which all voids in the rock have water.
- **Permeability** - The property of rock or soil permits water to pass by flowing through interconnected voids (spaces). Permeable bedrock makes a good aquifer, a rock layer that yields water to wells.
- **Porosity** - The volume of void space (space filled with air or water) in soil or bedrock. When these voids are interconnected, water or air (or other fluids) can migrate from void to void. Thus interconnected pores make the soil or bedrock permeable.
- **Pseudokarst** – this type of landscape is very different from the Karst as it mainly develops in unconsolidated sediments or volcanic ash, lava, basalt flows, talus, or ice and permafrost regions.
- **Speleology** - The exploration and study of caves.
- **Troglobites** ("cave dwellers") – A group of animals that complete their life cycle in caves and exhibit adaptations to the dark cave environment.
- **Water table** - The surface between the zone of pure saturation and zone of pure aeration underground.

11.8 ANSWER TO CHECK YOUR PROGRESS

1. The presence of thick massive soluble rocks, preferably limestone, dolomite, or chalk at the surface or sub-surface level
2. These rocks should be dense, highly jointed, mechanically strong, and thinly bedded.
3. Rocks should not be porous but should be permeable.
4. The presence of entrenched valleys below the upland is favorable as it helps in the downward movement of groundwater through the rocks.
5. Considerable relief should be present so that the circulation of water is facilitated to cause typical karst topography.
6. Moderate to heavy rainfall to cause the solution of rocks.

7. There should be a perennial source of water.

4. (i) Italy (ii) Slovenia

5. (i) Jovan Cvijic

Fill in the blanks:

(a) Youthful stage – (i) ………………………………… (ii)…………………………

- *Sink holes*
- *Swallow holes*
- *Sinking creeks*
- *Lapies or Karren*
- *Bogas*
- *Blind valleys*

(b) Mature stage - (i) ………………………………… (ii)…………………………

- *caves* and *caverns;*
- *swallow holes*
- *dolines*

(c) Late Maturity stage - (i) ………………………………… (ii)…………………………

- *Uvalas,*
- *Poljes*,
- *Hums*

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11.10 TERMINAL QUESTIONS

1. Answer the following questions briefly?

a. How does the process of solution occur in the Karst landscape?

b. Write briefly about the location of Classic Karst?

c. Write the three scales in which the landforms in the karst region develop?

2. Distinguish between the following pairs with suitable diagrams:

a. Arch and Natural Bridge

b. Stalactites and Stalagmites

3. The following landforms have been formed in a Karst Region. Group them under erosional and depositional features.

Karren, Traventines, Dolines, Flowstones, Grikes, Solution Pan, Cave Pillars, Poljes, Arch

4. Explain the different formations of dripstones in a cavern with a suitable diagram?

5. Discuss the Karst Cycle of Erosion.

UNIT- 12 MARINE AND COASTAL LANDFORMS

12.1 OBJECTIVES:

After studying this lesson, you will be able to:

- Explain the agents and processes involved in the formation of marine and coastal landforms.
- Describe, with the help of diagrams, different types of erosional and depositional landforms produced in such a landscape
- Understand the Marine cycle of erosion

12.2 INTRODUCTION

You have learned how different erosion and deposition agents work on the Earth's surface in the previous chapters. You have already learned about landforms formed by periglacial, glacial, aeolian, karst, and water processes. In this unit, we will study the marine landscape and the coastal landforms. Here we will learn about the process of erosion that occurs in the marine landscape. Under this section, you will come to know about the agents of erosion and their mechanism. Different landforms have formed because of marine erosion and deposition in such a landscape. We will be discussing these landforms in this chapter. Finally, you will also know about the marine cycle of erosion on the shoreline of emergence and the shoreline of submergence. The coastline is the zone where waves erode, transport, and deposit materials. Landforms created along the coastline depend on several factors like the size and intensity of waves, direction of the wind and speed, and rock-types along the coasts. Waves can be constructive or destructive. Destructive waves create caves, stacks, bays, etc., whereas the constructive waves create depositional features such as spits, bars, dunes, and marshes. Coasts are continuously changing due to human activities and the action of the sea. Coasts are famous tourist destinations as they attract tourists to beaches and other relief features. It benefits the country and the fishing community in that area by providing them work.

12.3 PROCESS OF EROSION

The marine environment is composed of a variety of landforms in a broad spectrum of sizes and shapes. Before knowing about these landforms, you must be aware of the agents of erosion that are active in such a landscape. Apart from that, you should also know about the different processes responsible for marine and coastal action. All these will be discussed in this section.

12.3.1 Agents of Erosion

Waves, tides, and currents are the most predominant action of erosion in a marine environment. These actors have been discussed in this section.

Waves

- Waves are the most powerful force that acts in a marine landscape.
- These are periodic undulations over the water surface which are wind-driven.
- Frictional drag is the primary process that results in the formation of waves.
- They are dynamic systems that bring both constructive and destructive changes to the marine environment.
- The action of a wave is of two types – the swash and the backwash.
- They change every day; they will construct beaches or lead to depositional landform formation on a calm day. While on a stormy day, they can be very destructive.
- Waves can erode, transport, and deposit marine sediments.

Tides

- Tides are the daily or semi-diurnal rise and fall of the Earth's mean sea-level caused by the sun's and moon's gravitational force.
- Tides cause a change in the water level and coastal areas, and they also shape the coastal landforms as they erode, transport, and deposit sediments by ocean water.
- There are two high tides, called *flood tides*, and two lows tides called *ebb tides* in a day.
- Spring tides occur every 14- 75 days when Sun and the Moon are aligned on the opposite sides of the Earth and are higher than normal high tides.
- Neap tides occur when the Sun and the Moon are positioned at an angle of 90◦ to the Earth's position and are generally lower than normal low tides.
- Tides carry fine silt and clay, deposit it in the floors of the bays.

Currents

- The waves in the near-shore zone produce currents.
- Currents are of utmost importance as they act as sources of sediment supply, energy, and the

coastal area's biotic element.

- They are effectively involved in shaping seafloor topography and beaches.
- Currents may include longshore currents, rip currents, and off-shore currents.
- Longshore currents travel parallel to the coast, and it approaches the coast obliquely.
- Rip currents develop at regular intervals perpendicularly to the beach.
- Onshore currents are the slowest among all, and it develops between rip currents.

Tsunami

- The faulting of the sea floor produces it.
- It is named after a Japanese term meaning 'harbour wave.'
- They are referred to as tidal waves or seismic sea waves.
- Waves travel at a speed of 700 to 800 km/hour in all directions from the point of source.
- In the deep ocean water, the waves' motion is very gentle, but once it reaches the land, it destroys the coastal features and helps in the deposition of materials or loose sediments.
- It reshapes the coastal landscape and also affects hundreds and millions of people living near the coasts.

12.3.2 Mechanism of Marine Erosion

Let us now look at the various mechanisms of marine erosion that operate in the coastal areas to transform the coasts' landscape. The tides, waves, tsunami, and currents affect the topographical features made through sea waves' action (Figure 12.1). It depends on the nature of rocks, effects of marine agents of erosion, amount of topography exposed to the sea, and human interference. There are four processes involved in the erosion of marine landforms are as follows:

Corrosion or Abrasion is the process of wearing away surfaces against the boulders, pebbles, and rock fragments and breaks up the rock while moving with the water body. It is a mechanical tear and wear process and is considered to be a powerful agent of erosion.

Attrition occurs when rock debris such as boulders, pebbles, and fine sand, hit against each other, thus eroding them into smaller particles. This process is called attrition when broken materials are responsible for the formation of the beaches.

Hydraulic action is the process when waves move forward and splash the coast to enter into the rock fractures (joints and crevices). When the waves retreat, the air pressure is released, and repeated action causes large rock pieces to break away. These actions directly affect the coastal landforms.

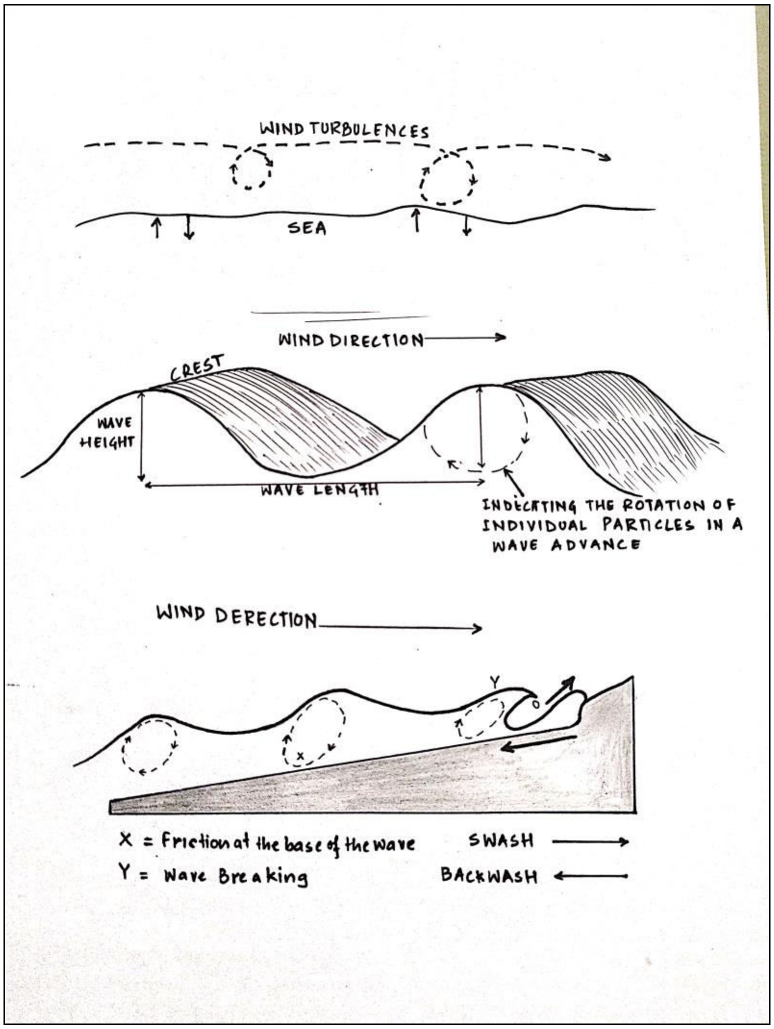

Figure 12.1: Mechanism of Wave Motion, Source Prepared by Author

Solvent action refers to the chemical alteration of the rocks due to contact with the seawater. The solution is an essential process in the limestone areas where soluble rocks are exposed to seawater's solvent calcium carbonate. It leads to the solution of rocks due to the physical and chemical process of erosion.

12.4 COASTLINES

12.4.1 Coastline of Emergence

- Coastlines of emergence are formed by an upliftment of the land or by lowering of the sea level.

- Some features of these coasts are spits, lagoons, beaches, cliffs, etc.
- Depositional landforms are common in the coastline of emergence, and they are less common.
- The depositional landforms are formed due to the supply of sediments along the coasts (Figure 12.2).
- These coasts are associated with the tectonic upliftment of land.
- Marshes and swamps are common along the emergent coasts.
- The eastern coast of India (**Tamil Nadu or Coromandal coast**) is an example of a coastline of emergence.
- The **Malabar Coast of Kerala Coast** is the coastline of emergence.

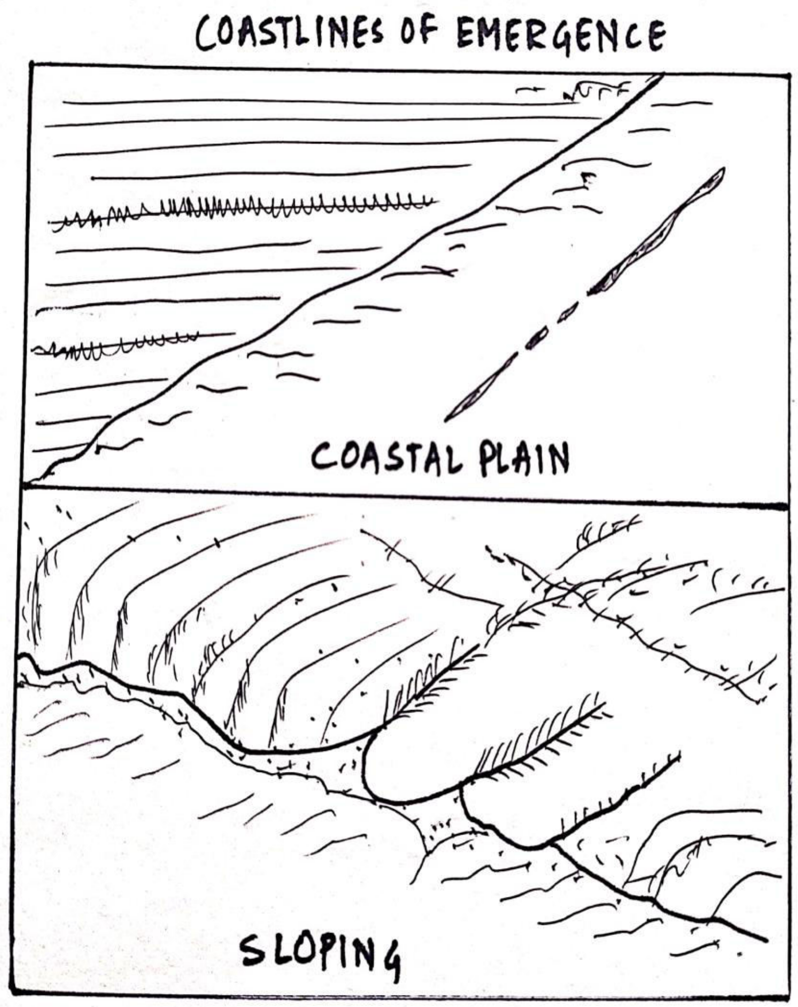

Figure 12.2 Coastal, Source Prepared by Author

12.4.2 Coastline of Submergence

- The coastline of submergence is formed due to the submergence of land or sea-level rise.
- Many deltaic areas are getting submerged due to a rise in the sea level or human interference.
- Some features of submerged coastlines are Ria coasts, Dalmatian coast, Fiords, and drowned lowlands.
- In the coastline of submergence, erosional agents are more dominating
- Waves and currents carry materials along with them and deposit them as beaches, bars, and spits.
- Subsidence can be due to natural phenomena such as tectonic processes or some areas due to anthropogenic processes such as groundwater mining.
- India's northern, western coast (**Konkan or Maharashtra coast**) is an example of a submergence coastline.

12.4.3 Other Types

Ria

- A coast with many estuaries or long fingers of seawater projecting inland is called a ria shoreline.
- The term 'ria' is derived from a Spanish word meaning 'river.'
- An example of the Ria coast is the Atlantic type of coast: south-west Ireland, north-west France, and north-west Spain.
- It is a long, narrow inlet of a river that decreases in depth from mouth to head and produces an irregular shoreline on the Ria coast.
- These coasts are a unique habitat for plants and animals as the valleys add freshwater to the bays making the saltwater and freshwater mixed.
- The shoreline rises the sides of the stream-carved valleys, creating narrow bays. Streams that flowed through the valleys add freshwater to the bays, making them estuaries of mixed fresh and saltwater, thereby producing a unique habitat for many plants and animals (Figure 12.3).

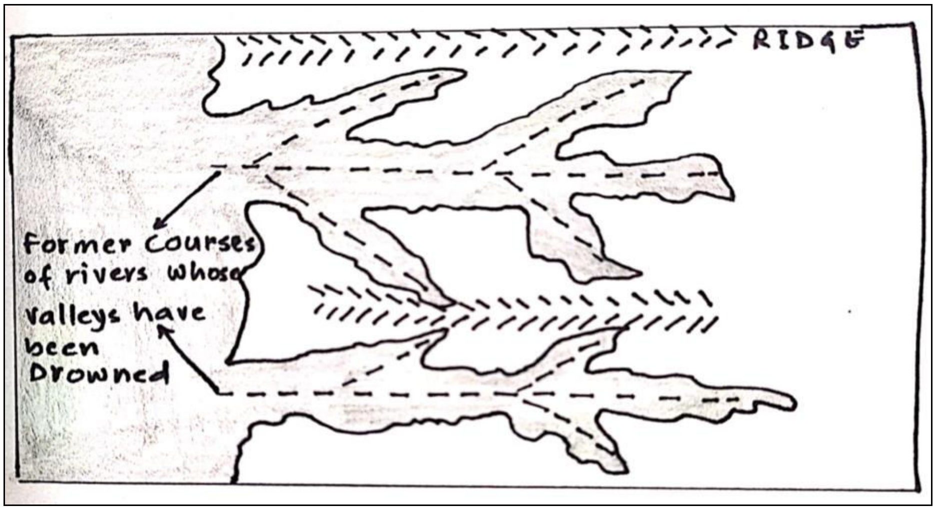

Figure 12.3: A Ria Coast, Source Prepared by Author

Fiord

- These coasts are highly susceptible to landslides due to the coarse sediments and steep nature of fiords.
- The examples are Maine in the USA, Norway, Alaska, British Columbia, South Island of New Zealand, and southern Chile.
- A fiord coastline emerges when the glaciers heavily erode coastal areas.
- Fiords are irregular as they are long, narrow fingers of saltwater reaching hundreds of meters more in-depth than the adjacent seas, and they meander tens of kilometers inland.
- The valley glacier troughs are so deep that their bottoms are below sea level now, and they got filled up with seawater during the Pleistocene period (Figure 12.4).

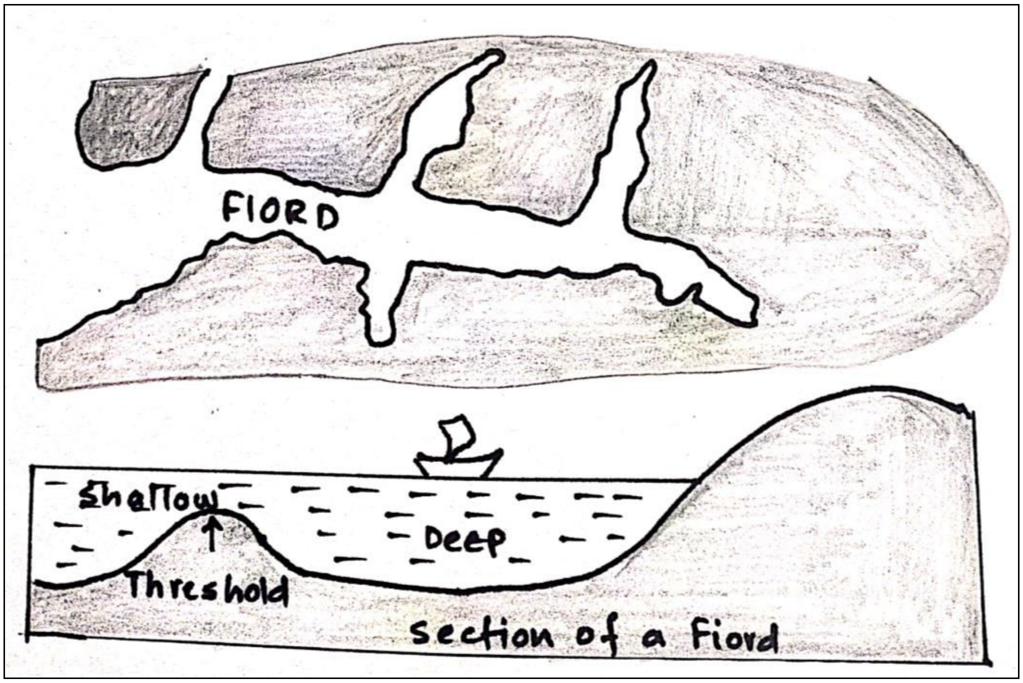

Figure 12.4: A Fiord Coast, Source Prepared by Author

Dalmatian

- These are the longitudinal coasts formed due to the submergence of mountains running parallel or concordant to the sea coasts are Dalmatian coasts (Figure 12.5).
- The Coast of Dalmatia, Yugoslavia, along the Adriatic Sea is a typical example.

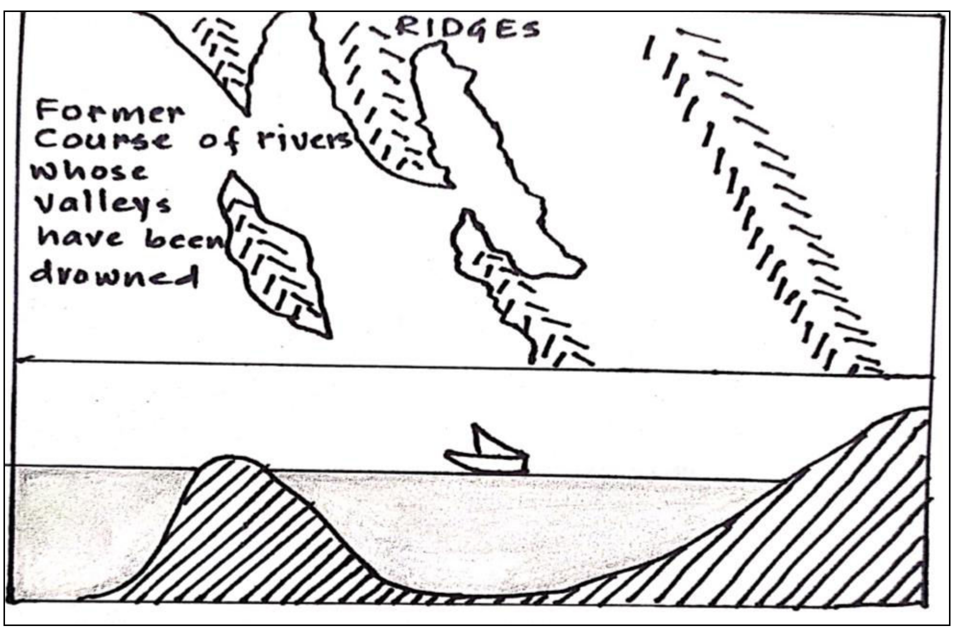

Figure 12.5: A Dalmatian Coast, Source Prepared by Author

Neutral Coastlines

When there is no relative change in the sea level, and the coastal areas are neutral coastlines. Such coastlines are deltaic coastline, volcanic coastlines, coral reef coastlines, and alluvial fan-shaped coastlines. Neutral coastlines are formed when new materials are being built out into the water.

Compound Coastlines

Compound coastlines are the formation of two coastlines, such as submergence followed by emergence or vice versa. The coastlines of Norway and Sweden are typical examples of compound coastlines.

Fault Coastlines

The fault coastlines result from the submergence of downthrown blocks along a fault such that the uplifted block has its steep side standing against the sea (Figure 12.6).

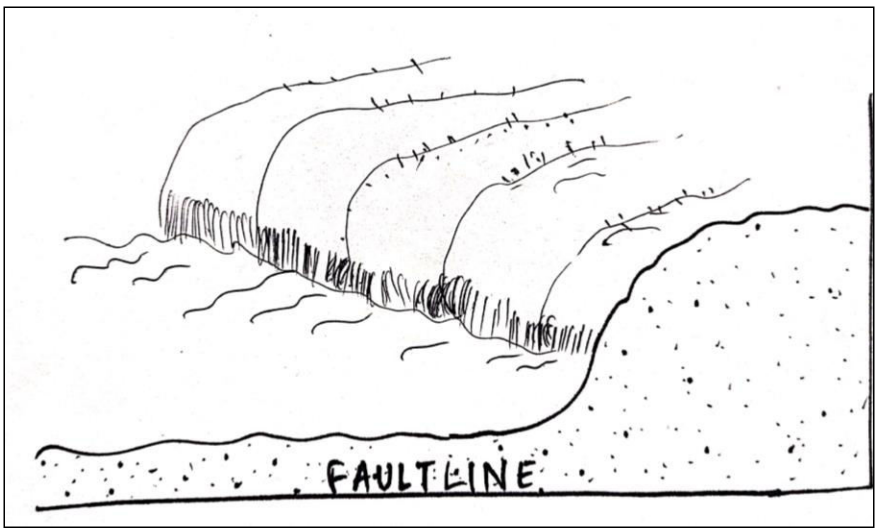

Figure 12.6: A Faultline Coast, Source Prepared by Author

2. Name any two neutral coastlines.

3. Give some examples of submerged coastline features.

4. Define Dalmatian coasts.

12.5 LANDFORMS

12.5.1 Erosional Landforms

The erosional landforms produce several distinctive features along the coastline. These are:

Cliffs and Wave-cut Platform

- Cliffs are steep or vertical slopes at a rocky headland, leading to steep wave-cut cliffs rising perpendicularly from the sea level.
- The waves erode the cliff gradually to carve out a wave-cut platform (*wave-cut bench*), leaving a flat surface behind.
- Wave cut surfaces are few meters to hundreds of meters wide.
- Cliffs are created due to hydraulic action, Abrasion, chemical solution, and pneumatic push at the base of the cliff.
- Waves impact the lower parts of the rocks intensively, leading to the notch formation at this position.
- Sea cliffs are a common feature along the Konkan coast of India, and some best-known cliffs are the Chalk Cliff of the English Channel (Figure 12.7, 12.8, 12.9 and 12.10).

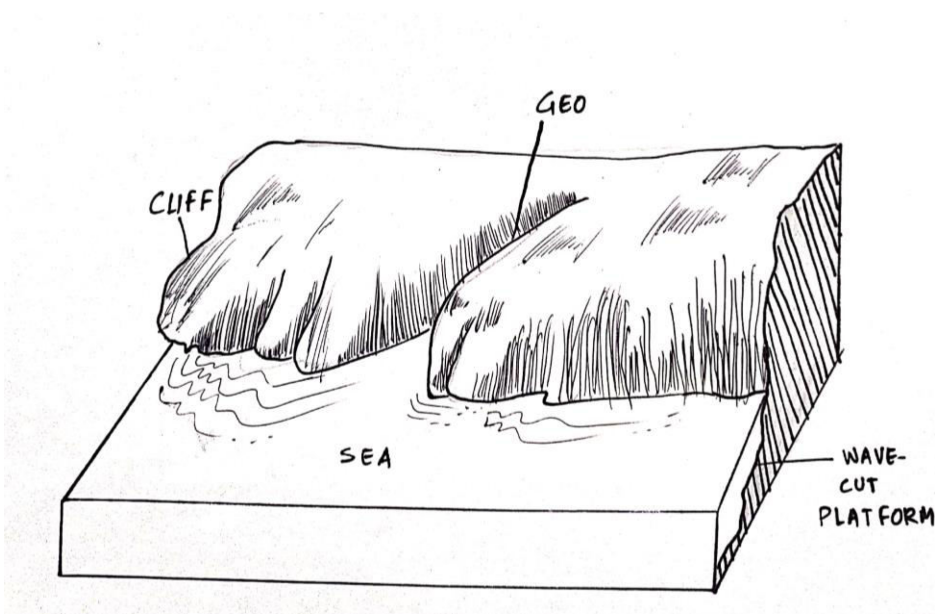

Figure 12.7: Cliff and Wave-Cut Platform, Source Prepared by Author

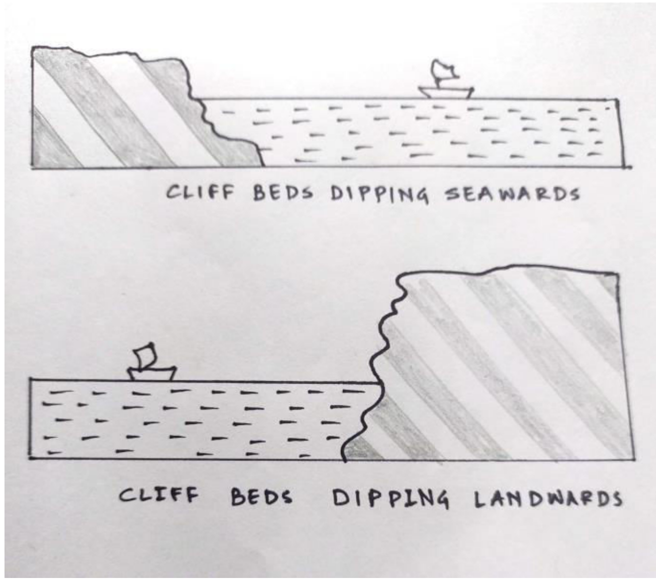

Figure 12.8: Cliff Beds Dipping Seawards and Landwards, Source Prepared by Author

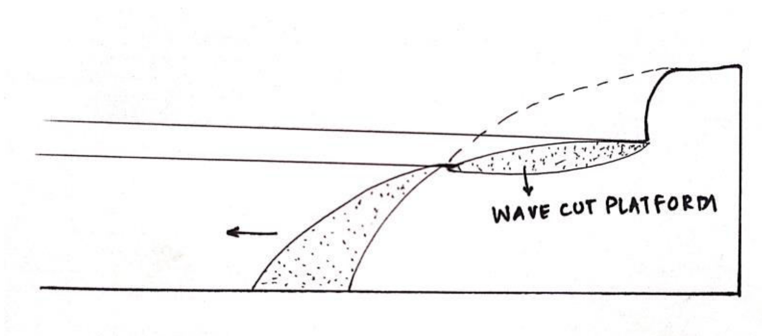

Figure 12.9: Wave-Cut Platform Profile, Source Prepared by Author

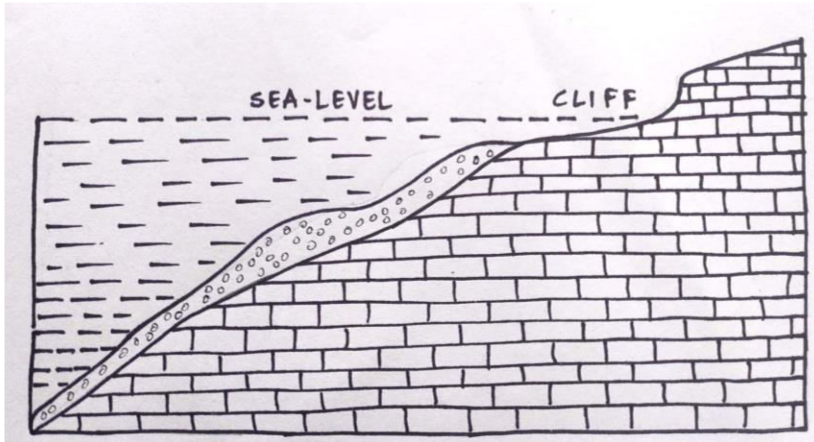

Figure 12.10: Cliff, Source Prepared by Author

Marine Terraces

- Marine Terraces are formed due to the tectonic upliftment of wave-cut platforms.
- During the Pleistocene period, some of the marine terraces were formed due to changes in sea level.
- With the fall in the sea level, the wave-cut platform remains above the sea level, whereas the terraces remain high due to tectonic uplift.
- These are common features in the island coasts of the Pacific Ocean.

Sea Caves

- Caves are formed by the action of waves against the base of the cliff.
- When the upper part of the coast is hard, and the lower part is soft, repeated erosion may create a hollow or cavity at the lower part of the cliff creating a hole in that region.
- These holes get widened to form the shape of a sea cave.
- Flamborough head in England is a typical example of a sea cave (Figure 12.11).

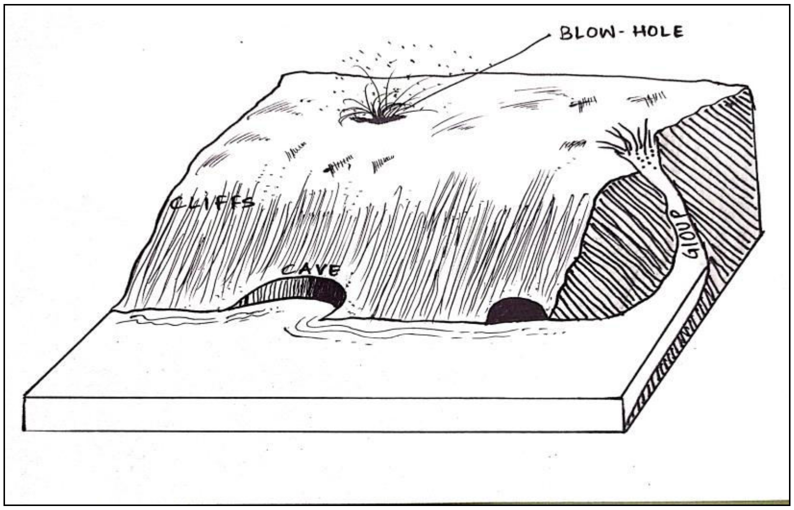

Figure 12.11: Sea Caves and Blow Holes, Source: Prepared by Author

Blow Holes and Geos

- Blow Holes or Gloup are formed when the waves attack the roof of a cave forming a natural shaft.
- Air gets trapped inside the caves causing the joints to enlarge, eventually piercing through the surface.
- One of the best-known examples of blowholes is Holborn Head, Scotland (Figure 12.11).

Sea Arches

- A bridge-like structure is formed when two caves unite from either side of a headland to form an arch or natural bridge.

- These are formed due to differential erosion of the rocks.
- Their height can be up to tens of meters above sea level.
- Initially, they are narrow holes, but it develops into broad arches over time.
- Needle Eye near Wick, Scotland, is an example of sea arches (Figure 12.12).

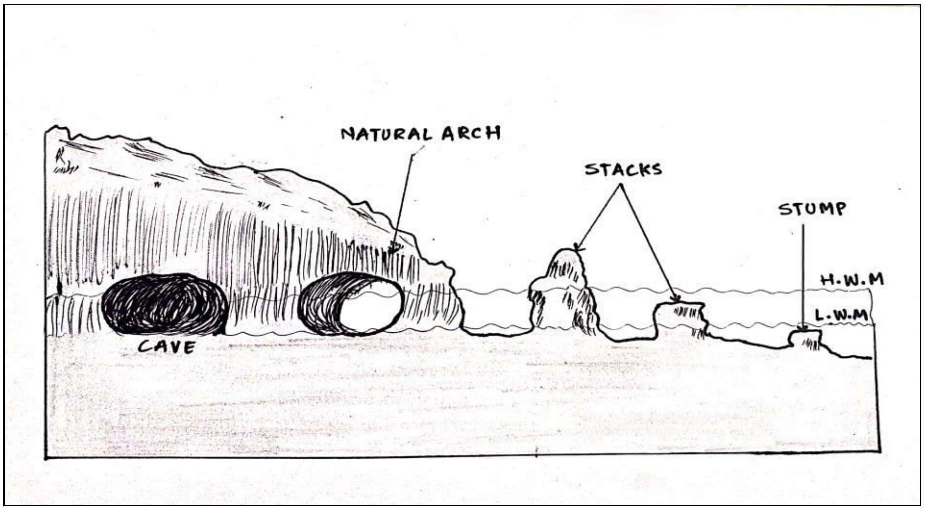

Figure 12.12: Natural Arches, Stacks and Stump, Source Prepared by Author

Stacks/Chimney Rock

- Sea Stacks or Chimney Rocks are isolated pillars of rock formed when the roof of an arch is broken due to its weight, folding, and different rock types.
- It can also develop due to erosion of the cliff or collapse of the arch roof.
- There are several types of stacks based on the shape and the nature of the rock material.
- The Orkney Islands in Scotland, the Old Man of Hoy are an example of the stack (Figure 12.12).

Stump

- Small underground stacks are known as stumps
- It is developed due to gradual erosion.
- It is only visible above sea level (Figure 12.12).

Gorges

- Gorges are narrow, steep clefts formed due to erosion or collapse of lava or mining tunnels.
- In Scotland, Gorges are also known as geos.
- Geos are long, narrow inlet and deep clefts formed when the blowholes get enlarged due to waves' continuous action weakening the cave roof.
- An example of Geo is Land's End in Cornwall in south-west England.

12.5.2 Depositional Landforms

The sediments along the coastline reach the onshore by transportation and deposition of loose sediments. Depositional features disappear, appear, or migrate because of seasonal changes, storms, human interference, waves, winds, etc (Figure 12.13).

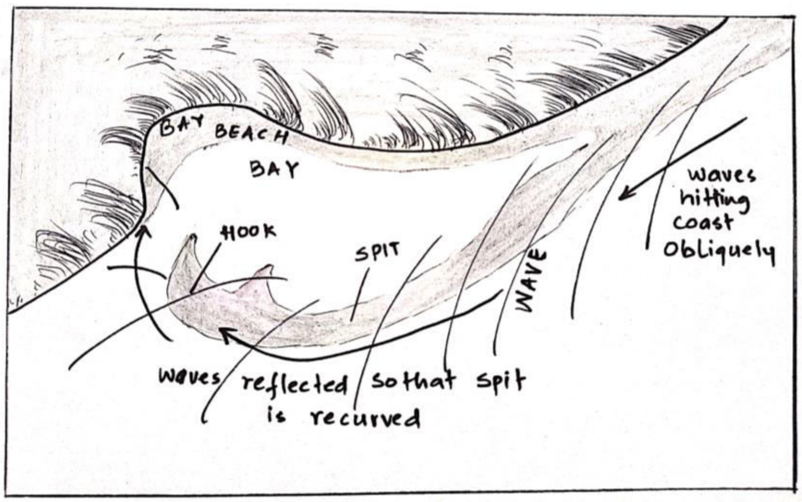

Figure 12.13: Depositional Landforms, Source Prepared by Author

Beach

- Beaches are the wedge-shaped deposits of loose sediments composed of fine sand or gravel between land and water.
- Beaches are a temporary feature made up of sediments coming from the land being deposited along the shore by waves' action.
- Due to eroded material deposition, the sea becomes shallow, forming a raised portion of gravel and sand along the coast is called a beach.
- Marina Beach of Chennai and Baga Beach in Goa are some of the famous beaches in India.

Bar

- Bars are aggradational ridges of sand and shingle at the off-shore zone across the mouth of a river delta, estuary, or continental shelf.
- Bars may be distinguished based on their shape, such as linear, sinuous, or crescentic, and transverse bars.

- These are formed parallel to the coast.

Barrier

- Coastal barriers are the deposition of beach material across the mouth of a river and inlets of a bay.
- These are composed mainly of sand or gravel and usually occur in chains.
- Barriers form at the mouth of a bay and enclose lagoons or swamps.
- Cuspate barriers and looped barriers are formed by growing spits touching an opposite shore (Figure 12.14).

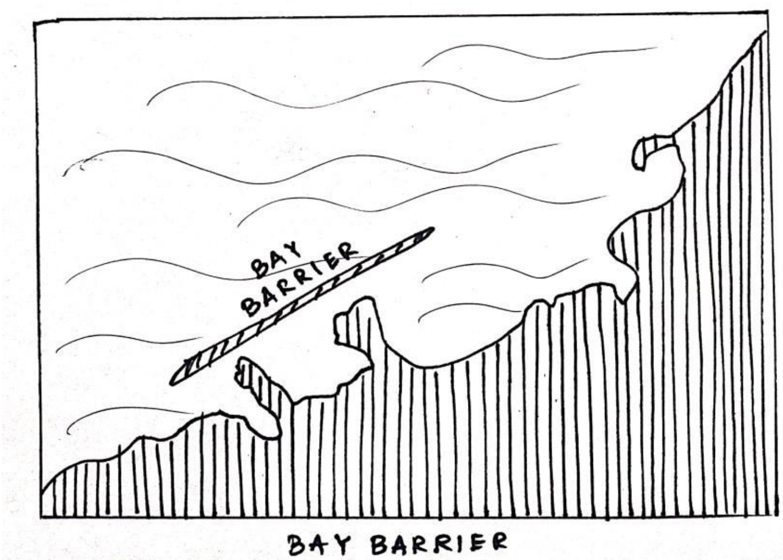

Figure 12.14: Barrier, Source Prepared by Author

Dunes

- Dunes are formed due to large sand supplies by the action of wind, currents, and waves.
- These are heaps of sediments deposited at the edge of the coast.
- Coastal dunes are medium-sized to fine grains found along the onshore.
- Human activities, waves, and wind erosion may affect the size and shape of the dunes.
- Sand dunes are a common feature along the coast of Denmark, Belgium, and the Netherlands.

Spit and Hook

- Spit is an extended stretch of beach material, with one end attached to the land and the other end extending into the sea.
- A hook is created by water movement in the bay, causing the deposited material to curve towards the mainland, forming a hook at the spit's outer end.
- These are formed by the accumulation of sediments brought by the waves.
- Its elongation is dependent on the availability of sediments and transporting potential of the waves.
- Spits can vary in size, and they are mainly dominated by sand.

Tombolos

- Tombolos are a sandbar, barrier, or spits connecting an island to the mainland.
- These are constructive features created at the shoreline of submergence.
- Chesil Beach, South England, is an example of Tombolo.
- Tombolos exist in single, double multiple, forked, parallel, or complex forms. It restricts the flow of the sea and the intertidal zone, which forms a **lagoon**.**Estuaries**

- It is a long and narrow coastal wetland where saltwater from tides and freshwater from river runoff is mixed.

- These are the transition basin- like zone between rivers and the sea where fresh river water mixes with salty ocean water.
- The topography of the coastal area determines Their shape.

12.6 MARINE CYCLE OF EROSION

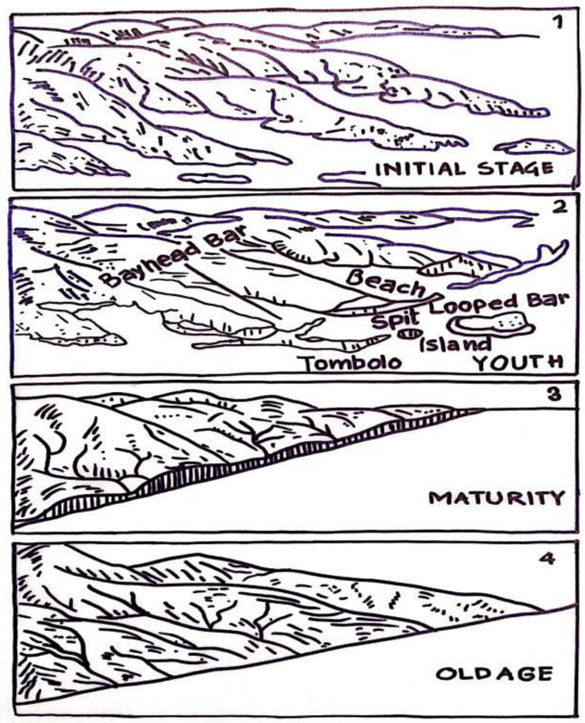

Figure 12.15: Marine Cycle of Erosion on the Shoreline of Emergence, Source Prepared by Author

12.6.1 On the shoreline of emergence

Initial Stage: The Shoreline of Emergence in the initial stages are generally straight and regular.

Emergence can take place due to:

(a) Negative change or fall in the sea level

(b) Due to upliftment of the land

YOUTH STAGE:

The youthful stage begins with the emergence of bars and barriers above sea level. These bars act as a barrier for waves. Water gets locked between these bars are lagoons, which eventually become swamps and marshes. These lagoons become narrow with repeated erosion in the bars' seaward side and deposition on the landward side.

MATURE STAGE:

In the mature stage, the water depth increases, and the slope becomes steeper. Sea waves erode the wave-cut platform. Lagoons, estuaries, swamps, and marshes are also obliterated with the mature stage's beginning on the coastline of submergence.

OLD STAGE:

In the shoreline of emergence, the old stage is practically not possible. It is a theoretical concept with lesser value (Figure 12.15).

12.6.2 On the shoreline of submergence

Initial Stage: Due to rising sea levels or the submergence of land, the marine cycle of erosion begins in the shoreline of submergence.

Submergence can take place due to:

(a) Submergence of land under seawater

(b) Positive change or rise in the sea level

YOUTH STAGE:

In the youthful stage of marine erosion, waves or currents erode the coastal rocks due to hydraulic action and Abrasion. The coastline becomes irregular because of waves attacking the large rock structures leading to the formation of caves and headlands. Wave cut platforms,

arches, stacks, caves are also developed in the early youth stage due to erosion. Cliffs are formed because of repeated erosion at the lower part of the rocks. Some depositional features such as bars, spits, hooks, Tombolo, beaches, etc., are formed in the late youth stage.

MATURE STAGE:

The headlands characterize the mature stage cut back to the intervening bays, and coastlines are straightened. Connecting bars or barriers disappears in the late maturity stage. The coastline becomes straight and regular. Most of the relief features formed in the youthful stage are destroyed in the mature stage

OLD STAGE:

This stage is theoretically possible because both submergence and emergence take place due to diastrophism. The coastal areas or shore are eroded significantly because of weathering and erosion by the waves and currents, reducing the relief's shape and size. Therefore, the shore becomes gentle towards the sea (Figure 12.16).

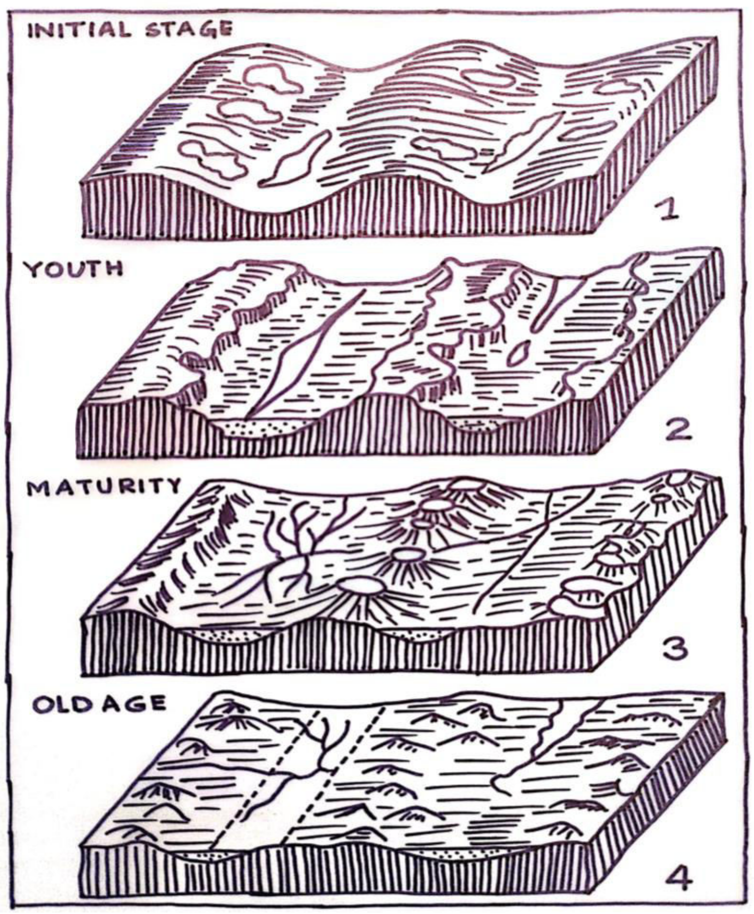

Figure 12.16: Marine Cycle of Erosion on the Shoreline of Submergence, Source Prepared by Author

12.7 SUMMARY

This unit has described the processes and landforms associated with the action of waves, or wind-driven waves. Waves produce a distinctive set of landforms by breaking up the rocks, transporting and depositing the sediments in different parts of the coasts. The agents of erosion in the marine cycle of erosion are Abrasion, attrition, hydraulic action, and solution. Erosion

produces relief features such as cliffs, arches, stacks, sea caves, etc. Transportation helps in the movement of eroded material and its deposition near the coastal region. Deposition produces

features like bars, lagoons, estuaries, beaches, etc. Weathering destroys the coastlines, whereas deposition creates landforms along the coasts.

Sea level changes lead to the formation of submerged and emerged coastal features due to increase and decrease, or fluctuation in the sea level. The submerged coastal features are rias, benches, Dalmatian, Fjords, notches, etc. At the same time, emerged coastal features are marshes and swamps.

12.8 GLOSSARY

- **Coastline:** Coastline is the zone of shallow water and nearby land that fringes the shoreline.
- **Shoreline:** The shoreline is the dynamic zone of contact between water and land.
- **Fjords:** Fjords are irregular as they are long, narrow fingers of saltwater reaching hundreds of meters more in-depth than the adjacent seas.
- **Ria Shoreline:** A coast along which there are numerous estuaries is usually called a ria shoreline.
- **Tombolo:** It is a depositional feature that connects a near-shore island with the mainland.
- **Backshore:** It is the upper part of the beach, landward of the high-water line.
- **Foreshore:** The foreshore is the zone that is regularly covered and uncovered by the rise and fall of tides.

- **Off-shore:** The off-shore zone is permanently underwater and deep enough that wave action rarely influences the bottom.
- **Lagoon**: A body of quiet salt or brackish water in an area between a barrier island or a barrier reef and the mainland.
- **The intertidal zone** is between high and low tides.

12. 9 ANSWER TO CHECK YOUR PROGRESS

1. Waves cause constructive and destructive changes to the marine landscape. They can erode, transport, and deposit the sediments by the action of swash and backwash. Waves construct beaches on a calm day or can destroy landforms on stormy days.

2. Tsunamis are strong tidal waves caused due to faulting of the seafloor. These waves destroy the coastal landscapes killing millions of people near the coasts. It also helps in reshaping the coasts by eroding and depositing the loose sediments.

3. The Konkan or Maharashtra Coast is an example of the coastline of Submergence

4. In the shoreline of emergence, bars and barriers emerge above the sea level and act as a barrier for sea waves. Lagoons are formed because of water getting locked between these bars. Whereas in the shoreline of submergence, the waves erode the rocks by hydraulic action and Abrasion, leading to the formation of cliffs, wave-cut platforms, arches, caves, Tombolo, hooks, etc. Cliffs, Arches, Stacks, Caves, and Lagoons

5. Waves are periodic undulations over the water surface that can erode, transport and deposit the sediments by swash and backwash.

6. Currents occur in the near-shore zone and help in shaping the seafloor topography. Currents act as a source of sediment supply, energy, and the coastal area's biotic element.

7. Beaches formed by the deposition of sediments along the coasts by the action of waves. Two

examples of beaches in India are Marina Beach of Chennai and Baga Beach in Goa.

8. (a) Neutral coastlines are formed where there is no relative change in the level of the sea and new materials are being built out into the water. Whereas, the compound coastlines are formed by the combination of two coastlines such as the coastline of submergence followed by emergence or vice versa.

(b) Sea Arches are a bridge-like structure formed when two caves unite from either side of a headland to form an arch or natural bridge. Whereas stacks are isolated pillars of rock developed when the roof of an arch is broken due to its weight, folding, and different rock types.

(c) Coastline of Emergence is formed by an upliftment of the land or by lowering of the sea level. The depositional landforms are formed due to the supply of sediments along the coasts.

(d)Submergence is formed due to the submergence of land or the rise in sea level. Some features of submerged coastlines are Ria coasts, Dalmatian coast, Fiords, and drowned lowlands.

9. Ria coast is a long, narrow inlet of a river that decreases in depth from mouth to head and produces an irregular shoreline. It is a coast with a large number of estuaries or long fingers of seawater projecting inland.

10. Fjords are irregular as they are long, narrow fingers of saltwater reaching hundreds of meters more in-depth than the adjacent seas, and they meander tens of kilometers inland. They are highly susceptible to landslides due to the coarse sediments and steep nature of fjords.

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12.9TERMINAL QUESTIONS

1. Name any three relief features made through the depositional action of marine waves.
2. Name any two agents of erosion involved in the formation of sea cliffs.
3. Give two reasons for the emergence of the shoreline.
4. Give any two reasons for the Shoreline of Submergence.
5. How is the youthful stage of the shoreline of emergence different from the coastline of submergence?
6. Name the features that develop in the youthful stage.
7. How do currents and waves produce landforms?
8. Explain the formation of beaches. Give any two examples of beaches in India.

9. Differentiate between the following:

(a) Neutral Coastline and Compound Coastlines

(b) Sea Arches and Sea Stacks

(c) Coastline of Emergence and Coastline of Submergence

10. Explain the formation of the ria coastline and fjords.

(a) (i) Solution (ii) Attrition (iii) Abrasion (iv) Hydraulic Action

(b) (i) Waves (ii) Tides (iii) Currents

(c) Solvent action

11. How waves act as an agent of erosion in coastal regions?

BLOCK -3 LANDFORMS AND THEIR DEVELOPMENT

UNIT – 13 TECTONIC PROCESS AND LANDFORMS BOTH LARGE AND AMALL SCALE

13.1. OBJECTIVES

After reading this unit you will be able to:

- To provide an overview of tectonic processes and the formation of tectonic landforms
- To identify the different types of tectonic landforms and their characteristics
- To understand the relationship between tectonic processes and the formation of landforms on a large and small scale

13.2. INTRODUCTION

The evolution of tectonic processes on Earth has been a gradual and complex process spanning over millions of years. The movements of the Earth's crustal plates and the resulting geological features have been influenced by a variety of factors, including changes in the Earth's climate, the impact of asteroids, and the actions of living organisms.

The earliest stages of tectonic activity on Earth are believed to have begun around 4 billion years ago, during the Hadean Eon. During this period, the Earth's crust was constantly being remodeled through volcanic activity, with the production of large amounts of basaltic lava creating new crustal plates. This process was accompanied by the release of massive amounts of gas, including water vapour and carbon dioxide, which helped to shape the planet's atmosphere and climate.

Over time, the Earth's tectonic processes became more complex, with the formation of large-scale tectonic plates that moved and collided with each other. This resulted in the creation of mountain ranges, subduction zones, and oceanic trenches, which continue to shape the planet's surface today.

One of the key drivers of tectonic activity on Earth has been the movement of the Earth's mantle, which is made up of solid rock that is capable of flowing slowly over long periods of time. This movement creates convection currents within the mantle, which in turn generate the forces that drive the movement of the crustal plates. One of the major impacts of tectonic activity on Earth is the formation of mountain ranges. The collision of crustal plates can lead to the creation of large-scale folds and faults, which can uplift vast areas of land and form towering peaks. Mountain ranges play a key role in shaping regional climate patterns, influencing precipitation and creating unique ecosystems that are home to a wide variety of plant and animal species. Tectonic activity can also lead to the formation of volcanic islands and oceanic trenches. Volcanic islands are created by the upwelling of magma from the Earth's mantle, while oceanic trenches form at subduction zones where one crustal plate is forced beneath another. These trenches can reach depths of over 10,000 meters and are home to a variety of unique deep-sea species. Another important aspect of tectonic activity on Earth is the formation of mineral deposits. As crustal plates move and collide, they can cause the accumulation of mineral-rich fluids beneath the Earth's surface. These fluids can then become concentrated over time to form valuable mineral deposits, such as gold, copper, and iron.

The topography of the Earth's surface is influenced to some degree by geodynamic processes that take place deep within the Earth. Subsequently, the surface is altered by natural agents such as wind, water, and ice. This interplay between "endogenic" (deep-seated) and "exogenic" (atmospheric) processes is referred to as the "*Principle of Antagonism*". Given the rapid geomorphic evolution of the Earth's surface (with uplift and erosion rates typically around 1 km/m.y.), most of the present-day features are not more than a few million years old.

Another important factor in the evolution of tectonic processes on Earth has been the influence of living organisms. For example, the buildup of organic matter on the seafloor has played a role in the formation of oil and gas deposits, which have had a significant impact on the global economy. In addition, the activities of coral reefs and other marine organisms have helped to shape the contours of the ocean floor.

13.3 TECTONIC PROCESSES AND TECTONIC LANDFORMS BOTH LARGE AND SMALL SCALES

13.3.1 Tectonic Processes and Tectonic Landforms:

Tectonic processes are responsible for shaping the earth's surface, creating a wide variety of large and small landforms. These processes involve the movement of tectonic plates, which can form mountains, valleys, rifts, and other unique features. Tectonic landforms are not only geologically significant but also play an important role in shaping landscapes and ecosystems, influencing human settlement patterns and resource distribution.

Tectonic processes are a result of the movement and interaction of tectonic plates. There are three types of tectonic plate boundaries: divergent, convergent, and transform. At divergent boundaries, plates move away from each other, resulting in the formation of new crust. This process is responsible for the creation of mid-ocean ridges and rift valleys. Convergent boundaries occur when plates collide, resulting in the formation of subduction zones or collisional mountains. Transform boundaries involve the sliding of two plates past each other, resulting in the formation of fault lines.

Tectonic processes are the movements and interactions of the Earth's crust or lithosphere that result in the formation and deformation of landforms and geological structures. Tectonic processes are driven by the heat and forces generated within the Earth's interior, such as convection currents, mantle plumes, and gravity. Tectonic processes can be classified into three main types according to the direction and nature of the movement of the lithospheric plates:

- Divergent tectonic processes: involve the separation or rifting of plates, creating new crust, and widening ocean basins or continental rifts. Divergent tectonic processes occur at mid-ocean ridges, where oceanic plates move away from each other due to seafloor spreading, and at continental rifts, where continental plates stretch and thin due to extensional forces.
- Convergent tectonic processes: this involves the collision or subduction of plates, destroying old crust and forming mountain ranges or volcanic arcs. Convergent tectonic processes occur at subduction zones, where oceanic plates sink beneath continental or oceanic plates due to gravity, and at continental collision zones, where continental plates collide and crumple due to compressional forces.
- Transform tectonic processes: The lateral sliding or shearing of plates, neither creating nor destroying crust but causing earthquakes and faults. Transform tectonic processes occur at transform faults, where plates slide past each other horizontally along fracture zones that offset segments of mid-ocean ridges or continental margins.

Tectonic processes shape the Earth's surface by creating various landforms and features, such as mountains, volcanoes, islands, valleys, basins, faults, folds, and earthquakes. Tectonic processes also influence the distribution and evolution of life on Earth by affecting the climate, biogeography, biodiversity, and natural resources. Tectonic processes are part of the theory of plate tectonics, which explains how the Earth's lithosphere is divided into several rigid plates that move relative to each other on a plastic layer called the asthenosphere[4]. Plate tectonics is a unifying framework for understanding the dynamic history and structure of the Earth.

Tectonic landforms refer to the relief features that are primarily created by the uplift or subsidence of the Earth's crust or by upward movements of magma, such as mountains, plateaus, and rift valleys. While erosion plays a role in shaping landforms, their origins can be attributed to tectonic processes that construct the major structures of the Earth. The term tectonic comes from the Greek word *Tekton,* which means *"Builder*," as these processes build landforms primarily by inducing the uplift or subsidence of rock material, including blocks, layers, or slices of the Earth's crust, molten lavas, and even large masses that consist of the entire crust and the uppermost part of the mantle. In certain regions, these processes generate high elevations, such as mountains and plateaus, while in others, they result in topographic depressions, as seen in Death Valley in the western United States, the Dead Sea in the Middle East, or the Turfan Depression in western China. Nearly all areas below sea level have been shaped by tectonic processes.

Numerous landforms are a result of the prevailing geodynamic conditions, such as certain mountain peaks, karst caves, and glacial cirques. In general, tectonic landforms can be classified into first, second, and third-order patterns, where the first and second-order features are primarily due to the geotectonic stress field, and the third-order is caused by self-induced gravity stresses, not geo-dynamically induced. Since all these features are caused by stresses and have an endogenic origin, they tend to be statistically systematic. However, only the first and second-order features are directly influenced by deep-seated processes, while third-order features are self-induced. While the term "*Structural Landform*" has been used to refer to these features, it has a broader meaning, as it includes forms that result from the exploitation of weaknesses in the Earth's crust by exogenic agents. The genuine tectonic features are designed directly by the action of deep-seated processes, but they may be enhanced by the intervention of exogenic agents.

Plate Tectonics, Process and Its Types

The theory of plate tectonics brought a revolutionary understanding of Earth sciences by providing a unified framework for comprehending various geologic phenomena, such as mountain-building processes, volcanic eruptions, and earthquakes. The plate tectonics concept was developed during the 1960s and proposes that the Earth's lithosphere, an outer rigid layer approximately 100 km thick, overlies the asthenosphere, a partially molten and malleable layer. The lithosphere is fragmented into seven extensive continental and oceanic plates, several medium-sized regional plates, and some small ones. These plates move relative to each other at speeds of about 5 to 10 cm per year and interact with each other at their boundaries, where they converge, diverge, or slide past one another. These plate interactions are believed to be responsible for most of the seismic and volcanic activity on Earth, although earthquakes and volcanoes can also occur in the plate interiors. Plate motions cause mountain formation when plates collide or converge, while continents fracture, and oceans form when plates pull apart or diverge. The plates carry the continents along with them, leading to significant changes in Earth's geography over millions of years.

The theory builds on the earlier idea of continental drift and incorporates the concept of seafloor spreading, providing a comprehensive framework to explain the past geography of continents and oceans, the formation and erosion of landforms, and the evolution of Earth's crust, atmosphere, biosphere, hydrosphere, and climate.

The internal structure of Earth can be differentiated into various layers based on variations in *chemical* and *physical* properties. ***Chemically***, Earth can be classified into three distinct layers. The outermost layer, called the *crust*, ranges in thickness from a few kilometres to about 40 km (25 miles) and sits on top of the *mantle*, which is significantly thicker than the crust and constitutes about 83 percent of Earth's volume. The mantle extends to a depth of 2,900 km (1,800 miles). Below the mantle lies the *Core*, which reaches down to the center of the Earth, nearly 6,370 km (4,000 miles) below the surface., composed of metallic iron, accompanied by smaller amounts of nickel, cobalt, and lighter elements such as carbon and sulfur.

There are two types of crust, *continental* and oceanic, which differ in their composition and thickness

Plate Boundaries and Its Type:

The thickness of lithospheric plates exceeds that of oceanic and continental crust. The boundaries between these plates do not typically align with those separating oceans and continents, and their behavior is only partially influenced by the presence of either or both.

Divergent Plate Boundary:

At divergent plate boundaries, where plates move apart, the decrease in pressure results in the partial melting of the underlying mantle, creating buoyant magma with a basaltic composition that rises to the surface and cools to form new crust. Such margins are called constructive margins as they generate new crust.

Convergent Plate Boundary:

At convergent plate boundaries, one plate descends at an angle, or subducts, beneath the other, and this type of boundary is also known as a destructive plate boundary.

Transform Plate Boundary:

Along the third type of plate boundary, two plates move laterally and slide past each other along massive fractures in the Earth's crust. These fractures, known as transform faults, are named so because they are associated with other types of plate boundaries. The majority of transform faults connect the offset segments of oceanic ridges.

13.3.2 Tectonic Landforms

Tectonic landforms can be classified into two broad categories: large-scale and small-scale. Large-scale tectonic landforms are the result of long-term tectonic processes, while small-scale landforms are created by more localized, short-term tectonic activity.

Large-Scale Tectonic Landforms

Large-scale landforms are geological features on the Earth's surface that span vast areas and are typically the result of tectonic activity, erosion, or volcanic activity. These landforms are characterized by their size and often have a significant impact on the surrounding environment and human populations. One such large-scale landforms are mountain ranges, which are created by the collision and movement of tectonic plates.

These landforms can span hundreds or even thousands of kilometers and can have a significant impact on climate patterns, vegetation, and water resources. Mountain ranges are often associated with significant geological and natural resources, such as mineral deposits, timber, and wildlife habitats. Another example of large-scale landforms is ocean basins, which are large, deep depressions on the Earth's surface that hold oceanic crust. Ocean basins are created by the movement and separation of tectonic plates, and their formation can have a significant impact on ocean currents, sea levels, and marine ecosystems. Volcanic activity creates large-scale landforms, such as volcanic islands and volcanic arcs. These landforms can be hundreds of kilometers long and can have a significant impact on surrounding ecosystems and human populations. Volcanic eruptions can lead to the formation of new land and can significantly alter the surrounding environment through the deposition of ash and other volcanic material. Large-scale landforms are important features of the Earth's surface that have a significant impact on the environment and human populations. Understanding the processes that contribute to their formation and their impact on the surrounding environment is crucial for effective management and conservation of natural resources.

A. Mountains

Mountains are large landforms that rise significantly above the surrounding terrain, typically characterized by steep slopes and peaks. They are created by geological processes, primarily through the collision and movement of tectonic plates, as well as volcanic activity and erosion. Mountain ranges are typically elongated and can span hundreds or even thousands of kilometers, such as the Andes in South America, the Himalayas in Asia, and the Rocky Mountains in North America. Mountains are often the result of the uplift and folding of rock layers as a result of tectonic forces, with many mountain ranges being formed as a result of the collision of two tectonic plates.

Mountains have a significant impact on their surrounding environment, including climate, vegetation, and water resources. Their high elevations can affect precipitation patterns and create microclimates, and they often serve as important habitats for wildlife and plant species. Mountains are also valuable sources of natural resources, including minerals, timber, and water.

Tectonic geomorphology refers to the interpretation of particular landforms based on the underlying tectonic processes, while neotectonics is the study of geological processes that are either recent or ongoing.

Types of Mountains

Tectonic processes give rise to various types of mountains, including volcanic, fold, plateau, fault-block, and dome. A more detailed classification system that predates plate tectonics supplements these categories and is useful at the local scale.

Volcanic Mountains

Volcanic mountains, for instance, are formed when tectonic plate movements create volcanoes along plate boundaries. These volcanoes erupt, spewing out molten material, and eventually form mountains. A volcanic arc system, which is a series of volcanoes, develops near a subduction zone mountain here the sinking oceanic plate's crust melts and drags water down with it.

Most volcanoes are found in two bands - the Pacific Ring of Fire and a band extending from the Mediterranean across Asia to the Indonesian Archipelago. The two primary types of volcanic mountains are composite cones or stratovolcanoes, such as Vesuvius, Kilimanjaro, and Mount Fuji, and shield volcanoes, such as Hawaii's Mauna Loa, which is a hotspot volcano. A shield volcano has a gently sloping cone due to the low viscosity of the emitted material, which is primarily basalt. Mauna Loa is a classic example with a slope of 4°-6°. On the other hand, the composite volcano or stratovolcano has a more steeply rising cone (33°-40°) due to the higher viscosity of the emitted material. The eruptions from these volcanoes are more violent and less frequent than those from shield volcanoes. Some examples of composite volcanoes include Mount Shasta, Mount Hood, and Mount Rainier. Vitosha, which is a domed mountain located next to the Bulgarian capital of Sofia, is also the result of volcanic activity.

Folded Mountains

Fold mountains are formed by the convergence of two or more tectonic plates, where rocks and debris are compressed and folded over millions of years to create mountains, hills, and entire mountain ranges. This process is known as *Orogeny*, which can be replicated on a smaller scale by pushing the edge of a tablecloth or rug to create wrinkles and folds. The vocabulary used to describe fold mountains, such as "nappe," which refers to dramatic folded rock formations, originates from the French word for "*Tablecloth*." Unlike the tabletop experiment, where the table remains unchanged, fold mountains are created when the Earth's crust is warped and folded. These mountains are typically found on the edges or former edges of continental plate boundaries, where weaker and less stable rocks are more susceptible to folding and warping. Fold mountains are predominantly composed of sedimentary and metamorphic rock formed under high pressure and relatively low temperatures, and may also be formed where an underlying layer of ductile minerals, such as salt, is present.

Fold mountains are the most common type of mountain in the world. The rugged, soaring heights of the Himalayas, Andes, and Alps are all active fold mountains.

Folds are the complex and crucial geologic forms that define fold mountains, and they are categorized by geologists primarily based on their shape. The folds can be characterized by their sharp turns or gentle curves, and whether they are convex or concave. In fold mountains, various types of folds are commonly observed, such as anticlines and synclines, which are up-and-down folds resulting from compression. An anticline has a ∩-shape, and the oldest rocks are present in the centre of the fold. A syncline is a U-shape, and the youngest rocks are in the centre. Domes and basins are also considered types of folds. A dome is a series of symmetrical anticlines with the oldest rocks in the centre, while a basin is a depression with the youngest rocks in the centre, similar to a syncline. Other types of folds include monoclines, chevron folds with sharp zig-zags, slump folds resulting from slope failure, ptygmatic folds created where the folding material is much more viscous than the surrounding material, and disharmonic folds where different rock layers have different fold shapes.

Block Mountains

Block mountains are mountains that result from faulting caused by endogenetic forces within the Earth, and are also known as fault block mountains. They represent the upstanding parts of the ground between two faults, or on either side of a rift valley or a graben, due to tensile and compressive forces.

Block mountains are generally categorized into two basic types: a) tilted block mountains and lifted block mountains. Tilted block mountains have one steep side represented by a fault scarp and one gentle side, b). while lifted block mountains represent real horst and are characterized by flattened summit of tabular shape and very steep side slopes represented by two boundary fault scarps. These types of mountains are also referred to as horst mountains.

Circum-Erosional or Relict Mountains

Circum-erosional or relict mountains are created by the remnants of a former mountain or plateau that has undergone rock erosion, resulting in a degraded, flat area. A relict mountain is a landform that is created through the gradual erosion of already elevated lands, such as Fold, Block, or Volcanic Mountains. Over time, the agents of denudation such as wind, water, glacier, waves, and more wear away the high mountains, leaving behind the remaining parts that are known as residual mountains. These mountains are known as residual mountains (for instance, the Aravallis in India and the Urals in Russia), and they are the remaining parts of previous fold mountains that were formed due to denudation. Additionally, residual mountains may also arise from plateaus formed by river-cutting that have been eroded into valleys and hills.

Examples of residual mountains include the Namuli Mountains in Mozambique and the Hanbori Mountains in Mali.

Dome Mountains

Dome Mountains are a type of mountain range that forms because of the dissection of a structural dome. Dome mountains are a type of landform created when magma, or melted rock, rises through the earth's crust and pushes the overlying rocks into a rounded shape. Unlike folded mountains, the magma does not press forcefully enough to create tall peaks. Instead, when the magma cools and hardens over time, it forms a dome-shaped mountain. Dome mountains are usually the result of a structural dome, which occurs when flat layers of sedimentary rock are bent or bowed upward. As erosion occurs, the top of the dome is gradually worn away, exposing a circular mountain range with individual peaks formed from the worn-away domes. The terrain of dome mountains is mostly flat, and the mountain bases can have diameters of hundreds of kilometers.

B. **Plateaus**

A plateau is a level or gently sloping raised area that has one or more steep edges. It usually has a higher elevation than the surrounding region. Plateaus are also referred to as high plains or tablelands. The key distinction between a plateau and a mountain is that a plateau typically has a flat top. A plateau is a type of elevated flat land that stands above the surrounding terrain. They are flat-topped tablelands that can vary in height from several hundred meters to several thousand meters. Like mountains, plateaus can range from being young to ancient. Plateaus are a prevalent type of landform that can be found in many parts of the world.

The formation of plateaus can be attributed to the erosion caused by rivers, floods, and glaciers, as well as repeated lava flows over time. Plateaus can emerge in various ways, such as the ascent of magma towards the crust's surface without breaking through it, resulting in the formation of a plateau. Wind and water erosion can also play a significant role in shaping a plateau's appearance over millions of years. Over time, streams carve channels and layer rock, which eventually leads to the creation of deep valleys and steep slopes on the plateau's edges.

The East African Plateau in Kenya, Tanzania, and Uganda, as well as Australia's Western Plateau, are some of the most well-known examples of plateaus.

Small Scale Landforms

Small-scale tectonic landforms refer to features that are smaller in size and scale compared to larger tectonic structures such as mountains and plateaus. Small-scale tectonic landforms are geological features that result from tectonic forces on a relatively small scale. These landforms are typically found at the edges of tectonic plates and are the result of either compression or tension forces.

Some examples of small-scale tectonic landforms include:

- **Faults:** These are fractures in the earth's crust where movement has occurred. Faults can be small or large, and can be seen as linear features on the landscape.
- **Folds:** Folds are the bending or curving of rock layers caused by compressive forces. They can range in size from small-scale to large-scale and can be found in sedimentary, metamorphic, and igneous rock formations.

- **Grabens and Horsts:** Grabens are elongated, depressed areas of land that are bounded by fault lines, while horsts are elongated, uplifted areas of land between two parallel faults.
- **Dikes:** Dikes are tabular intrusions of magma that cut across existing rock layers.
- **Sills:** Sills are horizontal intrusions of magma that occur between layers of sedimentary or volcanic rock.
- **Cuestas:** These are asymmetrical ridges that form when tilted rock layers are exposed on one side and gently dipping layers are exposed on the other side.
- **Hogbacks:** Hogbacks are long, narrow ridges that form along the edge of a fault line, and are often steep and jagged.
- **Anticlines and Synclines:** Anticlines are upfolded or arched rock layers, while synclines are downfolded or trough-shaped rock layers.
- **Escarpments:** Escarpments are steep slopes or cliffs that separate two relatively level areas of differing elevations.
- **Fault scarps:** These are steep slopes or cliffs formed by the displacement of rock along a fault. Fault scarps are commonly found in areas of high seismic activity, where the ground is prone to sudden movement.
- **Grabens:** These are elongated depressions that form when two parallel faults move apart from each other, causing the land in between to sink down. Grabens are typically linear in shape and may contain small lakes or rivers.
- **Horsts:** These are elongated uplifted blocks of land that form between two parallel faults. Horsts may be linear or irregular in shape, and can be several kilometers in length.
- **Monoclines:** These are large, step-like folds in rock layers that form when one side of a geological formation is uplifted while the other side remains relatively flat. Monoclines are often associated with sedimentary rock formations.
- **Fold mountains:** These are large-scale tectonic landforms that form because of the compression and folding of rock layers. Fold mountains are typically associated with convergent plate boundaries, where two tectonic plates are colliding. Examples of fold mountains include the Himalayas and the Andes.

13.4 SUMMARY

The Earth's surface is constantly changing due to the movements and interactions of the lithosphere, which is the outer layer of the Earth. The lithosphere consists of the crust and uppermost mantle, and it is divided into several plates that move relative to each other. These plates can collide, separate, or slide past each other, creating different types of landforms and features. Some examples of these landforms are mountains, volcanoes, valleys, and faults. These landforms are the result of various tectonic processes, such as plate tectonics, faulting, and volcanism. Plate tectonics is the process of plate movement and collision, which can form mountain ranges or volcanic arcs. Faulting is the process of movement along cracks in the crust, which can form fault-block mountains or transform faults. Volcanism is the process of magma rising to the surface, which can form volcanic cones or shield volcanoes. These tectonic processes have shaped the Earth's surface over millions of years, and they continue to do so today. By studying these processes, we can learn more about the Earth's history and its future.

Tectonic processes are not only important for creating landforms, but also for influencing other aspects of the Earth system, such as the climate and the biosphere. For example, plate tectonics can affect the distribution of continents and oceans, which can alter the patterns of ocean currents and wind circulation. Tectonic movements and interactions of the Earth's lithosphere, which is composed of the crust and uppermost part of the mantle. These processes are responsible for the formation of various landforms on Earth. One of the most common tectonic processes is plate tectonics, which involves the movement and collision of large pieces of the Earth's crust. When two plates collide, they can form mountains, such as the Himalayas, or volcanic arcs, like the Andes. When plates pull apart, they create rift valleys and ocean basins, such as the Mid-Atlantic Ridge.

These patterns can affect the temperature, precipitation, and weather of different regions. Plate tectonics can also affect the evolution of life on Earth, by creating barriers or bridges for the migration and dispersal of organisms, or by causing mass extinctions or diversifications due to volcanic eruptions or asteroid impacts. Tectonic processes can also pose hazards or opportunities for human society, by causing earthquakes, volcanic eruptions, landslides, or tsunamis, or by providing resources such as minerals, geothermal energy, or fertile soils.

Another important tectonic process is faulting, which occurs when there is movement along a crack in the Earth's crust. This can create different types of landforms such as fault-block mountains, like the Sierra Nevada, or transform faults, such as the San Andreas Fault in California.

Volcanism is also a significant tectonic process that creates landforms. When magma rises to the surface, it can create volcanic cones, like Mount Fuji in Japan, or shield volcanoes, such as Mauna Loa in Hawaii.

13.5 GLOSSARY

- **Anticline**: A fold in rock layers that has an arch-like shape and the oldest rocks at its core.
- **Asthenosphere**: The layer of the Earth's mantle that lies below the lithosphere and is partially molten and plastic.
- **Basin**: A low-lying area of land that is surrounded by higher land or that collects water from a drainage system.
- **Convection current**: A circular movement of fluid caused by differences in temperature and density within the fluid.
- **Convergent tectonic process**: A tectonic process that involves the collision or subduction of plates, destroying old crust and forming mountain ranges or volcanic arcs.
- **Crust**: The outermost layer of the Earth, composed of solid rock.
- **Divergent tectonic process**: A tectonic process that involves the separation or rifting of plates, creating new crust and widening ocean basins or continental rifts.
- **Earthquake**: A sudden shaking of the ground caused by the release of energy from the movement of tectonic plates or faults.
- **Fault**: A fracture or crack in the Earth's crust along which movement has occurred.
- **Fault-block mountains**: Mountains formed when large blocks of rock are displaced along faults.
- **Faulting**: The movement along a crack in the Earth's crust, responsible for the formation of fault-block mountains, transform faults, and other landforms.
- **Fold**: A bend or curve in rock layers caused by compression or shear forces.

- **Landform**: A natural feature of the Earth's surface, such as a mountain, valley, island, or plain.
- **Landforms**: Natural features of the Earth's surface, shaped by a variety of geological processes, including tectonic activity.
- **Lithosphere**: Earth's crust and uppermost part of the mantle.
- **Lithosphere**: The rigid outer layer of the Earth, composed of the crust and uppermost mantle.
- **Magma**: Molten rock that exists below the Earth's surface.
- **Mantle**: The layer of the Earth's interior that lies between the crust and the core, composed of hot and dense rock.
- **Mountain range**: A series of mountains that are connected by high ground or have a common origin.
- **Mountains**: Landforms created by the collision of tectonic plates, characterized by steep slopes and high elevations.
- **Ocean basins**: Large, deep depressions on the Earth's surface that hold oceanic crust.
- **Ocean ridge**: An underwater mountain range that forms at divergent plate boundaries where seafloor spreading occurs.
- **Ocean trench**: An underwater valley that forms at convergent plate boundaries where subduction occurs.
- **Plate tectonics**: The movement and collision of large pieces of the Earth's crust, responsible for the formation of mountains, volcanic arcs, rift valleys, and ocean basins.
- **Plate tectonics**: The theory that explains how the Earth's lithosphere is divided into several plates that move relative to each other on the asthenosphere and interact along their boundaries, creating various landforms and features.
- **Plate**: A large and rigid segment of the Earth's lithosphere that moves relative to other plates on the asthenosphere.
- **Pull-apart basin**: A depression that forms between two segments of a strike-slip fault due to their lateral movement away from each other.
- **Rift valley**: A long and narrow valley that forms at divergent plate boundaries where continental crust is stretched and thinned.

- **Rift valleys**: Linear-shaped lowland areas created by the splitting apart of tectonic plates.
- **Seafloor spreading**: The process by which new oceanic crust is formed at mid-ocean ridges by the upwelling and cooling of magma from the mantle.
- **Shield volcanoes**: Broad, gently sloping mountains formed by the accumulation of fluid lava flows.
- **Strike-slip fault**: A fault along which two plates slide past each other horizontally with no vertical movement.
- **Subduction zone**: A region where an oceanic plate sinks beneath another plate into the mantle due to gravity.
- **Tectonic process**: A movement or interaction of the Earth's crust or lithosphere that results in the formation and deformation of landforms and geological structures.
- **Tectonic processes**: Movements and interactions of the Earth's lithosphere, responsible for the formation of various landforms.
- **Transform faults:** Tectonic plate boundaries where plates slide past each other horizontally, responsible for the formation of features such as offset rivers and valleys.
- **Transform tectonic process**: A tectonic process that involves the lateral sliding or shearing of plates, neither creating nor destroying crust but causing earthquakes and faults.
- **Volcanic arc**: A chain of volcanoes that forms parallel to a subduction zone where magma rises from the mantle to the surface.
- **Volcanic arcs**: Curved chains of volcanoes formed at the boundary where one tectonic plate subducts under another.
- **Volcanic cone**: A conical-shaped landform that forms around a volcanic vent where lava and ash erupt.
- **Volcanic cones**: Steep-sided, conical-shaped mountains formed by the accumulation of lava, ash, and other volcanic material.
- **Volcanism**: The eruption of molten rock, ash, and gas from the Earth's interior, responsible for the formation of volcanic cones, shield volcanoes, and other landforms.

- **Volcanism**: The process by which magma rises from the mantle to the surface and forms volcanoes.

13.6 ANSWER TO CHECK YOUR PROGRESS

1. Which of the following processes is responsible for the movement and collision of large pieces of the Earth's crust?

A) Volcanism

B) Faulting

C) Plate tectonics

D) Erosion

Answer: C) Plate tectonics

2. What type of landform is created when two tectonic plates collide?

A) Rift valleys

B) Ocean basins

C) Mountains

D) Volcanic cones

Answer: C) Mountains

3. Which tectonic process is responsible for the formation of fault-block mountains?

A) Plate tectonics

B) Volcanism

C) Faulting

D) Erosion

Answer: C) Faulting

4. What type of landform is created when magma rises to the surface?

A) Mountains

B) Rift valleys

C) Volcanic arcs

D) Ocean basins

Answer: C) Volcanic arcs

5. Which tectonic process is responsible for the formation of shield volcanoes?

A) Plate tectonics

B) Volcanism

C) Faulting

D) Erosion

Answer: B) Volcanism

6. What is the lithosphere?

A) The Earth's atmosphere

B) The Earth's oceans

C) The Earth's crust and uppermost part of the mantle

D) The Earth's core

Answer: C) The Earth's crust and uppermost part of the mantle

7. Which tectonic process creates linear-shaped lowland areas?

A) Plate tectonics

B) Volcanism

C) Faulting

D) Erosion

Answer: A) Plate tectonics

8. What type of landform is created by transform faults?

A) Mountains

B) Rift valleys

C) Volcanic cones

D) Offset rivers and valleys

Answer: D) Offset rivers and valleys

9. What type of landform is created by the splitting apart of tectonic plates?

A) Mountains

B) Rift valleys

C) Volcanic arcs

D) Ocean basins

Answer: B) Rift valleys

10. Which tectonic process is responsible for the formation of volcanic cones?

A) Plate tectonics

B) Volcanism

C) Faulting

D) Erosion

Answer: B) Volcanism

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13.8 TERMINAL QUESTIONS

1) How do tectonic processes influence the formation of landforms? Provide examples to support your answer.
2) Discuss the different types of plate boundaries and their associated landforms. How do the types of plate boundaries differ from each other, and how do they affect the formation of landforms?
3) Explain how faulting contributes to the formation of landforms. Provide examples of landforms that are created by faulting, and describe the processes that lead to their formation.
4) Describe the process of volcanism and the types of landforms that are created as a result. How does the type of volcano determine the shape of the landform, and what factors contribute to the formation of different types of volcanoes?
5) Discuss the role of erosion in shaping landforms. How do geological processes such as weathering and erosion interact with tectonic processes to shape the Earth's surface, and what are some examples of landforms that are created by erosion?

UNIT-14 ANTHROPOGENIC GEOMORPHOLOGY

14.1 OBJECTIVES

After reading this unit learners will able to:

- Understand and quantify the impact of human activities on geomorphic processes.
- Understand environmental change and degradation resulting from human-induced modifications.
- Understand socio-environmental interactions shaping landscape modification.

14.2 INTRODUCTION

The intricate relationships between natural system elements and the increasing and varied external human interventions into these systems create complexity. The physical environment, which encompasses the Earth's geographical sphere, is significantly influenced by human activities, often resulting in cascading effects that impact human society.

Currently, the role of human agency is as significant as other factors in shaping the Earth's landforms. While the extent of human influence is less powerful compared to endogenic forces like tectonic movements, volcanic activity, and earthquakes, it is still comparable to, and in some cases even exceeds, the energy driving many exogenic processes.

Since around 1860 and particularly after the Second World War, human beings have become a significant force in shaping the Earth's landforms due to scientific advancements and technological development. Humans now can modify the Earth's surface at a much faster rate than natural geomorphological processes. As a result, geomorphological processes can be categorized into two broad categories: natural geomorphological processes and anthropogenic geomorphological processes. Anthropogenic geomorphology focuses on studying the changes brought about by human economic activities and developmental works on the physical natural systems. It examines how human activities modify natural processes and landscapes. This branch of geomorphology falls under applied geomorphology, which primarily investigates the role of humans as geomorphic agents and the unintended and planned effects of their economic activities on geomorphic processes and landforms.

Environmental or geomorphological processes encompass both internal and external forces that operate on the Earth's surface. Internal or endogenetic processes, influenced by diastrophic and sudden forces resulting from the Earth's thermal conditions and varying physical and chemical properties, create vertical irregularities and different habitats for biotic communities. External or exogenetic forces, driven by solar energy and originating from the atmosphere, alter the Earth's surface through erosion and deposition. The interactions between endogenetic and exogenetic processes generate complex physical landscapes that impact biotic communities within the biospheric ecosystem. These environmental processes operate through various feedback mechanisms, and while their actions and responses differ in scale, frequency, and magnitude, they ultimately lead to similar end-forms through the principle of equifinality.

If left undisturbed by human interference, the changes caused by environmental processes on the Earth's surface maintain equilibrium through negative feedback mechanisms. However, human beings have now become a highly influential geomorphic agent (anthropogenic process) capable of altering the Earth's surface at a much faster pace. Human activities have the potential to modify environmental processes at a significantly accelerated rate compared to many natural processes. Therefore, it is crucial to investigate the impact of human actions on these environmental processes, as they influence physical landscapes and crucial components such as the energy system, hydrological cycle, chemical element cycle, and sediment cycle. These interconnected processes play a vital role in maintaining the unity and balance of the biospheric ecosystem.

Anthropogenic geomorphology focuses on describing the vast and expanding range of surface landforms created by human society, which differ in origin and purpose. While human constructions like buildings and industrial plants modify the landscape, they are not typically the main subjects of geomorphological investigation. However, these artificial structures significantly influence their surroundings in terms of size and other properties, and they can have diverse impacts on the environment, such as alterations in microclimate, biota, and natural processes.

The complexity of anthropogenic geomorphology arises from the interaction between natural systems and human activities. Human interventions disrupt the natural order and dynamic equilibrium of processes that have developed over varying timescales. The introduction of human-made landforms into the landscape disturbs the equilibrium, and without human intervention and maintenance, these landforms begin to exhibit tendencies towards a new equilibrium. This transition period can be unpredictable and may pose uncertainties or even threats to society and other natural systems. It is challenging to anticipate the direction and nature of the new equilibrium, which can have detrimental effects. During the initial stages of the relaxation period required to reach a new equilibrium, rapid changes can occur, sometimes leading to disastrous consequences.

14.3 ANTHROPOGENIC GEOMORPHOLOGY

One approach widely employed to categorize human actions in anthropogenic geomorphology is based on distinguishing between direct and indirect impacts on the Earth's surface. Direct impacts are typically intentional and conscious, resulting in easily identifiable consequences. However, it is essential to also include the less obvious outcomes of indirect human impacts within the scope of anthropogenic geomorphology. Spencer and Hale (1961) developed a classification system based on the relationship between human actions and their effects on the initial surface. Their classification includes constructive, excavational, hydrological, and agricultural interventions. The latter two can be considered as surface modifications or plantation. Haigh (1978) built on this framework, offering a simplified classification system that includes the following distinctions:

1. Direct anthropogenic processes

Direct anthropogenic processes are those that are derived from human activities that modify the Earth's surface or subsurface[1]. They can be classified into three groups according to whether they are subsurface processes, surface processes, or both[2]. Here are some definitions of the processes you listed

1.1. **Constructive Actions**: are those that add material to the surface or subsurface, such as landfilling, embankment construction, or injection of fluids

1.2. **Excavational Activities**: are those that remove material from the surface or subsurface, such as mining, quarrying, dredging, or tunneling

1.3. **Hydrological Interventions**: are those that alter the natural flow or storage of water, such as dam construction, irrigation, drainage, or groundwater abstraction

2. Indirect anthropogenic processes

Indirect anthropogenic processes are those that result from environmental changes that are brought about by human activities but do not directly modify the Earth's surface or subsurface. They are not easily recognizable unless they are involved in the formation of natural processes. Some examples of indirect anthropogenic processes are:

These are some processes that can be influenced by indirect anthropogenic processes, such as climate change, land degradation, or ocean acidification:

2.1. Acceleration of erosion and sedimentation- is an increase in the rate of detachment, transport, and deposition of soil and rock particles by natural agents such as water, wind, ice, or gravity. Indirect anthropogenic processes can affect the factors that control erosion and sedimentation, such as vegetation cover, soil properties, rainfall intensity and frequency, runoff generation, and sediment supply.

2.1. Subsidence - is a downward movement of the Earth's surface relative to a reference level, such as sea level or a geodetic datum[2]. Indirect anthropogenic processes can cause subsidence by altering the hydrological balance, thermal regime, or chemical composition of the subsurface, leading to compaction, dissolution, or consolidation of the underlying materials.

2.3. Slope failure - is a mass movement of soil and rock material down a slope under the influence of gravity[3]. Indirect anthropogenic processes can trigger or enhance slope failure by changing the slope stability factors, such as slope angle, material strength, pore water pressure, seismic activity, or vegetation cover[3].

2.4 - Triggering earthquakes** is a phenomenon where human activities induce seismic activity in fault zones or fracture systems. Indirect anthropogenic processes can trigger earthquakes by altering the stress state, fluid pressure, or temperature of the crust, leading to fault reactivation or rock failure.

2.5 Climate change - is a global change in the average weather patterns and conditions, caused by the increase of greenhouse gases in the atmosphere due to human activities such as fossil fuel combustion, deforestation, agriculture, and industrialization[2]. Climate change can affect natural processes such as precipitation, evaporation, runoff, erosion, sedimentation, glacial melting, sea level rise, and biogeochemical cycles.

2.6. Land degradation- is a decline in the quality and productivity of land resources, caused by human activities such as overgrazing, overcultivation, deforestation, urbanization, and pollution[2]. Land degradation can affect natural processes such as soil formation, nutrient cycling, water retention, vegetation cover, and biodiversity.

2.7. Ocean acidification - is a decrease in the pH of seawater, caused by the uptake of carbon dioxide from the atmosphere due to human activities such as fossil fuel combustion and land use change. Ocean acidification can affect natural processes such as coral reef formation, calcification, photosynthesis, respiration, and marine food webs.

These classifications provide a basis for understanding and organizing the various ways in which human actions impact the Earth's surface within the field of anthropogenic geomorphology.

Erosion, which involves material loss and the formation of "negative landforms" such as surface depressions, can be considered as excavation in anthropogenic geomorphology. Accumulation on the surface, resulting in "positive landforms" such as elevations, is referred to as constructive, aggregational, or accumulational landforms. However, a third type of landform called planation does not fit unambiguously into the categories of natural geomorphic processes. Plantation can occur through both erosional and accumulation processes under natural conditions and is often observed in anthropogenic geomorphology as well. Through plantation, humans can even destroy landforms created by themselves or by nature, such as filling a valley with debris or smoothing a sand dune or settlement. In general, plantation reduces the slope of the surface and poses long-term hazards to the natural environment.

When classifying direct impacts, another aspect to consider is whether the generation of the landform is the explicit objective of human action or an unavoidable by-product. For example, when terraces are created on slopes for agricultural purposes, the changes in slope character are intentional and terraces are primary landforms in this case. In contrast, waste tips accumulated during mining result from the need to deposit "useless" material to extract useful resources, making waste tips secondary landforms in terms of the goal of the activity.

Indirect impacts can be further divided into different groups. One group includes processes and landforms that would not have occurred without human action. Examples include gorges or "barrancos" on the slopes of waste tips and alluvial fans at the foot slopes of tips. These processes and landforms follow physical rules and are indistinguishable from those in natural systems, but their origin and significance require information about their environmental and geomorphological implications. These new quality processes and landforms are labelled as semi-anthropogenic processes.

Another form of indirect human impact involves modifying the extent and rate of already operating processes without inducing new ones. This type of impact is quantitative rather than qualitative and affects the natural evolution of an area. For instance, forest clearance increasing surface runoff and causing floods or mine water extraction altering river morphology and nearby areas are examples of quantitative changes or natural-anthropogenic processes. Anthropogenic geomorphology encompasses a wide range of direct and indirect human impacts on landforms and processes, including erosion, accumulation, planation, and qualitative and quantitative changes to the natural environment.

14.3.1 Human Impact on the Environment

Human activities have a significant impact on various environmental processes that originate from the atmosphere and are influenced by solar energy. These processes include fluvial (related to rivers), glacial, periglacial (occurring in areas near glaciers), and aeolian (involving wind) processes. The efficiency of these environmental processes is determined by the potential energy stored in the Earth's surface features. Human interventions can disrupt the natural balance by altering solar radiation and, consequently, heat energy distribution. This, in turn, can have effects on precipitation patterns and air circulation, ultimately impacting the environment by bringing changes and transforming environmental process.

Human impact on the environment refers to the changes to the natural world, either directly or indirectly. These changes can affect the biophysical environment, such as the land, water, air, climate, and biodiversity, as well as the natural resources that humans depend on for their survival and well-being[1]. Some examples of human impact on the environment are:

- Overpopulation – this is the situation where the number of people exceeds the carrying capacity of the environment. Overpopulation can lead to increased consumption, waste, pollution, deforestation, and land degradation.
- Pollution- The introduction of harmful substances or energy into the environment. Pollution can affect the quality of air, water, and soil, and cause health problems for humans and wildlife. Some sources of pollution are fossil fuel combustion, industrial activities, agriculture, and urbanization.
- Burning fossil fuels- The use of coal, oil, or natural gas as sources of energy. Burning fossil fuels releases greenhouse gases, such as carbon dioxide and methane, into the atmosphere. These gases trap heat and cause global warming, which can alter the climate patterns and affect the ecosystems.
- Deforestation - Clearing of forests for various purposes, such as agriculture, logging, mining, or urban development. Deforestation can reduce the biodiversity, carbon storage, and water cycle functions of forests, and increase soil erosion and desertification.

14.3.2 Human and Hydrological Processes

Almost every country has witnessed the alteration of hydrological processes within natural drainage basins due to human activities. In an undisturbed hydrological cycle, rainfall is the primary input to a basin. Initially, vegetation intercepts a portion of the rainfall, which then reaches the ground as "aerial streamlets" or "stemflow" and throughfall. When vegetation is absent, rainfall directly reaches the ground. A portion of the water is lost to the atmosphere through evapotranspiration.

Water available on the ground forms a "surface storage," with some of it moving down the slope as surface runoff, some being evaporated, some remaining on the ground surface, and some infiltrating downward into the soil to create a "soil moisture storage." Within the soil moisture storage, some water is lost through evaporation and plant transpiration, while some reappears as seepage, springs, throughflow, and interflow. Another portion percolates further downward, forming a "groundwater storage." From the groundwater storage, some water reaches the channel as base flow, some moves upward as capillary rise to replenish the soil moisture storage, and some is transferred deeply downward.

The "channel storage" receives water from the surface storage through surface runoff, from the soil moisture storage through interflow and throughflow, and from the groundwater storage through base flow. As a result, the initial input of precipitation finds two paths of output: (i) evapotranspiration from various types of storages mentioned above and (ii) channel runoff from the channel storage.

Human activities have a diverse range of impacts on the internal processes of the hydrological regime within a drainage basin, resulting in both positive and negative effects. The modifications caused by human activities affect various components of the hydrological cycle.

The input of precipitation into the hydrological cycle can be modified through techniques like "cloud seeding" for induced precipitation, atmospheric pollution (which can both increase or decrease precipitation input), altered atmospheric circulation due to urbanization (leading to increased precipitation), forest clearance (resulting in decreased precipitation), and modifications to vegetation (which can bring changes in precipitation patterns). Additional water input on the ground surface comes from irrigation of crops and the disposal of effluent from urban areas.

The "interception storage" is influenced by forest clearance (reducing the storage capacity) and changes to vegetation. The "surface storage" is modified by activities such as land clearance, cultivation, urbanization, land drainage, and mining. Deforestation and cultivation increase surface runoff, which can be further supplemented by channelled irrigation for cropland and effluent disposal from urban areas.

Infiltration is altered by factors like devegetation (resulting in decreased infiltration), urbanization (also decreasing infiltration), afforestation and reforestation (increasing infiltration), and irrigation (increasing infiltration). The "soil moisture storage" is positively affected by irrigation, planting of grasses and plants, artificial recharge, seepage from water supply systems, soak pits, and cesspools. Conversely, it is negatively affected by land clearance through deforestation, burning of grasslands, and urbanization.

"Groundwater storage" is influenced by the extraction of groundwater for domestic use and irrigation. The "channel storage" is modified through floodplain development, channel modifications (shortening or lengthening of channels), river regulation, and the construction of dams and reservoirs.

The impacts of human activities on different components of the basin's hydrological cycle can include an increased flood hazard and changes in river regime, reduced availability of groundwater, deterioration of water quality, and widespread eutrophication of water bodies and river systems due to increased nutrient loading.

Studies conducted in various regions around the world have established a correlation between land drainage practices, such as artificial field drains used to eliminate excess water from heavily farmed areas, commercial forests, and regions with impermeable soil prone to waterlogging, and changes in the hydrological characteristics of drainage basins. These changes have been associated with an increase in flood occurrences. The implementation of land drainage systems leads to a reduction in the water table by effectively clearing surface water, diminishing evapotranspiration rates, and consequently augmenting the average annual surface runoff.

Human activities, both intentional and unintentional, have had a significant impact on hydrological processes and the hydrological cycle. This influence is so substantial that it has been recognized as a major focus area in the International Hydrological Programme launched by UNESCO. The modifications caused by human activities can range from localized and insignificant effects to large-scale and catastrophic consequences, occurring at both the local and regional levels

14.3.3 Human Activities and Weathering & Mass Movement Processes

Weathering refers to the natural process of rock and regolith disintegration and decomposition in their original location. It occurs through various factors such as insolation (solar radiation), water, frost, air, pressure, oxygen, carbon dioxide, hydrogen, plants, and animals. However, human activities, acting as a biological agent, can either accelerate or decelerate the natural rate of weathering.

Certain human activities, such as mining for mineral extraction, blasting of hills and ridges for dam construction and mineral extraction, and quarrying for industrial and building materials (e.g., limestone for cement), can significantly increase the rate of geomaterial disintegration. In fact, these activities can cause such rapid disintegration that it surpasses the natural weathering processes that typically occur over thousands to millions of years.

Deforestation by human activities accelerates the rate of weathering on hillslopes by altering the ground surface. Vegetation, particularly dense forests with abundant trees, plays a crucial role in maintaining stability in hillslope profiles. This stability is achieved through the mechanical reinforcement provided by the intricate root networks, which enhance the cohesion of the underlying regolith and geomaterials. However, deforestation on hillslopes diminishes the mechanical reinforcement and cohesion of these unconsolidated geomaterials. As a result, slope instability increases, leading to various forms of mass movement, such as landslides, slumping, debris fall, and slides. The impact of deforestation-induced landslides has become a prevalent phenomenon in the foothills of the Himalayas.

Human activities contribute to the occurrence of mudflows and earthflows, which can be categorized into two main types.

Firstly, the accumulation of waste soil and rock fragments resulting from mining activities forms large piles that can trigger spontaneous lateral earthflows, engulfing the surrounding areas. **Secondly,** the removal of support through undermining of natural masses of soil, regolith, and rock fragments also plays a significant role. Construction activities, such as the building of dams, canals, and structures at the base of hillslopes, often result in the removal of support from the slope, leading to mass movement events. The expansion of urban settlements onto hillslopes has a notable impact on slope processes and the movement of rock waste. It is essential to highlight that the safety factor on the steeper sides of hillslopes is nearly at unity, indicating a relatively stable condition. However, any human activity aimed at altering the equilibrium state has the potential to destabilize the slope, leading to slope failures and mass movement. For instance, activities such as road construction, building development, installation of water pipes and power cables, as well as the construction of sewers on the higher portions of hillslopes, diminish the resisting force of the slope materials, thereby increasing the risk of instability.

14.3.4 Sea Coasts and Human Activities

Human intervention directly impacts coastal processes through various means. These include:

1. Disrupting wave motion and reducing the energy of coastal waves by using air bubble curtains.
2. Constructing structures like sea walls, groynes (groins), and breakwaters (masonry walls) to resist the effects of sea waves and currents.
3. Trapping or importing sediments to replenish eroded sea beaches.
4. Planting trees to stabilize beaches and coastal dunes.

However, man's efforts to control coastal erosion, promote deposition, and manipulate coastal processes for specific purposes (such as preventing erosion at harbors, creating beaches, restoring depleted beaches, or facilitating sea transport) have not been successful due to the complex nature of these mechanisms. These direct attempts to modify coastal processes bring about changes in nearshore topography, the behavior of waves and currents, coastal erosion patterns, and the movement and deposition of sediments along the adjacent coastline where such structural interventions have been implemented.

The construction of dams and reservoirs along major rivers that flow into the seas disrupts the natural growth process of beaches and deltas. This occurs because the dams trap sediment, causing it to settle in the reservoirs. Consequently, the supply of fluvial sediments through the river mouths significantly decreases. As a result, there is a rapid erosion of beaches and deltas, leading to retrogradation.

The intentional clearance of vegetation from stable coastal dunes, whether for economic purposes, through burning or grazing, exacerbates wind erosion of these dunes. The fine materials eroded by the onshore wind accumulate further inland, destabilizing the coastal dunes. A notable example of this can be observed along the southeastern coast of Australia.

Conversely, planting trees, shrubs, and grasses can stabilize destabilized coastal dunes. Regions such as the Landes region of southwestern France and the Culbin area on the Scottish coast have employed this approach successfully.

Expanding earth fills in urban and industrial areas along the seaboard for the reclamation of tidal marshes and mudflats create additional space for industrial installations, buildings, roads, and airfields. However, this practice presents challenges regarding weak foundations for structures such as buildings, highways, and airstrips. Moreover, it results in the destruction of estuarine environments, leading to the loss of marine food resources.

14.3.5 River Mechanism and Human Influence

Modifications to channel processes by humans can be categorized into two groups: (i) direct or intentional modifications for beneficial purposes, and (ii) indirect or inadvertent modifications that have adverse effects on society.

(i) Direct modifications of channel processes include various measures such as flood control initiatives, channel improvements, construction of dams and reservoirs, stream channelization (which involves straightening, widening, and deepening channels), and manipulating river banks through control structures. These control structures can include revetments made of rocks, concrete, or other materials, open fence and basket revetments, solid fences and groynes built at right angles to the channel flow, training structures like timber pile dikes, rock dikes, rock-filled pile dikes, artificial earthen levees, and closure of secondary channels. Additionally, irrigation diversions, such as canals, are another form of direct channel modification.

Direct modifications can occur at specific points or locations along the river, known as point modifications. Examples include the construction of dams and reservoirs for water supply, irrigation canals for crop irrigation, hydroelectric power generation, pumping water for local domestic use and lift irrigation canals, and the discharge of wastewater from urban and industrial areas into rivers at specific outfall points. Furthermore, the construction of road and rail bridges across rivers is also considered a point modification.

The second type of direct modification, known as reach modification, involves a significant length of the channel. Highly sinuous channels are straightened by cutting off meander loops to shorten the reach's length. This process increases water velocity, allowing for quicker water disposal downstream during floods through an increased frequency of peak discharge.

(ii) Indirect modifications of channel processes involve altering the overall surface characteristics of the entire catchment area or a portion of it through deforestation. Deforestation leads to the exposure of bare ground surfaces, which results in accelerated erosion and increased surface runoff. Consequently, both stream discharge and sediment load are heightened, causing changes in the channel regime known as river metamorphosis. These changes encompass alterations in channel geometry, channel planform, and sediment transport. Human activities contribute to the aggradation and siltation of river valleys due to the augmented supply of sediment. Factors responsible for this include intensive and extensive cultivation, deforestation, natural and intentional forest fires, mining operations, urbanization, and highway construction. These activities not only increase sediment supply, leading to channel aggradation but also elevate the suspended load within the channels. This suspended load travels downstream and deposits in lakes, reservoirs, and estuaries, adversely impacting aquatic life.

14.4 SUMMARY

Anthropogenic geomorphology is a branch of study that focuses on the influence of human activities on Earth's landforms and the processes that shape them. It examines how human actions, such as infrastructure development, deforestation, mining, and agriculture, alter the natural landscape and impact geomorphic processes. Anthropogenic geomorphology examines the impact of human activities on Earth's landforms and processes. It encompasses direct and indirect modifications to channel processes, coastal areas, hillslopes, and drainage basins.

Areas such as anthropogenic geomorphology on modifications of channel processes. Alterations aim to serve various human needs but can disrupt natural channel dynamics. Humans directly manipulate rivers and streams through measures like flood control, dam construction, and channelization, direct modifications involve flood control measures, channel improvements, dams, reservoir construction, stream channelization, and irrigation diversions. Indirect modifications, such as deforestation, alter the catchment's surface characteristics, leading to increased erosion, surface runoff, and changes in channel geometry and sediment transport. These modifications can result in channel aggradation, increased sediment load, and adverse effects on aquatic life downstream.

Interventions aim to manage water resources for various purposes, such as irrigation, hydropower generation, and navigation. While these modifications can provide benefits to human society, they often disrupt natural channel dynamics. Dams and reservoirs trap sediment, reducing the supply downstream and causing erosion and changes in channel geometry. Deforestation in catchment areas accelerates erosion, increases surface runoff, and alters sediment transport, leading to channel aggradation or degradation.

Coastal areas are another focus of anthropogenic geomorphology. Human activities like urbanization, construction of sea walls, and beach nourishment can significantly modify coastal processes. Urban encroachment on hillslopes affects slope stability, leading to slope failures and mass movements such as landslides. Construction activities at the base of hillslopes reduce the resistance of slope materials and increase the risk of slope failures. Structures like sea walls and breakwaters are built to control wave action and erosion. However, these modifications can have unintended consequences, altering sediment transport, and coastal erosion patterns, and affecting adjacent areas.

Hillslopes play a vital role in geomorphic processes, and human activities can have significant impacts. Deforestation and removal of vegetation accelerate weathering and destabilize slopes, leading to increased erosion and mass movements. On the other hand, stabilization measures, such as reforestation and planting vegetation, can help mitigate slope instability and erosion.

Drainage basins are also subject to anthropogenic influences. Land drainage for agriculture and forestry, as well as the alteration of impervious soils, can impact hydrological characteristics. Artificial field drains remove surface water from intensive farming and commercial forests, which can lower the water table, reduce evapotranspiration, and increase surface runoff. These modifications can lead to changes in the hydrological regime, affecting the occurrence and magnitude of floods.

Anthropogenic geomorphology recognizes the complex interactions between human activities and Earth's natural landscape. It highlights the need for sustainable land use practices and careful consideration of the environmental consequences of human modifications. Understanding the impacts of these modifications is crucial for effective land management, hazard mitigation, and the preservation of natural ecosystems.

14.5 GLOSSARY

1. **Anthropogenic Geomorphology**: The study of the influence of human activities on Earth's landforms and geomorphic processes.

2. **Channel Processes**: The natural processes involved in the formation and modification of river channels, including erosion, deposition, and sediment transport.

3. **Flood Control Measures**: Human interventions aimed at managing and controlling floods, such as the construction of levees, flood walls, and reservoirs.

4. **Channel Improvements**: Human-engineered modifications made to river channels to enhance their capacity for water conveyance and navigation.

5. **Channelization**: The process of straightening, widening, and deepening river channels to facilitate water flow, often for agricultural or navigational purposes.

6. **Sediment Trapping**: The process by which dams and reservoirs trap sediment, reducing the supply of sediment downstream and causing changes in channel morphology.

7. **Deforestation:** The clearing or removal of forests, often for agriculture, logging, or urban development, which can lead to increased erosion, altered hydrological patterns, and slope instability.

8. **Coastal Modifications**: Human activities that alter coastal processes, such as the construction of sea walls, groynes, breakwaters, and beach nourishment, with the aim of controlling erosion or protecting coastal infrastructure.

9. **Slope Stability:** The resistance of hillslopes to mass movements, such as landslides or slumping. Human activities that remove vegetation or alter slope geometry can destabilize slopes and increase the risk of slope failures.

10. **Hydrological Characteristics**: The properties and behavior of water within a drainage basin, including precipitation, evapotranspiration, runoff, and water storage.

11. **Land Drainage**: The artificial removal of surface water from agricultural fields or commercial forests through the use of drainage systems, which can affect the hydrological balance and increase surface runoff.

12. **Channel Aggradation**: The process of sediment accumulation in a river channel, leading to the elevation of the channel bed and potential changes in channel morphology.

13. **Channel Degradation**: The process of erosion and lowering of the river channel bed, often caused by a decrease in sediment supply or increased water velocity.

14. **Catchment Area:** The land area from which water drains into a river or stream, including all the tributaries and smaller watercourses that contribute to the flow.

14.6 ANSWER TO CHECK YOUR PROGRESS

1. **What is the negative impact of deforestation on natural geomorphology?**

   a) It leads to increased soil erosion and slope instability.

   b) It promotes the growth of vegetation and enhances ecosystem stability.

   c) It improves water retention and reduces flooding risks.

   d) It has no significant impact on geomorphological processes.

   Answer: a) It leads to increased soil erosion and slope instability.

2. **How do dams and reservoirs affect natural geomorphology?**

   a) They enhance sediment deposition and promote delta formation.

   b) They increase the natural flow of rivers and maintain channel stability.

   c) They trap sediments, leading to erosion downstream and retrogradation.

   d) They have no impact on the geomorphic processes of rivers.

   Answer: c) They trap sediments, leading to erosion downstream and retrogradation.

3. **What is the negative consequence of extensive cultivation in the catchment areas of rivers?**

   a) It promotes fluvial sediment deposition and delta growth.

   b) It reduces the risk of floods and sediment transport.

   c) It accelerates soil erosion and increases sediment supply to rivers.

   d) It has no effect on the geomorphological processes of rivers.

   Answer: c) It accelerates soil erosion and increases sediment supply to rivers.

4. How does urban development on hillslopes affect natural geomorphology?

a) It improves slope stability and reduces landslide risks.

b) It increases the natural vegetation cover and enhances erosion control.

c) It destabilizes slopes, leading to slope failures and mass movements.

d) It has no impact on the geomorphic processes of hillslopes.

Answer: c) It destabilizes slopes, leading to slope failures and mass movements.

5. What are the consequences of channelization on river geomorphology?

a) It restores natural meandering patterns and promotes ecosystem diversity.

b) It enhances sediment transport and promotes floodplain development.

c) It alters channel morphology, reduces sediment supply, and increases erosion downstream.

d) It has no significant impact on the geomorphic processes of rivers.

Answer: c) It alters channel morphology, reduces sediment supply, and increases erosion downstream.

6. How does excessive groundwater extraction affect natural geomorphology?

a) It increases water availability and enhances river flow.

b) It promotes aquifer recharge and reduces erosion risks.

c) It lowers the water table, reduces baseflow, and affects river channel stability.

d) It has no impact on the geomorphic processes related to groundwater.

Answer: c) It lowers the water table, reduces baseflow, and affects river channel stability.

7. What is the negative impact of intensive mining activities on natural geomorphology?

a) It promotes the deposition of sediments and enhances floodplain development.

b) It improves soil stability and enhances landform preservation.

c) It accelerates erosion, degrades landscapes, and alters river courses.

d) It has no significant impact on the geomorphic processes of mining areas.

Answer: c) It accelerates erosion, degrades landscapes, and alters river courses.

8. How does the construction of sea walls affect coastal geomorphology?

a) It promotes beach nourishment and enhances coastal stability.

b) It improves sediment transport and fosters dune formation.

c) It disrupts natural coastal processes, leading to erosion and loss of beaches.

d) It has no impact on the geomorphic processes of coastal areas.

Answer: c) It disrupts natural coastal processes, leading to erosion and loss of beaches.

9. What is the consequence of excessive soil erosion on natural geomorphology?

a) It enhances slope stability and promotes landform preservation.

b) It decreases sediment supply to rivers and reduces flood risks.

c) It alters river courses, increases sedimentation, and affects channel morphology.

d) It has no significant impact on the geomorphic processes related to soil erosion.

Answer: c) It alters river courses, increases sedimentation, and affects channel morphology.

10. How does excessive groundwater pumping affect karst landscapes?

a) It promotes the dissolution of soluble rocks and enhances cave formation.

b) It increases the water table, improves aquifer recharge, and maintains karst features.

c) It leads to land subsidence, disrupts underground drainage patterns, and affects sinkhole formation.

d) It has no impact on the geomorphic processes related to karst landscapes.

Answer: c) It leads to land subsidence, disrupts underground drainage patterns, and affects sinkhole formation.

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13.8 TERMINAL QUESTIONS

1. How has human activity impacted landforms and landscapes over time, and what are the key processes and mechanisms involved in anthropogenic geomorphology?

2. What are some of the major examples of human-induced landform modifications, such as the creation of reservoirs, mining activities, and urbanization, and how do these activities alter natural geomorphic processes?

3. How do anthropogenic factors, such as deforestation, agriculture, and construction, contribute to soil erosion and sedimentation, and what are the implications for landscape stability and environmental sustainability?

4. In what ways do human activities influence river systems and fluvial processes, including channelization, damming, and floodplain development, and how do these alterations impact riverine ecosystems and the overall functioning of river networks?

5. How can anthropogenic geomorphology contribute to mitigating the adverse effects of human activities on landforms?

UNIT – 15 LAKES: ORIGIN, TYPES, AND DISTRIBUTION

15.1 OBJECTIVES

After studying this lesson, you will be able to:

- Background of Limnology and its definition
- Trace the origin of lakes
- Describe different types and distribution of lakes

15.2 INTRODUCTION

You have already studied how different erosion and deposition agents work on the Earth's surface in the previous chapters. You have also learned about landforms formed by periglacial, glacial, arid, and water processes. This unit will focus on the lakes, their origin, types, and distribution.

A **lake** is an enclosed body of water by land. There are many lakes in different parts of the world, and they vary from continent to continent and area to area based on climatic or environmental conditions. The size of lakes may differ from more significant to smaller, and it can be a salt-water lake or fresh-water lake. They are relatively larger than ponds in terms of size. Lakes support different types of an ecosystem that depend on them for survival. Many factors influence the size, shape, and content, such as wind, temperature, sunlight, currents, evaporation rates, and plant-animal interaction. Lakes receive their water from streams, rivers, and glaciers. The term "*Lake*" has been derived from the Greek word *'Lakkos,'* meaning pond or basin. Lakes have an essential role to play in the hydrological cycle.

Carpenter (1928) formulated that the actual difference between lake and pond is the depth and not an area. Accordingly, a pond is a quiet body of water where floating vegetation extends to the middle of the basin. The biota is very similar to the littoral zone of the lake.

15.3 LIMNOLOGY

The term '*Limnology*' is derived from the Greek word '***limno***' meaning pool, lake, and '*logos*' meaning knowledge. The study of inland waters like rivers, lakes, and ponds can be termed Limnology. François- Alphonse Forel coined the term limnology in his study of Lake Geneva. According to Forel (1892), 'Limnology is the oceanography of lakes.' It is the study of all inland water (fresh or saline, natural or human-made). It is a multidisciplinary science as it studies the chemical, biological, geological aspects of inland waters and can be correlated with hydrology, oceanography, botany, and environmental science. Limnology has the following vital elements – water balance, temperature structure, circulation of water, chemistry, biology, and bottom sediments. The field of limnology originated in the 16th century, but Forel first used it in 1892. Lewis (1995) defined limnology as the study of the inland water ecological system.

Some of the aspects related to Limnology are discussed in the following section:

Residence Time: The ***residence time*** of a lake is defined as *the lake's water volume divided by the discharge into or out of the lake*. The residence time is necessary because it tells you something about how long it might take to clear pollutants from a lake.

The water Balance of Lakes: Lakes have many sources of both inflow and outflow. The primary sources of inflow are streams, precipitation onto the lake surface, and groundwater. The primary sources of outflow from a lake are streams, evaporation from the lake surface, and groundwater

Importance of lakes:

- A lake helps in the regulation of streamflow: E.g., Bhakra and Nangal Dam on River Sutlej.
- Lakes are an essential water source for industries, hydroelectric power plants, drinking, and other purposes. E.g., Hirakud Dam and Great Lakes of United States.
- It supports many types of plants, animals, and microscopic organisms.
- Lakes play an integral part in the fishing industry.
- Salt Lakes are a common source of rock salt. E.g., Dead Sea
- It maintains local climatic conditions.
- These are used for navigation purposes. E.g., Great Lake and St. Lawrence waterways
- Lakes control floods.
- It can be used for recreation and tourism purposes. E.g., Chilika Lake
- Lakes are stoppages for migratory birds and serve as breeding grounds for them.
- Lakes are home to many animals such as birds, animals, microscopic plants, fishes, etc.
- Lakes are a source of food for humans.
- Many aquatic animals live on lakes and breed in them.

15.4 ORIGIN OF LAKES

The origin of lakes is not always constant, and therefore it is related to the catastrophic movement of the Earth, such as volcanism, earthquake, etc. The type of lake influences the kind of flora and fauna in that area. Many external factors affect the lake, such as temperature, precipitation, sunshine, latitude, and altitude.

All lakes which are formed undergo three stages, such as Youth, Maturity, and old age. Once reaching old age, Lakes start to disappear as silt, sediments, pebbles, cobbles, etc., gets accumulated in those depressions. But this process is prolonged, and it may take hundreds and thousands of years. The first living organisms developed in lakes. A lake over the period becomes dry, and slowly they die. Many dead fishes and animals get accumulated on the bottom of the lake, along with plants, algae, soil, pebbles, etc., forming sediments. These get deposited on the lower surface layer of the lakes.

Water gets accumulated in a bowl-shaped depression, which is being filled by the lakes. These depressions are called **basins**, which are formed in many ways. Lakes are formed by tectonism, erosion, volcanism, and other external factors that operate on the surface of the Earth. Lakes, especially in the Northern Hemisphere formed by the glaciers. When glaciers melt, water gets filled up in depressions forming lakes. The glaciers created many lakes in Europe and the United States.

The tectonic movements include the movement of continental plates. These tectonic events cause the formation of large basins, thus accumulating water in them, forming lakes. Such tectonic activities took place during Miocene and tertiary periods. These activities forming lakes are as follows:

- Subsidence of land
- Erosion and deposition by the glaciers
- Volcanism, meteorite collision with earth surface, and landslides.

Some lakes are formed because of folds and faults. Rainfall, streams, or river water fills up the basins caused by faulting. Lake Baikal and Caspian formed in such a manner. Lakes that are volcanic in origin are a result of volcanoes. A dormant or inactive volcano receives water in its crate for an extended period due to melted snow or rain, thus forming a lake. When a large depression is formed during a volcano's sudden eruption, it collapses to form a caldera. A **crater**

lake is formed when rainwater gets filled up in them. An example of such a type of lake is Crater Lake in Oregon, the United States of America (USA), when Mount Mazama's was created by the collapse of volcanic cones. Lakes formed due to tremendous changes in the continental plates are tectonic in origin, and some of the well- known examples are the Aral Sea and the Caspian Sea.

Artificial lakes are an essential source of water, formed by the construction of dams across a river. When river water is diverted and stored in a reservoir, artificial lakes are formed. These lakes are fed by precipitation or runoff. In the United States of America (USA) of Nevada and Arizona, Lake Mead is an example of an artificial lake formed in this manner.

Lakes can also be formed by landslides or mudslides when soil, mud, silt, and rocks pile up in a dam and block water flow in the depression created due to landslides forming lakes.

Rivers play an essential role in forming lakes; such lakes are ox-bow lakes, lagoons, etc. When a river reaches the mature stage and starts meandering, leaving a body of standing water is known as ox-bow lakes.

Brackish or saline lakes are created by waves' action when waves hit the shoreline, eroding and damming river deltas and estuaries.

The wind's action can form lakes by creating depression and filling precipitation water in them by removing sand dunes. These are endorheic lakes that do not have natural outflow and lose their water by evaporation or seepage. Playas are formed in regions where winds move or erode soil-forming shallow lakes.

Karst Lakes are created by the process of solution of rocks when water percolates and gets dissolved, developing cavities in limestone regions. The roof of karst regions collapses, forming lakes. Such lakes can be found in the Karst region of Yugoslavia and the Alps.

15.4.1 Classification of Lakes based on their origin

Earth Movement

- **Tectonic Lakes:** Lake Titicaca (Border of Peru and Bolivia in South America), Caspian Sea
- **Rift Valley Lakes:** Lake Tanganyika (on the borders of Tanzania, Democratic Republic of Congo, Zambia, and Burundi in Africa) in South America), Dead Sea (Jordan), Lake Baikal (Russia) (Figure 15.1)

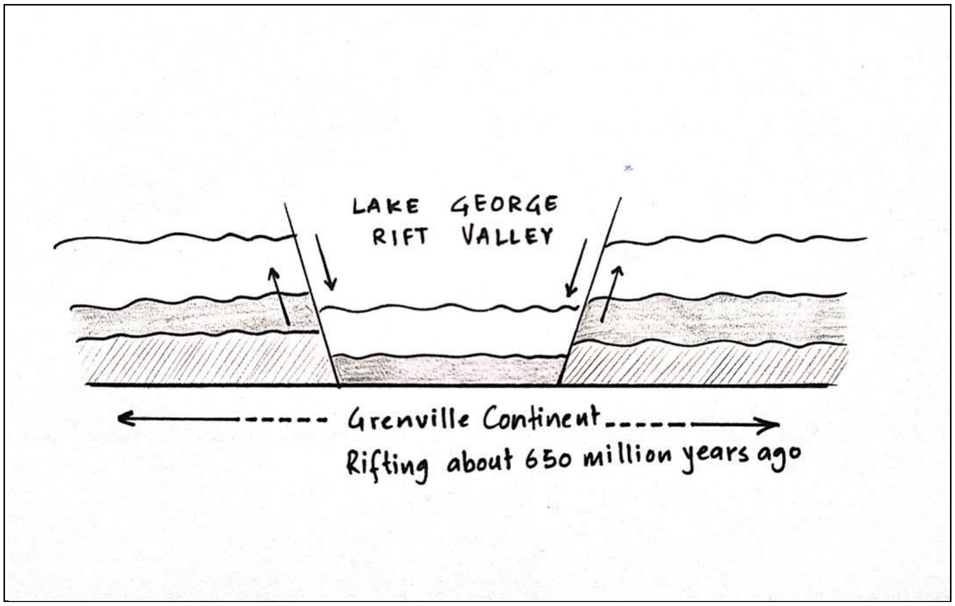

Figure 15. 1: Rift valley Lake, Source: Prepared by Author

- **Faulting-induced Lakes**: Abert Lake (**United States of America)**, Great Salt Lake (**United States of America)**
- **Earthquake-induced Lakes**: The Great basin of Australia

Deposition

- **Ox-bow Lakes:** Kanwar Lake Bird Sanctuary in Bihar, India; Lower Mississippi (United States of America) (Figure 15.2)

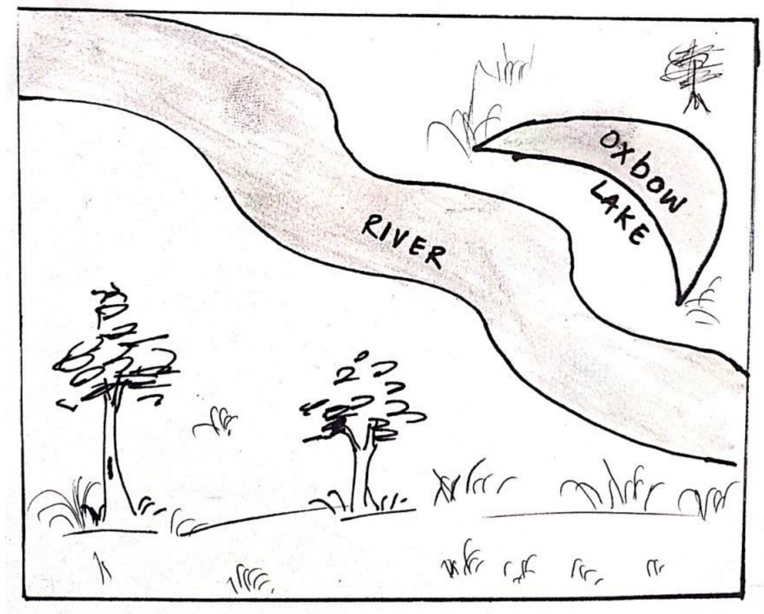

Figure 15. 2: Ox-Bow Lake, Source Prepared by Author

- **Barrier Lakes:** Lake Gormire in Yorkshire, the United Kingdom (Figure 15.3)

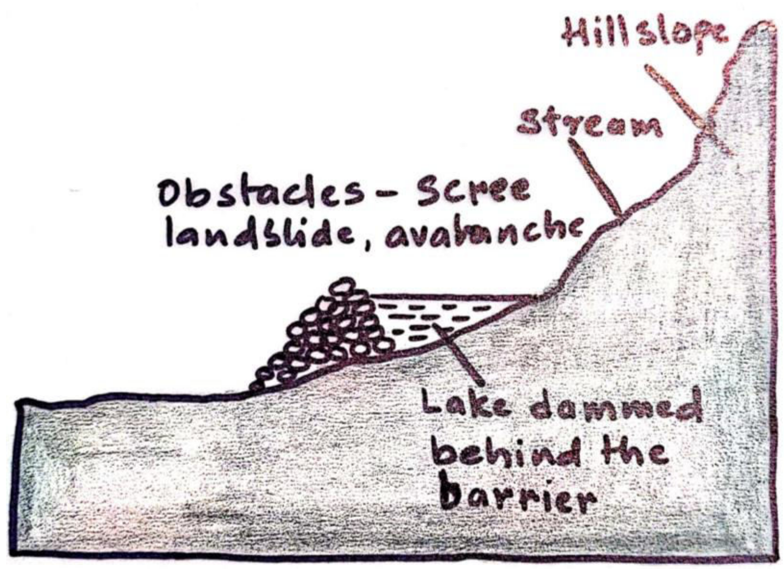

Figure 15. 3: Barrier Lake, Source Prepared by Author

Man-Made Lakes

- **Artificial lakes:** Guru Gobind Sagar Lake (India) (Figure 15.4)

Trophic level

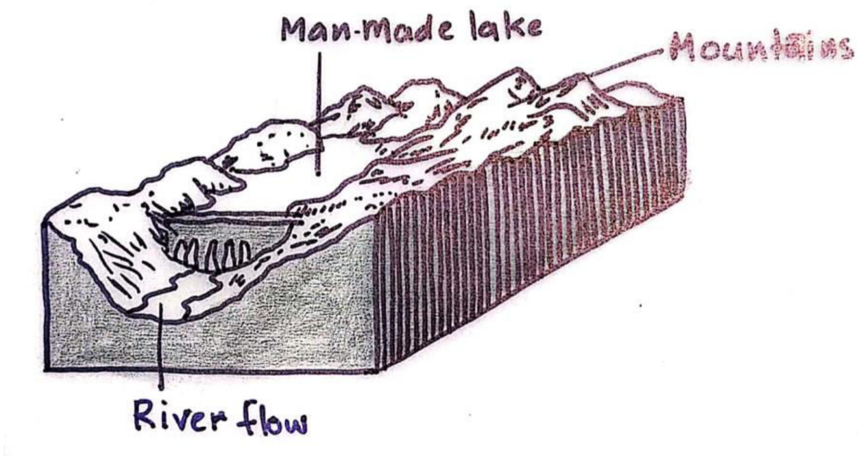

Figure 15. 4 Man-made Lake, Source Prepared by Author

- **Eutrophic Lake:** Udaisagar lake in Rajasthan and Dal Lake in Kashmir, India
- **Mesotrophic Lake:** Bassenthwaite and Derwentwater in the Lake District are two of the best examples of mesotrophic lakes in England.
- **Oligotrophic Lake:** Gangbal Lake, situated at the foothills of Mount Haramukh in Ganderbal district, Jammu and Kashmir, India.

Erosion

- **Karst Lake:** Lac de Chaillexon in the Jura mountains (Figure 15.5)
- **Wind deflated lakes:** Great Basin (Utah, United States of America)

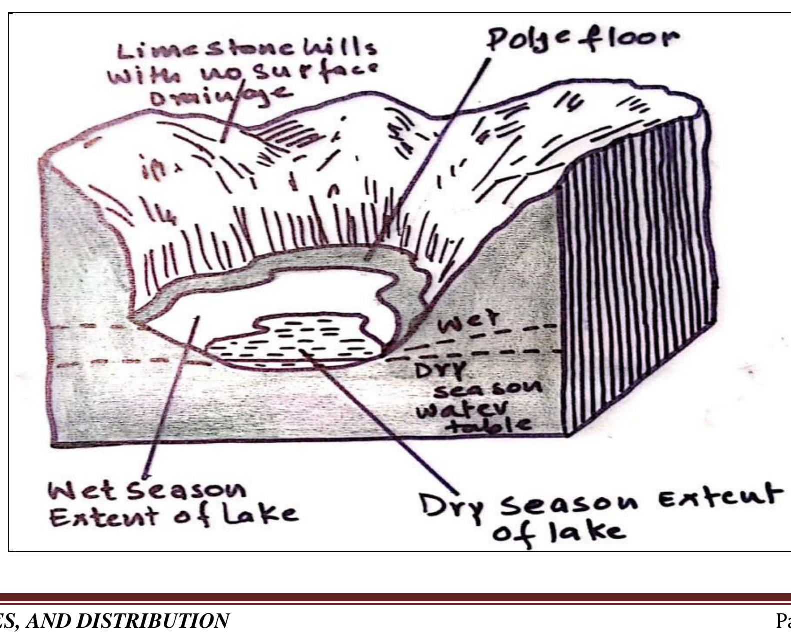

Figure 15. 5 Karst Lake, Source Prepared by Author

Glaciation

- **Kettle Lakes:** Orkney in Scotland
- **Cirque or tarn Lakes:** Ribbon lakes and Chandra Taal in Himachal Pradesh, India (Figure 15.6)

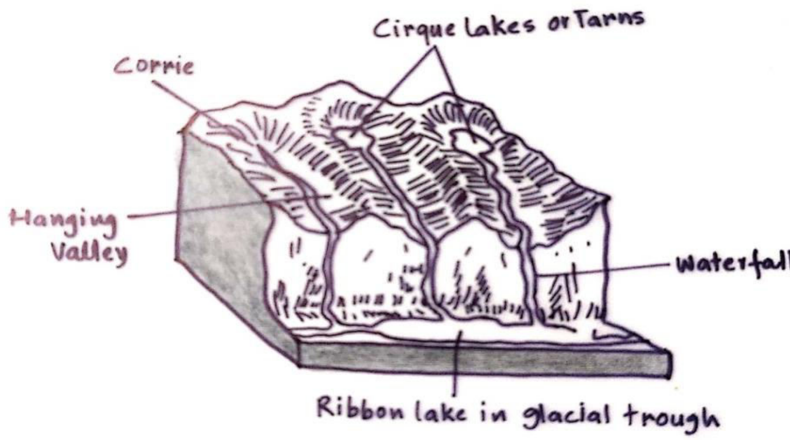

Figure 15. 6 Cirque Lake, Source Prepared by Author

Volcanism

- **Crater and Caldera Lakes:** Lonar Lake (Maharashtra, India), Crater Lake (United States of America), Lake Toba (Sumatra, Indonesia) (Figure 15.7)
- **Lava blocked Lakes:** The Sea of Galilee

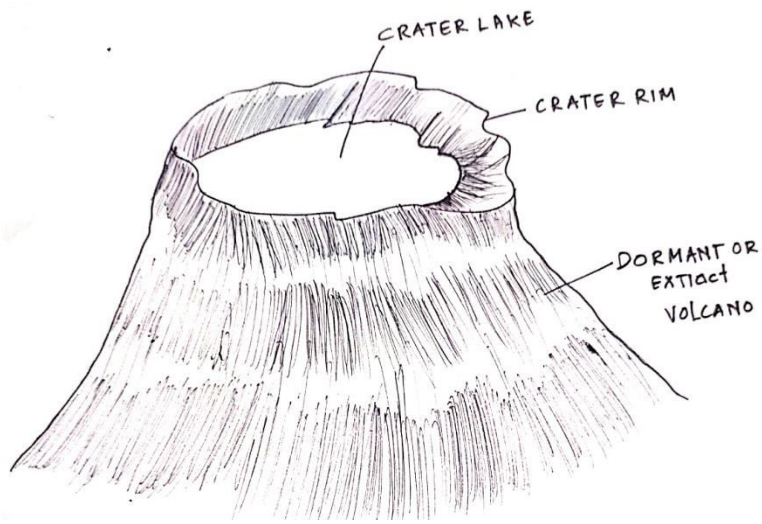

Figure 15. 7 Volcanic Lake, Source Prepared by Author

15.5 TYPES OF LAKES

There are different types of lakes according to the mode of origin. These are as follows:

Artificial Lakes: An artificial lake is created due to human excavation of land by flooding behind a dam. Artificial lakes are made for power generation, water supply to homes and industries. Examples of artificial lakes are Hirakud Dam in Odisha and Lake Mead in the USA.

Glacial Lake: Glacier lakes are quite common in the areas of glaciers. Glaciers create cirque, U-shaped valleys, and kettle lakes. An example of glacier lakes is Onega Lakes of USSR, Great Lakes of North America.

Meteorite Lakes: Lakes created due to the impact of meteorites or asteroids are called meteorite lakes. A meteorite hit the Earth's surface and forms a depression, forming lakes due to precipitation accumulation. An example of Crater Lake is Lake Bosumtwi in Ghana and Lonar Lake in Maharashtra, India.

Aeolian Lakes: Lakes that form due to wind action are called Aeolian Lakes, or interdunal lakes. They form in arid and dry environments, and precipitation accumulates in sand dunes. Moses Lake in Washington is an example of Aeolian Lake.

Tectonic Lakes: Lakes formed due to the Earth's crust's tectonic activity are called Tectonic Lakes. The tectonic activity includes folding, faulting, warping, etc. Examples of the tectonic lake are Lake Baikal, Wular Lake, Great Rift Valley in Africa, etc.

Volcanic Lakes: Volcanic lakes have been formed due to volcanism. Crater Lake and Malheur Lake in Oregon is an example of the volcanic lake formed due to massive volcanic eruption. Volcanic lakes are in the form of calderas or crater created due to volcanic activity.

Fluvial Lakes: Lakes that are formed due to the action of running water are fluvial. Rivers create meander lakes and plunge pool lakes. The middle and lower Ganga plain in the northern part of India and Brahmaputra Valley is a suitable area for forming ox-bow lakes.

Freshwater Lake: Freshwater lakes are non-saline water that receives water from rivers and streams. Examples of fresh-water lakes are the Great Lakes of the United States, Wular Lake in Jammu and Kashmir, and Loktak Lake in Manipur.

Saltwater Lakes: Salt-water lakes or saline lakes are typical in regions of the desert. The formation of these lakes is majorly due to more evaporation of water than outflow. Some of the salt-water lake's well-known examples are the Great Salt Lake, Sambhar Lake in Ajmer, Chilika Lake in Odisha, and Pangong Lake in Ladakh.

Organic Lakes: Lakes formed by the action of flora and fauna can be termed Organic Lakes. Coral lakes and beaver dams are formed due to vegetation's presence, and they are relatively small in size compared to other types of lakes.

Oceanic Lakes: Lagoons are typical examples of oceanic lakes, formed by spits and bars in coastal regions with shallow water bodies. Some of the well-known examples of oceanic lakes are Chilika Lake in Odisha, Kolleru Lake in Andhra Pradesh.

Underground Lakes: Lakes that are formed under the surface of the Earth are called underground lakes. These are associated with caves, springs, or aquifers. Examples of underground lakes are Dragon's Breath Cave in Namibia, and Craighead Caverns in Tennessee, USA.

Fjord Lakes: Fjord Lakes are formed due to glacial action when coastal areas are eroded below sea level.

15.6 DISTRIBUTION OF LAKES

The distribution of lakes on Earth is uneven. Some are located on the ground, and some on the underground surface. Recent researchers have found out that 117 million lakes account for 3.7 percent of total water. The numbers of small lakes are more than large lakes and are commonly found in the Northern Hemisphere at high altitudes of polar and subpolar regions. Around 50 to 60 percent of the lakes are in Canada. Many lakes are permanent, artificial, organic, saline, underground, etc., constructed for power generation, agricultural use, irrigation, water supply to homes, etc. Fresh-water is an essential source of water for consumption purposes, obtained from rivers, lakes, or streams, accounting for 0.003 percent of total water available, and 30 percent of it is in the ground.

Continent- wise distribution of Lakes

Most of the lakes in the world are found in the continents of Africa (30 percent), North America (25 percent), and Asia (20 percent)

Africa: One of the largest lakes in Africa is Lake Victoria (the second fresh-water lake in the world), Lake Tanganyika is the longest fresh-water and deepest lake in the world, Lake Nyasa, Lake Albert, Lake Chad, Lake Assal in Djibouti, Lake Retba. Other important lakes are Lake Kariba in Zambia, Lake Bogoria and Lake Nakuru in Kenya, Lake Bunyonyi in Uganda, and Lake Edward in Uganda, and DR Congo.

***North America*:** In the USA, Lake Superior is the largest lake, followed by Lake Huron, Lake Michigan, Lake Erie, Lake Ontario, Great Salt Lake, and Lake of the Woods. Some of the essential lakes in North America are Lake Chapala in Mexico, Moraine Lake, Lake Winnipeg, and Great Bear Lake in Canada.

Asia: the Caspian Sea is the largest water body in Asia and the world, followed by Lake Baikal in Siberia, Lake Balkhash in Kazakhstan, Lake Taymyr in Russia, Issyk- Kul Lake in Kyrgyzstan, Lake Urmia in Iran, Lake Sarygamysh, and many more. Other noteworthy names are Lake Toba in Indonesia, Inle Lake, Penang National Park in Myanmar, Pangong Tso Lake in India, Lake Attabad in Pakistan, and Lake Kawaguchi in Japan.

Europe: One of the largest lakes in Europe is Lake Ladoga in Russia, followed by Lake Onega in Russia. Other important lakes in Europe are Lake Como, Lake Orta, Lake Garda in Italy, Lake Geneva in Switzerland, Lake Bled in Slovenia, Lake Hallstatt in Austria, etc.

South America: The largest lake in South America is Lake Titicaca in Peru, Mar Chiquita, Lake Buenos Aires, Argentino Lake in Argentina, and Lake Maracaibo in Venezuela.

Australia: Australia has numerous lakes such as Dove Lake in Tasmania, Lake Alexandria, Lake McKenzie, Lake Albina, Lake Hillier, and Blue Lake.

Antarctica: Some of the well- known lakes of Antarctica are Amphitheatre Lake, Ablation Lake, Beaver Lake, Deep Lake, Lake Vostok, Lake Ellsworth, and Smith Lake etc.

Table mo. 15.1 Distribution of Lakes by Surface Area

Names	Countries	Area
Caspian Sea	Kazakhstan Russia Iran Azerbaijan Turkmenistan	143,000 sq. mi
Lake Superior	Canada United States	31,700 sq. mi
Lake Victoria	Uganda Kenya Tanzania	26,590 sq. mi
Lake Huron	Canada United States	23,000 sq. mi
Lake Michigan	United States	22,000 sq. mi
Lake Tanganyika	Burundi Tanzania Zambia D.R. of Congo	12,600 sq. mi
Lake Baikal	Russia	12,200 sq. mi
Great Bear Lake	Canada	12,000 sq. mi
Lake Malawi	Malawi Mozambique Tanzania	11,400 sq. mi
Great Slave Lake	Canada	10,000 sq. mi

Table no.15.2 Distribution of Lakes by Volume

The distributions of lakes according to the volume are as follows:

Names	Countries	Water Volume
Caspian Sea	Kazakhstan Russia Iran Azerbaijan Turkmenistan	18,800 cu mi
Lake Baikal	Russia	5,700 cu mi
Lake Tanganyika	Burundi Zambia Tanzania D.R. of Congo	4,500 cu mi
Lake Superior	Canada United States	2,900 cu mi
Lake Malawi	Malawi Mozambique Tanzania	2,000 cu mi
Lake Vostok	Antarctica	1,300 ± 380 cu mi
Lake Michigan	United States	1,200 cu mi
Lake Huron	Canada United States	850 cu mi
Lake Victoria	Uganda Tanzania Kenya	660 cu mi
Great Bear Lake	Canada	536cu mi

Some important Lakes in the world

- **Lake Michigan**

  Among all the Great Lakes, Lake Michigan is the third-largest located entirely in the United States. The second largest of the Great Lakes with total volume of Lake Michigan is 1,180 cubic mi with 45,600 square mi of drainage basin. The total water surface area is around 22,300 square mi. It lies in the states of Indiana, Illinois, Michigan, and Wisconsin.

- **Lake Mansarovar**

  Lake Mansarovar lies in Tibet and is considered the world's highest sizeable fresh-water lake globally. It is the source of Ghaghara, Brahmaputra, Sutlej, and Sindhu. It is a sacred place for Buddhism, Jainism, Hinduism, and Bön religion.

- **Dead Sea**

  The Dead Sea or Salt Sea borders the country of Israel and Jordan. It is the lowest water body on the Earth's surface, with the lowest elevation of 400 meters below sea level. Due to the arid desert climate and closed water body, the evaporation increases, causing increased salinity of 34.2%.

- **Lake Tanganyika**

  It is the longest fresh-water lake (660 meters) globally by volume, second largest in east Africa, and second deepest (1,436 meters) after Lake Baikal in Russia. It is also one of the oldest lakes in the world. It lies in Burundi, Tanzania, Zambia, and the Democratic Republic of Congo. It lies along continental rift zones and is created by the crust's subsidence as two plates are pulled apart. It is one of the oldest lakes in the world.

- **Lake Baikal**

  Lake Baikal is in south-east Siberia; Russia is the deepest (1,620 meters) and oldest fresh-water lake in the world. It is 20 to 30 million years old and is the world's largest lake by volume of 23,600 km3. It is also known as the 'Galapagos of Russia', and its total area is around 31,500 square km with 20% of Earth's fresh-water. It also lies along continental rift zones and is created by the crust's subsidence as two plates are pulled apart.

- **Lake Titicaca**

  Lake Titicaca is the world's highest navigable fresh-water lake and the second-largest lake in South America. It borders Peru to the west and Bolivia to the eastern parts in the Andes ranges at 3,810 meters above sea level.

- Ojos del Salado

  Ojos del Salado is the highest altitude lake globally, with a permanent crater lake, located at 6,390 meters on a volcano in South America.

❖ Taal Lake

In Luzon, Philippines, Taal Lake is a fresh-water lake with a volcanic crater formed by the eruption of Taal Volcano. With a 244 square km area, it is the third-largest lake in the Philippines, located within a national park. Volcano Island, also known as Taal Volcano has recently erupted in 2020.

❖ Wollaston lake

It is in Saskatchewan, Canada, in the southern part of Barren Grounds. It drains naturally in two directions, with a total surface area of 2,681 square km. It is the largest bifurcation lake in the world. It was named after an English scientist William Hyde Wollaston.

❖ Lake Toba

Lake Toba is located in the north-central part of Sumatra, Indonesia. It is the largest natural volcanic lake with an area of 1,140 square km in the world.

❖ Nettilling Lake

Nettilling Lake is one of the fresh-water lakes lying on Baffin Island, Canada. It is the world's largest lake on an island, covering an area of 5,542 square km. It is the eleventh largest lake in Canada and 30th in the world. It lies in the Great Plain of Koukdjuak and an important area for caribou feeding and bird migration.

Some Important lakes in India

In this section, you will learn about the different lakes of India. In India, there are both fresh-water and salt-water lakes.

Fresh-water lakes

❖ **Wular Lake**

- Wular Lake is the largest fresh-water lake in the country and is being fed by the Jhelum River.
- It is in Jammu and Kashmir.
- It is formed because of tectonic activity.

❖ **Loktak Lake**

- It is one of the largest lakes in northeast India.
- Loktak Lake is a fresh-water lake and was designated as Ramsar Convention in 1990.

- Different types of weeds cover about 40% of the lake surface area, both floating and submerged.
- Keibul Lamjao is the only floating national park in the world. It is composed of a continuous mass of floating *phumdi* occupying an area of 40 sq. km.

❖ **Kolleru Lake**

- It is the largest shallow fresh-water lake in Asia and India.
- This lake was declared a wildlife sanctuary, known as Atapaka Bird Sanctuary.
- It is in Krishna and Godavari delta.
- It was declared as Ramsar Convention site in 2002.
- It is one of the largest bird sanctuaries, home to nearly 188 species of birds.

❖ **Dal Lake**

- It is also known as *Srinagar's Jewel* or *Jewel in the crown of Kashmir*.
- It is in Srinagar and is the second largest lake in Jammu and Kashmir.
- Nishant Bagh and Shalimar Bagh lie on the banks of Dal Lake.

Salt-water lakes

❖ **Sambhar Lake**

- Sambhar Lake is India's largest inland salt-water lake.
- It is in Ajmer, Rajasthan.
- Sambhar Lake is a significant source of salt in Rajasthan.

❖ **Pangong Tso**

- It is the highest altitude salt-water lake in the world.
- It is a landlocked lake which is in the Ladakh region of India.
- The brackish water freezes in winter and becomes ideal for ice skating.

❖ **Pulicat Lake**

- It is the second-largest brackish water lake in India, separated by a barrier on an island named Sriharikota.
- Satish Dhawan Space Centre is located here.
- It lies in the states of Andhra Pradesh and Tamil Nadu.

- Flamingo Festival is held every year as migratory birds reach here from Siberia and Mongolia.

❖ **Chilika Lake**

- Chilika Lake is the largest coastal lagoon lake in India in the Mahanadi delta.
- The pear-shaped lagoon has a maximum length of 64 km and an average width of 20 km.
- It is a brackish water lagoon and home for migratory birds during winters.
- Irrawaddy dolphins can be found here.

Natural lakes

❖ **Vembanad Lake**

- It is the longest and largest human-made lake in India, situated in Kerala.
- This lake has lagoons, mangroves, and marshes.
- This lake has the largest wetland ecosystem in India.
- The Nehru Trophy boat race is held on this lake.

❖ **Nainital Lake**

- Naini Lake or Nainital Lake is a natural fresh-water lake located in Nainital, Uttarakhand.
- It is kidney-shaped with a tectonic origin.
- Nainital is known as the Lake District of India.

❖ **Kanwar Lake**

- Kanwar Lake or Kabar Taal lies in Begusarai district of Bihar.
- It is Asia's largest fresh-water ox-bow lake.

❖ **Lonar Lake**

- It is in the Buldhana district of Maharashtra.
- It was created due to the impact of a meteorite collision.
  Its water is saline and alkaline.

Artificial lakes

❖ **Guru Gobind Sagar**

- It is in Bilaspur district, Himachal Pradesh.
- It is a human-made reservoir built-in 1976.

- It is named after the 10th Sikh guru, Guru Gobind Singh.
- It is the world's highest gravity dam located on the river Sutlej.

❖ **Sardar Sarovar**

- Sardar Sarovar Lake is located on the Narmada River, Gujarat.
- It is a concrete gravity dam built-in 1987.
- It is situated in one of the oldest dams in the country.

❖ **Nagarjuna Sagar**

- It is situated on the Krishna River in Hyderabad.
- It is the largest stone masonry dam in the world.
- It is the largest human-made lake in the world.

15.7 SUMMARY

You have now learned that lakes are an enclosed body of water by land. The size and shape of lakes vary from country to country based on many internal and external factors. Lakes play an important role in hydrological cycles, and they receive water from rivers, streams, glaciers, and precipitation. Limnology is the study of inland waters like rivers, lakes, and ponds. It is a multidisciplinary science as it studies the chemical, biological, geological aspects of inland waters.

The formation of lakes is associated with the catastrophic movement of the Earth. These movements are volcanism, earthquake, tectonism, etc. Many external or internal factors operate on lakes, which influence the type of lake. The process of lake formation is prolonged, and the lake undergoes three stages of Youth, Maturity, and old age. When a bowl-shaped basin gets filled up with water is called a basin. Once experiencing old age, these basins start to disappear due to silting sediments, cobbles, pebbles, rocks, etc. Lakes in Europe and the United States are mainly glacial. In the northern hemisphere, glacial lakes are more common. The origins of lakes are influenced by land subsidence, erosion and deposition by the glaciers, volcanism, meteorite collision with earth surface, and landslides. The origin of lakes can be artificial, natural, fresh-water, saline water, volcanic, crater, tectonic, etc., in nature.

As you know, the distribution of lakes is uneven on the Earth. One hundred seventeen million lakes are accounting 3.7 percent of total water. Some lakes are permanent, artificial, organic, saline, underground, etc., constructed for power generation, agricultural use, irrigation, water supply to homes, etc. The Caspian Sea is the largest lake globally in terms of surface area and volume of water.

15.8 GLOSSARY

- **Artificial lake:** An artificial lake is created due to human excavation of land by flooding behind a dam.
- **Basin:** A basin is a natural depression in the surface of the land. A lake basin is a geographic land area draining into a lake, also referred to as a drainage basin or watershed. Source: EEA
- **Fjord Lakes:** Lakes are formed due to glacial action; when coastal areas are eroded below sea level are called Fjord lakes.
- **Freshwater Lake:** Freshwater lakes are non-saline water that receives water from rivers and streams.
- **Lake:** A lake is an area filled with water and is surrounded by land**.**
- **Limnology:** The study of inland waters like rivers, lakes, and ponds can be termed Limnology.
- **Meteorite Lakes:** Lakes created due to the impact of meteorites or asteroids are called meteorite lakes.
- **Reservoir:** A reservoir is an artificial lake where water is collected and kept in an open-air storage area constructed across a river.
- **Volcanism:** Volcanism is a complex process in which molten magma erupts on the surface of the Earth, where lava, pyroclastic, and volcanic gases erupt through a vent.

15.9 ANSWER TO CHECK YOUR PROGRESS

1. List the classification of the lake based on:

a. Tectonic lakes and Rift Valley lakes
b. Ox-bow lakes and Barrier lakes
c. Kettle lakes and Cirque lakes
d. Crater lakes and caldera lakes
e. Karst lakes and wind deflated lakes

2. **Five types of lakes with examples:**

i. Glacial Lake: Great Lakes of North America
ii. Artificial Lake: Hirakud Dam in Odisha
iii. Meteorite Lake: Lonar Lake in Maharashtra
iv. Tectonic Lake: Lake Baikal and Wular lake
v. Freshwater Lake: Loktak lake and Wular lake

4. Canada

5. the Caspian Sea

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15.11 TERMINAL QUESTIONS

1) Write any four advantages of lakes.
2) Define Limnology.
3) Explain the process of lake formation.
4) Give any two characteristics of Lonar Lake?
5) Name any four fresh-water lakes in India?
6) List the top five lakes according to the surface area.
7) When was the term limnology first used?

UNIT- 16 INTERRUPTION IN THE EVOLUTION OF LANDFORM " POLYCYCLIC LANDFORM"

16.1 OBJECTIVES

After reading this unit learners will able to:

- Understand polycyclic process
- Understand landforms associated with polycyclic process
- Understand rejuvenated landforms

16.2 INTRODUCTION

The concept of cyclic nature in the history of the Earth was likely first proposed by James Hutton, a Scottish geologist, in 1785. Hutton introduced the idea that the Earth's history is characterized by cycles and that there is no discernible beginning or end, emphasizing the importance of the present in understanding the past. Later, this concept evolved into the notion of uniformitarianism, which states that the same physical processes and laws that operate today have been in effect throughout geological time, although not necessarily with the same intensity. This concept drew influence from Hutton's idea of the cyclic nature of Earth's history and evolutionary concepts put forth by Charles Darwin (regarding the origin of species through natural selection) and William Morris Davis (1850-1934 A.D.), who presented the concept of the *Cycle of Erosion* in 1899. Davis' geographical cycle of erosion model was based on the fundamental concept of sequential changes in landforms over time, like the evolution of organic life. According to Davis, landforms undergo sequential changes over time, progressing through three stages. His theory was the result of various theories and models he presented over time, including the "complete cycle of river life" in his essay on "The Rivers and Valleys of Pennsylvania" in 1889, the "geographical cycle" in 1899, and "slope evolution." Geographical cycle is a period of time during which an uplifted land mass undergoes its transformation by the process of land sculpture, ending in a low featureless plain or peneplain." According to Davis, three factors—structure, process, and time—play important roles in the origin and development of landforms in a particular area. These three factors, known as the "*Trio of Davis*," are expressed as follows:

"Landscape is a function of structure, process, and time". Structure refers to the lithological (rock types) and structural characteristics (folding, faulting, joints, etc.) of rocks. Time is not only considered in a temporal context but is also seen as a process itself, leading to an inevitable progression of landform changes. Process refers to the agents of denudation, including weathering and erosion (running water in the case of the geographical cycle).

The primary aim of Davis' model and the general theory of landform development was to provide a systematic description and genetic classification of landforms. The reference system for Davis' general theory is that landforms change in an orderly manner as processes operate through time, resulting in an orderly sequence of landform development under uniform external environmental conditions. Various models were developed based on this reference system, such as the normal cycle of erosion, the arid cycle of erosion, the glacial cycle of erosion, marine cycle of erosion, and more.

16.3 DAVIS CYCLE OF EROSION

The Davis cycle of erosion is a conceptual model to describe the sequential development of landforms through the process of erosion. According to “landforms undergo a cyclical evolution involving stages of youth, maturity, and old age.”
The Davis cycle of erosion consists of the following stages:

1. **Youth Stage**: In the youth stage, uplift and tectonic forces create an initial landform, typically a mountain or upland area. The landscape is characterized by steep slopes, deep valleys, and narrow ridges. Erosional processes, such as weathering, mass wasting, and the action of running water, are active and shape the landform. The dominant erosional agent in this stage is often rivers and streams.

2. **Maturity Stage:** As the landform progresses into the maturity stage, significant changes occur. The once steep and rugged features start to evolve into a more subdued and mature form. River valleys widen and deepen, creating a more gently sloping topography. The landscape exhibits a well-developed drainage system with meandering rivers, floodplains, and broader valleys. Erosional processes continue to shape the landform, but at a slower rate compared to the youth stage.

3. **Old Age Stage:** The old age stage represents the final phase of the cycle of erosion. The landform becomes highly subdued, and erosion has significantly worn down the landscape. The once prominent features are eroded, resulting in a low-relief, featureless plain called a peneplain. River valleys become wider and less defined, and the erosional processes primarily involve weathering and slow, meandering streams.

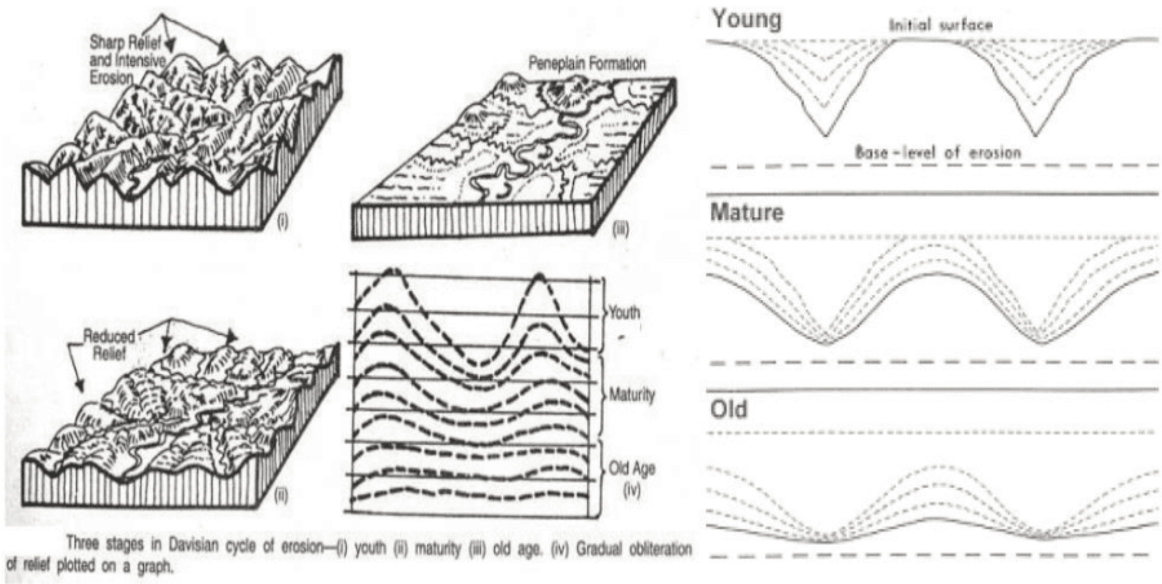

Fig. 16.1 The Davis cycle of erosion Source: google image

16.4 PENK'S CYCLE OF EROSION

Penck's cycle of erosion is a model of landscape development that was proposed by Walther Penck, a German scientist, in 1924. Penck challenged the Davisian model of geographical cycle, which was based on time-dependent stages of landform development. Penck argued that the landforms of a region are related to the tectonic activity of that region, and that the landforms reflect the balance between the intensity of endogenetic processes (i.e., uplift rate) and the displacement of materials by exogenetic processes (erosion and removal rate).

Penck's model assumed that erosion of landforms starts with the start of the upliftment process, and that upliftment and erosion processes go simultaneously. Penck did not use the concept of stages in his model, but used the term *Entwickelung* meaning 'development'. He used the terms *Aufsteigende Entwickelung* (increasing or accelerated development), *Gleichformige Entwickelung* (constant or uniform development), and *Absteigende Entwickelung* (decreasing or decelerated development) to describe the different phases of landscape development**.**

Penck used the term *Primarumpf* to represent the initial surface or primary peneplain before upliftment. This surface could be either newly emerged from below sea level or a peneplain type of land surface converted into a featureless landmass by uplift. Penck also used the term *Fastenbene* to describe a peneplain type of surface that is formed by erosion after upliftment**.**

According to Penck, during Aufsteigende Entwickelung, the upliftment rate is higher than the erosion rate, and the landforms are characterized by steep slopes, high relief, and convex profiles. The rivers are actively incising their valleys, creating features such as waterfalls, rapids, gorges, and knick points. The hillslopes are dominated by mass wasting processes, creating features such as talus slopes, debris cones, and landslides.

During Gleichformige Entwickelung, the upliftment rate and the erosion rate are balanced, and the landforms are characterized by moderate slopes, moderate relief, and straight profiles. The rivers are in equilibrium with their base level, creating features such as graded streams, meanders, floodplains, and terraces. The hillslopes are dominated by weathering processes, creating features such as soil creep, solifluction, and sheet erosion.

During Absteigende Entwickelung, the upliftment rate is lower than the erosion rate, and the landforms are characterized by gentle slopes, low relief, and concave profiles. The rivers are overgraded and aggrading their valleys, creating features such as braided streams, alluvial fans, deltas, and lakes. The hillslopes are dominated by deposition processes, creating features such as pediments, inselbergs, and loess.

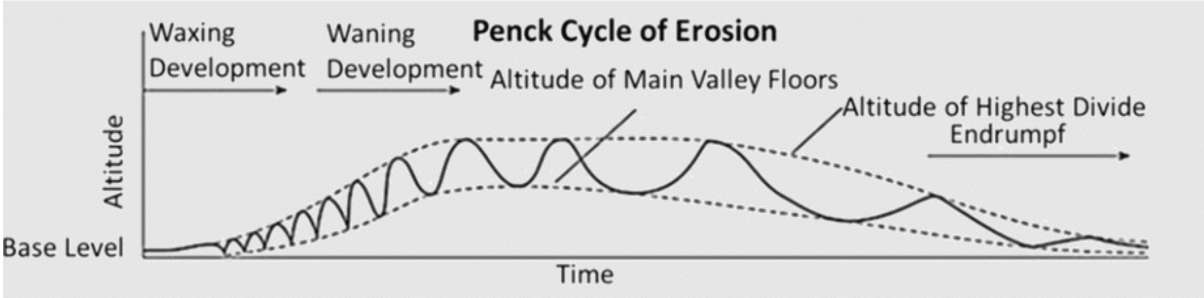

Fig. 16.2 Penck's cycle of erosion, Source: google image

16.5 NORMAL CYCLE OF EROSION

The cycle of landform development by fluvial processes is termed the normal cycle of erosion, as fluvial processes are the most prevalent and influential geomorphic agent on the planet. Water also influences geomorphic change in glacial and arid environments. W.M. Davis assumed that humid temperate regions represented the most standard case for the normal cycle of erosion, but this is questionable.

The normal cycle of erosion commences with the tectonic uplift of a landmass above sea level, which triggers the initiation of rivers and their erosional activity. The uplift rate surpasses the erosion rate initially, and the landmass exhibits high relief and steep slopes. Subsequently, the uplift rate declines and the erosion rate intensifies, and the landmass exhibits moderate relief and moderate slopes. Eventually, the uplift rate ceases and the erosion rate dominates, and the landmass exhibits low relief and gentle slopes.

The normal cycle of erosion progresses through three stages: youth, mature, and old (or senile or penultimate). The outcome of the normal cycle of erosion is a low-lying plain with minimal relief and residual hills with convexo-concave shapes called 'monadnocks', 'unakas', and 'mosores'. This plain is referred to as a peneplain. The peneplain can undergo tectonic uplift again, which initiates a new cycle of erosion.

Polycyclic landforms, on the other hand, are a result of interruptions in the normal progression of the Davis cycle of erosion. These interruptions occur due to various factors, such as tectonic activity, climatic changes, or geological events. When the cycle of erosion is interrupted, the landform does not reach the old age stage and undergoes a new cycle of erosion, resulting in the formation of a new set of landforms.

Polycyclic landforms often exhibit characteristics of rejuvenation, where the landscape experiences renewed erosion and incision. This can be caused by positive or negative changes in the base level of erosion. Positive changes, such as subsidence of the land or a rise in sea level, cause the cycle to advance quickly to the next stage. Conversely, negative changes, such as uplift or a drop in sea level, push the cycle backward, resulting in renewed erosion and a return to the youth or maturity stage.

16.6 INTERRUPTIONS IN THE EVOLUTION OF LANDFORM "POLYCYCLIC LANDFORMS"

Davis introduced his concept of the "geographical cycle," popularly known as the "cycle of erosion," in 1899 to present a genetic classification and systematic description of landforms. The completion of a generalized and ideal cycle of erosion depends on long-term tectonic stability, which is rarely achievable in nature due to the Earth's inherent instability. As a result, the cycle of erosion is frequently interrupted, leading to an imbalance in the cyclic model. Any obstruction that disrupts the normal functioning of the cycle of erosion is referred to as an *interruption of the cycle*. When these polycycles occur successively, they are known as successive cycles of erosion, resulting in landscapes known as polycyclic or multi-cyclic landscapes.

Cycles that are punctuated by interruptions are referred to as interrupted cycles, which give rise to the occurrence of multiple cycles in a region. Interruptions in the cycle of erosion caused by a positive shift in the base level (resulting from subsidence of landmass or a rise in sea level) accelerate the cyclic timeline. For instance, if the cycle is in the youthful stage, it may advance to the mature stage due to a positive shift in the base level. Conversely, a negative change in the base level (caused by upliftment of landmass or a drop in sea level) extends the cyclic timeline, pushing the cycle backward. For example, if the cycle is in the late mature stage and experiences sudden land upliftment or sea level drop, it regresses to the youthful stage, characterized by renewed valley incision known as rejuvenation. These interruptions can be caused by climatic factors, tectonic factors, or a combination of both. Tectonic factors are associated with the upward or downward movement of erosion base levels.

The interruption of the cycle of erosion is typically categorized into two types:

(i) If the interruption results in either lengthening or shortening of the cycle period (due to rejuvenation or base level change), it is simply referred to as an interruption of cycles or base level change interruption.

(ii) if the interruption causes the ongoing cycle to end abruptly and a new cycle to begin after a significant time gap, it is called an accident. Such interruptions can be caused by climatic changes or volcanic eruptions.

Regions like the Appalachian Mountains in the United States and the Chotanagpur Region in India are typical examples of polycyclic landscapes where multiple cycles have been completed. Features such as paired terraces, valley-in-valley topography, and incised meanders in the Damodar Valley at Rajroppa in Hazaribagh (Bihar) and valley-in-valley topography, paired terraces, Dhunwadhar Falls, and incised meanders of the Narmada River at Bhedaghat near Jabalpur (Madhya Pradesh) indicate the occurrence of rejuvenation and polycyclic relief.

Example as, a fluvial cycle of erosion is in the mature stage. If there is a widespread volcanic fissure flow that pours a massive volume of lava, leading to the complete destruction of existing streams, it would mark the closure of the chapter of the cycle of erosion. Once the lava cools and solidifies, new streams would appear on the fresh surface, initiating a new cycle of erosion.

Climate-Related Interruption

Major changes in climate can indeed lead to interruptions in the cycle of erosion. For instance, if a fluvial cycle of erosion in a humid region is in the mature stage and experiences a sudden climate change, such as extreme dryness or extreme cold, the cycle can be significantly disrupted. In such cases, the ongoing cycle of erosion is closed, and a new set of cycles is initiated based on the new climatic conditions.

If the climate becomes extremely hot and arid, an arid cycle of erosion may ensue. Alternatively, if the climate becomes glacial, periglacial, or sub-glacial, a glacial or periglacial cycle of erosion may develop. These new cycles are characterized by different erosional processes and landform evolution compared to the previous cycle.

It is to mention that minor changes in climate may not necessarily close the chapter of the current cycle. Instead, they can either augment or slow down the cycle. For example, if the climate becomes more humid, resulting in increased rainfall, surface runoff and stream discharge will naturally rise. This localized interruption in the cycle can accelerate erosion rates, leading to a rejuvenation effect. The effects of this rejuvenation may extend over larger areas depending on the scale and intensity of the climatic changes.

Interruption Due to Change in Base Level

Any alteration in the base level of erosion, which is determined by the sea level, can lead to interruptions in the cycle of erosion and potentially initiate a new cycle, regardless of whether the previous cycle has been completed or not. Changes in the base level of erosion can occur in two main forms:

- positive change caused by a rise in sea level and
- negative change caused by a fall in sea level.

These base level changes driven by sea-level fluctuations are referred to as eustatic changes, as they affect a wide area. In addition to sea-level changes, tectonic factors also contribute to variations in the base level of erosion. Subsidence of the landmass results in a positive change, while upliftment of the landmass leads to a negative change in the base level. Importantly, these tectonic-induced alterations may or may not be associated with sea-level fluctuations.

A positive change in the base level, or a rise in base level, reduces the duration of the erosion cycle, whereas a negative change, or a fall in base level, prolongs the cyclic period. Moreover, a positive change in the base level indicates an intensified process of alluviation or deposition.

while a negative change trigger accelerated erosion or rejuvenation. Rejuvenation, when involves intensified erosion, plays a crucial role in interrupting the fluvial cycle of erosion and giving rise to the formation of polycyclic or multi-cyclic landforms.

Here are some examples of polycyclic landforms:

1. Older alluvium terraces, such as the Bhangar terraces in the northern Indian plains.

2. Presence of synclinal ridges and anticlinal valleys in successive cycles of erosion.

3. Rejuvenated landforms resulting from interruptions in the erosion cycle.

4. Scarped erosional surfaces of different ages, found in regions like the Appalachians and the Western Ghats.

5. Faultline scarps formed due to differential erosion.

6. Uplifted peneplains, which are remnants of older, flattened land surfaces that have been uplifted.

7. Palaeomorphic landforms, which were formed under conditions that no longer exist. These include relict landforms, such as the drainage systems of the North Sahara in Africa, buried landforms formed by continental glaciers in the USA, and exhumed landforms that were initially buried but have been exposed again.

The interruptions in the fluvial cycle of erosion and the process of rejuvenation give rise to distinct landforms, resulting in a mosaic of poly or multi-cyclic landscapes. These landforms include topographic discordance, multistoried valleys, or valley in valley formations, uplifted peneplains, incised meanders, paired terraces, and nick points, among others.

Rejuvenation

Rejuvenation refers to the increase in the erosive power of fluvial processes, leading to the acceleration of erosion. It extends the duration of the erosion cycle. For instance, when a cycle of erosion is in its senile stage, characterized by gentle channel gradients, sluggish river flow, and broad and shallow alluvial valleys, rejuvenation can interrupt the cycle and revert it back to the youthful stage. In the youthful stage, the channel gradient becomes steeper and valley incision is accelerated. Rejuvenation can be categorized into three types:

1. Dynamic Rejuvenation:
   Causes:
   - Upliftment of the landmass
   - Tilting of land areas
   - Lowering of outlet

2. Eustatic Rejuvenation:
   Causes:
   - Changes in sea level due to diastrophic events such as subsidence of the sea floor or rise of coastal land
   - Glaciation leading to a fall in sea level

3. Static Rejuvenation:
   Causes:
   - Decrease in the amount of sediment carried by the river
   - Increase in water volume and subsequent stream discharge due to increased rainfall or melting water

Rejuvenation can occur due to various factors and results in the intensification of erosional processes, shaping the landscape in different stages of the erosion cycle.

- ***Dynamic Rejuvenation*** occurs when a region experiences uplift, resulting in a decrease in base level and initiating renewed downward erosion by streams. Elevating a landmass through epeirogeny uplift can lead to dynamic rejuvenation. The bending or faulting of a drainage basin causes an increase in the steepness of the stream gradient, followed by intensified downcutting. The impact of seaward tilting becomes apparent immediately, but only when the stream's direction aligns parallel to the direction of tilting.

- ***Eustatic Rejuvenation*** can occur due to a global decline in sea level and is categorized into two types. Diastrophic eustasy refers to sea level changes resulting from variations in the capacity of ocean basins, while glacio-eustasy involves sea level changes due to the accumulation or melting of successive ice sheets, leading to the withdrawal or return of water into the oceans.
  During eustatic rejuvenation, the mouth of a stream undergoes relocation. The stream gradually shifts its course towards a lower base level, moving upstream. This process can create a disrupted profile where the old and new base levels intersect.

- ***Static Rejuvenation*****,** on the other hand, can occur due to three factors affecting the stream. Firstly, a decrease in sediment loads carried by the stream can contribute to static rejuvenation. Secondly, an increase in runoff resulting from heightened rainfall can also trigger rejuvenation. Lastly, the acquisition of new tributaries that increase the stream's volume can bring about static rejuvenation.

Topographic Discordance

Also known as topographic unconformity, occurs when older topographic forms are present above younger forms. It refers to the disruption of topographic harmony or uniformity within a river valley, resulting from an interruption in the fluvial cycle of erosion caused by rejuvenation. This phenomenon is characterized by a mismatch between the upper and lower parts of the valley. The upper portion of the valley exhibits features indicative of a senile or mature stage, while the lower part belongs to the youthful stage. Typically, at the end of the mature stage and the beginning of the senile stage, the river develops a flat and shallow valley. However, if there is a sudden negative change in the base level of erosion due

to either a drop in sea level or upliftment of the landmass, the river undergoes rejuvenation. As a result, it resumes active downcutting of its valley, displaying increased erosive power.
The formation of a deep and narrow valley within a previously flat and broad valley results in a distinctive topography known as "valley in valley topography," "two-storied valley," or "two-cycle valley." This new deep and narrow valley is flanked by terraces on either side, representing the remnants of the earlier, older valley. Over time, as the rejuvenated river continues its erosive processes, it deepens the valley to a new base level, giving rise to a second broad and flat valley within the original valley formed during the initial cycle of erosion.

Uplifted Peneplains

Uplifted peneplains are formed because of interruptions caused by rejuvenation following regional uplift. These uplifted peneplains are characterized by remnants of summit levels that rise above the current plain surface. They represent the culmination of successive cycles of erosion, where multiple fluvial erosion cycles occur in succession. In the Appalachian Mountains, three uplifted peneplains have been identified, indicating phases of uplift, rejuvenation, and erosion. These include the Schooley peneplain, Harrisburg peneplain, and Sommerville peneplain.
Another example of an uplifted peneplain is found in the Patland region of the Ranchi Plateau. It is higher in elevation compared to the central Ranchi plateau, with a height of 610 meters above mean sea level (mamsl).
In the North Koel region and its numerous tributaries, the uplifted peneplains have been dissected, forming segmented tableaus locally known as "pats." These pats, such as Netharhat pat, Kamar pat, Rudni pat, and Jamira pat, are fine examples of mesas and buttes.

Incised Meanders

There are five alternative terms used to describe river meanders*: incised meanders, entrenched meanders, intrenched meanders, enclosed meanders*, and *ingrown meanders*. Incised meanders are characteristic features of rejuvenation and polycyclic reliefs. They form through vertical erosion, which leads to the incision of the valley due to renewed erosive power resulting from rejuvenation. These meanders are narrow and deep compared to the simple broad meanders formed during the first cycle of erosion, which are characterized by wide and shallow valleys formed through lateral erosion.
Incised meanders can be further classified into two types: entrenched meanders and ingrown meanders. Entrenched meanders have uniform slopes on both sides of the meander loops, while ingrown meanders have unequal slopes on their valley sides. In ingrown meanders, the concave side of the valley is deeply undercut, while the outer side (convex side) exhibits gentler slopes.

Knick Points

A knick point, commonly referred to as a nick, is a feature in the longitudinal profile of a river where there is a noticeable change in slope caused by rejuvenation. It is also known as the head of rejuvenation as it marks the upstream retreat of the river. Knick points are characterized by abrupt drops in elevation along the river's profile, creating opportunities for water to cascade vertically and form waterfalls of various sizes. These waterfalls associated with nick points are called nick point falls or simply Knickfalls.

Paired terraces

Paired terrace is a type of river terrace that occurs when a river erodes both sides of its valley equally, leaving two flat surfaces at the same height on opposite sides of the valley. These terraces represent former levels of the valley floor that were abandoned when the river started to cut deeper into its bed. Paired terraces are different from unpaired terraces, which occur when one side of the valley resists erosion more than the other, leaving a single terrace. Paired terraces are usually formed by rejuvenation of a river, which means an increase in its erosive power due to changes in climate, sea level, or tectonic uplift.

Example: - The Yellow River in China, which has several levels of paired terraces along its course, formed by cycles of river incision and aggradation.

- The Indus River in Pakistan, which has paired terraces up to 300 m above the present floodplain, indicating a long history of river downcutting.

- The Kanab Creek in Utah, USA, which has a fill terrace 18 m thick that was eroded by the stream in 1884, leaving behind paired cut terraces.

River rejuvenation

When a river responds to a decrease in its base level by actively eroding the surrounding landscape, it is considered rejuvenated. This rejuvenation process is typically triggered by a sudden drop in sea level or an uplift of the land. Because of these changes, the river's potential energy is heightened, leading to an accelerated rate of erosion on its riverbed. This erosion occurs as the river adapts to its new base level.

Multi-Storied Valleys or Valley in Valley

The formations are geomorphic features that consist of multiple levels of terraces or benches along the sides of a river valley. These terraces or benches are remnants of former valley floors that were eroded by the river at different stages of its fluvial cycle. Multi-storied valleys are formed when the river is rejuvenated, meaning that its erosional power is increased due to tectonic uplift, sea level fall, climate change, or other factors. The rejuvenated river cuts deeper into its old valley, leaving behind the terraces or benches as evidence of its history.

16.7 SUMMARY

Polycyclic landforms are the result of multiple cycles of erosion and rejuvenation, shaping the Earth's surface over geologic time. These landforms exhibit complex characteristics and provide valuable insights into landscape evolution. Synclinal ridges and anticlinal valleys are manifestation of polycyclic landforms. These features develop over successive cycles as tectonic forces uplift and deform the land, resulting in alternating ridges and valleys. Scarped erosional surfaces are also observed in polycyclic reliefs.

Faultline scarps are formed due to differential erosion, creating distinct breaks in the landscape. These scarps provide evidence of the dynamic nature of the Earth's crust and the influence of tectonic activity on landform development.

Paired terraces found in the Himalayas are significant polycyclic landforms. These terraces indicate multiple phases of uplift and subsequent rejuvenation, reflecting the complex tectonic history of the region.

Rejuvenation refers to the increase in erosive power and the resetting of the erosion cycle. It can occur due to various factors, such as upliftment of the landmass, changes in sea level, or changes in sediment load and water volume. Rejuvenation leads to the acceleration of erosion and the formation of new landforms.

Rejuvenated landforms exhibit distinct characteristics resulting from increased erosional activity. Incised meanders are deep and narrow valleys formed through vertical erosion during rejuvenation. They occur within simple broad meanders and can be classified as entrenched meanders or ingrown meanders, depending on the uniformity of slopes on both sides.

Paired terraces are another significant feature of polycyclic reliefs. They represent terraces formed during different phases of uplift and consequent rejuvenation. In the Himalayas, three pairs of terraces indicate three distinct phases of uplift and erosion cycles.

Knickpoints, also known as heads of rejuvenation, are breaks in the slope of a river's longitudinal profile. These abrupt drops in elevation result in waterfalls of varying sizes. Knickpoints occur due to the vertical incision caused by rejuvenation, and they signify the upstream recession of the river.

Polycyclic and rejuvenated landforms are the result of complex processes of erosion and landscape evolution. These landforms exhibit multiple cycles of erosion, interrupted by periods of rejuvenation that enhance erosive power and reshape the terrain. Here is a summary of polycyclic and rejuvenated landforms:

16.8 GLOSSARY

- **Antecedent Drainage**: A river system that predates the uplift of a mountain range and maintains its original course by cutting through the rising mountains. Antecedent rivers often form deep, narrow valleys or gorges.
- **Fault Scarp**: A steep slope or escarpment that forms along the fault line due to vertical displacement of rock blocks during tectonic activity. Fault scarps are characteristic features of active fault zones.

- **Knickpoint**: A sharp break or change in slope along a river course, indicating a change in erosional processes and potential rejuvenation. Knickpoints often form due to tectonic uplift or changes in base level and can lead to the formation of waterfalls or rapids.
- **Polycyclic Landforms**: Landforms that have experienced multiple cycles of erosion, deposition, and uplift over long periods of time, resulting in their complex and varied shapes and features.
- **Rejuvenated Escarpment**: An escarpment or steep slope that experiences renewed erosion, resulting in the formation of a more pronounced and prominent feature. Rejuvenated escarpments are often associated with tectonic uplift or changes in base level.
- **Rejuvenated Escarpment:** An escarpment or steep slope that experiences renewed erosion, resulting in the formation of a more pronounced and prominent feature. Rejuvenated escarpments are often associated with tectonic uplift or changes in base level.
- **Rejuvenated Landform**: A landform that has been reshaped, modified, or reinvigorated by renewed erosional processes or tectonic activity. Rejuvenated landforms exhibit youthful characteristics within a landscape that may be otherwise mature or old.
- **Rejuvenated Landforms**: Landforms that have experienced renewed uplift, erosion, and reshaping due to tectonic activity or changes in base level, resulting in the development of youthful features in previously mature or old landscapes.
- **Rejuvenated Waterfall**: A waterfall that forms or experiences renewed erosion due to changes in the landscape, such as tectonic uplift or variations in the rock resistance. Rejuvenated waterfalls often exhibit steep drops and cascades.
- **Rejuvenated Waterfall:** A waterfall that forms or experiences renewed erosion due to changes in the landscape, such as tectonic uplift or variations in the rock resistance. Rejuvenated waterfalls often exhibit steep drops and cascades.
- **Rejuvenation Tectonics:** Tectonic processes that result in the renewal or intensification of erosion and landform development. Rejuvenation tectonics can uplift previously eroded surfaces, initiate incision, and shape youthful landforms.
- Rejuvenation: The renewal or resurgence of erosional processes and landform development, often triggered by changes in tectonic activity, base level, or other factors. Rejuvenation leads to the creation of youthful features within older, more mature landscapes.
- **Rift Valley**: A long, linear valley that forms as a result of tectonic forces causing the Earth's crust to stretch and thin. Rift valleys can exhibit steep sides and flat bottoms and are often associated with the formation of new plate boundaries.
- **Rift Valley:** A long, linear valley that forms as a result of tectonic forces causing the Earth's crust to stretch and thin. Rift valleys can exhibit steep sides and flat bottoms and are often associated with the formation of new plate boundaries.

- **River Incision**: The deepening and downcutting of a river channel into the underlying bedrock due to renewed uplift, tectonic activity, or changes in base level. River incision can result in the formation of steep-sided valleys and gorges.
- **River Incision**: The process of deepening a river channel due to renewed uplift or a drop in the base level of the river. River incision results in the formation of steep-sided valleys and gorges.
- **Water Gap**: A narrow passage or valley carved by a river that cuts through a mountain ridge or range. Water gaps are often formed when the river maintains its course during uplift, resulting in the erosion of the rising landmass.

16.9 ANSWER TO CHECK YOUR PROGRESS

1. **Which term describes landforms that have undergone multiple cycles of erosion, deposition, and uplift over long periods?**
   a. Polycyclic landforms
   b. Rejuvenated landforms
   c. Differential landforms
   d. Antecedent landforms
   Answer: a) Polycyclic landforms

2. **What process is responsible for shaping polycyclic landforms through the wearing away and removal of soil, rock, or other materials?**
   a. Deposition
   b. Tectonic uplift
   c. Erosion
   d. Weathering
   Answer: c) Erosion

3. **Which of the following landforms is a characteristic feature of polycyclic landscapes formed by wind erosion?**
   a. Mesa
   b. River terrace
   c. Glacial cirque
   d. Water gap
   Answer: a) Mesa

4. **What term describes the renewed or resurgence of erosional processes and landform development due to changes in tectonic activity or base level?**
   a. Mass wasting
   b. River incision
   c. Rejuvenation
   d. Weathering
   Answer: c) Rejuvenation

5. **Which process involves the deepening and downcutting of a river channel into the underlying bedrock due to renewed uplift or changes in base level?**
   a. River incision
   b. Fault scarp
   c. River capture
   d. Stream piracy
   Answer: a) River incision

6. **What term describes the selective erosion of different rock types or layers at varying rates, contributing to the complex nature of polycyclic landforms?**
   a. Differential erosion
   b. Fluvial processes
   c. Aeolian processes
   d. Mass wasting
   Answer: a) Differential erosion

7. **What is the process of rejuvenation in landforms?**
   a. Renewed erosion and reshaping of landforms
   b. Deposition of sediment on landforms
   c. Weathering of rocks and minerals
   d. Formation of new landforms from volcanic activity
   Answer: a) Renewed erosion and reshaping of landforms

8. **What causes rejuvenation in landforms?**
   a. Changes in tectonic activity or base level
   b. Glacial erosion
   c. Aeolian deposition
   d. Chemical weathering processes
   Answer: a) Changes in tectonic activity or base level

9. **What is a characteristic feature of a rejuvenated escarpment?**
   a. Steep slopes
   b. Flat plains
   c. Gentle slopes
   d. Cavern systems
   Answer: a) Steep slopes

10. **Which term refers to the selective erosion of different rock types or layers at varying rates, contributing to the formation of rejuvenated landforms?**
    a. Mass wasting
    b. Differential erosion
    c. Glacial deposition

d. Fluvial processes
Answer: b) Differential erosion

11. Eustatic rejuvenation is a result of which global phenomenon?

a. Increase in sea level due to oceanic expansion
b. Worldwide decrease in sea level
c. Tectonic uplift leading to higher base level
d. Glacial deposition causing river incision

Answer: b) Worldwide decrease in sea level

12. Diastrophic eustasy refers to changes in sea level due to:

a. Variation in capacity of ocean basins
b. Accumulation of ice sheets
c. Changes in precipitation patterns
d. Tectonic uplift along fault lines

Answer: a) Variation in capacity of ocean basins

13. During eustatic rejuvenation, the mouth of a stream:

a. Remains unchanged in its position
b.Shifts towards a higher base level
c. Shifts towards a lower base level
d. Undergoes lateral erosion

Answer: c) Shifts towards a lower base level

14. Static rejuvenation of a stream can occur due to which of the following factors?

a. Increase in sediment loads carried by the stream
b. Decrease in runoff due to decreased precipitation
c. Decrease in stream volume caused by loss of tributaries
d. Tectonic subsidence leading to a decrease in stream gradient

Answer: a) Increase in sediment loads carried by the stream

15. "A point on the river's course where there is a change in the gradient of the river profile" is called ….?

a. River terraces
b. Knick point
c. George
d. Canyons

Answer) Knick point.

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16.11 TERMINAL QUESTIONS

1. Explain the concept of polycyclic landforms and the processes involved in their formation. Provide examples of polycyclic landforms and discuss how differential erosion contributes to their complexity.

2. Describe the rejuvenation process in landforms and discuss the factors that can trigger rejuvenation.

3. Compare and contrast polycyclic and rejuvenated landforms. Discuss the similarities and differences in their formation processes, erosion characteristics, and resulting landform features. Provide examples to support your answer.

4. Discuss the significance of differential erosion in shaping polycyclic and rejuvenated landforms.

5. Analyze the role of base level changes in the formation of rejuvenated landforms. Explain how a sudden fall in sea level or uplift of land can trigger river incision, leading to the development of water gaps, terraces, and incised meanders.

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