Advanced Geomorphology

Unit I: Geomorphology: Meaning, Scope and Content - Fundamental Concepts in Geomorphology – Geological timescale.

Geomorphology - Meaning

- Geomorphology is an important branch of Physical Geography. It is concerned with the scientific study of the origin and evolution of the relief features of the earth.
- The term geomorphology has been derived from the Greek words..'ge' meaning earth, 'morphe' meaning form and 'logos' meaning discourse. Thus geomorphology is the discourse on the form of the earth
- According to Worcester, 'Geomorphology is the interpretative description of the relief features of the earth'
- In the opinion of Strahler, geomorphology is an analysis of the origin and evolution of earth features. Geomorphology does not study merely the physical, chemical and biological processes affecting the evolution of land forms but also structure of the earth's crust, the geological processes as well as the climatic influences, because it is the combined influence of all these factors that determines the land forms.

- Thornbury says that geomorphology is the science of land forms including the submarine topography
- Bloom defines geomorphology as ‘systematic description and analysis of landscapes and the processes that change them’
- In the words of Spark, geomorphology is the study of the evolution of land forms, especially land forms produced by the processes of erosion.

Scope of Geomorphology

- Geomorphology is the study of landforms, their processes, form and sediments at the surface of the Earth (and sometimes on other planets).
- Study includes looking at landscapes to work out how the earth surface processes, such as air, water and ice, can mould the landscape.
- Landforms are produced by erosion or deposition, as rock and sediment is worn away by these earth-surface processes and transported and deposited to different localities.
- The different climatic environments produce different suites of landforms. The landforms of deserts, such as sand dunes and ergs, are a world apart from the glacial and periglacial features found in polar and sub-polar regions.
- Geomorphologists map the distribution of these landforms so as to understand better their occurrence.

- Earth-surface processes are forming landforms today, changing the landscape, albeit often very slowly.
- Most geomorphic processes operate at a slow rate, but sometimes a large event, such as a landslide or flood, occurs causing rapid change to the environment, and sometimes threatening humans.
- So geological hazards, such as volcanic eruptions, earthquakes, tsunamis and landslides, fall within the interests of geomorphologists.
- Advancements in remote sensing from satellites and GIS mapping has benefited geomorphologists greatly over the past few decades, allowing them to understand global distributions.

- Geomorphologists are also “landscape-detectives” working out the history of a landscape.
- Most environments, such as Britain and Ireland, have in the past been glaciated on numerous occasions, tens and hundreds of thousands of years ago.
- These glaciations have left their mark on the landscape, such as the steep-sided valleys in the Lake District and the drumlin fields of central Ireland.
- Geomorphologists can piece together the history of such places by studying the remaining landforms and the sediments – often the particles and the organic material, such as pollen, beetles, diatoms and macrofossils preserved in lake sediments and peat, can provide evidence on past climate change and processes.

- So geomorphology is a diverse discipline.
- Although the basic geomorphologic principles can be applied to all environments, geomorphologists tend to specialize in one or two areas, such Aeolian (desert) geomorphology, glacial and periglacial geomorphology, volcanic and tectonic geomorphology, and even planetary geomorphology.
- Most research is multi-disciplinary, combining the knowledge and perspectives from two contrasting disciplines, combining with subjects as diverse as ecology, geology, civil engineering, hydrology and soil science.

Content of Geomorphology

- Geomorphology is the scientific discipline concerned with the description and classification of the earth's topographic features.
- Geomorphology is closely allied with a number of other scientific disciplines that are concerned with natural processes.
- Fluvial and coastal geomorphology rely heavily on fluid mechanics and sedimentology.
- Studies of mass movement, weathering, wind action, and soils draw on the atmospheric sciences, soil physics, soil chemistry, and soil mechanics.
- Research on certain landform types entails the principles and methods of geophysics and volcanology; and
- The study of human impact upon landforms relies on the disciplines of geography and human ecology.

- Geomorphologic research focuses on the forces that mould and alter the primary relief elements of the terrestrial surface. These forces include tectonic activity and surficial earth movements (e.g., landslides and rockfalls).
- They also involve weathering and the erosion and deposition of the resulting rock debris by wind, glacial ice, and streams. In recent years, increasing attention has been given to the effects of human action on the physical environment as well.
- Geomorphology also deals with various theories related to the origin and development of landforms.
- In recent year there has been an increasing recognition of the practical applications of geomorphic principles and the findings of geomorphologic research to the understanding and solution of the problems facing mankind.

Fundamental Concepts of Geomorphology

1. The same physical processes and laws that operate today operated throughout geologic time, although not necessarily with the same intensity as now.
2. Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them.
3. To a large degree the earth's surface possesses relief because the geomorphic processes operate at different rates.
4. Geomorphic processes leave their distinctive imprint upon land forms, and each geomorphic process develops its own characteristic assemblage of land forms.

5. As the different erosional agents act upon the earth’s surface there is produced an orderly sequence of land forms.
6. Complexity of geomorphic evolution is more common than simplicity
7. Little of earth’s topography is older than Tertiary and most of it no older than Pleistocene.
8. Proper interpretation of present-day landscape is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene.

9. An appreciation of world climate is necessary to a proper understanding of the varying importance of the different geomorphic processes.
10. Geomorphology, although concerned primarily with present day landscape, attains its maximum usefulness by historical extension.

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

- ‘Principle of Uniformitarianism’
- First propounded by James Hutton in 1785
- Paraphrased as ‘the present is key to the past’
- According to Hutton geologic processes operated with the same intensity throughout geologic time
- But it is not true...

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

- Structure means fold, fault, joints, bedding plane, hardness, permeability, rock massiveness, susceptibility of rock minerals to chemical reaction...
- Structure is older than the landform

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

- Rocks offer varying degree of resistance to gradational process.
- Differences in rock composition reflect in regional & local geomorphic variability

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

- Endogenic and Exogenic processes
- Land forms have their unique features depending upon the geomorphic process responsible for their development
- Land forms are developed with respect to one another

5. As the different erosional agents act upon the earth's surface there is produced an orderly sequence of land forms.

- Land forms possess unique characteristics depending upon the stage of their development.
- Youthful, mature and old stages (W.M.Davis)
- Erosional agents: Rivers, Glaciers, Wind, Waves

6. Complexity of geomorphic evolution is more common than simplicity

- Most topographic features are produced during the current cycle of erosion
- But there may exist areas remnants of features produced during prior cycles also.
- Horberg (1952) divided the landscapes into 5 major categories; 1. simple, 2. compound, 3. monocyclic, 4. multicyclic and 5. exhumed
- 1.simple: one geomorphic process
- 2.compound: more than one geomorphic processes
- 3.monocyclic: one cycle of erosion
- 4.multicyclic: more than one cycle of erosion
- 5.exhumed:past landscape-buried-exposed now
-

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

- Most of our present topographic details are produced after Pleistocene epoch
- Only little of topographic features existed as surface topography back of the Tertiary
- The Himalayas were first folded during Cretaceous period and later in Eocene and Miocene
- But did not attain present elevation till Pleistocene.

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

- Glaciation affected larger area, say 10,000,000 square miles
- Many regions that are arid and semi-arid today had humid climates in glacial ages
- Pleistocene diastrophism – reason for present day landscapes around the Pacific Ocean

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

- Climatic variations may affect the operation of geomorphic processes directly or indirectly
- Indirect effect: amount, kind and distribution of vegetal cover
- Direct effect: amount and kind of precipitation, intensity, daily range of temperature, relationship between precipitation and evaporation...

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

- Paleo-geomorphology
- Present landscapes may have originated in the past geologic periods or epochs.

Geologic Time Scale

Younger

Eon	Era	Period		Epoch
Phanerozoic	Cenozoic	Quaternary		Holocene
				Pleistocene
		Neogene		Pliocene
				Miocene
		Paleogene		Oligocene
				Eocene
				Paleocene
	Mesozoic	Cretaceous		~
		Jurassic		~
		Triassic		~
	Paleozoic	Permian		~
		Carboni-ferous	Pennsylvanian	~
			Mississippian	~
		Devonian		~
		Silurian		~
		Ordovician		~
		Cambrian		~
Proterozoic	~	~		~
Archean	~	~		~
Hadean	~	~		~

Older

Today
11.8 Ka
66 Ma
252 Ma
541 Ma
2.5 Ga
4.0 Ga
4.54 Ga

- Geologists have divided Earth's history into a series of time intervals.
- They are; 1. Eon, 2. Era, 3. Period, and 4. Epoch
- These time intervals are not equal in length like the hours in a day.
- Instead the time intervals are variable in length.
- This is because geologic time is divided using significant events in the history of the Earth.
- For example, the boundary between the Permian and Triassic is marked by a global extinction in which a large percentage of Earth's plant and animal species were eliminated.
- Another example is the boundary between the Precambrian and the Paleozoic, which is marked by the first appearance of animals with hard parts.

Eons

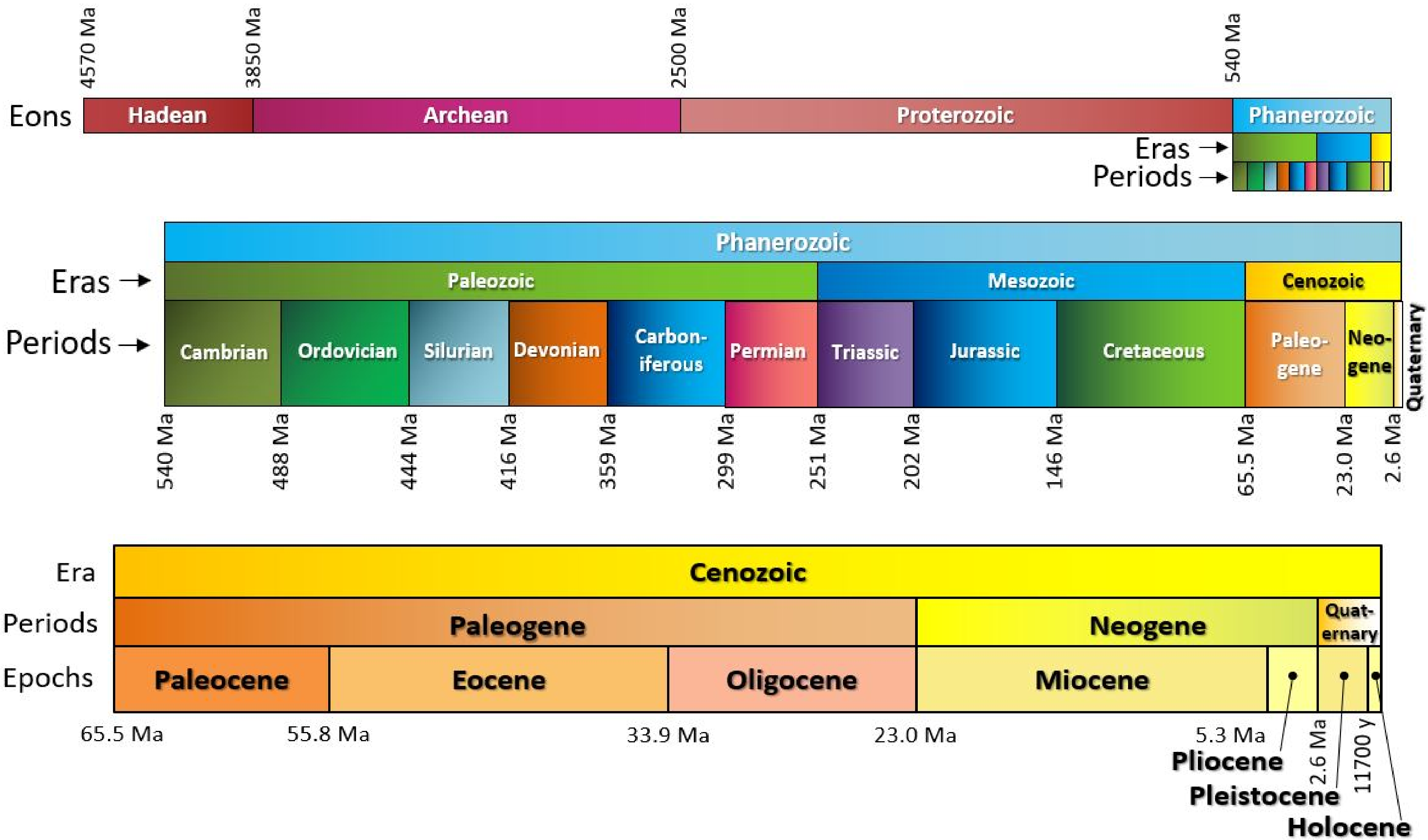
- Eons are the largest intervals of geologic time
- They are hundreds of millions of years in duration.
- Geological time has been divided into four eons:
  1. Hadean (4570 to 3850 Ma),
  2. Archean (3850 to 2500 Ma),
  3. Proterozoic (2500 to 540 Ma), and
  4. Phanerozoic (540 Ma to present).

  – the first three of these represent almost 90% of Earth's history. The last one, the Phanerozoic (meaning "visible life"), is the time that we are most familiar with because Phanerozoic rocks are the most common on Earth, and they contain evidence of the life forms that we are familiar.

Eras

- Eons are divided into smaller time intervals known as **eras**.
- The Phanerozoic eon—the past 540 Ma of Earth's history—is divided into three eras:

1. the Paleozoic ("early life"),
2. the Mesozoic ("middle life"), and
3. the Cenozoic ("new life"), and each of these is divided into a number of periods.


4570 Ma
3850 Ma
2500 Ma
540 Ma
Eons
Hadean
Archean
Proterozoic
Phanerozoic
Eras
Periods
Phanerozoic
Eras
Paleozoic
Mesozoic
Cenozoic
Periods
Cambrian
Ordovician
Silurian
Devonian
Carbon-iferous
Permian
Triassic
Jurassic
Cretaceous
Paleo-gene
Neo-gene
Quaternary
540 Ma
488 Ma
444 Ma
416 Ma
359 Ma
299 Ma
251 Ma
202 Ma
146 Ma
65.5 Ma
23.0 Ma
2.6 Ma
Era
Cenozoic
Periods
Paleogene
Neogene
Quat-ernary
Epochs
Paleocene
Eocene
Oligocene
Miocene
65.5 Ma
55.8 Ma
33.9 Ma
23.0 Ma
5.3 Ma
2.6 Ma
11700 y
Pliocene
Pleistocene
Holocene

Periods

- Eras are subdivided into **periods**.
- The Paleozoic Era is subdivided into the Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician and Cambrian periods.

The Eras and Periods of Phanerozoic Eon		
Era	Period	Time span
Paleozoic	Cambrian	488 to 540 Ma
Paleozoic	Ordovician	488 to 444 Ma
Paleozoic	Silurian	444 to 416 Ma
Paleozoic	Devonian	416 to 359 Ma
Paleozoic	Carboniferous	359 to 299 Ma
Paleozoic	Permian	299 to 251 Ma
Mesozoic	Triassic	251 to 202 Ma
Mesozoic	Jurassic	202 to 146 Ma
Mesozoic	Cretaceous	146 to 65.5 Ma
Cenozoic	Paleogene	65.5 to 23 Ma
Cenozoic	Neogene	23 to 2.6 Ma
Cenozoic	Quaternary	2.6 Ma to present

The Periods and Epochs of Cenozoic era.		
Period	Epoch	Time span
Paleogene	Paleocene	65.5 to 55.8 Ma
Paleogene	Eocene	55.8 to 33.9 Ma
Paleogene	Oligocene	33.9 to 23.0 Ma
Neogene	Miocene	23.0 to 5.3 Ma
Neogene	Pliocene	5.3 to 2.6 Ma
Quaternary	Pleistocene	2.6 Ma to 11,700 years ago
Quaternary	Holocene	11,700 years ago to the present

Epochs

- Finer subdivisions of time are possible, and the periods of the Cenozoic are frequently subdivided into **epochs**.
- Subdivision of periods into epochs can be done only for the most recent portion of the geologic time scale.
- This is because older rocks have been buried deeply, intensely deformed and severely modified by long-term earth processes.
- As a result, the history contained within these rocks cannot be as clearly interpreted.

UNIT II: Endogenetic Forces - Earth Movements: Orogenic Movements - Folds and Faults and their types - Eperogenic Movements - Volcanoes – Earthquakes - Causes,consequences and geographical distribution - Exogenetic forces-Weathering.

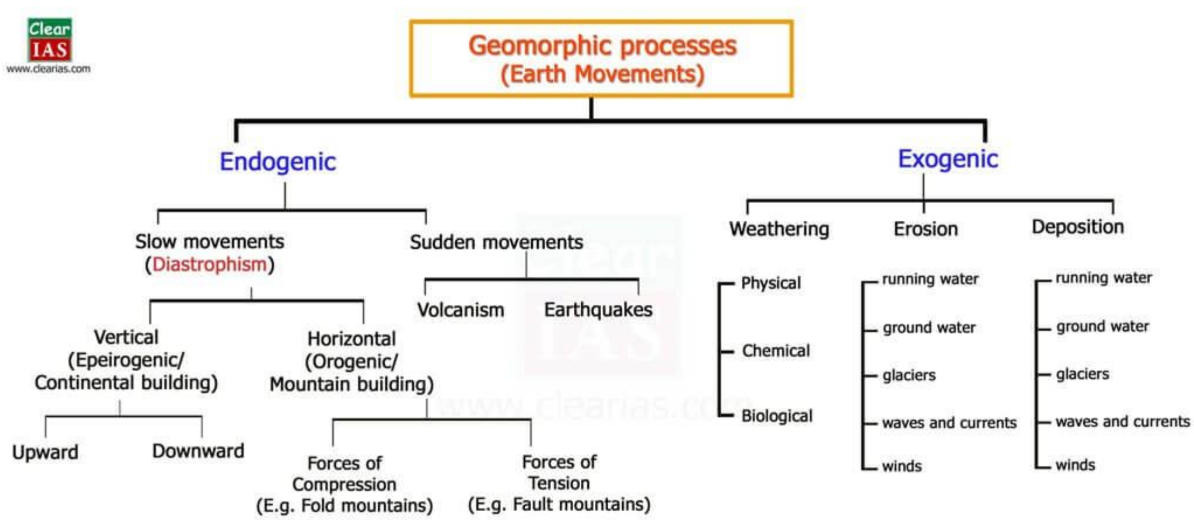
Geomorphic Processes and Earth Movements

Geomorphic Process

The formation and deformation of landforms on the surface of the earth are a continuous process which is due to the continuous influence of external and internal forces. The internal and external forces causing stresses and chemical action on earth materials and bringing about changes in the configuration of the surface of the earth are known as geomorphic processes.

Mind Map to Study Geomorphic Processes/Earth Movements

The below mind map will help to study geomorphic processes and their sub-classification in a matter of minutes.



Endogenic Forces

- Endogenic forces are those internal forces which derive their strength from the earth's interior and play a crucial role in shaping the earth crust.
- Examples – mountain building forces, continent building forces, earthquakes, volcanism etc.
- The endogenic forces are mainly land building forces.

The energy emanating from within the earth is the main force behind endogenic geomorphic processes. This energy is mostly generated by radioactivity, rotational and tidal friction and primordial heat from the origin of the earth.

Exogenic Forces

- Exogenic forces are those forces which derive their strength from the earth's exterior or are originated within the earth's atmosphere.
- Examples of forces – the wind, waves, water etc.
- Examples of exogenic processes – weathering, mass movement, erosion, deposition.
- Exogenic forces are mainly land wearing forces.

Exogenic forces can take the form of weathering, erosion, and deposition. Weathering is the breaking of rocks on the earth's surface by different agents like rivers, wind, sea waves and glaciers. Erosion is the carrying of broken rocks fThe actions of exogenic forces result in wearing down (**degradation**) of relief/elevations and filling up (**aggradation**) of basins/ depressions, on the earth's surface. The phenomenon of wearing down of relief variations of the surface of the earth through erosion is known as **gradation**.

Geomorphic Agents

Running water, groundwater, glaciers, the wind, waves, and currents, etc., can be called geomorphic agents.

Geomorphic Processes vs Geomorphic Agents

A process is a force applied on earth materials affecting the same. An agent is a mobile medium (like running water, moving ice masses, the wind, waves, and currents etc.) which removes, transports and deposits earth materials.

Earth Movements

- They are the movements in the earth's crust caused by the endogenic or exogenic forces. These movements are also termed as Tectonic movements.
- The term 'Tectonic' derived from the Greek word 'Tekton' which means builders.
- As the word means, these movements are mainly builders and have been responsible for building up of different types of landforms.

INTERNAL FORCES

The internal forces are also called as the tectonic forces. They generally occur in the plate boundaries. They are caused by convection cell and plate movement. They form fold, fault, earthquake and volcano.

OROGENIC MOVEMENTS

Fold

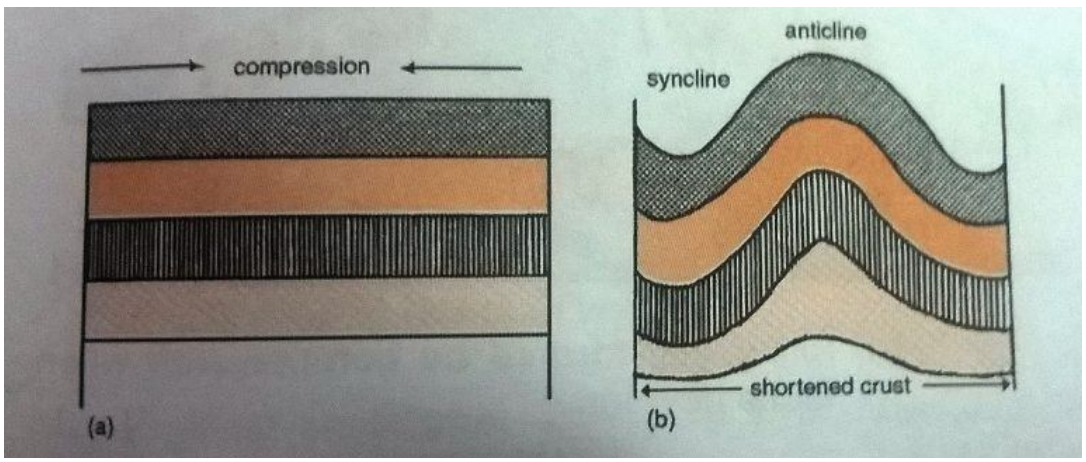
Fold mountains are the result of folding of the Earth's crustal rocks by compressive forces. They are considered as the "true mountains" and the term

Orogenesis or mountain building is commonly used for Fold mountains. **Examples -** Rockies (North America), Andes (South America), Alps (Europe), Atlas(Africa), Himalayas (Asia) etc.

Fold Mountain

In this article, we will discuss in detail about the various types of fold mountains, their characteristics, location and touch upon the theories of fold mountain formation.

Fig.- Compressive Forces leading to the folding of Earth's crust. (Source - Certificate Physical and Human Geography by G. C. Leong)



A Brief on Mountains in general

Mountains are natural elevated second order relief features (*refer to Table 1*) on the Earth s surface.

The Penguin Dictionary of Geography defines a mountain as any natural elevation on earth s surface with a summit small in proportion to its base, rising more or less abruptly from the surrounding level.

Based on their mode of formation, mountains can be classified into four main types

1. Fold Mountain
2. Block Mountain
3. Volcanic Mountain
4. Residual Mountain

Table 1: Classification of features on Earth's surface

First order relief	Oceans and Continents	Eg - Asia, Atlantic
Second order relief	Features on the oceans and continents due to Endogenous Processes (caused by forces from within the Earth)	Eg: Fold mountains, Volcanic mountains, Rift valley, Trenches
Third order relief	Features on the ocean and continents due to Exogenous Processes (caused by forces on or above the Earth's surface like wind erosion).	Eg: River valley, waterfalls, Gorges, Canyons etc.

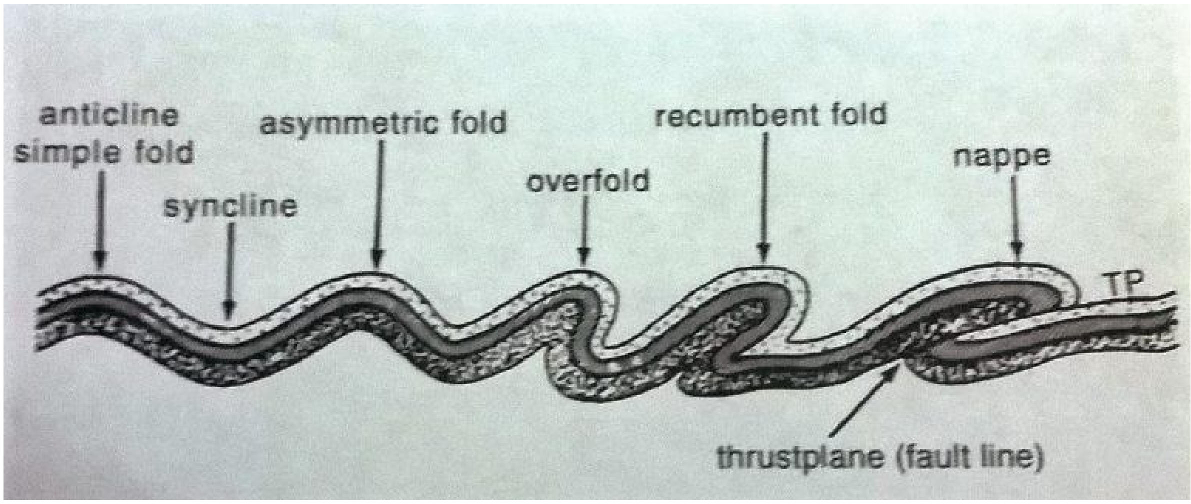
Types of Fold Mountains

On the basis of Nature of Fold

1. Simple folded mountains - folds are arranged in waves like pattern with a well-developed system of anticline and synclines.

2. Complex folded mountains - folds are complex in nature due to extreme compressional forces like overfold, recumbent fold and nappe.

Fig.- Types of Folding (Source - Certificate Physical and Human Geography by G. C. Leong)



ON THE BASIS OF THE PERIOD OF ORIGIN

1. Old fold mountains - Those mountains which originated before the Tertiary period. These mountains have been so greatly denuded (or eroded) that they have become residual fold mountains. For example, Aravalis, Appalachians etc.

Table 2: Major mountain building phases

Era	Mountain Building phase	Age/Years before present	Examples
Pre-Cambrian	Archean	2500-3800 Million years	Aravali Range in India

Era	Mountain Building phase	Age/Years before present	Examples
Pre-Cambrian	Proterozoic	570-2500 Million years	Wopmay Orogen in northwest Canada
Paleozoic	Caledonian	320 Million years	Scandinavian Highlands, Scotland mountains
Paleozoic	Hercynian	240 Million years	Ural, Pennines, Appalachians
Cenozoic	Tertiary	65 Million years	Alps, Rockies, Andes, Himalayas

2. Young or New fold mountains - These are the fold mountains of the Tertiary period. They are further subdivided based on their location

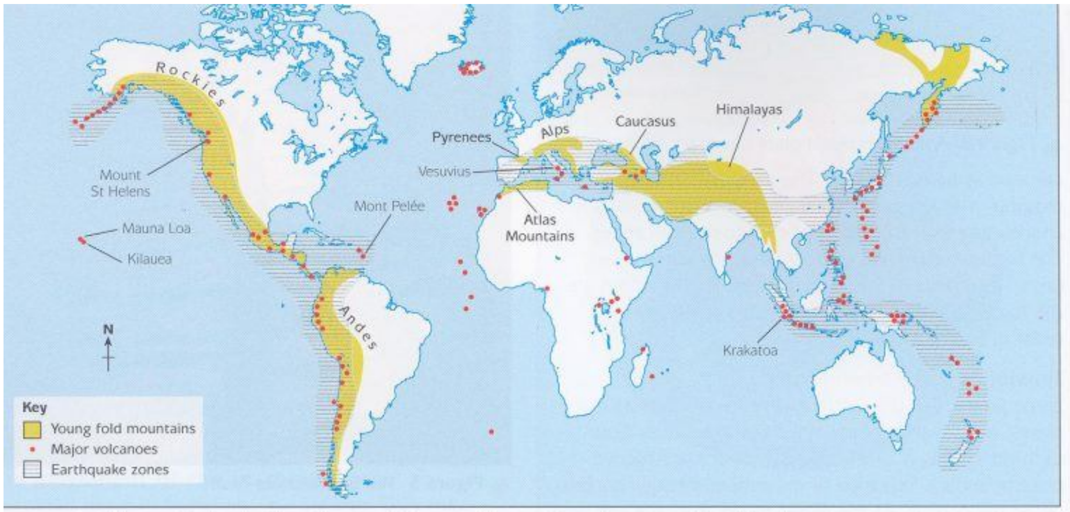
(i) Andean type of fold mountains - At the ocean - continental convergent boundaries (C-O). They are prone to both earthquakes and volcanic activities. Example - the Rockies, Andes

(ii) Himalayan type of fold mountains - At the continental - continental convergent boundaries (C-C). There is an absence of active volcanism here. Example - Great Himalayas

Characteristics of Fold Mountains

- **Rock Type - Formed due to the folding of sedimentary rocks by strong compressive forces. Furthermore, these rocks are of marine origin i.e. formed due to deposition and consolidation of sediments in water bodies.**
- **Shallow water deposits -** The marine fossils found in the sedimentary rocks belong to such organisms which can survive only in shallow waters.
- **Size -** They are the **loftiest, most extensive and elongated** mountain chains on the Earth s surface. Their length is far greater than their width. For example, the Himalayas have an east-west length of 2400 km but their maximum width is only 400 km.
- **Volcanicity -** They may or may not have active volcanism but volcanic rocks of ancient times may be found there. For example, Himalayas don t have active volcanism but volcanic rocks are found in Pir Panjal, Dalhauji (Himachal Pradesh) and Bhimtal (Kumaun).
- **Earthquake -** Generally the region is prone to earthquakes due to the presence of active plate boundaries.
- They are one of the **youngest mountains** of the world.
- Generally **found in an arc shape** with one side having a concave slope and the other having convex slope.

Where are the Fold Mountains Located?



The world distribution of young fold mountains, active volcanoes and earthquake zones.

Preliminary analysis of the above world map shows that

- They aren t located randomly on the Earth s surface.
- Young fold mountains are generally located on the margins of the continents.
- They are present mostly in the northern and western direction of the continents, like the Atlas in Africa, the Rockies and the Andes in North and south America.
- If we consider the former Tethys sea, then the Himalayas were also once located along the margins of the continent.
- They mark some of the major plate boundaries.
- Old fold mountains are present inside the current continents. They represent the ancient plate boundaries and orogenic movements of those times.

Fold Mountains of India

1. Himalayan mountains - Young fold mountains, formed during the Tertiary period.

2. Aravali Range - Oldest fold mountain of India, formed during the Archean period (2500 million years ago). Erosion over time has reduced their size
3. Vindhyan Range - formed during a Proterozoic period (500 million years ago), erosion over time has left them to
4. Satpura Mountains - meaning "seven folds", they are the fold mountains of the Precambrian era and are highly deluded.
5. Eastern Ghat - they were once fold mountains but have been eroded by the east-flowing peninsular rivers.

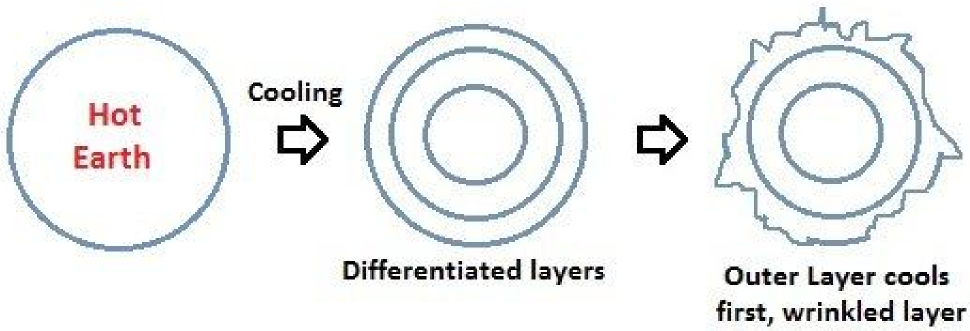
Fold Mountain formation

Various theories have been proposed to explain the formation of fold mountains. A good theory should be able to explain various unique characteristics of fold mountains and their location.

Thermal Contraction Model of Harold Jeffrey

- He proposed mountains as the wrinkles on the Earth surface formed when Earth's crust cooled and contracted while differentiating from other parts
- He used an analogy of layer of cream separating from a hot milk vessel cooling slowly. **Limitation**
- Cannot explain the variation in age of various mountains on the Earth s surface.
- It proposes same types of rocks and random distribution of mountains.

Figure - Illustration of Harold Jeffery model, Showing layer differentiation and surface features formation



Horizontal Displacement Theory by F.B.Taylor

- According to him mountains formed due to equator side movement and collision of two ancient continents (Laurasia and Gondwanaland).
- Force causing movement - Gravitational and tidal pull of Sun and Moon. **Limitation**
- Can best explain only Transeurasian mountains (the Alps + the Himalayas) but not other mountains
- Incorrect reason for the movement of continents

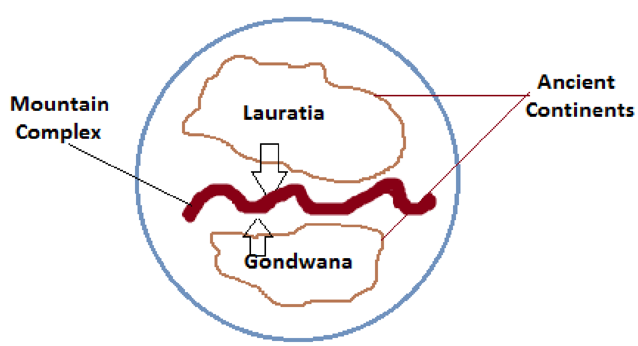


Fig: Illustration of Taylor's Horizontal Displacement Theory

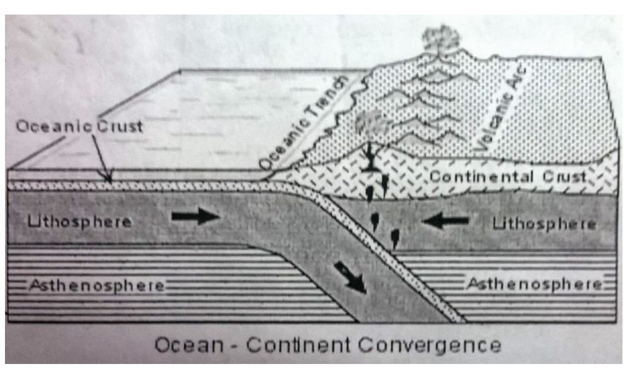
Continental Drift Theory by Alfred Wegener

- It was an extension of Taylor s displacement hypothesis.
- He proposed mountains as an accumulation of oceanic sediments (SIMA) scrapped by floating continents (SIAL) along the leading edge.
- This helped explain the marine origin of sediments and their general presence on the western and northern side of the continents. **Limitation**
- Wrong concept of SIAL and SIMA.
- The mechanism suggested for movement (Tidal pull of Sun and Moon and the pole-fleeing force) was wrong

Modern Theory of Plate Tectonics

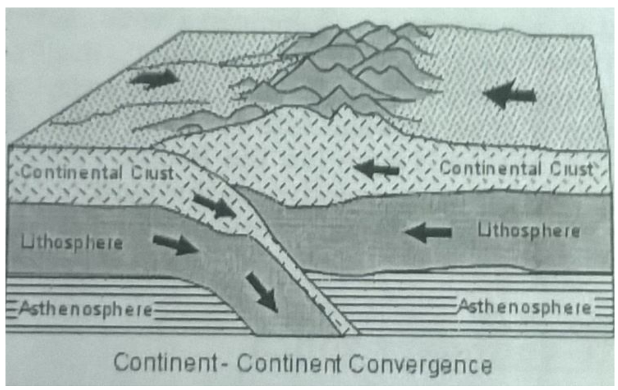
- According to Plate Tectonics mountains were formed due to colliding lithospheric plates along the convergent boundaries.
- The colliding plates compress, accumulates and uplifts sediments between the two plates.
- Arthur Holmes' concept of Mantle Convection Currents explains the driving force behind the lithospheric plate movements.
- At Oceanic-Continental (O-C) convergent plate boundary, the denser oceanic crust gets subducted under the relatively lighter continental crust.

Figure - Ocean-Continental Convergence



- The subduction causes lateral compressive force which ultimately squeezes and folds the sediments.
- At Continental-Continental (C-C) convergent plate boundary, the amount of sedimentation is maximum resulting in the formation of the highest mountains of the world.
- C-C convergence is also associated with the strongest compressive forces, hence the fold mountains here develop complex folds and reverse faults.

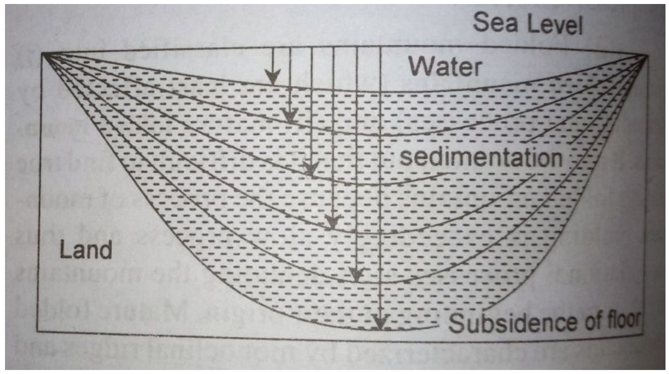
Figure - Continental - Continental Convergence



Geosynclinal Theory of Mountain Building

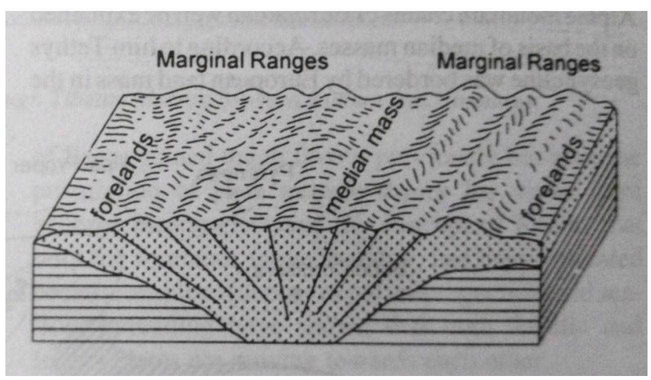
- Geosynclines are the long and relatively narrow depressions on the Earth s surface.
- They are characterised by the continuous sediment accumulation, which causes gradual subsidence of the floor of Geosyncline.

Figure - Sedimentation causing subsidence of Geosyncline Floor (Source - Physical Geography by Savindra Singh)



- Geosyncline as a concept helps in explaining the origin of an enormous amount of marine sediments that were uplifted into fold mountains.
- Tethys sea was one of the major Geosyncline, which was uplifted to form the Himalayan system of mountains.

Figure - Mountain Formation as per Kober's Geosynclinal Theory(Source - Physical Geography by Savindra Singh)



Fold Mountains and Human Life

Fold mountains impact the climate, vegetation, lifeforms and human activities in the area. A sudden increase in altitude presents a large variation in the climate of the region. For example, in the Andes mountain, equatorial rainforest exist just miles away from its snow-covered peak Cotopaxi.

Similarly, the Himalayan fold mountains are responsible for the unique climate of the Indian subcontinent. They block the cold Siberian winds, preventing people from harsh winters. Also, they are responsible for the orographic rainfall from the south-eastern monsoonal winds.

Fold mountains have significant economic importance as well. These areas house major tourist spots of the world. They are a pleasant holiday destination in summers and provide an opportunity for adventure sports.

Their steep slope and melting water from glaciers provide huge potential for Hydro Electric Power, which is a cleaner energy source than the coal-based thermal power.

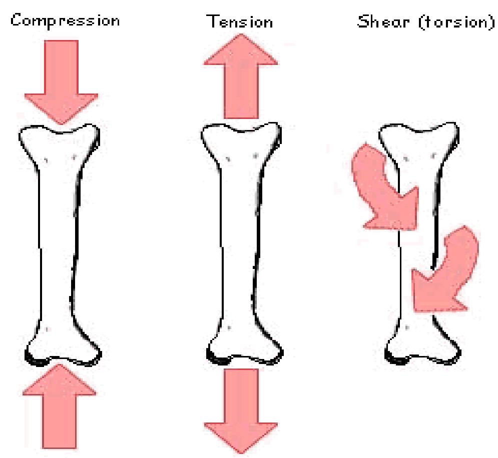
Apart from this forest produce like timber, fuel-wood etc, agriculture activities (limited to sun-facing slope) and mining materials are some of the major economic benefits from these mountains.

However, fold mountains are prone to disasters both natural and man-made. Almost all of them are prone to Earthquakes and many are also vulnerable to Volcanic eruptions as well. Soft soil of these mountains makes these areas prone to landslides as well in the event of heavy rainfall or earthquakes. Human activities have further destabilized the balance of nature in the area and increased the vulnerability in the region as seen during the Nepal earthquake, 2015 and Uttrakhand mountain Tsunami of 2103.

FAULT IN GEOLOGY

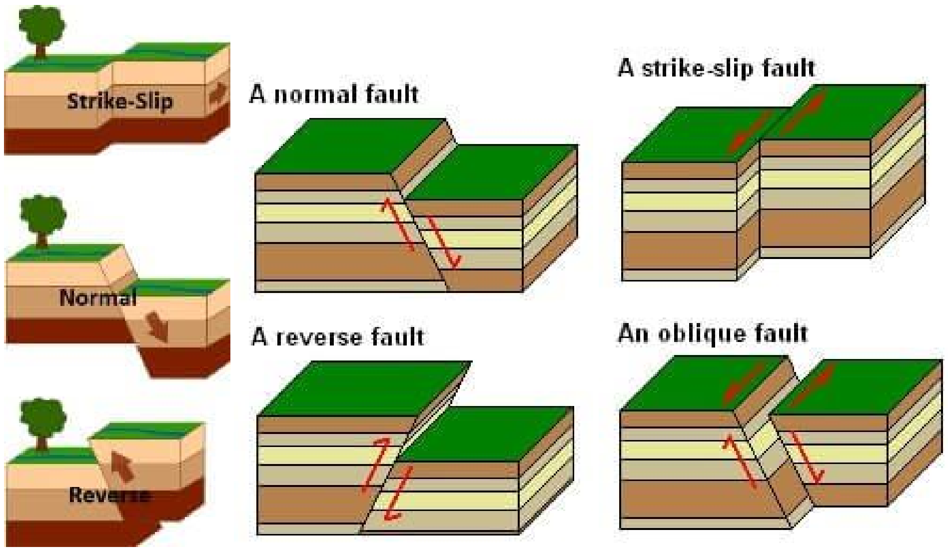
- When the earth's crust bends folding occurs, but when it cracks, faulting takes place.

- A fault is a planar fracture (crack) in a volume of earth's crust, across which there has been significant displacement of a block/blocks of crust.
- The **faulted edges are usually very steep**, e.g. the Vosges and the Black Forest of the Rhineland.
- Faults occur due to tensile and compressive forces acting on the parts of the crust.



- Large faults within the Earth's crust result from the action of plate tectonic forces, such as subduction zones or **transform faults**.
- Energy release associated with rapid movement on active faults is the cause of most **earthquakes**.
- In an active fault, the pieces of the Earth's crust along a fault move over time.
- Inactive faults had movement along them at one time, but no longer move.
- The type of motion along a fault depends on the type of fault.

TYPES OF FAULT



Types of faults (Actualist, from Wikimedia Commons)

Strike-slip fault

- In a strike-slip fault (also known **transcurrent fault**), the plane of the fault is usually **near vertical,** and the blocks move laterally either **left or right** with very little vertical motion (the displacement of the block is **horizontal**).

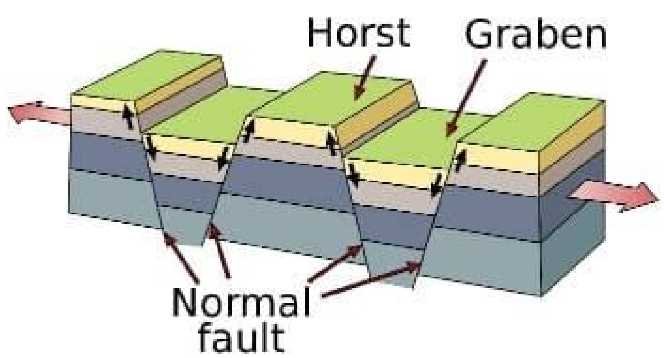
Transform fault

- A special class of strike-slip fault is the transform fault or transform boundary **when it forms a plate boundary**.
- **A transform fault is the only type of strike-slip fault that is classified as a plate boundary**.
- Most of these faults are hidden in the deep ocean, where they offset divergent boundaries in short zigzags resulting from seafloor spreading.
- They are less common within the continental lithosphere. The best example is the **Dead Sea transform fault**.

- The transform boundary ends abruptly and is connected to another transform, a spreading ridge, or a subduction zone.

Dip-slip faults

- Dip-slip faults can be either **normal or reverse**.
- In a normal fault, the hanging wall (displaced block of crust) moves **downward**, relative to the footwall (stationary block). In a **reverse fault (thrust fault)** the hanging wall moves **upwards**.
- Reverse faults occur due to compressive forces whereas normal faults occur due to tensile forces.
- A downthrown block between two normal faults is a **graben**.
- An upthrown block between two normal faults is a **horst**.
- Normal faults occur mainly in areas where the crust is being extended such as a **divergent boundary**.
- **Reverse faults** occur in areas where the crust is being shortened such as at a **convergent boundary**.



Rift Valley system

- Tension causes the central portion to be let down between two adjacent fault blocks forming a graben or rift valley, which will have steep walls.
- The East African Rift Valley system is the best example.

- In general, large-scale block mountains and rift valleys are due to tension rather than compression.

Block Mountains

- Block mountains may originate when the middle block moves downward and becomes a rift valley while the surrounding blocks stand higher as block mountains.

Plateaus

- Sometimes, the surrounding blocks subside leaving the middle block stationary. Such cases are found in high plateau regions.

Oblique-slip faults

- A fault which has a component of **dip-slip** and a component of **strike-slip** is termed an oblique-slip fault.
- Nearly all faults have some component of both dip-slip and strike-slip.
- **Many disastrous earthquakes** are caused along the oblique slip.

EPEROGENIC MOVEMENTS
VOLCANO

- A **volcano** is a rupture in the crust of a planetary-mass object, such as Earth, that allows hot lava, volcanic ash, and gases to escape from a magma chamber below the surface.

Distribution of Volcanoes

- World's active volcanoes are found along the **constructive plate margins** or **divergent plate margins** (along the mid-oceanic ridges where two plates move in opposite directions) whereas 80 per cent volcanoes are associated with the **destructive** or **convergent plateboundaries** (where two plates collide).

- Besides, some volcanoes are also found in **intraplate regions** g. volcanoes of the Hawii Island, fault zones of East Africa etc.
- Two plates move in opposite directions from the mid-oceanic ridges due to thermal convective currents which are originated in the mantle below the crust (plates). This splitting and lateral spreading of plates creates **fractures** and **faults** (transform faults) which cause pressure release and lowering of melting point and thus materials of upper mantle lying below the mid- oceanic ridges are melted and move upward as magmas under the impact of enormous volume of accumulated gases and vapour. This rise of magmas along **the mid-oceanic ridges** (constructive or divergent plate boundaries) causes fissure eruptions of volcanoes and there is constant upwelling of lavas.

CLASSIFICATION ON THE BASIS OF PERIODICITY OF ERUPTIONS

Volcanoes are divided into 3 types on the basis of period of eruption and interval period between two eruptions of a volcano e.g. (i) active volcanoes, (ii) dormant volcanoes and (iii) extinct volcanoes

i. ACTIVE VOLCANOES

- Active volcanoes are those which constantly eject volcanic lavas, gases, ashes and fragmental material.
- It is estimated that there are about more than 500 volcanoes in the world. Etna and Stromboli of the Mediterranean Sea are the most significant examples of this category.
- Most of the active volcanoes are found along the mid-oceanic ridges representing divergent plate margins (constructive plate margins) and convergent plate margins (destructive plate margins represented by eastern and western margins of the Pacific Ocean).

ii. DORMANT VOLCANOES

- **Dormant volcanoes** are those which become quiet after their eruptions for some time and there are no indications for future eruptions but suddenly they erupt very violently and cause enormous damage to human health and wealth.

iii. EXTINCT VOLCANOES

- The volcanoes are considered extinct when there are no indications of future
- They become explosive if somehow water gets into the vent; otherwise, they are characterised by low- explosivity.The upcoming lava moves in the form of a fountain and throws out the cone at the top of the vent and develops into cinderThe crater is filled up with water and Jakes are formed. It may be pointed out that no volcano can be declared permanently dead as no one knows,what is happening below the ground surface.

CLASSIFICATION OF VOLCANOES BASED ON NATURE OF ERUPTION

- Volcanoes are classified on the basis of nature of eruption and the form developed at the surface.

Major types of volcanoes are as follows:

SHIELD VOLCANOES

- Barring the basalt flows, the shield volcanoes are the largest of all the volcanoes on the earth.
- The **Hawaiian volcanoes** are the most famous examples. These volcanoes are mostly made up of **basalt,** a type of lava that is very fluid when erupted.
- For this reason, these volcanoes are not sleep.
- They become explosive if somehow water gets into the vent; otherwise, they are characterised by low-explosivity.
- The upcoming lava moves in the form of a fountain and throws out the cone at the top of the vent and develops into cinder cone.

COMPOSITE VOLCANOES

- These volcanoes are characterised by eruptions of cooler and moreviscous lavas than basalt. These volcanoes often result in explosive eruptions. Along with lava, large quantities of pyroclastic material and ashes find their way to the ground. This material accumulates in the vicinity of the vent openings leading to formation of layers, and this makes the mounts appear as composite volcanoes.

CALDERA

- These are the most explosive of the earth's volcanoes. They are usually so explosive that when they erupt they tend to collapse on themselves rather than building any tall structure. The collapsed depressions are called **calderas.**
- Their explosiveness indicates that the magma chamber supplying the lava is not only huge but is also in close vicinity.

FLOOD BASALT PROVINCES

- These volcanoes outpour highly fluid lava that flows for long distance.
- Some parts of the world are covered by thousands of km of thick basalt lava flows.
- There can be a series of flows with some flows attaining thickness of more than 50 m. Individual flows may extend for hundreds of Km.
- **The Deccan Traps** from India, presently covering most of the Maharashtra plateau, are a much larger flood basalt province.
- It is believed that initially the trap formations covered a much larger area than the present.

MID-OCEAN RIDGE VOLCANOES

- These volcanoes occur in the oceanic areas. There is a system of mid-ocean ridges more than 70,000 km long that stretches through all the ocean basins.

- The central portion of this ridge experiences frequent eruptions.

EARTHQUAKE

- The study of seismic waves provides a complete picture of the layered interior.
- An earthquake in simple words is shaking of the earth. It is a natural event. It is caused due to **release of energy**, which generates waves that travel in all direction.
- The release of energy occurs along a Fault (A fault is a sharp break in the crustal rocks).
- Rocks along a fault tend to move in opposite direction.
- As the overlying rock strata press them, the friction locks them together.
- However, their tendency to move apart at some point of time overcomes the
- As a result, the blocks get deformed and eventually, they slide past one another abruptly.
- This causes a release of energy, and the energy waves travel in all directions.
- The point where the energy is released is called the focus of an earthquake, alternatively, it is called the **hypocentre.**
- The energy waves travelling in different directions reach the The point on the surface, nearest to the focus, is called **epicentre.** It is the first one to experience the waves. It is a point directly above the focus.

EARTHQUAKES – ORIGIN BASED ON PLATE TECTONICS

- As per theory of the plate tectonics the crust or the earth is composed of solid and moving plates having either continental crust or oceanic crust or even both continental- oceanic crusts.

- The earth's crust consists of 6 major plates (Eurasian plate, American plate, African plate, Indian plate, Pacific plate and Antarctic plate) and 20 minor plates. These plates are constantly moving in relation to each other due to thermal convective currents originating deep within the earth.
- Thus, all the tectonic events take place along the boundaries of these moving plates.

TYPES OF PLATE BOUNDARIES

- constructive plates boundaries,
- destructive plate boundaries and
- conservative plate

1. **Constructive plate boundaries** represent the trailing ends of divergent plates which move in opposite directions from the mid- oceanic ridges,
2. **Destructive plate boundaries** are those where two convergent plates collide against each other and the heavier plate boundary is subducted below the relatively lighter plate boundary.
3. **Conservative plate boundaries** are those where two plates slip past each other without any collision.

MAGNITUDE OF EARTHQUAKES ON DIFFERENT PLATE BOUNDARIES

- **Major tectonic events** associated with these plate boundaries are ruptures and faults along the **constructive plate boundaries**, **faulting** and **folding** along the **destructive plate boundaries** and **transform faults** along the **conservative plate boundaries.**
- All sorts of disequilibrium are caused due to different types of plate motions and consequently earthquakes of varying magnitudes are caused
- **Moderate earthquakes** are caused along the **constructive plate boundaries** because the rate of rupture of the crust and consequent

movement of plates away from the mid-oceanic ridges is rather slow and the rate of upwelling of lavas due to fissure flow is also slow.

- Consequently, **shallow focus earthquakes** are caused along the **constructive plate boundaries** or say along the mid- oceanic ridges.
- Earthquakes of **high magnitude** and **deep focus** are caused along the **convergent** or **destructive plate boundaries** because of collision of two convergent plates and consequent subduction of one plate boundaries.
- Here mountain building, faulting and violent volcanic eruptions (central explosive type of eruptions) cause severe and disastrous earthquakes having the focus at the depth upto 700 km.

DISTRIBUTION OF EARTHQUAKE

- The earthquakes of the Mid- Continental Belt along the Alpine- Himalayan Chains are caused due to collision of Eurasian plates and African and Indian plates.
- The earthquakes of the western marginal areas of North and South Americas are caused because of subduction of Pacific plate beneath the American plate and the resultant tectonic forces whereas the earthquakes of the eastern margins of Asia are originated because of the subduction of Pacific plate under Asiatic plate.
- Similarly, the subduction of African plate below European plate and the subduction of Indian plate under Asiatic plate cause earthquakes of the mid-continental belt.
- Creation of transform faults along the conservative plate boundaries explains the occurrence of severe earthquakes of California (USA).
- Here one part of California moves north-eastward while the other part moves south-westward along the fault plane and thus is formed transform fault which causes earthquakes.

EARTHQUAKE WAVES

- All natural earthquakes take place in the lithosphere.
- It is sufficient to note here that the lithosphere refers to the portion of depth up to 200 km from the surface of the earth.
- An instrument called 'seismograph' records the waves reaching the surface.
- Earthquake waves are basically of two types — **body waves** and **surface waves**.

BODY WAVES

- Body waves are generated due to the release of energy at the focus and move in **all directions travelling through the body of the earth**. Hence, they are known as body waves.

SURFACE WAVES

- The body waves interact with the surface rocks and generate new set of waves called **surface waves**. These waves move along the surface.
- The velocity of waves changes as they travel through materials with different densities.
- The denser the material, the higher is the velocity.
- Their direction also changes as they reflect or refract when coming across materials with different densities.
- The surface waves are the last to report on seismograph.
- These waves are **more destructive.**
- They cause displacement of rocks, and hence, the collapse of structures occurs.

TYPES OF BODY WAVES

- There are two types of body waves. They are called **P** and **S- waves**.

P-W AVES

- P-waves move faster and are the first to arrive at the These are also called **'primary waves'.**
- The P-waves are similar to sound waves.
- This characteristic of the S-waves is quite important, as it has helped scientists to understand the structure of the interior of the earth.They travel through gaseous, liquid and solid.

S-W AVES

- S-waves arrive at the surface with some time lag. These are called **secondary waves.**
- An important fact about S-waves is that they can **travel only through solid materials**.
- This characteristic of the S-waves is quite important, as it has helped scientists to understand the structure of the interior of the earth.

Long Period waves or Lwaves:

- These waves generally affect only the surface of the earth and die out a smaller depth. T. These waves cover longest distances of all the seismic waves. Though their speed is lower than P and S waves but these are most violent and destructive.

PROPAGATION OF EARTHQUAKE WAVES

- Different types of earthquake waves travel in different manners.
- As they move or propagate, they cause vibration in the body of the rocks through which they pass.
- P-waves vibrate parallel to the direction of the wave. This exerts pressure on the material in the direction of the propagation.

- As a result, it creates density differences in the material leading to stretching and squeezing of the material.
- Other three waves vibrate perpendicular to the direction of propagation.
- The direction of vibrations of S- waves is perpendicular to the wave direction in the vertical plane.
- Hence, they create troughs and crests in the material through which they pass.

EMERGENCE OF SHADOW ZONE

- Earthquake waves get recorded in seismographs located at far off locations.
- However, there exist some specific areas where the waves are not reported. Such a zone is called the **'shadow zone'**
- The study of different events reveals that for each earthquake,there exists an altogether different shadow zone.
- It was observed that seismographs located at any distance within **105°** from the **epicentre,** recorded the arrival of both P and S-waves.
- However, the seismographs located **beyond 145°** from epicentre; record the arrival of P- waves, but not that of S-waves.
- Thus, a **zone between 105° and 145°** from epicentre was identified as the **shadow zone** for both the types of waves.
- The entire zone beyond 105° does not receive S-waves.
- The shadow zone of S-wave is much larger than that of the P- waves.
- The **shadow zone** of **P-waves** appears as a band around the earth between **105°** and **145°** away from the epicenter.
- The shadow zone of S-waves is not only larger in extent but it is also a little over 40 per cent of the earth surface.

TYPES OF EARTHQUAKES

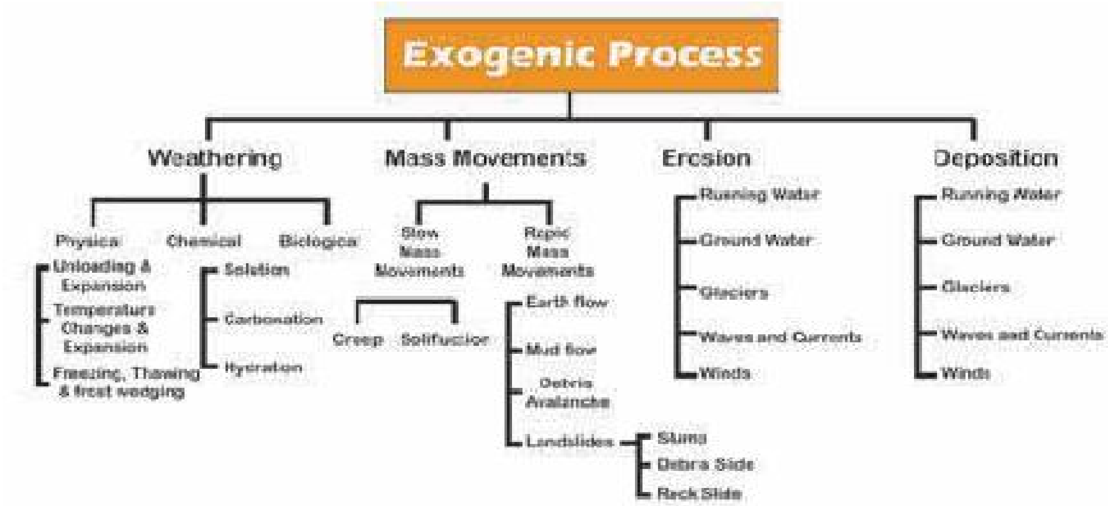
- The most common ones are the **tectonic earthquakes**. These are generated due to sliding of rocks along a fault plane.
- A special class of tectonic earthquake is sometimes recognised as **volcanic earthquake.** However, these are confined to areas of active volcanoes.
- In the areas of intense mining activity, sometimes the roofs of underground mines collapse causing minor tremors. These are called **collapse earthquake.**
- Ground shaking may also occur due to the explosion of chemical or nuclear devices. Such tremors are called explosion earthquakes
- The earthquakes that occur in the areas of large reservoirs are referred to as **reservoir induced earthquakes.**

MEASURING EARTHQUAKES

- The earthquake events are scaled either according to the magnitude or intensity of the shock.
- The **magnitude scale** is known as the **Richter**
- The magnitude relates to the energy released during the quake.
- The magnitude is expressed in absolute numbers, 0-10.
- The **intensity scale** is named after **Mercalli**, an Italian seismologist.
- The intensity scale takes into account the visible damage caused by the event.
- The range of intensity scale is from 1-12.

EXOGENETIC FORCES

The processes which occur on earth's surface due to the influence of external forces are called as exogenic processes. Weathering, mass wasting and denudation are the major exogenic processes. The elements of nature capable of doing these exogenic processes are termed as gradational agents. For instance, the wind, river, glacier, waves and ground water.



WEATHERING

- Weathering is action of elements of weather and climate over earth materials.
- There are a number of processes within weathering which act either individually or together to affect the earth materials in order to reduce them to fragmental state.
- Weathering is defined as mechanical disintegration and chemical decomposition of rocks through the actions of various elements of weather and climate.
- As very little or no motion of materials takes place in weathering, it is an **in-situ** or **on- site process.**

CHEMICAL WEATHERING PROCESSES

- A group of weathering processes viz; **solution, carbonation, hydration, oxidation** and **reduction** act on the rocks to decompose, dissolve or reduce them to a fine clastic state through chemical reactions by oxygen, surface and/or soil water and other acids.

- Water and air (oxygen and carbon dioxide) along with heat must be present to speed up all chemical reactions.
- Over and above, the carbon dioxide present in the air, decomposition of plants and animals increases the quantity of carbon dioxide underground.

SOLUTION

- When something is dissolved in water or acids, the water or acid with dissolved contents is called solution.
- This process involves removal of solids in solution and depends upon solubility of a mineral (like nitrates, sulphates, and potassium) in water or weak acids.
- So, these minerals are easily leached out without leaving any residue in rainy climates and accumulate in dry regions.
- Minerals like calcium carbonate and calcium magnesium bicarbonate present in limestones are soluble in water containing carbonic acid (formed with the addition of carbon dioxide in water), and are carried away in water as solution.
- Carbon dioxide produced by decaying organic matter along with soil water greatly aids in this reaction.

CARBONATION

- Carbonation is the reaction of carbonate and bicarbonate withminerals and is a common process helping the breaking down of feldspars and carbonate minerals.
- Carbon dioxide from the atmosphere and soil air is absorbed by water, to form carbonic acid that acts as a weak acid.

- Calcium carbonates and magnesium carbonates are dissolved in carbonic acid and are removed in a solution without leaving any residue resulting in **cave information.**

HYDRATION

- Hydration is the chemical addition of water. Minerals take up water and expand; this expansion causes an increase in the volume of the material itself or rock.
- Calcium sulphate takes in water and turns to **gypsum**, which is more unstable than calcium sulphate.
- This process is reversible and long, continued repetition of this process causes fatigue in the rocks and may lead to their disintegration.
- Many clay minerals swell and contract during wetting and drying and a repetition of this process results in cracking of overlying material.
- Salts in pore spaces undergo rapid and repeated hydration and help in **rock fracturing**.

OXIDATION AND REDUCTION

- In weathering, oxidation means a combination of a mineral with oxygen to form oxides or hydroxides.
- In the process of oxidation rock breakdown occurs due to the disturbance caused by addition of oxygen.
- Red colour of iron upon oxidation turns to brown or yellow.
- When oxidised minerals are placed in an environment where oxygen is absent, reduction takes place.
- Such conditions exist usually below the water table, in areas of stagnant water and waterlogged ground.

- Red colour of iron upon reduction turns to greenish or bluish grey. These weathering processes are interrelated.
- Hydration, carbonation and oxidation go hand in hand and hasten the weathering process.

PHYSICAL WEATHERING PROCESSES

- Physical or mechanical weathering processes depend on some applied forces.

The applied forces could be:

- Gravitational forces such as overburden pressure, load and shearing stress;
- Expansion forces due to temperature changes, crystal growth or animal activity;
- Water pressures controlled by wetting and drying cycles.
    - Many of these forces are applied both at the surface and within different earth materials leading to rock fracture.
    - Most of the physical weathering processes are caused by thermal expansion and pressure release.
    - These processes are small and slow but can cause great damage to the rocks because of continued fatigue the rocks suffer due to repetition of contraction and expansion.

UNLOADING AND EXPANSION

- Removal of overlying rock load because of continued erosion causes vertical pressure release with the result that the upper layers of the rock expand producing disintegration of rock masses.
- Fractures will develop roughly parallel to the ground surface.

- Large, smooth rounded domes called **exfoliation domes** result due to this process.

TEMPERATURE CHANGES AND EXPANSION

- Various minerals in rocks possess their own limits of expansion and contraction.
- Because of diurnal changes in the temperatures, this internal movement among the mineral grains of the superficial layers of rocks takes place regularly.
- This process is most effective in **dry climates** and **high elevations** where diurnal temperature changes are drastic.
- In rocks like **granites**, smooth surfaced and rounded small to big boulders called **tors** form due to such exfoliation..

FREEZING, THAWING AND FROST WEDGING

- Frost weathering occurs due to growth of ice within pores and cracks of rocks during repeated cycles of freezing and melting.
- This process is most effective at high elevations in mid-latitudes where freezing and melting is often repeated.
- Glacial areas are subject to frost wedging In this process, the rate of freezing is important.
- Rapid freezing of water causes its sudden expansion and high pressure.
- The resulting expansion affects joints, cracks and small inter granular fractures to become wider and wider till the rock breaks apart.

SALT WEATHERING

- Salts in rocks expand due to thermal action, hydration and crystallisation. Many salts like **calcium, sodium, magnesium potassium** and **barium** have a tendency to expand.

- Salt crystals in near-surface pores cause splitting of individual grains within rocks, which eventually fall off. This process of falling off of individual grains may result in granular disintegration or granular foliation.
- Salt crystallisation is most effective of all salt-weathering processes.
- Sodium chloride and gypsum crystals in desert areas heave up overlying layers of materials and with the result polygonal cracks develop all over the heaved surface.
- With salt crystal growth, chalk breaks down most readily, followed by limestone, sandstone, shale, gneiss and granite etc.

BIOLOGICAL ACTIVITY AND WEATHERING

- Biological weathering is contribution to or removal of minerals and ions from the weathering environment and physical changes due to growth or movement of organisms..
- Burrowing and wedging by organisms like earthworms, termites, rodents etc., help in exposing the new surfaces to chemical attack and assists in the penetration of moisture and air.
- Human beings by disturbing vegetation, ploughing and cultivating soils, also help in mixing and creating new contacts between air, water and minerals in the earth material.
- Decaying plant and animal matter help in the production of humic, carbonic and other acids which enhance decay and solubility of some elements.
- Algae utilise mineral nutrients for growth and help in concentration of iron and manganese oxides.
- Plant roots exert a tremendous pressure on the earth materials mechanically breaking them apart.

SIGNIFICANCE OF WEATHERING

- Weathering processes are responsible for breaking down the rocks into smaller fragments and preparing the way for formation of not only regolith and soils, but also erosion and mass movements.
- Biomes and biodiversity is basically a result of forests (vegetation) and forests depend upon the depth of weathering mantles.
- Weathering aids mass wasting, erosion and reduction of relief and changes in landforms are a consequence of erosion.
- Weathering of rocks and deposits helps in the enrichment and concentrations of certain valuable ores of iron, manganese, aluminium, copper etc., which are of great importance for the national economy.
- Weathering is also an important process in the formation of soils.

Advanced Geomorphology

Unit III: Wegener's Theory of Continental Drift - Theory of Plate Tectonics - Cycle of Erosion: Davis and Penck - Concept of Slope development: W.M Davis and Penck.

Alfred Wegener (1880-1930)

Continental Drift Theory

Background

- The idea of a large-scale displacement of continents has a long history.
- Noting the apparent fit of the bulge of eastern South America into the bight of Africa, the German naturalist Alexander von Humboldt theorized about 1800 that the lands bordering the Atlantic Ocean had once been joined
- In 1958, Antonio Snider-Pellegrini, a French scientist, argued that the presence of identical fossil plants in both North American and European coal deposits could be explained if the two continents had formerly been connected, a relationship otherwise difficult to account for
- In 1910, F.B. Taylor of America introduced hypothesis of continental displacement with a view to explaining the distribution of mountain ranges – Received scant attention.
- In 1912, Alfred Wegener, a German Professor, put forward this idea as a theory and published a detailed discussion of it in 1915 – due to world war (1914-1918), this could not attract many scientists.
- In 1924, Wegener’s book was translated into English. Since then, it has attracted much attention and publicity.

About Alfred Wegener

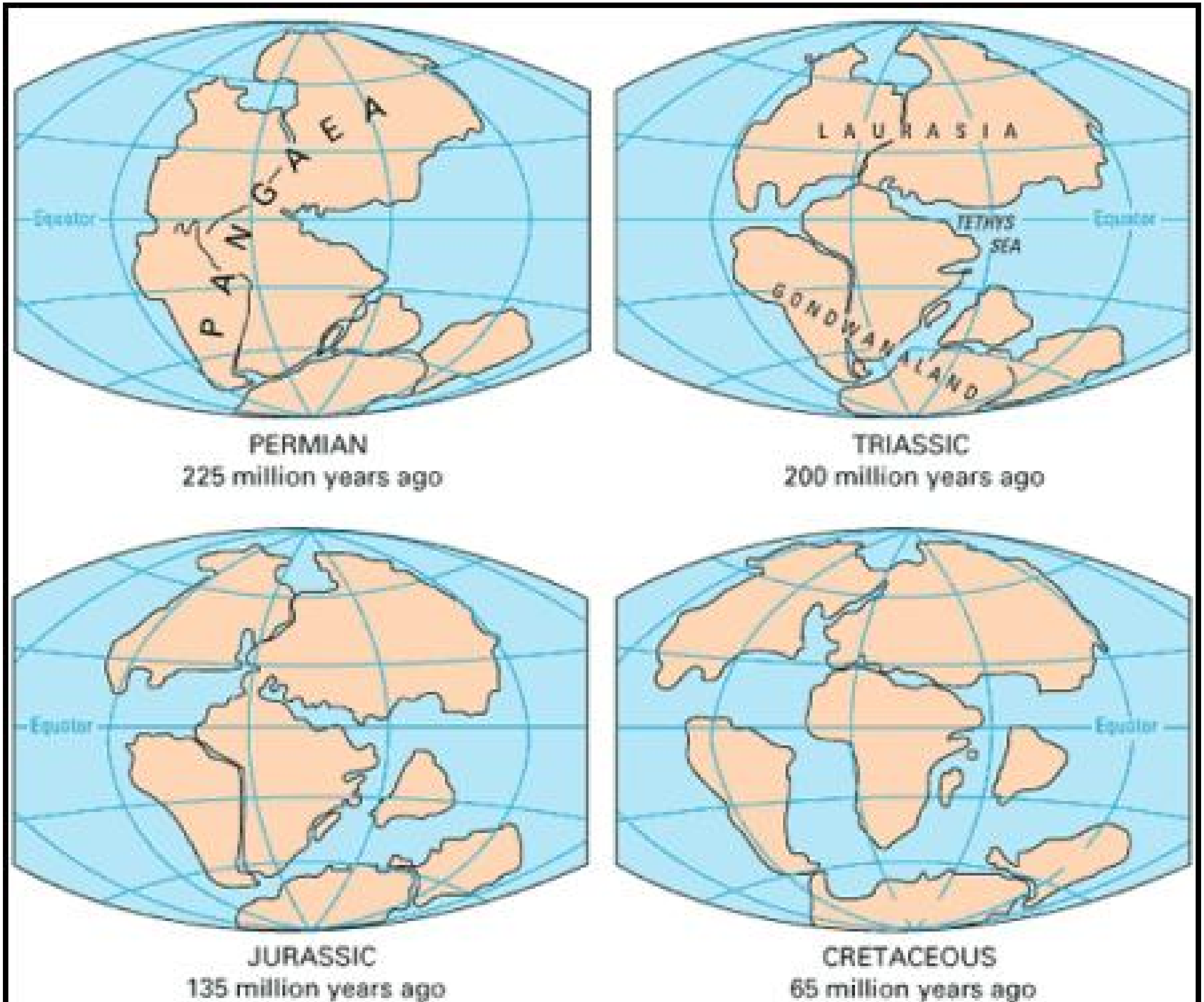
- Wegener was a German Meteorologist
- He wanted to explain the climate change in the geological past.
- There are geological evidences to show that there have been important and large scale changes in the climate in the geological past
- His first evidence: the occurrence of coal in the cool mid latitudes indicate that the climate of these region was hot and humid in the Carboniferous period & natural vegetation was dense forest which ultimately resulted in the formation of huge coal deposits
- His second evidence: there are evidence of cold climate and the presence of glaciers in the Carboniferous period in India, Brazil, S.Africa, S.Australia.
- Conclusion: Either climate zones have moved or landmasses...

Pangaea

- Greek word meaning ‘all land’
- All the continents were joined together and formed one huge land mass called ‘Pangaea’, a super-continent.
- Laurasia: the northern part of Pangaea – comprised of North America, Europe and Asia
- Gondwana: the southern part of Pangaea – comprised of S.America, Africa, India, Australia and Antarctica
- Tethys: a long shallow inland sea found between Laurasia and Gondwana
- Panthalasa: extensive water mass surrounding Pangaea. Also known as the primeval Pacific Ocean.

Theory

- Continental drift refers to the movement of the continents relative to each other.
- Drift started around 200 million years ago (Triassic Period), and the continents began to break up and drift away from one another.
- The continents are drifting in two directions – a) equator-ward and b) westward
- Equator-ward movement is due to the interaction of forces of gravity, pole-fleeing force (due to centrifugal force caused by earth's rotation) and buoyancy (ship floats in water due to buoyant force offered by water), India and Africa were separated from Antarctica and Australia
- Westward movement is due to tidal currents because of the earth's motion (earth rotates from west to east, so tidal currents act from east to west, according to Wegener)North America and South America were drifting towards west. Wegener suggested that tidal force (gravitational pull of the moon and to a lesser extent, the sun) also played a major role.


PANGAEA
Equator
PERMIAN
225 million years ago
LAURASIA
TETHYS SEA
GONDWANALAND
Equator
TRIASSIC
200 million years ago
Equator
JURASSIC
135 million years ago
Equator
CRETACEOUS
65 million years ago

Perimian Period (300-250 mya)

- Pangaea intact
- Covered by Panthalassa

Triassic Period (250-200mya)

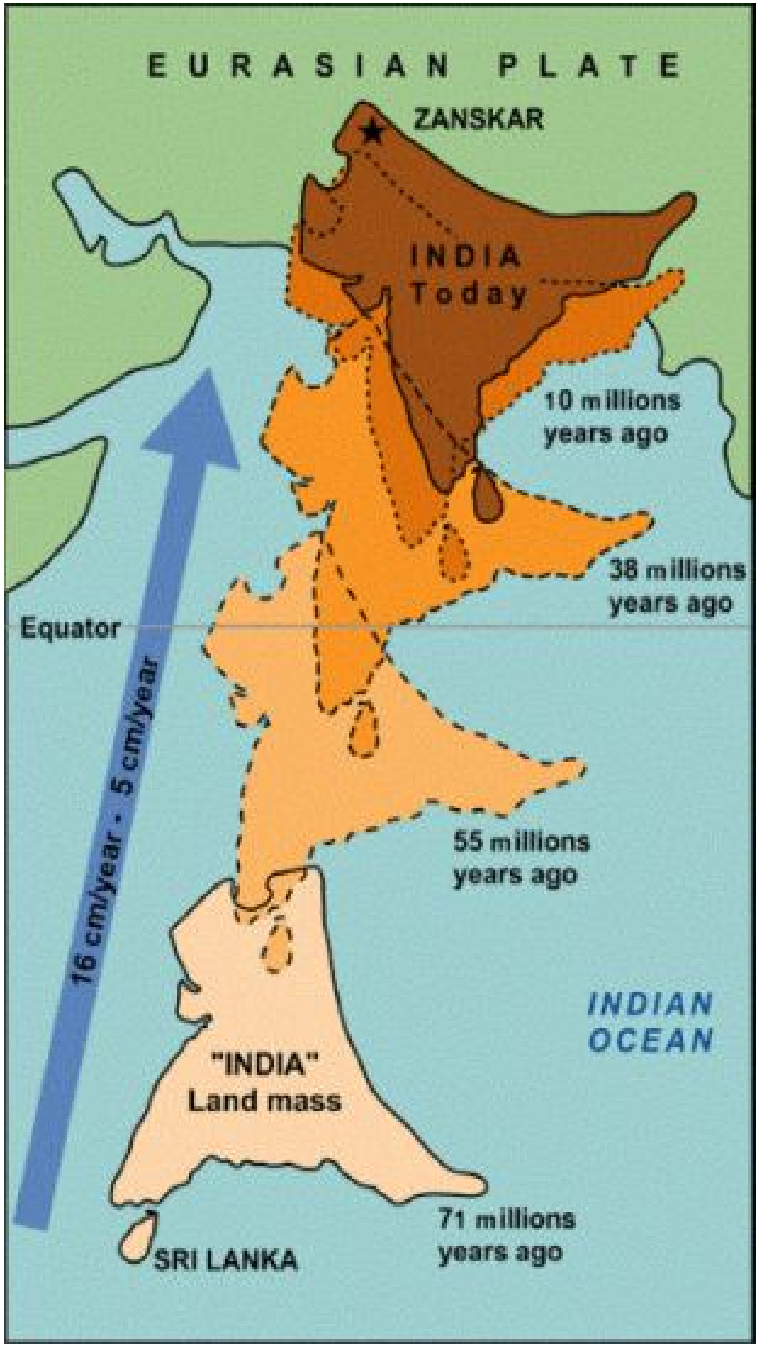
- Pangaea broke up into Laurasia and Gondwana
- The Tethys sea separated the two
- Western part of Gondwana separated from East Gondwana
- India separated from Antarctica
- Laurasia split from Africa and S.America

Jurassic Period (200-145 mya)

- Sea floor spreading opened Indian Ocean and Central North Atlantic Ocean
- Split S.America from Africa

Cretacious Period (145-65mya)

- Madagascar drifted away from Africa
- Northward drift by India
- Australia moved away from Antarctica



Cenozoic Era (65mya-Present)

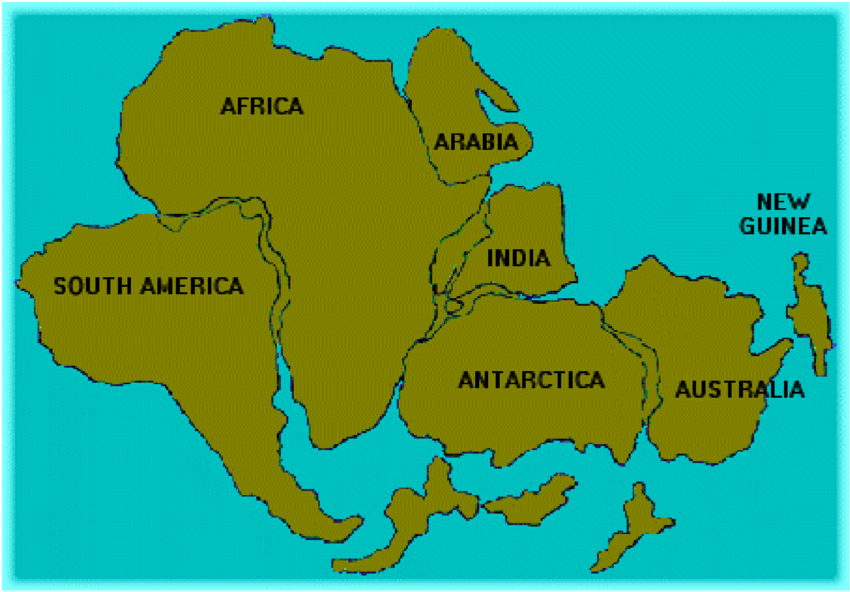
- Paleogene Period (65-23mya)
  - -Paleocene (65-56 mya)
  - -Eocene (56-33mya)
  - -Oligocene (33-23mya)
- Neogene Period (23-2.58mya)
  - \- Miocene (23-5.3mya)
  - -Pliocene (5.3-2.58mya)
- Quaternary Period (2.58mya-Present)
  - -Pleistocene (2.58mya-11,700ya)
  - -Holocene (11,700ya – Present)

- The polar-fleeing force, Wegener described this as 'Polflucht' or 'flight from the Poles', relates to the rotation of the earth. Earth is not a perfect sphere; it has a bulge at the equator. This bulge is due to the rotation of the earth (greater centrifugal force at the equator).
- Centrifugal force increases as we move from poles towards the equator. This increase in centrifugal force has led to pole fleeing, according to Wegener.
- Tidal force is due to the attraction of the moon and the sun that develops tides in oceanic waters (tides explained in detail in oceanography).
- According to Wegener, these forces would become effective when applied over many million years, and the drift is continuing.

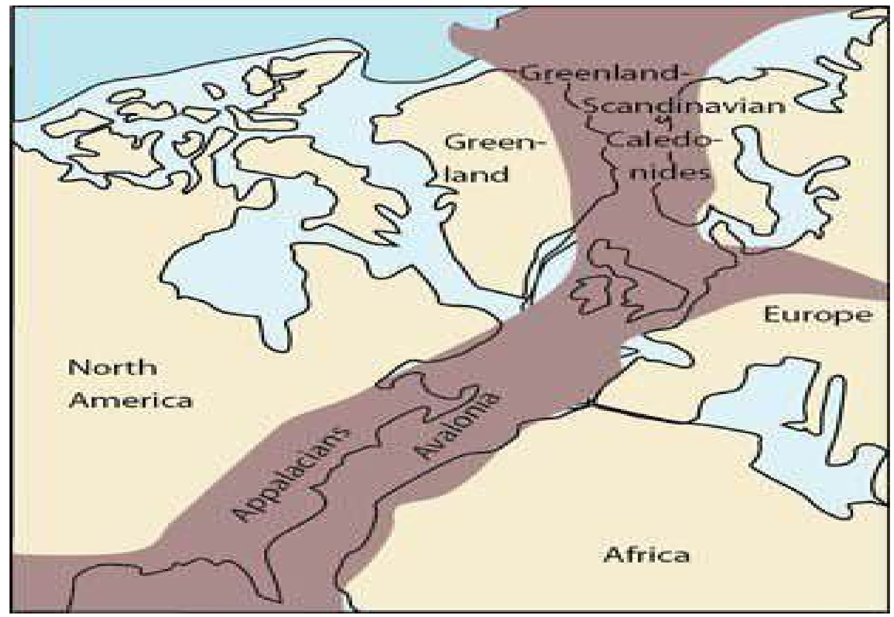
Evidences

1. "Jigsaw" fit- Wegener was struck by the geographical similarity between the opposite coasts of the Atlantic Ocean. The outlines of the two coasts appear to be the detached portion of the other ie. The east coast of North and South America can be exactly fit into the left coast of Africa and Europe. fit – Similarity between the opposing coasts of the Atlantic Ocean
2. Geological structure- there is a remarkable similarity in geological structure along the two coasts of the Atlantic. The best example is provided by the Appalachian mountains of North America which come right up to the coast and continue their trend across the ocean in the old Hercynian Mountains of southwest Ireland, Wales, and central Europe. The opposite coasts of Africa and Brazil display even greater resemblance in their structure and rocks.
3. Permo-carboniferous glaciations- it presents strong proof that at one point in time these landmasses were assembled together since the evidence of this glaciation is found in Brazil, Falkland island, South Africa, the Indian peninsula as well as Australia. It is difficult to explain these extensive glaciations on the basis of the existing distribution of landmass and water. According to Wegener at the time of Pangaea, the South Pole was situated near Durban of the present coast of South Africa.

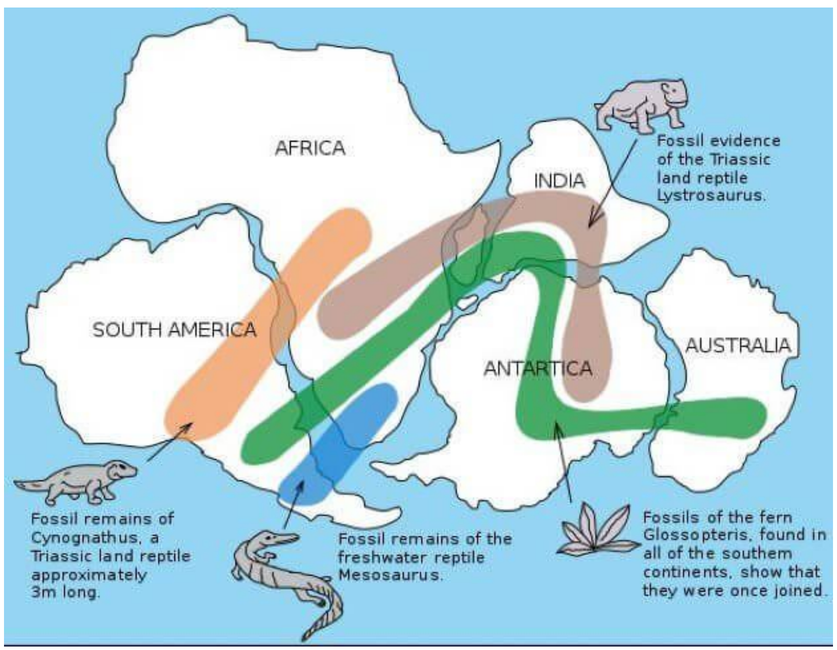
4. Similar Fossil remains of terrestrial animals are found on both coasts of the Atlantic. This cannot be possible if the two landmasses were not joined as it quite impossible for these animals to swim across the Atlantic.
5. Paleoclimatic evidence- Coal deposits have been found in temperate and polar regions; however, coal is formed in tropical regions.
6. Biological evidence- Presence of glossopteris vegetation in Carboniferous rocks of India, Australia, South Africa, Falkland Islands (Overseas territory of UK), Antarctica, etc. (all split from the same landmass called Gondwana) can be explained from the fact that parts were linked in the past.



AFRICA
ARABIA
NEW GUINEA
INDIA
SOUTH AMERICA
ANTARCTICA
AUSTRALIA



Greenland-Scandinavian Caledo-nides
Green-land
Europe
North America
Appalacians
Avalonia
Africa



AFRICA
INDIA
Fossil evidence of the Triassic land reptile Lystrosaurus.
SOUTH AMERICA
ANTARTICA
AUSTRALIA
Fossil remains of Cynognathus, a Triassic land reptile approximately 3m long.
Fossil remains of the freshwater reptile Mesosaurus.
Fossils of the fern Glossopteris, found in all of the southern continents, show that they were once joined.

Criticism

- The forces mentioned by Wegener were inadequate to cause drift.

  -the tidal force of the moon and the sun should have been thousand million times more

  -the equator ward movement due to gravitational force exerted by earth’s equatorial bulge....is so feeble
- The Rockies and the Andes mountain systems could not have been formed in the manner envisaged by Wegener...because if the Sial is floating over the Sima, the Sima could not offer so much resistance to the Westward movement of the continents.
- Jig-saw fit of the opposing coasts of the Atlantic Ocean is oversimplified
- The similarity in the structural and stratigraphical features of the two coasts of the Atlantic Ocean need not be an extension of the other.

New evidences

1. Computer estimates of the topographic fit of the continents
   – In 1958, S.W. Carey shows that the fit of S.Atlantic coasts was so good that it could not be called accidental
   – In 1965, E.C. Bullard, Everett and Smith demonstrated with the help of a computer that the African and S.American coasts could be fitted into each other at a depth of 500 fathoms (1000m)
   – In 1969, W.P. Sproll and R.S. Diets prepared a computer fit of Australia and Antarctica
   – In 1970, A.G. Smith, A. Hallam prepared a computer fit of S.America, Arabia, Africa, Australia, Antarctica along the 500 fathom isobath

2. Geological similarities have been confirmed by isotopes and radiometric dating of rocks on both the coasts of the Atlantic

- P.M. Hurley (1967) and his associates found great similarity in the geological age provinces of Western Africa and Eastern Brazil.

- In the west of West Africa, the age of rocks is about 2000 million years and in the eastern part about 550 million years. The age of the rocks in the Brazil is the same

- Glacial deposits are found in both sides of the Atlantic Ocean during Permo-Carboniferous period (350-250 million years)

- Great flood of basalt inundated the Triassic deserts of both the continents in the early Jurassic times

- Fossils of ’glossopteris’ flora is found in the Sedimentary rocks of the Gondwana land in S.Africa, India, Australia, S.America.

- Reptile fossil – ‘Mesosaurus’ in the Permian deltaic deposits of both Brazil and South Africa
- In 1967, fossils of fresh water amphibians called ‘Lobyrinthodonts’ (developed in Devonian period) were discovered in the Antarctica.
- In 1969, Edwin Colbert and others found reptile fossils of the Triassic period in the Antarctica called ‘Lystrasaurus’, a reptile which lived in swamps and lakes

3. Paleomagnetism
   - According to Wegener there has been changes in the position of the Poles in the geological periods which he called ‘Polar wandering’
   - Recent paleomagnetic studies have made it clear the location of poles in geological periods
   - the magnetic declination and inclination are different in rocks of different ages.

4. Sea floor spreading

- Sea floor spreading theory was proposed claiming that the crust below the oceans is expanding.
- The magma from inside the earth is being released deep below oceans on the oceanic crust which is causing the lava to be pushed on either side of mid-ocean ridges and thus spreading of the floor.
- Recurring of episodes of continental break-up, drift and collision was held since earlier times
- each cycle lasting for a few hundred million years called ‘Wilson cycle’, after J.Tuzo Wilson, one of the pioneers of Plate Tectonics.

Conclusion

- Wegener failed to explain why the drift began only in Mesozoic era and not before.
- The theory doesn’t consider oceans.
- Proofs heavily depend on assumptions that are generalistic.
- Forces like buoyancy, tidal currents and gravity are too weak to be able to move continents.
- Modern theories (Plate Tectonics) accept the existence of Pangaea and related landmasses but give a very different explanation to the causes of drift.
- Though scientifically unsound on various grounds, Wegener’s theory is a significant milestone in the study of tectonics, and it laid a strong foundation for future the theories like seafloor spreading and plate tectonics.

Plate Tectonics

https://www.nationalgeographic.org/media/plate-tectonics/#alien-deep-tectonic-plates

Important Events that led to the Theory of Plate Tectonics

- 1890: First scientifically used seismograph developed by Englishmen Thomas Gray, John Milne, and James A. Ewing
- 1909: Demonstration of layered Earth. Yugoslav scientist A. Mohorovicic uses seismic waves to characterize continental crust
- 1913: Beno Gutenberg (Gotingen University) determines depth to core
- 1915: Alfred Wegener, of Germany, advances first theory of continental drift based on geological data on different continents
- 1929: Arthur Holmes (Durham University) proposes model of continental drift driven by subcrustal convection currents.
- 1946-50: Scientists begin to use echo sounders, hydrophones, magnetometers, navigational aids, and other instruments developed in World War II to explore ocean basins. They show that ocean crust is basaltic and 5 km thick, in contrast to 40 km thick granitic continental crust.

- 1954: Hugo Benioff (Caltech) describes pattern of deep-focus earthquakes that lie along a dipping plane beneath ocean trenches and active island arcs.
- 1956: Cambridge University physicists Patrick M.S. Blackett, Edward Irving, and S. Keith Runcorn argue that their paleomagnetic measurements of rocks of different continents support continental movements according to Wegener’s theory
- 1959: Columbia University scientists Bruce Heezen and Marie Tharp develop first detailed topographic maps of the seafloor showing global mid-ocean ridge-rift system.
- 1962: Princeton geologist Harry Hess, using newest results from seafloor exploration, buttresses the case that continents drift by riding on top of seafloor that spreads laterally from mid-ocean ridges. Seafloor is consumed by sinking back into mantle at deep-sea trenches. Proposes mantle convection as the driving force.

- 1963: Allan Cox of Stanford and U.S. Geological Survey scientists Richard Doell and Brent Dalrymple use reversals in magnetization of continental layered basal flows and the radiometric ages of these flows to establish a new geomagnetic time scale to date rocks.
- 1963: In a major breakthrough, Frederic Vine and Drummond Matthews of Cambridge University relate the bands of alternately reversed magnetization of seafloor crust to lateral spreading of seafloor from mid-ocean ridges. Canadian scientist Lawrence Morley independently advances this concept.
- 1965: Canadian geologist J. Tuzo Wilson proposes transform faults as the explanation of ocean-ridge offsets.
- 1966: Columbia University scientists Neil Opdyke, Walter Pitman, and J.R. Heirtzler link the geomagnetic and radiometric time scale of continental basaltic flows, the geomagnetic and paleontological time scales of deep-sea sediment cores, and the time scales of seafloor magnetic bands. The ages of the seafloor and spreading rates for all of the oceans can now be determined.

- 1968: Drilling ship Glomar Challenger begins to drill and recovers cores of sediment and basaltic crust of seafloor that corroborate and fill in details of seafloor spreading.
- Late 1960s: Tuzo Wilson suggests pattern of rigid plates; Dan McKenzie (Cambridge), Robert Parker (Scripps), W. Jason Morgan (Princeton), and French scientist Xavier LePichon work out the shapes of plates and the geometry and history of their motion on a sphere.
- 1968: Final chapter. Columbia seismologists Jack Oliver, Lynn Sykes, and Bryan Isaacs show that precise locations, depths and mechanisms of earthquakes conform to plate-tectonics predictions for mid-ocean ridge spreading centers, transform faults, and subduction zones.

Introduction

- The unifying theory of plate tectonics describes the movement of plates and the forces acting between them. It also explains the distribution of many large scale geologic features – mountain chains, rock assemblages, structures on the seafloor, volcanoes, and earthquakes – that result from movements at plate boundaries.
- The theory of plate tectonics states that the Earth's solid outer crust, the lithosphere, is separated into plates that move over the asthenosphere, the molten upper portion of the mantle. Oceanic and continental plates come together, spread apart, and interact at boundaries all over the planet.

- Plates vary from minor plates to major plates, continental plates (Arabian plate) to oceanic plates (Pacific plate), sometimes a combination of both continental and oceanic plates (Indo-Australian plate).

Major tectonic plates

1. Antarctica and the surrounding oceanic plate
2. North American plate
3. South American plate
4. Pacific plate
5. India-Australia-New Zealand plate
6. Africa with the eastern Atlantic floor plate
7. Eurasia and the adjacent oceanic plate

Minor tectonic plates

1. Cocos plate: Between Central America and Pacific plate
2. Nazca plate: Between South America and Pacific plate
3. Arabian plate: Mostly the Saudi Arabian landmass
4. Philippine plate: Between the Asiatic and Pacific plate
5. Caroline plate: Between the Philippine and Indian plate (North of New Guinea)
6. Fuji plate: North-east of Australia
7. Turkish plate
8. Aegean plate (Mediterranean region)
9. Caribbean plate
10. Juan de Fuca plate (between Pacific and North American plates)
11. Iranian plate.

There are many more minor plates other than the ones mentioned above.

Most of these minor plates were formed due to **stress created by converging major plates**.

Example: the Mediterranean Sea is divided into numerous minor plates due to the compressive force exerted by Eurasian and African plates.

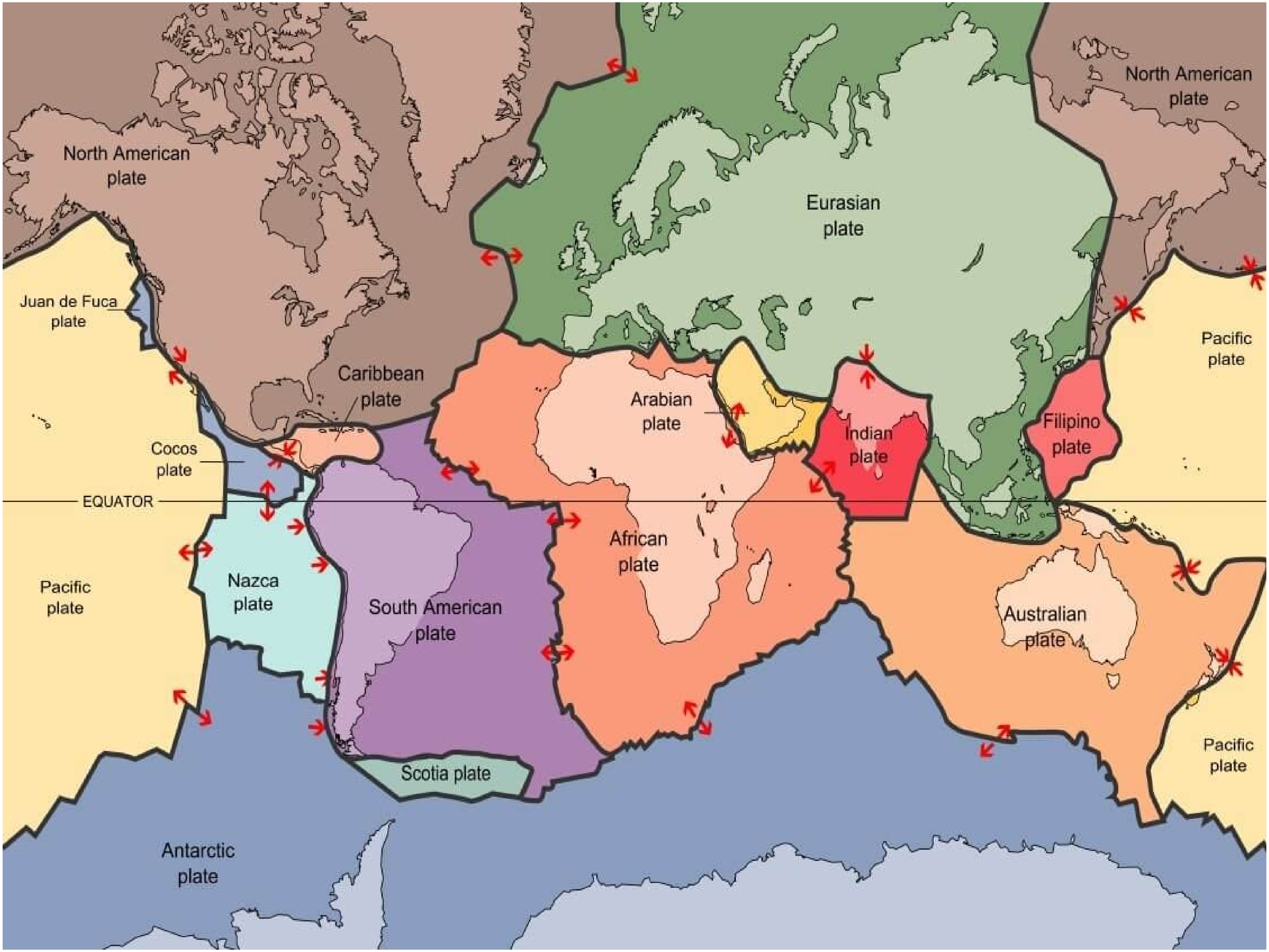

North American plate
Eurasian plate
North American plate
Juan de Fuca plate
Pacific plate
Caribbean plate
Arabian plate
Indian plate
Filipino plate
Cocos plate
EQUATOR
African plate
Nazca plate
Pacific plate
South American plate
Australian plate
Pacific plate
Scotia plate
Antarctic plate

Plate Boundaries

1. Divergent Boundary
2. Convergent Boundary
3. Transform Boundary

Divergent Boundary: At divergent boundaries, where plates move apart, partially molten mantle material rises and fills the gap between them.

- This material becomes new lithosphere added to the trailing edges of the diverging plates.
- On the seafloor, the boundary between separating plates is marked by a mid-ocean ridge that exhibits active basaltic volcanism, shallow-focus earthquakes, and normal faulting caused by tensional or stretching forces created by the pulling apart of two plates.
- The process by which plates separate and ocean crust is created is called seafloor spreading.
- The mid-Atlantic Ridge and the East Pacific Rise are spreading centers that have created millions of square kilometers of seafloor.
- Iceland is an exposed segment of the Mid-Atlantic Ridge.

- The Great Rift Valley of East Africa, between the African plate and the Somali Sub plate, is thought to represent an early stage of plate separation within a continent.
- The continental rifting may slow down or stop before the continent splits apart a new ocean basin opens up.
- The East African Rift Valley and the Rhine valley in Europe are still mildly active.
- The Red Sea and Gulf of California are rifts that are farther along in spreading
- The Arabian Peninsula is splitting away from Africa at the Red Sea and Baja California is separating from the Mexican mainland at the Gulf of California.

Convergent Boundary: At convergent boundaries, plates collide with one another.

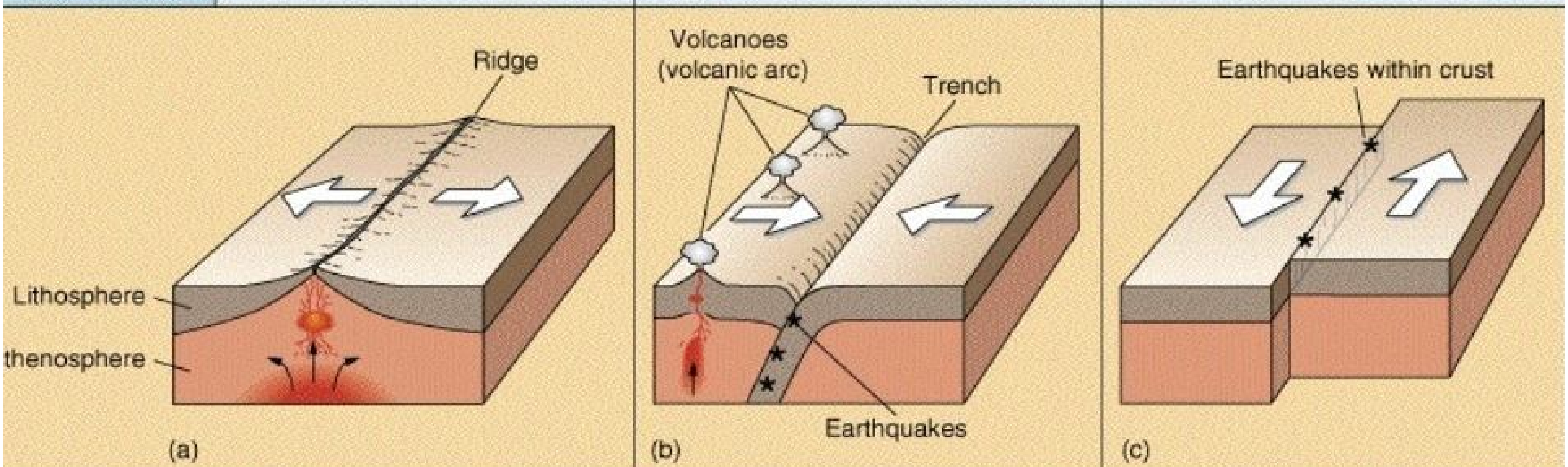
- The collision buckles the edge of one or both plates, creating a mountain range or subducting one of the plates under the other, creating a deep seafloor trench.
- At convergent boundaries, continental crust is created and oceanic crust is destroyed as it subducts, melts, and becomes magma.
- Convergent plate movement also creates earthquakes and often forms chains of volcanoes. The highest mountain range above sea level, the Himalayas, was formed 55 million years ago when the Eurasian and Indo-Australian continental plates converged.
- The Mediterranean island of Cyprus formed at a convergent boundary between the African and Eurasian plates.
- Nazca plate and South American plate: the Peru-Chile deep-sea trench, the Andes Mountains with their many volcanoes, some of the world's largest shallow and deep focus earthquakes are here.

Transform Boundaries: At transform boundaries, plates slide past each other, neither creating nor destroying lithosphere.

- Transform faults occur where the continuity of a divergent boundary is broken and offset.
- The San Andreas Fault in California, where the Pacific plate slides by the North American plate, is an example of a transform boundary.
- Shallow-focus earthquakes with horizontal slips occur on transform boundaries.
- These boundaries don't produce spectacular features like mountains or oceans, but the halting motion often triggers large earthquakes, such as the 1906 one that devastated San Francisco.

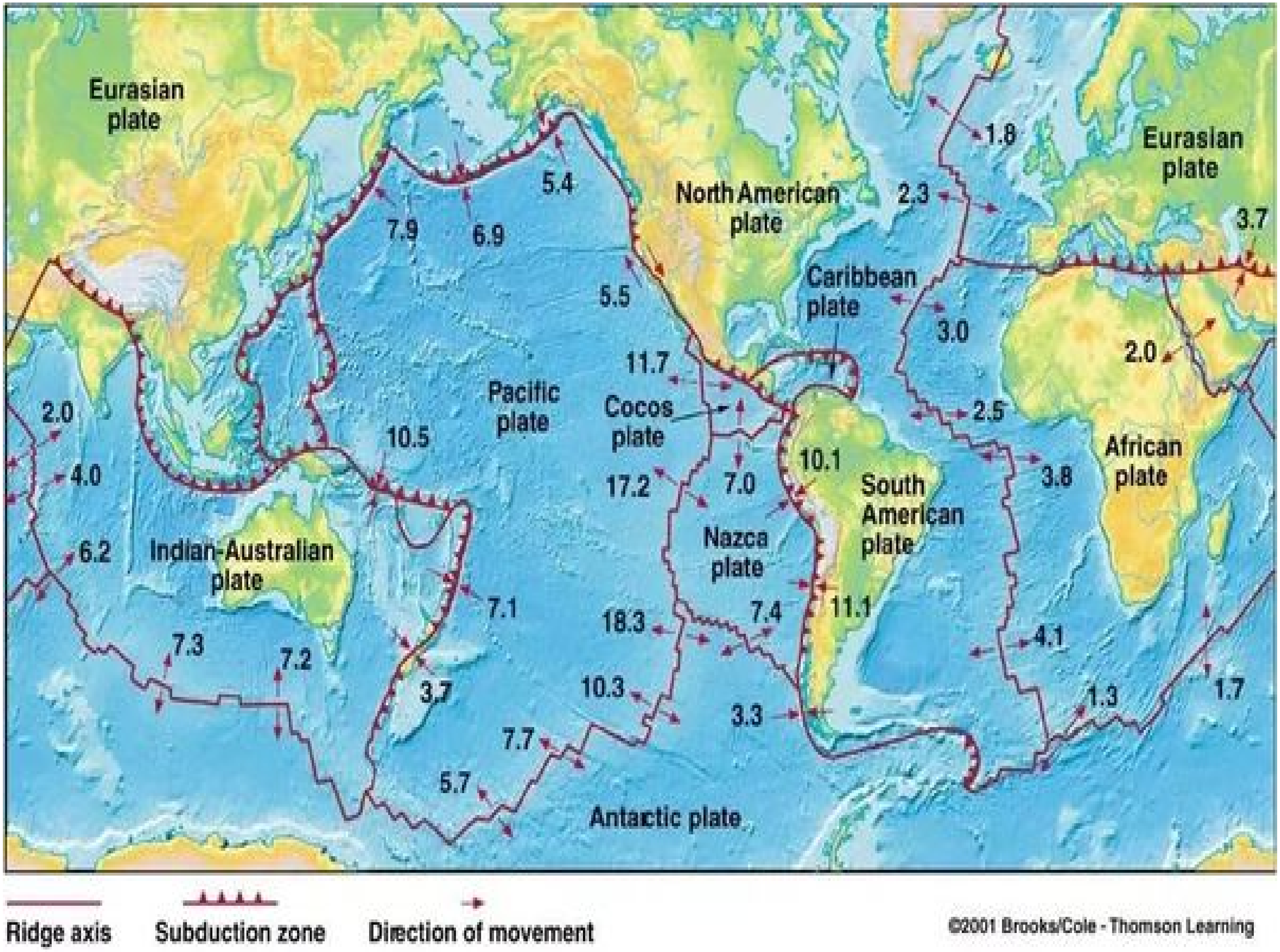
Different types of plate boundaries

ype of Margin	Divergent	Convergent	Transform
otion	Spreading	Subduction	Lateral sliding
fect	Constructive (oceanic lithosphere created)	Destructive (oceanic lithosphere destroyed)	Conservative (lithosphere neither created or destroyed)
pography	Ridge/Rift	Trench	No major effect
lcanic activity?	Yes	Yes	No



Rates of Plate Movement

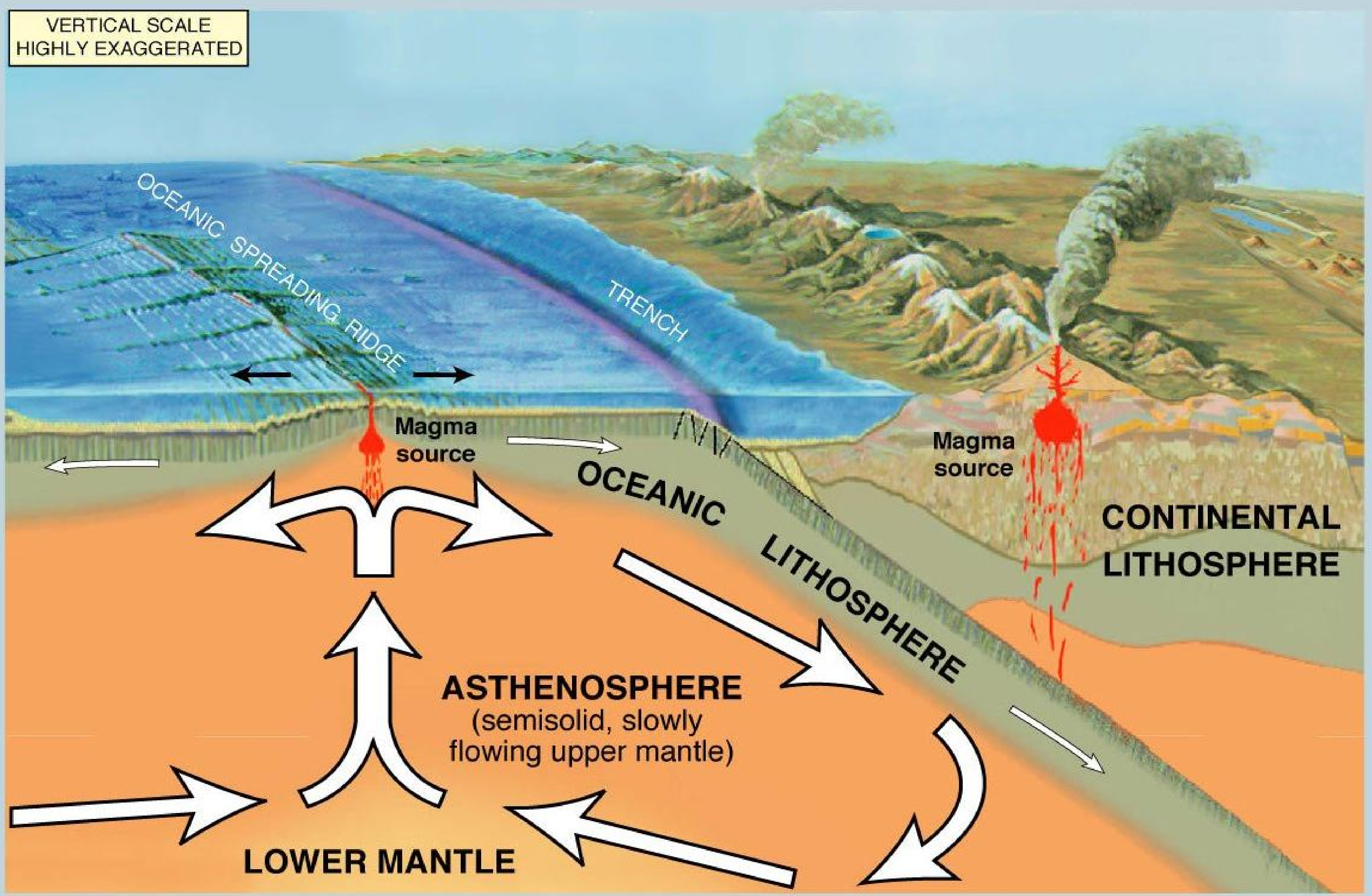
- The rate of plate movement is determined by the bands of normal and reverse magnetic fields that parallel the mid-oceanic ridge.
- The rates of plate movement have a considerable variation.
- For example, while the Arctic Ridge has the slowest rate (less than 2.5 cm/yr), the East Pacific Rise in the South Pacific has the fastest rate (more than 15 cm/yr).
- An interesting fact is that the movement of Indian plate from south to equator was one of the fastest plate movements in history.


Eurasian plate
Eurasian plate
North American plate
Caribbean plate
Pacific plate
Cocos plate
Nazca plate
South American plate
African plate
Indian-Australian plate
Antactic plate
1.8
2.3
3.0
3.7
2.0
2.5
3.8
4.1
1.3
1.7
5.4
7.9
6.9
5.5
11.7
10.5
7.0
10.1
17.2
2.0
4.0
6.2
7.1
18.3
7.4
11.1
7.3
7.2
3.7
10.3
3.3
7.7
5.7
Ridge axis
Subduction zone
Direction of movement

The force behind the Movement of Plates

- Intense heat generated from the radioactive decay of substances deep inside the Earth (the mantle) which creates magma consisting of molten rocks, volatiles and dissolved gases.
- These produce convectional currents when the magma, heat and gases seek a path to escape in the mantle.
- The force behind the movement of the plates are these convectional currents generated by the upwelling of hot magma which causes the overlying lithospheric slabs to uplift and stretch.

Convection in the molten rock of Earth's mantle drives the movement of the plates. Hotter material rises to the surface, while cooler material sinks toward the core. This creates pushing and spreading apart at mid-ocean ridges and subduction (sinking) of one plate under another at subduction zones.



Importance of the theory of Plate Tectonics

- It is the unifying theory of geology, which further explains large-scale geological phenomena, such as earthquakes, volcanoes, and the existence of ocean basins and continents.
- Plate tectonics theory explains why there are lots of volcanoes in Iceland and Japan, but far fewer in Russia and Africa. This is because Iceland was created by a mid-oceanic ridge. Similarly, Japan is located on a fault line. The constant pressure around the fault line causes many earthquakes and volcanic eruptions.
- For geographers, the theory of Plate tectonics aids in the interpretation of landforms. It ultimately explains why and where deformation of Earth s surface occurs.
- Further, the concept of plate tectonics explains mineralogy. New minerals pour up from the core along with the magmatic ejections. The plate boundaries are the pathways through which rocks from the mantle come out as deposits on lithosphere. These rocks are the source of many minerals.
- The famous Pacific Ring of fire known for its violent volcanic activity is also a ring of mineral deposits.

Cycle of Erosion

The concept of Davis

- The originator is an American Geomorphologist William Morris Davis (1850-1934)
- Professor of Physical Geography at Harvard University
- Founded the Association of American Geographers in 1904
- He published the concept in 1899 and called it the 'geographical cycle'
- According to this concept a landscape has a definite life history, and as the processes of land sculpture operate on it the surface features are marked by several changes in its life-time.
- The changes in the surface features follow a definite sequence where the initial forms pass through sequential forms and finally reach the ultimate form.
- Thus the evolution of the landscape passes through a cycle, and the cycle follows a definite sequence of development.

- It is an important landmark in the history of geomorphology
- Developed to cope with the sequences found in humid temperate regions, the cycle should be divided into three components, a) a cycle of river development b) a cycle of slope development c) a cycle of landscape development
- The successive stages of development sequence can be divided into three parts..1.youth, 2. maturity, 3. old
- Davis states that landscape is a function of i)structure, ii)process and iii) stage – the ‘trio of geographic controls’
- Davis believed that humid temperate landscapes evolve through a fixed sequence of forms that reflect the interaction of the above three factors – structure, process and stage.

Structure: includes not only regional geological structure, folds, faults and such other broad features but also the nature of rocks and their characteristics, their physical and chemical properties, their permeability and solubility, the nature of joints, etc.,

- Thus on a very permeable rock, there will be minimum run-off and so erosion by running water will be slower than on an adjacent impermeable rock.

  (E.g., Soft shale erode readily than massive quartzite)

- In general, structural features of rocks are much older than the geomorphic forms developed upon them (Remember Concept No.2).

Process: includes the action of all the forces which bring about changes in the configuration of the earth's surface.

- Internal or Endogenic forces: volcanicity and diastrophism – produce irregularities on the earth's surface by building and uplifting mountains, plateaus and hills.
- External or Exogenic forces: tend to level down the earth's surface. Running water, moving ice, groundwater, waves and wind – agents
- Landscape changes with a change in the process. A particular process gives rise to distinctive landforms (Remember Concept Nos. 4 and 5)
- For instance, alluvial fans, flood-plain and deltas are produced by river....

Stage: three stages of evolution may be identified. 1) Youthful stage, 2) Mature stage and, 3) Old stage

- Each stage of the cycle of erosion is characterized by distinctive landforms with the help of which it is possible o identify the stage of evolution of the landscape.
- Landforms are time-dependent
- The division of erosion cycle into stages is intended to emphasize the orderly evolution of landforms.

Initial Stage: the upliftment of landmass. No diversity of relief.

Youthful stage: The uplift is complete and has stopped. Immediately erosion of the uplifted block sets in.

- The streams follow initial irregularities available without adjusting to the structure. These are consequent streams.
- The floors of the valley suffer down cutting while the summits remain almost unaffected.
- Increased relief heralds the beginning of mature age, indicated by widening of the gap between lines ‘A’ and ‘B’

Mature stage: At this stage, the vertical erosion slows down and the horizontal action increases.

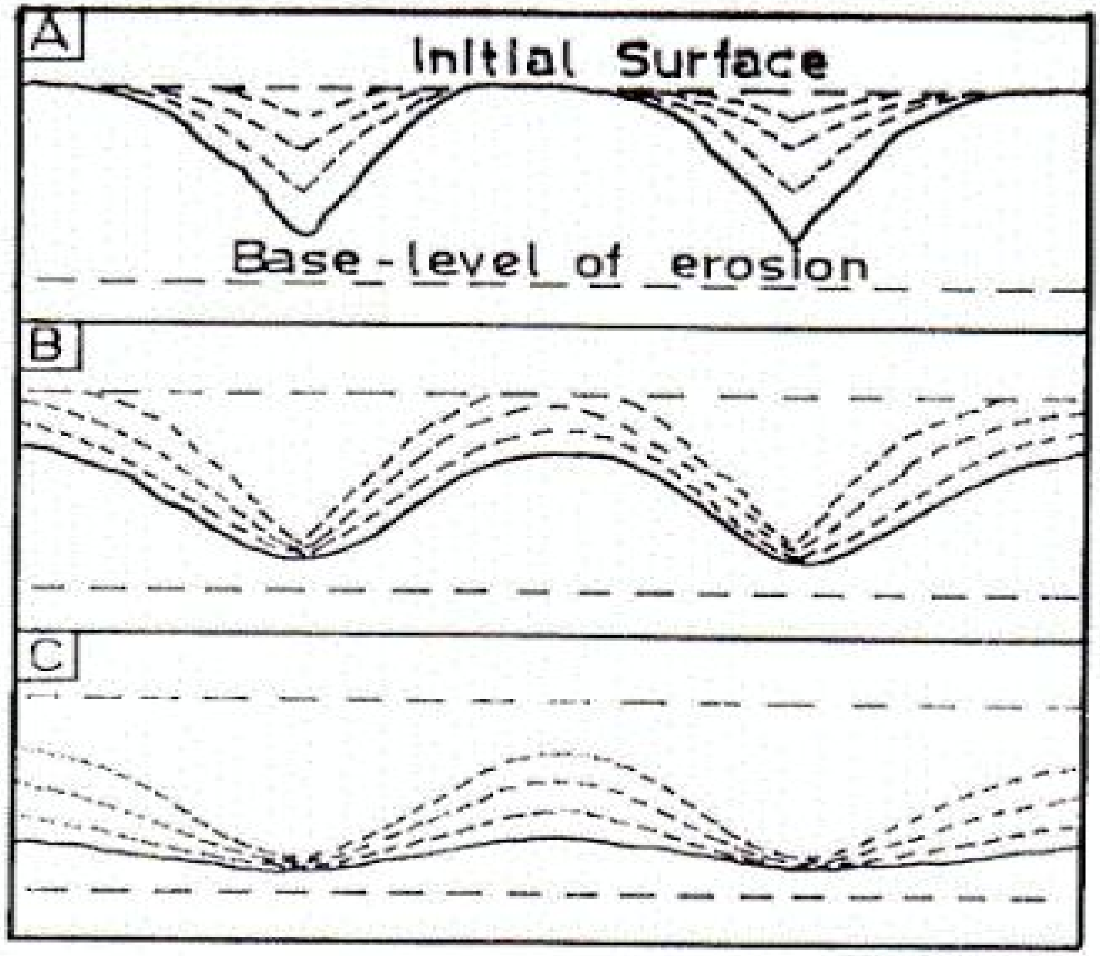
- A characteristic feature is the erosion of mountain tops at a faster rate than lowering of the valley floor.
- The coming closer of lines 'A' and 'B' indicates emergence of a gentle slope.
- The subsequent streams gain importance now.

Old stage: A gentle gradient, accentuated by horizontal action and deposition, reduces the erosion intensity.

- A thick layer of sediment represents the earlier erosion activity. The landforms get reduced—lines 'A' and 'B' run parallel to each other.
- Relicts of mountains or monadnocks are dotting the water divides and a featureless plain—peneplain/peneplane is produced.

- Peneplain is not really a plain with a level surface, but is a rolling lowland where the different rivers are separated from one another by slightly higher ground and flow slowly down very gentle slopes.
- In this stage the influence of rock differences on the landscape is almost entirely lost
- Here and there some resistant rocks may remain as high ground or form residual hills called ‘monadnocks’. (after Mt.Monadonock in New Hampshire, northeastern USA)

DAVICIAN CYCLE OF EROSION



A. YOUTH
B. MATURITY
C. OLD AGE

Graphical Representation of the Cycle of Erosion

- The cycle of erosion begins with the upliftment of landmass. There is a rapid rate of short-period upliftment of landmass of homogeneous structure. This phase of upliftment is not included in the cyclic time as this phase is, in fact, the preparatory stage of the cycle of erosion.
- The figure represents the model of geographical cycle wherein UC (upper curve) and LC (lower curve) denote the hill-tops or crests of water divides (absolute reliefs from mean sea level) and valley floors (lowest reliefs from mean sea level) respectively.
- The X-axis denotes time whereas Y-axis depicts altitude from sea level. AC represents maximum absolute relief whereas BC denotes initial average relief.

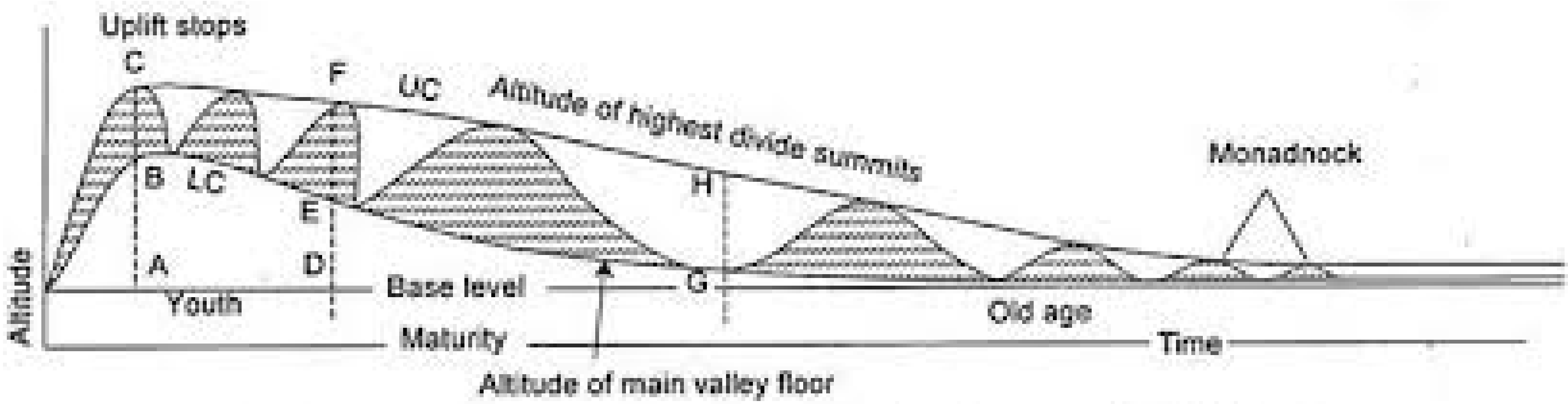


Fig. 16.1 : Graphical presentation of geographical cycle presented by W.M. Davis.

- Initial relief is defined as difference between upper curve (summits of water divides) and lower curve (valley floors) of a landmass. In other words, relief is defined as the difference between the highest and the lowest points of a landmass. ADG line denotes base level which represents sea level. No river can erode its valley beyond base level (below sea level).
- Thus, base level represents the limit of maximum vertical erosion (valley deepening) by the rivers. The upliftment of the landmass stops after point C as the phase of upliftment is complete.

Positive Aspects

- (1) Davis' model of geographical cycle was highly simple and applicable.
- (2) He presented his model in a very lucid, com-pelling and disarming style using very simple but expressive language. Commenting on the language of Davis used in his model Bryan remarked, "Davis rhetorical style is just ad-mired and several generations of readers became, slightly bemused by long though mild intoxication of the limpid prose of Davis remarkable essay."
- (3) Davis based his model on detailed and careful field observations.
- (4) Davis' model came as a general theory of landform development after a long gap after Hutton's cyclic nature of the earth history.
- (5) This model synthesized the current geological thoughts. In other words, Davis incorpo-rated the concept of 'base level' and genetic classification of river valleys, the concept of 'graded streams' of G.K. Gilbert and French engineers' concept of 'profile of equilibrium' in his model.
- (6) His model is capable of both predictions and historical interpretation of landform evolution.

Criticism

- (1) Davis concept of upliftment is not acceptable. He has described rapid rate of upliftment of short duration but as evidenced by plate tectonics upliftment is exceedingly a slow and long continued process.
- (2) Davis' concept of relationship between upliftment and erosion is erroneous. According to him no erosion can start unless upliftment is complete. Can erosion wait for the completion of upliftment? It is a natural process that as the land rises, erosion begins. Davis has answered this question.
- **He admitted that he deliberately excluded erosion from the phase of upliftment because of two reasons:**
- (i) To make the model simple, and
- (ii) Erosion is insignificant during the phase of upliftment.
- (3) The Davisian model requires a long period of crustal stability for the completion of cycle of erosion but such eventless long period is tectonically not possible as is evidenced by plate tectonics according to which plates are always in motion and the crust is very often affected by tectonic events. Davis has also offered explanation to this objection. Accord-ing to him if crustal stability for desired pe-riod is not possible, the cycle of erosion is interrupted and fresh cycle of erosion may start.

- (4) Walther Penck objected to over emphasis of time in Davis' model. In fact, Davisian model envisages 'time-dependent series' of landform development whereas Penck pleaded for time- independent series' of landforms. According to Penck landforms do not experience progressive and sequential changes through time. He, thus, pleaded for deletion of 'time' (stage) from Davis' 'trio' of 'structure, process and time'. According to Penck "geomorphic forms are expressions of the phase and rate of upliftment in relation to the rate of degradation".
- (5) A.N. Strahler, J.T. Hack and R.J. Chorley and several others have rejected the Davisian con-cept of 'historical evolution' of landforms. They have forwarded the dynamic equilib-rium theory for the explanation of landform development.
- It may be pointed out that non- cyclic concept of 'dynamic equilibrium' as valid substitute of Davis' cyclic concept of landform development and other so called 'open system' and non-cyclic models of landform development could not arouse any enthusiasm among the modern geomorphologists.
- It may be concluded in the words of Charles Higgins (1975) that "If the desire for a cyclic, time-dependent model stems from an unacknowledged fundamental postulate that the history of the earth is itself cyclic, then no non-cyclic theory of landscape development can win with general acceptance until this postulate is unearthed, examined, and possibly rejected."

Penck's Cycle of Erosion

Also known as 'morphological system' or 'morphological analysis' of landscape development

Key Terminologies

1. Entwickelung – Development
2. Aufsteingende Entwickelung – accelerated rate of development
3. Gleichformige Entwickelung – uniform rate of development
4. Absteigende Entwickelung – decelerating rate of development
5. Primarumf – landscape before upliftment
6. Endrumf – landscape at the end
7. Boschungen – gravity slope
8. Haldenhang – wash slope
9. Treppen – Stairs/staircases

Background

- German geologist Walther Penck – the prominent critic of Davis.
- Penck’s book in German was published in 1924 and was translated into English in 1953, titled as ‘Morphological Analysis of Land forms’.
- He criticized mainly for the Davis’ assumption that erosion starts only after complete uplift and that uplift is short-lived while the landmass stands still during the long period of erosion.
- Penck has also expressed disagreement with the stage concept of Davis
- In his view the cyclic evolution of landscape on a still-stand landmass for such a long duration of time can be considered only exceptional.
- According to Penck the landscape is the result of the relative intensity of the degradational processes and the phase and rates of uplift.
- In other words, the landforms were determined by the rate of uplift and the rate of erosion.
- Penck talks of three phases in place of the three stages of Davis
- These three phases are related to the rate of uplift.

- As the rates of uplift and degradation are different in the three phases, different kinds of slopes developed in them resulting in the formation of different landscapes.
- The uplift was rapid in the beginning, moderate in the middle, and decreased in intensity towards the end.
- After sometime the uplift stops altogether and from that point onwards there is continuous degradation of the landscape.
- Penck has assumed a low, featureless plain called 'primarumpf' by him, for the initiation of the erosion cycle. In primarumpf, there is neither appreciable height nor appreciable relief.
- Initially when the land rises above the sea level the uplift is so slow that uplift and degradation are almost equal, and irrespective of the geological structure, a low surface without relief is formed which is called the 'primarumpf'.
- Penck calls the terminal plain which is formed at the end of degradation by the name of 'endrumpf'. It is the last stage or phase of degradation and the ultimate landform of the cycle, which closely resembles the peneplain of Davis.

Graphical Representation of Penck's concept

- In the diagram, the upper curve represents the average maximum height, and the lower curve represents the average height of the valley floor.
- The entire cycle has been divided into three phases, but these relate to the changing conditions of the evolution of relief which are related to the rate of uplift and the rate of degradation.

Phase : 1. Aufsteigende Entwickelung

- Aufsteigende entwickelung means the phase of waxing (accelerating) rate of landform development.
- Initially, the land surface rises slowly but after some time the rate of upliftment is accelerated.
- Because of upliftment and consequent increase in channel gradient, flow velocity and kinetic energy and of course increase in discharge (not due to uplift) the rivers continue to degrade their valleys with accelerated rate of down-cutting (valley deepening or incision) but the rate of upliftment far exceeds the rate of valley deepening (say degradation of uplifted landmass).

- Continuous active downcutting and valley deepening results in the formation of deep and narrow V shaped valleys.
- As the rate of uplift (aufsteigende entwickelung) continues to increase the V shaped valleys are further deepened and sharpened.
- Since valley deepening does not keep pace with the upliftment of landmass the absolute height continues to increase.
- In other words, the altitudes of divide summits as well as the altitudes of valley bottoms continue to increase as the rate of upliftment far exceeds the rate of vertical erosion (fig)
- But the relative or available reliefs continue to increase due to ever-increasing rate of vertical erosion or valley deepening. Thus, both maximum altitude (absolute height from sea level) and maximum relief (relative) increase.
- The slopes of valley sides are convex.

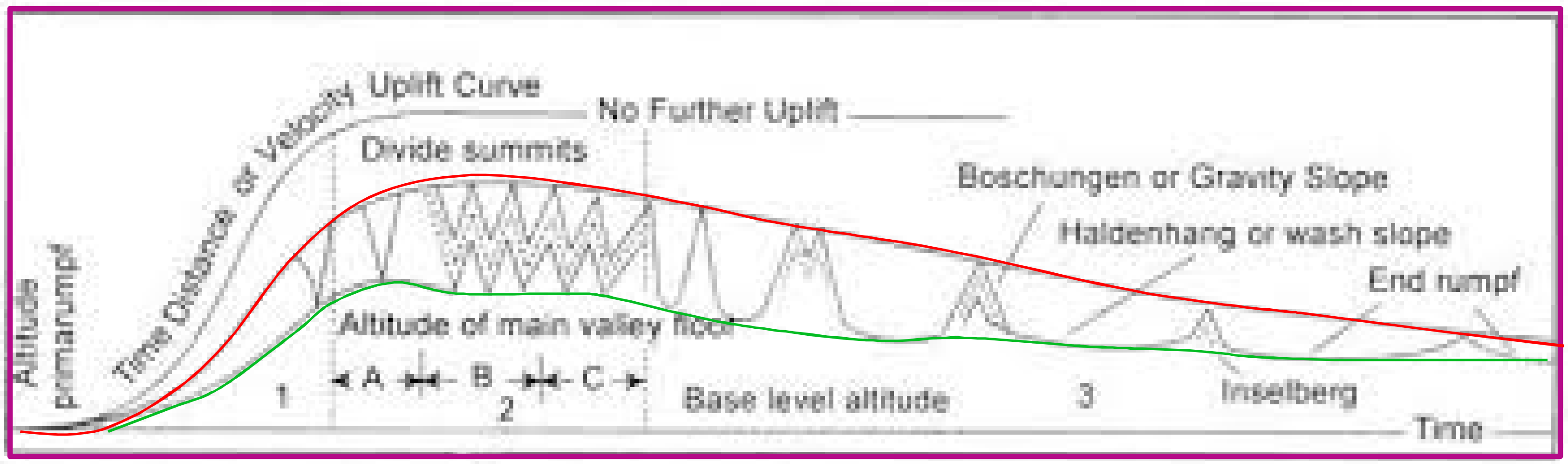


Fig. 16.2 : Graphic presentation of Penck's model of landform development.

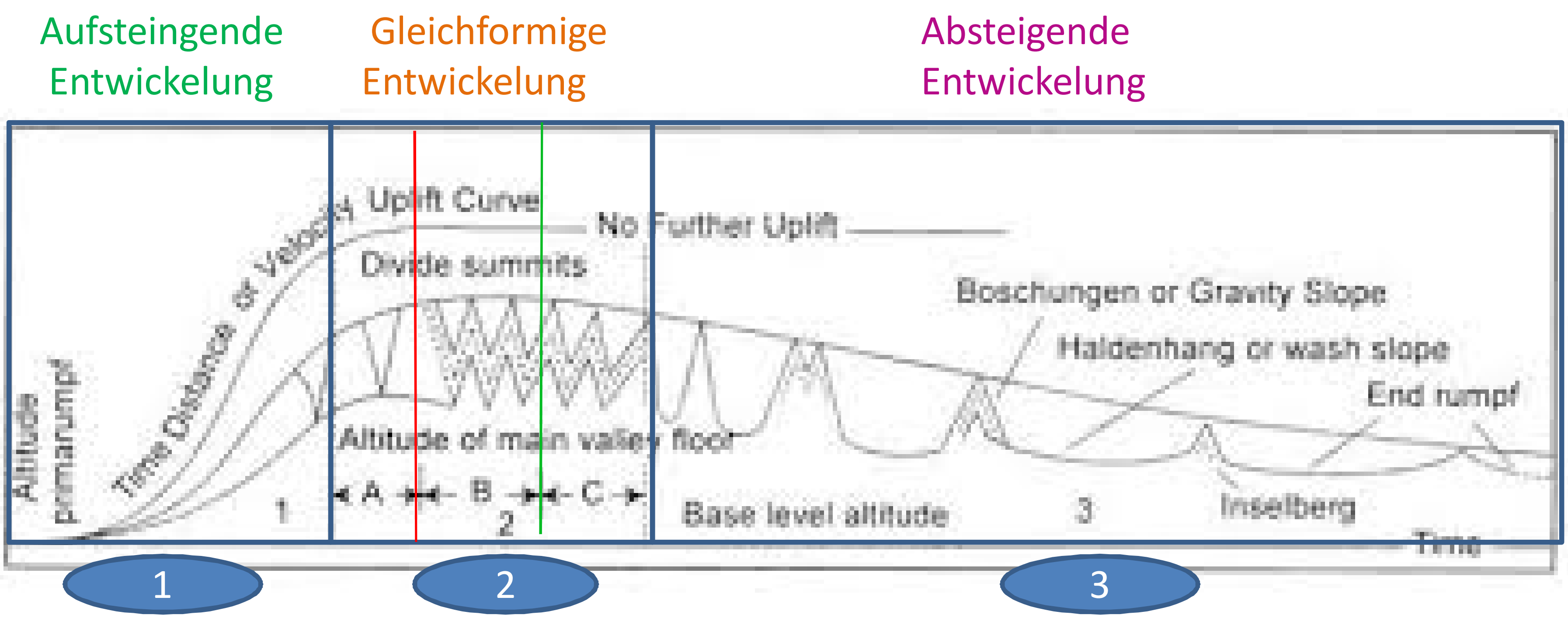


Fig. 16.2 : Graphic presentation of Penck's model of landform development.

- The valley side slopes are continuously steep-ened due to continued valley deepening.
- The radius of convexity of slopes is reduced with passage of time due to parallel retreat of the steeper slope segments.
- With the passage of time and more accelerated uplift and degradation the primary peneplain or say primarumpf is surrounded by a series of benches called as piedmont treppen. Each of such benches develops as a piedmont flat, called in German as piedmontflache on the slowly rising margins of the dome.

Phase 2: Gleichformige Entwickelung

- Gleichformige entwickelung means uniform development of landforms. This phase may be divided into 3 subphases on the basis of rate of uplift and degradation

  Phase (a)

- Is characterized by still accelerated rate of uplift.
- Absolute height still increases because the rate of erosion is still less than the rate of upliftment.
- Altitudes of both summits of water divides and valley floors continue to increase but at relatively lower rate than in the phase of Aufsteigende entwickelung.
- Maximum altitude (absolute relief) is attained but relative relief remains constant because the rate of valley deepening equals the rate of lowering of divide summits.
- The valley sides are characterized by straight slopes

- This phase is called the phase of uniform development probably because of uniform rate of valley deepening and lowering of divide summits.

Phase (b)

- Altitude (absolute relief) neither increases nor decreases i.e. remains constant due to matching of upliftment by the lowering of divide summit due to denudation.
- It means that upliftment still continues.
- Relative relief also remains constant because the rate of erosion of divide summits matches with the rate of valley deepening while both are up-lifted uniformly.
- The slopes of valley sides are still straight because of parallel retreat. This phase is, thus, characterized by constant absolute and relative reliefs and thus uniform development of landforms.

Phase (c)

- Upliftment of the land stops completely.
- Absolute reliefs or altitudes of summit divides start decreasing because of absence of upliftment but continued erosion of summits of divides.
- Relative reliefs also remain constant because the rate of the lowering of divide summits equals the rate of valley deepening.
- Thus, this subphase is also characterized by uniform development of landscape.

Phase 3: Absteigende Entwickelung

- Absteigende entwickelung means waning development of landscape during which the landscape is progressively dominated by the erosional process of lateral erosion and consequent valley widening and marked decrease in the rate of valley deepening through vertical downcutting.
- This phase is marked by progressive decline of landforms.
- Absolute relief (altitude from sea level) decreases remarkably because of total absence of upliftment but continued down wasting of divide summits.
- Relative relief also decreases because the divide summits are continuously eroded down and lowered in height while downcutting of valley floor decreases remarkably due to decrease in channel gradient and kinetic energy.
- Parallel retreat of valley side slopes still continues.

- Now the valley side slope consists of two segments.
- The uppermost segment maintains its steep angle inspite of continuous lowering of ridge crests. This slope is called gravity slope or boschungen.
- The lower segment of the valley sides is called wash slope or haldenhang.
- Haldenhang, composed of talus materials of lower inclination, is formed at the base of the valley sides due to rapid parallel retreat of gravity slope or boschungen and consequent elimination of much of the convex waxing slopes.
- Divide summits are continuously lowered by the inter-section of the retreating boschungen of adjoining valleys.
- Thus, the intersection of boschungen and haldenhang produces sharp knick (break in slope). Haldenhang or wash slope continues to expand at the cost of upper gravity slopes.
- In the advanced stage of the phase of absteigende entwickelung the gravity slopes or boschungen are reduced to steep-sided conical residuals called inselbergs
- Eventually, inselbergs are also consumed and the whole landscape is dominated by a series of concave wash slopes or haldenhang.
- Such extensive surface produced at the end of absteigende entwickelung is called 'endrumpf', which may be considered equivalent to Davis' peneplain.

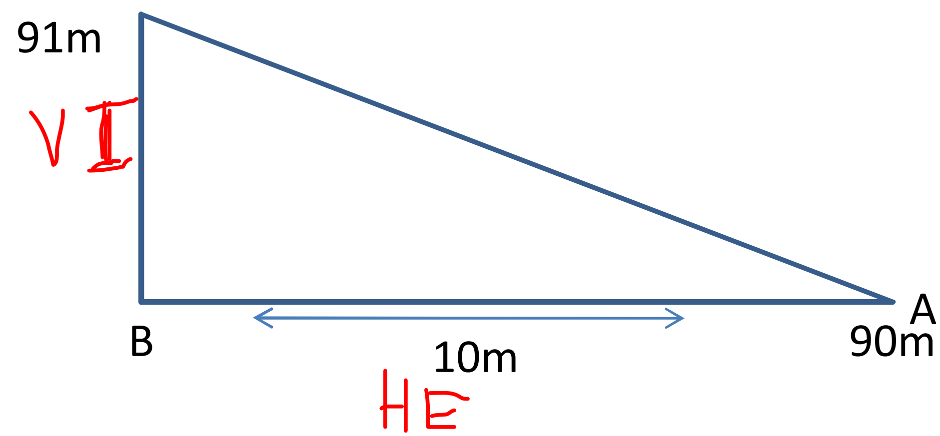
A comparison

Sl.No.	W.M. Davis	W. Penck
1	Sudden upliftment of landmass	Gradual upliftment of landmass
2	Erosion starts only after upliftment stops	Erosion & upliftment go together
3	Landscape is the function of structure, process, and stage	Landscape is the function of rate of upliftment and rate of degradation
4	Applicable to Humid Temperate region, later on to other regions	Applicable to all regions including arid, semi-arid, tropics.
5	End product is ‘peneplane’ or ‘peneplain’	End product is ‘Endrumpf’
6	Monodnocks	Inselbergs

Theories of Slope Development

General Aspects

- Slope is a measurement of vertical irregularity in angles.
- Vertical irregularity means difference in height from sea level or datum plane.
- Slope in angles
- tanØ=VI/HE
- Gradient=1m/10m



- If the vertical distance and horizontal distance are equal, then the value is 1, i.e., 45 degree
- If the VI decreases/increases, the angle also decreases/increases
- All landforms have their identity due to slope, like mountains, valleys and waterfalls
- Landform is part of land having some shape. Shape is given by angle.
- Landscape or slope evolution tries to explain how the landscape evolves and change with time. The way landscape is today is different to the way it was a million years ago.
- Factors changing slope: 1. Endogenic or tectonic forces lead to slope evolution or creation of new slope, causing vertical irregularities2. Exogeneic or denudational forces lead to development or levelling of slope

Introduction

- A major portion of the earth’s land surface consists of slopes.
- Slopes are present almost everywhere except plains and their maximum development is found in the hilly areas.
- Slopes provide the key to the study and analysis of landforms.
- Slopes also exercise an influence on soils and natural vegetation.
- Land utilization, agriculture, settlements, transport and urban activities are all not only visibly influenced by slope but to a every great extent are controlled by it.
- The increase in slope results in an increase in the danger of soil erosion.
- The higher the slope angle, the lesser the soil depth
- For all these reasons scientific analysis of slopes is being given special emphasis in geomorphological studies in recent years.

Elements of Slope

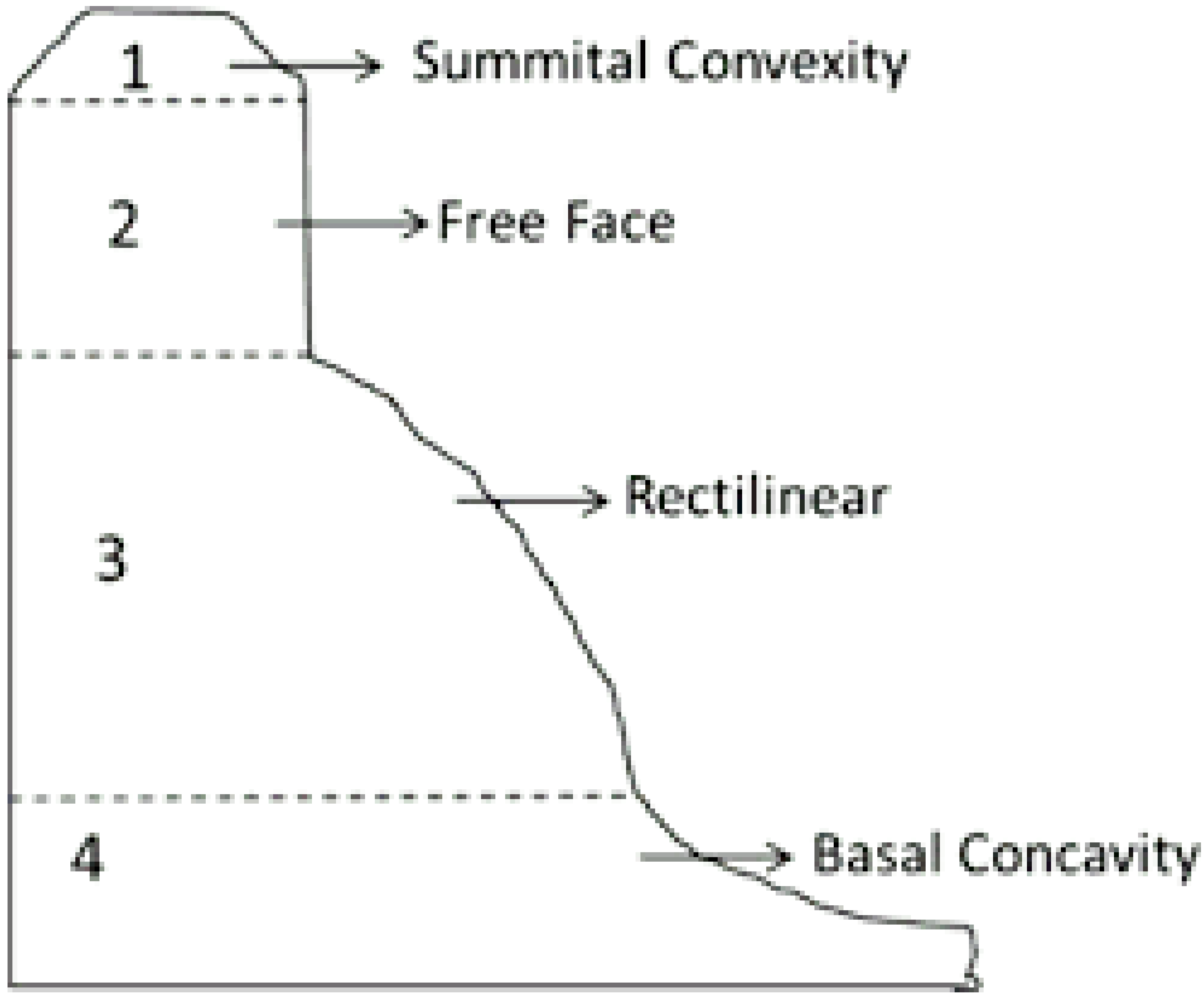
- According to L.C. King (1957-1962) and A. Wood (1942), a composite slope profile consists of four distinct parts or elements.

Convex Slope: sometimes the whole of the slope may assume a convex form, but it is more usual for the convexity to be developed only on the upper part of the slope.

- In the uppermost portion of hill slope is called the crest or summit
- The slope angle constantly increases down slope from the summit
- Weathering and soil creep are the processes causing this slope
- Also referred to 'upper wash slope'

Free face slope: a steep wall-like slope below the convex slope is called the scarp or free face slope

- It consists of bare rock and on account of the steepness , no rock debris or regolith is found on it.
- Along this slope the weathered material moves down with water or rock fragments fall down due to land slides
- The simplest example of free face slope is the cliff, developed along the coast by wave undercutting, or the scarp in deep river gorges or in faulted structures.
- The cliff is so steep (above 40 degree) that the products of weathering fall immediately to the base and the weathered material accumulates at the foot of the cliff in the form of scree slope.


1
Summital Convexity
2
Free Face
3
Rectilinear
4
Basal Concavity

Rectilinear slope: below the free face slope is a straight slope where the slope angle remains constant.

- This is called rectilinear slope as it is straight in profile
- Here the debris falling from free face slope are deposited
- The angle of this slope is determined by the angle at which the coarse rock debris can come to rest.
- These debris become finer with weathering and the finer debris are carried downwards by the rain water.
- The slope of this section remains constant. Therefore it is referred to as constant slope
- Also called 'debris controlled slope'

Concave slope: it is found in the lowest portion of the ideal slope profile.

- It is found at the bottom of a hill slope and extends down to the river valley or the alluvial plain.
- Although it is covered with a layer of debris, its form is really controlled by rainwash or surface wash.
- In the course of its development through time, the slope angle tends to become less and less.
- Also called a 'waning slope' or 'lower wash slope' or 'valley floor basement slope'

Theories of Slope Evolution

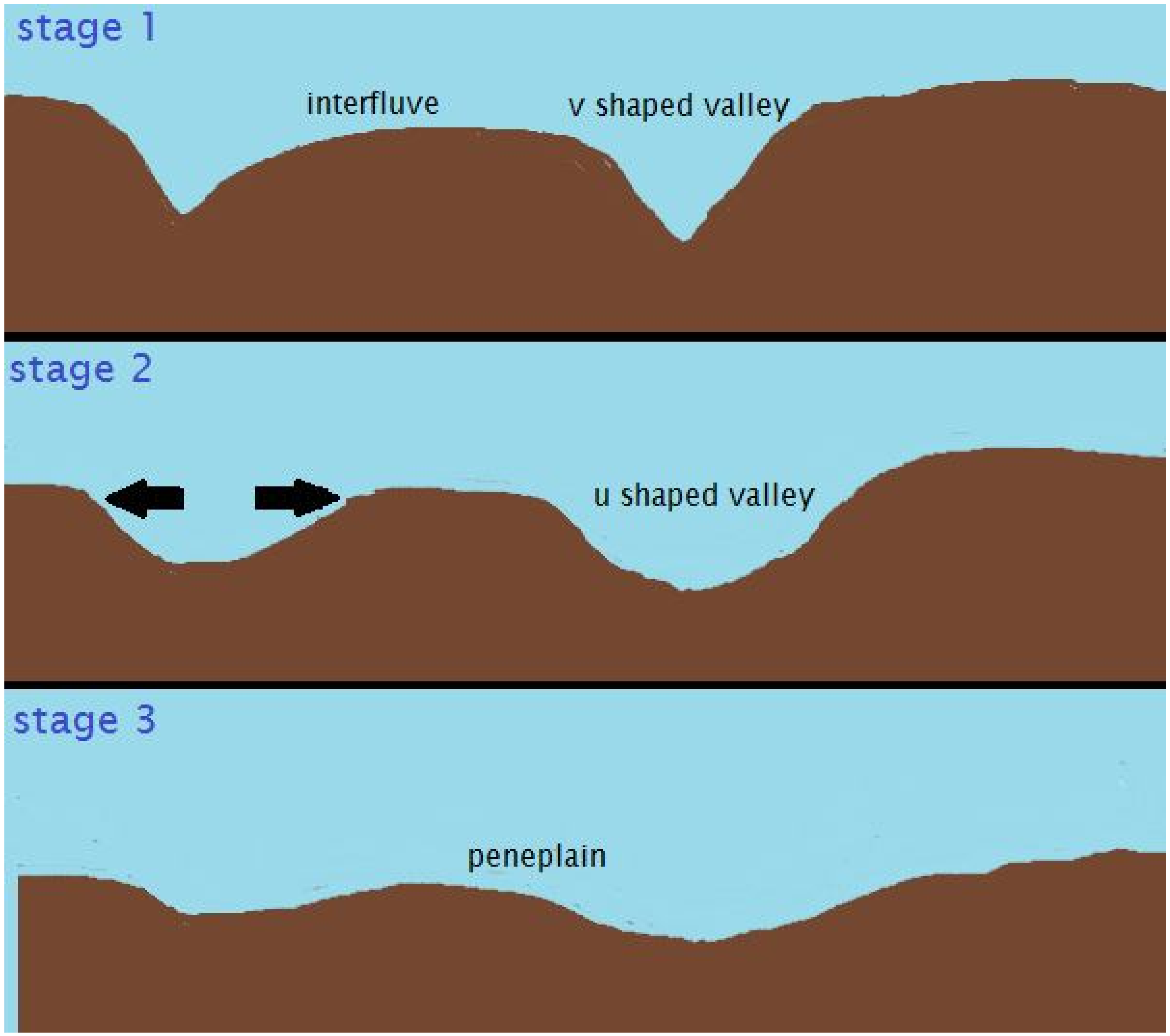
- In slope evolution we study the change of slope form with time.
- A basic question is, under certain given conditions and after the processes have worked for a period of time, whether the slope angle increases or decreases or remains constant.
- In this connection three important theories have been put forward by

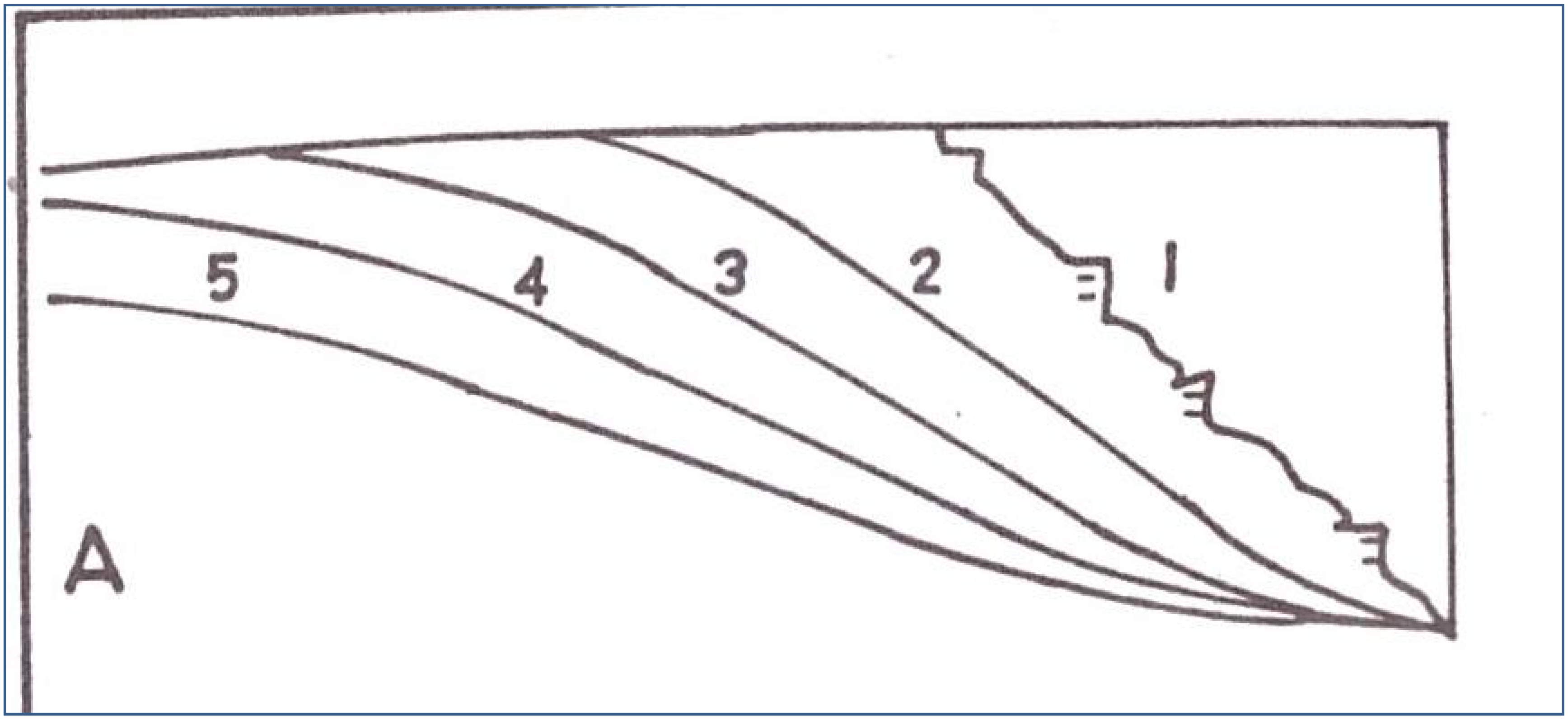
1. Slope decline theory of W.M. Davis
2. Slope replacement theory of W. Penck
3. Parallel retreat theory of L.C. King

Slope decline theory of W.M.Davis

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

- Davis had laid stress on the fact that the upper convex part of the slope is produced by soil creep.
- As we move down the slope, the amount of surface wash goes on increasing but at the divide summit soil creep is far more important than surface wash.
- Davis has also put forward the concept of graded slope or graded valley sides and graded waste sheets.


stage 1
interfluve
v shaped valley
stage 2
u shaped valley
stage 3
peneplain



5
4
3
2
1
A

In stage 1, the elimination of the free faces is done by the processes of fall and slump of the bedrock until the slope is gentle enough to develop a cover of regolith.

Stage 2 shows this phase which is called the graded slope. The regolith maintains a constant thickness over the slope and all the weathered materials is transported by mass movements and wash. The form of the slope is concave-convex.

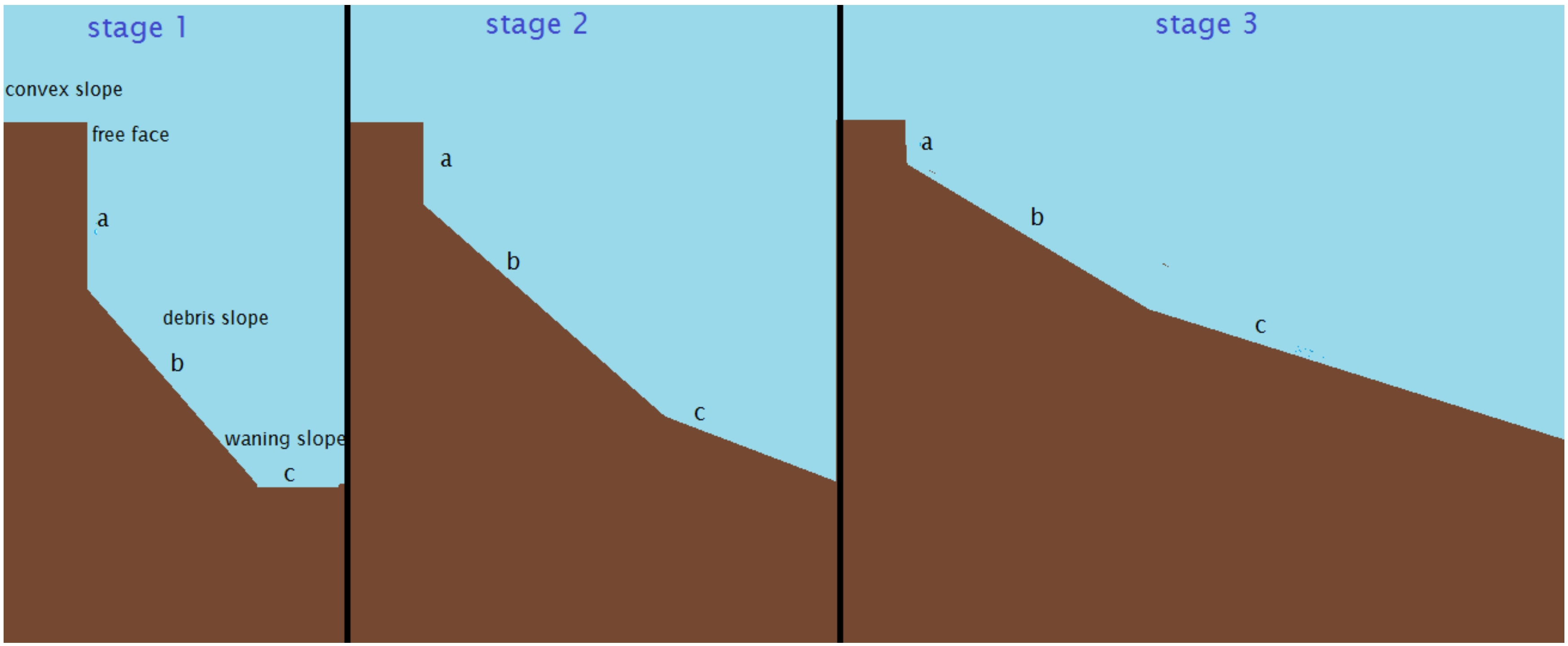
- Stage 3,4 & 5, the length of the straight segment increased. The curvature of the elements decreases as the slope continues to decline, and the length of straight segment diminishes.
- The upper convexity experiences more and more output than input, whereas the lower concavity receives more input than what it can output. Lower part of the slope - with the accumulation of the transported regolith, lowering is less.
- Davis based his arguments on visual assessment of slopes in humid temperate areas.

Slope Replacement Theory by W. Penck

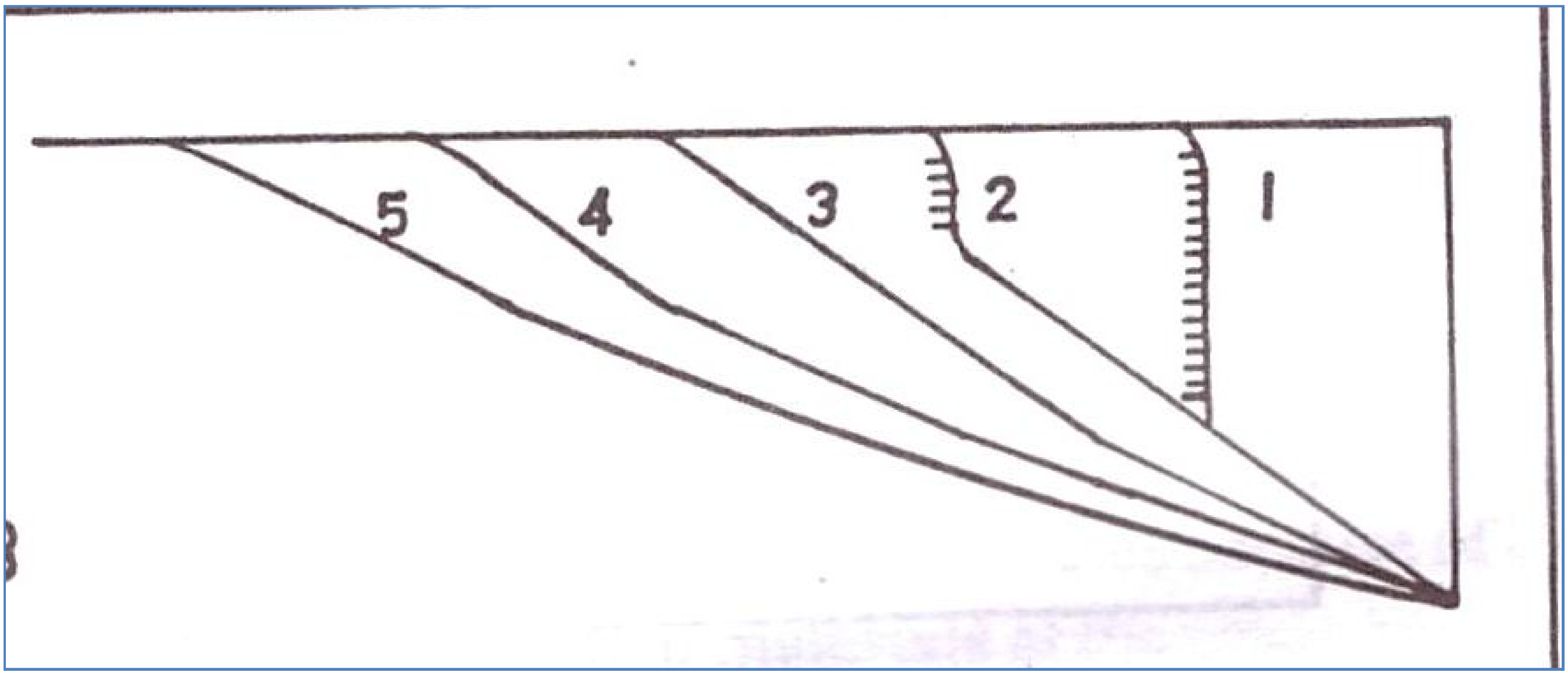
- The views of Penck are completely at variance with those of Davis. He did not agree with the Davisian assumption that during an erosion cycle uplift is complete before erosion which in turn is largely determined by the nature of the uplift.
- When uplift is rapid down cutting by streams would be more pronounced and the valley slopes would be convex. In a state of constant uplift, i.e., where rate of uplift is equalled by erosion the streams would cut down only as fast as the land rose, and the slopes will be straight.
- In a state of decreasing uplift or stability, the rate of erosion will be less and concave slopes will develop.
- Undercutting by streams does commonly steepen adjacent valley side slopes, resulting in local convexities. Straight slopes are associated with high relief which may result locally from the rate of uplift being equal to rate of erosion.

- Penck’s main thesis was that slopes don’t necessarily change form in an evolutionary manner with the passage of time as assumed by Davis but that slope forms (and the way they are altered) are determined by one overriding control-the rate of downward erosion of the river flowing at their bases.
- According to Penck (A)concave profile develops above rivers which are cutting down at a decelerating rate, (B)rectilinear slopes develop above rivers that are eroding at a constant rate, and (C) convex slopes are formed above rivers cutting down at an accelerating rate.
- In his view the precise rate of river erosion was of the utmost importance. A river cutting down at a rapid constant rate will give rise to a steeper rectilinear slope than a river cutting down at a slow constant rate.

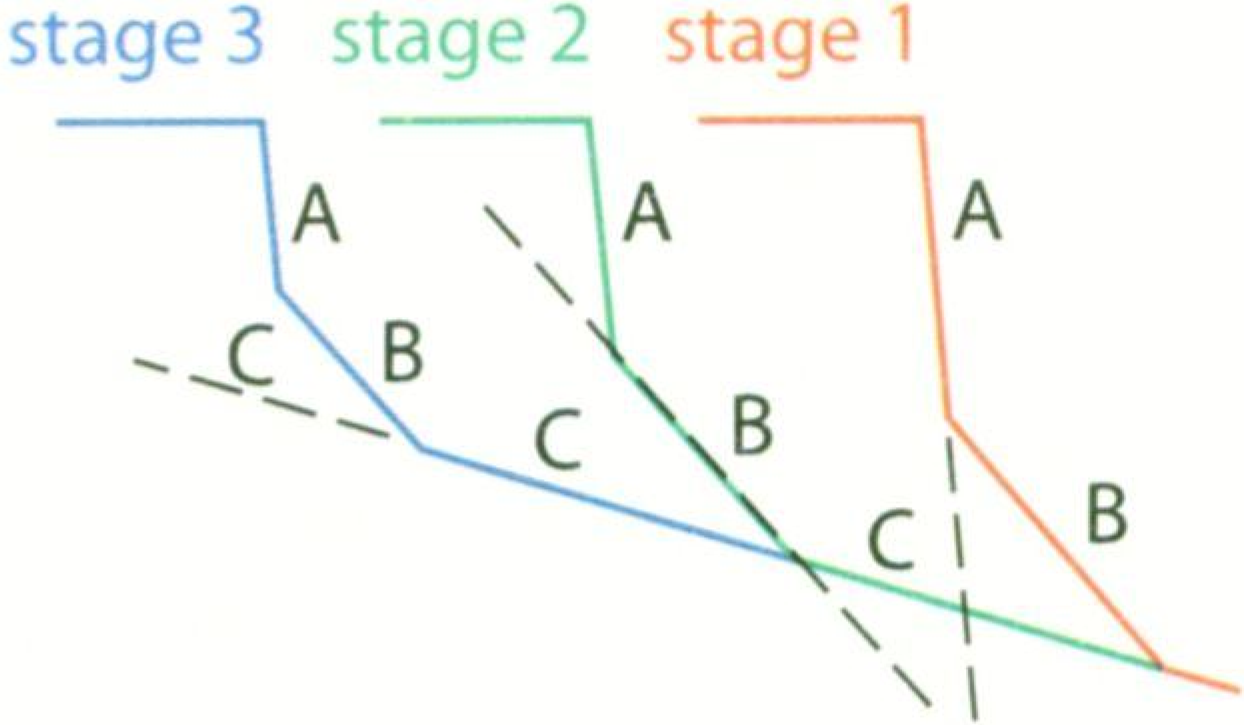
- Slope replacement means original steep slopes being replaced by lower angle slopes which extend upwards from the base at a constant angle.
- A free face slope is slowly buried by scree which accumulates at the base of cliff. (It means the replacement of a cliff by scree).
- All parts of the cliffs face are exposed to weathering. The scree accumulating at the base increase in height and if it is not removed, it will eventually replace the entire cliff by a gentle slope, the angle of rest.
- Continued weathering and removal leads to an upward extension of this gentler slope.
- This continues until the whole of the slope has been replaced from below by the gentler slope.


stage 1
convex slope
free face
a
debris slope
b
waning slope
c
stage 2
a
b
c
stage 3
a
b
c

Slope Replacement



Slope replacement



talus-scree slope B will replace slope A; slope C will eventually replace slope B