INDIAN GEOGRAPHY

PM IAS ACADEMY

CREATIVE THOUGHT AND ACTION

BASICS OF INDIA

CONTENTS:

1. Location, latitude, longitude, time zone, etc.
2. Neighbours
3. Important straits
4. States and their position
5. States with international boundaries

LATITUDES

EQUATOR

- Equator is an imaginary line running on the globe that divides it into two equal parts.
- Northern half of the earth is known as the Northern Hemisphere and Southern half is known as the Southern Hemisphere.

PARALLELS OF LATITUDES

- Parallels of latitudes are parallel circles from the equator up to the poles.
- They are measured in degrees.
- The equator represents the zero degrees latitude. Its distance from the equator to either of the poles is one-fourth of a circle round the earth, it will measure ¼th of 360 degrees, i.e. 90°.
- Thus, 90 degrees north latitude marks the North Pole and 90 degrees south latitude marks the South Pole.

IMPORTANT PARALLELS OF LATITUDES

- Tropic of Cancer (23½° N) in the Northern Hemisphere
- Tropic of Capricorn (23½° S) in the Southern Hemisphere
- Arctic Circle at 66½° north of the equator
- Antarctic Circle at 66½° south of the equator

LONGITUDES

PRIME MERIDIAN

- The meridian which passed through Greenwich, where the British Royal Observatory is located.
- Its value is 0° longitude and from it we count 180° eastward & westward. The Prime Meridian and 180° meridian divide the earth into two equal halves, the Eastern and the Western Hemisphere

LONGITUDE AND TIME

- The best means of measuring time is by the movement of the earth, the moon and the planets. The sun regularly rises and sets every day.
- When the Prime Meridian of Greenwich has the sun at the highest point in the sky, all the places along this meridian will have mid-day or noon.

- As the earth rotates from west to east, those places east of Greenwich will be ahead of Greenwich time and those to the west will be behind it.
- It can be calculated this way- The earth rotates 360° in about 24 hours, which means 15° an hour or 1° in four minutes. Thus, when it is 12 noon at Greenwich, the time at 15° east of Greenwich will be $15 \times 4 = 60$ minutes, i.e., 1 hour ahead of Greenwich time, But at 15° west of Greenwich, the time will be behind Greenwich time by one hour

Why do we have Standard Time?

- The local time of places which are on different meridians are bound to differ.
- In India, for instance, there will be a difference of about 1 hour and 45 minutes in the local times of Dwarka in Gujarat and Dibrugarh in Assam.
- In India, the longitude of 82½° E (82° 30'E) is treated as the standard meridian. The local time at this meridian is taken as the standard time for the whole country.

HEAT ZONES OF THE ERATH

TORRID ZONE

- The mid-day sun is exactly overhead at least once a year on all latitudes in between the Tropic of Cancer and the Tropic of Capricorn. It therefore, receives the maximum heat.

TEMPERATE ZONES

- The mid-day sun never shines overhead on any latitude beyond the Tropic of Cancer and the Tropic of Capricorn.
- The angle of the sun's rays goes on decreasing towards the poles. and the Tropic of Capricorn and the Antarctic Circle in the Southern Hemisphere, They have moderate temperatures

FRIGID ZONES

- Areas lying between the Arctic Circle and the North Pole in the Northern Hemisphere and the Antarctic Circle and the South Pole in the Southern Hemisphere, are very cold.
- It is because here the sun does not rise much above the horizon.

Locational Extent:

- 8° 4′ N to 37° 6′ N latitude and 68° 7′ E to 97° 25′ East longitude.
- East-West Extent of Main Land India (Including Pak occupied Kashmir-POK):
- 68° 7′ east to 97° 25′ east longitude
- South-North Extent of Main Land India
- 8° 4′ north to 37° 6′ north latitude
- The southernmost point of the country is the Pygmalion Point or Indira Point is located at 6° 45′ N latitude.
- North-south extent from Indira Col in Kashmir to Kanniyakumari is 3,214 km.
- East-west width from the Rann of Kachachh to Arunachal Pradesh is 2,933 km.
- With an area of 32,87,263 sq km, India is the seventh largest country of the world.
- India accounts for about 2.4 per cent of the total surface area of the world.
- The Tropic of Cancer passes through the middle of the country dividing it into two latitudinal halves.

- The area to the north of Tropic of Cancer is nearly twice the area which lies to the south of it.
- South of 22° north latitude, the country tapers off over 800 km into the Indian Ocean as a peninsula.

EAST WEST TIME DIFFERENCE

- The earth moves [rotation and revolution] around its axis through 360° in 24 hours. Thus, a difference of 1° longitude will make a difference of 4 minutes in time.
- Therefore the difference of local time between western-most point and eastern-most point is 30 x 4 = 120 minutes or 2 hours.

India, Tropical or Temperate Country?

- The temperate part (north of Tropic of Cancer) is twice the area of tropical part.
- But India has always been treated as a tropical country for two different reasons – physical and cultural.

PHYSICAL GEOGRAPHICAL REASONS

- The country is separated from the rest of Asia by Himalayas.
- Its climate is dominated by the tropical monsoons and the temperate air masses are blocked by Himalayas.
- Entire area south of the Himalayas is essentially tropical from climatic point of view: Although the night temperatures in Winter at several places in North India may come down to the level of those prevailing in temperate lands, yet clear skies and intense insolation raise the day temperatures to a tropical level.

CULTURAL GEOGRAPHICAL REASONS

- Settlements, diseases, agricultural and primary economic activities are all tropical in nature.
- It is primarily because of Himalayas that India is a tropical country.

INDIA'S FRONTIORS

Data from Ministry Of Home Affairs (Department Of Border Management)

- India has 15106.7 Km of land border running through 92 districts in 17 States and a coastline of 7516.6 Km [6100 km of mainland coastline + coastline of 1197 Indian islands] touching 13 States and Union Territories (UTs).
- Barring Madhya Pradesh, Chhattisgarh, Jharkhand, Delhi, Haryana and Telangana, all other States in the country have one or more international borders or a coastline and can be regarded as frontline States from the point of view of border management.
- India's longest border is with BANGLADESH while the shortest border is with Afghanistan.

The length of India's land borders with neighbouring countries is as under:

BORDER WITH CHINA	This is the second longest border of India

	Five Indian states, namely Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh touch the Indian boundary with China. The Sino-Indian border is generally divided into: (i) the Western sector (ii) the Middle sector (iii) the Eastern sector.
THE WESTERN SECTOR	Separates Jammu and Kashmir state of India from the Sinkiang (Xinjiang) province of China. The western sector boundary is largely the outcome of the British policy towards the state of Jammu and Kashmir. China claims the Aksai Chin district, the Changmo valley, Pangong Tso and the Sponggar Tso area of north-east Ladakh as well as a strip of about 5,000 sq km down the entire length of eastern Ladakh. China also claims a part of Huza-Gilgit area in North Kashmir (ceded to it in 1963 by Pakistan).
THE MIDDLE SECTOR	Two Indian states of Himachal Pradesh and Uttarakhand touch this border
THE EASTERN SECTOR	The 1,140 km long boundary between India and China runs from the eastern limit of Bhutan to a point near Diphu pass (Talu Pass) at the trijunction of India, Tibet and Myanmar. This line is usually referred to as the Mc Mahon Line after Sir Henry Mc Mahon, then foreign secretary of British India, who negotiated the boundary agreement between Great Britain and Tibet at Shimla accord in 1913-14
THE INDIA-NEPAL BOUNDARY	Five states of India, namely Uttarakhand, Uttar Pradesh, Bihar, West Bengal and Sikkim touch the Nepalese border with India. The border is a porous one with unrestricted movement of goods and people between Indian and Nepal. Major portion of Indo-Nepalese border runs in the east-west direction almost along the foothill of the Shiwalik Range.
THE INDIA-BHUTAN BOUNDARY	Quite peaceful border and there is no boundary dispute between the two countries
THE INDO-PAKISTAN BOUNDARY	The Indo-Pakistan boundary is the result of partition of the country in 1947 under the Radcliffe award of which Sir Cyril Radcliffe was the chairman. Jammu and Kashmir, Sir Creek are the major disputed regions. Sir Creek - india pakistan disputed
THE INDIA-BANGLADESH BORDER	India's 4,096 km long border with Bangladesh is the longest. This boundary has been determined under the Radcliffe Award which divided the erstwhile province of Bengal into two part
INDIA-MYANMAR BOUNDARY	This boundary runs roughly along the watershed between the Brahmaputra and Ayeyarwady [Irrawaddy]. It passes through thickly forested regions, with Mizo Hills, Manipur and Nagaland on the Indian side and Chin Hills, Naga Hills and Kachin state on the Myanmar side

INDIA-SRI LANKA BOUNDARY	India and Sri Lanka are separated by a narrow and shallow sea called Palk Strait. Dhanushkodi on the Tamil Nadu coast in India is only 32 km away from Talaimanar in Jaffna peninsula in Sri Lanka. These two points are joined by a group of islets forming Adam's Bridge

PHYSICAL FEATURES

- The Himalayas – geological formation, climate, vegetation, soil, biodiversity, physiographic divisions, major passes, significance
- The Great North Indian Plains – geological formation, physiographic divisions, climate, vegetation, soil, biodiversity, significance
- Peninsular Plateau – geological formation, Central Highlands, Deccan Plateau, Western Ghats, Eastern Ghats
- Indian Desert
- Coastal plains and islands

The Himalayas (young fold mountains),

1. Indo-Gangetic Plain (monotonous topography – featureless topography),
2. The Peninsular Plateau (one of the most stable landmasses; one of the oldest plateaus of the world),
3. Coastal Plains (Sediments due to fluvial action).
4. The Indian Islands [Coral Islands == coral reef built up on atolls – Lakshadweep. Tectonic == Andaman and Nicobar Islands – Interaction between Indian Plate and Eurasian plate]

PENINSULAR PLATEAU	It includes the entire south India, central India, Aravalis, Rajmahal hills, Meghalaya plateau, Kuchchh-Kathiawar region (Gujarat) etc.. It is the oldest and the most stable landmass of India.
HIMALAYAS	Includes the Himalayas, Purvanchal and their extensions Arakan Yoma (Myanmar) and Andaman and Nicobar Islands (but we will consider these as islands only). It is the youngest and highly unstable landmass of India. [Continent – Continent Convergence] Tectonic movements are very common
INDO-GANGETIC PLAIN	Between Peninsular and Himalayan region. Most youthful, monotonous [lack of change or variety] region prone to tectonic forces
COASTAL PLAINS	Eastern Coastal Plains and Western Coastal Plains. Formed due to consolidation of sediments brought by rivers (fluvial deposits). Highly stable just like peninsular plateau
INDIAN ISLANDS	Two major groups – Lakshadweep and, Andaman and Nicobar islands. Lakshadweep [Hotspot] are group of atolls occupied by coral reefs. No significant volcanism or tectonic activity in recent past. Highly vulnerable to sea-level rise. Andaman and Nicobar islands – Continuation of Arakan Yoma. Has active volcanoes and is tectonically active.

TYPE OF TOPOGRAPHY

Mountainous (more than 2135 m above sea level)	10.7 %
Hilly area (305 – 2135 m above sea level)	18.6 %
Plateau (305 – 915 m above sea level)	27.7 %
Plains	43 %

DIVISION OF HIMALAYAS

NOTE: Formation of Himalayas explained in Continent – Continent Convergence.

1. Shiwaliks or outer Himalayas
2. Lesser or Middle Himalayas
3. The Greater Himalayas
4. The Trans-Himalayas – Tibetan Himalayas.
5. The Eastern Hills – Purvanchal: A chain of hills in North-East India.

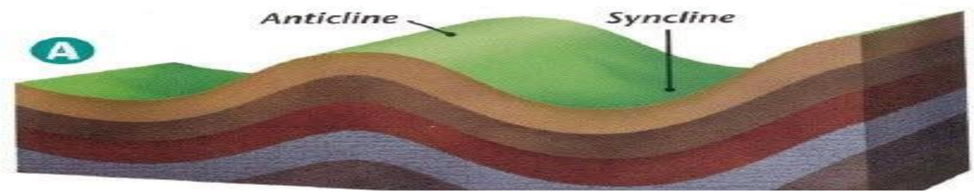
HIMALAYAN RANGES

Series of several parallel or converging ranges.

- The ranges are separated by deep valleys creating a highly dissected topography [(of a plateau or upland) divided by a number of deep valleys].
- The southern slopes have steep gradients and northern slopes have comparatively gentler slopes. [Scaling Mount Everest is less hectic from the northern side. But China puts restrictions so climbers take the steeper southern slopes from Nepal]
- Most of the Himalayan ranges fall in India, Nepal and Bhutan. The northern slopes are partly situated in Tibet (trans-Himalayas) while the western extremity lies in Pakistan, Afghanistan and Central Asia.
- Himalayas between Tibet and Ganga Plain is a succession of three parallel ranges.

SHIWALIK RANGE

- Also known as Outer Himalayas-Located in between the Great Plains and Lesser Himalayas.
- The altitude varies from 600 to 1500 metres.
- Runs for a distance of 2,400 km from the Potwar Plateau to the Brahmaputra valley.
- The southern slopes are steep while the northern slopes are gentle.
- The width of the Shiwaliks varies from 50 km in Himachal Pradesh to less than 15 km in Arunachal Pradesh.
- They are almost unbroken chain of low hills except for a gap of 80-90 km which is occupied by the valley of the Tista River and Raidak River.
- Shiwalik range from North-East India up to Nepal are covered with thick forests but the forest cover decreases towards west from Nepal (The quantum of rainfall decreases from east to west in Shiwaliks and Ganga Plains).
- The southern slopes of Shiwalik range in Punjab and Himachal Pradesh are almost devoid of forest cover. These slopes are highly dissected by seasonal streams called Chos.
- Valleys are part of synclines and hills are part of anticlines or antisynclines.



- Shiwaliks were formed last of all the ranges (2-20 million years ago).
- The Shiwaliks are consolidated sands, gravels and conglomerate deposits [Alluvial fans] which were brought by the rivers flowing from the higher ranges.
- These deposits were folded and hardened due to compression offered by the northward movement of Indian plate.

The Shiwaliks are known by different names in different areas:

Region	Name of Shiwaliks
Jammu Region	Jammu Hills
Dafla, Miri, Abor and Mishmi Hills	Arunachal Pradesh
The Dhang Range, Dundwa Range	Uttarakhand
Churia Ghat Hills	Nepal

Explaining the formation of Duns (Duras):

- Shiwalik Hills were formed by the accumulation of conglomerates (sand, stone, silt, gravel, debris etc.).
- These conglomerates, in the initial stages of deposition, obstructed the courses of the rivers draining from the higher reaches of the Himalayas and formed temporary lakes.
- The conglomerates were well settled at the bottom of the lakes in the long run.
- When the rivers were able to cut their courses through the lakes filled with conglomerate deposits, the lakes were drained away leaving behind plains called 'duns' or 'doons' in the west and 'duars' in the east.

1. Dehra Dun in Uttarakhand is the best example [75 km long and 15-20 km wide]
2. Kotah, Patli Kothri, Chumbi, Kyarda, Chaukhamba, Udhampur and Kotli are other important duns.

MIDDLE OR LESSER HIMALAYAS

- In between the Shiwaliks in the south and the Greater Himalayas in the north.
- Runs almost parallel to both the ranges.
- It is also called the Himachal or Lower Himalaya.
- Lower Himalayan ranges are 60-80 km wide and about 2400 km in length.
- Elevations vary from 3,500 to 4,500 m above sea level.
- Many peaks are more than 5,050 m above sea level and are snow covered throughout the year.
- Lower Himalayas have steep, bare southern slopes [steep slopes prevents soil formation] and more gentle, forest covered northern slopes.
- In Uttarakhand, the Middle Himalayas are marked by the Mussoorie and the Nag Tibba ranges.
- The Mahabharat Lekh, in southern Nepal is a continuation of the Mussoorie Range
- East of the Kosi River, the Sapt Kosi, Sikkim, Bhutan, Miri, Abor and Mishmi hills represent the lower Himalayas.

- The Middle Himalayan ranges are more friendly to human contact.
- Majority of the Himalayan hill resorts like Shimla, Mussoorie, Ranikhet, Nainital, Almora and Darjeeling, etc. are located here.

Important ranges of Lesser Himalayas	Region
The Pir Panjal Range	Jammu and Kashmir - south of Kashmir Valley
The Dhaola Dhar Range	Himachal Pradesh
The Mussoorie Range and The Nag Tiba Range	Uttarakhand
Mahabharat Lekh	Nepal

PIR PANJAL RANGE

- The Pir Panjal range in Kashmir is the longest and the most important range.
- It extends from the Jhelum river to the upper Beas river for over 300 km.
- It rises to 5,000 metres and contains mostly volcanic rocks.

PASSES IN PIRPANJAL RANGE

1. Pir Panjal Pass (3,480 m), the Bidil (4,270 m), Golabghar Pass (3,812 m) and Banihal Pass (2,835 m).
2. The Banihal Pass is used by the Jammu-Srinagar highway and Jammu-Baramula railway.
3. The Kishanganga, the Jhelum and the Chenab cut through the range.
4. Southeast of the Ravi, the Pir Panjal continues as Dhaola Dhar range, passing through Dalhousie, Dharmshala, and Shimla.

IMPORTANT VALLEYS

- Between the Pir Panjal and the Zaskar Range of the main Himalayas, lies the valley of Kashmir. (average elevation is 1,585 m above mean sea level)
- The synclinal basin of the valley is floored with alluvial, lacustrine [lake deposits], fluvial [river action] and glacial deposits. {Fluvial Landforms, Glacial Landforms}
- Jehlum River meanders through these deposits and cuts a deep gorge in Pir Panjal through which it drains. (Kashmir is like a basin with very few outlets)
- In Himachal Pradesh there is Kangra Valley. It is a strike valley and extends from the foot of the Dhaola Dhar Range to the south of Beas.
- On the other hand, the Kulu Valley in the upper course of the Ravi is transverse valley.

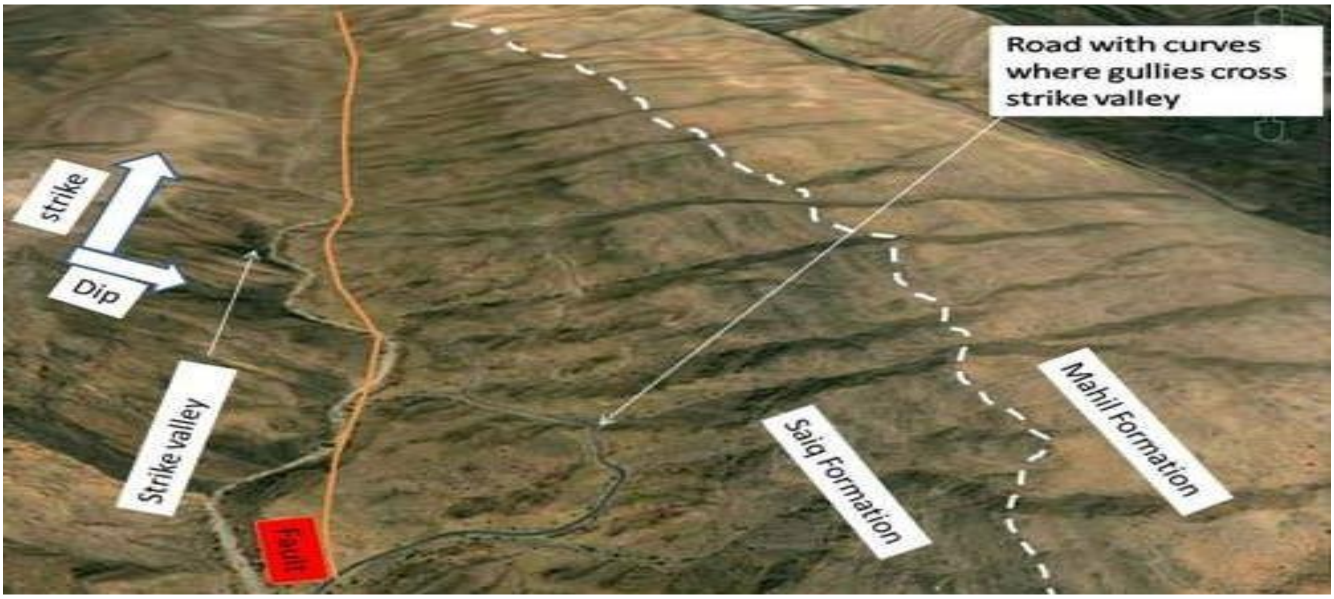
Strike valley vs. Transverse valley

Strike valley :

- A valley perpendicular to the slope or parallel to the ridge [also called as longitudinal valley]

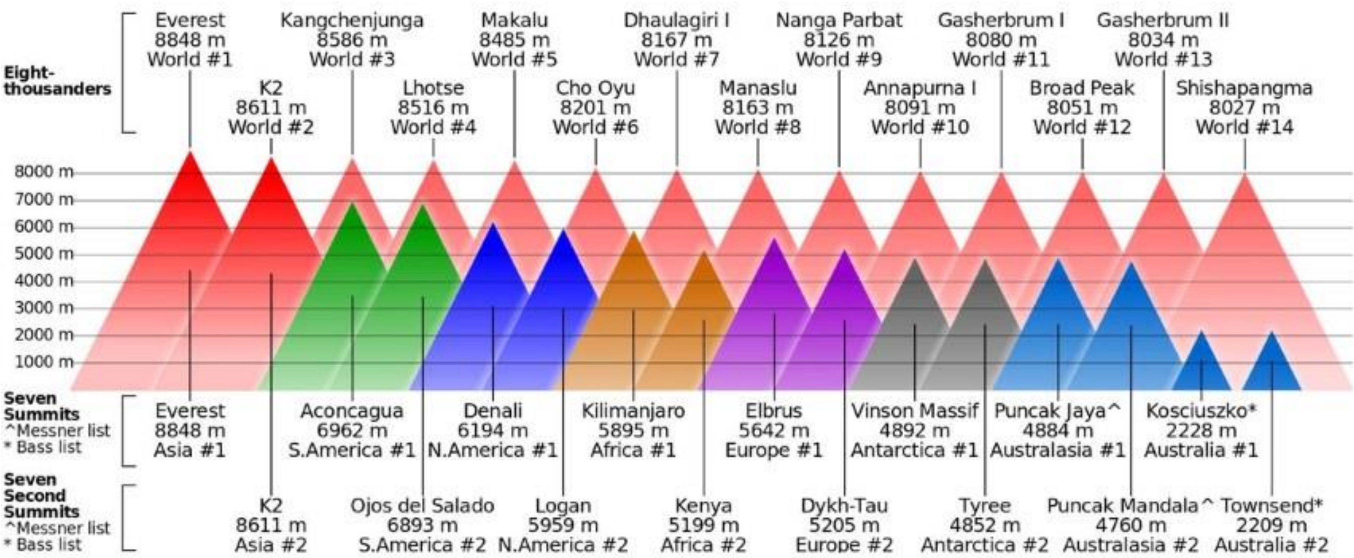
Transverse valley

- In contrast, transverse streams cut valleys parallel to the slope (along the dip).



THE GREAT HIMALAYA'S

- Also known as Inner Himalaya, Central Himalaya or Himadri.
- Average elevation of 6,100 m above sea level and an average width of about 25 km.
- It is mainly formed of the central crystallines (granites and gneisses) overlain by metamorphosed sediments [limestone]
- Terminates abruptly at the syntaxial bends - Nanga Parbat in north-west and Namcha Barwa in the north-east.
- This mountain range boasts of the tallest peaks of the world.



Regional name of Mount Everest	Region
Sagarmatha (The Goddess of the Sky)	Nepal
Chomlungma (Mother of the World)	China (Tibet)

PASSES IN GREATER HIMALAYA'S

Passes of Greater Himalayas	State
Burzil Pass	Jammu and Kashmir

Zoji La [La means pass]	
Bara Lacha La Shipki La [The Hindustan-Tibet Road connecting Shimla with Gartok in Western Tibet]	Himachal Pradesh
Thaga La Niti Pass Lipu Lekh	Uttarakhand
Nathu La Jelep La [important trade route connecting Kalimpong (near Darjeeling) with Lhasa in Tibet, passes through Jelep La (4,386 m)]	Sikkim

TRANS OR TIBETAN HIMALAYA'S

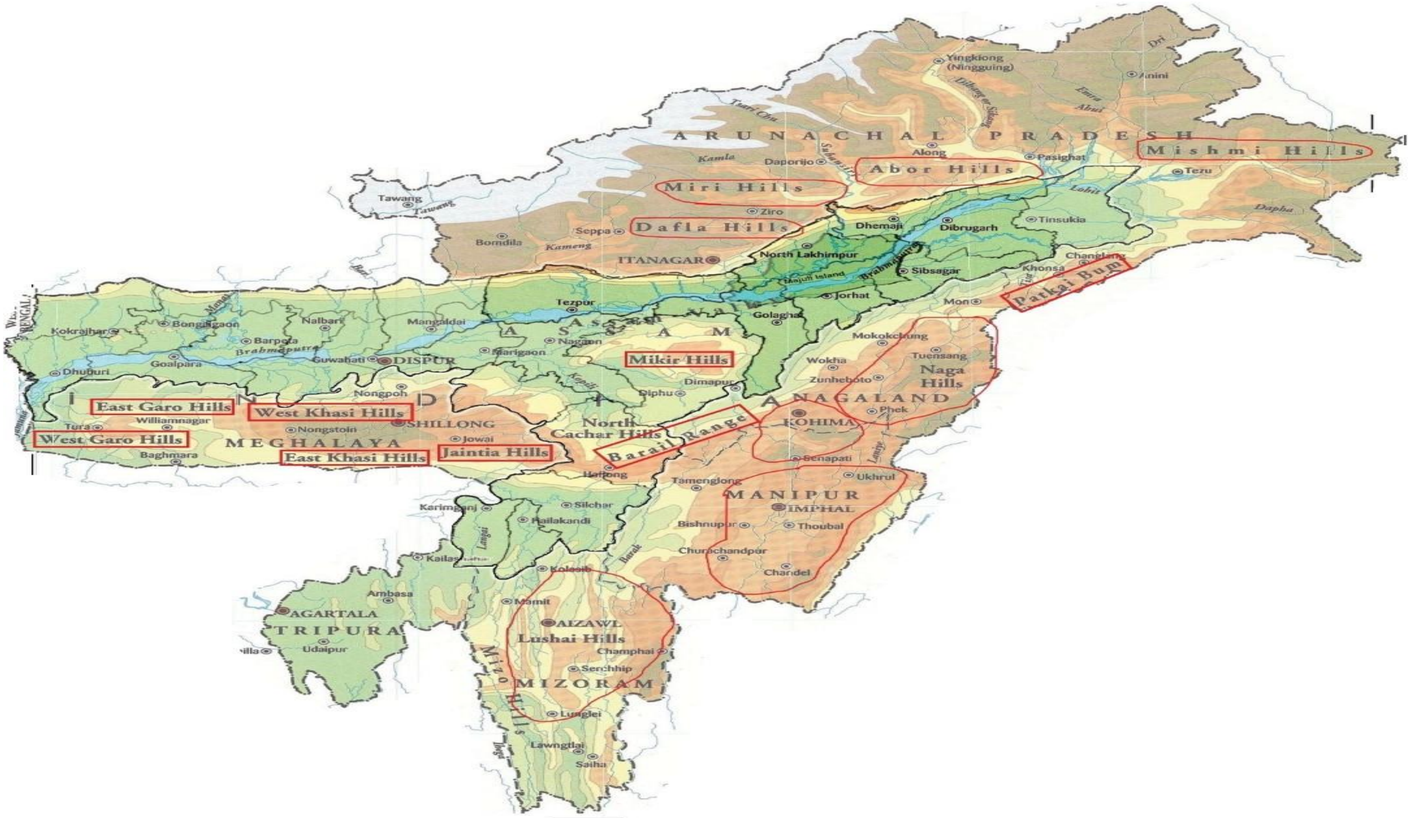
- The Himalayan ranges immediately north of the Great Himalayan range.
- The Zaskar, the Ladakh, the Kailas and the Karakoram are the main ranges.
- The Nanga Parbat (8126 m) is an important range which is in The Zaskar Range.
- North of the Zaskar Range and running parallel to it is the Ladakh Range.
- The highest peak is Mount Kailas (6714 m). River Indus originates in this region.
- The northern most range of the Trans-Himalayan Ranges in India is the Great Karakoram Range also known as the Krishnagiri range.
- Mount K2 [Godwin Austen or Qogir] is the 2nd highest peak in the world and the highest peak in Indian.
- The Ladakh Plateau lies to the north-east of the Karakoram Range. It has been dissected into a number of plains and mountains [Soda Plains, Aksai Chin, Lingzi Tang, Depsang Plains and Chang Chenmo]

PURVANCHAL OR EASTERN HIMALAYA'S

- Eastern Hills or The Purvanchal are the southward extension of Himalayas running along the north-eastern edge of India.
- At the Dihang gorge, the Himalayas take a sudden southward bend and form a series of comparatively low hills which are collectively called as the Purvanchal.
- Purvanchal hills are convex to the west.
- They run along the India-Myanmar Border extending from Arunachal Pradesh in the north to Mizoram in the south.
- Patkai Bum and Naga Hills form the watershed between India and Myanmar.
- South of Naga Hills are the Manipur hills which are generally less than 2,500 metres in elevation.
- The Barail range separates Naga Hills from Manipur Hills.
- Further south the Barail Range swings to west into Jaintia, Khasi and Garo hills which are an eastward continuation of the Indian peninsular block. They are separated from the main block by Ganga and Brahmaputra rivers.
- South of the Manipur Hills are the Mizo Hills (previously known as the Lushai hills).

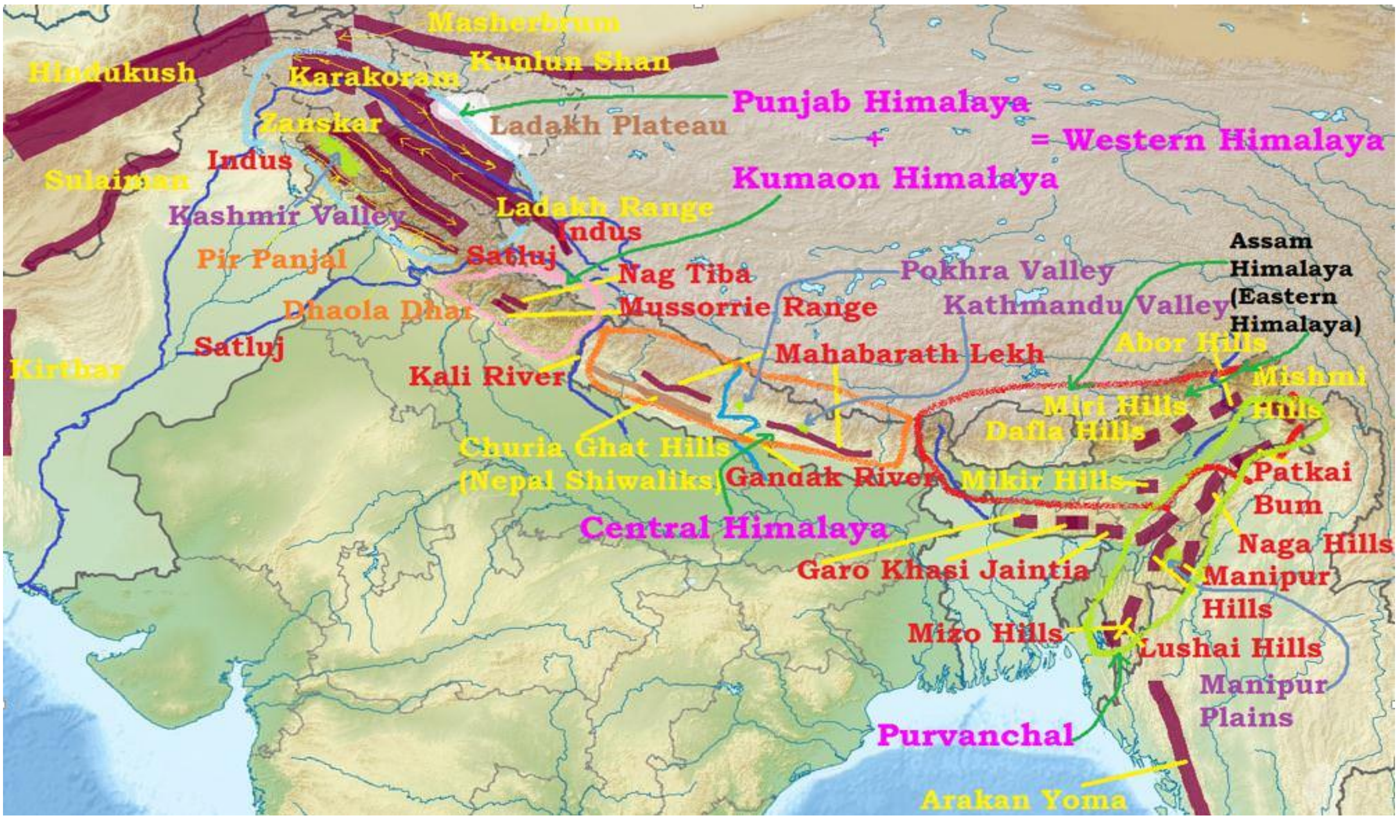
SYNTAXIAL BENDS OF HIMALAYA'S

- Himalayas extend in the east-west direction from the Indus gorge in the west to the Brahmaputra gorge in the east.
- Himalayan ranges take sharp southward bends at these gorges.



HIMALAYAS – REGIONAL DIVISIONS-----PUNJAB HIMALAYAS

- Between the Indus and the Satluj rivers [560 km long].
- All the major rivers of Indus river system flow through Punjab Himalayas.
- A large portion of Punjab Himalayas is in Jammu and Kashmir and Himachal Pradesh.
- Karakoram, Ladakh, Pir Panjal, Zaskar and Dhaola Dhar are the major ranges in this section.



ASSAM HIMALAYAS	Spreads over Sikkim, Assam and Arunachal Pradesh. Elevation here is much lesser than that of the Nepal Himalayas. The southern slopes are very steep but the northern slopes are gentle. The Lesser Himalayas are very narrow and are very close to the Great Himalayas
WESTERN HIMALAYAS	Between the Indus in the west and the Kali river in the east (880 km). Spread across three states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. It encompasses three physiographic provinces namely Kashmir Himalaya, Himachal Himalaya and Kumaon Himalaya (Uttarakhand Himalayas). The Ladakh plateau and the Kashmir valley are two important areas of the Kashmir Himalayan region. The Kumaon Himalayas lie in Uttarakhand and extend from the Satluj to the Kali river. The Lesser Himalayas in Kumaon Himalaya is represented by the Mussoorie and Nag Tiba ranges. The Shiwalik in this region runs south of the Mussoori range between the Ganga and the Yamuna rivers. The flat valleys between the Lesser Himalaya and the Shiwalik range are called 'doons' or 'Duns' of which Dehra Dun is the most famous.
CENTRAL HIMALAYAS	800 km between river Kali in the west and river Tista in the east. The Great Himalaya range attains maximum height in this portion. Some of the world famous peaks Mt. Everest, Kanchenjunga, Makalu, Annapurna, Gosainthan and Dhaulagiri are located here. The Lesser Himalaya is known as Mahabharat Lekh in this region. The range is crossed by rivers like Ghaghara, Gandak, Kosi, etc. In between the Great and the Lesser Himalayas, there are Kathmandu and Pokhra lacustrine valleys (previously, they were lakes). The Shiwalik range come very close to the lesser Himalaya towards the east and is almost non-existent beyond Narayani (Gandak).
EASTERN HIMALAYAS	This part of the Himalayas lies between the Tista river in the west and the Brahmaputra river in the east and stretches for a distance of about 720 km. Also known as the Assam Himalayas, the Eastern Himalayas occupy mainly the areas of Arunachal Pradesh and Bhutan. The Assam Himalayas show a marked dominance of fluvial erosion due to heavy rainfall. The extension of the Purvanchal Himalaya continues southwards upto Andaman and Nicobar Islands through the Myanmar range (Arakan Yoma) and even upto the Indonesian archipelago.

HIMALAYA'S GLACIERS, VALLEYS & SNOWLINE

The most important valleys in the Himalayan region:

1. The valley of Kashmir and the Karewas
2. The Kangra and Kulu valley in Himachal Pradesh

3. The Dun valley (Doon valley, Dehradun valley) the Bhagirathi valley (near Gangotri) and the Mandakini valley (near Kedarnath) in Uttarakhand and
4. The Kathmandu valley in Nepal.

KAREWAS	Karewas are deposits in lake in the Valley of Kashmir and in Bhadarwah Valley of the Jammu Division. These are the flat topped mounds that border the Kashmir Valley on all sides. They are characterized with fossils of mammals and at places by peat.
FORMATION	During the Pleistocene Period (1 million years ago), the entire Valley of Kashmir was under water. Subsequently, due to endogenetic forces, the Baramullah Gorge was created and the lake was drained through this gorge. The deposits left in the process are known as karewas & thickness of karewas is about 1400 m. In fact, the karewas have been elevated, dissected and removed by subaerial denudation as well as by the Jhelum river giving them the present position
ECONOMIC SIGNIFICANCE	The karewas are mainly devoted to the cultivation of saffron, almond, walnut, apple and orchards
SNOW IN HIMALAYAS – SNOWLINE	In Eastern Himalayas and Kumaon Himalays the snowline is around 3,500 m above sea level whereas in western Himalays snowline is about 2,500 m above sea level. But the major factor is precipitation. Precipitation in western Himalayas is comparatively low and occurs mostly as snowfall where as in eastern Himalayas the precipitation is greater and occurs mostly in the form of rain. In the Great Himalayan ranges, the snow line is at lower elevation on the southern slopes than on the northern slopes because the southern slopes are steeper and receive more precipitation as compared to the northern slopes
GLACIERS IN HIMALAYAS	There are about 15,000 glaciers in the Himalayas. The snow line (the lowest level of perpetual snow) varies in different parts of the Himalayas depending upon latitude, amount of precipitation and local topography.
GLACIERS OF THE KARAKORAM RANGE	Maximum development of glaciers occurs in the Karakoram range. The 75 km long Siachen Glacier in Nubra valley has the distinction of being the largest glacier outside the polar and the sub-polar regions. The second largest is the 74 km long Fedchenko Glacier (Pamirs) Third largest is the Hispar Glacier. It is 62 km long and occupies a tributary of the Hunza River
GLACIERS OF THE PIR PANJAL RANGE	The glaciers are less numerous and smaller in size as compared to those of the Karakoram Range. The longest Sonapani Glacier in the Chandra Valley of Lahul and Spiti region is only 15 km long
GLACIERS OF THE KUMAON-GARHWAL REGION	In the Kumaon-Garhwal region of the Himalayas, the largest is the 30 km long Gangotri Glacier which is the source of the holy Ganga.

GARHWAL REGION	Lying in the Himalayas, it is bounded on the north by Tibet, on the east by Kumaon region, on the south by Uttar Pradesh state, and on the northwest by Himachal Pradesh state. It includes the districts of Chamoli, Dehradun, Haridwar, Pauri Garhwal, Rudraprayag, Tehri Garhwal, and Uttarkashi
GLACIERS OF CENTRAL NEPAL	Zemu and the Kanchenjunga glaciers are the major ones.

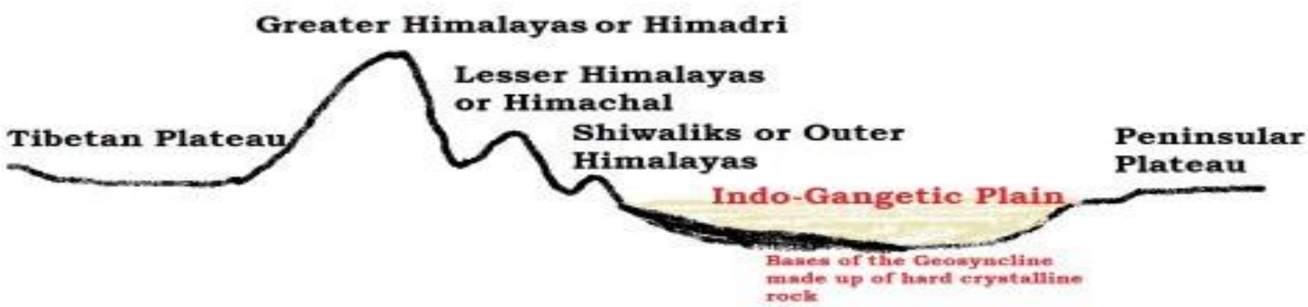
SIGNIFICANCE OF THE HIMALAYAS

Influence on Indian Climate:	They intercept the summer monsoons coming from the Bay of Bengal and Arabian Sea causing precipitation in the entire Ganga Plains, North-Eastern Hills. They direct the monsoon winds towards north-western India (Punjab, Haryana etc.. But these regions receive most of the rainfall due to Western Disturbances coming from the Mediterranean regions). They protect northern-plains from the cold continental air masses of central Asia. The Himalayas influence the path of Sub-tropical Jet stream flowing in the region. They split the jet stream and this split jet stream plays an important role in bring monsoons to India. Had there been no Himalayas, the whole of India would have been a desert and its winters would have been very severe. [Mechanism of monsoons will be explained in detail later]
Defense	The Himalayas are a natural defense barrier. But the Chinese aggression on India in 1962 has reduced the defense significance of the Himalayas
Source of Rivers	Rivers that feed nearly half a billion population of India originate in Himalayas. [we will study this in detail later in drainage system] All the rivers are perennial supplying water year round.
Fertile Soil	The swift flowing rivers from Himalayas bring enormous amount of silt (alluvium) which constantly enrich the Ganaga and Bramhaputra plains
Hydroelectricity	Due to its natural topography and swift flowing perennial rivers, the Himalayan region offers several natural sites with great hydroelectric power generation potential. But all this comes at a great environmental costs
Forest Wealth	The Himalayan host rich coniferous and evergreen forests. Lower levels have tropical evergreen forests and higher levels have Alpine vegetation (Coniferous). Himalayan forests host wide variety of medicinal plants, timbers and grasses offering rich pastures for grazing animals

Agriculture	Due to rugged and sloped terrain, the Himalayas are not potential agricultural sites. Some slopes are terraced for cultivation. Rice is the main crop on the terraced slopes. The other crops are wheat, maize, potatoes, etc. Tea is a unique crop which can be grown only on the Shiwalik hill slopes in the region. Fruit cultivation is a major occupation. A wide variety of fruits such as apples, pears, grapes, mulberry, walnut, cherries, peaches, apricot, etc. are also grown in the Himalayan region.
Tourism	The hilly areas in the Himalayas are not affected by hot winds like loo. Hence they offer cool and comfortable climate. The increasing popularity of winter sports has increased the rush of tourists in winters. Srinagar, Dalhousie, Dharamshala, Chamba, Shimla, Kulu, Manali, Mussoorie, Nainital, Ranikhet, Almora, Darjeeling, Mirik, Gangtok, etc. are important tourist centres in the Himalayas.
Cultural Tourism	Himalayas host many Hindu and Buddist shrines. Kailas, Amarnath, Badrinath, Kedarnath, Vaishnu Devi, Jwalaji, Uttarkashi, Gangotri, Yamunotri, etc. are important places of pilgrimage.
Mineral Resources in Himalayas	Geosynclinical deposits in tertiary rocks are regions of potential coal and oil reserves. Coal is found in Kashmir, Copper, lead, zinc, gold, silver, limestone, semi-precious and precious stones occur at some places in the Himalayas. But the exploitation of these resources require advanced technologies which are not yet available. Also, disturbing such a fragile environment leads to more pain than gain (present hydroelectric power projects have already proved this).
Formation of Indo – Gangetic – Brahmaputra trough:	The rivers which were previously flowing into Tethys sea (Before Indian Plate collided with Eurasian Plate – continental drift, plate tectonics) deposited huge amount of sediments in the Tethys Geosyncline. [Geosyncline – a huge depression] Himalayas are formed out of these sediments which were uplifted, folded and compressed due to northern movement of Indian Plate. Northern movement of Indian Plate also created a trough to the south of Himalayas
Depositional Activity	During the initial stages of upliftment of sediments, the already existing rivers changed their course several times and they were rejuvenated each time (perpetual youth stage of rivers {Fluvial Landforms}). The rejuvenation is associated with intense headward and vertical downcutting of the soft strata overlying the harder rock stratum. Headward erosion and vertical erosion of the river valley in the initial stages, lateral erosion in later stages contributed huge amount of conglomerates (detritus)(rock debris, silt, clay etc.) which were carried downslope.

	[Head ward erosion == Erosion at the origin of a stream channel, which causes the origin to move back away from the direction of the stream flow, and so causes the stream channel to lengthen] These conglomerates were deposited in the depression (Indo-Gangetic Trough or Indo-Gangetic syncline) (the base of the geosyncline is a hard crystalline rock) between peninsular India and the convergent boundary (the region of present day Himalayas).
New rivers and more alluvium	Rivers along with glacial erosion {Glacial Landforms}, supplied more alluvium which intensified the filling of the depression. With the accumulation of more and more sediments (conglomerates), the Tethys sea started receding. With passage of the time, the depression was completely filled with alluvium, gravel, rock debris (conglomerates) and the Tethys completely disappeared leaving behind a monotonous aggradational plain. [monotonous == featureless topography; aggradational plain == plain formed due to depositional activity. Indo-Gangetic plain is a monotonous aggradational plain formed due to fluvial depositions]. Upper peninsular rivers have also contributed to the formation of plains, but to a very small extent. During the recent times (since few million years), depositional work of three major river systems viz., the Indus, the Ganga and the Brahmaputra have become predominant. Hence this arcuate (curved) plain is also known as Indo-Gangetic-Brahmaputra Plain.

INDO – GANGETIC – BRAHMAPUTRA PLAIN – ELEVATION



Features of Indo – Gangetic – Brahmaputra Plain

- Indo-Gangetic-Brahmaputra Plain is the largest alluvial tract of the world.
- The northern boundary is well marked by the Shiwaliks and the southern boundary is a wavy irregular line along the northern edge of the Peninsular India.
- The western boarder is marked by Sulaiman and Kirthar ranges. On the eastern side, the plains are bordered by Purvanchal hills.
- The thickness of the alluvium deposits also vary from place to place.

- The cones or alluvial fans of Kosi in the north and those of Son in the south exhibit greater alluvial thickness while the intra-cone areas have relatively shallower deposits.

Geomorphological features of Indo – Gangetic – Brahmaputra Plain

THE BHABAR	THE TERAI
• It is a narrow, porous, northern most stretch of Indo-Gangetic plain. • They show a remarkable continuity from the Indus to the Tista. • Rivers descending from the Himalayas deposit their load along the foothills in the form of alluvial fans. • These alluvial fans have merged together to build up the bhabar belt. • The porosity is due to deposition of huge number of pebbles and rock debris across the alluvial fans. • The streams disappear once they reach the bhabar region because of this porosity. • Therefore, the area is marked by dry river courses except in the rainy season. • The Bhabar belt is comparatively narrow in the east and extensive in the western and north-western hilly region. • The area is not suitable for agriculture and only big trees with large roots thrive in this belt.	• Terai is an ill-drained, damp (marshy) and thickly forested narrow tract to the south of Bhabar running parallel to it - The Terai is about15-30 km wide. • The underground streams of the Bhabar belt re-emerge in this belt. • This thickly forested region provides shelter to a variety of wild life. [Jim Corbett National Park in Uttarakhand and Kaziranga National Park in Assam lie in terai region] • The Terai is more marked in the eastern part than in the west because the eastern parts receive comparatively higher amount of rainfall. • Most of the Terai land, especially in Punjab, Uttar Pradesh and Uttarakhand, has been turned into agricultural land which gives good crops of sugarcane, rice and wheat.

THE BHANGAR	THE KHADAR
• The Bhangar is the older alluvium along the river beds forming terraces higher than the flood plain.	• The Khadar is composed of newer alluvium and forms the flood plains along the river banks.

• The terraces are often impregnated with calcareous concretions known as 'KANKAR'. • 'The Barind plains' in the deltaic region of Bengal and the 'bhur formations' in the middle Ganga and Yamuna doab are regional variations of Bhangar. • [Bhur denotes an elevated piece of land situated along the banks of the Ganga river especially in the upper Ganga-Yamuna Doab. This has been formed due to accumulation of wind-blown sands during the hot dry months of the year] • Bhangar contains fossils of animals like rhinoceros, hippopotamus, elephants, etc	• A new layer of alluvium is deposited by river flood almost every year. • This makes them the most fertile soils of Ganges. **REH OR KOLLAR** • Reh or Kollar comprises saline efflorescence's of drier areas in Haryana. • Reh areas have spread in recent times with increase in irrigation (capillary action brings salts to the surface).

REGIONAL DIVISIONS OF THE INDO-GANGETIC-BRAHMAPUTRA PLAINS [GREAT PLAINS]:

SINDH PLAIN [PAKISTAN]	Mainly formed of Bhangar Plains. Dhors: Long narrow depressions which are the remnants of the course of former rivers. Dhand: Alkaline lakes on some dhors
RAJASTHAN PLAIN	Occupied by Thar or the Great Indian Desert. This plain is an undulating plain [wave like] The desert region is called Marusthali and forms a greater part of the Marwar plain. It has a few outcrops of gneisses, schists and granites which proves that geologically it is a part of the Peninsular Plateau. It is only at the surface that it looks like an aggradational plain. The eastern part of the Thar Desert up to the Aravali Range is a semi-arid plain known as Rajasthan Bagar. Luni is an important seasonal stream which flows into Rann of Kuchchh. The tract north of the Luni is known as thali or sandy plain.
SALINE LAKES	North of the Luni, there is inland drainage having several saline lakes. They are a source of common salt and many other salts. Sambhar, Didwana, Degana, Kuchaman, etc. are some of the important lakes. The largest is the Sambhar lake near Jaipur.
PUNJAB PLAIN	This plain is formed by five important rivers of Indus system. The plain is primarily made up of 'doabs' —the land between two rivers. Punjab literally means "(The Land of) Five Waters" referring to the following rivers: the Jhelum, Chenab, Ravi, Sutlej, and Beas. The eastern boundary of Punjab Haryana plain is marked by subsurface Delhi-Aravali ridge. The northern part of this plain [Shiwalik hills] has been intensively eroded by numerous streams called Chos. This has led to enormous gullying [Arid Landforms].

	The area between the Ghaggar and the Yamuna rivers lies in Haryana and often termed as 'Haryana Tract'. It acts as water-divide between the Yamuna and the Satluj rivers. The only river between the Yamuna and the Satluj is the Ghaggar which is considered to be the present day Successor of the legendary Saraswati River

THE GANGA PLAINS

- This is the largest unit of the Great Plain of India stretching from Delhi to Kolkata (about 3.75 lakh sq km).
- The Ganga & its tributaries originating in the Himalayans deposit the alluvium to build this extensive plain.
- The peninsular rivers such as Chambal, Betwa, Ken, Son, etc. joining the Ganga river system have also contributed to the formation of this plain.
- Rivers flow sluggishly in the lower sections of Ganges as a result of which the area is marked by local prominences such as levees, bluffs, oxbow lakes, marshes, ravines, etc. {Fluvial Landforms, Arid Landfroms}
- Almost all the rivers keep on shifting their courses making this area prone to frequent floods.
- The Kosi river is very notorious in this respect. It has long been called the 'Sorrow of Bihar'.

Regional divisions of Ganga plains

1. Rohilkhand plains
2. Avadh Plains
3. Mithila Plain
4. Magadh Plain.

GANGA-BRAHMAPUTRA DELTA	This is the largest delta in the world. The Ganga river divides itself into several channels in the delta area. [Highly vulnerable to sea level changes] The seaward face of the delta is studded with a large number of estuaries, mud flats, mangrove swamps, sandbanks, islands and forelands. Large part of the coastal delta is covered tidal forests. These are called the Sunderbans because of the predominance of Sundri tree here.
BRAHMAPUTRA PLAIN	This is also known as the Brahmaputra valley or Assam Valley or Assam Plain as most of the Brahmaputra valley is situated in Assam. Its western boundary is formed by the Indo-Bangladesh border as well as the boundary of the lower Ganga Plain. Its eastern boundary is formed by Purvanchal hills. It is an aggradation plain built up by the depositional work of the Brahmaputra and its tributaries. The alluvial fans formed by the coarse alluvial debris have led to the formation of terai or semi-terai conditions

Significance of the Plain

- This one fourth of the land of the country hosts half of the Indian population.
- Fertile alluvial soils, flat surface, slow moving perennial rivers and favorable climate facilitate intense agricultural activity.

- The extensive use of irrigation has made Punjab, Haryana and western part of Uttar Pradesh the granary of India (Prairies are called the granaries of the world).
- The entire plain except the Thar Desert, has a close network of roads and railways which has led to large scale industrialization and urbanization.

Cultural tourism:

- There are many religious places along the banks of the sacred rivers like the Ganga and the Yamuna which are very dear to Hindus.
- Here flourished the religions of Budha and Mahavira and the movements of Bhakti and Sufism.

THE PLATEAU:

FEATURES OF THE PENINSULAR PLATEAU

- Roughly triangular in shape with its base coinciding with the southern edge of the great plain of North India. Apex of the triangular plateau is at Kanniyakumari.
- The average height of the plateau is 600-900 m above sea level (varies from region to region).
- Most of the peninsular rivers flow west to east indicating it's general slope.
- Narmada-Tapti are the exceptions which flow from east to west in a rift (rift is caused by divergent boundary (Refer Interaction of plates).
- The Peninsular Plateau is a one of the oldest landforms of earth.
- It is a highly stable block composed mostly of the Archaean gneisses and schists {Rock System}.
- It has been a stable shield which has gone through little structural changes since its formation.
- Since few hundred million years, Peninsular block has been a land area and has never been submerged beneath the sea except in a few places.
- Peninsular Plateau is an aggregation of several smaller plateaus, hill ranges interspersed with river basins and valleys.

Minor Plateaus in the Peninsular Plateau

MARWAR PLATEAU OR MEWAR PLATEAU	It is the plateau of eastern Rajasthan. [Marwar plain is to the west of Aravalis whereas Marwar plateau is to the east]. The average elevation is 250-500 m above sea level. It is made up of sandstone, shales and limestones of the Vindhayan period. The Banas river, along with its tributaries [Berach river, Khari rivers] originate in the Aravali Range and flow towards northwest into Chambal river. The erosional activity of these rives make the plateau top appear like a rolling plain. [Rolling Plain: 'Rolling plains' are not completely flat: there are slight rises and fall in the land form. Ex: Prairies of USA]
CENTRAL HIGHLAND	Also called the Madhya Bharat Pathar or Madhya Bharat Plateau. It is to the east of the Marwar or Mewar Upland. Most of plateau comprises the basin of the Chambal river which flows in a rift valley. The Kali Sindh, flowing from Rana Prataph Sagar, The Banas flowing through Mewar plateau and The Parwan and the Parbati flowing from Madhya Pradesh are its main tributaries. It is a rolling plateau with rounded hills composed of sandstone. Thick forests grow here. To the north are the ravines or badlands of the Chambal river [They are typical to Chambal river basin]{ Arid landforms}.

BUNDELKHAND UPLAND	Yamuna river to the north, Madhya Bharat Pathar to the west, Vindhyan Scarplands to the east and south-east and Malwa Plateau to the south. It is the old dissected (divided by a number of deep valleys) upland of the 'Bundelkhand gneiss' comprising of granite and gneiss. Spreads over five districts of Uttar Pradesh and four districts of Madhya Pradesh. The area is marked by a chain of hillocks (small hill) made of granite and sandstone. The erosional work of the rivers flowing here have converted it into an undulating (wave like surface) area and rendered it unfit for cultivation. The region is characterized by senile (characteristic of or caused by old age) topography. Streams like Betwa, Dhasan and Ken flow through the plateau
MALWA PLATEAU	The Malwa Plateau roughly forms a triangle based on the Vindhyan Hills, bounded by the Aravali Range in the west and Madhya Bharat Pathar to the north and Bundelkhand to the east. This plateau has two systems of drainage; one towards the Arabian sea (The Narmada, the Tapi and the Mahi), and the other towards the Bay of Bengal (Chambal and Betwa, joining the Yamuna). In the north it is drained by the Chambal and many of its right bank tributaries like the Kali, the Sindh and the Parbati. It also includes the upper courses of the Sindh, the Ken and the Betwa. It is composed of extensive lava flow and is covered with black soils. This is a rolling plateau dissected by rivers. In the north, the plateau is marked by the Chambal ravines
BAGHELKHAND	North of the Maikal Range is the Baghelkhand. Made of limestones and sandstones on the west and granite in the east. It is bounded by the Son river on the north. The central part of the plateau acts as a water divide between the Son drainage system in the north and the Mahanadi river system in the south. The region is uneven with general elevation varying from 150 m to 1,200 m. The Bhanrer and Kaimur are located close to the trough-axis. The general horizontality of the strata shows that this area has not undergone any major disturbance
CHOTANAGPUR PLATEAU	Chotanagpur plateau represents the north-eastern projection of the Indian Peninsula. Mostly in Jharkhand, northern part of Chhatisgarh and Purulia district of West Bengal. The Son river flows in the north-west of the plateau and joins the Ganga. This plateau is composed mainly of Gondwana rocks. The plateau is drained by numerous rivers and streams in different directions and presents a radial drainage pattern. {Drainage Pattern} Rivers like the Damodar, the Subarnrekaha, the North Koel, the South Koel and the Barkar have developed extensive drainage basins. The Damodar river flows through the middle of this region in a rift valley from west to east. Here are found the Gondwana coal fields which provide bulk of coal in India. North of the Damodar river is the Hazaribagh plateau with an average elevation of 600 m above mean sea level. This plateau has isolated hills. It looks like a peneplain due to large scale erosion. The Ranchi Plateau to the south of the Damodar Valley rises to about 600 m above mean sea level. Most of the surface is rolling where the city of Ranchi (661 m) is located.

	At places it is interruped by monadnocks (an isolated hill or ridge of erosion-resistant rock rising above a peneplain. Ex: Ayers Rock in Australia) and conical hills. The Rajmahal Hills forming the north eastern edge of the Chotanagpur Plateau are mostly made of basalt and are covered by lava flows {Basaltic Lava}.
MEGHALAYA PLATEAU	The peninsular plateau extends further east beyond the Rajmahal hills to from Meghalaya or the Shillong plateau. Garo-Rajmahal Gap separates this plateau from the main block. This gap was formed by down-faulting (normal fault: a block of earth slides downwards). It was later filled by sediments deposited by the Ganga and Brahmaputa. The plateau is formed by Archaean quartzites, shales and schists. The plateau slopes down to Brahmaputra valley in the north and the Surma and Meghna valleys in the south. Its western boundary more or less coincides with the Bangladesh border. The western, central and the eastern parts of the plateau are known as the Garo Hills (900 m), the Khasi-Jaintia Hills (1,500 m) and the Mikir Hills (700 m). Shillong (1,961 m) is the highest point of the plateau
DECCAN PLATEAU	It covers an area of about five lakh sq km. It is triangular in shape and is bounded by the Satpura and the Vindhya in the north-west, the Mahadev and the Maikal in the north, the Western Ghats in the west and the Eastern Ghats in the east. Rivers have further subdivided this plateau into a number of smaller plateaus
MAHARASHTRA PLATEAU	The Maharashtra Plateau lies in Maharashtra. It forms the northern part of the Deccan Plateau. Much of the region is underlain by basaltic rocks of lava origin [Most of the Deccan Traps lies in this region]. The area looks like a rolling plain due to weathering. The horizontal lava sheets have led to the formation of typical Deccan Trap topography [step like]. The broad and shallow valleys of the Godavari, the Bhima and the Krishna are flanked [bordered on the opposite sides] by flat-topped steep sided hills and ridges. The entire area is covered by black cotton soil known as regur
KARNATAKA PLATEAU	The Karnataka Plateau is also known as the Mysore plateau. Lies to the south of the Maharashtra plateau. The area looks like a rolling plateau with an average elevation of 600-900 m. It is highly dissected by numerous rivers rising from the Western Ghats. The general trend of the hills is either parallel to the Western Ghats or across it. The highest peak (1913 m) is at Mulangiri in Baba Budan Hills in Chikmaglur district. The plateau is divided into two parts called Malnad and Maidan. The Malnad in Kannada means hill country. It is dissected into deep valleys covered with dense forests. The Maidan on the other hand is formed of rolling plain with low granite hills. The plateau tapers between the Western Ghats and the Eastern Ghats in the south and merges with the Niligiri hills there

TELANGANA PLATEAU	The Telangana plateau consists of Archaean gneisses. The southern part is higher than its northern counterpart. The region is drained by three river systems, the Godavari, the Krishna and the Penneru. The entire plateau is divided into Ghats and the Peneplains (a vast featureless, undulating plain which the last stage of deposition process).

HILL RANGES OF PENINSULAR PLATEAU

- Most of the hills in the peninsular region are of the relict type (residual hills).
- They are the remnants of the hills and horsts formed many million years ago (horst: uplifted block; graben: subsided block).
- The plateaus of the Peninsular region are separated from one another by these hill ranges and various river valleys.

ARAVALLI RANGE

- They are aligned in north-east to south-west direction.
- They run for about 800 km between Delhi and Palanpur in Gujarat.
- They are one of the oldest (very old) fold mountains of the world and the oldest in India. {Fold Mountains – Block Mountains}
- Now they are relict (remnants after severe weathering and erosion since millions of years) of the world's oldest mountain formed as a result of folding (Archaean Era).
- They continue up to Hariddwar buried under the alluvium of Ganga Plains.
- The range is conspicuous in Rajasthan (continuous range south of Ajmer where it rises to 900 m.) but becomes less distinct in Haryana and Delhi (characterized by a chain of detached and discontinuous ridges beyond Ajmer).
- According to some geographers, one Branch of the Aravalis extends to the Lakshadweep Archipelago through the Gulf of Khambhat and the other into Andhra Pradesh and Karnataka.
- At the south-west extremity the range rises to over 1,000 m. Here Mt. Abu (1,158 m), a small hilly block, is separated from the main range by the valley of the Banas. Guru Sikhar (1,722 m), the highest peak, is situated in Mt. Abu.
- Pipli Ghat, Dewair and Desuri passes allow movement by roads and railways.

VINDHYAN RANGE

- The Vindhyan Range, overlooking the Narmada valley, rises as an escarpment (a long, steep slope at the edge of a plateau or separating areas of land at different heights) flanking (neighboring on one side) the northern edge of the Narmada-Son Trough (the rift through which the Narmada river flows)(trough is opposite of ridge. It is a narrow depression).
- It runs more or less parallel to the Narmada Valley in an east-west direction
- Most parts of the Vindhayan Range are composed of horizontally bedded sedimentary rocks of ancient age. {Rock System}
- The Vindhyas are continued eastwards as the Bharner and Kaimur hills.
- The rivers Chambal, Betwa and Ken rise within 30 km of the Narmada.

SATPURA RANGE

- Satpura range is a series of seven mountains ('Sat' = seven and 'pura' = mountains)
- It runs in an east-west direction south of the Vindhyas and in between the Narmada and the Tapi, roughly parallel to these rivers.
- Parts of the Satpuras have been folded and upheaved. They are regarded as structural uplift or 'horst'.

- Dhupgarh (1,350 m) near Pachmarhi on Mahadev Hills is the highest peak.
- Amarkantak (1,127 m) is another important peak.

WESTERN GHATS / SHAYADRIS

- They form the western edge of the Deccan tableland.
- Run from the Tapi valley to a little north of Kanniyakumari
- The Western Ghats are steep-sided, terraced, flat-topped hills presenting a stepped topography facing the Arabian Sea coast.
- This is due to the horizontally bedded lavas, which on weathering, have given a characteristic 'landing stair aspect' to the relief of this mountain chain.
- South of Malabar, the Nilgiris, Anamalai, etc. present quite different landscape due to the difference in geological structure.

The northern section

- The northern section of the Ghats from Tapi valley to a little north of Goa is made of horizontal sheets of Deccan lavas (Deccan Traps).
- Kalasubai (1,646 m) near Igatpuri, Salher (1,567 m) about 90 km north of Nashik, Mahabaleshwar (1,438 m) and Harishchandragarh (1,424 m) are important peaks.
- Thal ghat and Bhor ghat are important passes which provide passage by road and rail between the Konkan Plains in the west and the Deccan Plateau in the east.

[Konkan coast == Maharashtra coast and Goa coast;

Malabar Coast == Kerala and Karnataka coast]

The Middle Sahyadri

- The Middle Sahyadri runs from 16°N latitude upto Nilgiri hills.
- This part is made of granites and gneisses and This area is covered with dense forests.
- The western scarp is considerably dissected by headward erosion of the west flowing streams.
- The Vavul Mala (2,339 m), the Kudremukh (1,892 m) and Pashpagiri (1,714 m) are important peaks.
- The Nilgiri Hills which join the Sahyadris near the trijunction of Karnataka, Kerala and TN, rise abruptly to over 2,000 m.
- They mark the junction of the Western Ghats with Eastern Ghats.
- Doda Betta (2,637 m) and Makurti (2,554 m) are important peaks of this area.

The southern section

- The southern part of the Western Ghats is separated from the main Sahyadri range by Pal ghat Gap [Palakkad Gap].
- The high ranges terminate abruptly on either side of this gap.
- Pal ghat Gap it is a rift valley. This gap is used by a number of roads and railway lines to connect the plains of Tamil Nadu with the coastal plain of Kerala.
- It is through this gap that moist-bearing clouds of the south-west monsoon can penetrate some distance inland, bringing rain to Mysore region.
- South of the Pal ghat Gap there is an intricate system of steep and rugged slopes on both the eastern and western sides of the Ghats.
- Anai Mudi (2,695 m) is the highest peak in the whole of southern India.
- Three ranges radiate in different directions from Anai Mudi. These ranges are the Anaimalai (1800-2000 m) to the north, the Palani (900-1,200 m) to the north-east and the Cardamom Hills or the Ealaimalai to the south.

EASTERN GHATS

- Eastern Ghats run almost parallel to the east coast of India leaving broad plains between their base and the coast.
- It is a chain of highly broken and detached hills starting from the Mahanadi in Odisha to the Vagai in Tamil Nadu. They almost disappear between the Godavari and the Krishna.
- They neither have structural unity nor physiographic continuity. Therefore these hill groups are generally treated as independent units.
- It is only in the northern part, between the Mahanadi and the Godavari that the Eastern Ghats exhibit true mountain character. This part comprises the Maliya and the Madugula Konda ranges.
- The peaks and ridges of the Maliya range have a general elevation of 900-1,200 m and Mahendra Giri (1,501 m) is the tallest peak here.
- Between the Godavari and the Krishna rivers, the Eastern Ghats lose their hilly character and are occupied by Gondwana formations (KG Basin is here).
- The Eastern Ghats reappear as more or less a continuous hill range in Cuddapah and Kurnool districts of Andhra Pradesh where they are called as Nallamalai Range [Naxalite hideout in AP] with general elevation of 600-850 m.
- The southern part of this range is called the Palkodna range.
- To the south, Javadi Hills and the Shevroy-Kalrayan Hills form two distinct features of 1,000 m elevation.
- The Biligiri Rangan Hills in Karnataka (at its border with Tamil Nadu) attain a height of 1,279 m.
- Further south, the Eastern Ghats merge with the Western Ghats.

Significance of the Peninsular Plateau

- There are huge deposits of iron, manganese. copper, bauxite, chromium, mica, gold, etc.
- 98 per cent of the Gondwana coal deposits of India are found in the Peninsular Plateau.
- Besides there are large reserves of slate, shale, sandstones, marbles, etc.
- A large part of north-west plateau is covered with fertile black lava soil which is extremely useful for growing cotton.
- Some hilly regions in south India are suitable for the cultivation of plantation crops like tea, coffee, rubber, etc..
- Some low lying areas of the plateau are suitable for growing rice.
- The highlands of the plateau are covered with different types of forests which provide a large variety of forest products.
- The rivers originating in the Western Ghats offer great opportunity for developing hydroelectricity and providing irrigation facilities to the agricultural crops.
- The plateau is also known for its hill resorts such as Udagamangalam (Ooty), Panchmarhi, Kodaikanal, Mahabaleshwar, Khandala, Matheron, Mount Abu, etc.

COASTLINE OF INDIA

- India has a coastline of 7516.6 Km [6100 km of mainland coastline + coastline of 1197 Indian islands] touching 13 States and Union Territories (UTs).
- The straight and regular coastline of India is the result of faulting of the Gondwanaland during the Cretaceous period. {Continental Drift}
- As such the coast of India does not offer many sites for good natural harbours.
- The Bay of Bengal and the Arabian Sea came into being during the Cretaceous or early Tertiary period after the disintegration of Gondwanaland

[Indented coastlines of Europe provide good natural harbours whereas African and Indian coastlines are not indented].

TYPES OF COASTLINES

Already explained in Marine Landforms. I am discussing here for continuity.

1. Coastline of Emergence
2. Coastline of Submergence
3. Coastlines of Emergence and Submergence

Coastline of emergence is formed either by an uplift of the land or by the lowering of the sea level. Coastline of submergence is an exact opposite case.
Bars, spits, lagoons, salt marshes, beaches, sea cliffs and arches are the typical features of emergence. {Marine Landforms}
The east coast of India, especially its south-eastern part (Tamil Nadu coast), appears to be a coast of emergence.
The west coast of India, on the other hand, is both emergent and submergent.
The northern portion of the coast is submerged as a result of faulting and the southern portion, that is the Kerala coast, is an example of an emergent coast.

Coramandal coast (Tamil Nadu) ==> Coastline of emergence
Malabar coast (Kerala Coast) ==> Coastline of emergence
Konkan coast (Maharashtra and Goa Coast) ==> Coastline of submergence.

East Coast of India	Lies between the Eastern Ghats and the Bay of Bengal. It extends from the Ganga delta to Kanniyakumari. It is marked by deltas of rivers like the Mahanadi, the Godavari, the Krishna and the Cauvery. Chilka lake and the Pulicat lake (lagoon) are the important geographical features of east coast.
Regional Names of The East Coast of India	In Orissa (Odisha) it is known as Utkal coast. From the southern limit of the Utkal plain, stretch the Andhra coast. In the south of the Andhra plain is the Tamil Nadu coast. The Tamil Nadu coast and parts of Andhra coast together are known as Coramandal Coast or Payan Ghat [False Divi Point in AP (Krishna River Delta) in the north to Kanyakumari in the south.].
West Coast of India	The west coast strip extends from the Gulf of Cambay (Gulf of Khambhat) in the north to Cape Comorin (Kanniyakumari).

	Starting from north to south, it is divided into (i) the Konkan coast, (ii) the Karnataka coast and (iii) the Kerala cost. It is made up of alluvium brought down by the short streams originating from the Western Ghats. It is dotted with a large number of coves (a very small bay), creeks (a narrow, sheltered waterway such as an inlet in a shoreline or channel in a marsh) and a few estuaries. {Marine Landforms} The estuaries, of the Narmada and the Tapi are the major ones. The Kerala coast (Malabar Coast) has some lakes, lagoons and backwaters, the largest being the Vembanad Lake.
	Regional Names of The West Coast of India 1. Konkan coast == Maharashtra coast and Goa coast; 2. Malabar Coast == Kerala and Karnataka coast.
Western Coastal Plains of India:	Rann of Kachchh in the north to Kanniyakumari in the South. These are narrow plains with an average width of about 65 km.
Kutch and Kathiawar region	Kutch and Kathiawar, though an extension of Peninsular plateau (because Kathiawar is made of the Deccan Lava and there are tertiary rocks in the Kutch area), they are still treated as integral part of the Western Coastal Plains as they are now levelled down. The Kutch Peninsula was an island surrounded by seas and lagoons. These seas and lagoons were later filled by sediment brought by the Indus River which used to flow through this area. Lack of rains in recent times has turned it into arid and semi-arid landscape. Salt-soaked plain to the north of Kutch is the Great Rann. Its southern continuation, known as the Little Rann lies on the coast and south-east of Kachchh. The Kathiawar Peninsula lies to the south of the Kachchh. Mt. Girnar (1,117 m) is the highest point and is of volcanic origin. The Gir Range is located in the southern part of the Kathiawar peninsula. It is covered with dense forests and is famous as home of the Gir lion
Gujarat Plain	The Gujarat Plain lies east of Kachchh and Kathiawar and slopes towards the west and south west. Formed by the rivers Narmada, Tapi, Mahi and Sabarmati, the plain includes the southern part of Gujarat and the coastal areas of the Gulf of Khambhat. The eastern part of this plain is fertile enough to support agriculture, but the greater part near the coast is covered by windblown loess (heaps of sand).
Konkan Plain	The Konkan Plain south of the Gujarat plain extends from Daman to Goa (50 to 80 km wide). It has some features of marine erosion including cliffs, shoals, reefs and islands in the Arabian Sea. The Thane creek around Mumbai is an important embayment (a recess in a coastline forming a bay) which provides an excellent natural harbour
Karnataka Coastal Plain	Goa to Mangalore. The Sharavati while descending over such a steep slope makes an impressive waterfall known as Gersoppa (Jog) Falls which is 271 m high. [Angel falls (979 m) in Venezuela is the highest waterfall on earth. Marine topography is quite marked on the coast

Kerala Plain	The Kerala Plain also known as the Malabar Plain Between Mangalore and Kanniyakumari. This is much wider than the Karnataka plain. It is a low lying plain. The existence of lakes, lagoons, backwaters, spits, etc. is a significant characteristic of the Kerala coast. The backwaters, locally known as kayals are the shallow lagoons or inlets of the sea, lying parallel to the coastline. The largest among these is the Vembanad Lake which is about 75 km long and 5-10 km wide and gives rise to a 55 km long spit {Marine Landforms}.
Eastern Coastal Plains of India	Extending from the Subarnarekha river along the West Bengal-Odisha border to Kanniyakumari. A major part of the plains is formed as a result of the alluvial fillings of the littoral by the rivers Mahanadi, Godavari, Krishna and Cauvery comprising some of the largest deltas. This plain is known as the Northern Circars between the Mahanadi and the Krishna rivers and Carnatic between the Krishna and the Cauvery rivers.
Utkal Plain	The Utkal Plain comprises coastal areas of Odisha including Mahanadi delta. The most prominent physiographic feature of this plain is the Chilka Lake. It is the biggest lake in the country South of Chilka Lake, low hills dot the plain.
Andhra Plain	South of the Utkal Plain and extends upto Pulicat Lake. This lake has been barred by a long sand spit known as Sriharikota Island (ISRO launch facility). The most significant feature of this plain is the delta formation by the rivers Godavari and Krishna. The two deltas have merged with each other and formed a single physiographic unit. The combined delta has advanced by about 35 km towards the sea during the recent years. This is clear from the present location of the Kolleru Lake which was once a lagoon at the shore but now lies far inland {Coastline of Emergence}.
Tamil Nadu Plain	The Tamil Nadu Plain stretches for 675 km from Pulicat lake to Kanniyakumari along the coast of Tamil Nadu. Its average width is 100 km. The most important feature of this plain is the Cauvery delta where the plain is 130 km wide. The fertile soil and large scale irrigation facilities have made the Cauvery delta the granary of South India.

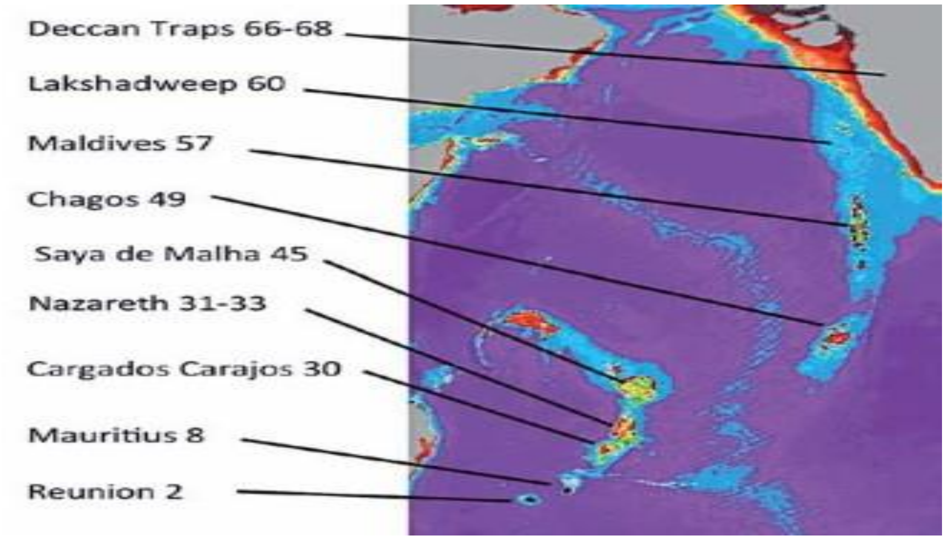
Significance of the Coastal Plains

1. Large parts of the coastal plains of India are covered by fertile soils on which different crops are grown. Rice is the main crop of these areas.
2. Coconut trees grow all along the coast.
3. The entire length of the coast is dotted with big and small ports which help in carrying out trade.
4. The sedimentary rocks of these plains are said to contain large deposits of mineral oil (KG Basin).
5. The sands of Kerala coast have large quantity of MONAZITE which is used for nuclear power.
6. Fishing is an important occupation of the people living in the coastal areas.
7. Low lying areas of Gujarat are famous for producing salt.
8. Kerala backwaters are important tourist destinations.
9. Goa provides good beaches. This is also an important tourist destination.

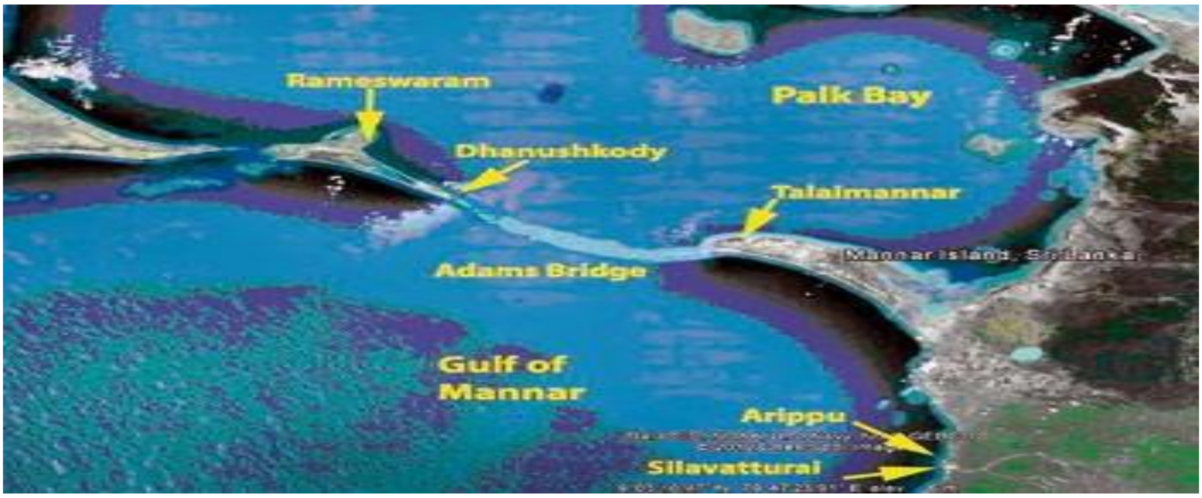
Indian Islands:

- The major islands groups of India are Andaman and Nicobar Archipelago (A chain of islands similar in origin) in Bay of Bengal and Lakshadweep islands in Arabian Sea.

REUNION HOT SPOT VOLCANISM



- Andaman and Nicobar Islands were formed due to collision between Indian Plate and Burma Minor Plate [part of Eurasian Plate][Similar to formation of Himalayas].
- Lakshadweep Islands are coral islands. These islands are a part Reunion Hotspot volcanism. [Both these concepts are explained in previous posts]
- Other than these two groups there are islands in Indo-Gangetic Delta [they are more a part of delta than islands] and between India and Sri Lanka [Remnants of Adams Bridge; formed due to submergence].

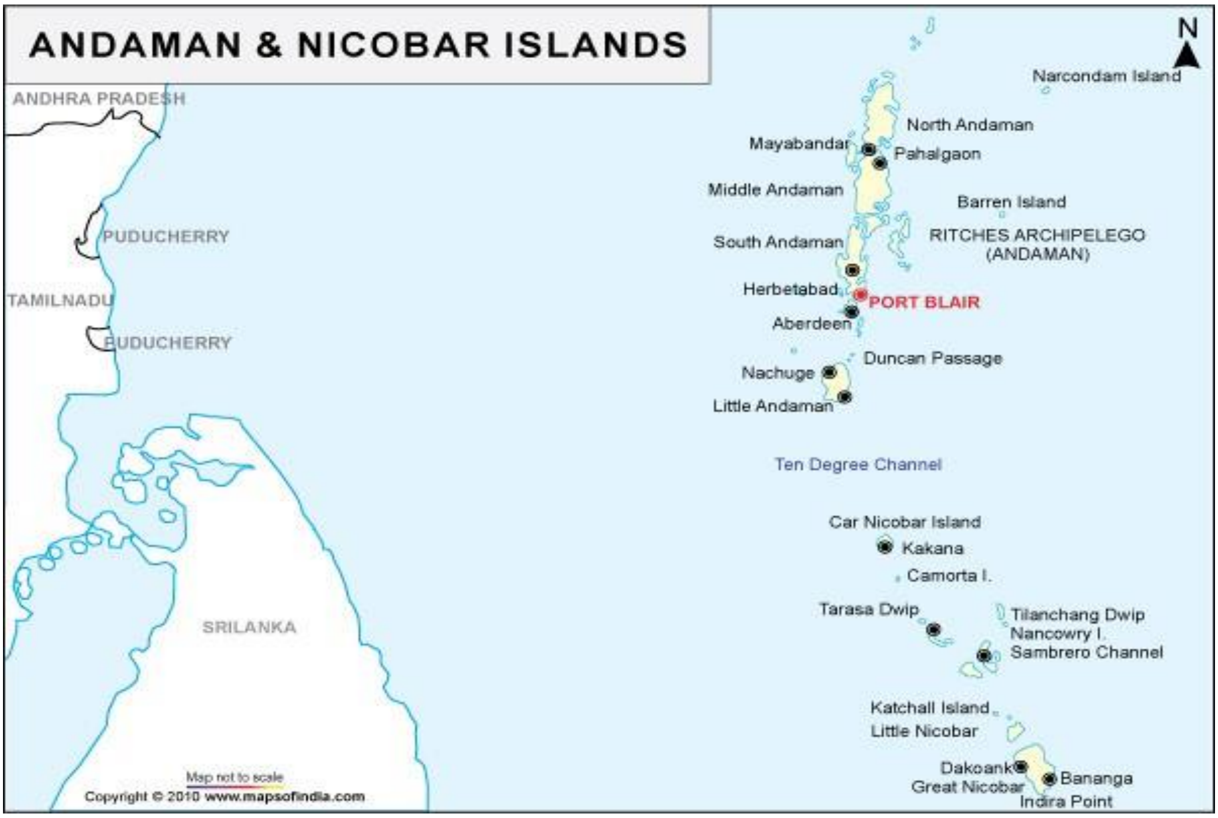


ANDHAMAN & NICOBAR

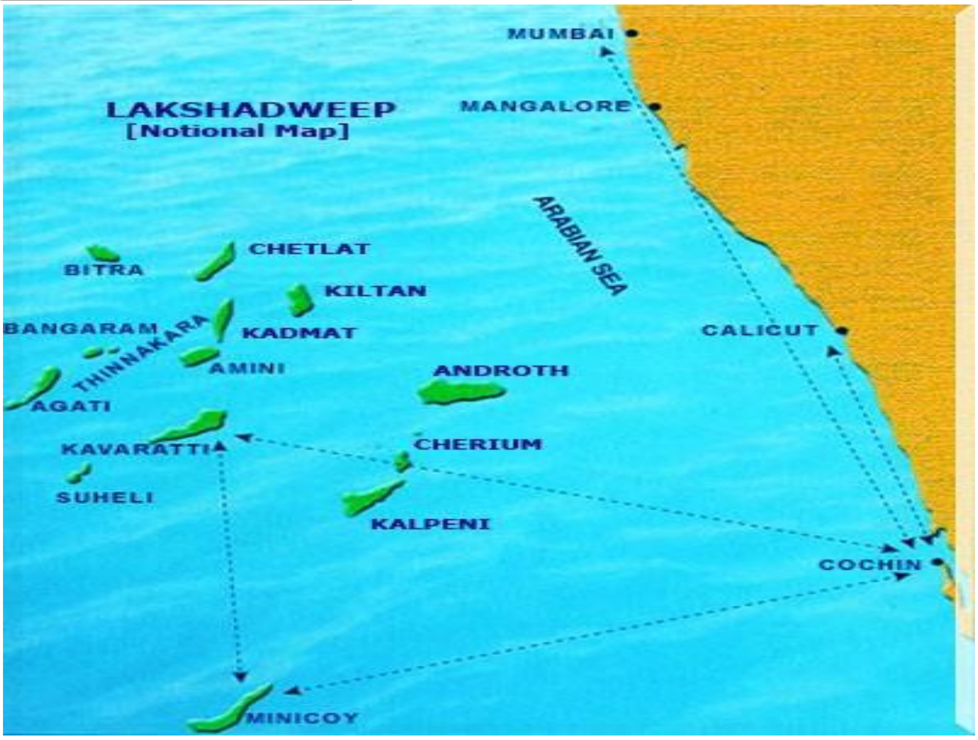
- This archipelago is composed of 265 big and small islands [203 Andaman islands + 62 Nicobar Islands][Numbers are just for understanding. You need not remember trivial facts].
- The Andaman islands are divided into three main islands i.e. North, Middle and South.
- Duncan passage separates Little Andaman from South Andaman.
- The Great Andaman group of islands in the north is separated by the Ten Degree Channel from the Nicobar group in the south.
- Port Blair, the capital of Andaman Nicobar Islands lies in the South Andaman.
- Among the Nicobar islands, the Great Nicobar is the largest. It is the southernmost island and is very close to Sumatra island of Indonesia.

- Most of these islands are made of tertiary sandstone, limestone and shale resting on basic and ultrabasic volcanoes [Similar to Himalayas].
- THE BARREN AND NARCONDAM ISLANDS, north of Port Blair, are volcanic islands [these are the only active volcanoes in India][There are no active volcanoes in main land India].
- Some of the islands are fringed with coral reefs. Many of them are covered with thick forests. Most of the islands are mountainous.
- Saddle peak (737 m) in North Andaman is the highest peak.

Andaman and Nicobar islands - ten degree channel



LAKSHADWEEP



- The Lakshadweep Islands are a group of 25 small islands.
- Amendivi Islands are the northern most while the Minicoy island is the southernmost.
- All are tiny islands of coral origin {Atoll} and are surrounded by fringing reefs.
- Most of the islands have low elevation and do not rise more than five metre above sea level (Extremely Vulnerable to sea level change).
- Their topography is flat and relief features such as hills, streams, valleys, etc. are absent.

In the Arabian Sea, there are three types of islands.

Amindivi Islands (consisting of six main islands of Amini, Keltan, Chetlat, Kadmat, Bitra and Perumul Par). [don't have to remember all these names] Laccadive Islands (consisting of five major islands of Androth, Kalpeni, Kavaratti, Pitti and Suheli Par) and Minicoy Island. At present these islands are collectively known as Lakshadweep.

New Moore Island - india-bangladesh dispute

- It is a small uninhabited offshore sandbar landform {Marine Landforms} in the Bay of Bengal, off the coast of the Ganges-Brahmaputra Delta region.
- It emerged in the Bay of Bengal in the aftermath of the Bhola cyclone in 1970. It keeps on emerging and disappearing.
- Although the island was uninhabited and there were no permanent settlements or stations located on it, both India and Bangladesh claimed sovereignty over it because of speculation over the existence of oil and natural gas in the region.

INDIAN RIVER SYSTEM

1. Himalayan rivers
2. Peninsular rivers
3. River basins
4. Regional development and planning
5. Hydropower projects, major dams
6. West-flowing and east-flowing rivers
7. Interlinking of rivers

CLASSIFICATION OF DRINAGE SYSTEMS OF INDIA

1. Major river 20,000
2. Medium river 20,000 – 2,000
3. Minor river 2,000 and below

DRINAGE SYSTEM BASED ON ORGIN

The Himalayan Rivers:

- Perennial rivers: Indus, the Ganga, the Brahmaputra and their tributaries.

The Peninsular Rivers:

- Non-Perennial rivers: Mahanadi, the Godavari, the Krishna, the Cauvery, the Narmada and the Tapi and their tributaries.

DRINAGE SYSTEM BASED ON TYPES OF DRINAGE

The river systems of India can be classified into four groups:

- Himalayan rivers, Deccan rivers and Coastal rivers that drain into the sea.
- Rivers of the inland drainage basin (endorheic basin).
- Streams like the Sambhar in western Rajasthan are mainly seasonal in character, draining into the inland basins and salt lakes.
- In the Rann of Kutch, the only river that flows through the salt desert is the Luni.
- The Bay of Bengal drainage (Rivers that drain into Bay of Bengal)(East flowing rivers)
- Arabian sea drainage - West flowing rivers.
- The rivers Narmada (India's holiest river) and Tapti flow almost parallel to each other but empty themselves in opposite directions (West flowing).
- The two rivers make the valley rich in alluvial soil and teak forests cover much of the land.

DRAINAGE SYSTEM BASED ON ORIENTATION TO THE SEA

The Bay of Bengal drainage	Arabian Sea drainage
~ 77 per cent of the drainage area of the country is oriented towards the Bay of Bengal – East Flowing	~ 23 per cent of the drainage area of the country is oriented towards the Arabian sea – West flowing
The Ganga, the Brahmaputra, the Mahanadi, the Godavari, the Krishna, the Cauvery, the Penneru, the Penneiyar, the Vaigai, etc.	The Indus, the Narmada, the Tapi, the Sabarmati, the Mahi and the large number of swift flowing western coast rivers descending from the Sahyadris.

LOOP SIDED DISTRIBUTION

- The Arabian Sea drainage or Western drainage receive less rainfall [Rajasthan, Haryana and Punjab receive very low rainfall].
- The Eastern drainage or the Bay of Bengal drainage receives rainfall both from South-west and North-east monsoons.
- Most of the Himalayan waters (perennial rivers) flow into eastern drainage (Ganges and Brahmaputra).
- Indian Rivers that flow into Arabian Sea are seasonal or non-perennial (Luni, Narmada, etc.).

DRINAGE PATTERNS

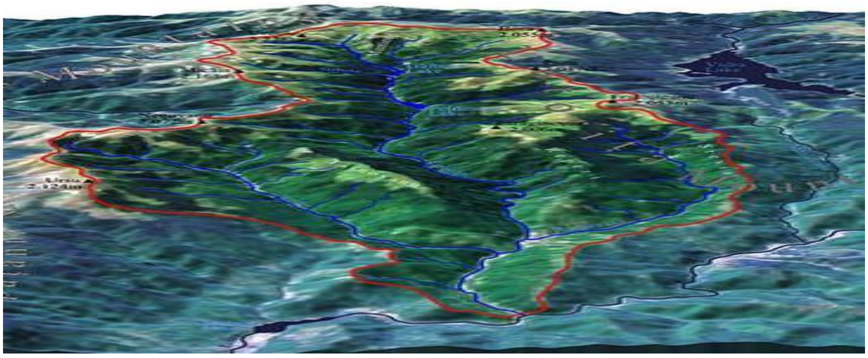
TWO TYPES:

- Discordant drainage patterns & Concordant Drainage Patterns:

Drainage basin

- Other terms that are used to describe drainage basins are catchment, catchment area, catchment basin, drainage area, river basin, and water basin.

(Drainage basin)



- The drainage basin includes both the streams and rivers and the land surface.
- The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channelling it to a single point.
- In closed ("endorheic") drainage basins the water converges to a single point inside the basin, known as a sink, which may be a permanent lake [Lake Aral], dry lake [some desert lakes], or a point where surface water is lost underground [sink holes in Karst landforms]. Other Examples: Lake Chad [Africa], Dead Sea etc.

DRINAGE DIVIDE

- Adjacent drainage basins are separated from one another by a drainage divide. Drainage divide is usually a ridge or a high platform.
- Drainage divide is conspicuous in case of youthful topography [Himalayas] and it is not well marked in plains [Ganga plains] and senile topography [old featureless landforms – Rolling plateaus of Peninsular region though which South Indian rivers flow].

DIFFERENCE BETWEEN RIVER BASIN AND WATER SHED

- Both river basins and watersheds are areas of land that drain to a particular water body, such as a lake, stream, river or estuary.
- In a river basin, all the water drains to a large river. The term watershed is used to describe a smaller area of land that drains to a smaller stream, lake or wetland. There are many smaller watersheds within a river basin.
- Example: watershed of Yamuna + water shed of Chambal + watershed of Gandak + ... = Drainage basin of Ganga.

Discordant drainage patterns

- If it does not correlate to the topology [surface relief features] and geology [geological features based on both Endogenetic and exogenetic movements] of the area.
- In simple words: In a discordant drainage pattern, the river follows its initial path irrespective of the changes in topography.

Discordant drainage patterns are classified into two main types:

1. antecedent
2. superimposed.

ANTECEDENT OR INCONSEQUENT DRAINAGE	SUPERIMPOSED OR EPIGENETIC OR SUPERINDUCED DRAINAGE
A part of a river slope and the surrounding area gets uplifted and the river sticks to its original slope, cutting through the uplifted portion like a saw [Vertical erosion or Vertical down cutting], and forming deep gorges: this type of drainage is called Antecedent drainage. Example: Indus, Sutlej, Brahmaputra and other Himalayan rivers that are older than the Himalayas themselves. There are usually called as ANTECEDENT RIVERS	When a river flowing over a softer rock stratum reaches the harder basal rocks but continues to follow the initial slope, it seems to have no relation with the harder rock bed. This type of drainage is called superimposed drainage. Usually, the drainage patterns (dendritic, trellis, etc.) are strongly influenced by the hardness and softness of the rock and patterns of faults or fractures. Sometimes, however, the land rises rapidly relative to the base level of the stream. This increases the gradient of the stream and therefore, gives the stream more erosive power. The stream has enough erosive power that it cuts its way through any kind of bedrock, maintaining its former drainage pattern.

	The stream pattern is thus superposed on, or placed on structural features that were previously buried. The Damodar, the Subarnarekha, the Chambal, the Banas and the rivers flowing at the Rewa Plateau present some good examples of superimposed drainage. Examples: The Damodar, the Subarnarekha, the Chambal, the Banas and the rivers flowing at the Rewa Plateau, rivers of eastern USA and southern France. [In simple words, the river flow becomes independent of present Topography. It flows in its initial paths without being influenced by changing topography].

Antecedent Drainage == Cut through the newly formed landform and maintain the same path == Himalayan Rivers.

Superimposed Drainage == Cut deeper through the existing landform and maintain the same path == Some medium scale rivers of the Northern and Eastern peninsular India.

Antecedent Drainage == The soil formed is weak and it is easily eroded by the rivers.

Superimposed Drainage == The rivers have high erosive power so that they can cut through the underlying strata.

Usually, rivers in both these drainage types flow through a highly sloping surface.

CONCORDANT DRAINAGE PATTERNS

- A drainage pattern is described as concordant if it correlates to the topology and geology of the area.
- In simple words: In a concordant drainage pattern, the path of the river is highly dependent on the slope of the river and topography.
- Concordant drainage patterns are the most commonly found drainage patterns and are classified into many types.

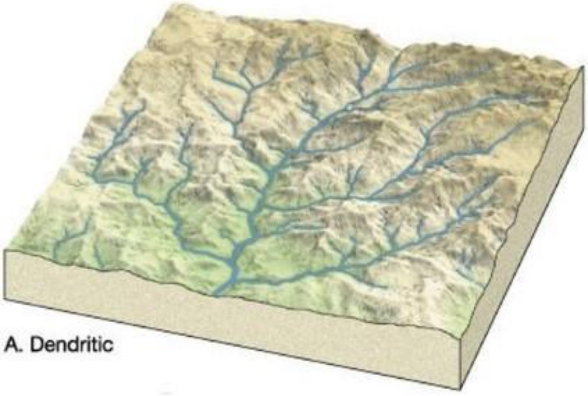
Consequent Rivers

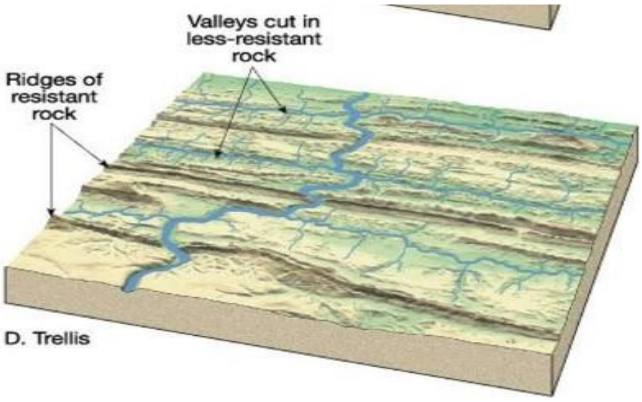
- The rivers which follow the general direction of slope are known as the consequent rivers.
- Most of the rivers of peninsular India are consequent rivers.
- For example, rivers like Godavari, Krishna and Cauvery, descending from the Western Ghats and flowing into the Bay of Bengal, are some of the consequent rivers of Peninsular India.

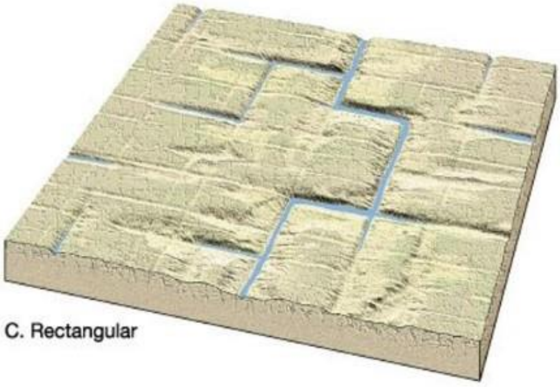
Subsequent Rivers

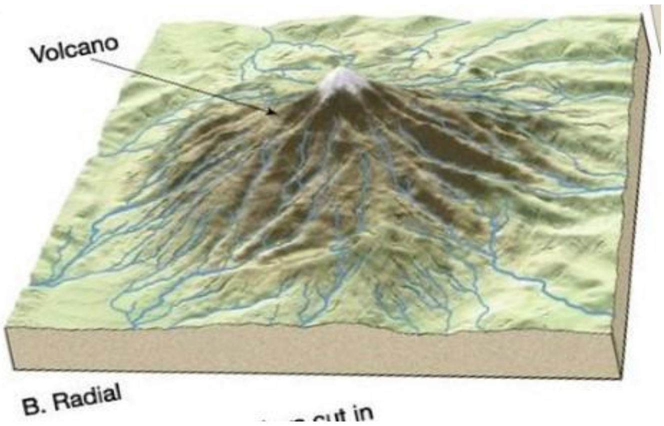
- A tributary stream that is eroded along an underlying belt of non-resistant rock after the main drainage pattern (Consequent River) has been established is known as a subsequent river.
- The Chambal, Sind, Ken, Betwa, Tons and Son meet the Yamuna and the Ganga at right angles. They are the subsequent drainage of the Ganga drainage system.
- These streams have generally developed after the original stream.

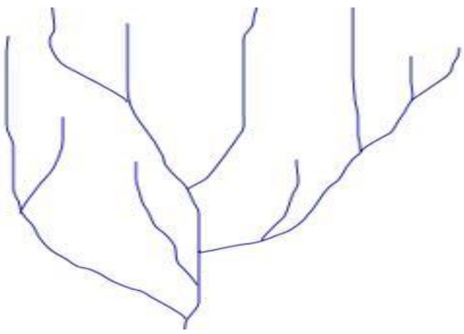
VARIOUS DRAINAGE SYSTEM

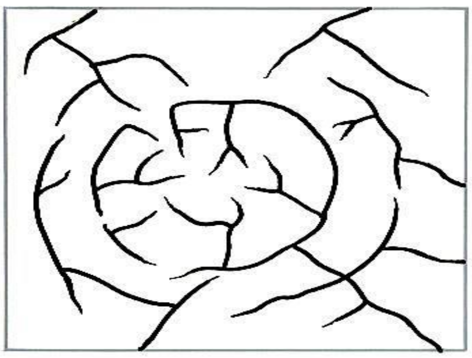




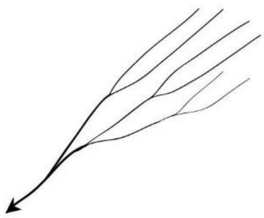




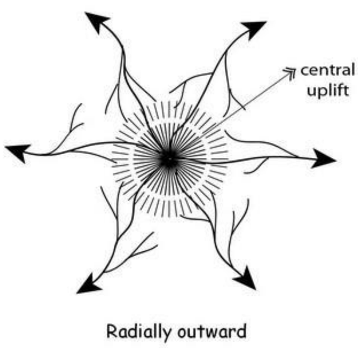


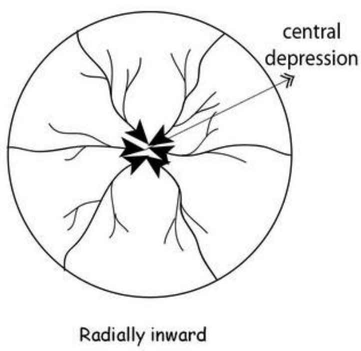


ANNULAR



PARALLEL





DENDRIC OR PINNATE PATTERN	This is an irregular tree branch shaped pattern. A dendritic pattern develops in a terrain which has uniform lithology, and where faulting and jointing are insignificant. Examples: Indus, Godavari, Mahanadi, Cauvery, Krishna.
TRELLIS DRAINAGE PATTERN	In this type of pattern the short subsequent streams meet the main stream at right angles, and differential erosion through soft rocks paves the way for tributaries. Examples: The old folded mountains of the Singhbhum (Chotanagpur Plateau) and Seine and its tributaries in Paris basin (France) have a drainage of trellis pattern.
ANGULAR DRAINAGE PATTERN	The tributaries join the main stream at acute angles. This pattern is common in Himalayan foothill regions.
RECTANGULAR DRAINAGE PATTERN	The main stream bends at right angles and the tributaries join at right angles creating rectangular patterns. This pattern has a subsequent origin. Example: Colorado river (USA), streams found is the Vindhyan Mountains of India
RADIAL DRAINAGE PATTERN	The tributaries from a summit follow the slope downwards and drain down in all directions. Examples: Streams of Saurashtra region, Central French Plateau, Mt. Kilimanjaro. Example: the rivers originating from the Amarkantak Mountain. Rivers like Narmada, Son and Mahanadi originating from Amarkantak Hills flow in different directions and are good examples of radial pattern. Radial drainage patterns are also found/in the Girnar Hills (Kathiwar, Gujarat), and Mikir Hills of Assam
ANNULAR DRAINAGE PATTERN	When the upland has an outer soft stratum, the radial streams develop subsequent tributaries which try to follow a circular drainage around the summit. Example: Black Hill streams of South Dakota. This is not a very common drainage pattern in India. Some examples of this are however found in Pithoragarh (Uttarakhand), Nilgiri Hills in Tamil Nadu and Kerala.
PARALLEL DRAINAGE PATTERN	The tributaries seem to be running parallel to each other in a uniformly sloping region. Example: Rivers of lesser Himalayas and The small and swift rivers originating in the Western Ghats that flow into Arabian Sea
CENTRIPETAL DRAINAGE PATTERN	In a low lying basin the streams converge from all sides. Examples: streams of Ladakh, Tibet, and the Baghmati and its tributaries in Nepal
DERANGED DRAINAGE PATTERN	This is an uncoordinated pattern of drainage characteristic of a region recently vacated by an ice-sheet. This type of drainage is found in the glaciated valleys of Karakoram.

BARBED DRAINAGE PATTERN	A pattern of drainage in which the confluence of a tributary with the main river is characterized by a discordant junction—as if the tributary intends to flow upstream and not downstream. This pattern is the result of capture of the main river which completely reverses its direction of flow, while the tributaries continue to point in the direction of former flow. The Arun River (Nepal), a tributary of the Kosi is an interesting example of barbed drainage pattern

MAJOR RIVER SYSTEMS IN INDIA

Himalayan River systems	Peninsular River Systems	West Flowing Peninsular River Systems
1. Indus River System 2. Brahmaputra River System 3. Ganga River System	1. Godavari River System 2. Krishna River System 3. Cauvery River System 4. Mahanadi River System	1. Narmada River System 2. Tapti River System

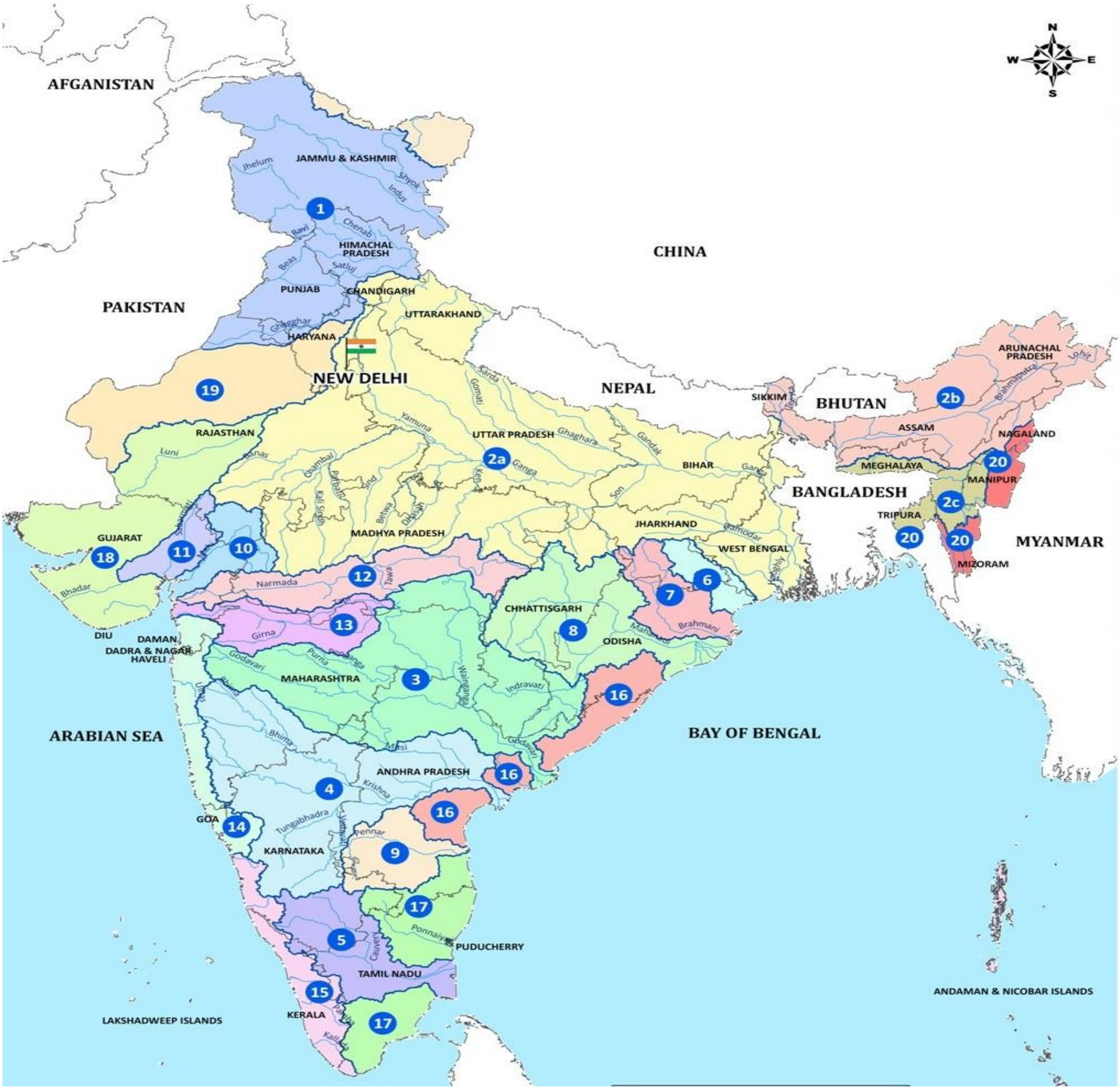
HIMALAYAN RIVER SYSTEM

- The Indus, the Ganga and the Brahmaputra comprise the Himalayan river systems.
- The Himalayan Rivers existed even before the formation of Himalayas i.e. before the collision of Indian Plate with the Eurasian plate. {Antecedent Drainage}
- They were flowing into the Tethys Sea. These rivers had their source in the now Tibetan region.
- The deep gorges of the Indus, the Satluj, the Brahmaputra etc. clearly indicate that these rivers are older than the Himalayas.

INDUS RIVER SYSTEM ORGIN

Sindhu	Sanskrit
Sinthos	Greek
Sindus	Latin

- It flows in north-west direction from its source (Glaciers of Kailas Range – Kailash range in Tibet near Lake Manasarovar) till the Nanga Parbhat Range.
- It is joined by Dhar River near Indo-China border.
- After entering J&K it flows between the Ladakh and the Zaskar Ranges. It flows through the regions of Ladakh, Baltistan and Gilgit.
- It is joined by the Zaskar River at Leh (these kind of points are important for prelims).
- Near Skardu, it is joined by the Shyok at an elevation of about 2,700 m.
- The Gilgit, Gartang, Dras, Shiger, Hunza are the other Himalayan tributaries of the Indus.
- Kabul river from Afghanistan joins Indus near Attock. Thereafter it flows through the Potwar plateau and crosses the Salt Range (South Eastern edge of Potwar Plateau).
- Some of the important tributaries below Attock include the Kurram, Toch and the Zhob-Gomal.
- Just above Mithankot, the Indus receives from Panjnad (Panchnad), the accumulated waters of the five eastern tributaries—the Jhelum, the Chenab, the Ravi, the Beas and the Satluj.



MAJOR TRIBUTARIES OF INDUS RIVER

Jhelum River

- The Jhelum has its source in a spring at Verinag in the south-eastern part of the Kashmir Valley.
- It flows northwards into Wular Lake (north-western part of Kashmir Valley). From Wular Lake, it changes its course southwards. At Baramulla the river enters a gorge in the hills.
- The river forms steep-sided narrow gorge through Pir Panjal Range below Baramula.
- At Muzaffarabad, the river takes a sharp hairpin bend southward.
- Thereafter, it forms the India-Pakistan boundary for 170 km and emerges at the Potwar Plateau near Mirpur.
- After flowing through the spurs of the Salt Range it debouches (emerge from a confined space into a wide, open area) on the plains near the city of Jhelum.

- It joins the Chenab at Trimmu.

Chenab River

- The Chenab originates from near the Bara Lacha Pass in the Lahul-Spiti part of the Zaskar Range.
- Two small streams on opposite sides of the pass, namely Chandra and Bhaga, form its headwaters at an altitude of 4,900 m.
- The united stream Chandrabhaga flows in the north-west direction through the Pangi valley, parallel to the Pir Panjal range.
- Near Kistwar, it cuts a deep gorge.
- It enters the plain area near Akhnur in Jammu and Kashmir.
- From here it through the plains of Pakistani Punjab to reach Panchnad where it joins the Satluj after receiving the waters of Jhelum and Ravi rivers.

Ravi River

- The Ravi has its source in Kullu hills near the Rohtang Pass in Himachal Pradesh.
- It drains the area between the Pir Panjal and the Dhaola Dhar ranges.
- After crossing Chamba, it takes a south-westerly turn and cuts a deep gorge in the Dhaola Dhar range.
- It enters Punjab Plains near Madhopur and later enters Pakistan below Amritsar.
- It debouches into the Chenab a little above Rangpur in Pakistani Punjab.

Beas River

- The Beas originates near the Rohtang Pass, at a height of 4,062 m above sea level, on the southern end of the Pir Panjal Range, close to the source of the Ravi.
- It crosses the Dhaola Dhar range and it takes a south-westerly direction and meets the Satluj river at Harike in Punjab.
- It is a comparatively small river which is only 460 km long but lies entirely within the Indian territory.

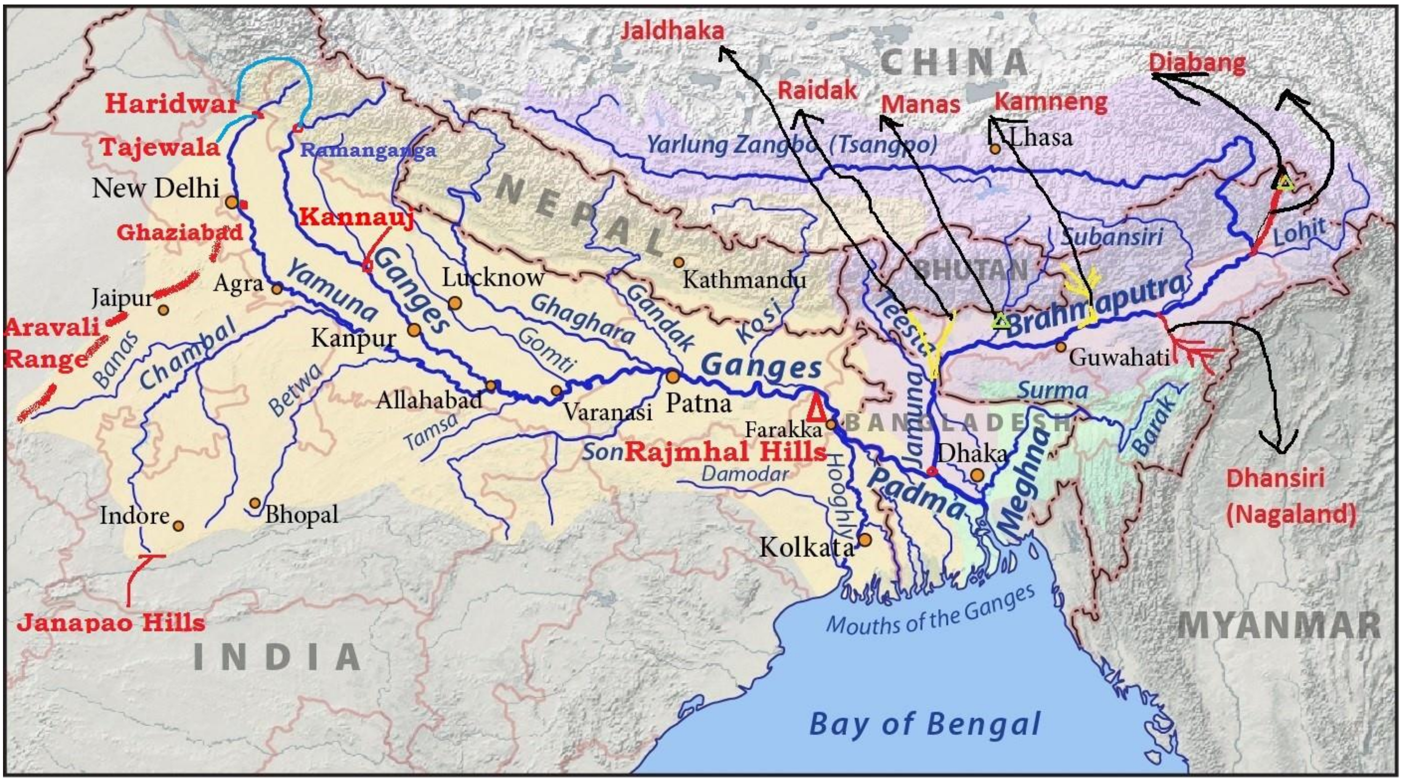
Satluj River

- The Satluj rises from the Manasarovar-Rakas Lakes in western Tibet at a height of 4,570 m within 80 km of the source of the Indus.
- Like the Indus, it takes a north-westerly course upto the Shipki La on the Tibet-Himachal Pradesh boundary.
- It cuts deep gorges where it pierces the Great Himalaya and the other Himalayan ranges.
- Before entering the Punjab plain, it cuts a gorge in Naina Devi Dhar, where the famous Bhakra dam has been constructed.
- After entering the plain at Rupnagar (Ropar), it turns westwards and is joined by the Beas at Harike.
- From near Ferozepur to Fazilka it forms the boundary between India and Pakistan for nearly 120 km.
- During its onward journey it receives the collective drainage of the Ravi, Chenab and Jhelum rivers. It joins the Indus a few kilometres above Mithankot.
- Out of its total length of 1,450 km, it flows for 1,050 km in Indian territory.

Indus water treaty

- The waters of the Indus river system are shared by India and Pakistan according to the Indus Water Treaty signed between the two countries on 19th September, 1960.
- According to this treaty, India can utilize only 20 per cent of its total discharge of water.

GANGA – BRAHMAPUTRA RIVER SYSTEM



River	Source
Bhagirathi (Ganga)	Gangotri glacier
Yamuna	Yamnotri glacier on the Bandarpunch Peak
Chambal	Janapao Hills in the Vindhya Range
Banas	Aravali Range

Betwa	Bhopal district
Ken	Barner Range
Son	Amarkantak Plateau
Damodar ('Sorrow of Bengal')	Chotanagpur plateau
Ramganga River	Garhwal district of Uttarakhand
Ghaghra River	Gurla Mandhata peak, south of Manasarovar in Tibet (river of the trans-Himalayan origin)
The Kali River (border between Nepal and Uttarakhand)	Glaciers of trans-Himalayas
Gandak River	Tibet-Nepal border
Burhi Gandak	Sumesar hills near the India-Nepal border
Kosi ('Sorrow of Bihar')	Tumar, Arun and Sun Kosi unite at Triveni north of the Mahabharata Range to form the Kosi

GANGA RIVER

- The Ganga originates as Bhagirathi from the Gangotri glacier in Uttar Kashi District of Uttarakhand at an elevation of 7,010 m.
- Alaknanda River joins Bhagirathi at Devaprayag.
- From Devapryag the river is called as Ganga.

The Ganges was ranked as the fifth most polluted river of the world in 2007.
Pollution threatens many fish species and amphibian species and the endangered Ganges river dolphin (Blind Dolphin).
The Ganga Action Plan, an environmental initiative to clean up the river, has been a major failure thus far, due to corruption, lack of technical expertise, poor environmental planning, and lack of support from religious authorities.

Major tributaries of Alaknanda

1. East Trisul (joins Alaknanda at Karan Prayag)
2. Pindar (rises from Nanda Devi)
3. Mandakini or Kali Ganga (joins Alaknanda at Rudra Prayag)
4. Dhauliganga
5. Bishenganga.
6. Kishenganga is the tributary of Jhelum]
7. Major tributaries of Bhagirathi - Bheling

- Ganga debouches [emerge from a confined space into a wide, open area] from the hills into plain area at
- It is joined by the Yamuna at Allahabad.
- Near Rajmahal Hills it turns to the south-east.
- At Farraka, it bifurcates into Bhagirathi-Hugli in West Bengal and Padma-Meghna in Bangladesh (it ceases to be known as the Ganga after Farraka).
- Brahmaputra (or the Jamuna as it is known here) joins Padma-Meghna at
- The total length of the Ganga river from its source to its mouth (measured along the Hugli) is 2,525 km.

GANGA BRAMAPUTRA DELTA

- Before entering the Bay of Bengal, the Ganga, along with the Brahmaputra, forms the largest delta of the world between the Bhagirathi/Hugli and the Padma/Meghna covering an area of 58,752 sq km.
- The coastline of delta is a highly indented area.
- The delta is made of a web of distributaries and islands and is covered by dense forests called the

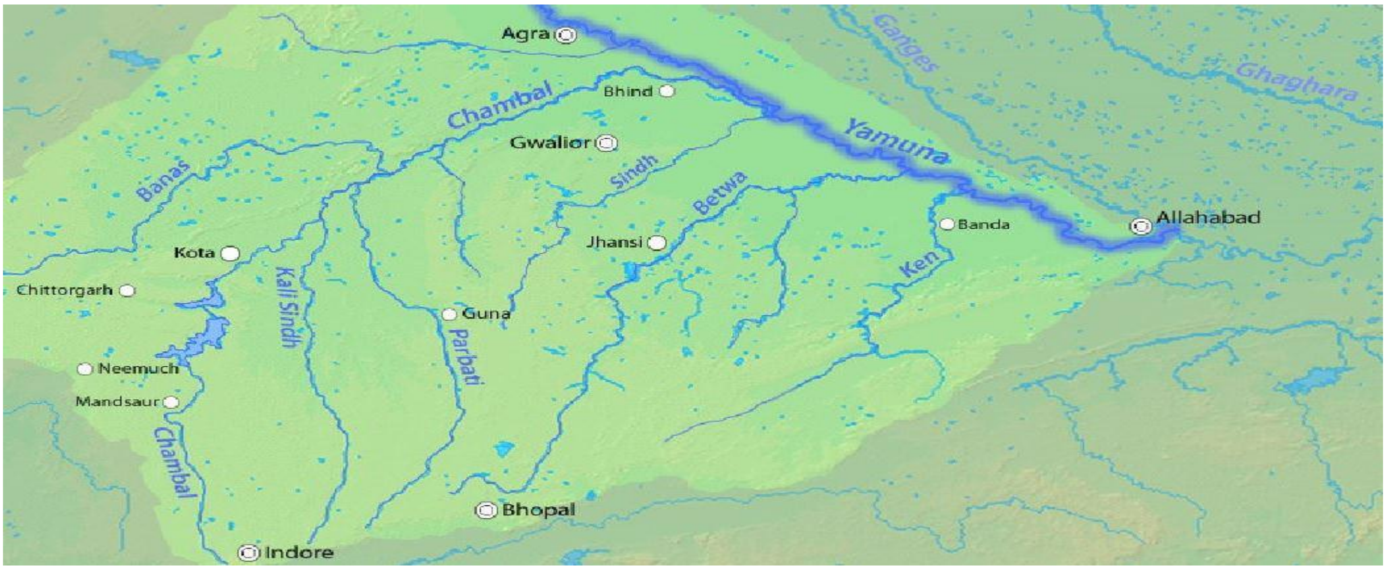
- A major part of the delta is a low-lying swamp which is flooded by marine water during high tide.

Right Bank Tributaries of The Ganga

- Most of them except Yamuna originate in the peninsular region.

YAMUNA RIVER

- Largest and the most important tributary.
- It originates from the Yamnotri glacier on the Bandarpunch Peak in the Garhwal region in Uttarakhand at an elevation of about 6,000 meters.
- It cuts across the Nag Tibba, the Mussoorie and the Shiwalik ranges.
- It emerges out of the hilly area and enters plains near
- Its main affluent in the upper reaches is the Tons which also rises from the Bandarpunch glacier.
- It joins Yamuna below Kalsi before the latter leaves the hills.
- At this site, the water carried by the Tons is twice the water carried by the Yamuna



Non – Peninsular Tributaries	Peninsular Tributaries
1. Rishiganga 2. Uma 3. Hanuman Ganga and 4. Tons join it in the mountains. 5. Hindon joins at Ghaziabad in the plain area	Most of the Peninsular rivers flow into the Yamuna between Agra and Allahabad. 1. Chambal 2. Sind 3. Betwa 4. Ken.

- It unites with the Ganga near Triveni Sangam, Allahabad.
- The total length of the Yamuna from its origin till Allahabad is 1,376 km.
- It creates the highly fertile alluvial, Yamuna-Ganges Doab region between itself and the Ganges in the Indo-Gangetic plain.

CHAMBAL RIVER

- The Chambal rises in the highlands of Janapao Hills (700 m) in the Vindhyan Range.

- It flows through the Malwa Plateau.
- It joins the Yamuna in Etawah district of Uttar Pradesh.
- The river flows much below its banks due to severe erosion because of poor rainfall and numerous deep ravines have been formed in the Chambal Valley, giving rise to badland topography. {Arid Landforms}
- The total length of the river is 1,050 km.

Dams on the Chambal

- The Gandhi Sagar dam is the first of the four dams built on the Chambal River, located on the Rajasthan-Madhya Pradesh border.
- The Rana Pratap Sagar dam is a dam located 52 km downstream of Gandhi Sagar dam on across the Chambal River in Chittorgarh district in Rajasthan.
- The Jawahar Sagar Dam is the third dam in the series of Chambal Valley Projects, located 29 km upstream of Kota city and 26 km downstream of Rana Pratap Sagar dam.
- The Kota Barrage is the fourth in the series of Chambal Valley Projects, located about 0.8 km upstream of Kota City in Rajasthan.
- Water released after power generation at Gandhi Sagar dam, Rana Pratap Sagar dam and Jawahar Sagar Dams, is diverted by Kota Barrage for irrigation in Rajasthan and in Madhya Pradesh through canals.
- Keoladeo National Park is supplied with water from Chambal river irrigation project.

Banas River

- The Banas is a tributary of the Chambal.
- It originates in the southern part of the Aravali Range.
- It join the Chambal on Rajasthan – Madhya Pradesh border near Sawai Madhopur.

Sind River

- The Sind originates in Vidisha Plateau of Madhya Pradesh.
- It flows for a distance of 415 km before it joins the Yamuna.

Betwa River

- The Betwa rises in Bhopal district (Vindhyan Range) and joins the Yamuna near
- It has a total length of 590 km.
- The Dhasan is its important tributary.

Ken River

- The Ken river rising from the Barner Range of Madhya Pradesh joins the Yamuna near Chila.

Son River

- The Son River rises in the Amarkantak Plateau.
- Its source is close to the origin of the Narmada.
- It passes along the Kaimur Range.
- It joins the Ganga near Danapur in Patna district of Bihar.
- It flows for a distance of 784 km from its source.
- The important tributaries of the Son are the Johilla, the Gopat, the Rihand, the Kanhar and the North Koel. Almost all the tributaries join it on its right bank.

DAMODAR RIVER

- The Damodar river rises in the hills of the Chotanagpur plateau and flows through a rift valley.
- Rich in mineral resources, the valley is home to large-scale mining and industrial activity.

- It has a number of tributaries and subtributaries, such as Barakar, Konar, Bokaro, Haharo, etc.
- The Barakar is the most important tributary of the Damodar.
- Several dams have been constructed in the valley, for the generation of hydroelectric power. The valley is called "the Ruhr of India".
- The first dam was built across the Barakar River, a tributary of the Damodar river.
- It used to cause devastating floods as a result of which it earned the name 'Sorrow of Bengal'. Now the river is tamed by constructing numerous dams.
- It joins the Hugli River 48 km below Kolkata.
- The total length of the river is 541 km.

LEFT BANK TRIBUTARIES OF THE GANGA RIVER

- These rivers originate in the Himalayas.
- The major tributaries apart from the Yamuna, are the Ramganga, the Gomati, the Ghaghra, the Gandak, the Burhi Gandak, the Bagmati, and the Kosi.

RAM GANGA RIVER

- The Ramganga river rises in the Garhwal district of Uttarakhand.
- It enters the Ganga Plain near Kalagarh.
- It joins the Ganga at
- The Khoh, the Gangan, the Aril, the Kosi, and the Deoha (Gorra) are important tributaries of Ramganga.

GHAGRA RIVER

- Its source is near Gurla Mandhata peak, south of Manasarovar in Tibet (river of the trans-Himalayan origin).
- It is known as the Karnaili in Western Nepal.
- Its important tributaries are the Sarda, the Sarju (Ayodhya is located on its bank) and the Rapti.
- The Ghaghara joins the Ganga a few kilometres downstream of Chhapra in Bihar.
- After reaching the plain area, its stream gets divided into many branches of which, Koriyab and Garwa are important.
- The river bed is sandy and sudden bends start occurring in the stream.
- The river has a high flood frequency and has shifted its course several times.

KALI RIVER

- Rises in the high glaciers of trans-Himalaya.
- It forms the boundary between Nepal and Kumaon.
- It is known as the Sarda after it reaches the plains near Tanakpur.

GANDAK RIVER

- Originates near the Tibet-Nepal border at a height of 7,620 m
- It receives a large number of tributaries in Nepal Himalaya.
- Its important tributaries are the Kali Gandak, the Mayangadi, the Bari and the Trishuli.
- It debouches into the plains at
- It flows into Ganga at Hajipur in Bihar.

BHURI GANDAK

- Originates from the western slopes of Sumesar hills near the India-Nepal border.
- It joins the Ganga near Monghyr town.

KOSI RIVER

- The Kosi river consists of seven streams namely Sut Kosi, Tamba Kosi, Talkha, Doodh Kosi, Botia Kosi, Arun and Tamber and is popularly known as
- These streams flow through eastern Nepal which is known as the Sapt Kaushik region.
- The sources of seven streams of the Kosi are located in snow covered areas which also receive heavy rainfall.
- Consequently, huge volume of water flows with tremendous speed.
- Seven streams mingle with each other to form three streams named the Tumar, Arun and Sun Kosi.
- They unite at Triveni north of the Mahabharata Range to form the Kosi.
- The river enters the Tarai of Nepal after cutting a narrow gorge in the Mahabharata Range.
- Soon after debouching onto the plain the river becomes sluggish.
- Large scale deposition of eroded material takes place in the plain region.
- The river channel is braided and it shifts its course frequently. This has resulted in frequent devastating floods and has converted large tracts of cultivable land into waste land in Bihar. Thus the river is often termed as the 'Sorrow of Bihar'.
- In order to tame this river, a barrage was constructed in 1965 near Hanuman Nagar in Nepal.
- Embankments for flood control have been constructed as a joint venture of India and Nepal.

BRAMAPUTRA RIVER SYSTEM

Region	Name
Tibet	Tsangpo (meaning 'The Purifier')
China	Yarlung Zangbo Jiangin
Assam Valley	Dihang or Siong, South of Sadiya: Brahmaputra
Bangladesh	Jamuna River Padma River: Combined Waters of Ganga and Brahmaputra Meghana: From the confluence of Padma and Meghna

The Brahmaputra (meaning the son of Brahma).

- It is 2,900 km in length.
- Source: Chemayungdung glacier (Kailas Range) at an elevation of about 5,150 m. It's source is very close to the sources of Indus and Satluj.
- Mariam La separates the source of the Brahmaputra from the Manasarovar Lake.
- Brahmaputra flows eastwards in Southern Tibet for about 1,800 km.
- In Tibet it passes through the depression formed by the Indus-Tsangpo Structure Zone between the Great Himalayas in the south and the Kailas Range in the north.
- Inspite of the exceptionally high altitude, the Tsangpo has a gentle slope. The river is sluggish and has a wide navigable channel for about 640 km.
- It receives a large number of tributaries in Tibet. The first major tributary is the Raga Tsangpo meeting the Tsangpo near Lhatse Dzong.
- The river Ngangchu flows through the trade centre of Gyantse in the south and joins the main river.
- Towards the end of its journey in Tibet, its course abruptly takes a south ward turn around Namcha Barwa (7,756 m)(Syntaxial Bend).
- Here it cuts across the eastern Himalaya through the Dihang or Siang Gorge and emerges from the mountains near Sadiya in the Assam Valley.
- Here it first flows under the name of Siong and then as the Dihang.

- In the north-eastern parts of Assam Valley, it is joined by two important tributaries viz, the Dibang (or Sikang) from the north and Lohit from the south.
- From Sadiya (Assam Valley) onwards, this mighty river is known as the
- The main streams merging with the Brahmaputra from the north are, Subansiri, Kameng, Dhansiri (north), Raidak, Tista etc..
- The Tista was a tributary of the Ganga prior to the floods of 1787 after which it diverted its course eastwards to join the Brahmaputra.
- The Brahmaputra has a braided channel (flow into shallow interconnected channels divided by deposited earth) for most of its passage through Assam where channels keep shifting. It carries a lot of silt and there is excessive meandering.
- The river is nearly 16 km wide at Dibrugarh and forms many islands, the most important of which is MAJULI. It is 90 km long and measures 20 km at its widest.
- With rainfall concentrated during the monsoon months only the river has to carry enormous quantities of water and silt which results in disastrous floods. The Brahmaputra is thus truly a River of Sorrow.
- The river is navigable for a distance of 1,384 km upto Dibrugarh from its mouth and serves as an excellent inland water transport route.
- Brahmaputra bends southwards and enters Bangladesh near Dhubri.
- It flows for a distance of 270 km in the name of Jamuna river and joins the Ganga at
- The united stream of the Jamuna and the Ganga flows further in the name of
- About 105 km further downstream, the Padma is joined on the left bank by the Meghna, originating in the mountainous region of Assam.
- From the confluence of Padma and Meghna, the combined river is known as the Meghna which makes a very broad estuary before pouring into the Bay of Bengal.

PENINSULAR RIVER SYSTEM OR PENINSULAR DRAINAGE VS HIMALAYAN RIVER SYSTEM:

EVOLUTION OF PENINSULAR DRINAGE SYSTEM

Theory 1

- Geologists believe that the Sahyadri-Aravali axis was the main water divide in the past.
- According to one hypothesis, the existing peninsula is the remaining half of bigger landmass.
- The Western Ghats were located in the middle of this landmass.
- So one drainage was towards east flowing into Bay of Bengal and the other towards west draining into Arabian Sea.
- The western part of the Peninsula cracked and submerged in the Arabian Sea during the early Tertiary period (coinciding with the formation of Himalayas).
- During the collision of the Indian plate, the Peninsular block was subjected to subsidence in few regions creating a series of rifts (trough, faults).
- The now west flowing rivers of the Peninsula, namely the Narmada and the Tapi flow through these rifts.
- Straight coastline, steep western slope of the Western Ghats, and the absence of delta formations on the western coast makes this theory a possibility.

Theory 2

- It is believed that the west flowing peninsular rivers do not flow in the valleys formed by the rivers themselves.
- Rather they have occupied two fault rifts in rocks running parallel to the Vindhyas.

- These faults are supposed to be caused by bend of the northern part of the Peninsula at the time of upheaval of the Himalayas.
- Peninsular block, south of the cracks, tilted slightly eastwards during the event thus giving the orientation to the entire drainage towards the Bay of Bengal.
- Criticism: Tilting should have increased the gradient of the river valleys and caused some rejuvenation of the rivers. This type of phenomenon is absent in the Peninsula, barring a few exceptions such as waterfalls.

- Rivers that drain into Bay of Bengal: The Mahanadi, the Godavari, the Krishna, the Cauvery and several smaller rivers drains south-east into the Bay of Bengal.
- Rivers that drain into Arabian Sea: The Narmada, the Tapi, the Mahi flowing west as well as several small streams originating from the Western Ghats flow westwards into the Arabian Sea.
- Rivers that drain into the Ganges: Tributaries of the Ganga and the Yamuna such as the Chambal, the Betwa, the Ken, the Son and the Damodar flow in the north-easterly direction.

The Difference:

	The Himalayan River System	The Peninsular River System
	These rivets originate from the lofty Himalayan ranges and are named as the Himalayan rivers.	These rivers originate in the Peninsular Plateau and are named as Peninsular rivers.
Catchment area	These rivers have large basins and catchment areas. The total basin area of the Indus, the Ganga and the Brahmaputra is 11.78, 8.61 and 5.8 lakh square kilometres respectively.	These rivers have small basins and catchment areas. The Godavari has the largest basin area of 3.12 lakh square kilometres only which is less than one-third the basin area of the Indus.
Valleys	The Himalayan rivers flow through deep V – shaped valleys called gorges. These gorges have been carved out by down cutting carried on side by side with the uplift of the Himalayas.	The Peninsular rivers flow in comparatively shallow valleys. These are more or less completely graded valleys. The rivers have little erosional activity to perform.
Drainage Type	These are examples of antecedent drainage.	These are examples of consequent drainage.
Water Flow	The Himalayan rivers are perennial in nature, i.e., water flows throughout the year in these rivers. These rivers receive water both from the monsoons and snow-melt. The perennial nature of these rivers makes them useful for irrigation.	The Peninsular rivers receive water only from rainfall and water flows in these rivers in rainy season only. Therefore, these rivers are seasonal or non-perennial. As such these rivers are much less useful for irrigation.
Stage	These rivers flow across the young fold mountains and are still in a youthful stage.	These rivers have been flowing in one of the oldest plateaus of the world and have reached maturity.
Meanders	The upper reaches of the Himalayan rivers are highly tortuous. When they enter the plains, there is a sudden reduction in the speed of flow of water. Under these circumstances these rivers form meanders and often shift their beds.	The hard rock surface and non-alluvial character of the plateau permits little scope for the formation of meanders. As such, the rivers of the Peninsular Plateau follow more or less straight courses.

Deltas and Estuaries	The Himalayan rivers form big deltas at their mouths. The Ganga-Brahmaputra delta is the largest in the world.	Some of the Peninsular rivers, such as the Narmada and the Tapi form estuaries. Other rivers such as the Mahanadi, the Godavari, the Krishna and the Cauvery form deltas. Several small streams originating from the Western Ghats and flowing towards the west enter the Arabian Sea without forming any delta.

East Flowing Peninsular Rivers

1. Mahanadi River 2. Godavari River 3. Krishna River 4. Kaveri (Cauvery) River 5. Pennar River 6. Subarnarekha River	7. Brahamani River 8. Sarada River 9. Ponnaiyar River 10. Vaigai River 11. Mahanadi River

TRIBUTARIES OF MAHANADI RIVER

- Its upper course lies in the saucer-shaped basin called the 'Chhattisgarh Plain'.
- This basin is surrounded by hills on the north, west and south as a result of which a large number of tributaries join the main river from these sides.
- Left bank Tributaries: The Seonath, the Hasdeo, the Mand and the Ib.
- Right bank Tributaries: The Ong, the Tel and the Jonk.

Projects on Mahanadi River

- Two important projects completed during pre-plan period in the basin are the Mahanadi main canal and Tandula reservoir in Chhattisgarh.
- During the plan period, the Hirakud dam, Mahanadi delta project, Hasdeo Bango, Mahanadi Reservoir Project were completed.

Industry in Mahanadi River Basin

- Three important urban centes in the basin are Raipur, Durg and Cuttack.
- Mahanadi basin, because of its rich mineral resource and adequate power resource, has a favorable industrial climate.
- The Important industries presently existing in the basin are the Iron and Steel plant at Bhilai, aluminium factories at Hirakud and Korba, paper mill near Cuttack and cement factory at Sundargarh.
- Other industries based primarily on agricultural produce are sugar and textile mills.
- Mining of coal, iron and manganese are other industrial activities.

Floods in Mahanadi River Basin

- The basin is subject to severe flooding occasionally in the delta area due to inadequate carrying capacity of the channels.
- The multi-purpose Hirakud dam provides some amount of flood relief by storing part of flood water.
- However, the problem still persists and a lasting solution need to be evolved.

GODAVARI RIVER

- The Godavari is the largest river system of the Peninsular India and is revered as Dakshina Ganga.
- The Godavari basin extends over states of Maharashtra, Andhra Pradesh, Chhattisgarh and Odisha in addition to smaller parts in Madhya Pradesh, Karnataka and Union territory of Puducherry (Yanam) having a total area of ~ 3 lakh Sq.km.
- The basin is bounded by Satmala hills, the Ajanta range and the Mahadeo hills on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west.
- The Godavari River rises from Trimbakeshwar in the Nashik district of Maharashtra about 80 km from the Arabian Sea at an elevation of 1,067 m.
- The total length of Godavari from its origin to outfall into the Bay of Bengal is 1,465 km.

Tributaries of Godavari River

- The left bank tributaries are more in number and larger in size than the right bank tributaries.
- The Manjra (724 km) is the only important right bank tributary. It joins the Godavari after passing through the Nizam Sagar.
- Left Bank Tributaries: Dharna, Penganga, Wainganga, Wardha, Pranahita [conveying the combined waters of Penganga, the Wardha and Wainganga], Pench, Kanhan, Sabari, Indravati etc.
- Right Bank Tributaries: Pravara, Mula, Manjra, Peddavagu, Maner etc.
- Below Rajahmundry, the river divides itself into two main streams, the Gautami Godavari on the east and the Vashishta Godavari on the west and forms a large delta before it pours into the Bay of Bengal.
- The delta of the Godavari is of lobate type with a round bulge and many distributaries

Mineral Resources in Godavari Basin

- The upper reaches of the Godavari drainage basin are occupied by the Deccan Traps containing minerals like magnetite, epidote, biotite, zircon, chlorite etc (metallic minerals)..
- The middle part of the basin is principally composed of phyllites, quartzites, amphiboles and granites (rocks).
- The downstream part of the middle basin is occupied mainly by sediments and rocks of the Gondwana group.
- The Gondwanas are principally detritals (waste or debris, in particular organic matter produced by decomposition or loose matter produced by erosion) with some thick coal seams. [Singareni Coal Seam]
- The Eastern Ghats dominate the lower part of the drainage basin and are formed mainly from the Khondalites.

Projects on Godavari River

- Important projects completed during the plan period are Srirama Sagar, Godavari barrage, Upper Penganga, Jaikwadi, Upper Wainganga, Upper Indravati, Upper Wardha.
- Among the on-going projects, the prominent ones are Prnahita-Chevala and Polavaram.

Industry in Godavari Basin

- The major urban Centers in the basin are Nagpur, Aurangabad, Nashik, Rajhmundry.
- Nashik and Aurangabad have large number of industries especially automobile.
- Other than this, the industries in the basin are mostly based on agricultural produce such as rice milling, cotton spinning and weaving, sugar and oil extraction.
- Cement and some small engineering industries also exist in the basin.

Floods and Droughts in Godavari Basin

- Godavari basin faces flooding problem in its lower reaches.
- The coastal areas are cyclone-prone.
- The delta areas face drainage congestion due to flat topography.
- A large portion of Maharashtra falling (Marathwada) in the basin is drought prone.

KRISHNA RIVER

- The Krishna is the second largest east flowing river of the Peninsula.
- The Krishna Basin extends over Andhra Pradesh, Maharashtra and Karnataka having a total area of ~2.6 lakh Sq.km.
- It is bounded by Balaghat range on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west.
- The Krishna River rises from the Western Ghats near Jor village of Satara district of Maharashtra at an altitude of 1,337 m just north of Mahabaleshwar.
- The total length of river from origin to its outfall into the Bay of Bengal is 1,400 km.
- The major part of basin is covered with agricultural land accounting to 75.86% of the total area.
- The Krishna forms a large delta with a shoreline of about 120 km. The Krishna delta appears to merge with that formed by the Godavari and extends about 35 km into the sea.

Tributaries of Krishna River

- Right bank: the Ghatprabha, the Malprabha and the Tungabhadra.
- Left Bank: the Bhima, the Musi and the Munneru.
- The Koyna is a small tributary but is known for Koyna Dam. This dam was perhaps the main cause of the devastating earthquake (6.4 on richter scale) in 1967 that killed 150 people.
- The Bhima originates from the Matheron Hills and joins the Krishna near Raichur after for a distance of 861 km.
- The Tungabhadra is formed by the unification of the Tunga and the Bhadra originating from Gangamula in the Central Sahyadri. Its total length is 531 km.

- At Wazirabad, it receives its last important tributary, the Musi, on whose banks the city of Hyderabad is located.

Projects on Krishna River

- Important ones are the Tungabhadra, Ghataprabha, Nagarjunasagar, Malaprabha, Bhima, Bhadra and Telugu Ganga.
- The major Hydro Power stations in the basin are Koyna, Tungabhadara, Sri Sailam, Nagarjuna Sagar, Almatti, Naryanpur, Bhadra.
- Tunagabhadra is a major inter-States project in the basin. In order to operate the project and to regulate the flows among the beneficiary States of Karnataka and Andhara Pradesh.

Resources in Krishna Basin

- The basin has rich mineral deposits and there is good potential for industrial development.
- Iron and steel, cement, sugar cane vegetable oil extraction and rice milling are important industrial activities at present in the basin.
- Recently oil has been struck in this basin which is bound to have an effect on the future industrial scenario of this basin.

Industry in Krishna Basin

- The major Urban Centers in the Basin are Pune, Hyderabad.
- Hyderabad is the state capital of Telangana and is now a major IT hub.
- Pune in Maharashtra has number of automobile and IT industry and is major education centre.

Drought and Floods in Krishna Basin

- Some parts of the basin, especially the Rayalaseema area of Andhra Pradesh, Bellary, Raichur, Dharwar, Chitradurga, Belgaum and Bijapur districts of Karnataka and Pune, Sholapur, Osmanabad and Ahmedanagar districts of Maharashtra are drought-prone.
- The delta area of the basin is subject to flooding. It has been observed that the river bed in delta area is continuously raised due to silt deposition resulting in reduction in carrying capacity of the channel.
- The coastal cyclonic rainfall of high intensity and short duration makes the flood problem worse.

EAST FLOWING PENINSULAR RIVERS:

CAUVERY, PENNAR, SUBARNAREKHA, PONNAIYAR & VAIGAI:

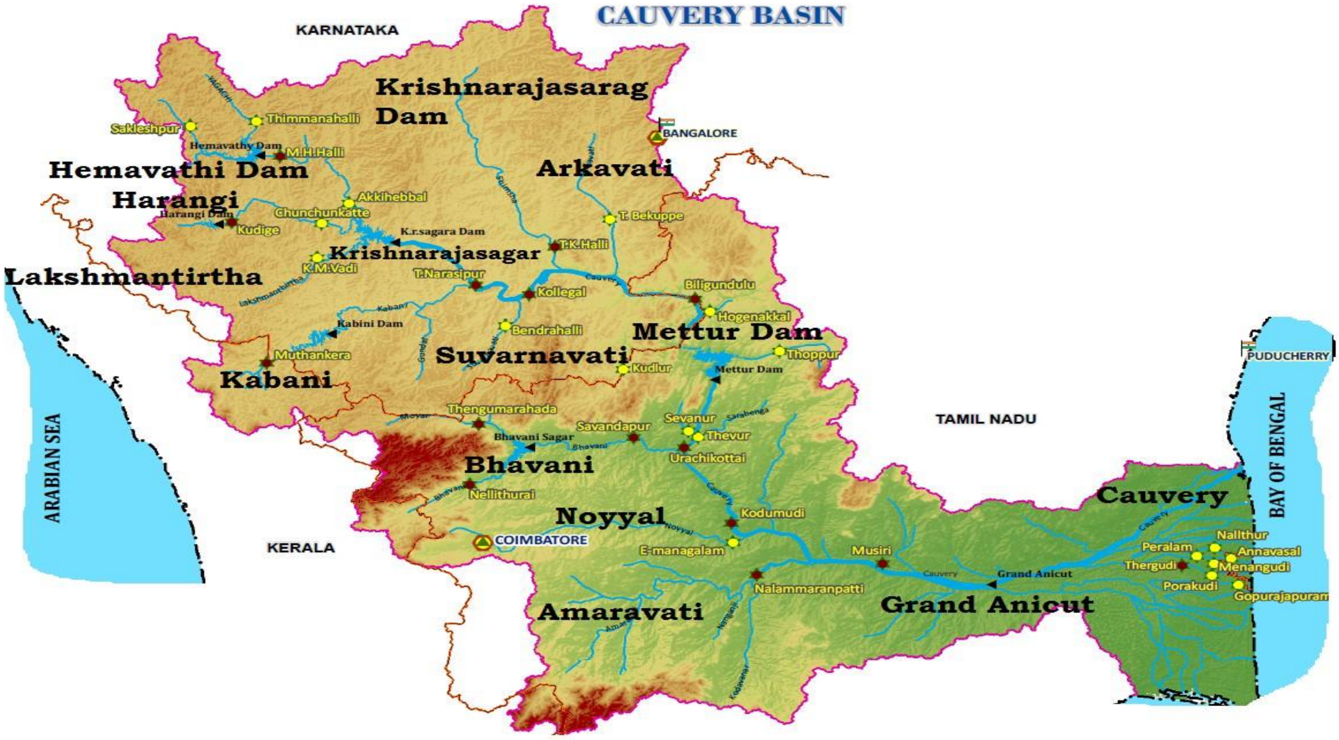
CAUVERY RIVER

- The Kaveri (Cauvery) is designated as the 'the Ganga of the South'.
- The Cauvery River rises at an elevation of 1,341 m at Talakaveri on the Brahmagiri range near Cherangala village of Kodagu (Coorg) district of Karnataka.
- The total length of the river from origin to outfall is 800 km.
- The Cauvery basin extends over states of Tamil Nadu, Karnataka, Kerala and Union Territory of Puducherry draining an area of 81 thousand Sq.km.
- It is bounded by the Western Ghats on the west, by the Eastern Ghats on the east and the south and by the ridges separating it from Krishna basin and Pennar basin on the north.
- The Nilgiris, an offshore of Western ghats, extend Eastwards to the Eastern ghats and divide the basin into two natural and political regions i.e., Karnataka plateau in the North and the Tamil Nadu plateau in the South.
- Physiographically, the basin can be divided into three parts – the Westen Ghats, the Plateau of Mysore and the Delta.

- The delta area is the most fertile tract in the basin. The principal soil types found in the basin are black soils, red soils, laterites, alluvial soils, forest soils and mixed soils. Red soils occupy large areas in the basin. Alluvial soils are found in the delta areas.
- The basin in Karnataka receives rainfall mainly from the S-W Monsoon and partially from N-E Monsoon. The basin in Tamil Nadu receives good flows from the North-East Monsoon.
- Its upper catchment area receives rainfall during summer by the south-west monsoon and the lower catchment area during winter season by the retreating north-east monsoon.
- It is, therefore almost a perennial river with comparatively less fluctuations in flow and is very useful for irrigation and hydroelectric power generation.
- Thus the Cauvery is one of the best regulated rivers and 90 to 95 per cent of its irrigation and power production potential already stands harnessed.
- The river drains into the Bay of Bengal. The major part of basin is covered with agricultural land accounting to 66.21% of the total area.

Tributaries of the Cauvery River

- **Left Bank**: the Harangi, the Hemavati, the Shimsha and the Arkavati.
- **Right Bank**: Lakshmantirtha, the Kabbani, the Suvarnavati, the Bhavani, the Noyil and the Amaravati joins from right.
- The river descends from the South Karnataka Plateau to the Tamil Nadu Plains through the Sivasamudram waterfalls (101 m high).
- At Shivanasamudram, the river branches off into two parts and falls through a height of 91 m. in a series of falls and rapids.
- The falls at this point is utilized for power generation by the power station at Shivanasamudram.
- The two branches of the river join after the fall and flow through a wide gorge which is known as 'Mekedatu' (Goats leap) and continues its journey to form the boundary between Karnataka and Tamil Nadu States for a distance of 64 km.
- At Hogennekkal Falls, it takes Southerly direction and enters the Mettur Reservoir.
- A tributary called Bhavani joins Cauvery on the Right bank about 45 Kms below Mettur Reservoir. Thereafter it enters the plains of Tamil Nadu.
- Two more tributaries Noyil and Amaravathi join on the right bank and here the river widens with sandy bed and flows as 'Akhanda Cauvery'.
- Immediately after crossing Tiruchirapalli district, the river divides into two parts, the Northern branch being called 'The Coleron' and Southern branch remains as Cauvery and from here the Cauvery Delta begins.
- After flowing for about 16 Kms, the two branches join again to form 'Srirangam Island'.
- On the Cauvery branch lies the "Grand Anicut" said to have been constructed by a Chola King in 1st Century A.D.
- Below the Grand Anicut, the Cauvery branch splits into two, Cauvery and Vennar.
- These branches divide and sub-divide into small branches and form a network all over the delta.



Floods in Cauvery Basin

- The Cauvery basin is fan shaped in Karnataka and leaf shaped in Tamil Nadu. The run-off does not drain off quickly because of its shape and therefore no fast raising floods occur in the basin.

Projects on Cauvery River

- During the pre-plan period many projects were completed in this basin which included Krishnarajasagar in Karnataka, Mettur dam and Cauvery delta system in Tamil Nadu.
- Lower Bhavani, Hemavati, Harangi, Kabini are important projects completed duing the plan period.

Industry in Cauvery Basin

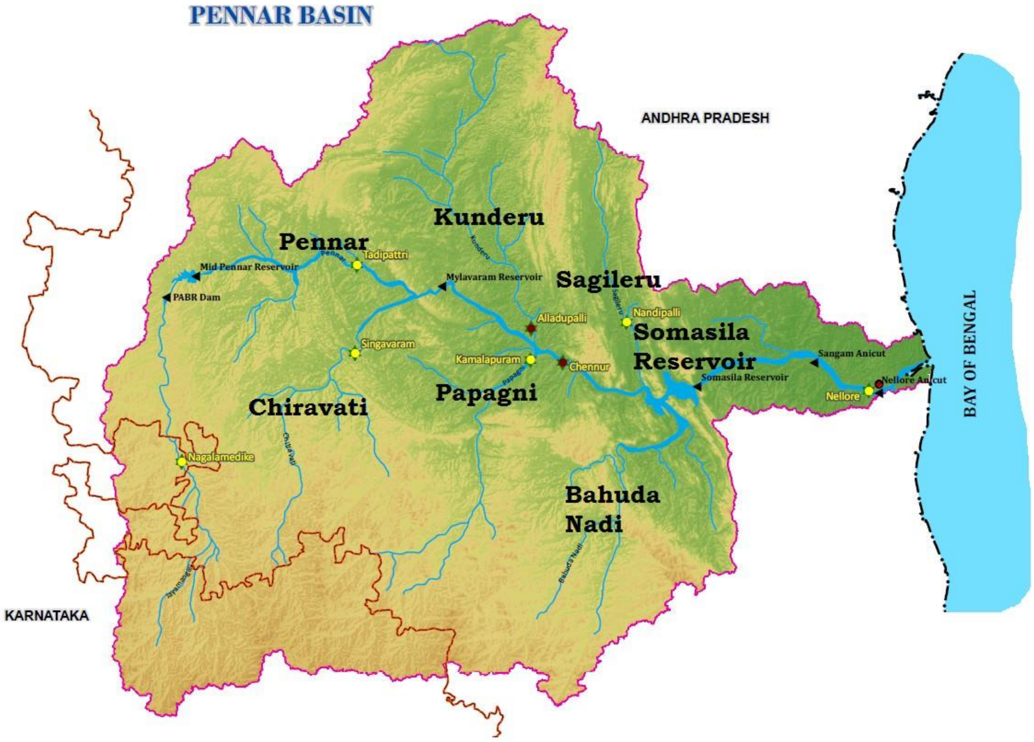
- The city of Bangalore is situated just outside this basin.
- Important industries in the basin include cotton textile industry in Coimbatore and Mysore, cement factories in Coimbatore and Trichinapally and industries based on mineral and metals.
- The Salem steel plant and many engineering industies in Coimbatore and Trichinapally are also situated in this basin.

PENNAR RIVER

- The Pennar (also known as Uttara Pinakini) is one of the major rivers of the peninsula.
- The Pennar rises in the Chenna Kasava hill of the Nandidurg range, in Chikkaballapura district of Karnataka and flows towards east eventually draining into the Bay of Bengal.
- The total length of the river from origin to its outfall in the Bay of Bengal is 597 km.
- Located in peninsular India, the Pennar basin extends over states of Andhra Pradesh and Karnataka having an area of ~55 thousand Sq.km
- The fan shaped basin is bounded by the Erramala range on the north, by the Nallamala and Velikonda ranges of the Eastern Ghats on the east, by the Nandidurg hills on the south and by the narrow ridge separating it from the Vedavati valley of the Krishna Basin on the west.
- The other hill ranges in the basin to the south of the river are the Seshachalam [famous for Red Sanders] and Paliconda ranges.
- The major part of basin is covered with agriculture accounting to 58.64% of the total area.

Tributaries of Pennar River

- Left Bank: the Jayamangali, the Kunderu and the
- Right bank: the Chiravati, the Papagni etc.



Projects on Pennar River

- Tungabhadra high level canal in Krishna basin irrigated areas in Pennar basin also. The only major project in the basin is the Somasila project.

Industry in Pennar Basin

- The only important town in the basin is With limited water and power potential and mineral resources, the scope for industrial development is limited in the basin.
- There are no major industries. The existing small industries are mostly based on agricultural produce such as cotton weaving, sugar mills, oil mills, rice mills etc.

Subarnarekha

- The Subarnarekha originates from the Ranchi Plateau in Jharkhand forming the boundary between West Bengal and Odisha in its lower course.
- It joins Bay of Bengal forming an estuary between the Ganga and Mahanadi deltas. Its total length is 395 km.

Brahamani River

- The Brahmani river comes into existence by the confluence of the Koel and the Sankh rivers near Rourkela. It has a total length of 800 km.
- The basin is bounded in the North by Chhotanagpur plateau, in the West and South by the Mahanadi basin and in the East by the Bay of Bengal.
- The basin flows through Jharkhand, Chhattisgarh and Orissa States and drains into Bay of Bengal.

Ponnaiyar River

- The Ponnaiyar is a small stream which is confined to the coastal area only.
- It covers a small area in the state of Tamil Nadu, Karnataka and Andhra Pradesh.
- The Basin is bounded on the North -West and South by various ranges of the Eastern Ghats like the Velikonda Range, the Nagari hills, the Javadu hills, the Shevaroy hills, the Chitteri hills and the Kalrayan hills and in the East by the Bay of Bengal.

Vaigai River

- South of the Cauvery delta, there are several streams, of which the Vaigai is the longest.
- The Vaigai basin is an important basin among the 12 basins lying between the Cauvery and Kanyakumari.
- This basin is bounded by the Varushanadu hills, the Andipatti hills, the Cardaman hills and the Palani hills on the West and by the Palk strait and Palk Bay on the East.
- The Vaigai drains an area of 7,741 Sq.Km, which entirely lies in the state of Tamil Nadu.
-

WEST FLOWING PENINSULAR RIVERS

Narmada, Tapti, Sabarmati, Mahi, Luni & Ghaggar:

- The west flowing rivers of the Peninsular India are fewer and smaller as compared to their east flowing counterparts.
- The two major west flowing rivers are the Narmada and the Tapi.
- This exceptional behavior is because these rivers didn't form valleys and instead they flow through faults (linear rift, rift valley, trough) created due to the bending of the northern peninsula during the formation process of Himalayas.
- These faults run parallel to the Vindhyas and the Satpuras.
- The Sabarmati, Mahi and Luni are other rivers of the Peninsular India which flow westwards.
- Hundreds of small streams originating in the Western Ghats flow swiftly westwards and join the Arabian Sea.
- It is interesting to note that the Peninsular rivers which fall into the Arabian Sea do not form deltas, but only estuaries. {Fluvial Depositional Landforms}
- This is due to the fact that the west flowing rivers, especially the Narmada and the Tapi flow through hard rocks and hence do not carry any good amount of silt.
- Moreover, the tributaries of these rivers are very small and hence they don't contribute any silt.
- Hence these rivers are not able to form distributaries or a delta before they enter the sea.

NARMADA RIVER

- Narmada is the largest west flowing river of the peninsular India.
- Narmada flows westwards through a rift valley between the Vindhyan Range on the north and the Satpura Range on the south.
- It rises from Maikala range near Amarkantak in Madhya Pradesh, at an elevation of about 1057 m.
- Narmada basin extends over states of Madhya Pradesh, Gujarat, Maharashtra and Chhattisgarh having an area ~1 Lakh Sq.km.
- It is bounded by the Vindhyas on the north, Maikala range on the east, Satpuras on the south and by the Arabian Sea on the west.
- Its total length from its source in Amarkantak to its estuary in the Gulf of Khambhat is 1,310 km.
- The hilly regions are in the upper part of the basin, and lower middle reaches are broad and fertile areas well suited for cultivation.
- Jabalpur is the only important urban centre in the basin.

- The river slopes down near Jabalpur where it cascades (a small waterfall, especially one in a series) 15 m into a gorge to form the Dhuan Dhar (Cloud of Mist) Falls.
- Since the gorge is composed of marble, it is popularly known as the Marble Rocks.
- It makes two waterfalls of 12 m each at Mandhar and Dardi. Near Maheshwar the river again descends from another small fall of 8 m, known as the Sahasradhara Falls.
- There are several islands in the estuary of the Narmada of which Aliabet is the largest.
- The Narmada is navigable upto 112 km from its mouth.

Tributaries of Narmada River

- Since the river flows through a narrow valley confined by precipitous (dangerously high or steep) hills, it does not have many tributaries.
- The absence of tributaries is especially noted on the right bank of the river where the Hiran is the only exception.
- The other right bank tributaries are the Orsang, the Barna and the Kolar.
- A few left bank tributaries drain the northern slopes of the Satpura Range and join the Narmada at different places.
- The major Hydro Power Project in the basin are Indira Sagar, Sardar Sarovar, Omkareshwar, Bargi & Maheshwar.

TAPTI RIVER

- Second largest west flowing river of the Peninsular India and is known as 'the twin' or 'the handmaid' of the Narmada.
- It originates near Multai reserve forest in Madhya Pradesh at an elevation of 752 m.
- Flows for about 724 km before outfalling into the Arabian Sea through the Gulf of Cambay [Gulf of Khambhat].
- The basin extends over states of Madhya Pradesh, Maharashtra and Gujarat having an area of ~ 65,000 Sq.km
- Situated in the Deccan plateau, the basin is bounded by the Satpura range on the north, Mahadev hills on the east, Ajanta Range and the Satmala hills on the south and by the Arabian Sea on the west.
- The hilly region of the basin is well forested while the plains are broad and fertile areas suitable for cultivation.
- There are two well defined physical regions, in the basin, viz hilly region and plains; the hilly regions comprising Satpura, Satmalas, Mahadeo, Ajanta and Gawilgarh hills are well forested.
- The plain covers the Khandesh areas (Khandesh is a region of central India, which forms the northwestern portion of Maharashtra state) which are broad and fertile suitable for cultivation primarily.

Tributaries of Tapti River

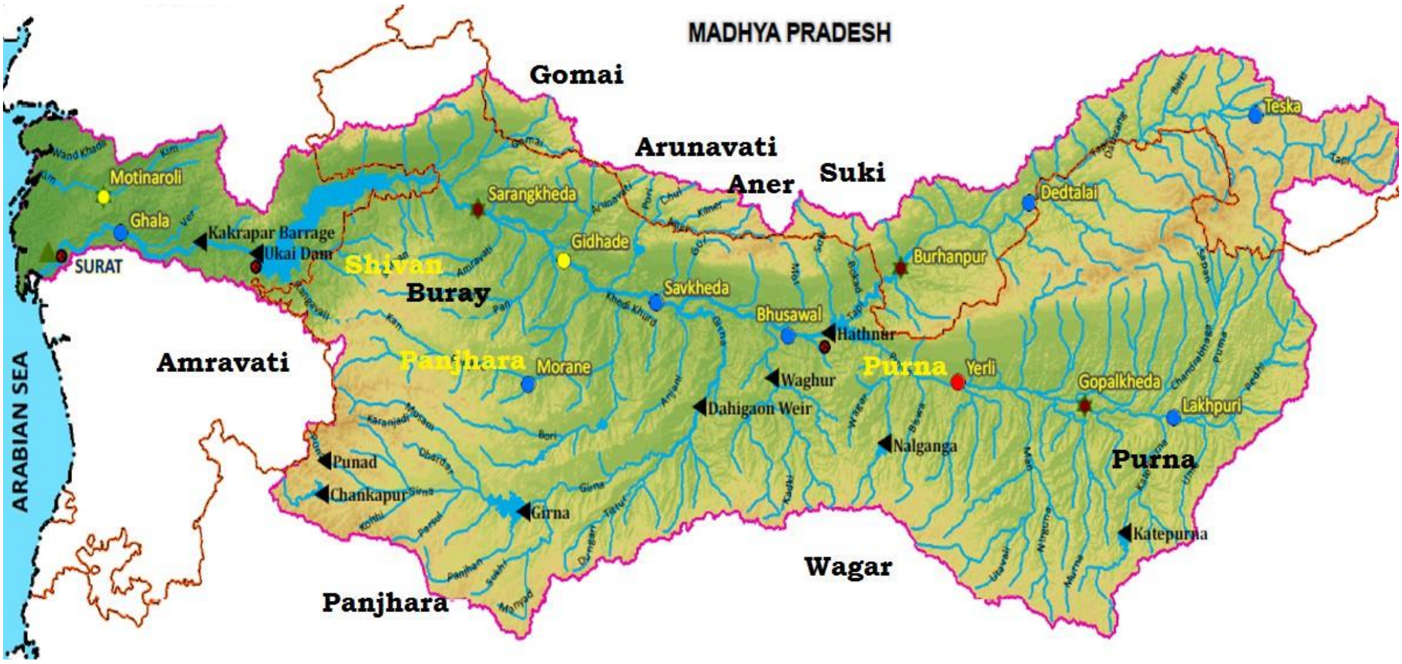
- Right Bank: the Suki, the Gomai, the Arunavati and the Aner.
- Left Bank: the Vaghur, the Amravati, the Buray, the Panjhra, the Bori, the Girna, the Purna, the Mona and the Sipna.

Projects on Tapti River

- Hathnur Dam of Upper Tapi Project (Maharashtra)
- Kakrapar weir and Ukai Dam of Ukai Project (Gujarat)
- Girna Dam and Dahigam Weir of Girna Project (Maharashtra)

Industry in the Tapti Basin

- Important industries in the basin are textile factories in Surat and paper and news print factory at Nepanagar.



SABARMATI RIVER

- The Sabarmati basin extends over states of Rajasthan and Gujarat having an area of 21,674 Sq km.
- The basin is bounded by Aravalli hills on the north and north-east, by Rann of Kutch on the west and by Gulf of Khambhat on the south.
- The basin is roughly triangular in shape with the Sabarmati River as the base and the source of the Vatrak River as the apex point.
- Sabarmati originates from Aravalli hills

TRIBUTARIES:

- Left bank tributaries: the Wakal, the Hathmati and the Vatrak.
- Right bank tributaries: the Sei.

PROJECTS

- Sabarmati reservoir (Dharoi), Hathmati reservoir and Meshwo reservoir project are major projects completed during the plan period.

INDUSTRY IN SABARMATI BASIN

- Gandhinagar and Ahmedabad are the important urban centers in the basin.

- Important industries are textiles, leather and leather goods, plastic, rubber goods, paper, newsprint, automobile, machine tools, drugs and pharmaceuticals etc.

MAHI RIVER

- The Mahi basin extends over states of Madhya Pradesh, Rajasthan and Gujarat having total area of 34,842 Sq km.
- It is bounded by Aravalli hills on the north and the north-west, by Malwa Plateau on the east, by the Vindhyas on the south and by the Gulf of Khambhat on the west.
- Mahi is one of the major interstate west flowing rivers of India.
- It drains into the Arabian Sea through the Gulf of Khambhat.
- Vadodara is the only important urban centre in the basin. There are not many industries in the basin.
- Some of the industries are cotton textile, paper, newsprint, drugs and pharmaceuticals. Most of these industries are located at Tatlam.

LUNI RIVER

- The Luni or the Salt River (Lonari or Lavanavari in Sanskrit) is named so because its water is brackish below Balotra.
- Luni originates from western slopes of the Aravalli ranges &, it finally flow into the Rann of Kachchh (it gets lost in the marsh). Its total catchment area falls in Rajasthan.
- The peculiarity of this river is that it tends to increase its width rather than deepening the bed because the banks are of soils, which are easily erodible whereas beds are of sand. The floods develop and disappear so rapidly that they have no time to scour the bed.

West flowing Rivers of the Sahyadris (Western Ghats)

- The western slopes of the Western Ghats receive heavy rainfall from the south-west monsoons and are able to feed such a large number of streams.
- Although only about 3% of the areal extent flow swiftly down the steep slope and some of them make waterfalls.
- The Jog or Gersoppa Falls (289 m) made by the Sharavati river is the most famous waterfall of India.

Ghaggar River – Inland Drainage

- Some rivers of India are not able to reach the sea and constitute inland drainage.
- Large parts of the Rajasthan desert and parts of Aksai Chin in Ladakh have inland drainage.
- The Ghaggar is the most important river of inland drainage. It is a seasonal stream which rises on the lower slopes of the Himalayas and forms boundary between Haryana and Punjab.
- It gets lost in the dry sands of Rajasthan near Hanumangarh after traversing a distance of 465 km.
- Its main tributaries are the Tangri, the Markanda, the Saraswati and the Chaitanya.

Usability of Rivers

- Source of fresh water, irrigation, hydro-electric production, navigation etc.
- The Himalayas, Vindhyas, Satpuras, Aravalis, Maikala, Chhotanagpur plateau, Meghalaya plateau, Purvachal, Western and the Eastern Ghats offer possibilities of large scale water power development.
- Lakes and tidal creeks in coastal states possess some of the important and useful waterways
- In the past they were of great importance, which suffered a great deal with the advent of rail and roads.
- Withdrawal of large quantities of water for irrigation resulted in dwindling flow of many rivers.

THE CLIMATE

1. Monsoons – driving mechanism, El Nino, La Nina
2. Seasons
3. Cyclones

INDIAN MONSOONS

- The term monsoon has been derived from the Arabic word mausin or from the Malayan word monsin meaning 'season'.
- Monsoons are seasonal winds (Rhythmic wind movements)(Periodic Winds) which reverse their direction with the change of season.
- The monsoon is a double system of seasonal winds – They flow from sea to land during the summer and from land to sea during winter.
- Some scholars tend to treat the monsoon winds as land and sea breeze on a large scale.
- Monsoons are peculiar to Indian Subcontinent, South East Asia, parts of Central Western Africa etc..
- They are more pronounced in the Indian Subcontinent compared to any other region.
- Indian Monsoons are Convection cells on a very large scale.
- They are periodic or secondary winds which seasonal reversal in wind direction.

SOUTH WEST & NORTH EAST MONSSON

- India receives south-west monsoon winds in summer and north-east monsoon winds in winter.
- South-west monsoons are formed due to intense low pressure system formed over the Tibetan plateau.
- North-east monsoons are associated with high pressure cells over Tibetan and Siberian plateaus.
- South-west monsoons bring intense rainfall to most of the regions in India and north-east monsoons bring rainfall to mainly south-eastern coast of India (Southern coast of Seemandhra and the coast of Tamil Nadu.).
- Countries like India, Indonesia, Bangladesh, Myanmar etc. receive most of the annual rainfall during south-west monsoon season where as South East China, Japan etc., during north-east rainfall season.

Factors responsible for south-west monsoon formation

1. Intense heating of Tibetan plateau during summer months.
2. Permanent high pressure cell in the South Indian Ocean (east to north-east of Madagascar in summer).
3. Factors that influence the onset of south-west monsoons

Above points +

1. Subtropical Jet Stream (STJ).
2. Tropical Easterly Jet (African Easterly Jet).
3. Inter Tropical Convergence Zone.

Factors that influence the intensity of south-west monsoons

1. Strengths of Low pressure over Tibet and high pressure over southern Indian Ocean.
2. Somali Jet (Findlater Jet).
3. Somali Current (Findlater Current).
4. Indian Ocean branch of Walker Cell.
5. Indian Ocean Dipole.

Factors responsible for north-east monsoon formation

- Formation and strengthening of high pressure cells over Tibetan plateau and Siberian Plateau in winter.

- Westward migration and subsequent weakening of high pressure cell in the Southern Indian Ocean.
- Migration of ITCZ to the south of India.

All these will be discussed in detail.

MECHANISM OF INDIAN MONSSONS

1. The origin of monsoons is not fully understood.
2. There are several theories that tried to explain the mechanism of monsoons.

Classical Theory

- Monsoons are mentioned in scriptures like the Rig Veda. But these scriptures didn't make any mention of the monsoon mechanism.
- The first scientific study of the monsoon winds was done by Arab traders.
- Arab traders used the sea route to carry out trade with India and monsoon patterns were of prime importance for them.
- In the tenth century, Al Masudi, an Arab explorer, gave an account of the reversal of ocean currents and the monsoon winds over the north Indian Ocean.
- In seventeenth century, Sir Edmund Halley explained the monsoon as resulting from thermal contrasts between continents and oceans due to their differential heating.

Modern Theories

- Besides differential heating, the development of monsoon is influenced by the shape of the continents, orography (mountains), and the conditions of air circulation in the upper troposphere {jet streams}.
- Therefore, Halley's theory has lost much of its significance and modern theories based on air masses and jet stream are becoming more relevant.

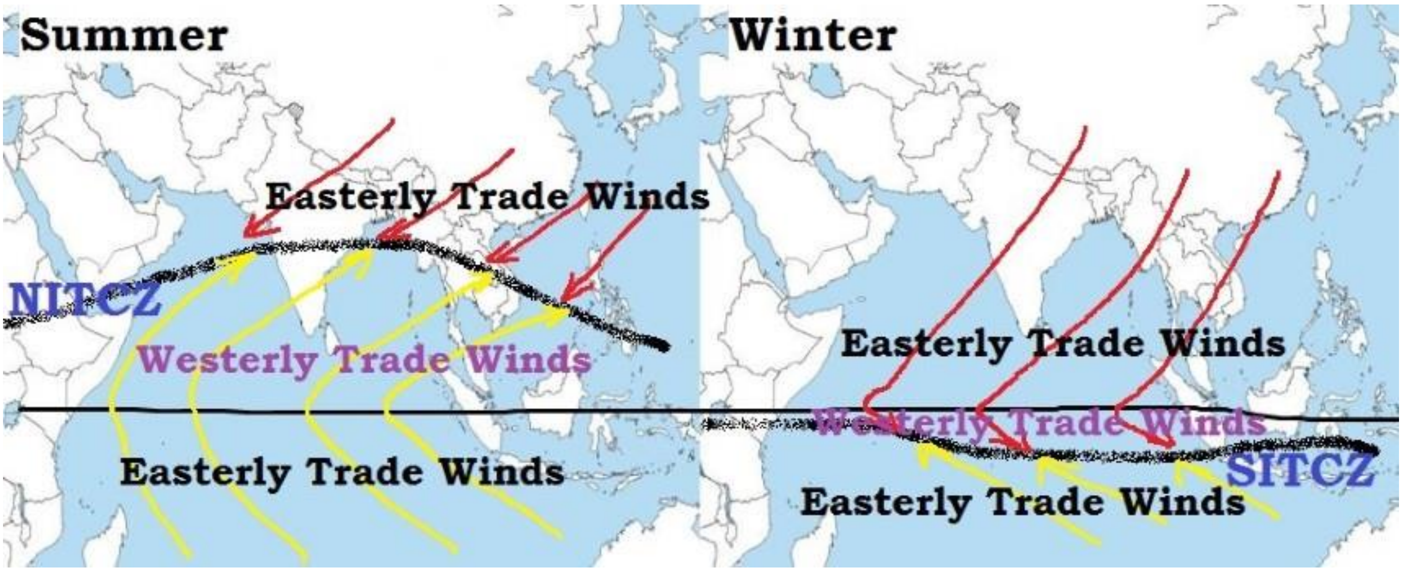
Indian Monsoons – Classical Theory: Sir Edmund Halley's Theory

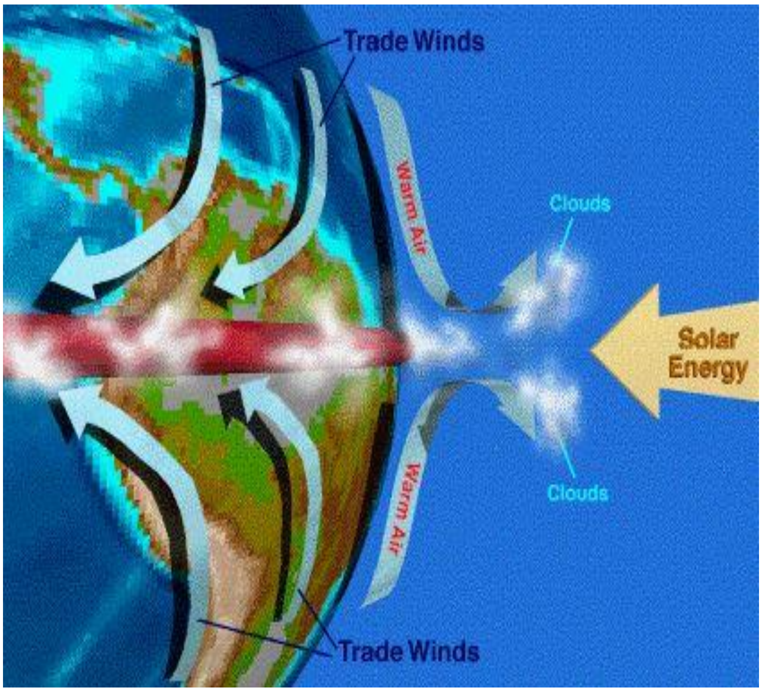
Summer Monsoon	Winter Monsoon
In summer the sun's apparent path is vertically over the Tropic of Cancer resulting in high temperature and low pressure in Central Asia. The pressure is sufficiently high over Arabian Sea and Bay of Bengal. Hence winds flowed from Oceans flow towards landmass in summer. This air flow from sea to land bring heavy rainfall to the Indian subcontinent.	In winter the sun's apparent path is vertically over the Tropic of Capricorn. The north western part of India grows colder than Arabian Sea and Bay of Bengal and the flow of the monsoon is reversed. The basic idea behind Classical theory is similar to land and sea breeze formation except that in the case of monsoons the day and night are replaced by summer and winter.

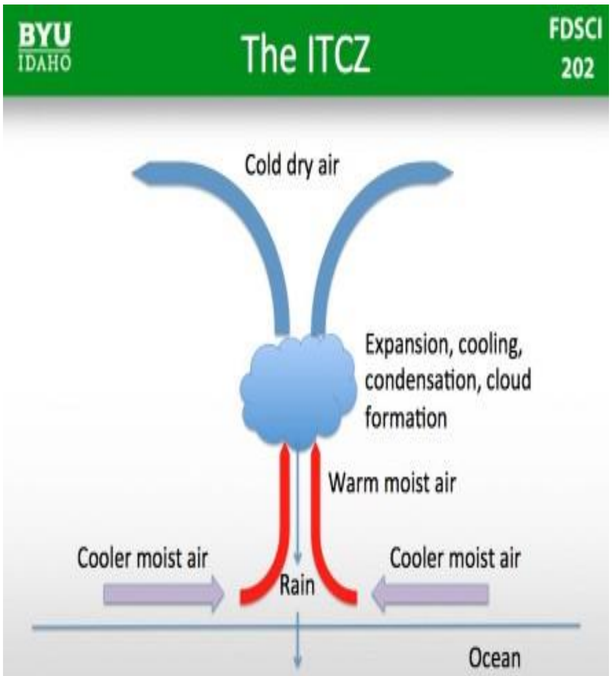
Drawbacks: The monsoons do not develop equally everywhere on earth and the thermal concept of Halley fails to explain the intricacies of the monsoons such as the sudden burst of monsoons, delay in on set of monsoons sometimes, etc..

Indian Monsoons – Modern theory: Air Mass Theory

- According to this theory, the monsoon is simply a modification of the planetary winds of the tropics.
- The theory is based on the migration of ITCZ based on seasons.
- Indian Monsoons – Role of ITCZ [Inter-Tropical Convergence Zone]
- The southeast trade winds in the southern hemisphere and the northeast trade winds in the northern hemisphere meet each other near the equator.
- The meeting place of these winds is known as the Inter-Tropical Convergence Zone (ITCZ).





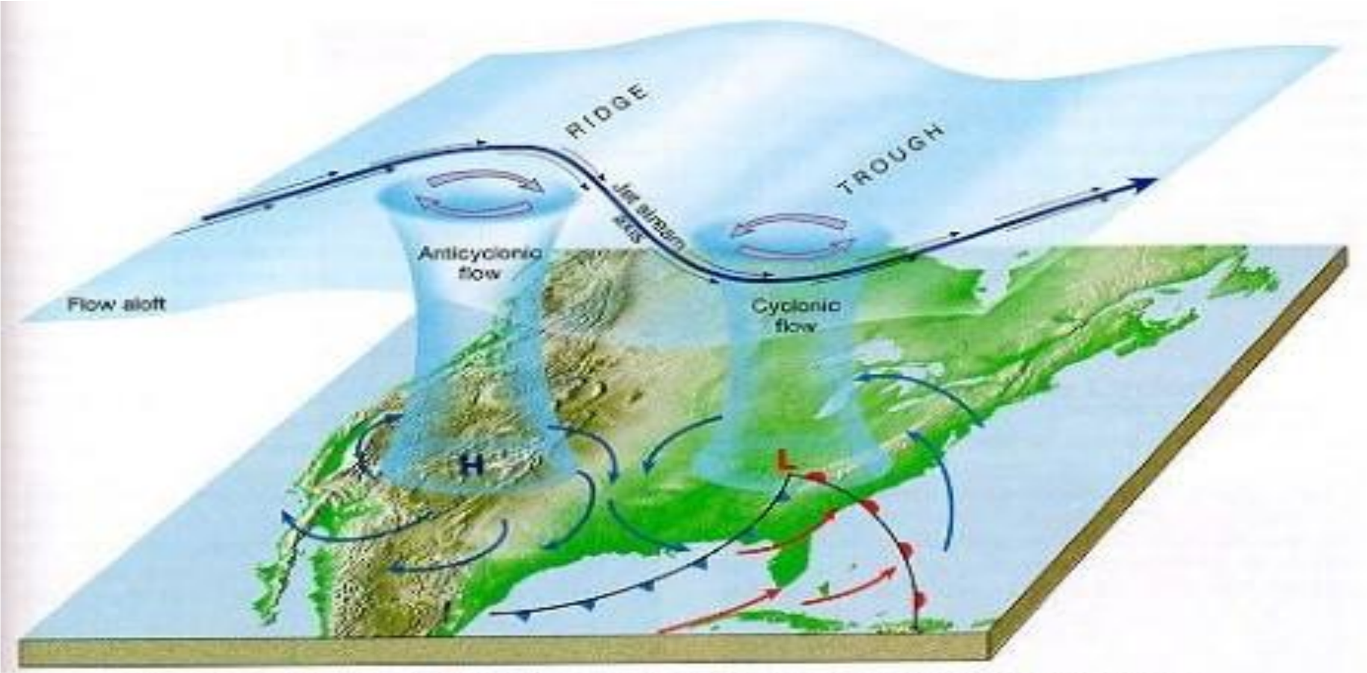


- This is the region of ascending air, maximum clouds and heavy rainfall.
- The location of ITCZ shifts north and south of equator with the change of season.
- In the summer season, the sun shines vertically over the Tropic of Cancer and the ITCZ shifts northwards.
- The southeast trade winds of the southern hemisphere cross the equator and start blowing in southwest to northeast direction under the influence of Coriolis force.
- These displaced trade winds are called south-west monsoons when they blow over the Indian sub-continent.
- The front where the south-west monsoons meet the north-east trade winds is known as the Monsoon Front (ITCZ). Rainfall occurs along this front.
- In the month of July the ITCZ shifts to 20°- 25° N latitude and is located in the Indo-Gangetic Plain and the south-west monsoons blow from the Arabian Sea and the Bay of Bengal. The ITCZ in this position is often called the Monsoon Trough [maximum rainfall].
- The seasonal shift of the ITCZ has given the concept of Northern Inter-Tropical Convergence Zone (NITCZ) in summer (July – rainy season) and Southern Inter-Tropical Convergence Zone (SITCZ) in winter (Jan – dry season).
- NITCZ is the zone of clouds and heavy rainfall that effect India.

ModernJet Stream Theory.

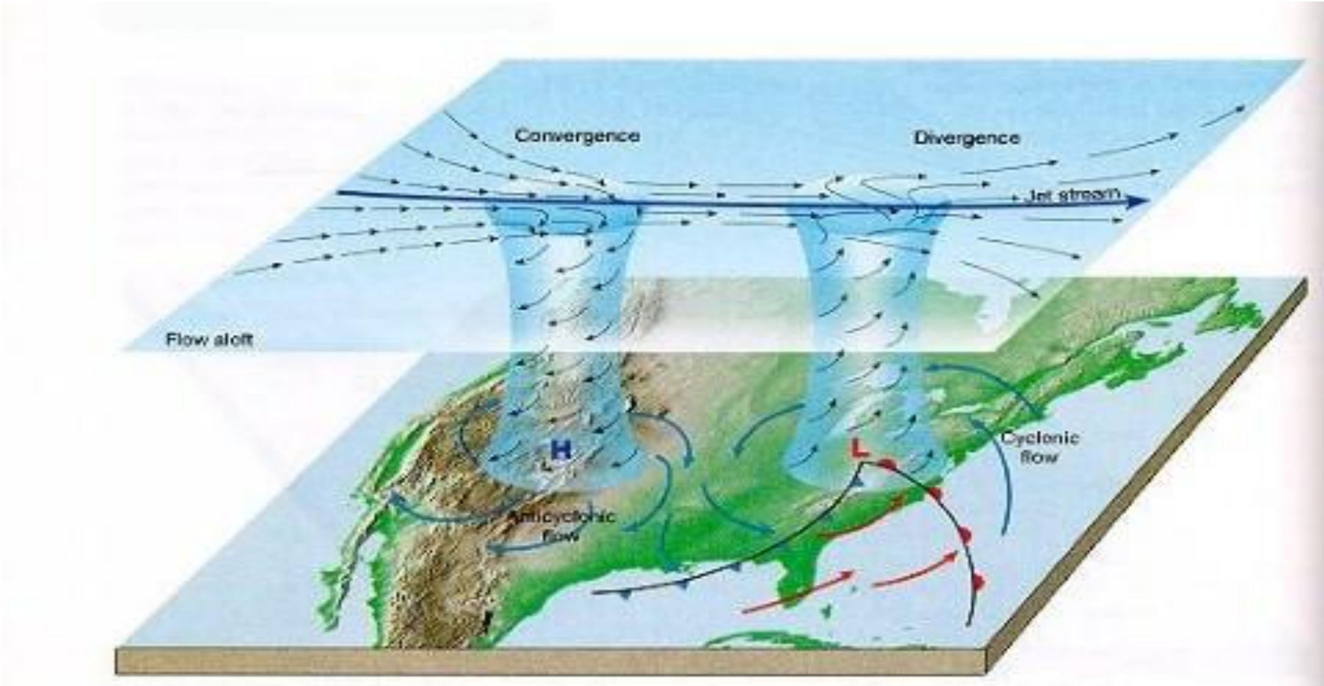
- Jet stream Theory is the latest theory regarding the origin of the monsoons and has earned worldwide acceptance from the meteorologists.
- To understand how Jet streams affect Indian monsoons, we need to know the basic mechanism of Jet Stream induced weather conditions.

How Jet Streams Affect Weather?

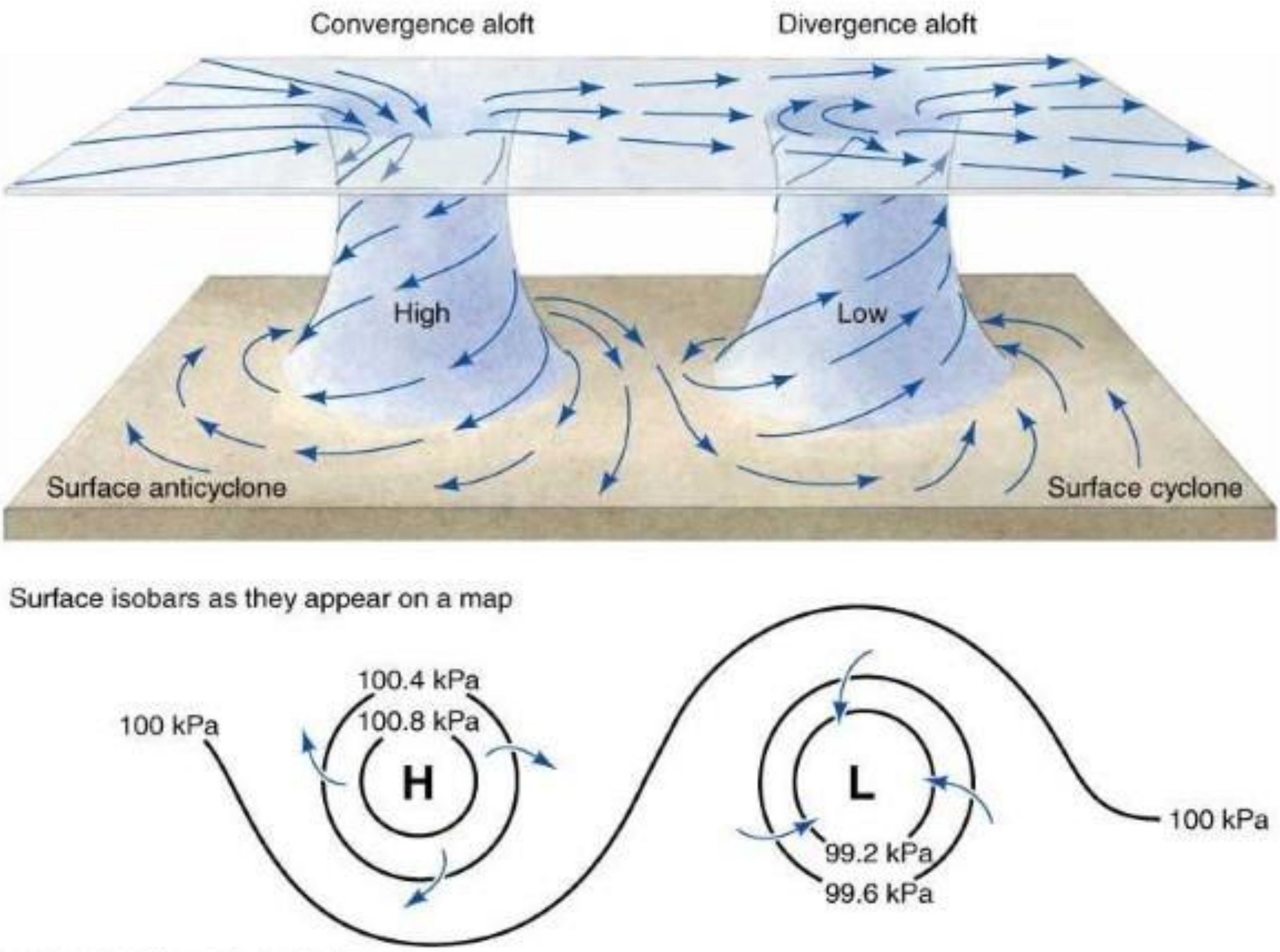


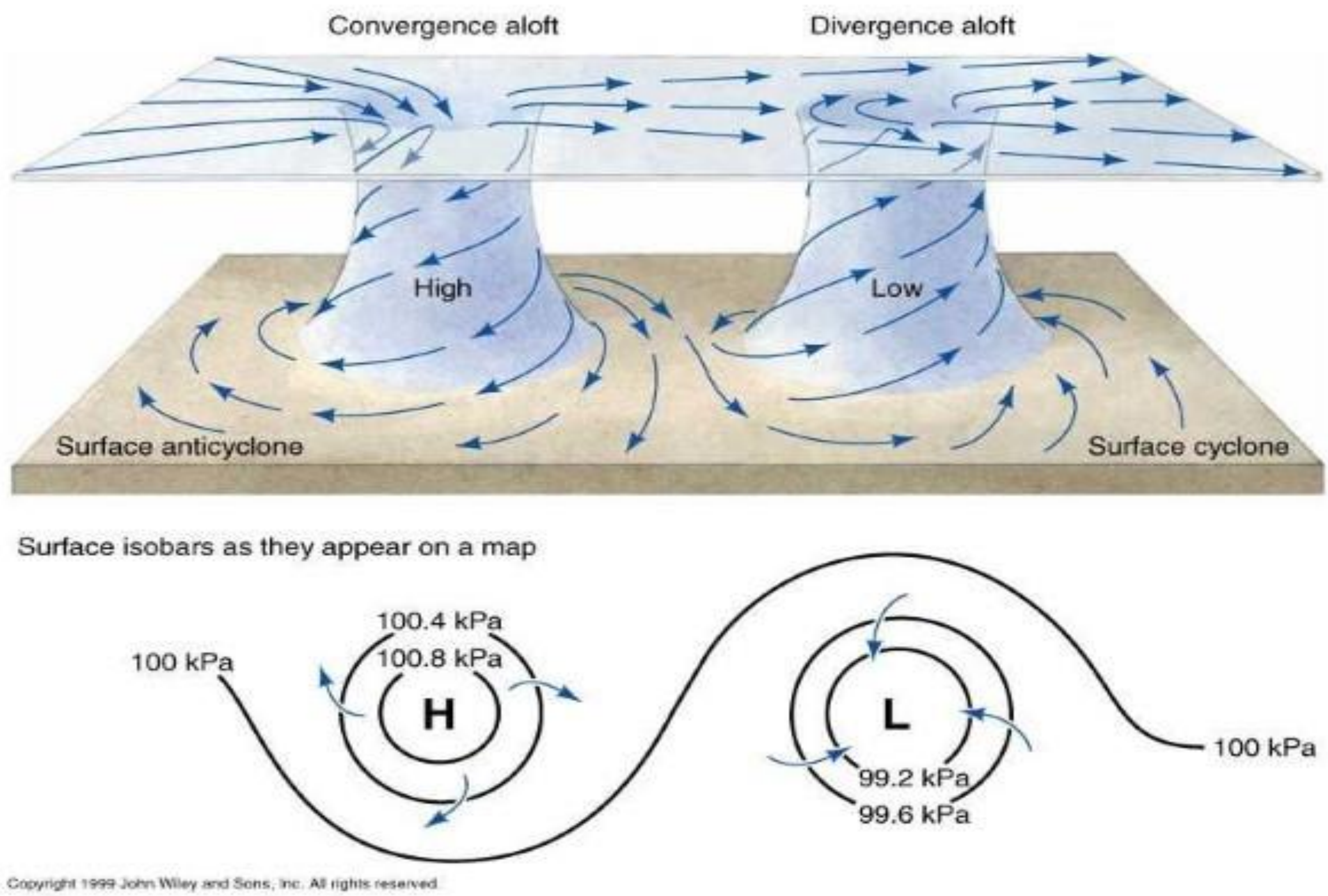
Vorticity provided by flow in the jet stream generates cyclonic flow near a trough and anticyclonic flow adjacent to a ridge.

- Jet streams have distinct peaks (ridges) and troughs.
- Ridges occur where the warm air mass pushes against the cold air mass. Troughs occur where cold air mass drops into warm air.
- The region on earth below the trough is at low pressure and the region below ridge is at high pressure.
- This condition occurs due to weakening of jet stream due to lesser temperature contrast between sub-tropics and temperate region (Our concern is STJ only).
- Usually the trough region [the region exactly below the jet stream trough] creates cyclonic condition (low pressure) at the surface of earth whereas the ridge regions creates anticyclonic condition.
- Troughs create upper level divergence which is associated with convergence at the surface (low pressure – cyclonic conditions) and ridges create upper level convergence which is associated with divergence at the surface (high pressure – cyclonic conditions).
- These ridges and troughs give rise to jet streaks which are also responsible for cyclonic and anticyclonic weather conditions at the surface.



Idealized depiction of the support that divergence and convergence aloft provide to cyclonic and anticyclonic circulation at the surface.





- The winds leaving the jet streak are rapidly diverging, creating a lower pressure at the upper level (Tropopause) in the atmosphere. The air below rapidly replaces the upper outflowing winds. This in turn creates the low pressure at the surface. This surface low pressure creates conditions where the surrounding surface winds rush inwards. The Coriolis effect creates the cyclonic rotation (cyclonic vortex) that is associated with depressions [low pressure cells].
- The winds entering the jet streak are rapidly converging because of the high pressure at the upper level (Tropopause) in the atmosphere. This convergence at upper troposphere leads to divergence (high pressure) at the surface (anticyclonic condition).
- The Coriolis effect creates the anticyclonic rotation that is associated with clear weather.

But how does this mechanism of jet streams influence Indian Monsoons?

SUB TROPICAL JET STREAM

- Sub-Tropical Jet stream plays a significant role in both hindering the monsoon winds as well as in quick onset of monsoons.
- Sub-Tropical Jet stream is a narrow band of fast moving air flowing from west to east [Westerlies].
- STJ in northern hemisphere flows between 25° to 35° N in the upper troposphere at a height of about 12-14 km (all this already discussed in previous posts on Jet Streams). (Here we will consider STJ only. Polar Jet has no influence on Indian monsoons).
- The wind speeds in a westerly jet stream are commonly 150 to 300 km p.h. with extreme values reaching 400 km p.h.
- The burst of monsoons depends upon the upper air circulation which is dominated by STJ.

SEASONAL MIGRATION OF SUB TROPICAL JET STREAM

- In winter STJ flows along the southern slopes of the Himalayas but in summer it shifts northwards, rather dramatically, and flows along the northern edge of Himalayas in early June and in late summer (July-August) along the northern edge of the Tibetan Plateau.
- The periodic movement of the Jet stream is often the indicator of the onset (STJ shits to the north of Himalayas in a matter of days) and subsequent withdrawal (STJ returns back to its position – south of Himalayas) of the monsoon.
- Northward movement of the subtropical jet is the first indication of the onset of the monsoon over India.

STJ – IN WINTER

- Westerly jet stream blows at a very high speed during winter over the sub-tropical zone.
- This jet stream is bifurcated by the Himalayan ranges and Tibetan Plateau.
- The two branches reunite off the east coast of China.
- The northern branch of this jet stream blows along the northern edge of the Tibetan Plateau.
- The southern branch blows to the south of the Himalayan ranges along 25° north latitude.
- A strong latitudinal thermal gradient (differences in temperature), along with other factors, is responsible for the development of southerly jet.

WESTERN DISTURBANCES

- Meteorologists believe that southern branch of jet stream exercises a significant influence on the winter weather conditions in India.
- The upper jet is responsible for steering of the western depressions [Western Disturbances] from the Mediterranean Sea.
- Some of the depressions continue eastwards, redeveloping in the zone of jet stream confluence about 30° N, 105° E (near east coast of China).
- Winter rain and heat storms in north-western plains and occasional heavy snowfall in hilly regions are caused by these disturbances.
- These are generally followed by cold waves in the whole of northern plains.
- The southern branch is stronger, with an average speed of about 240 km compared with 70 to 90 km p.h. of the northern branch.
- Air subsiding beneath this upper westerly current gives dry out blowing northerly winds from the subtropical anticyclone over northwestern India and Pakistan.

Why no south-west monsoons during winter?

Reason 1:

- ITCZ has left India (the winds that blow over India are mostly offshore –– land to land or land to ocean –– so they carry no moisture).

Reason 2:

- During winter, the southern branch of STJ is strong and is to the south of Himalayas. The ridge of the jet lies over north-western India and is associated with strong divergence of winds and creates a high pressure region (sub-tropical high pressure belt) over entire north India. [This is how the mechanism of jet streams influence Indian Monsoons in winter season]

Reason 3:

- There is already a strong high pressure over Tibet. [High Pressure due to STJ + High Pressure over Tibet = strong divergence = no rainfall]

Sub-Tropical Jet Stream – STJ in Summer

- With the beginning of summer in the month of March, the STJ [upper westerlies] start their northward march.
- The southerly branch of STJ remains positioned south of Tibet, although weakening in intensity.
- The weather over northern India becomes hot, dry and squally due to larger incoming solar radiation and hot winds like loo.
- Over India, the Equatorial Trough (ITCZ) pushes northwards with the weakening of the STJ [upper westerlies] south of Tibet, but the burst of the monsoon does not take place until the upper-air circulation has switched to its summer pattern.
- By the end of May the southern jet breaks and later it is diverted to the north of Tibet Plateau and there is sudden burst of monsoons (the ridge moves northwards into Central Asia = high pressure over north-west India moves northwards into Central Asia = makes way for south-west monsoon winds). An Easterly jet emerges over peninsular India with the northward migration of STJ.
- The upper air circulations are reversed with the emergence of Easterly jet [convergence in upper layers is replaced by divergence == divergence in lower layers is replaced with convergence == high pressure at lower layers is replaced by low pressure system]. The easterly winds become very active in the upper troposphere and they are associated with westerly winds in the lower troposphere (south-west monsoon winds).
- Western and eastern jets flow to the north and south of the Himalayas respectively. The eastern jet becomes powerful and is stationed at 15° N latitude.
- This results in more active south-west monsoon and heavy rainfall is caused.

Why no south-west monsoons in March – May (summer)?

- There is good sun's insolation from March – May but still there is no s-w monsoons.
- Reason: The ridge region of Southern branch of STJ creates strong divergence (high pressure) in north-west India. The diverging air blocks incoming winds and prevents strong convergence of winds along ITCZ.
- During the summer season in the Northern Hemisphere, low pressure areas develop at the ground surface near Peshawar (Pakistan) and north-west India due to intense heating of ground surface during April, May, and June.
- As long as the position of the upper air jet stream is maintained above the surface low pressure (to the south of Himalayas), the dynamic anti-cyclonic conditions persist over north-west India.
- The winds descending from the upper air high pressure [because of the ridge of STJ] obstructs the ascent of winds from the surface low pressure areas, with the result that the weather remains warm and dry.
- This is why the months of April and May are generally dry and rainless in spite of high temperatures (low pressure on land) and high evaporation.

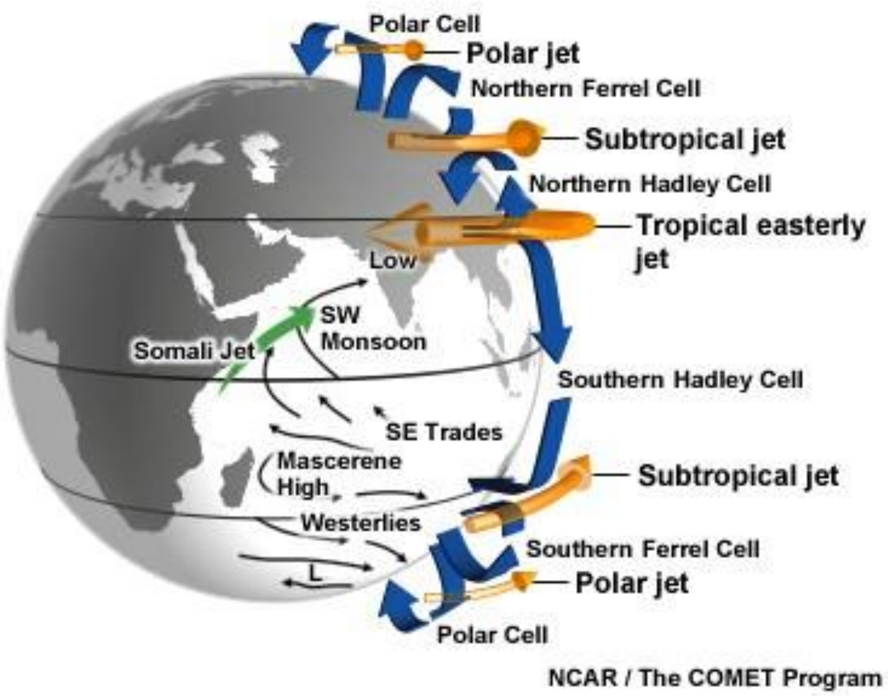
Indian Monsoons – Role of Tropical Easterly Jet (TEJ) [African Easterly Jet]

- The establishment and maintenance of the TEJ is not fully understood but it is believed that the jet may be caused by the uniquely high temperatures and heights over the Tibetan Plateau during summer.
- The TEJ plays an important role in kick starting southwest monsoon.
- This jet descends over the Indian Ocean (near Madagascar) and intensifies its high pressure cell so as to move as south-west monsoon.

Tropical Easterly Jet (TEJ)

- There are major high velocity winds in the lower troposphere called low-level jets (LLJs).

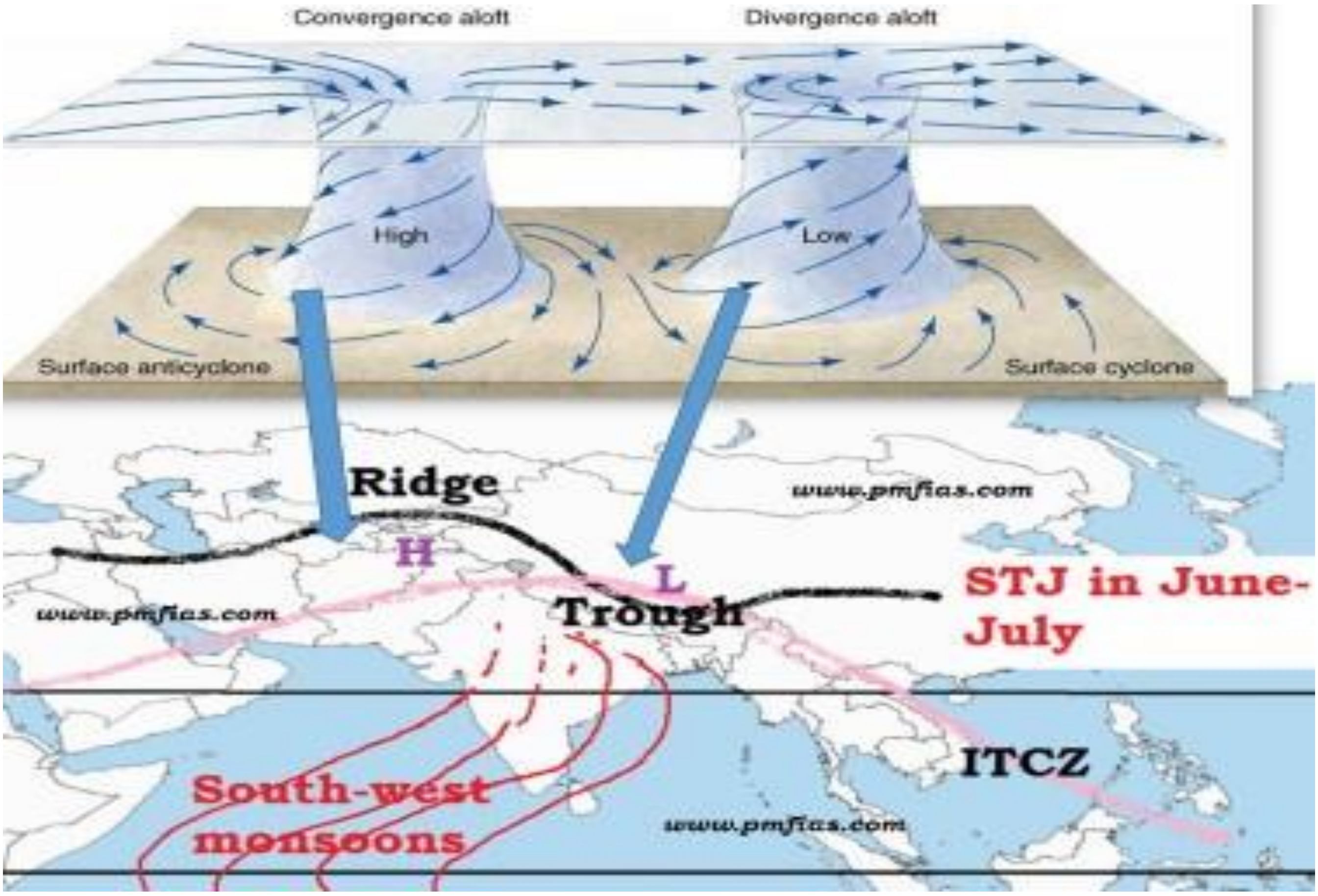
- In the tropics, the most prominent of these are the Somali Jet and the African Easterly Jet [Tropical Easterly Jet].
- The TEJ is a unique and dominant feature of the northern hemispheric summer over southern Asia and northern Africa. The TEJ is found near between 5° and 20°N.
- It is fairly persistent in its direction, and intensity from June through the beginning of October. It's position fluctuates between 5° and 20°N.
- TEJ comes into existence quickly after the STJ has shifted to the north of the Himalayas (Early June).
- TEJ flows from east to west over peninsular India at 6 – 9 km and over the Northern African region.
- The formation of TEJ results in the reversal of upper air circulation patterns [High pressure switches to low pressure] and leads to the quick onset of monsoons.
- Recent observations have revealed that the intensity and duration of heating of Tibetan Plateau has a direct bearing on the amount of rainfall in India by the monsoons.
- When the summer temperature of air over Tibet remains high for a sufficiently long time, it helps in strengthening the easterly jet and results in heavy rainfall in India.
- The easterly jet does not come into existence if the snow over the Tibet Plateau does not melt. This hampers the occurrence of rainfall in India.
- Therefore, any year of thick and widespread snow over Tibet will be followed by a year of weak monsoon and less rainfall.



INDIAN MONSOON ROLE OF TIBET

- The Tibetan Plateau is an enormous block of highland acting as a formidable barrier.
- Due to its protruded height it receives 2-3°C more insolation than the neighboring areas.
- The plateau affects the atmosphere in two ways: (a) as a mechanical barrier, and (b) as a high- level heat sources.
- At the beginning of June the subtropical jet stream is completely withdrawn from India and occupies a position along 40° N (to the north of Tibetan Plateau).
- The plateau accentuates the northward displacement of the jet stream. Hence the burst of monsoon in June is prompted by the Himalayas and not by the thermally induced low pressure cell over Tibet. (Tibetan plateau is responsible for south-west monsoons. But it is the STJ that facilitates sudden outburst of monsoons with its sudden northward migration)

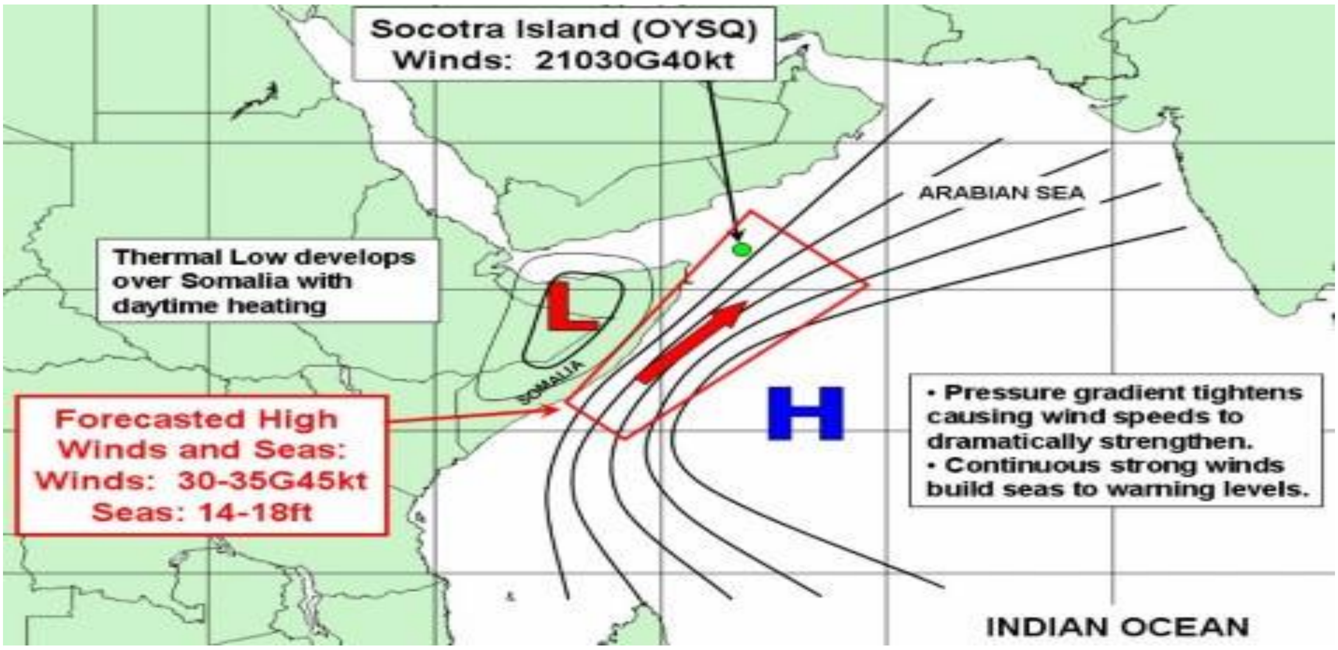
- In the middle of October the plateau proves to be the most important factor in causing the advance of the jet south of the Himalayas or bifurcating it into two parts.
- The winter Tibetan Plateau cools rapidly and produces a high pressure cell. (Cyclonic condition over Tibet ceases and an anticyclonic condition is established). The high pressure cell over Tibet strengthens N-E monsoons.
- Tibet gets heated in summer and is 2°C to 3°C warmer than the air over the adjoining regions.
- Because the Tibet Plateau is a source of heat for the atmosphere, it generates an area of rising air (convergence)(intense low pressure cell).
- During its ascent the air spreads outwards in upper troposphere (divergence) and gradually sinks (subsidence) over the equatorial part of the Indian Ocean.
- It finally approaches the west coast of India as a return current from a south-westerly direction and is termed as equatorial westerlies.
- It picks up moisture from the Indian Ocean and causes rainfall in India and adjoining countries.



INDIAN MONSOON ROLE OF SOMALI JET STREAMS

- Polar and subtropical jet streams are the permanent jet streams which greatly influence the weather of temperate regions.
- Temporary jet streams are narrow winds with speeds more than 94 kph in the upper, middle and sometimes in lower troposphere. They are few. Important ones are Somali Jet and The African Easterly jet or Tropical Easterly Jet.
- These two jet streams play an important role in the formation and progression of Indian Monsoons.
- The progress of the southwest monsoon towards India is greatly aided by the onset of Somali jet that transits Kenya, Somalia and Sahel.

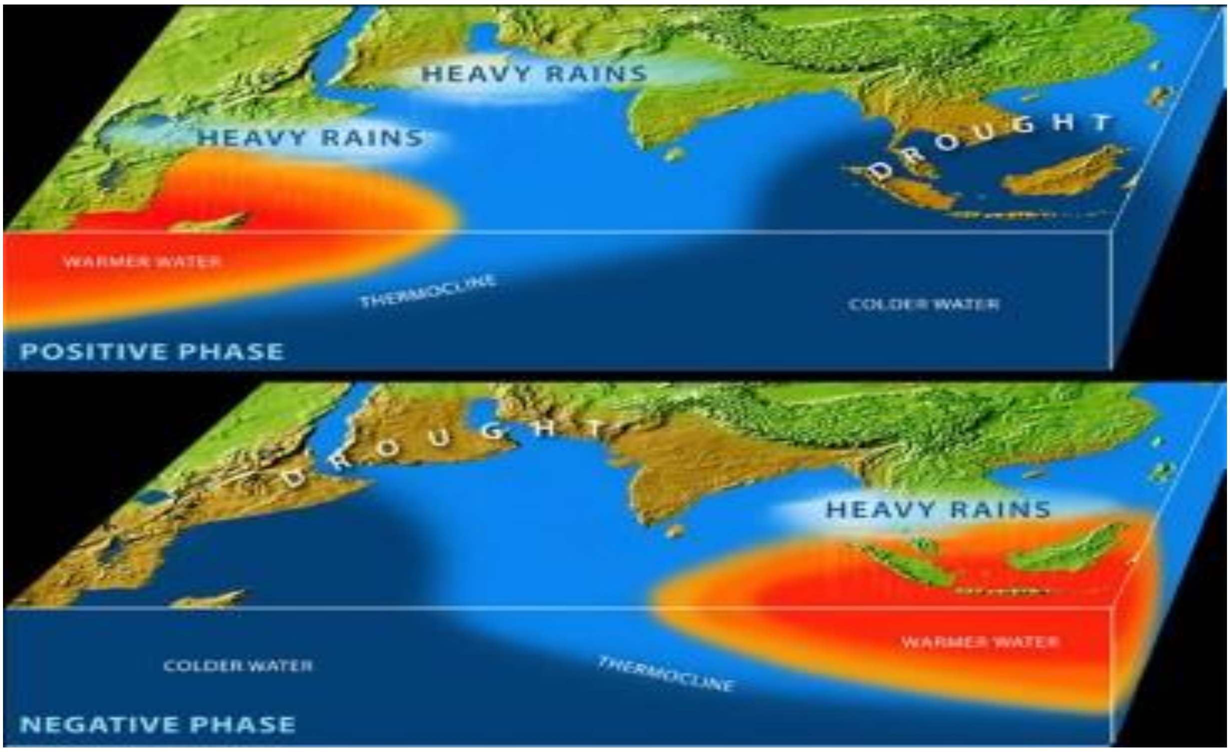
- It was observed to flow from Mauritius and the northern part of the island of Madagascar before reaching the coast of Kenya at about 3º S.
- It strengthens permanent high near Madagascar and also helps to drive S-W monsoons towards India at a greater pace and intensity.
- The importance of the low level jet arises from the fact that its path around 9º N coincides with a zone of coastal upwelling.
- As the strong winds drive away the surface coastal waters towards the east, extremely cold water from the depths of the sea rise upwards to preserve the continuity of mass.
- The peculiar feature of Somali Current is reversal in direction with the onset of the summer monsoon.
- In winter, this current is from north to the south running southwards from the coast of Arabia to the east African coastline; but with the advent of the summer monsoon it reverses its direction and flows from the south to the north.



INDIAN MONSOON ROLE OF INDIAN OCEAN DIPOLE

- Indian ocean Dipole is a recently discovered phenomena that has a significant influence on Indian monsoons.
- Indian ocean Dipole is a SST anomaly (Sea Surface Temperature Anomaly – different from normal) that occurs occasionally in Northern or Equatorial Indian Ocean Region (IOR).
- The Indian Ocean Dipole (IOD) is defined by the difference in sea surface temperature between two areas (or poles, hence a dipole) – a western pole in the Arabian Sea (western Indian Ocean) and an eastern pole in the eastern Indian Ocean south of Indonesia.
- IOD develops in the equatorial region of Indian Ocean from April to May peaking in October.
- With a positive IOD winds over the Indian Ocean blow from east to west (from Bay of Bengal towards Arabian Sea). This results in the Arabian Sea (western Indian Ocean near African Coast) being much warmer and eastern Indian Ocean around Indonesia becoming colder and dry.
- In the negative dipole year, reverse happens making Indonesia much warmer and rainier.
- Positive IOD is good for Indian Monsoons as more evaporation occurs in warm water.
- Similar to ENSO, the atmospheric component of the IOD is named as Equatorial Indian Ocean Oscillation (EQUINOO)(Oscillation of pressure cells between Bay of Bengal and Arabian Sea).

- During the positive phase of the ‘Equatorial Indian Ocean Oscillation (EQUINOO),’ there is enhanced cloud formation and rainfall in western part of the equatorial ocean near the African coast while such activity is suppressed near Sumatra.
- While EQUINOO and IOD go in step during strong positive IOD events, they do not always do so.



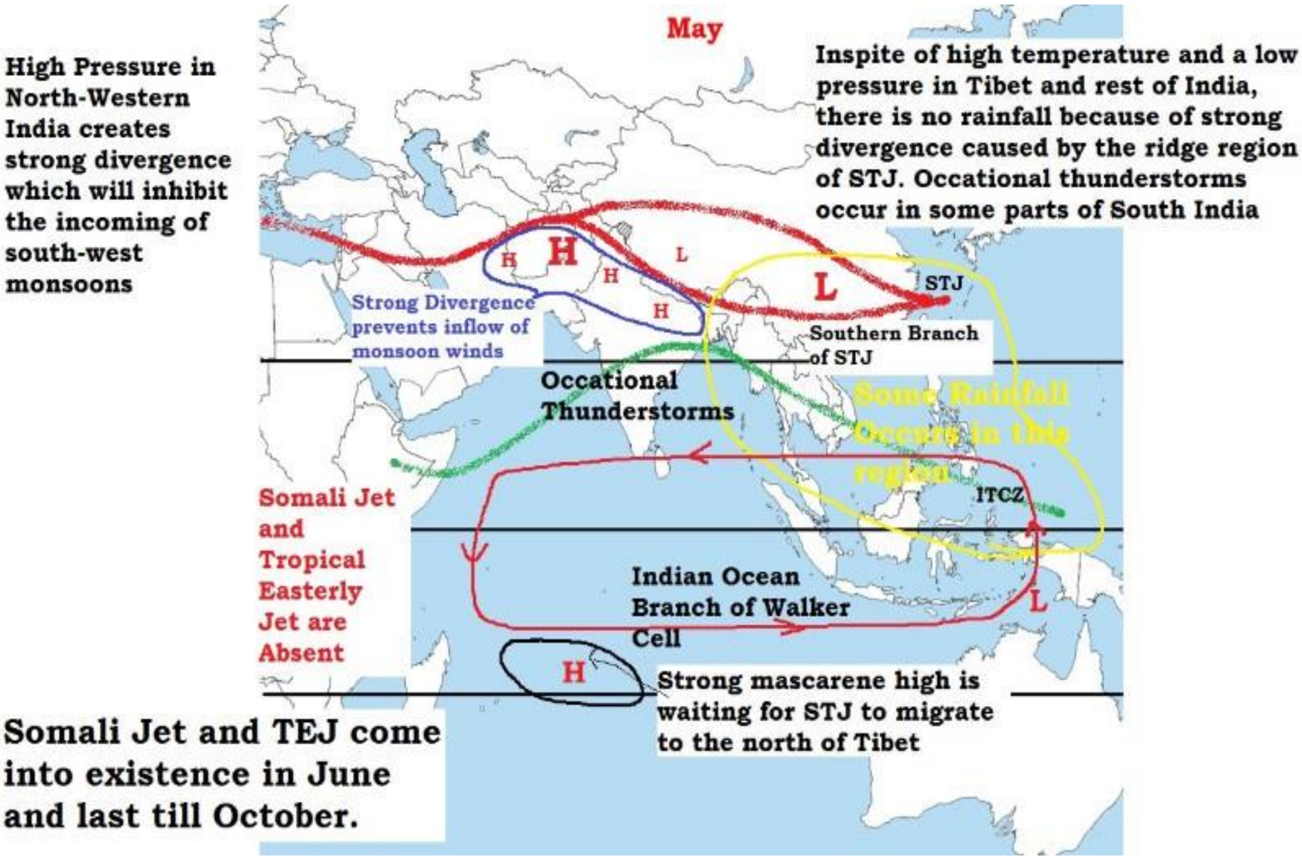
Summing up all the points:

- As the summer time approaches, there is increased solar heating of the Indian subcontinent and the Tibetan Plateau.
- In the peak summer months (25th of May – 10th of Jun), with the apparent northward movement of the sun, the southern branch of the SJT, which flows to the south of the Himalayas, shifts to the north of the Himalayas.
- When the sun’s position is about to reach the Tropic of Cancer (June), the SJT shifts to the north of the Tibetan Plateau (1st of Jun – 20th of June). The ITCZ is close to its peak position over the Tibetan Plateau.
- The altitude of the mountains initially disrupts the jet but once it has cleared the summits it is able to reform over central Asia.
- Its movement towards the north is one of the main features associated with the onset of the monsoon over India.
- With the northward shift of SJT, an Easterly Jet is formed over the Indian plains. It generally forms in the first week of June and lasts till late October.
- It can be traced in the upper troposphere right up to the west coast of Africa.
- The northward shift of SJT and ICTZ moves the subtropical high pressure belt to the north of the Tibetan Plateau and the Easterly Jet creates a low pressure region in the Indian plains (Easterly Jet creates anticyclonic conditions in upper troposphere).
- This low pressure in the northern plains coupled with the intense low of the Tibetan Plateau leads to the sudden onset of south-west monsoons (1st of Jun – 20th of June).
- The monsoon cell is situated between the Indian Ocean (North of Madagascar)(High Pressure Cell) and Tibetan plateau (Low Pressure Cell).
- In summer the sub-tropical easterly jet fluctuates between the plains region of India and peninsular India varying the intensity of rainfall from location to location.

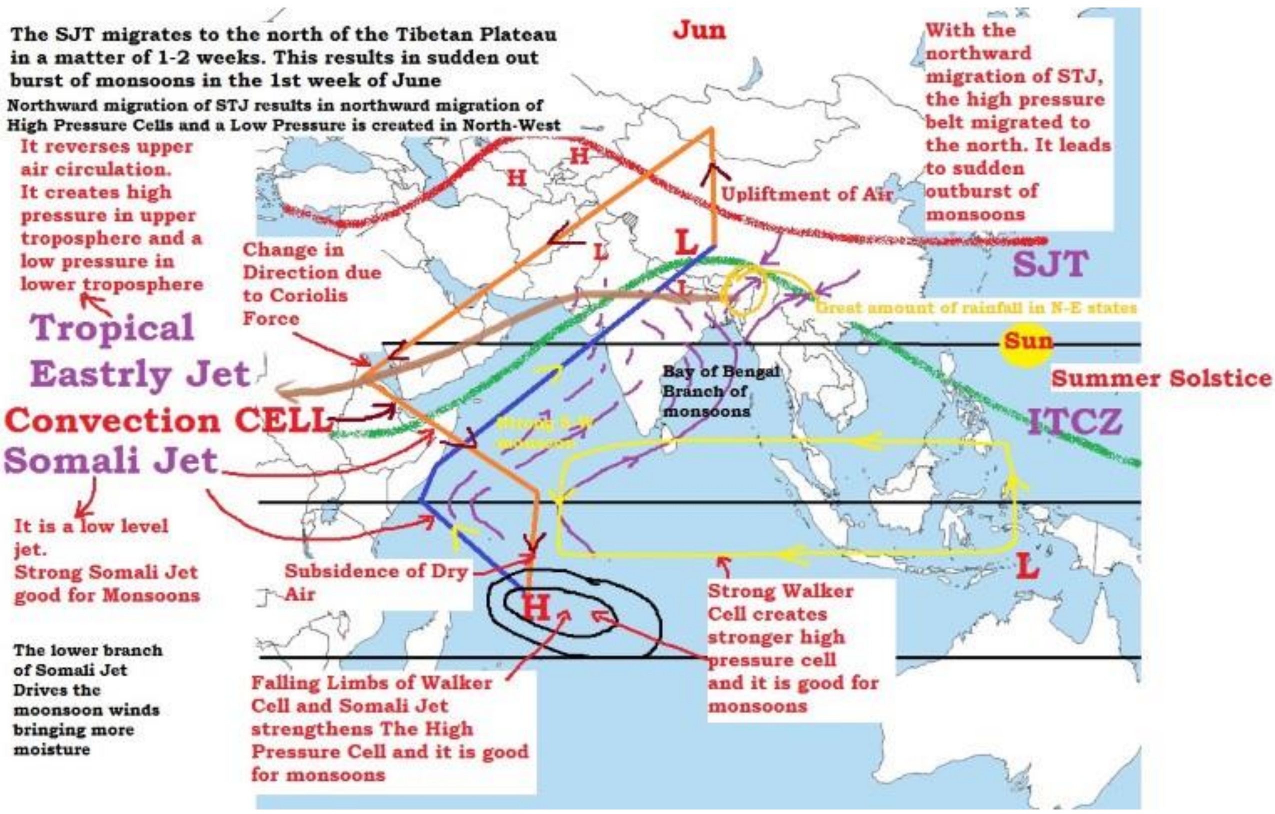
- During March to May, the building up of this cell is blocked by the STJ which tends to blow to the south of the Himalayas (Northwest India and Plains region are occupied by Subtropical High Pressure Belt. This high pressure belt undermines the influence of low pressure cell over Tibet).
- As long as the STJ is in this position the development of summer monsoons is inhibited (the high pressure belt stays over north India).
- With the STJ out of the way (high pressure belt migrates to the north of Tibet) the sub continental monsoon cell develops (Somali Jet) very quickly indeed, often in a matter of a few days.
- Warmth and moisture are fed into the cell by a lower level tropical jet stream which brings with it air masses laden with moisture from the Indian Ocean.
- The end of the monsoon season is brought about when the atmosphere over the Tibetan Plateau begins to cool (August – October), this enables the STJ to transition back across the Himalayas.
- With the southward shift of ITCZ, subtropical high pressure belt returns back to the Indian plains and the rainfall ceases.
- This leads to the formation of a anticyclonic winter monsoon cell typified by sinking air masses over India and relatively moisture free winds that blow seaward.
- This gives rise to relatively settled and dry weather over India during the winter months.

INDIAN MONSOONS SEASONAL VARIATIONS

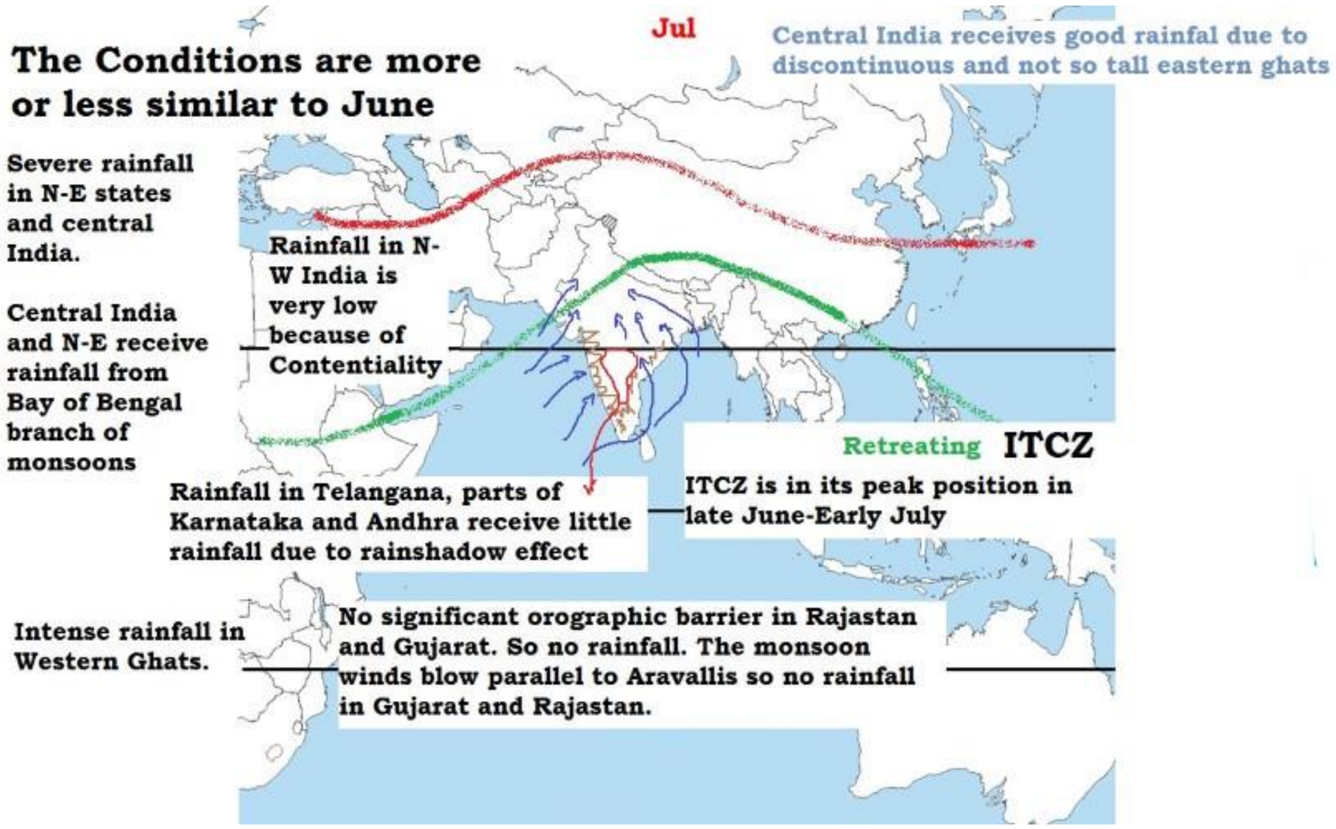
INDIAN MONSOON IN MAY – DRY SEASON



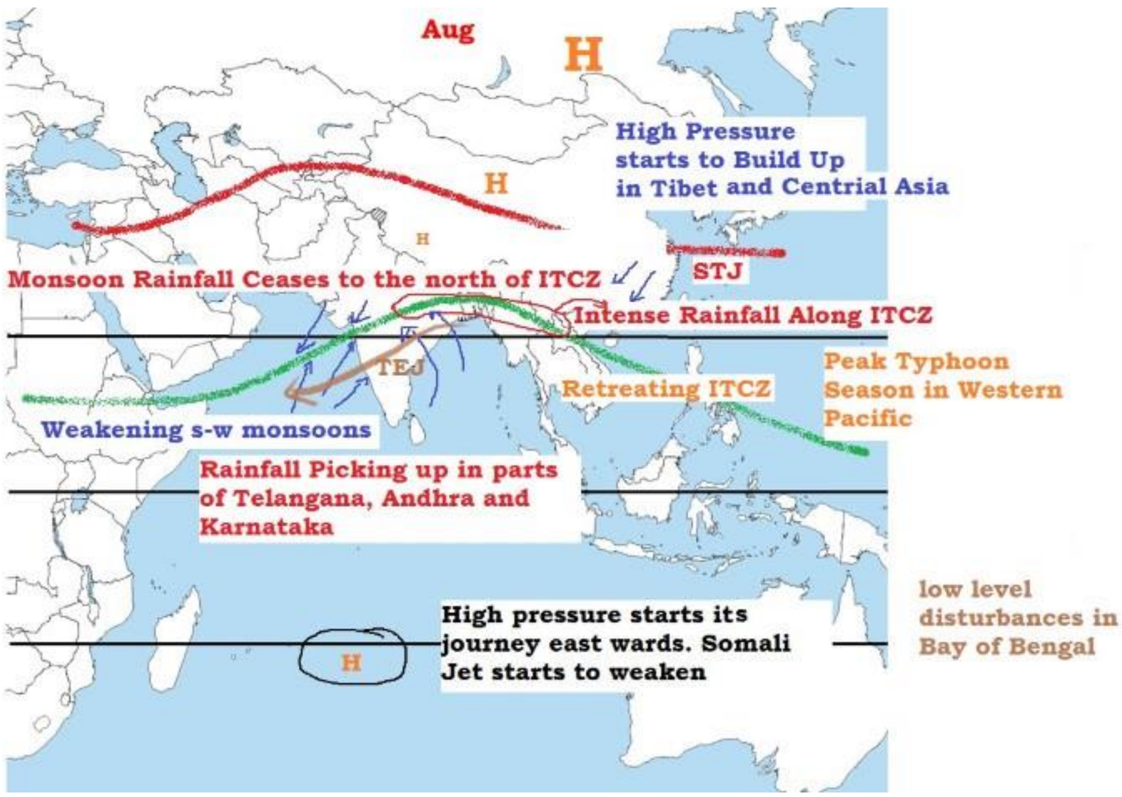
INDIAN MONSOON IN JUNE – ONSET OF S.W . MONSSON



INDIAN MONSOON IN JULY – NORTH WEST INDIA



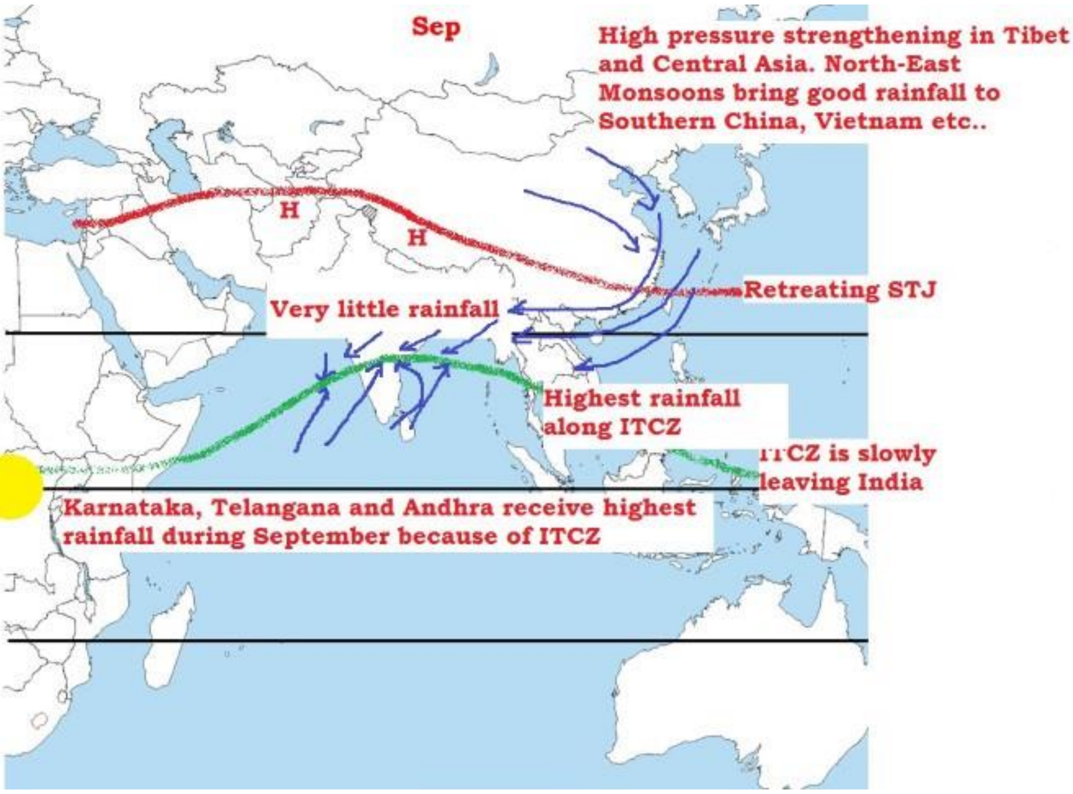
INDIAN MONSOON IN AUGUST – NORTH WEST INDIA



INDIAN MONSOON IN SEPTEMBER – REMAINING PARTS ON SOUTH INDIA

Occational Depressions in Arabian Sea.

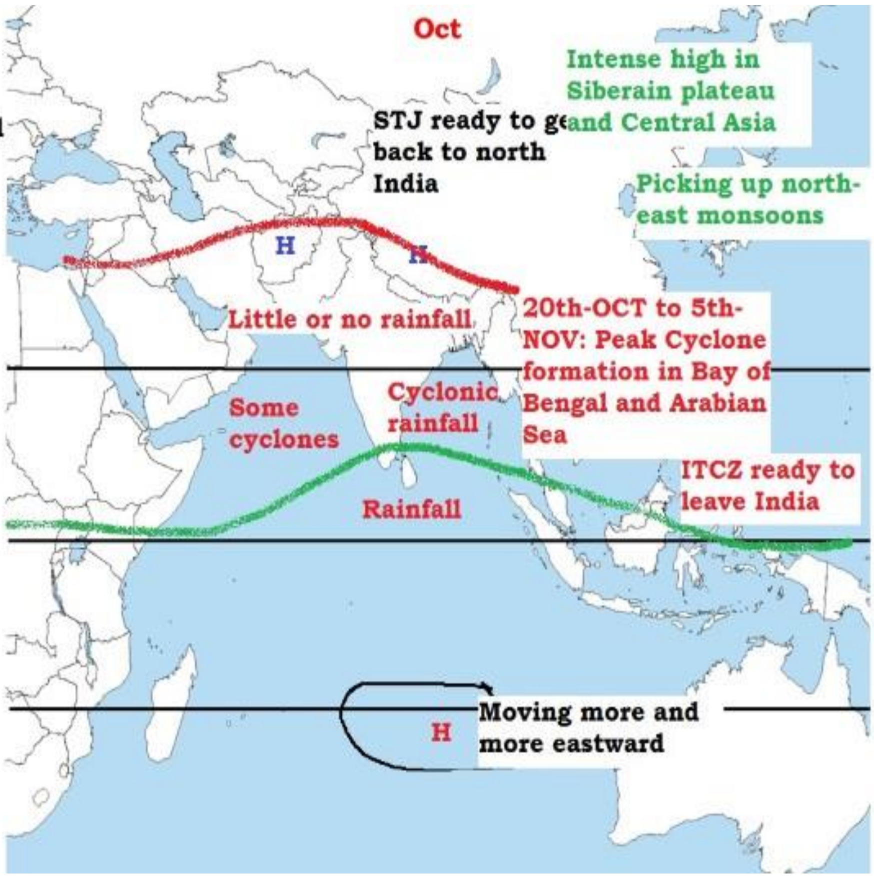
Cyclones in northern Bay of Bengal. Cyclones are too weak because of quick landfall.
Cyclones during September are less destructive



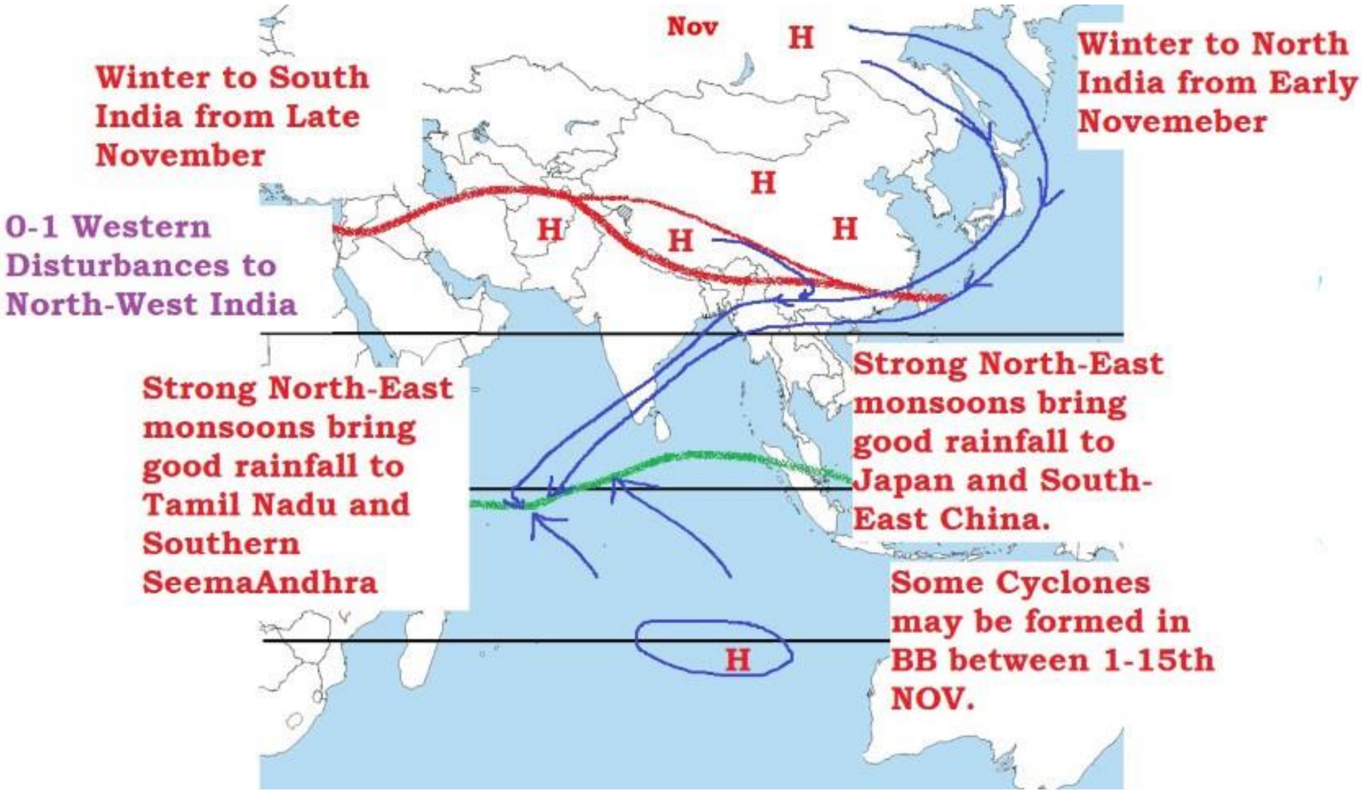
INDIAN MONSOON IN OCTOBER – RETREATING MONSOONS – CYCLONES IN LATE OCTOBER

Somali Jet and Eastern Tropical Jets die by the end of October

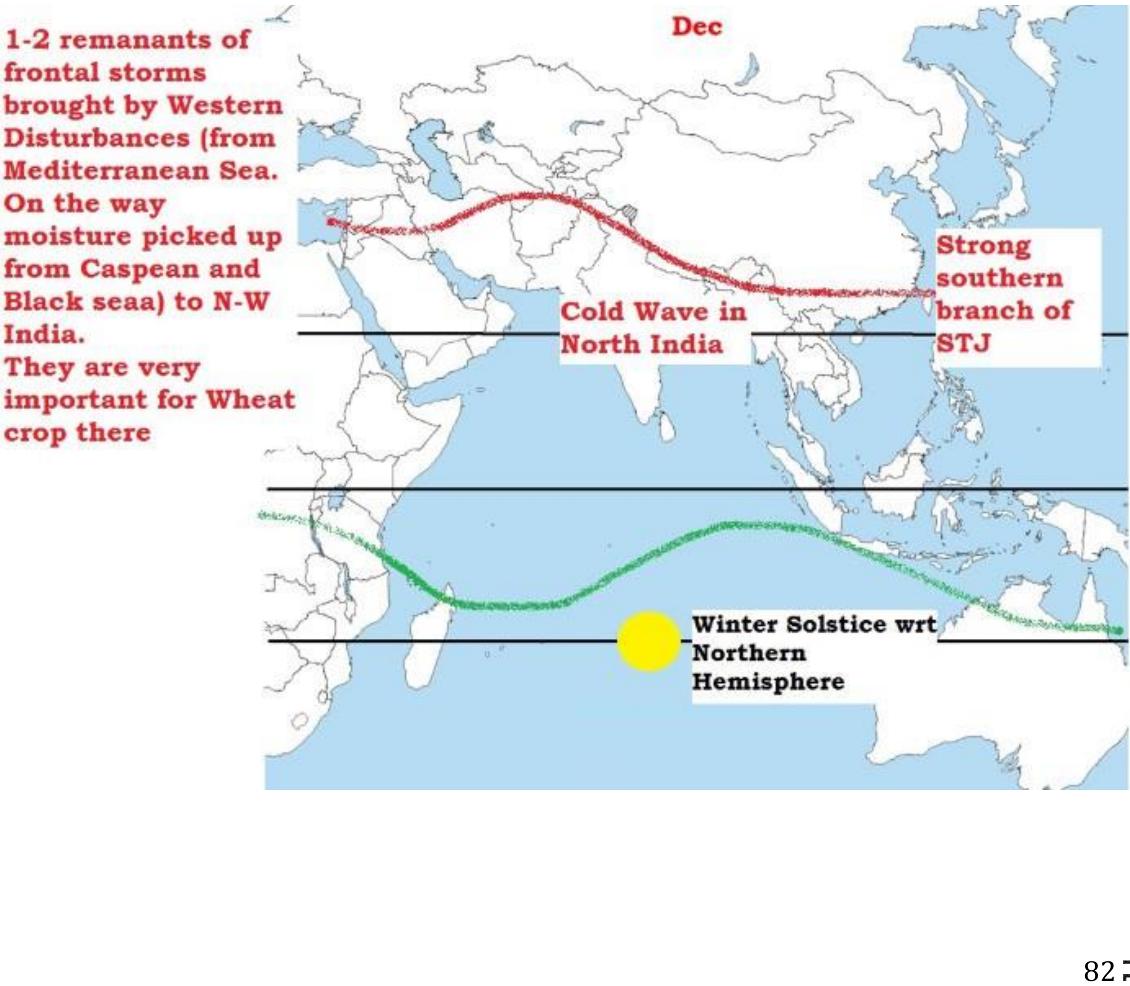
END OF RAINY SEASON



INDIAN MONSOON IN NOVEMBER – NORTH EAST MONSOON – PEAK CYCLONE

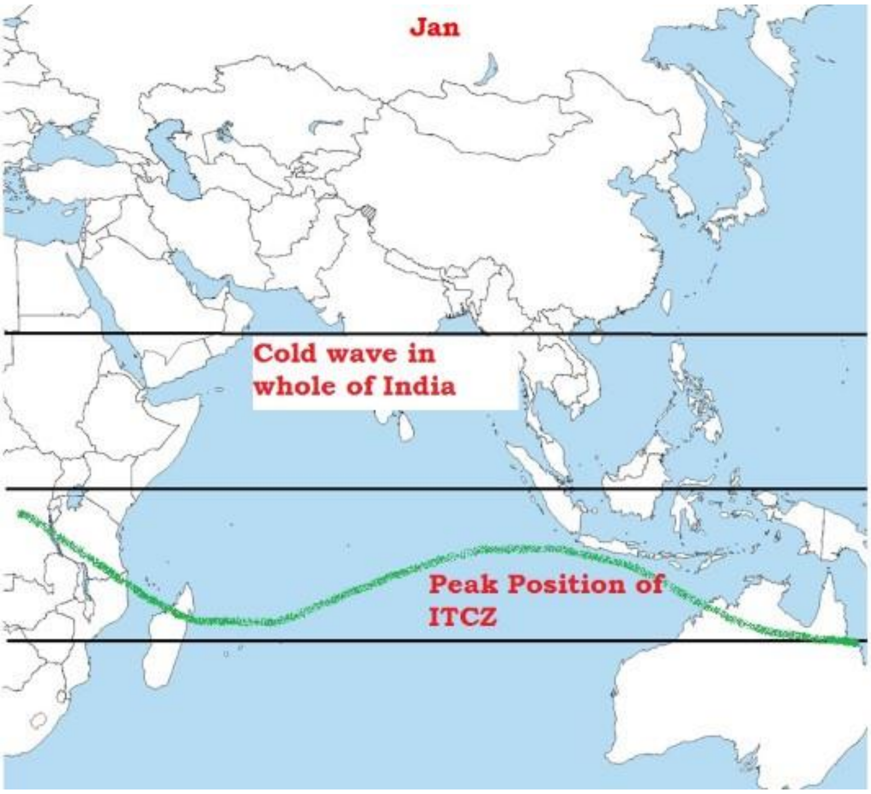


INDIAN MONSOON – DECEMBER – MAXIMUM RAIN IN AP & TN



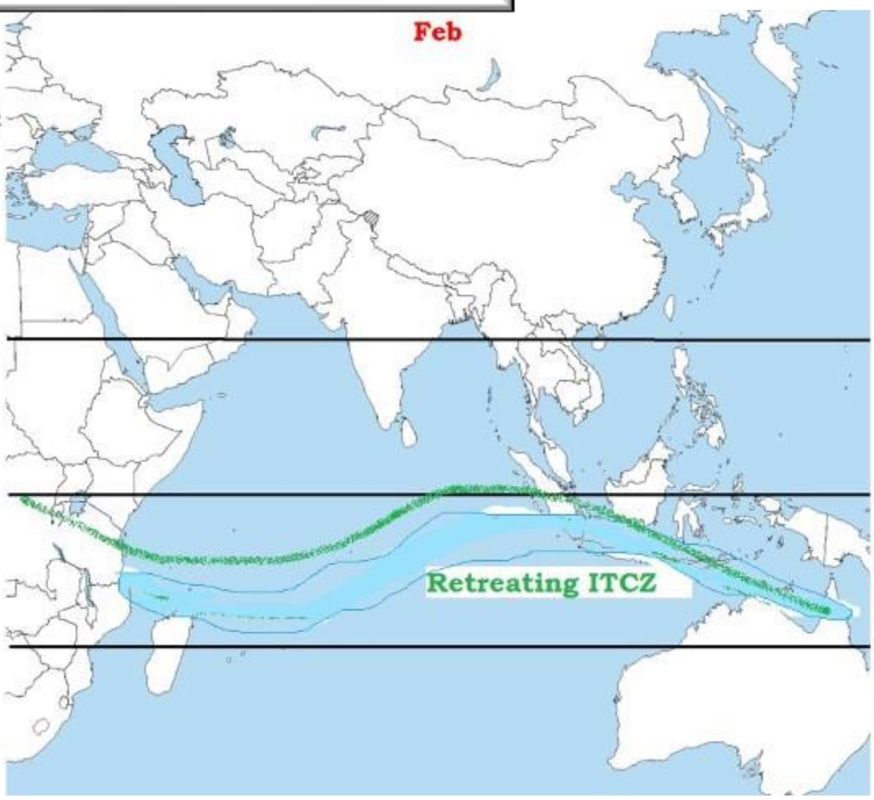
INDIAN MONSOON IN JANUARY – NORTH EAST MONSOON - WEAKEN

SIMILAR TO DECEMBER

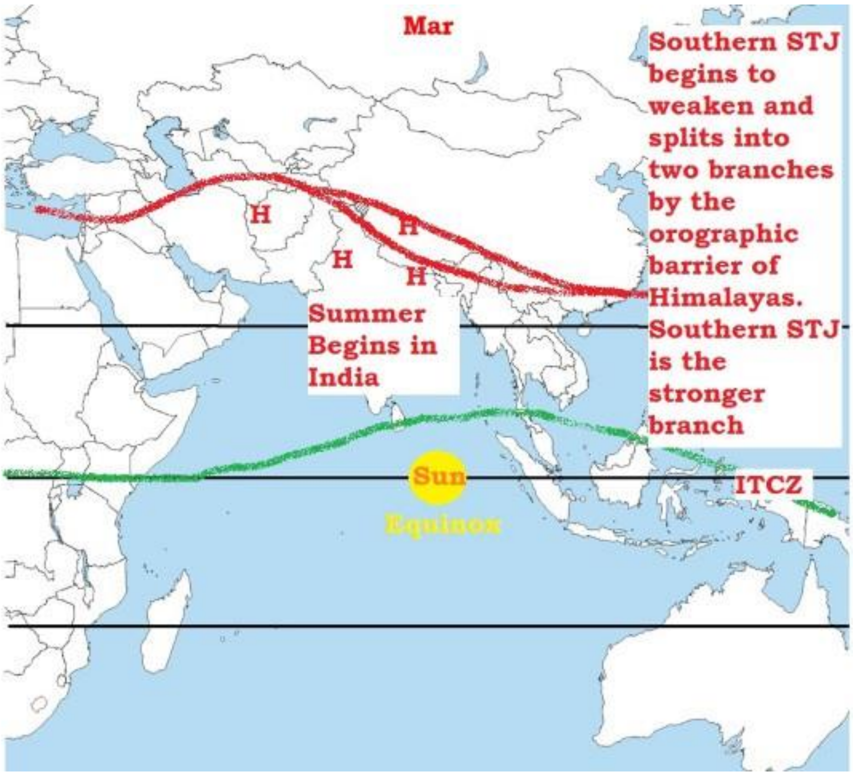


INDIAN MONSOON IN FEBRUARY – DRY SEASON BEGINS

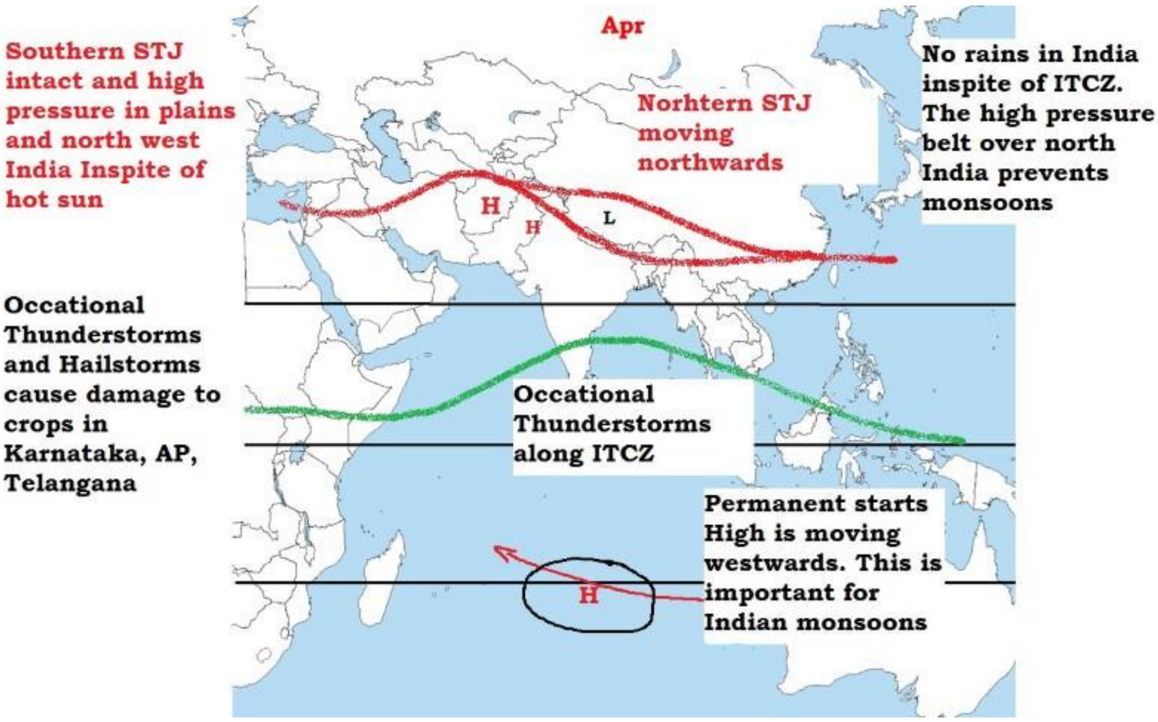
Similar to DEC and JAN



INDIAN MONSOON IN MARCH – DRY SEASON INTENSIFIES



INDIAN MONSOON IN APRIL – OCCASIONAL THUNDER STROMS IN SOUTH / CENTRAL INDIA



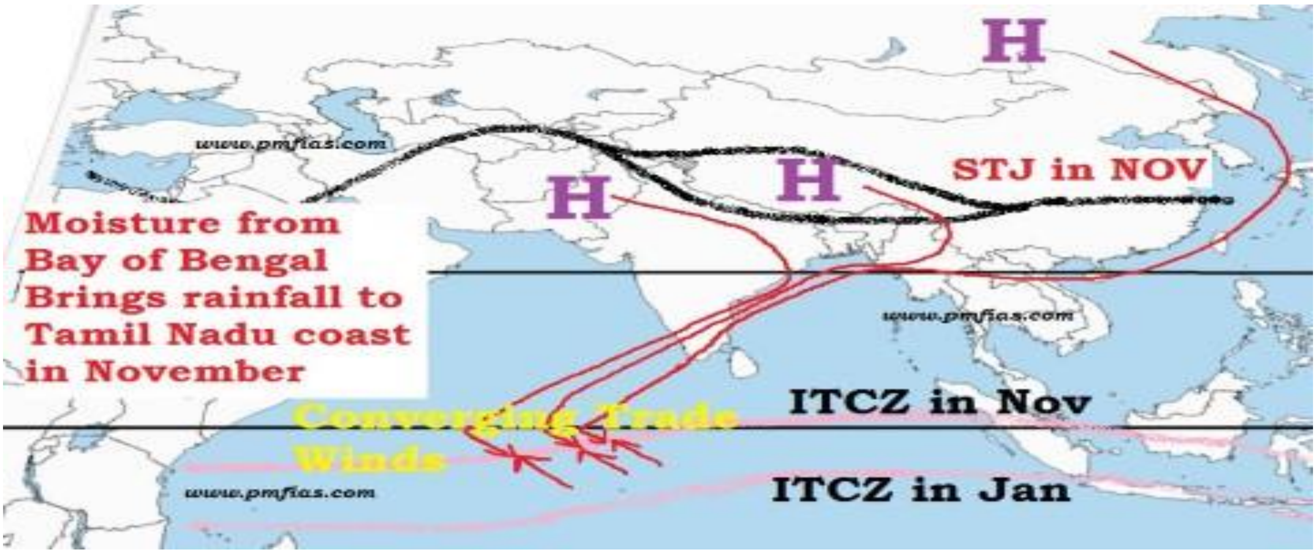
Projects to understand monsoons

- First attempt was made during International India Ocean Expedition (HOE) from 1962 to 1965.
- It was organized jointly by the International Council of Scientific Unions (ICSU), Scientific Committee on Ocean Research (SCOR) and UNESCO with World Meteorological Organization (WMO) joining the meteorology programme.

ISMEX	Two more experiments were conducted, jointly, by India and the former USSR in 1973 and 1977, with limited participation from other countries. These experiments are known as the Indo-Soviet Monsoon Experiment (ISMEX) and Monsoon-77 respectively.
MONEX	Data collection effort was made under the aegis of MONEX-1979. It was organised jointly by many researching organizations and the World Meteorological Organisation (WMO) under their World Weather Watch (WWW) programme. It is so far the largest scientific effort made to understand monsoons. Details are not necessary. Remember the names. They can be asked in prelims. MONEX was asked in previous papers

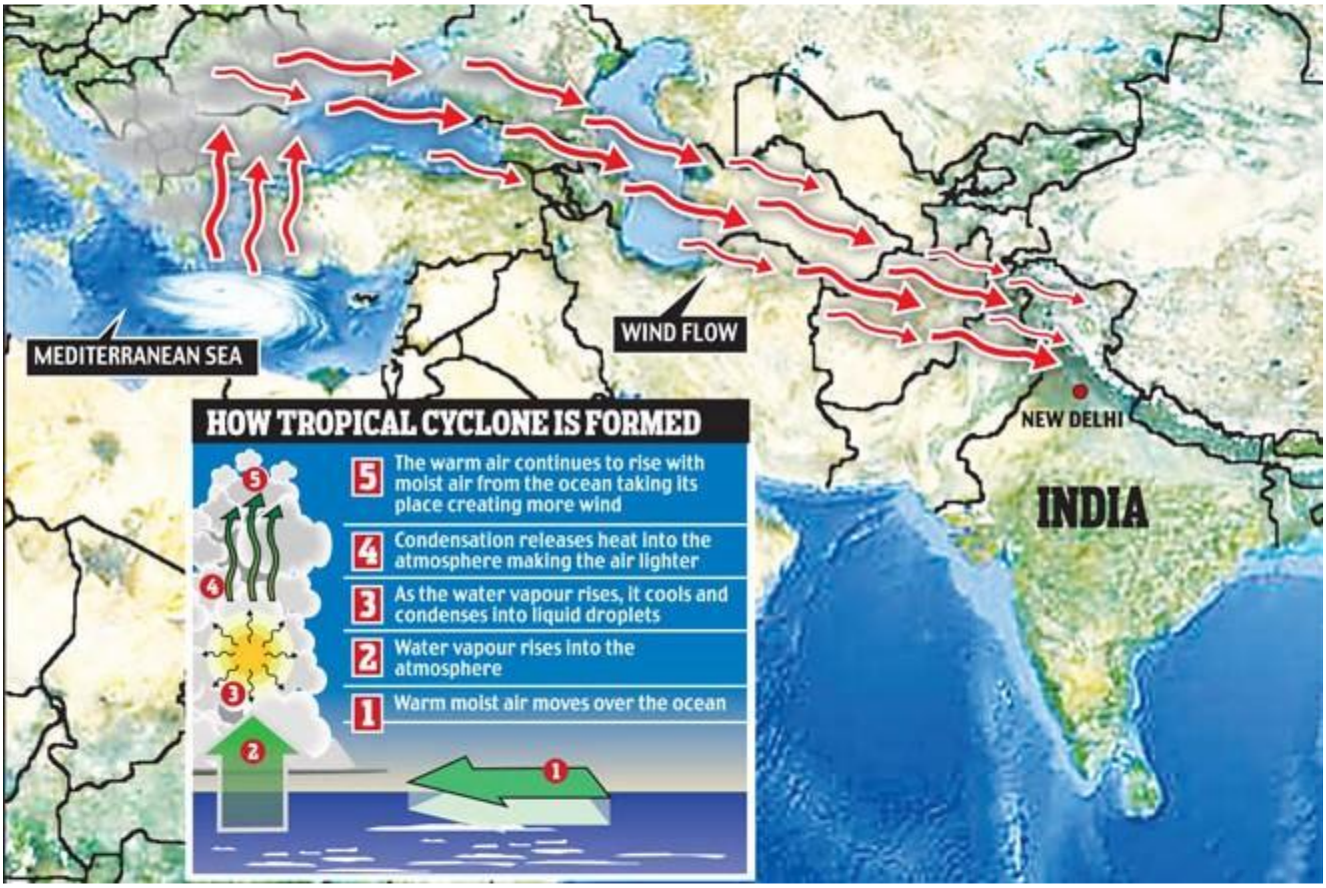
WESTERN DISTURBANCES

- In the winter season, the sub-tropical jet (STJ) is bifurcated into two branches due to physical obstruction of the Himalayas and Tibetan Plateau.
- One branch is flows to the south of the Himalayas, while the second branch is positioned to the north of the Tibetan Plateau.



- The ridge of the jet stream creates anticyclonic (with clockwise air circulation) conditions over North-West India.
- Consequently, the winds tend to descend over the north-western parts of India, resulting into the development of atmospheric stability and dry conditions (anticyclonic condition = no rainfall).
- But the sub-tropical jet (STJ) causes periodic changes in general weather conditions.
- The STJ drives the temperate low pressures over Mediterranean Sea towards east across Afghanistan, Pakistan and reach north-west India.
- These storms are residual frontal cyclones which move at the height of 2000 metres from the mean sea level.

- On an average, 4 to 6 cyclonic waves reach north-western India between October and April each year.



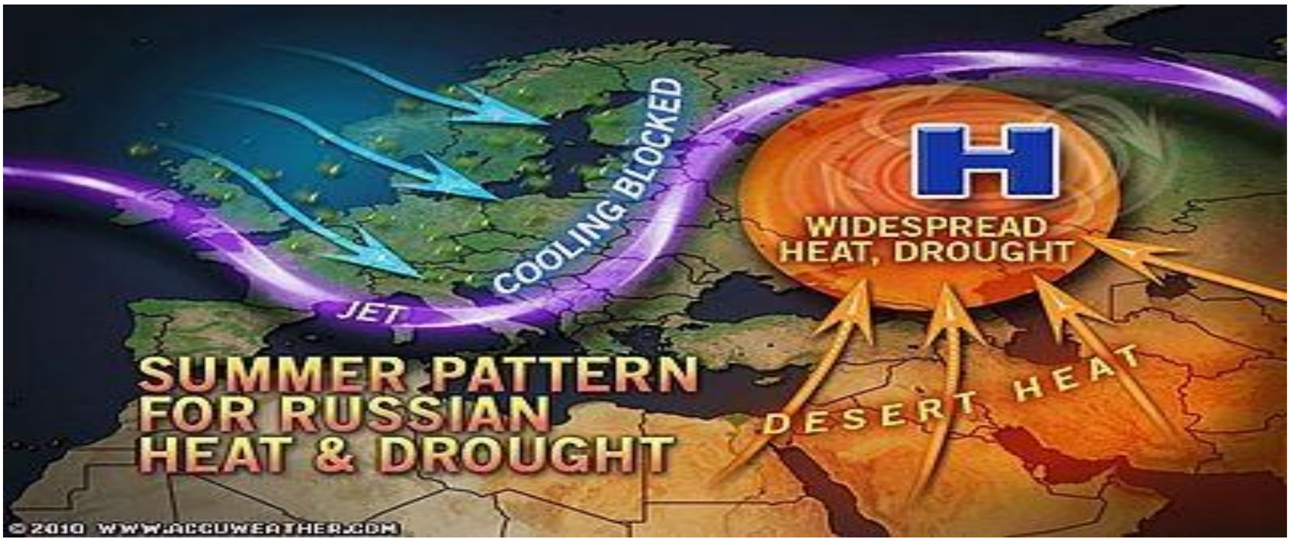
Weather associated with Western Disturbances

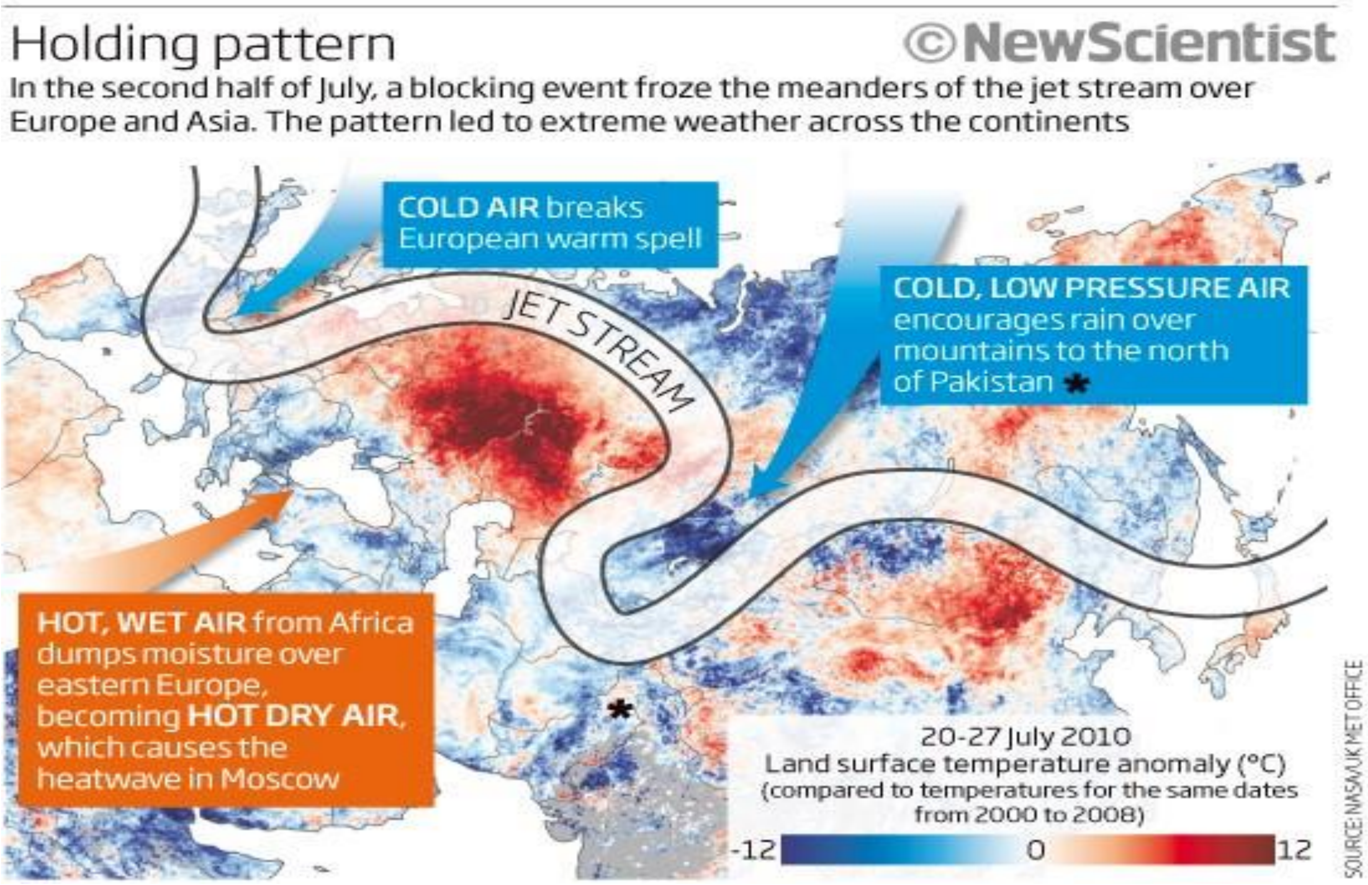
- The arrival of these temperate storms [remnants of temperate cyclones] [western disturbances] causes precipitation leading to an abrupt decrease in air temperature over North-West India.
- The weather becomes clear after the western disturbances passes away.
- Western Disturbances also bring heavy snowfall in the Himalayan Region and a cold wave to north Indian plains.

Importance of Western Disturbances

- The western disturbances affect weather conditions during the winter season up to Patna (Bihar) and give occasional rainfall which is highly beneficial for the standing rabi crops, (wheat, barley, mustard, gram, lentil, etc.).
- Cloudburst in Jammu and Kashmir, Himachal Pradesh, Uttarakhand
- A cloudburst is an intense torrential rainfall brought by a thunderstorm that lasts for a relatively short duration (few minutes to few hours).
- Cloudburst leads to flash floods and causes lot of damage to life and property.
- Every intense rainfall is not a Cloudburst. Cloudburst specifically occurs when an air mass with high humidity is struck at a place due to various reasons.
- In 2010, South-Western strip of Russia (Caucasus Region, Moscow etc.) saw higher than normal temperatures (highest in in the last 100 years) and there were numerous cloudbursts in Jammu and Kashmir.
- A strong upper-atmospheric high was located over European Russia towards the beginning of summer.
- It diverted the jet stream (meandering of Sub-Tropical Jet Stream) and its rain-giving train (trough) of summer storms farther north than usual, giving much of Southern European Russia drought conditions.

- In addition, southern desert heat from central Asia, the Arabian Peninsula and North Africa began to flow northward, which strengthened this ridge of STJ and tightened its hold over the region.





- The stalled system prevented weather systems being drawn across Russia and the obstacle acted as a barrier trapping hot air to the south and cold air to the north.
- The consequence of this static mass of hot air was the heat wave that devastated Russia.
- With the jet stream stalled the Sub-Tropical Jet was unable to transit across the Himalayas as it would do ordinarily, the monsoon cell to the south, fed by warmer waters in the Indian Ocean, had nowhere to go and as a consequence it deposited vast amounts of rain over Pakistan, Himalchal Pradesh and Jammu and Kashmir and this led to extensive flooding.

Indian Climate – What type of Climate Does India Have?

- India's climate closely resembles the climate that of a tropical country although its northern part (north of tropic of cancer) is situated in the temperate belt.
- Indian subcontinent is separated from the rest of Asia by the lofty Himalayan ranges which block the cold air masses moving southwards from Central Asia.
- As a result, during winters, the northern half of India is warmer by 3°C to 8°C than other areas located on same latitudes.
- During summer, due to over the head position of the sun, the climate in the southern parts resemble equatorial dry climate.
- The north Indian plains are under the influence of hot dry wind called 'loo' blowing from the Thar, Baloch and Iranian Deserts, increasing the temperatures to a level comparable to that of the southern parts of the country.
- Thus the whole of India, south of the Himalayas can be climatically treated as a tropical country.
- The seasonal reversal of winds in Arabian Sea and Bay of Bengal give India a typical tropical monsoon climate.
- So Indian climate, to be precise, is tropical monsoon type (a distinct wet and dry climate) rather than just a tropical or half temperate climate.

FEATURES OF INDIAN CLIMATE

- India has high Regional Climatic Diversity because of its topographical diversity (location, altitude, distance from sea and relief).

Rainfall	• The climate in most of the regions is characterized by distinct wet and dry seasons. Some places like Thar desert, Ladakh have no wet season. • Mean annual rainfall varies substantially from region to region. Mawsynram and Cherrapunji in Meghalaya receives around 1,000 cm of annual rainfall while at Jaisalmer the annual rainfall rarely exceeds 12 cm. • The Ganga delta and the coastal plains of Odisha see intense rainfall in July and August while the Coromandel Coast goes dry during these months. Places like Goa, Hyderabad and Patna receive south-west monsoon rains by the first quarter of June while the rains are awaited till early July at places in Northwest India
Temperature	• Diurnal and annual temperature ranges are substantial. • Highest diurnal temperature ranges occur in the Thar desert and the highest annual temperature ranges are recorded in the Himalayan regions. • Both diurnal and mean annual temperature ranges are least in coastal regions. • In December, the temperature may dip to – 40°C at some places in J&K while in many coastal regions average temperature is 20-25°C. • Winters are moderately cold in most of the regions while the summers are extremely hot. Himalayan regions experience brutal winters while the summers are moderate
Factors Influencing Indian Climate	1. Latitudinal location 2. Distance from the Sea 3. The Himalayas 4. Physiography 5. Monsoon Winds 6. Upper Air Circulation

	7. El Nino and La Nina 8. Tropical Cyclones and Western Disturbances 9. Latitudinal location

Indian climate resembles the climate of a tropical country.

- The mainland of India extends between 8°N to 37°N.
- Areas south of the Tropic of Cancer are in tropics and hence receive high solar insolation. The summer temperatures are extreme and winters temperatures are moderate in most of the regions.
- The northern parts on the other hand lie in the warm temperate zone. They receive comparatively less solar insolation. But summer are equally hot in north India because of hot local wind called 'loo'. Winter are very cold due to cold waves brought by the western disturbances.
- Some places in Himalayas record low temperatures particularly in winter.
- Coastal regions see moderate climatic conditions irrespective of latitudinal position.

Distance from the Sea

- Coastal regions have moderate or equable or maritime climate where as interior locations are deprived of the moderating influence of the sea and experience extreme or continental climate.
- The monsoon winds first reach the coastal regions and hence bring good amount of rainfall.

Himalayas and Indian Climate

- This is the most important factor that influences Indian Climate.
- The Himalayas act as a climatic divide between India and Central Asia.
- During winter, Himalayas protect India from cold and dry air masses of Central Asia.
- During monsoon months these mountain ranges act as an effective physical barrier for rain bearing south-west monsoon winds.
- Himalayas divide the Bay of Bengal branch of monsoon winds into two branches – one branch flowing along the plain regions towards north-west India and the other towards South-East Asia.
- If the Himalayas were not present, the monsoon winds would simply move into China and most of the north India would have been a desert.

Why rainfall decreases form east to west in plains region (Indus-Ganga Plains)?

- In summer, there are many minor low pressure cells that exist all over the plain region.
- As the monsoon winds move from east to west the moisture levels decrease due to successive rainfall at each low pressure regions.
- By the time winds reach western parts of the plains (Delhi, Haryana etc.) all the moisture in the monsoon winds in exhausted.

Then how come Haryana and Punjab not deserts like Rajasthan?

- They receive rainfall due to Western Disturbances in winter. (In summer the rainfall is very low.)

Physiography and Indian Climate

- Physiography is the most important factor that determines the mean annual rainfall received by a region.

Why are some parts in peninsular India semi-arid?

- Places on the windward side of an orographic barrier receive great amount of rainfall where as those on the leeward side remain arid to semi-arid due to rain-shadow effect.

Example: The south-west monsoon winds from the Arabian sea strike almost perpendicular at the Western Ghats and cause copious rainfall in the Western Coastal plain and the western slopes of the Western Ghats.

On the contrary, vast areas of Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu lie in rain-shadow or leeward side of the Western Ghats and receive scanty rainfall.

Why no significant rainfall in Gujarat and Rajasthan? Explain the formation of Thar Desert?

- Monsoons winds flowing in Rajasthan and Gujarat are not obstructed by any orographic barrier and hence these regions receive no rainfall.
- [Monsoon winds blow almost parallel to Aravalis and hence there is no orographic rainfall].
- [No convection cell or vertical wind movements arise in Rajasthan and Gujarat: Monsoon winds blow towards low pressure cells in Tibet and hence only horizontal wind movements exist in Gujarat and Rajasthan]
- [Sub-tropical high pressure belt: In winter the region experiences strong divergence because of the STJ – Sub-Tropical Jet.]

How come Cherrapunji and Mawsynram receive abnormally high rainfall?

- Mawsynram and Cherrapunji are the wettest places on earth with mean annual rainfall over 1000 cm.
- Copious rainfall in these places is due to funneling effect followed by orographic upliftment. [Funneling effect = clouds are channeled into a narrow region between mountains and hence the cloud density is extraordinary]

Monsoon Winds and Indian Climate

- The most dominating factor of the Indian climate is the 'monsoon winds'.

IMPORTANT FEATURES OF INDIAN MONSOONS ARE	1. Sudden onset (sudden burst) 2. Gradual progress 3. Gradual retreat 4. Seasonal reversal of winds • The complete reversal of the monsoon winds brings about a sudden change in the seasons. • The harsh summer season suddenly giving way to monsoon or rainy season. • The south-west monsoons from the Arabian sea and the Bay of Bengal bring rainfall to the entire country. • The north-eastern winter monsoon do not cause much rainfall except along the Caromandel coast (TN coast) after getting moisture from the Bay of Bengal.
UPPER AIR CIRCULATION	• The changes in the upper air circulation over Indian landmass is brought about by Jet streams. (Explained in detail in Indian Monsoons)
WESTERLY JET STREAM	• Westerly jet stream blows at a very high speed during winter over the sub-tropical zone. • Southern branch of the jet stream exercises a significant influence on the winter weather conditions in India. • This jet stream is responsible for bringing western disturbances from the Mediterranean region in to the Indian sub-continent.

	• Winter rain and heat storms in north-western plains and occasional heavy snowfall in hilly regions are caused by these disturbances. These are generally followed by cold waves in the whole of northern plains
EASTERLY JET STREAM	• Reversal in upper air circulation takes place in summer due to the apparent shift of the sun's vertical rays in the northern hemisphere. • The westerly jet stream is replaced by the easterly jet stream which owes its origin to the heating of the Tibet plateau. • This helps in the sudden onset of the south-west monsoons.
TROPICAL CYCLONES AND WESTERN DISTURBANCES	• Tropical cyclones originate in the Bay of Bengal and Arabian Sea and the influence large parts of the peninsular India. • Majority of the cyclones originate in the Bay of Bengal and influence the weather conditions during the south-west monsoon season (low intensity cyclones). • Some cyclones are born during the retreating monsoon season, i.e., in October and November (high intensity cyclones) and influence the weather conditions along the eastern coast of India. • The western disturbances originate over the Mediterranean sea and travel eastward under the influence of westerly jet stream. • They influence the winter weather conditions over most of Northern-plains and Western Himalayan region.

EL-NINO, LA NINA, ENSO AND INDIAN CLIMATE

El Nino	• Adversely affects monsoon rainfall and cyclogenesis in Bay of Bengal. • Good for cyclogenesis in Arabian Sea. Droughts are common during El Nino events due to less monsoonal and cyclonic rainfall
La Nina	• Good for monsoons and cyclogenesis in Bay of Bengal. • Suppressed cyclogenesis in Arabian Sea. Floods are common
ENSO	• Southern Oscillation is simply the oscillation or alternating positions of low pressure and high pressure cells over eastern and western Pacific. • Southern Oscillation coinciding with El Nino is called ENSO or El Nino Southern Oscillation. (SO usually coincides with EL Nino. This why El Nino is usually referred to as ENSO) • ENSO = [warm water in eastern Pacific + low pressure over eastern Pacific] + [cool water in western Pacific + high pressure in western Pacific] • Climatic conditions same as El Nino.

Indian Climate – Seasons

1. The cold weather season or winter season,
2. The hot weather season or summer season,
3. The south-west monsoon season or Rainy season, and
4. The season of the retreating monsoon or cool season.
5. Winter Season in India

6. November – March. January is the coldest month.
7. Sun's apparent path is to the south of equator.
8. Clear sky, pleasant weather, low temperature, low humidity, high range of temperature, cool and slow north-east trade winds.
9. The diurnal range of temperature, especially in interior parts of the country, is very high.

TEMPERATURE IN WINTER SEASON	The isotherm of 20°C runs roughly parallel to the Tropic of Cancer. To the south of this isotherm the temperatures are above 20°C. Here there is no distinctly defined winter weather. Some parts of Kerala and Tamil Nadu typically experiences temperatures near 30°C. To the north mean temperatures are below 21°C and the winter weather is distinct. The mean minimum temperature is about 5°C over north-west India and 10°C over the Gangetic plains. Dras Valley in Kashmir is the coldest place in India. The minimum temperature recorded at Dras was – 45°C in 1908.
PRESSURE IN WINTER SEASON	High air pressure prevails over large parts of north-west India due to low temperatures coupled with divergence induced by the ridge of the STJ. Pressure is comparatively lower in south India. The winds start blowing from high pressure area of north-west to low pressure area of south-east. The wind velocity is low due to low pressure gradient. The path of the winds depend on pressure gradient and physiography
WESTERN DISTURBANCES IN WINTER SEASON	The spell of fine weather over north-western and northern India is often broken due to inflow of western disturbances. They intensify over Rajasthan, Punjab, and Haryana. They move eastwards across the sub-Himalayan belt up to Arunachal Pradesh. They cause light rain in the Indus-Ganga plains and snowfall in the Himalayan belt. After the passage of the disturbance, widespread fog and cold waves lowering the minimum temperature by 5° to 10°C below normal are experienced. Fog lowers visibility and causes great inconvenience for transportation
TROPICAL CYCLONES IN WINTER SEASON	This is the season of least tropical cyclone activity. The frequency of tropical cyclones decreases with the advancement of the season. This is due to low sea surface temperature and exit of ITCZ farthest south. The storms which are born in the Bay of Bengal strike Tamil Nadu and bring heavy rainfall. Some of them cross the southern peninsula over to the Arabian Sea. Some storms originate in the Arabian Sea and move towards either north or west.
PRECIPITATION IN WINTER SEASON	The retreating winter monsoons pick up some moisture while crossing the Bay of Bengal and cause winter rainfall in Tamil Nadu, south Andhra Pradesh, south-east Karnataka and south-east Kerala (Usually in the first weeks of November). The highest seasonal rainfall of about 75 cm between October and December. Most of it occurs along the south-eastern coast of Tamil Nadu and adjoining parts of Andhra Pradesh. Thereafter, it gradually decreases. The western disturbances also cause a little rainfall in north-west India. The amount of rainfall gradually decreases from the north and north-west to east (it is opposite in rainy season).

	The northeastern part of India also gets rainfall during the winter months Summer Season in India
MARCH TO JUNE.	High temperature and low humidity are the chief characteristics. Sometimes referred to as pre-monsoon period
TEMPERATURE IN SUMMER SEASON	High sun's insolation due to apparent movement of sun between the equator and the Tropic of Cancer. The southern parts of the country are distinctly warmer in March and April whereas in June, north India has higher temperatures. In March, the highest temperatures occur in the southern parts (40-45°C). In April the highest temperature of about 45°C is recorded in the northern parts of Madhya Pradesh. In May the highest temperature shifts to Rajasthan where temperatures as high as 48°C may be recorded. In June the maximum temperature is in Punjab and Haryana. The highest temperatures recorded are 50.5°C at Alwar on 10th May, 1956 and 50.6°C at Ganganagar on 14th June, 1935. The highest temperatures are recorded just before the onset of the southwest monsoons (late May). The diurnal range of temperature is also very high. It may be as high as 18°C in some parts. The maximum summer temperatures are comparatively lower in the costal and southern peninsular regions due to moderating effect of the sea. The temperatures along the west coast are comparatively lower than those prevailing on the east coast due to the prevailing westerly winds. There is large contrast between land and sea temperatures. Northern and central parts of India experience heat waves in this season. [A heat wave is an abnormally high temperature experienced by a regions. Temperature increase of the order of 6° to 7°C above normal is termed as 'moderate' and 8°C and more as 'severe' heat wave] Most of the heat waves develop over Rajasthan, Punjab and Haryana (location far away from the sea). From here they spread over Uttar Pradesh and Bihar. The strong north westerly winds (caused due to strong divergence in north-west India) with a long land journey over hot regions check the onward march of the sea breeze over eastern coastal belt and create heat wave conditions over Odisha and Andhra Pradesh. The heat waves strike by the end of April and their maximum occurrence is in May. They last till the onset of southwest monsoon. The normal duration of heat waves is 4 to 5 days. However, heat waves are rare over the peninsula south of 13°N latitude due to maritime conditions prevailing there.
PRESSURE IN SUMMER SEASON	The atmospheric pressure is low all over the country due to high temperature. But strong dynamically induced divergence over north-west India prevents the onset of south-west monsoons.

Winds in Summer Season

- There is a marked change in the direction and speed of the winds from winter.
- The winds are by and large light and variable.

Loo

- Loo winds originate over Iranian, Baloch and Thar deserts.
- In May and June, high temperature in northwest India builds steep pressure gradient.
- Hot, dust laden and strong wind known as loo blows.
- Loo normally starts blowing by 9.00 A.M., increases gradually and reaches maximum intensity in the afternoon.
- It blows with an average speed of 30-40 km per hour and persists for days.

Andhis

- The strong dust storms resulting from the convective phenomena are locally known as andhis (blinding storms). They move like a solid wall of dust and sand.
- The wind velocity often reaches 50-60 kmph and the visibility is reduced to a few metres.
- Such dust storms are common in Rajasthan, Haryana, Punjab, Jammu region, Delhi, Uttar Pradesh, Bihar and Madhya Pradesh.
- They are short lived. The squall and showers which follow these storms bring down the temperature sharply temporarily.

Frontal Thunderstorms in Summer Season

- The strong convectional movements related to the westerly jet stream lead to thunderstorms in eastern and north-eastern part of the country.
- They normally originate over Chota Nagpur plateau and are carried eastwards by westerly winds.
- The areas with highest incidence of thunderstorms are Assam, Arunachal Pradesh, Nagaland, Mizoram, Manipur, Tripura, Meghalaya, West Bengal and the adjoining areas of Odisha and Jharkhand.

Norwesters and Thunderstorms in Summer Season

- In West Bengal and the adjoining areas of Jharkhand, Odisha and Assam, the direction of squalls is mainly from the northwest, and they are called norwesters.
- They are often very violent with squall speeds of 60 to 80 km per hour.
- Hailstones sometimes accompany showers and occasionally attain the size of a golf ball.
- They cause heavy damage to standing crops, trees, buildings, livestock and even lead to loss of human lives.
- However, they are, sometimes, useful for tea, jute and rice cultivation. In Assam, these storms are known as 'Barodoli Chheerha'.
- The period of maximum occurrence of these storms is the month of Vaisakh (mid-March to mid-April) and hence, they are locally known as Kalabaisakhis, the black storms or a mass of dark clouds of Vaiasakha.

Convectional Thunderstorms in Summer Season

- In the south the thunderstorms occur in Kerala (Mango Showers) and adjoining parts of Karnataka (Blossom Showers) and Tamil Nadu, particularly during evenings and nights.

Western Disturbances in Summer Season

- Their frequency and intensity gradually decrease with advancement of summer.
- Approximately 4, 3 and 2 western disturbances visit north-west India in March, April and May respectively.

- They cause snowfall in higher reaches of the Himalayas.

Tropical Cyclones in Summer Season

- Tropical cyclones originate in the Bay of Bengal and Arabian Sea.
- A few cyclones are formed in the Bay of Bengal in the month of March but they do not affect the mainland of India.
- Their frequency rises steeply in April and the number of cyclones originating in May is more than double than those originating in April.
- About three-fourths of the tropical cyclones are born in the Bay of Bengal and the rest originate in the Arabian Sea.
- Most of the depressions in April originate to the south of 10°N while those originating in May are born to the north of this latitude.
- Most of the storms of this season initially move west or north-west but later they recurve northeast and strike Bangladesh and the Arakan Coast of Myanmar.
- Very few hit Indian coast while some dissipate over the sea itself.
- The whole of the east coast of India, the coastal areas of Bangladesh and Arakan Coast of Myanmar are liable to be hit by tropical storms in May.
- Many of them are quite severe and cause heavy damage to life and property.
- In the Arabian Sea, major storms are formed in May between 7° and 12° N latitudes.
- Most of them move away from the Indian coast in a north-westerly direction and dissipate in the sea.
- Few originate close to the Indian coast. They move towards the north-east and hit somewhere along the west coast of India.

Precipitation in Summer Season

- This season is not totally rainless (only one per cent of the annual rainfall).
- In the northeastern parts of the country, dust storms bring little rainfall.
- The precipitation in Kashmir is mainly in the form of snow caused by western disturbances.
- The norwesters bring some rainfall in Assam, West Bengal and Odisha. The intensity of rainfall is high.
- The rainfall brought by the norwesters is known as the spring storm showers.
- This small amount of rainfall is very useful for the cultivation of tea, jute and rice and is known as tea showers in Assam.
- Coastal areas of Kerala and Karnataka receive rainfall from thunderstorms.
- Such showers are called mango showers in Tamil Nadu and Andhra Pradesh because they are very beneficial to mango crop.
- In Karnataka they are called cherry blossoms due to their effect on the coffee plantations.

Isoline, Isobar, Isotherm & Isohyet:

ISOLINE: imaginary lines joining regions with equal rainfall or any other parameter.
ISOBAR: imaginary lines joining regions with equal pressure.
ISOTHERM: imaginary lines joining regions with equal temperature.
ISOHYET: imaginary lines joining regions with equal rainfall.

RAINY SEASON – SOUTH WEST MONSOON SEASON

- South West Monsoon Season – June to mid-September.
- South West Monsoon Season is also known as hot-wet season.
- Sudden onset is the important feature of South West Monsoons.
- With the onset of monsoons, temperature falls drastically and humidity levels rise.

Temperature during South West Monsoon Season

- Sudden onset of South West Monsoons leads to significant fall in temperature [3° to 6°C].
- The temperature remains less uniform throughout the rainy season.
- The temperature rises in September with the cease of south-west monsoons.
- There is rise in temperature whenever there is break in the monsoons.
- The diurnal range of temperature is small due to clouds and rains.
- The highest temperatures are experienced at places west of the Aravali [38° to 40°C]. This is due to lack of clouds and hot continental air masses.
- Other parts of Northwest India also have temperatures above 30°C.
- The temperatures are quite low over the Western Ghats due to heavy rainfall.
- The coastal areas of Tamil Nadu and adjoining parts of Andhra Pradesh have temperatures above 30°C as they receive little rainfall during this season.

Pressure and Winds During South West Monsoon Season

- Low pressure conditions prevail over northwest India due to high temperature.
- ITCZ (monsoon trough) lies along the Ganga plain. There are frequent changes in its location depending upon the weather conditions.
- The atmospheric pressure increases steadily southwards.
- Over the peninsular region, due to pressure gradient between north and south, winds blow in a southwest to northeast direction from Arabian sea and Bay of Bengal.
- Their direction undergoes a change in Indo-Gangetic plain where they move from east to west.

Rainfall During South West Monsoon Season

- Three fourths of the total annual rainfall is received during this season.
- The average rainfall over the plains of India in this season is about 87 per cent.
- Normal date of the arrival of the monsoon is 20th May in Andaman and Nicobar Islands.
- The advance of the monsoon is much faster in the Bay of Bengal than in the Arabian Sea.
- The normal date of onset of the southwest monsoon over Kerala i.e. the first place of entry in the mainland of India is 1st June.
- The monsoons advance quickly accompanied with a lot of thunder, lightning and heavy downpour. This sudden onset of rain is termed as monsoon burst.
- Sometimes monsoons are delayed or they come much earlier than normal.
- Normally the onset occurs between 29th May and 7th June.
- The earliest onset was on 11th May in 1918 and 1955, while the most delayed onset was on 18th June in 1972.
- South West Monsoons – Arabian Sea branch and Bay of Bengal branch
- Monsoon winds beyond south Kerala progress in the form of two branches viz. the Arabian Sea branch and the Bay of Bengal branch.

South West Monsoon – Arabian Sea branch and Bay of Bengal branch

- The Arabian Sea branch gradually advances northwards. It reaches Mumbai by 10th June.

- The Bay of Bengal branch spreads rather rapidly over most of Assam. The normal date of its arrival at Kolkata is 7th June.
- On reaching the foothills of the Himalayas the Bay branch is deflected westward by the Himalayan barrier and it advances up the Gangetic plain.
- The two branches merge with each other mostly around Delhi to form a single current.
- Both the branches reach Delhi more or less at the same time.
- The combined current gradually extends to west Uttar Pradesh, Haryana, Punjab, Rajasthan and finally to Himachal Pradesh and Kashmir.

1. By the end of June the monsoon is usually established over most parts of the country.
2. By mid-July, the monsoon extends into Kashmir and the remaining parts of the country.
3. By this time it reaches Kashmir, it has shed most of its moisture.
4. Arabian Sea branch of the monsoon is much powerful than the Bay of Bengal branch for reasons:

- The Arabian Sea is larger than the Bay of Bengal, and the entire Arabian Sea current advances towards India, whereas only a part of the Bay of Bengal current enters India, the remainder proceeding to Myanmar, Thailand and Malaysia.
- The Arabian Sea branch of the southwest monsoons is divided into three distinct streams on arriving in the mainland of India.
- The first stream strikes the west coast of India and gives extremely heavy rainfall of over 250 cm. It strike perpendicular to Western Ghats causing plentiful Orographic Rainfall [400 to 500 cm annual rainfall on the windward side].
- Rainfall is drastically reduced to about 30-50 cm on the leeward side of the crest.
- There is a narrow belt of marked aridity on the immediate leeward side of the Western Ghats. But once it is passed, the air starts rising again and the amount of rainfall increases further east.

The second stream enters Narmada—Tapi troughs

- (narrow rift valley) and reaches central India. It does not cause much rain near the coast due to the absence of major orographic obstacle across the rift. Some parts of central India receive rainfall from this stream (Ex: Nagpur).
- The third stream moves parallel to the Aravali Range without causing much rainfall. Consequently the whole of Rajasthan is a desert area.
- However, some orographic effect is occurs on the south-eastern edge of the Aravali Range. Mt. Abu gets about 170 cm rainfall while the surrounding plains have only 60 to 80 cm rainfall.

The Bay of Bengal Branch of the southwest monsoon is divided into two distinct streams.

- The first stream crosses the Ganga-Brahmaputra delta and reaches Meghalaya. Here that the orographic effect results in intense rainfall. Cherrapunji receives an annual rainfall of 1,102 cm, major portion of which occurs from June to August.
- Mawsynram (present champion) located at 1,329 m above sea level just 16 km to the west of Cherrapunji (X champion) records higher annual rainfall of 1,221 cm.
- Both the stations are located on the southern slopes of the Khasi hills at the northern end of a deep valley running from south to north.
- The second stream of the Bay of Bengal branch moves along Himalayan foothills as they are deflected to the west by the Himalaya and brings widespread rainfall to Ganga plain.

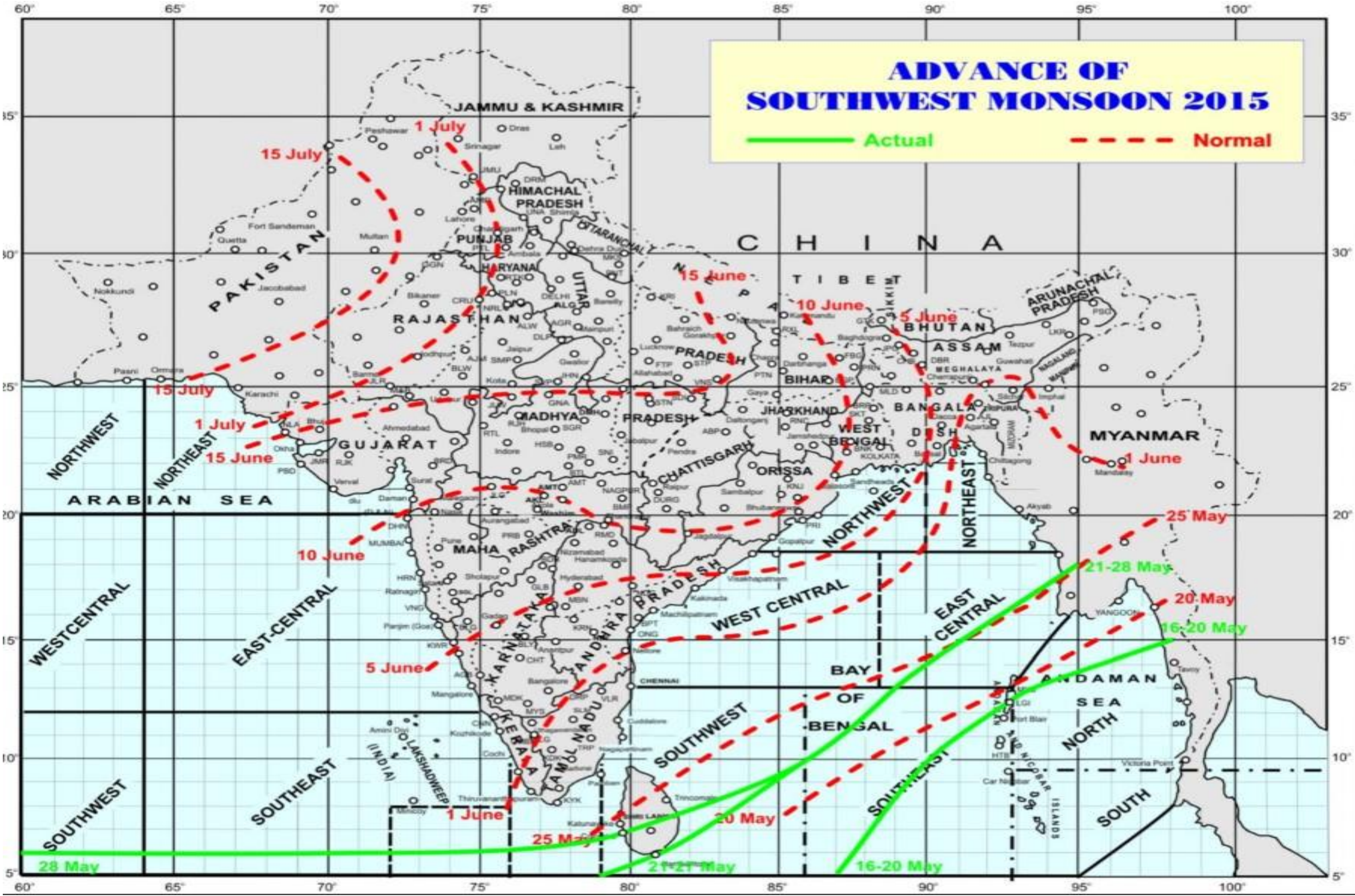
Break in the South West Monsoons

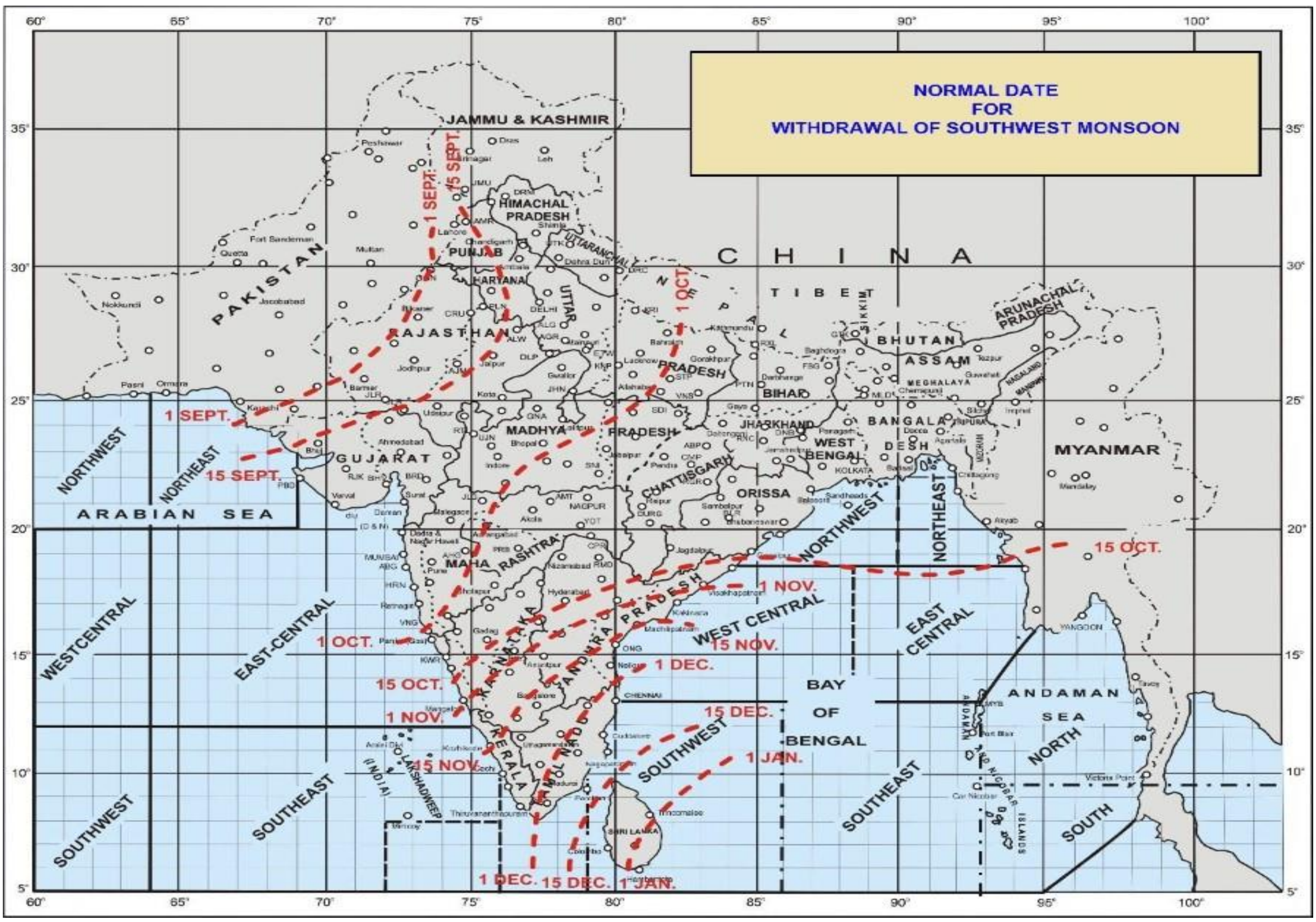
- During the Monsoon season, there are periods when the Monsoon trough shifts to the foothills of Himalayas, which leads to sharp decrease in rainfall over most parts of the country but increase along the Himalayas and parts of Northeast India and Southern Peninsula.
- During July and August, there are certain periods when the monsoons become weak. Rainfall practically ceases over the country outside the Himalayan belt and southeast peninsula. This is known as break in the monsoon.
- Breaks are likely to occur during the second week of August and last for a week.
- The breaks are believed to be brought about by the northward shifting of the monsoon trough (minimum low pressure cell in ITCZ). The axis of the trough lies at the foothills of the Himalayas during the break period.
- The monsoon trough is a portion of the Intertropical Convergence Zone as depicted by a line on a weather map showing the locations of minimum sea level pressure, and as such, is a convergence zone between the wind patterns of the southern and northern hemispheres.
- During the break period, heavy rainfall occurs over the sub-Himalayan regions and the southern slopes of the Himalayas.
- On an average one or two breaks do occur during the rainy season. 85 out of 100 years there is a break in the monsoons.

Depressions in South West Monsoon Season

- A major part of the South West Monsoon rainfall is generated by depressions [intense low pressure] originating in the Arabian Sea and Bay of Bengal. Some depressions develop over land also.
- About 3-4 depressions are formed per month from June to September.
- Almost all of them are sucked inward through the deltas of great rivers [They need moisture to be alive], the Ganga, the Mahanadi, the Godavari, the Krishna and the Cauvery and cause heavy rain in these areas.
- The location of depressions strongly coincide with the latitudinal position of ITCZ.
- Most of the depression originate to the west of 90^0 E in Bay of Bengal and move in north-west direction.
- In the Arabian Sea in June-July, the depressions move either in north-west or in northerly direction and may affect west Gujarat or Maharashtra.
- Storms during August and September are rare and are formed close to Maharashtra-Gujarat coast.
- Most of the rainfall in central and northern parts of the country is caused by these depressions.
- The absence of depressions or a change in their tracks result in deficit or no rain.

Advance and Withdrawal of South West Monsoons:


ADVANCE OF
SOUTHWEST MONSOON 2015
Actual
Normal
JAMMU & KASHMIR
HIMACHAL PRADESH
PUNJAB
HARYANA
UTTARANCHAL
UTTAR PRADESH
RAJASTHAN
GUJARAT
MADHYA PRADESH
CHATTISGARH
MAHA RASHTRA
KARNATAKA
ANDHRA PRADESH
TAMIL NADU
KERALA
ORISSA
JHARKHAND
BIHAR
WEST BENGAL
SIKKIM
ASSAM
MEGHALAYA
ARUNACHAL PRADESH
NAGALAND
TRIPURA
PAKISTAN
CHINA
TIBET
NEPAL
BHUTAN
BANGALADESH
MYANMAR
SRI LANKA
ARABIAN SEA
BAY OF BENGAL
ANDAMAN SEA
LAKSHADWEEP (INDIA)
NORTHWEST
NORTHEAST
WESTCENTRAL
EAST-CENTRAL
SOUTHWEST
SOUTHEAST
WEST CENTRAL
EAST CENTRAL
NORTH
SOUTH
15 July
1 July
15 June
10 June
5 June
1 June
25 May
20 May
21-28 May
16-20 May
28 May
21-21 May
16-20 May


NORMAL DATE
FOR
WITHDRAWAL OF SOUTHWEST MONSOON
JAMMU & KASHMIR
HIMACHAL PRADESH
PUNJAB
HARYANA
UTTARANCHAL
UTTAR PRADESH
RAJASTHAN
GUJARAT
MADHYA PRADESH
CHATTISGARH
MAHA RASHTRA
KARNATAKA
ANDHRA PRADESH
TAMIL NADU
KERALA
ORISSA
JHARKHAND
BIHAR
WEST BENGAL
ASSAM
MEGHALAYA
ARUNACHAL PRADESH
PAKISTAN
CHINA
TIBET
NEPAL
BHUTAN
BANGALADESH
MYANMAR
SRI LANKA
ARABIAN SEA
BAY OF BENGAL
ANDAMAN SEA
1 SEPT.
15 SEPT.
1 OCT.
15 OCT.
1 NOV.
15 NOV.
1 DEC.
15 DEC.
1 JAN.

Chief Characteristics of South West Monsoon Rainfall

- Major part of monsoon rains are received between June and September.
- Monsoonal rainfall is largely governed by relief and is orographic in its mode.
- The amount of rainfall decreases with increasing distance from the sea.
- The rainless interval during south west monsoon season is known as 'breaks'. The breaks in rainfall are related to tropical cyclones which originate in the Bay of Bengal.
- There are large scale spatial variations in the distribution of rainfall.
- Monsoons often fail to keep date. Sometimes the monsoons withdraw before the scheduled time causing considerable damage to the crops.

Retreating Monsoon Season – North East Monsoon Season

- Starts with the beginning of the withdrawal of southwest monsoon [middle of September – November] and lasts till early January.
- The monsoons withdraw from the extreme north-west end of the country in September, from the peninsula by October and from the extreme south-eastern tip by December.
- In Punjab the south-west monsoons reach in the first week of July and withdraw from there in the second week of September.
- The south-west monsoons reach Coromandel coast in the first week of June and withdraw from there only in the middle of December.
- Unlike the sudden burst of the advancing monsoons, the withdrawal is rather gradual and takes about three months.

Temperature during Retreating Monsoon Season

- With retreat of the monsoons, the clouds disappear and the sky becomes clear.
- The day temperature starts falling steeply.
- The diurnal range of temperature increases due to lack of cloud cover.
- Pressure and Winds during Retreating Monsoon Season
- As the monsoons retreat, the monsoon trough weakens and gradually shifts southward. Consequently the pressure gradient is low.
- Unlike south-west monsoon, the onset of the north monsoon is not clearly defined.
- The direction of winds over large parts of the country is influenced by the local pressure conditions.

Cyclones during Retreating Monsoon Season

- Most severe and devastating tropical cyclones originate in the Indian seas especially in the Bay of Bengal.
- The highest frequency of the cyclones is in the month of October and the first half of November.
- More cyclones are born in October and then in November and more cyclones originate in the Bay of Bengal than in the Arabian Sea.
- In October, the Cyclones of the Bay of Bengal originate between 8°N and 14°N.
- Initially they move in a west or northwesterly direction, but many of them later recurve and move towards the north-east.
- Near 55 per cent of the Bay storms cross or affect the Indian coast.
- The area's most vulnerable to these storms include the coastal belts of Tamil Nadu, Andhra Pradesh, Odisha and West Bengal.
- Many of the cyclones which strike the eastern coast of India, south of 15°N latitude cross the southern Peninsula and enter Arabian Sea.
- During this process, they may weaken, but on re-entry over the Arabian sea they intensify into cyclonic storms.

- The storms of Arabian sea originate between 12°N and 17°N latitudes in October and between 8° N and 13° N latitudes in November.
- Generally they move away from the coast in a north-westerly direction. But about 25% of them later recurve northeast and strike the Maharashtra or Gujarat coast.
- In north-west India the western disturbances produce clouding and light rainfall in the otherwise fine weather.
- The precipitation is in the form of snow in higher reaches of Jammu and Kashmir, Himachal Pradesh and in Kumaon Hills.
- Precipitation during Retreating Monsoon Season
- The humidity and cloud cover are much reduced with the retreat of the south-west monsoons and most parts of the country remain without much rainfall.
- October-November is the main rainy season in Tamil Nadu and adjoining areas of Andhra Pradesh to the south of the Krishna delta as well as a secondary rainy period for Kerala.
- The retreating monsoons absorb moisture while passing over the Bay of Bengal and cause this rainfall.
- Annual Rainfall [South West Monsoons + Retreating Monsoons]

Areas of very high rainfall

- Areas receiving an annual rainfall of 200 cm and above.
- These include western side of Western Ghats [Thiruvananthapuram in the south to Mumbai in the north].
- The average annual rainfall in this belt is 200-400 cm.
- Assam, Nagaland, Meghalaya, Mizoram, Arunachal Pradesh, Sikkim, parts of Manipur, Tripura and north-eastern tip of West Bengal also receive 200 cm or more, with isolated pockets receiving over 400 cm.
- Meghalaya (the abode of clouds) is the wettest part of the country with Mawsynram and Cherrapunji getting 1,221 and 1,102 cm of annual rainfall respectively.

Areas of high rainfall

- 100-200 cm annual rainfall.
- Eastern slopes of the Western Ghats, major part of the northern plain, Odisha, Madhya Pradesh, Andhra Pradesh and Tamil Nadu.
- Isohyet (the line joining places of equal rainfall).

Areas of low rainfall

- 50-100 cm annual rainfall.
- Large parts of Gujarat, Maharashtra. western Madhya Pradesh, Andhra Pradesh, Karnataka, eastern Rajasthan, Punjab, Haryana and parts of Uttar Pradesh.

Areas of very low rainfall

- These are desert and semi-desert areas receiving less than 50 cm of annual rainfall.
- They include large areas of western Rajasthan, Kachchh and most of Ladakh region of Jammu and Kashmir.

Forests – Natural Vegetation of India

- **Climate, soil and topography** are the major factors that influence Natural Vegetation of a place.
- The main climatic factors are **rainfall and temperature**. The amount of annual rainfall has a great bearing on the type of vegetation.

Annual Rainfall	Type of Vegetation
200 cm or more	Evergreen Rain Forests
100 to 200 cm	Monsoon Deciduous Forests
50 to 100 cm	Drier Deciduous or Tropical Savanna
25 to 50 cm	Dry Thorny Scrub (Semi-arid)
Below 25 cm	Desert (Arid)

- Temperature is the major factor in Himalayas and other hilly regions with an elevation of more than 900 metres.
- As the temperature falls with altitude in the Himalayan region the vegetal cover changes with altitude from **tropical to sub-tropical, temperate and finally alpine.**
- Soil is an equally determining factor in few regions. **Mangrove forests, swamp forests** are some of the examples where soil is the major factor.
- Topography is responsible for certain minor types e.g. **alpine flora, tidal forests, etc..**

Classification of Natural Vegetation of India

- Classification of Natural Vegetation of India is primarily based on spatial and annual variations in rainfall. Temperature, soil and topography are also considered.
- India's vegetation can be divided into 5 main types and 16 sub-types as given below.

A. Moist Tropical Forests

- Tropical Wet Evergreen
- Tropical Semi-Evergreen
- Tropical Moist Deciduous
- Littoral and Swamp

B. Dry Tropical Forests

- Tropical Dry Evergreen
- Tropical Dry Deciduous
- Tropical Thorn

C. Montane Sub-tropical Forests

- Sub-tropical broad leaved hill
- Sub-tropical moist hill (pine)
- Sub-tropical dry evergreen

D. Montane Temperate Forests

- Montane Wet Temperate
- Himalayan Moist Temperate
- Himalayan Dry Temperate

E. Alpine Forests

- Sub-Alpine
- Moist Alpine scrub
- Dry Alpine scrub

Forest Type in India	% of Total Area
Tropical Moist Deciduous	37
Tropical Dry Deciduous	28
Tropical Wet Evergreen	8
Sub-Tropical Moist Hill	6
Tropical Semi-Evergreen	4
Rest below 4 %	

PHYSICAL GEOGRAPHY

EARTH'S SURFACE

GEOMORPHIC FORCES

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.

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 from one place to another by natural agents like wind, water, and glaciers.

The 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.

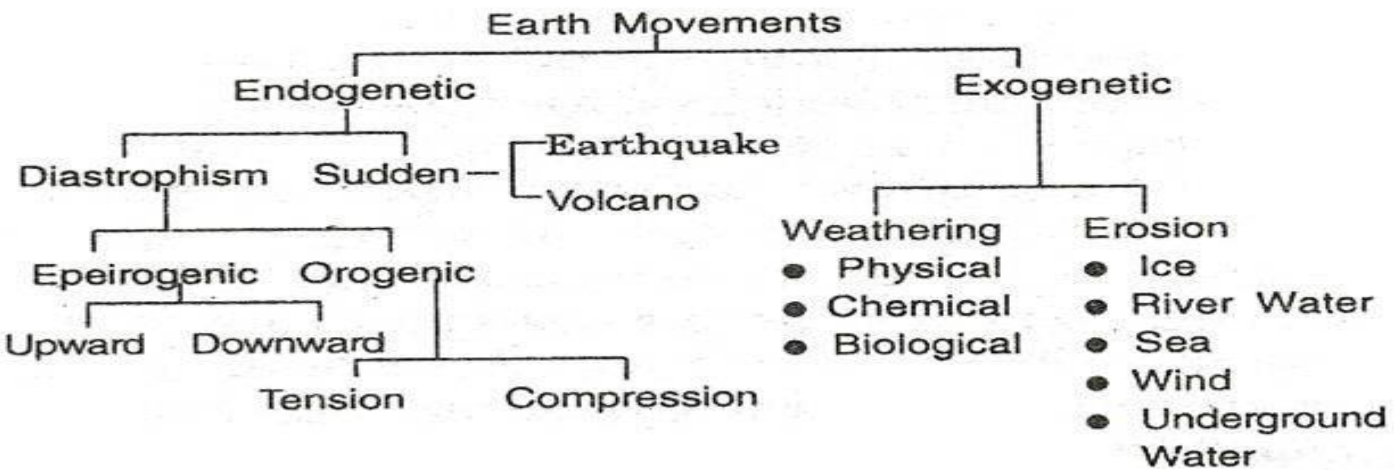
SOURCES OF EARTH HEAT

RADIOACTIVE DECAY	The high temperature below the crust is attributed to the disintegration of the radioactive substances. The nuclear decay happens primarily in the crust and the mantle. Scientists believe that uranium could become sufficiently concentrated at the base of Earth's mantle to ignite self-sustained nuclear fission, as in a human-made reactor. The new measurements suggest radioactive decay provides more than half of Earth's total heat. Nuclear fusion doesn't occur inside the earth. For nuclear fusion to occur there must be far more pressure and temperature inside the earth. The earth is not massive enough to cause such conditions.
PRIMORDIAL HEAT	The rest is the heat left over from Earth's formation known as the primordial heat. Primordial heat is the kinetic energy transferred to Earth by external impacts of comets and meteorites and the subsequent effects (friction caused by sinking of heavy elements like Fe, rising light elements like Si) and latent heat of crystallisation released as the core solidified.
TIDAL FRICTION	The ocean tides are not the only effect of tidal forces (gravitational influence of the moon and the sun on earth; tides are explained in oceanography). The solid body of the Earth also bulges slightly in this way. The daily flexing of the Earth (both solid body and the oceans) cause loss of energy of the Earth's rotation, due to friction. This energy goes into heat, leading to miniscule increase in the Earth's internal temperature. The loss of rotational energy means that the **Earth is slowing down in its rotation rate**, currently by about 0.002 seconds per century
SEISMIC WAVES	They are the most important source available to understand the layered structure of the earth. The velocity of seismic waves changes as they travel through materials with different **elasticity** and **density**. The **more elastic and denser the material is, the higher is the velocity**. They also undergo **refection or refraction** when they come across materials with different densities. Earth's internal structure can be understood by analysing the patterns of reflection, refraction and change in velocity of the seismic waves when they travel through it.

METEORITES	Meteorites and Earth are born from the same nebular cloud. Thus, they are likely to have a similar internal structure. When meteoroids they fall to earth, their outer layer is burnt during their fall due to extreme friction and the inner core is exposed. The heavy material composition of their cores confirms the similar composition of the inner core of the earth.
GRAVITATION	The gravitation force differs according to the mass of material. The uneven distribution of mass of material within the earth influences this value. Such a difference is called **gravity anomaly**. Gravity anomalies give us information about the **distribution of mass** in the crust of the earth.
MAGNETIC FIELD	The geodynamo effect helps scientists understand what's happening inside the Earth's core. Shifts in the magnetic field also provide clues to the inaccessible iron core

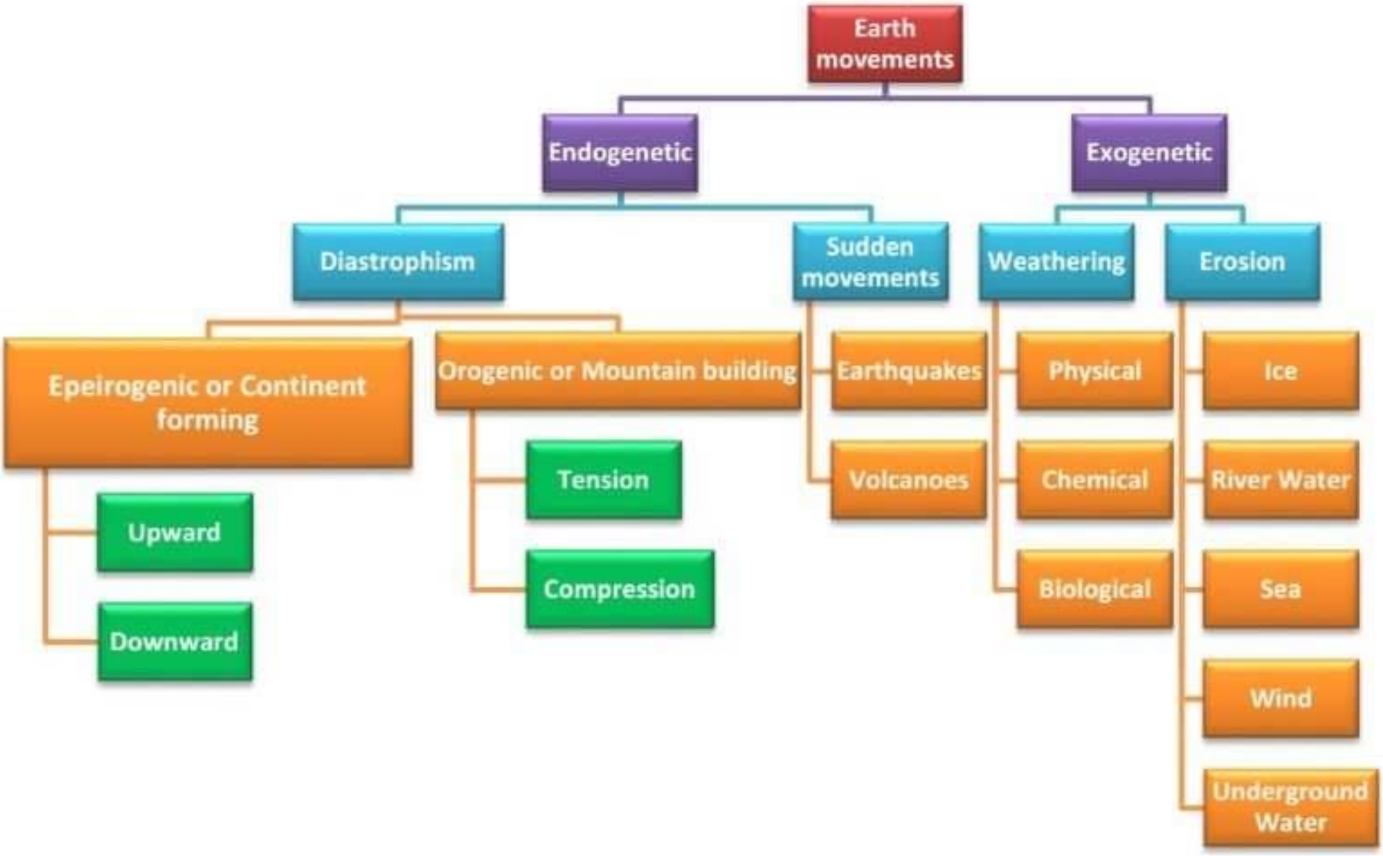
EARTH MOVEMENTS

- 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



Endogenic Geomorphic Movements

- The large-scale movements on the earth's crust or its surface brought down by the forces emanating from deep below the earth's surface are called as endogenic geomorphic movements or simply endogenic movements (endo: internal; genic: origin; geo: earth; morphic: form).
- The geomorphic processes that are driven by the forces emanating from deep below the earth's surface are called endogenic geomorphic processes (folding, faulting, etc.).



FORCES BEHIND ENDOGENIC MOVEMENTS

- The ultimate source of energy behind forces that drive endogenic movements is **earth's internal heat**.
- Earth's internal heat is a result of mainly radioactive decay (50% of the earth's internal heat) and gravitation (causes pressure gradients).
- Differences in temperature and pressure (temperature gradients or geothermal gradients and pressure gradients) among various layers of the earth give rise to **density differences** and these density differences give rise to **conventional currents**.
- Convectional currents in the mantle drive the **lithospheric plates** (crust and upper mantle) and the **movement of the lithospheric plates** (**tectonics**) is the cause behind endogenic movements.
- The Earth's rotation (**Coriolis effect**) can influence where convection currents travel.
- The destination of convection currents determines the nature and location of the endogenic movements.

CLASSIFICATION OF ENDOGENETIC MOVEMENTS

- Endogenic movements are divided into **diastrophic movements** and **sudden movements**.
- Diastrophism refers to **deformation** of the Earth's crust.
- Diastrophic movements are gradual and might stretch for thousands of years.
- On the other hand, sudden movements like earthquakes and volcanic eruptions occur in a very short period.
- Diastrophic movements are further classified into **epeirogenic movements (continent forming — subsidence, upliftment)** and **orogenic movements (mountain building — folding, faulting)**.

DIASTROPHISM

- Diastrophism refers to deformation of the Earth's crust due to diastrophic movements (deforming movements) such as **folding, faulting, warping (bending or twisting of a large area) and fracturing**.
- All processes that move, elevate or build up portions of the earth's crust come under diastrophism. They include:
- **orogenic processes** involving mountain building through severe folding (crust is severely deformed into folds) and affecting long and narrow belts of the earth's crust;
- **epeirogenic processes** involving uplift or warping of large parts of the earth's crust (simple deformation);
- **earthquakes and volcanism** involving local relatively minor movements;
- **plate tectonics** involving horizontal movements of crustal plates.
- The most obvious evidence of diastrophic movement can be seen where sedimentary rocks have been bent, broken or tilted.

EPIROGENIC / CONTINENT FORMING MOVEMENTS

- Epeirogenic or **continent forming** movements are **radial** movements (act along the radius of the earth).
- Their direction may be towards (subsidence) or away (uplift) from the centre.
- **They cause upheavals or depressions of land exhibiting undulations (wavy surface) of long wavelengths and little folding.**
- The broad central parts of continents are called cratons and are subject to epeirogeny, hence the name continent forming movements.

Uplift

- Raised beaches, elevated wave-cut terraces, sea caves and fossiliferous beds above sea level are evidence of upliftment.

Uplifted landforms

- In India, raised beaches occur at several places along the **Kathiawar, Nellore, and Tirunelveli coasts**.
- Several places which were on the sea some centuries ago are now a few miles inland due to upliftment.

- For example, Coringa near the mouth of the Godavari, Kaveripattinam in the Kaveri delta and Korkai on the coast of Tirunelveli, were all flourishing seaports about 1,000 to 2,000 years ago.

Subsidence

- Submerged forests and valleys, as well as buildings, are evidence of subsidence.
- In 1819, a part of the Rann of Kachchh was submerged as a result of an earthquake.
- Presence of peat and lignite beds below the sea level in Tirunelveli and the Sundarbans is an example of subsidence.
- The Andamans and Nicobars have been isolated from the Arakan coast by submergence of the intervening land.

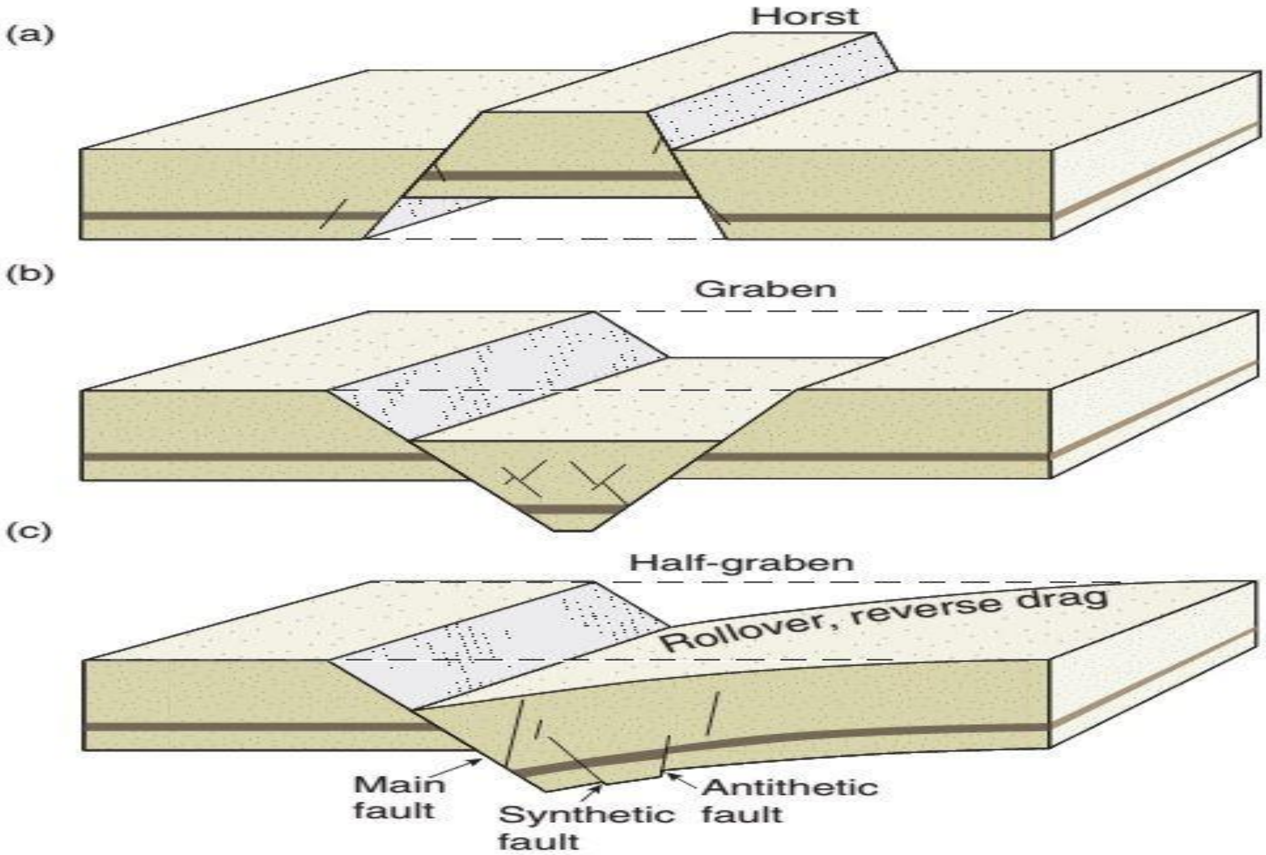
Arakan coast (Highlighted part)

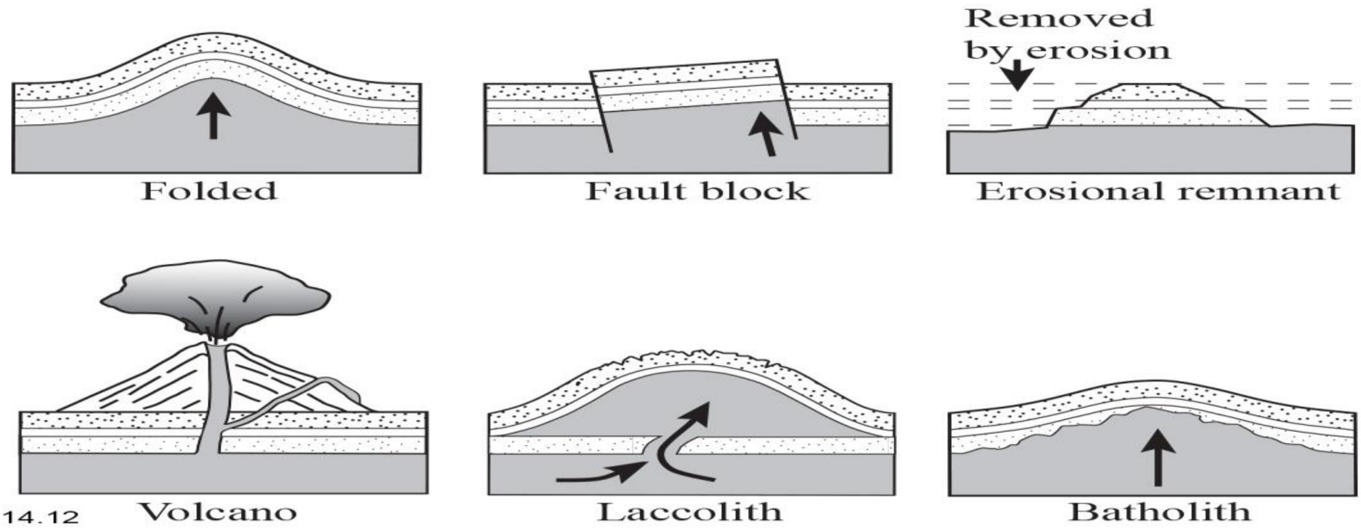
- On the east side of **Bombay island**, trees have been found embedded in the mud about 4 m below low water mark. A similar submerged forest has also been noticed on the Tirunelveli coast in Tamil Nadu.
- A large part of the Gulf of Mannar and Palk Strait is very shallow and has been submerged in geologically recent times. A part of the former town of Mahabalipuram near Chennai is submerged in the sea.

OROGENIC / MOUNTAIN FORMING MOVEMENTS

- In contrast to epeirogenic movement, the orogenic movement is a **more complicated deformation** of the Earth's crust, associated with **crustal thickening** (due to the convergence of tectonic plates).
- Such plate convergence forms orogenic belts that are characterised by "the folding and faulting of layers of rock, by the intrusion of magma, and by volcanism.
- Orogenic or the mountain-forming movements act tangentially to the earth surface, as in plate tectonics.
- Tension produces fissures (since this type of force acts away from a point in two directions), and compression produces folds (because this type of force acts towards a point from two or more directions).

Fissure and Fold





SUDDEN MOVEMENTS

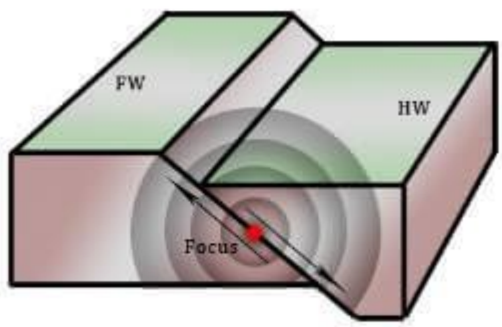
- Sudden geomorphic movements occur mostly at the **lithospheric plate margins** (tectonic plate margins).
- The plate margins are highly unstable regions due to pressure created by pushing and pulling of magma in the mantle (**convectional currents**).
- These movements cause considerable deformation over a short period.

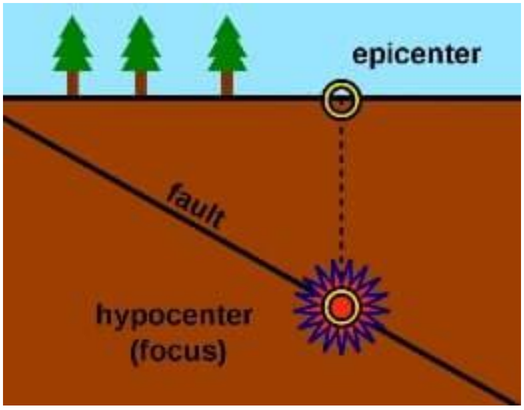
EARTH QUAKES

- Earthquakes occur when the surplus accumulated stress in rocks in the earth's interior due to folding, faulting or other physical changes is relieved through the weak zones over the earth's surface in the form of kinetic energy (seismic waves).

How are earthquake waves produced?

- The abrupt release of energy along a fault (sharp break in the crustal layer) causes earthquake waves.
- Rock layers along a fault tend to move in opposite directions due to the force excreted on them but are held in place by counteracting frictional force exerted by the overlying rock strata.

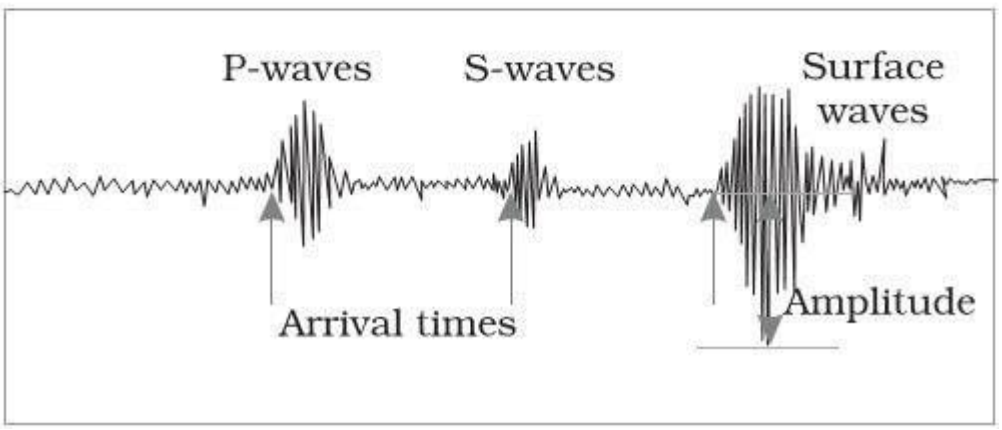




- The pressure on the rock layers builds up over a period and overcomes the frictional force resulting in a sudden movement generating shockwaves (seismic waves) that travel in all directions.
- The point where the energy is released is called the **focus** or the **hypocentre** of an earthquake.
- The point on the surface directly above the focus is called **epicentre**.
- An instrument called 'seismograph' records the waves reaching the surface.

Types of Seismic waves or earthquake waves

- The seismic waves or earthquake waves are basically of two types — **body waves** and **surface waves**.

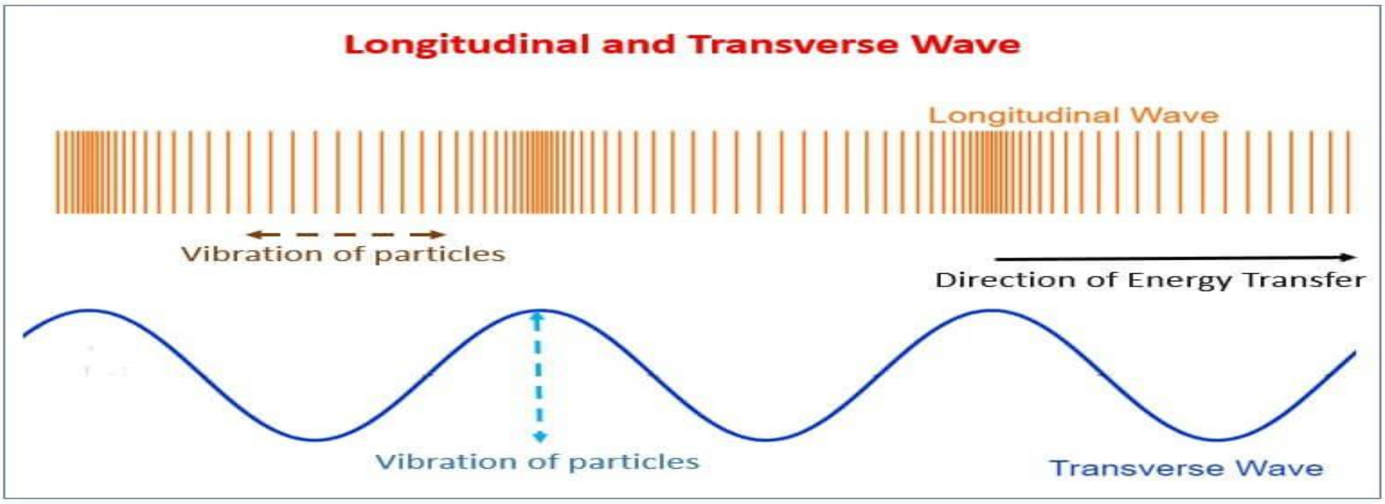


Body waves

- Body waves are generated due to the release of energy at the focus and **move in all directions** travelling through the interior of the earth. Hence, the name body waves.
- There are two types of body waves:
- the **P-waves or primary waves** (**longitudinal** in nature — wave propagation is similar to sound waves), and
- the **S-waves or secondary waves** (**transverse** in nature — wave propagation is similar to ripples on the surface of the water).

Primary Waves (P-waves)

- Primary waves are called so because they are the **fastest** among the seismic waves and hence are **recorded first on the seismograph**.
- P-waves are also called as the
- **longitudinal waves** because the displacement of the medium is in the same direction as, or the opposite direction to, (parallel to) the direction of propagation of the wave; or
- **compressional waves** because they produce compression and rarefaction when travelling through a medium; or
- **pressure waves** because they produce increases and decreases in pressure in the medium.
- P-waves creates density differences in the material leading to stretching (rarefaction) and squeezing (compression) of the material.



The vibration of particles in Longitudinal wave and Transverse wave

- These waves are of relatively high frequency and are the **least destructive** among the earthquake waves.
- The trembling on the earth's surface caused due to these waves is in the **up-down direction (vertical)**.
- **They can travel in all mediums,** and their velocity depends on **shear strength (elasticity)** of the medium.
- Hence, the velocity of the P-waves in **Solids > Liquids > Gases**.
- These waves take the form of **sound waves** when they enter the atmosphere.
- P-wave velocity in earthquakes is in the range 5 to 8 km/s.
- The precise speed varies according to the region of the Earth's interior, from less than 6 km/s in the Earth's crust to 13.5 km/s in the lower mantle, and 11 km/s through the inner core.

We usually say that the speed of sound waves depends on density. But there are few exceptions — **mercury is denser than iron**, but it is less elastic; hence the **speed of sound in iron is greater than that in mercury**

Why do P-waves travel faster than S-waves?

- **P-waves are about 1.7 times faster than the S-waves**.
- P-waves are compression waves that apply a force in the direction of propagation and hence transmit their energy quite easily through the medium and thus travel quickly.
- On the other hand, S-waves are **transverse waves** or **shear waves** (motion of the medium is perpendicular to the direction of propagation of the wave) and are hence less easily transmitted through the medium.

P-waves as an earthquake warning

- Advance earthquake warning is possible by detecting the non-destructive primary waves that travel more quickly through the Earth's crust than do the destructive secondary and surface waves.
- Depending on the depth of focus of the earthquake, the delay between the arrival of the P-wave and other destructive waves could be up to about 60 to 90 seconds (depends of the depth of the focus).

Secondary Waves (S-waves)

- Secondary waves (secondary they are recorded second on the seismograph) or S-waves are also called as **transverse waves or shear waves or distortional waves**.
- They are analogous to water ripples or light waves.
- **Transverse waves or shear waves** mean that the direction of vibrations of the particles in the medium is perpendicular to the direction of propagation of the wave. Hence, they create **troughs** and **crests** in the material through which they pass (they distort the medium).
- S-waves arrive at the surface after the P-waves.
- These waves are of high frequency and possess **slightly higher destructive power** compared to P-waves.
- The trembling on the earth's surface caused due to these waves is from **side to side (horizontal)**.
- S-waves **cannot pass through fluids (liquids and gases)** as fluids do not support **shear stresses**.
- They travel at varying velocities (proportional to shear strength) through the solid part of the Earth.

Surface waves (L-Waves)

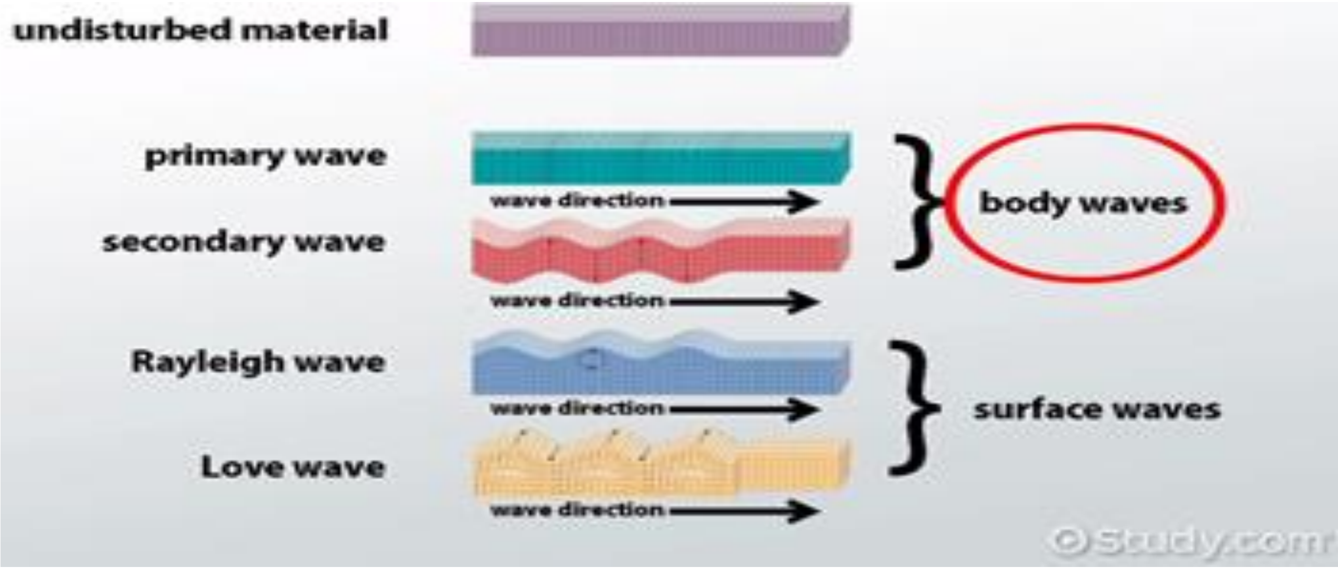
- The body waves **interact with the surface rocks and generate new set of waves called surface waves** (long or L-waves). **These waves move only along the surface**.
- Surface Waves are also called long period waves because of their **long wavelength**.
- They are **low–frequency transverse waves (shear waves)**.
- They develop in the **immediate neighbourhood of the epicentre** and affect only the surface of the earth and die out at smaller depth.
- **They lose energy more slowly with distance than the body waves** because they travel only across the surface unlike the body waves which travel in all directions.
- **Particle motion of surface waves (amplitude) is larger than that of body waves**, so surface waves are the **most destructive** among the earthquake waves.
- They are **slowest** among the earthquake waves and are recorded last on the seismograph.

Love waves

- It's the fastest surface wave and moves the ground from side-to-side.

Rayleigh waves

- A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean.
- Because it rolls, it moves the ground **up and down and side-to-side** in the same direction that the wave is moving.
- **Most of the shaking and damage** from an earthquake is due to the **Rayleigh wave**.



TPES OF EARTH WAVESQUAKES

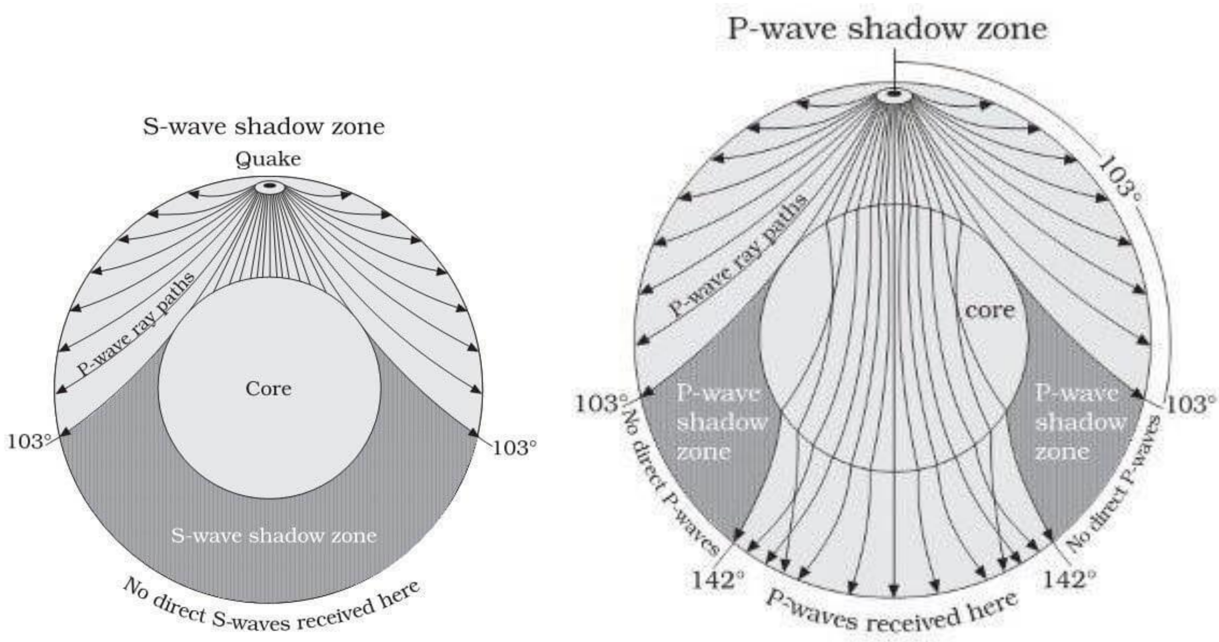
How do seismic waves help in understanding the earth's interior?

- Seismic waves get recorded in seismographs located at far off locations.
- Differences in arrival times, waves taking different paths than expected (due to refraction) and absence of the seismic waves in certain regions called as shadow zones, allow mapping of the Earth's interior.
- Discontinuities in velocity as a function of depth are indicative of changes in composition and density.
- That's is, by observing the changes in velocity, the density and composition of the earth's interior can be estimated (change in densities greatly varies the wave velocity).
- Discontinuities in wave motion as a function of depth are indicative of changes in phase.
- That is, by observing the changes in the direction of the waves, the emergence of shadow zones, different layers can be identified.

The emergence of Shadow Zone of P-waves and S-waves

- S-waves do not travel through liquids (they are **attenuated**).
- The entire zone beyond 103° does not receive S-waves, and hence this zone is identified as the shadow zone of S-waves. This observation led to the discovery of the **liquid outer core**.
- The shadow zone of P-waves appears as a band around the earth between 103° and 142° away from the epicentre.
- This is because P-waves are refracted when they pass through the transition between the semisolid mantle and the liquid outer core.
- However, the seismographs located beyond 142° from the epicentre, record the arrival of P-waves, but not that of S-waves. This gives clues about the **solid inner core**.

- Thus, a zone between **103° and 142°** from epicentre was identified as the **shadow zone for both the types of waves**.



Shadow Zone of P-waves and S-waves

- The seismographs located at any distance within 103° from the epicentre, recorded the arrival of both P and S-waves.

Why do sound waves travel faster in a denser medium whereas light travels slower?

- The sound is a mechanical wave and travels by compression and rarefaction of the medium.
- A higher density leads to more elasticity in the medium and hence the ease by which compression and rarefaction can take place. This way the velocity of sound increases with an increase in density.
- Light, on the other hand, is a transverse electromagnetic wave.
- An increase in the density increases effective path length, and hence it leads to higher refractive index and lower velocity.

- The span of the shadow zone of the P-Waves = 78° [2 x (142° – 103°)]
- The span of the shadow zone of the S-Waves = 154° [360° – (103° + 103°)]
- The span of the shadow zone common for both the waves = 78°

Effects of Earthquakes

SHAKING AND GROUND RUPTURE	Shaking and ground rupture result in severe damage to buildings and other rigid structures. Ground rupture (crack along the fault) is a major risk for large engineering structures such as dams, bridges and nuclear power stations.

LANDSLIDES AND AVALANCHES	Earthquakes, along with severe storms, volcanic activity, coastal wave attack, and wildfires, can produce slope instability leading to landslides, a major geological hazard.
FIRES	Earthquakes can cause fires by damaging electrical power or gas lines. More deaths in the 1906 San Francisco earthquake were caused by fire than by the earthquake itself.
SOIL LIQUEFACTION	Soil liquefaction occurs when water-saturated soil temporarily loses its strength and transforms from a solid to a liquid. Soil liquefaction may cause rigid structures, like buildings and bridges, to tilt or sink
TSUNAMI	Megathrust earthquakes can produce long-wavelength, long-period sea waves due to abrupt movement of large volumes of water
FLOODS	Floods may be secondary effects of earthquakes if dams are damaged. Earthquakes may cause landslips to dam rivers, which collapse and cause floods.

Tsunami: Mechanism & Properties, 2004 Indian Ocean Tsunami

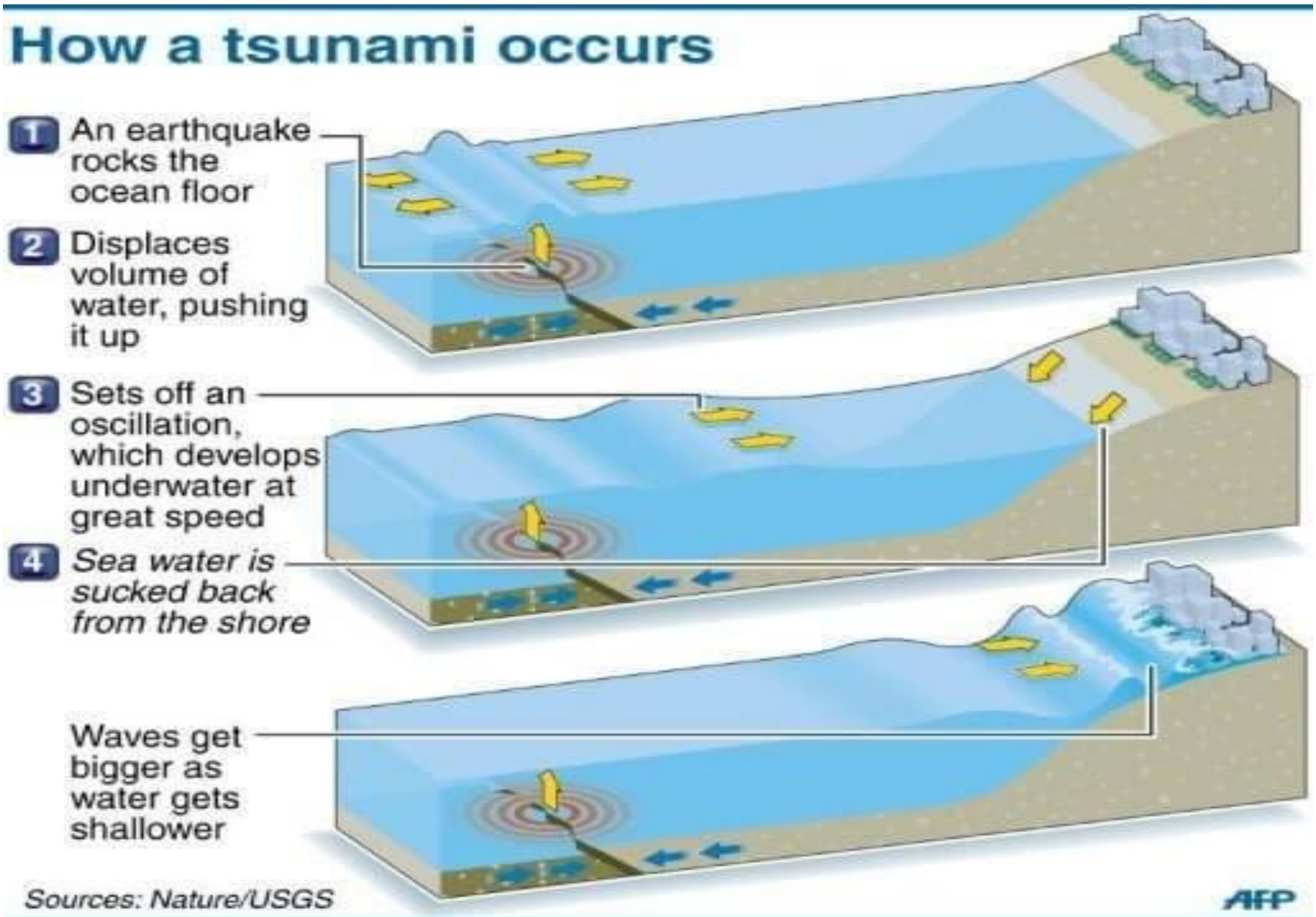
- Tsunami is a Japanese word for "**Harbour wave**". A tsunami is a series of **very long-wavelength** waves in large water bodies like seas or large lakes caused by a major disturbance above or below the water surface or due to the displacement of a large volume of water.
- They are sometimes referred to as tidal waves because of **long wavelengths**, although the attractions of the Moon and Sun play no role in their formation.
- Earthquakes (e.g. 2004 Indian Ocean Tsunami), volcanic eruptions (e.g. tsunami caused by the violent eruption of Krakatoa in 1883), landslides (tsunami caused by the collapse of a section of Anak Krakatoa in 2018), underwater explosions, meteorite impacts, etc. have the potential to generate a tsunami.
- Subduction zones off Chile, Nicaragua, Mexico and Indonesia have created killer tsunamis.
- The Pacific among the oceans has witnessed the greatest number of tsunamis (over 790 since 1990).

Mechanism of Tsunami Waves

- Megathrust earthquakes cause a sudden displacement in a seabed sufficient to cause the sudden raising of a large body of water.
- As the subducting plate plunges beneath the less dense plate, stresses build-up, the locked zone between the plates give way abruptly, and the parts of the oceanic crust is then upthrust resulting in the displacement of a large column of water vertically.
- The tsunami on December 26, 2004, was caused after an earthquake displaced the seabed off the coast of Sumatra, Indonesia.
- A marine volcanic eruption can generate an impulsive force that displaces the water column and gives birth to a tsunami.
- During a submarine landslide, the equilibrium sea-level is altered by sediment moving along the floor of the sea. Gravitational forces then propagate a tsunami.
- Most destructive tsunamis can be caused due to the fall of extra-terrestrial objects on to the earth.

Propagation of the waves

- Gravity acts to return the sea surface to its original shape.
- The ripples then race outward, and a tsunami is caused.
- As a tsunami leaves deep waters and propagates into the shallow waters, it transforms. This is because as the depth of the water decreases, the speed of the tsunami reduces. But the change of total energy of the tsunami remains constant.
- With the decrease in speed, the height of the tsunami wave grows. A tsunami which was imperceptible in deep water may grow to many metres high, and this is called the **'shoaling' effect**.
- Sometimes, the sea seems to at first draw a breath, but then this withdrawal is followed by the arrival of the crest of a tsunami wave. Tsunamis have been known to occur suddenly without warning.
- In some cases, there are several great waves separated by intervals of several minutes or more.
- The first of these waves is often preceded by an extraordinary recession of water from the shore, which may commence several minutes or even half an hour beforehand.



Properties of Tsunami Waves

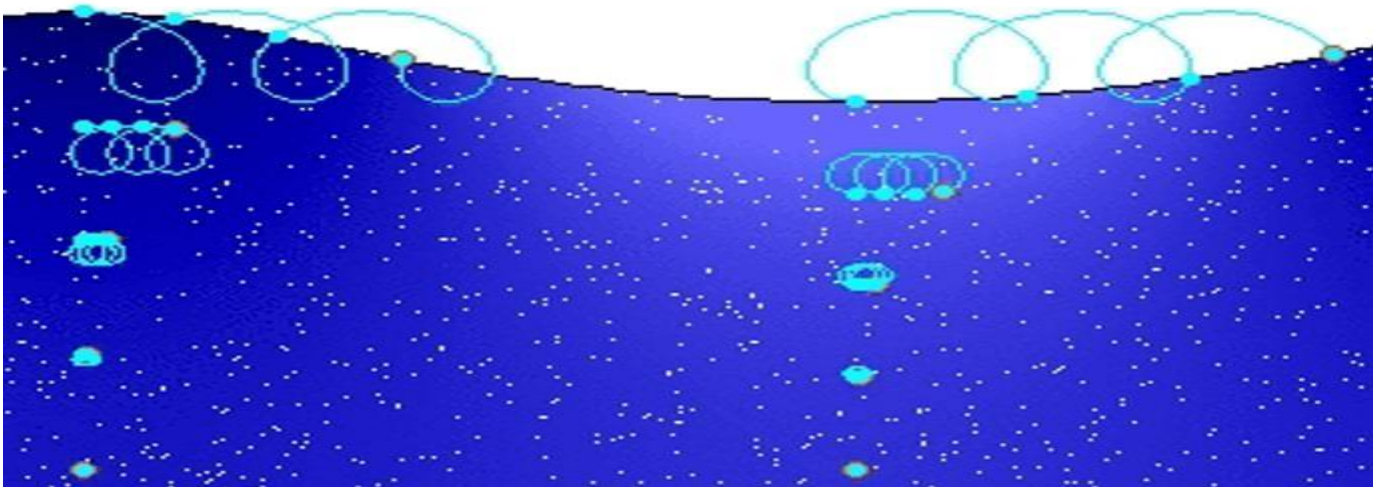
Basics

- Wave crest and trough: The highest and lowest points of a wave are called the crest and trough respectively.
- Wave height: It is the vertical distance from the bottom of a trough to the top of a crest of a wave.
- Wave amplitude: It is one-half of the wave height.
- Wave period: It is the time interval between two successive wave crests or troughs.

- Wavelength: It is the horizontal distance between two successive crests.
- Wave frequency: It is the number of waves passing a given point during a one second time interval.

Normal waves

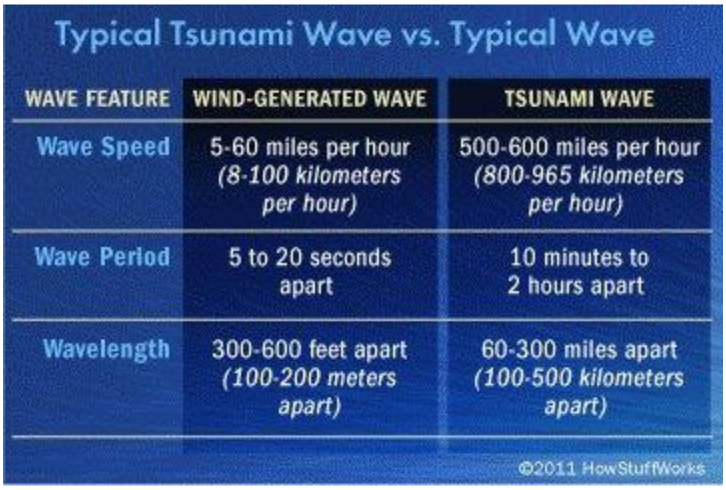
- The horizontal and vertical motions are common in ocean water bodies.
- The **horizontal motion** refers to the **ocean currents and waves**. The **vertical motion** refers to **tides**.
- Water moves ahead from one place to another through ocean currents while the water in the normal wind-generated waves do not move, but the **wave trains move ahead**.
- The motion of normal waves seldom affects the stagnant deep bottom water of the oceans.



Wind generated wave motion

- The actual motion of the water beneath the waves is **circular**. It indicates that things are carried up and forward as the wave approaches, and down and back as it passes.
- **As a wave approaches the beach, it slows down. And, when the depth of water is less than half the wavelength of the wave, the wave breaks (dies).**

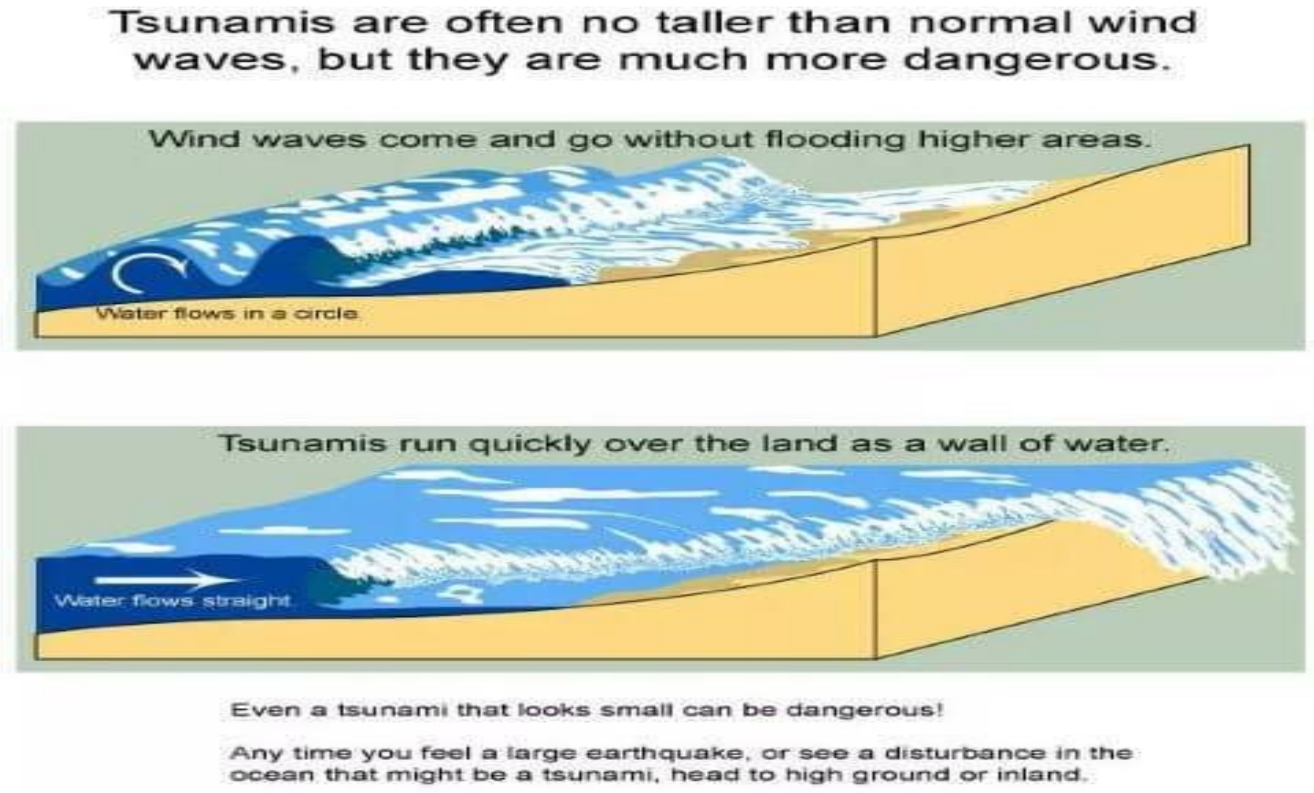
Normal waves vs Tsunami waves



Typical Tsunami Wave vs. Typical Wave

WAVE FEATURE	WIND-GENERATED WAVE	TSUNAMI WAVE
Wave Speed	5-60 miles per hour *(8-100 kilometers per hour)*	500-600 miles per hour *(800-965 kilometers per hour)*
Wave Period	5 to 20 seconds apart	10 minutes to 2 hours apart
Wavelength	300-600 feet apart *(100-200 meters apart)*	60-300 miles apart *(100-500 kilometers apart)*

©2011 HowStuffWorks



- Tsunamis are a series of waves of very, very long wavelengths and period.
- Tsunamis are different from the wind-generated waves (period of five to twenty seconds).
- Tsunamis behave as **shallow-water waves** because of their long wavelengths. They have a period in the range of ten minutes to two hours and a wavelength exceeding 500 km.
- The rate of energy loss of a wave is inversely related to its wavelength. So, tsunamis lose little energy as they propagate because of their very large wavelength.
- **They travel at high speeds in deep waters, and their speed falls when they hit shallow waters**.
- A tsunami that occurs 1000 metres deep in water has a speed of more about 350 km per hour. At 6000 m, it can travel at speeds about 850 km per hour.
- **Tsunami waves are not noticed by ships far out at sea.**
- Their amplitude is negligible when compared with their wavelength, and hence the waves go unnoticed in deep oceans.
- **When tsunamis approach shallow water, however, the wave amplitude increases (conservation of energy)**.
- The waves may occasionally reach a height of 20 to 30 metres above mean sea level in closed harbours and inlets (funnelling effect).

2004 Indian Ocean Tsunami

- Tsunami or the Harbour wave struck havoc in the Indian Ocean on the 26th of December 2004.
- The wave was the result of an earthquake that had its epicentre near the western boundary of Sumatra.
- The magnitude of the earthquake was 9.0 on the Richter scale.

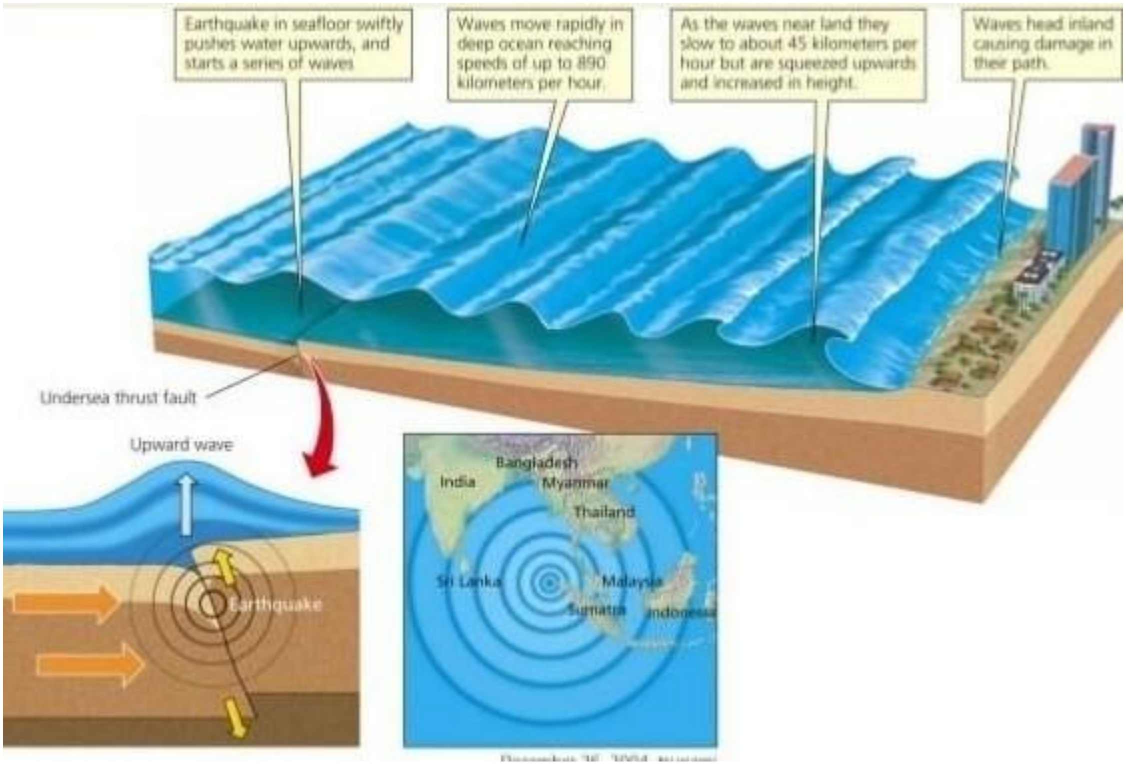
Plate tectonics

- **Indian plate** went under the **Burma plate**, there was a sudden movement of the sea floor, causing the earthquake.

- The ocean floor was displaced by about 10 – 20m and tilted in a downward direction.
- A huge mass of ocean water flowed to fill in the gap that was being created by the displacement.
- This marked the withdrawal of the water mass from the coastlines of the landmasses in the south and Southeast Asia.
- After thrusting of the Indian plate below the Burma plate, the water mass rushed back towards the coastline as a tsunami.

Tsunami waves

- Tsunami travelled at a speed of about 800 km. per hour, comparable to speed of commercial aircraft and completely washed away some of the islands in the Indian ocean.
- The Indira point in the Andaman and Nicobar Islands that marked the southernmost point of India got completely submerged.
- As the wave moved from earthquake epicentre from Sumatra towards the Andaman Islands and Sri Lanka, the **wavelength decreased with decreasing depth of water**.
- The travel speed also declined from 700-900 km per hour to less than 70 km per hour.
- Tsunami waves travelled up to a depth of 3 km from the coast killing more than 10,000 people and affected more than lakh of houses.
- In India, the worst affected were the coastal areas of Andhra Pradesh, Tamil Nadu, Kerala, Pondicherry and the Andaman and Nicobar Islands.



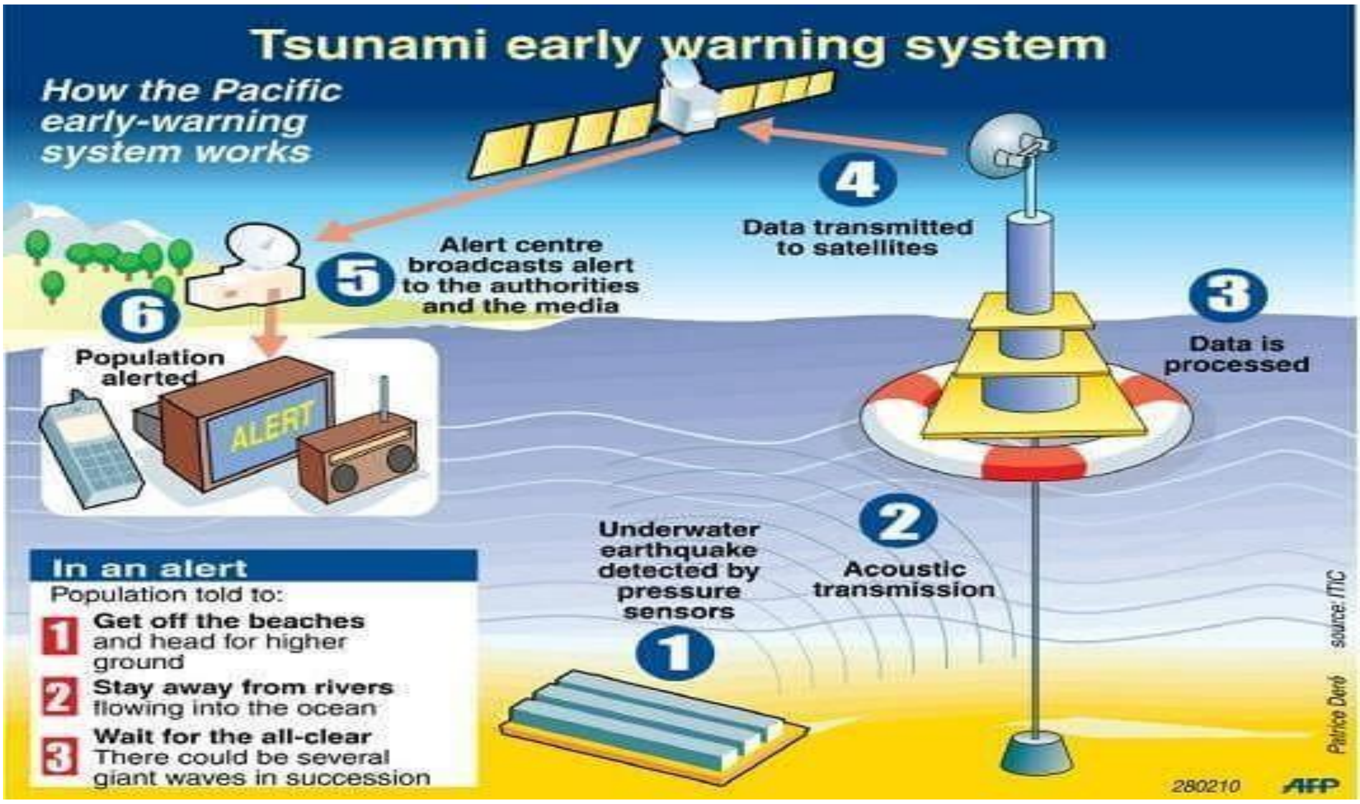
Shifts in Geography

- Tsunamis and earthquakes can cause changes in geography.
- The December 26 earthquake and tsunami shifted the North Pole by 2.5 cm in the direction of 145 degrees East longitude and reduced the length of the day by 2.68 microseconds.
- This, in turn, affected the velocity of earth's rotation and the Coriolis force which plays a strong role in weather patterns.

- The Andaman and Nicobar Islands may have (moved by about 1.25 m owing to the impact of the colossal earthquake and the tsunami.

Tsunami Warning Systems

- While the earthquake cannot be predicted in advance, it is possible to give a three-hour notice of a potential tsunami.
- Such early warning systems are in place across the Pacific Ocean. Post-2004, they were installed in the Indian Ocean as well.
- In 1965, early warning system was started by the National Oceanic and Atmospheric Administration (NOAA). The member states of the NOAA include the major Pacific Rim countries.
- **NOAA has developed the 'Deep Ocean Assessment and Reporting of Tsunamis' (DART) gauge.**
- Each gauge has a very sensitive pressure recorder on the sea floor. Data is generated whenever changes in water pressure occur.
- The data is transmitted to a surface **buoy** which then relays it over satellite.
- Computer systems at the **Pacific Tsunami Warning Centre (PTWC) in Hawaii** monitor data.
- Based on the data, warnings are issued.



India's preparedness

- The Deep Ocean Assessment and Reporting System (DOARS) was set up in the Indian Ocean post-2004.
- The Indian government plans to set up a network with Indonesia, Myanmar and Thailand etc.
- A **National Tsunami Early Warning Centre**, which can detect earthquakes of more than 6 magnitude in the Indian Ocean, was inaugurated in 2007 in India.
- Set up by the **Ministry of Earth Sciences** in the **Indian National Centre for Ocean Information Services (INCOIS), Hyderabad**, the tsunami warning system would take 10-30 minutes to analyse the seismic data following an earthquake.

VOLCANOES

- **Volcanism includes the movement of molten rock (magma) onto or towards the earth's surface through narrow volcanic vents or fissures.**
- A volcano is formed when the molten magma in the earth's interior escapes through the crust by vents and fissures in the crust, accompanied by steam, gases **(hydrogen sulphide, sulphur dioxide, hydrogen chloride, carbon dioxide** etc.) and pyroclastic material (cloud of ash, lava fragments carried through the air, and vapour).
- Depending on the chemical composition and viscosity of the lava, a volcano may take various forms.

Volcanism: Andesitic & Basaltic Lava, Distribution of Volcanoes

- A volcano is a vent or a fissure in the crust from which lava (molten rock), ash, gases, rock fragments erupt from a magma chamber below the surface. Volcanism is the phenomenon of eruption of molten rock, pyroclastics and volcanic gases to the surface through a vent.

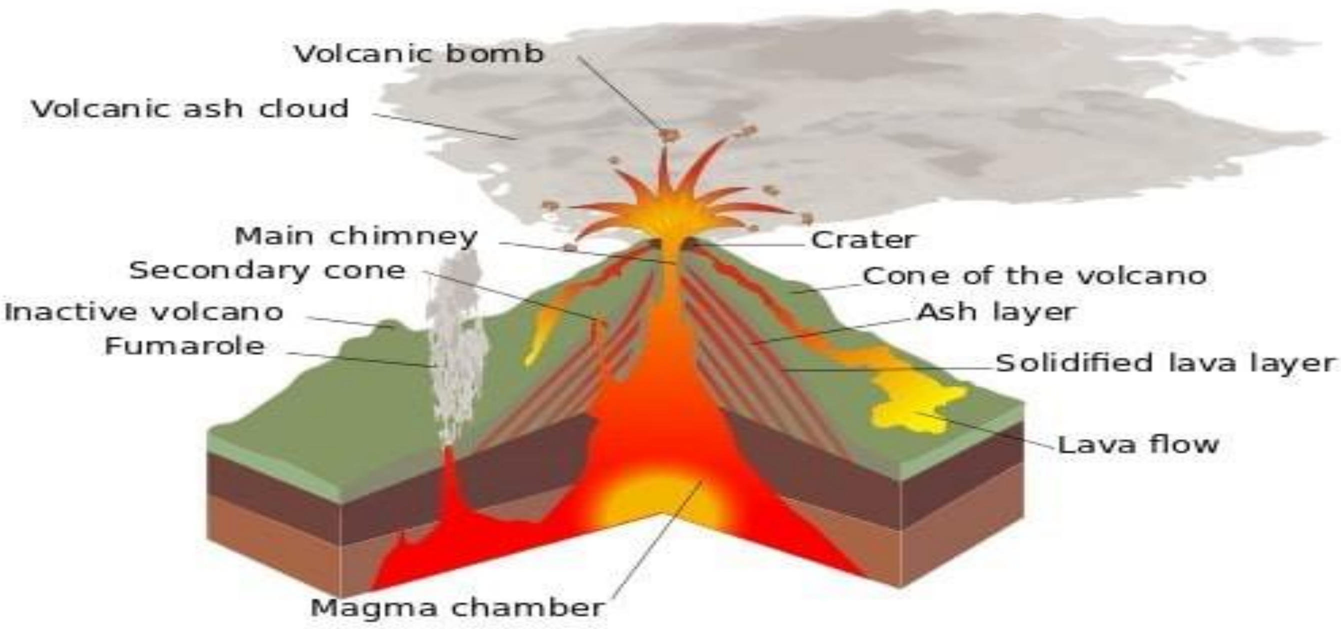
CAUSES OF VOLCANISM

- There is a **huge temperature difference** between the inner layers and the outer layers of the earth due to the differential amount of radioactivity.
- This temperature difference gives rise to **convectional currents** in the mantle.
- The convection currents in the mantle create convergent and divergent boundaries (weak zones).
- At the divergent boundary, molten, semi-molten and sometimes gaseous material appears on earth at the first available opportunity.
- The earthquakes here may expose fault zones through which magma may escape (**fissure type volcano**).
- At the convergent boundary, the subduction of denser plate creates magma at high pressure which will escape to the surface in the form of violent eruptions.

VOLCANISM LAVA TYPES

- Magma is composed of molten rock and is stored in the Earth's crust. Lava is magma that reaches the surface through a volcano vent.

ANDESITIC OR ACIDIC OR COMPOSITE OR STRATO VOLCANIC LAVA

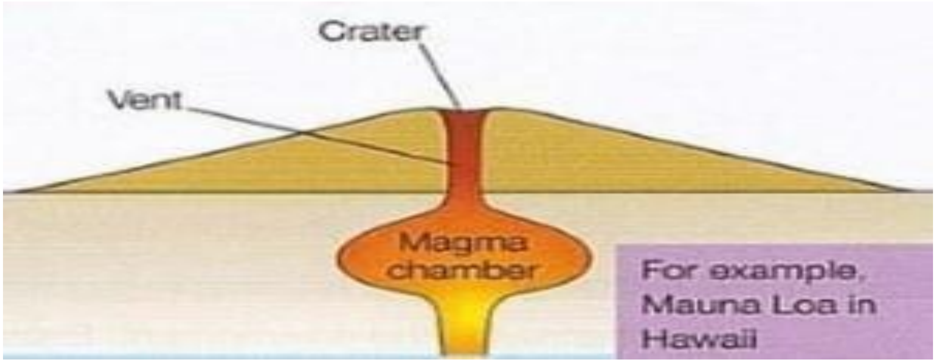


- These lavas are **highly viscous** with a high melting point.
- They are **light-coloured, of low density, and have a high percentage of silica**.
- They **flow slowly and seldom travel far** before solidifying.
- The resultant volcanic cone is therefore stratified (hence the name **stratovolcano**) and steep-sided.
- The **rapid solidifying of lava** in the vent obstructs the flow of the out-pouring lava, resulting in **loud explosions**, throwing out many volcanic **bombs or pyroclasts**.
- Sometimes the lavas are so viscous that they form a **lava plug** at the crater like that of **Mt. Pelée** in Martinique (an island in the Lesser Antilles, Caribbean Islands).
- Andesitic lava flow occurs mostly along the **destructive boundaries** (convergent boundaries).

Lava Plug at the crater

BASIC OR BASALTIC OR SHIELD VOLCANO

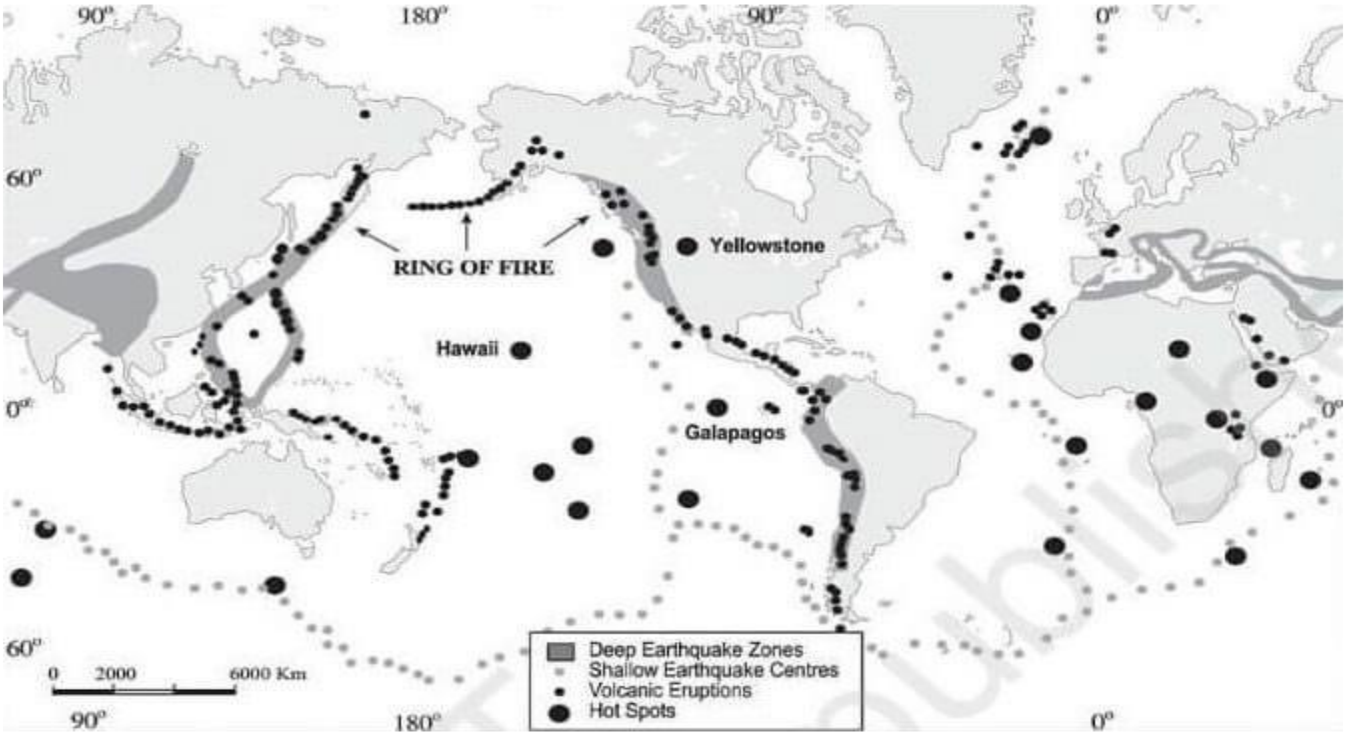
- These are the **hottest lavas**, about 1,000 °C and are **highly fluid**.
- They are **dark coloured basalt, rich in iron and magnesium but poor in silica**.
- They flow out of volcanic vent **quietly** and are **not very explosive**.
- Due to their **high fluidity**, they flow readily with a speed of 10 to 30 miles per hour.
- They affect extensive areas, spreading out as **thin sheets** over **great distances** before they solidify.
- The resultant volcano is **gently sloping** with a wide diameter and forms a flattened shield or dome.
- Shield type lava flow is common along the **constructive boundaries** (divergent boundary).



DRISTRIBUTION OF EARTHQUAKES & VOLCANOES ACROSS THE WORLD

- Most known volcanic activity and the earthquakes occur **along converging plate margins and mid-oceanic ridges**.
- It is said that nearly 70 per cent of earthquakes occur in the Circum-Pacific belt.

- Another 20 per cent of earthquakes take place in the Mediterranean-Himalayan belt including Asia Minor, the Himalayas and parts of north-west China.
- Since the 16th century, around 480 volcanoes have been reported to be active.
- Of these, nearly 400 are located in and around the Pacific Ocean, and 80 are in the mid-world belt across the Mediterranean Sea, Alpine-Himalayan belt and in the Atlantic and Indian Oceans.
- The belts of highest concentration are **Aleutian-Kurile islands** arc, **Melanesia** and **New Zealand-Tonga belt**.
- Only 10 per cent to 20 per cent of all volcanic activity is above the sea, and terrestrial volcanic mountains are small when compared to their submarine counterparts.

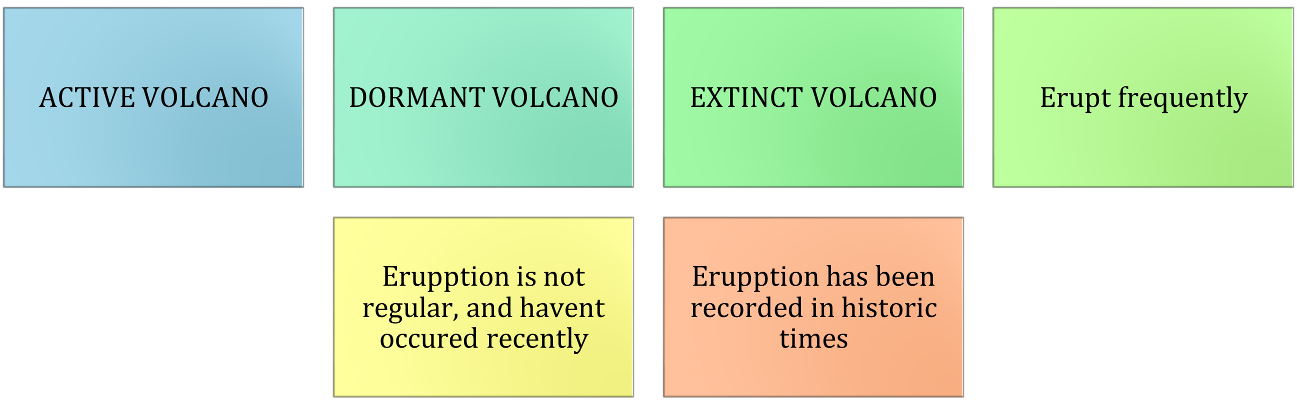


Volcanism along the Pacific Ring of Fire	Circum-Pacific region popularly termed the **'Pacific Ring of Fire'**, has the greatest concentration of active volcanoes. Volcanic belt and earthquake belt closely overlap along the 'Pacific Ring of Fire'.
Regions with active volcanism along 'Pacific Ring of Fire'	The Aleutian Islands into Kamchatka, Japan, the Philippines, and Indonesia (Java and Sumatra in particular), Pacific islands of Solomon, New Hebrides, Tonga and North Island, New Zealand. Andes to Central America (particularly Guatemala, Costa Rica and Nicaragua), Mexico and right up to Alaska.
The 5 countries with the most volcanoes	1. United States – 173 (most of them are in Alaska) 2. Russia – 166 3. Indonesia – 139 4. Iceland – 130 5. Japan – 112

Along the Atlantic coast	In contrast, the Atlantic coasts have comparatively few active volcanoes but many dormant or extinct volcanoes, e.g. St. Helena, Cape Verde Islands and the Canary Islands etc. But the volcanoes of **Iceland** and the **Azores** are active.
Great Rift region	In Africa, some volcanoes are found along the East African Rift Valley, e.g. **Mt. Kilimanjaro** and **Mt. Kenya**.
The West Indian islands	The Lesser Antilles (Part of West Indies Islands) are made up mainly of volcanic islands, and some of them still bear signs of volcanic liveliness
Mediterranean volcanism	Volcanoes of the Mediterranean region are mainly associated with the Alpine folds, e.g. **Vesuvius**, **Stromboli (Light House of the Mediterranean)** and those of the Aegean islands. A few continue into Asia Minor (Mt. Ararat, Mt. Elbruz). The volcanism of this broad region is largely the result of convergence between the Eurasian Plate and the northward-moving African Plate. This type of volcanism is mainly due to **breaking up of the Mediterranean plate** into multiple plates due to the interaction of African and Eurasian plate

Volcanism (Volcanos) in India

- There are **no volcanoes in the Himalayan region** or the Indian peninsula.
- **Barren Island** (**only active volcano in India**) in the Andaman and Nicobar Islands became active in the 1990s.
- It is now considered an active volcano after it spewed lava and ash in 2017.
- The other volcanic island in Indian territory is **Narcondam**, about 150 km north-east of Barren Island; it is **probably extinct**. Its crater wall has been destroyed.



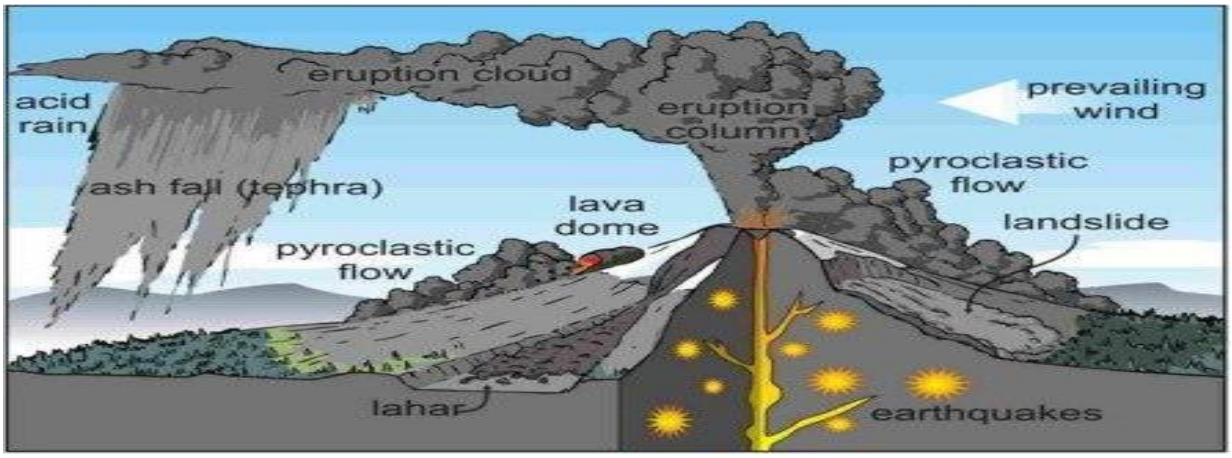
- **Barren Island in the Andaman and Nicobar Islands**, Anak Krakatoa are active volcanoes
- **Mount Kilimanjaro** (it has three volcanic cones), is a **dormant** stratovolcano in Tanzania.
- **Mount Kenya** is an extinct stratovolcano.
- The **Barren Island in the Andaman and Nicobar Islands** of India which was thought to be extinct erupted recently.
- **Before a volcano becomes extinct, it passes through a waning stage during which steam and other hot gases and vapours are exhaled. These are known as fumaroles or solfataras.**

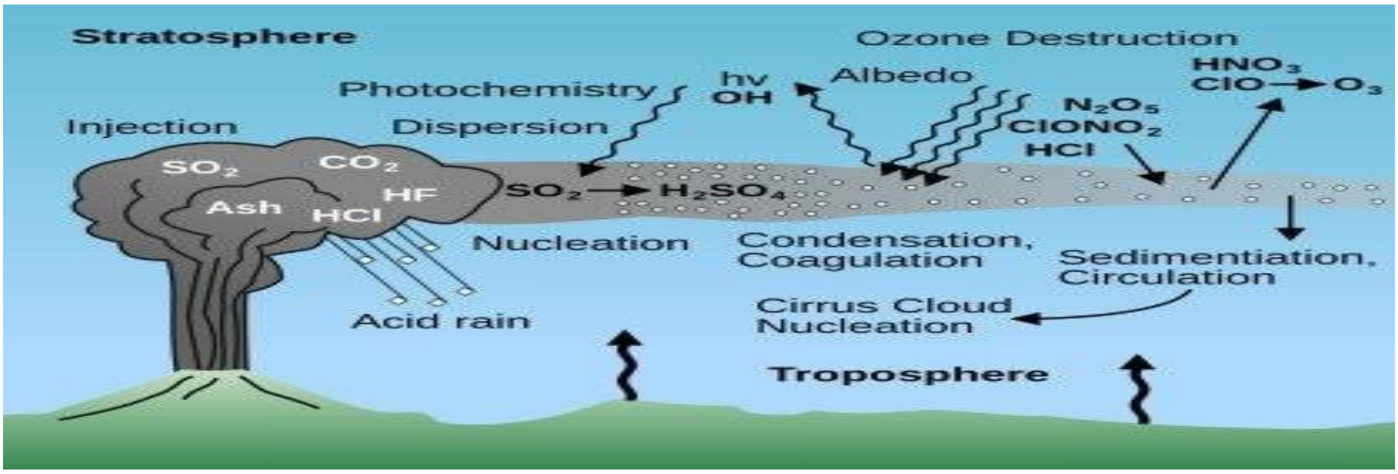
Destructive Effects of Volcanism

- Showers of cinders and bombs can cause damage to life. E.g. the eruption of **Mount Vesuvius** in 79 AD.
- Tsunamis can be generated in large water bodies due to violent eruptions. E.g. 1883 Krakatoa eruption.
- The collapse of the volcanic landforms in seas and oceans cause tsunamis. E.g. 2018 Sunda Strait tsunami.
- The ash from a larger eruption dispersing over a large area can lower temperatures at a regional or global scale. This could trigger famines on a large scale. E.g. 1815 eruption of Mount Tambora.
- In Hawaiian type eruption, a single flow spreads widely over open slopes or down the valleys as lava rivers engulfing entire cities.
- Lahars (a violent type of mudflow or debris flow) can bury entire cities in a matter of minutes causing a high number of causalities. E.g. 1985 eruption of Nevado del Ruiz volcano.
- The sudden collapse of lava domes can cause violent volcanic flows that destroy everything on their path. E.g. the 1902 eruption of Mount Pelée.
- Powerful winds drive the gas plume higher into the atmosphere and carry it to a greater distance disrupting air travel (this happened in 2010 when a stratovolcano in Iceland erupted and disrupted air travel over entire Europe for weeks).
- A supervolcanic super-eruption can cause a small-scale extinction event. E.g. The Toba eruption (Indonesia) triggered a dramatic global winter 74,000 years ago.

Volcanism – Acid Rain, Ozone Destruction

- The volcanic gases that pose the greatest potential hazard to people, animals, agriculture, and property are **sulphur dioxide, carbon dioxide, and hydrogen fluoride**.
- Locally, sulphur dioxide gas can lead to acid rain and air pollution downwind from a volcano.
- Globally, large explosive eruptions that inject a tremendous volume of sulphur aerosols into the stratosphere can lead to lower surface temperatures and **promote depletion of the Earth's ozone layer**.





Positive Effects of Volcanism

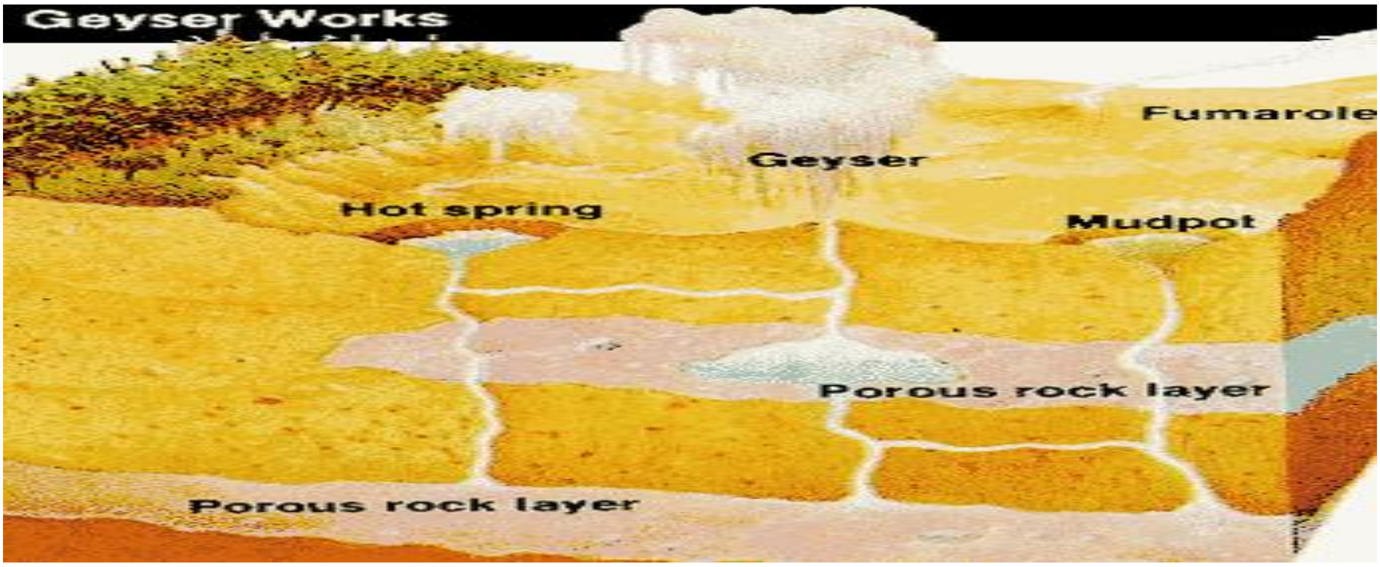
- Volcanism creates new fertile landforms like islands, plateaus, volcanic mountains etc. E.g. Deccan traps.
- The volcanic ash and dust are **very fertile** for farms and orchards.
- Volcanic rocks yield very fertile soil upon weathering and decomposition.
- Although steep volcano slopes prevent extensive agriculture, forestry operations on them provide valuable timber resources.
- Mineral resources, particularly metallic ores are brought to the surface by volcanoes. Sometimes copper and other ores fill the gas-bubble cavities.
- The famed Kimberlite rock of South Africa, the source of diamonds, is the pipe of an ancient volcano.
- In the vicinity of active volcanoes, waters in depth are heated from contact with hot magma giving rise to **springs and geysers**.
- The heat from the earth's interior in areas of volcanic activity is used to generate **geothermal electricity**. Countries producing geothermal power include USA, Russia, Japan, Italy, New Zealand and Mexico.
- The **Puga valley in Ladakh** region and **Manikaran (Himachal Pradesh)** are promising spots in India for the generation of geothermal electricity.
- Geothermal potential can also be used for space heating.
- As scenic features of great beauty, attracting a heavy tourist trade, few landforms outrank volcanoes.
- At several places, national parks have been set up, centred around volcanoes. E.g. Yellowstone National Park.
- As a source of crushed rock for concrete aggregate or railroad ballast and other engineering purposes, lava rock is often extensively used.

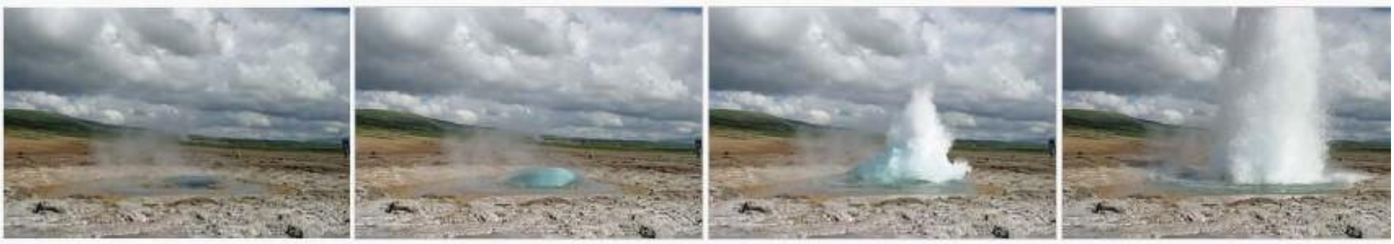
GEYSERS & HOT SPRINGS

- Water that percolated into the porous rock is subjected to intense heat by the underlying hard rock which is in contact with hot magma in the mantle or the lower part of the crust.
- Under the influence of intense heat, the water in the capillaries and narrow roots in the porous rock undergoes intense expansion and gets converted to steam resulting in high pressure.
- When this steam or water at high pressure finds a path to the surface through narrow vents and weak zones, appear at the surface as geysers and hot water springs.

Geyser	Hot water spring
Steam or water at high pressure, along its path, gets accumulated in small reservoirs, fissures and fractures. Once the pressure exceeds the threshold limit, the steam bursts out to the surface disrupting the water at the mouth. Hence the name geyser.	Steam or water at high pressure smoothly flows to the top through the vent and condense at the surface giving rise to a spring.
Silicate deposits at mouth give them their distinct colours.	Some springs are very colourful because of the presence of **cyanobacteria** of different colours.
Generally, geysers are located near active volcanic areas. **Iceland** is famous for its geysers.	Found all across the world

Usually, a carter like structure is created at the mouth.

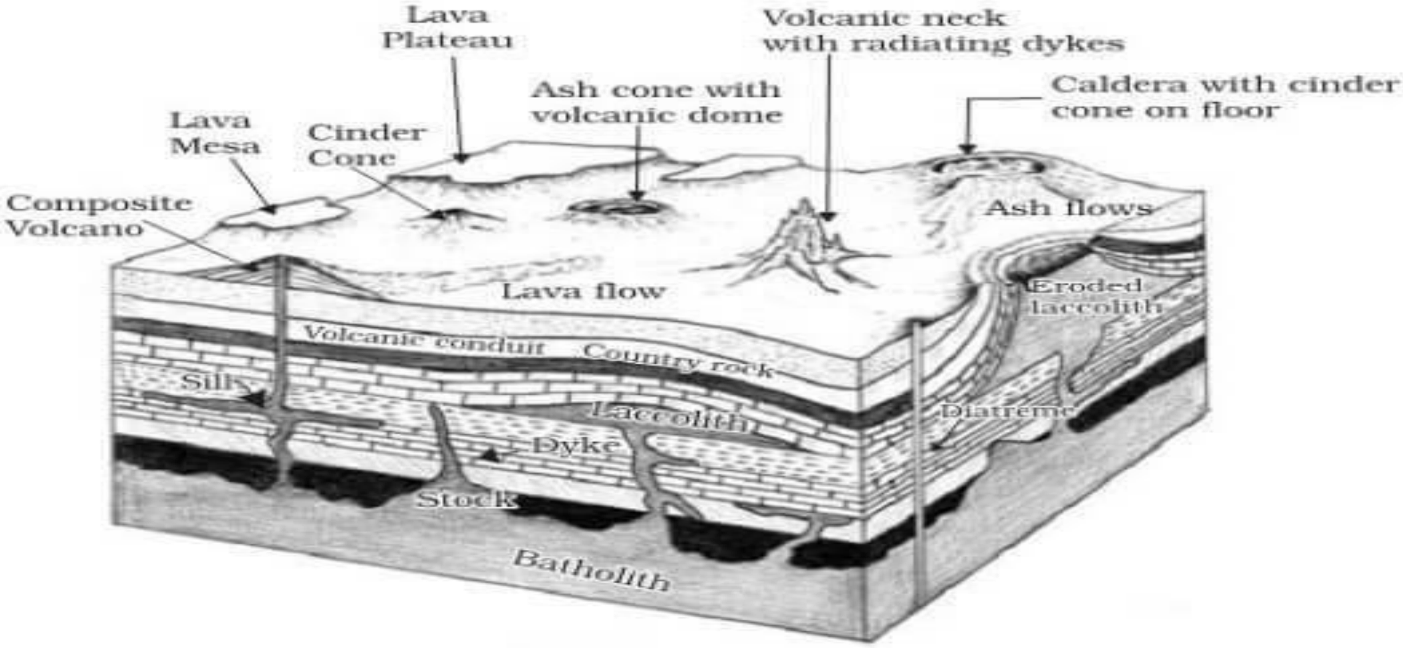




- **Almost all the world's geysers are confined to three major areas: Iceland, New Zealand and Yellowstone Park of U.S.A.**

Extrusive & Intrusive Volcanic Landforms

- Volcanic landforms are divided into **extrusive and intrusive landforms** based on whether magma cools within the crust or above the crust.
- Rocks formed by the cooling of magma within the crust are called **Plutonic rocks.**
- Rocks formed by the cooling of lava above the surface are called **Igneous rocks**.
- In general, the term 'Igneous rocks' is used to refer to all rocks of volcanic origin.



Extrusive and Intrusive volcanic landforms

Extrusive Volcanic Landforms

- Extrusive landforms are formed from material thrown out to the surface during volcanic activity.
- The materials thrown out include lava flows, pyroclastic debris, volcanic bombs, ash, dust and gases such as **nitrogen compounds, sulphur compounds** and minor amounts of **chlorine, hydrogen** and **argon**.

FISSURE VENT	CONICALVENT
A fissure vent (volcanic fissure) is a narrow, linear volcanic vent through which lava erupts, usually without any explosive activity. The vent is often a few meters wide and may be many kilometres long. Fissure vents are common in basaltic volcanism (shield type volcanoes).	A conical vent is a narrow cylindrical vent through which magma flows out violently. Conical vents are common in **andesitic volcanism** (**composite or stratovolcano**).

Mid-Ocean Ridges

- The system of mid-ocean ridges stretches for more than 70,000 km across all the ocean basins.
- The central portion of the mid-ocean ridges experiences frequent eruptions.
- **The lava is basaltic (less silica and hence less viscous) and causes the spreading of the seafloor.**

COMPOSITE TYPE VOLCANIC LAND FORMS

- They are conical or central type volcanic landforms.
- Along with andesitic lava, large quantities of pyroclastic material and ashes find their way to the surface.
- **Andesitic lava** along with pyroclastic material accumulates in the vicinity of the vent openings leading to the formation of layers, and this makes the mounts appear as a **composite volcano or a stratovolcano** (divided into layers).

- The highest and most common volcanoes have composite cones.
- **Mount Stromboli (the Lighthouse of the Mediterranean)**, Mount Vesuvius, Mount Fuji are examples.

SHIELD TYPE VOLCANIC LANDFORMS

- The **Hawaiian volcanoes** are the most familiar examples.
- These volcanoes are mostly made up of **basaltic lava** (very fluid).
- These volcanoes are not steep.
- They become explosive if somehow water gets into the vent; otherwise, they are less explosive.
- Example: Hawaiian volcanoes **Mauna Loa** (active shield volcano) and **Mauna Kea** (dormant shield volcano).

FISSURE TYPE BASALT LANDFORMS – LAVA PLATEAUS

- Sometimes, a very thin magma escapes through cracks and fissures in the earth's surface and flows after intervals for a **long time**, **spreading over a vast area**, finally producing a **layered, undulating (wave-like), flat surface**.
- **Example: Siberian Traps, Deccan Traps, Snake Basin, Icelandic Shield, Canadian Shield.**


Crater

- A crater is an inverted cone-shaped vent through which the magma flows out. When the volcano is not active the crater appears as a bowl-shaped depression.

The crater of Mount Fuji, Japan

- When water from rain or melted snow gets accumulated in the crater, it becomes a **crater lake**.

CALDERA

- In some volcanoes, the magma chamber below the surface may be emptied after volcanic eruptions.

- The volcanic material above the chamber **collapses** into the empty magma chamber, and the collapsed surface appears like a large cauldron-like hollow (tub shaped) called the caldera.
- When water from rain or melted snow gets accumulated in the caldera, it becomes a **caldera lake** (in general, the caldera lakes are also called crater lakes).
- Due to their unstable environments, some crater lakes exist only intermittently. Caldera lakes, in contrast, can be quite **large and long-lasting**.
- For example, **Lake Toba (Indonesia)** formed after its supervolcanic eruption around 75,000 years ago. It is the **largest crater lake in the world**.
- Mount Mazama (Cascade Volcanic Arc, USA) collapsed into a caldera, which was filled with water to form Crater Lake (the literal name of the lake formed by the collapse of Mount Mazama is 'Crater Lake'!).

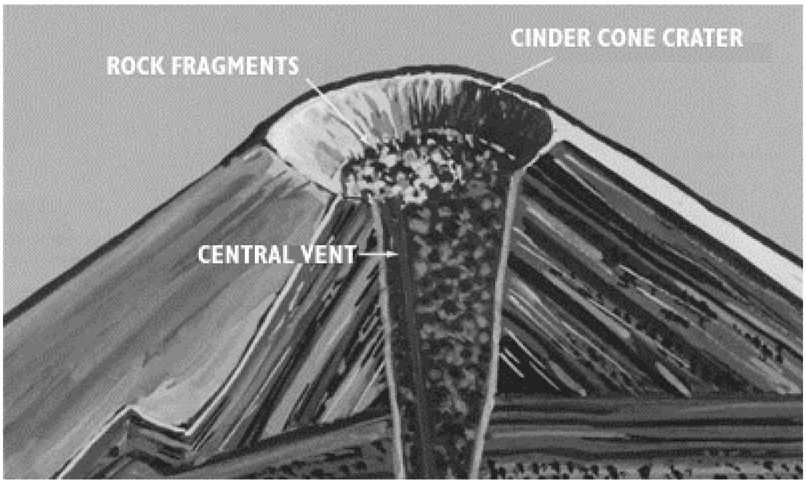
Caldera lake of Mount Mazama

A crater lake, in general, could be of volcanic origin (volcanic crater lake, volcanic caldera lake) or due to a meteorite impact (meteor crater or impact crater), or in the crater left by an artificial explosion caused by humans.

Lonar Lake, also known as Lonar crater (Lonar, Buldhana district, Maharashtra) was created by a meteor impact during the Pleistocene Epoch.

Cinder cone

- A cinder cone is a **steep circular or oval-shaped hill of loose pyroclastic fragments** that have been built around a volcanic vent.



Lava Dome

- A lava dome (volcanic dome) is a mound-shaped protrusion (a structure that extends outside the surface) resulting from the slow extrusion (coming out) of viscous lava from a volcano.
- In Lava domes, viscous **magma piles up** around the vent.
- The magma does not have enough gas or pressure to escape, although sometime later after sufficient pressure builds up, it may erupt explosively.

Lava dome protruding from a volcanic vent

PSEUDO VOLCANIC FEATURES

- Pseudo volcanic features are certain topographic features that resemble volcanic forms but are of non-volcan include **meteorite crater, salt plugs, and mud-volcanoes**.

METEORITE CRATERS

- Meteorite craters are impact craters that are formed when a meteorite strikes the surface of the earth creatin

SALT PLUG OR SALT DOME

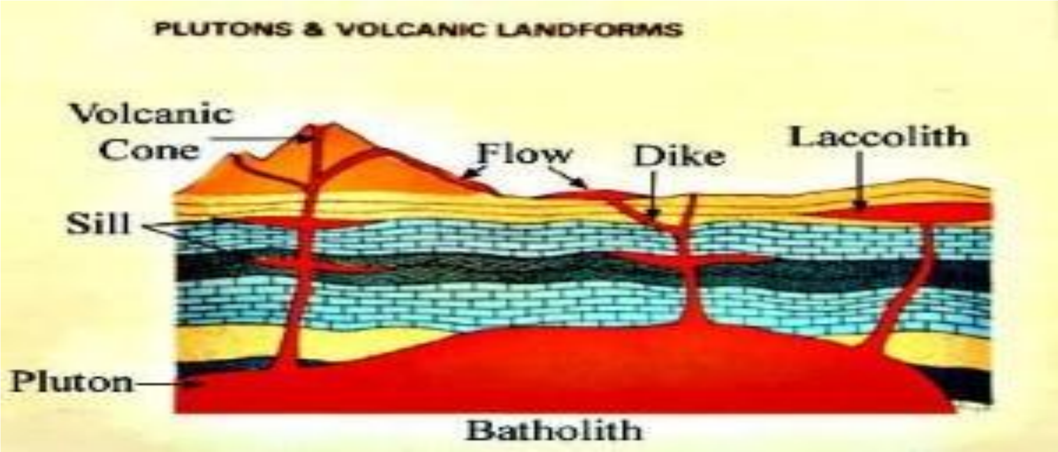
- A salt plug is formed when underground salt deposits at high pressure become ductile and pierce through the create a diapir (a dome-like intrusion forced into brittle overlying rocks.
- Salt extrusions may take the form of salt hills which exhibit volcanic crater like features.
- Salt structures are impermeable and can lead to the formation of a **stratigraphic trap** (an impermeable layer c hydrocarbons. **Structural traps**, in contrast, are cracks in faults and folds that can retain hydrocarbons).

MUD-VOLCANOES

- A mud volcano or mud dome is a landform created by the eruption of mud, water and gases.
- Mud-volcanoes have a similar shape to other types of volcanoes and contains several cones.
- They are usually found near the subduction zones and hot springs.
- Other mud volcanoes, entirely of a **non-volcanic origin**, occur near oil-fields where **methane and other volatile** with mud force their way upward.

INTRUSIVE VOLCANIC LANDFORMS

- Intrusive landforms are formed when magma cools within the crust.



Batholiths	These are large **granitic** rock bodies formed due to solidification of hot magma **inside the earth**. They appear on the surface only after the denudation processes remove the overlying materials. Batholiths **form the core of huge mountains** and may be exposed on the surface after erosion
Laccoliths	These are large dome-shaped intrusive bodies connected by a pipe-like conduit from below. These are intrusive counterparts of an exposed domelike batholith. The **Karnataka plateau** is spotted with dome hills of granite rocks. Most of these, now exfoliated, are examples of laccoliths or batholiths
Lapolith	As and when the lava moves upwards, a portion of the same may tend to move in a **horizontal** direction wherever it finds a weak plane. It may get rested in different forms. In case it develops into a saucer shape, concave to the sky body, it is called Lapolith
Phacolith	A wavy mass of intrusive rocks, at times, is found at the base of synclines or the top of the anticline in folded igneous strata. Such wavy materials have a definite conduit to source beneath in the form of magma chambers (subsequently developed as batholiths). These are called the Phacoliths
Sills	The near horizontal bodies of the intrusive igneous rocks are called sill. The thinner ones are called sheets.
Dykes	When the lava makes its way through cracks and the fissures developed in the land, it solidifies almost **perpendicular** to the ground. It gets cooled in the same position to develop a **wall-like structure**. Such structures are called dykes. These are the most commonly found intrusive forms in the western Maharashtra area. These are considered the **feeders for the eruptions** that led to the development of the **Deccan traps**

EXOGENIC GEOMORPHIC MOVEMENTS

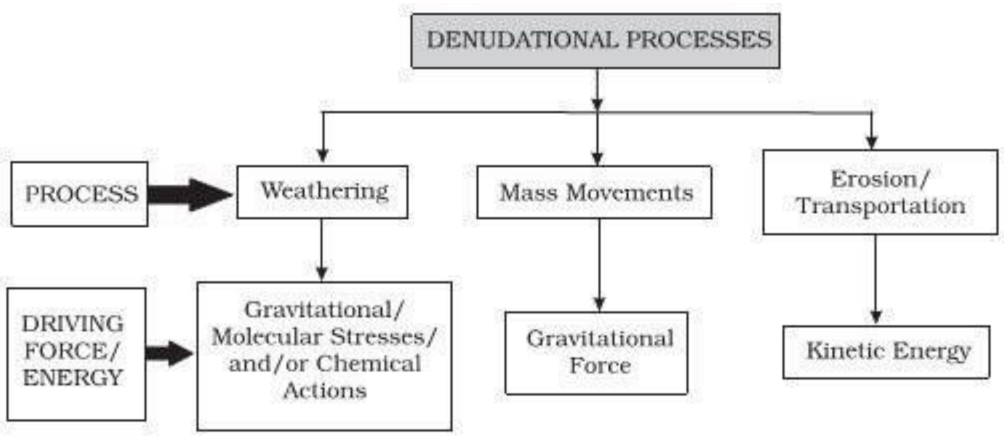
- The geomorphic processes on the earth's crust or its surface brought down by the **forces emanating from above the earth's surface** (wind, water) are called exogenic geomorphic process.
- Exogenic geomorphic process gives rise to exogenic geomorphic movements or simply exogenic movements such as **weathering** and **erosion**.
- The effects of most of the exogenic geomorphic processes are small and slow but will, in the long run, affect the rocks severely due to continued fatigue.

THE FORCE BEHIND EXOGENIC MOVEMENT

- Exogenic processes are a direct result of the sun's heat.
- Sun's energy dictates the weather patterns like winds, precipitation, etc.
- Sun's heat along with weather patterns are responsible for stress-induced in earth materials giving rise to exogenic movements (weathering and erosion).
- Earth materials become subjected to **molecular stresses** caused due to temperature changes.
- Chemical processes normally lead to **loosening of bonds** between grains.
- Stress is produced in a solid by pushing or pulling (**shear stresses** — separating forces) forces.

DENUDATION

- All the exogenic processes (weathering and erosion) are covered under a general term, denudation.
- The word 'denude' means to strip off or to uncover.
- Denudation depends on physical (folds, faults, orientation and inclination of beds, presence or absence of joints, bedding planes, hardness or softness of constituent minerals, permeability) and chemical (chemical susceptibility of mineral constituents to corrosion) properties of the rocks.



WEATHERING

- Weathering is the **disintegration** of rocks, soil, and minerals under the influence of physical (heat, pressure) and chemical (leaching, oxidation and reduction, hydration) agents.
- **As very little or no motion of materials takes place in weathering, it is an in-situ or on-site process.**
- **The weathered material is carried farther away by erosion.**
- **There are three major groups of weathering processes: 1) chemical; 2) physical or mechanical; 3) biological weathering processes. All the types of weathering often go hand in hand.**

PHYSICAL WEATHERING

- Physical weathering involves **mechanical disintegration** of rocks due to temperature changes, freeze-thaw cycles, wet-dry cycles, crystallisation of salts, animal and plant activity, etc.
- Various mechanisms of physical weathering are explained below.

EXFOLIATION

It is due to pressure release or unloading

- Intrusive igneous rocks formed deep beneath the Earth's surface are under tremendous pressure due to overlying load.
- Removal of the overlying load because of continued erosion causes vertical pressure release with the result that the upper layers of the rock expand and fracture parallel to the surface.
- Over time, sheets of rock break away from the exposed rocks along the fractures, a process known as **exfoliation**.
- Exfoliation due to pressure release is also known as "**sheeting**".

Exfoliation due to thermal stress weathering

- Thermal stress weathering results from the subsequent expansion and contraction of rocks caused by diurnal and seasonal variations in the temperatures.
- The surface layers of the rocks tend to expand more than the rock at depth, and this leads to peeling off of the surface layers (exfoliation).
- This process is most effective in **dry climates** and **high elevations** where **diurnal temperature changes are drastic**.
- Although temperature changes are the principal driver, moisture can enhance thermal expansion in rock.

GRANULAR DISINTEGRATIONS

- Granular disintegration happens in rocks composed of different types of coarse-grained minerals.
- Dark-coloured minerals absorb more heat than the light-coloured minerals.
- This leads to differential expansion and contraction of mineral grains resulting in grain by grain separation from the rock.

FROST WEATHERING

- During the warm season, the water penetrates the pore spaces or fractures in rocks.
- During the cold season, the water freezes into ice, and its volume expands as a result.
- This exerts tremendous pressure on rock walls to tear apart even where the rocks are massive.
- Frost weathering occurs due to the growth of ice within pores and cracks of rocks during repeated cycles of freezing and melting.
- Frost weathering is the collective name for several processes where ice is present.
- These processes include **frost shattering, frost-wedging** and **freeze-thaw weathering**.

FROST WEDGING

- Freeze wedging is caused by the repeated freeze-thaw cycle.
- Cracks filled with water are forced further apart with subsequent freezing and thawing.

SHATTERING

- Severe frost can disintegrate rocks along weak zones to produce **highly angular pieces** with sharp corners and edges through the process of shattering.
- Shattering piles up rock fragments called **scree** at the foot of mountain areas or along slopes.

BLOACK SEPERATION

(freeze-thaw weathering)

- Repeated freeze-thaw cycles weaken the rocks which, over time, break up along the joints into angular pieces. The splitting of rocks along the joints into blocks is called block disintegration.

Salt Weathering

- Salt weathering occurs when saline solutions seep into cracks and joints in the rocks and evaporate, leaving salt crystals behind.
- Salt crystals expand during the crystallization process and also when they are subjected to above normal temperatures.
- The expansion in near-surface pores causes splitting of individual grains within rocks, which eventually fall off (granular disintegration or granular foliation).
- Salt weathering is normally associated with **arid climates** where strong heating causes strong evaporation and crystallisation.

MASS WASTING

- Mass wasting is the mass movement of unconsolidated soil, sand, rocks, regolith (the layer of unconsolidated solid material covering the bedrock of a planet), etc. along a slope under the influence of gravity.
- Mass wasting occurs when the gravitational force acting on a slope exceeds its resisting force leading to **slope failure** (mass wasting).
- Timescales of the mass wasting process may be a few seconds (debris flows and mudflows) or hundreds of years (mass wasting along the slopes of stable mountains leaving behind alluvial fan like structures).

CHEMICAL WEATHERING

- Chemical weathering involves **chemical decomposition** of rocks and soil.
- Chemical weathering processes include **dissolution, solution, carbonation, hydration, oxidation and reduction** that act on the rocks to decompose, dissolve or reduce them to a fine state.

- These weathering processes are interrelated and go hand in hand and hasten the weathering process.
- Acids produced by microbial and plant-root metabolism, water and air (oxygen and carbon dioxide) along with heat speed up all chemical reactions.

NATURAL DISSOLUTION	Dissolution: a process where a solute in gaseous, liquid, or solid phase dissolves in a solvent to form a solution. Some minerals, due to their natural solubility (like nitrates, sulphates, and potassium), oxidation potential (iron-rich minerals) will weather through dissolution naturally (rains). These minerals are easily **leached** out without leaving any residue and accumulate in dry regions
SOLUTION WEATHERING	Solution weathering occurs **when the solvent is an acidic solution** rather than simple water. A solution is a liquid mixture in which the minor component (the solute) is uniformly distributed within the major component (the solvent). **Acidic solutions** are any solution that has a higher concentration of hydrogen ions than water; solutions that have a lower concentration of hydrogen ions than water is called **basic or alkaline solutions**.
CARBONATION – NATURAL SOLUTION WEATHERING	Carbonation refers to reactions of carbon dioxide to give **carbonates, bicarbonates, and carbonic acid**. Carbonation weathering is a process in which atmospheric carbon dioxide leads to **solution weathering**. As rain falls, it dissolves small amounts of carbon dioxide from the air, forming a weak acid that can dissolve some minerals like **limestone (calcium carbonate)** (solution weathering). When carbonic acid reacts with limestone, it produces calcium bicarbonate, which is partially soluble in water (dissolution weathering). Caves are formed when underground water containing carbonic acid travels through blocks of limestone, dissolves out the limestone, and leaves empty pockets (caves) behind (E.g. **Karst topography**). Carbonation process speeds up with a decrease in temperature because **colder water holds more dissolved carbon dioxide gas**. Carbonation is, therefore, a large feature of **glacial weathering**
ANTHROPOGENIC SOLUTION WEATHERING	**Rainfall is naturally acidic** — pH of ~5.6 (CO_2 dissolves in the rainwater producing **weak carbonic acid**). Acid rain occurs when gases such as **sulphur dioxide** and **nitrogen oxides** are present in the atmosphere. These oxides react in the rainwater to produce stronger acids and can lower the pH to less than 4. • These acids are capable of attacking certain kinds of rocks in much the way that carbonic acid does. Sulphur dioxide, SO2, comes from **volcanic eruptions or fossil fuels**. The conversion of metallic ores to the pure metals often results in the formation of sulphur dioxide.

HYDRATION	Hydration is the chemical addition of water that involves the rigid attachment of H+ and OH- ions to the atoms and molecules of a mineral. When rock minerals take up water, the increased volume creates physical stresses within the rock. For example, iron oxides are converted to iron hydroxides which are larger in volume. Hydration is reversible, and continued repetition of this process causes fatigue in the rocks and may lead to their disintegration. The volume changes in minerals due to hydration will also help in physical weathering through exfoliation and granular disintegration
HYDROLYSIS	In biological hydrolysis, a **water molecule is consumed** to affect the **separation of a larger molecule into component parts**. In biological hydrolysis pure water reacts with **silicate** or **carbonate minerals** resulting in the complete dissolution of the original mineral (dissolution weathering). Biological hydrolysis is an important reaction in **controlling the amount of CO_2 in the atmosphere** and can affect climate
OXIDATION AND REDUCTION	In weathering, oxidation means **a combination of a mineral with oxygen to form oxides** (rusting in case of iron) or hydroxides. **Red soils** appear red due to the presence of iron oxides. Oxidation occurs where there is ready access to the atmosphere and water. The minerals most commonly involved in this process are iron, manganese, sulphur etc. When oxidised minerals are placed in an environment where oxygen is absent, **reduction** takes place. Such conditions usually exist below the water table, in areas of stagnant water and waterlogged ground. The red colour of iron upon reduction turns to greenish or bluish grey.
BIOLOGICAL ACTIVITY AND WEATHERING	Biological weathering is the removal of minerals from the environment due to growth or movement of organisms. Living organisms contribute to both mechanical and chemical weathering. Lichens and mosses grow on essentially bare rock surfaces and create a more humid chemical microenvironment. On a larger scale, seedlings sprouting in a crevice and plant roots exert physical pressure as well as providing a pathway for water and chemical infiltration. Burrowing and wedging by organisms like earthworms, rodents etc., help in exposing the new surfaces to chemical attack and assists in the penetration of moisture and air. 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 the concentration of iron and manganese oxides.

Significance of weathering

- Weathering is the **first step in the formation of soil** from rocks.
- Weathering weakens soil and rocks and makes it easy to exploit natural resources.
- Weathering leads to **natural soil enrichment**.

- Weathering leads to **mineral enrichment** of certain ores by leaching unwanted minerals leaving behind the valuable ones.

EROSION:

Soil Erosion	Soil erosion is the loosening and displacement of topsoil from the land due to the action of agents like wind and water. Soil erosion in nature may be a slow process (geological erosion) or a fast process promoted by human activities like overgrazing, deforestation. Weathering and erosion lead to the simultaneous process of 'degradation' and 'aggradation'. Erosion is a mobile process while weathering is a static process (there is no motion of disintegrated material except the falling down under the force of gravity).
Water Erosion	Running water is one of the main agents, which carries away soil particles. Soil erosion by water occurs by means of raindrops, waves or ice. Erosion by water is termed differently according to the intensity and nature of erosion: **raindrop erosion, sheet erosion, rill and gully erosion, stream bank erosion, landslides, coastal erosion, glacial erosion**.
Raindrop erosion or splash erosion	A raindrop is approximately 5 mm in diameter and hits the soil at a velocity of 32 km/hr. Larger raindrops and gusts of wind hit the soil surface even at higher velocities. Raindrops behave like tiny bombs when falling on exposed soil, displace soil particles and destroy soil structure. Presence of vegetation on land prevents raindrops from falling directly on the soil thus erosion of soil in areas covered by vegetation is prevented.
Sheet erosion	With continued rainfall the displaced soil particles fill in the spaces between soil particles and prevent water from seeping into the soil. This results in surface runoff and even more erosion. The detachment and transportation of soil particles by flowing rainwater is called sheet or wash off erosion. Weathering and erosion tend to level down the irregularities of landforms and create a **peneplane**.
Rill and gully erosion	In rill erosion finger like rills appear on the cultivated land after it has undergone sheet erosion. These rills are usually smoothened out every year while forming. Each year the rills slowly increase in number become wider and deeper. Gully erosion is the removal of soil along drainage lines by surface water runoff. When rills increase in size, they become gullies. Once started, gullies will continue to move by headward erosion or by slumping of the side walls. Gullies formed over a large area gives rise to **badland topography (Chambal Ravines)**. When a gully bed is eroded further due to headward erosion, the bed gradually deepens and flattens out, and a **ravine** is formed. The depth of a ravine may extend to 30 metres or more. Further erosion of ravine beds gives rise to **canyons.** Canyons are few hundred meters deep and wide. (Grand Canyon on Colorado River).

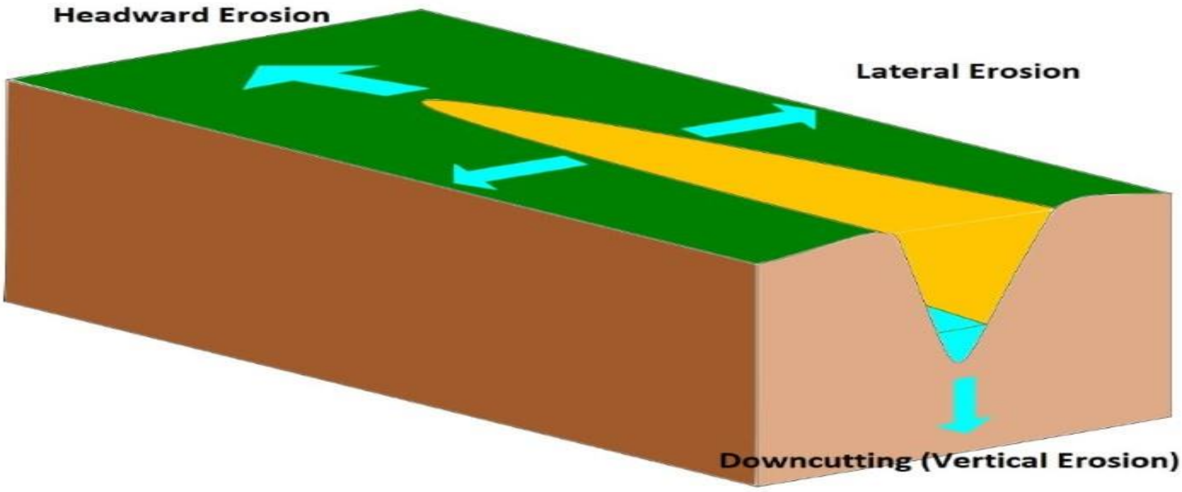
Streambank erosion	The erosion of soil from the banks (shores) of the streams or rivers due to the flowing water is called bank erosion. In certain areas where the river changes its course, the river banks get eroded at a rapid rate. Streambank erosion damages the adjoining agricultural lands, highways and bridges.
Landslide	The sudden mass movement of soil is called a landslide. Landslides occur due to instability or loss of balance of land mass with respect to gravity. The loss in balance occurred mainly due to excessive water or moisture in the earth mass. Gravity acts on such an unstable landmass and causes the large chunks of surface materials such as soil and rocks to slide down rapidly.
Coastal erosion	In the coastal areas, waves dash along the coast and cause heavy damage to the soil. During the landfall of cyclones, storm surges destroy beaches and wash away the top layer. In estuaries, tidal bores cause extensive damage to the surrounding banks.
Glacial erosion	In the polar regions and high mountainous regions like the Himalayas, soil erosion is caused by sowing moving glaciers. This is called glacial erosion.
Wind Erosion	Wind erosion or **aeolian erosion** is quite significant in arid and semi-arid regions. Winds usually blow at high speeds in deserts due to the absence of physical obstruction. These winds remove the fertile, arable, loose soils leaving behind a depression devoid of topsoil. The depression formation in deserts is the first step in Oasis formation. Oasis forms in depressions when there is underground water that gets accumulated above rocks. Very fine and medium sands are moved by wind in a succession of bounds and leaps, known as **saltation**. Small sand and dust particles are transported over long distances through the air by a process known as **suspension**. Coarse sand is not usually airborne but rather is rolled along the soil surface. This type of erosion is called **surface creep.** Very coarse sand and gravels are too large to be rolled by wind, so wind-eroded soils have surfaces covered with coarse fragments. This kind of arid soil surface is known as desert pavement.

FLUVIAL EROSIONAL LANDFORMS: MEANDER, OXBOW LAKE, PENEPLAIN

- The landforms created as a result of **degradational action (erosion and transportation)** or **aggradational work (deposition)** of running water are called fluvial landforms.

Fluvial Erosional Landforms

- Fluvial Erosional Landforms are landforms created by the erosional activity of rivers.
- Various aspects of fluvial erosive action include:
- **Hydration**: the force of running water wearing down rocks.
- **Corrosion**: chemical action that leads to weathering.
- **Attrition**: river load particles striking, colliding against each other and breaking down in the process.
- **Corrasion or abrasion**: solid river load striking against rocks and wearing them down.
- **Downcutting (vertical erosion)**: the erosion of the base of a stream (downcutting leads to valley deepening).
- **Lateral erosion:** the erosion of the walls of a stream (leads to valley widening).
- **Headward erosion**: erosion at the origin of a stream channel, which causes the origin to move back away from the direction of the stream flow, and so causes the stream channel to lengthen.

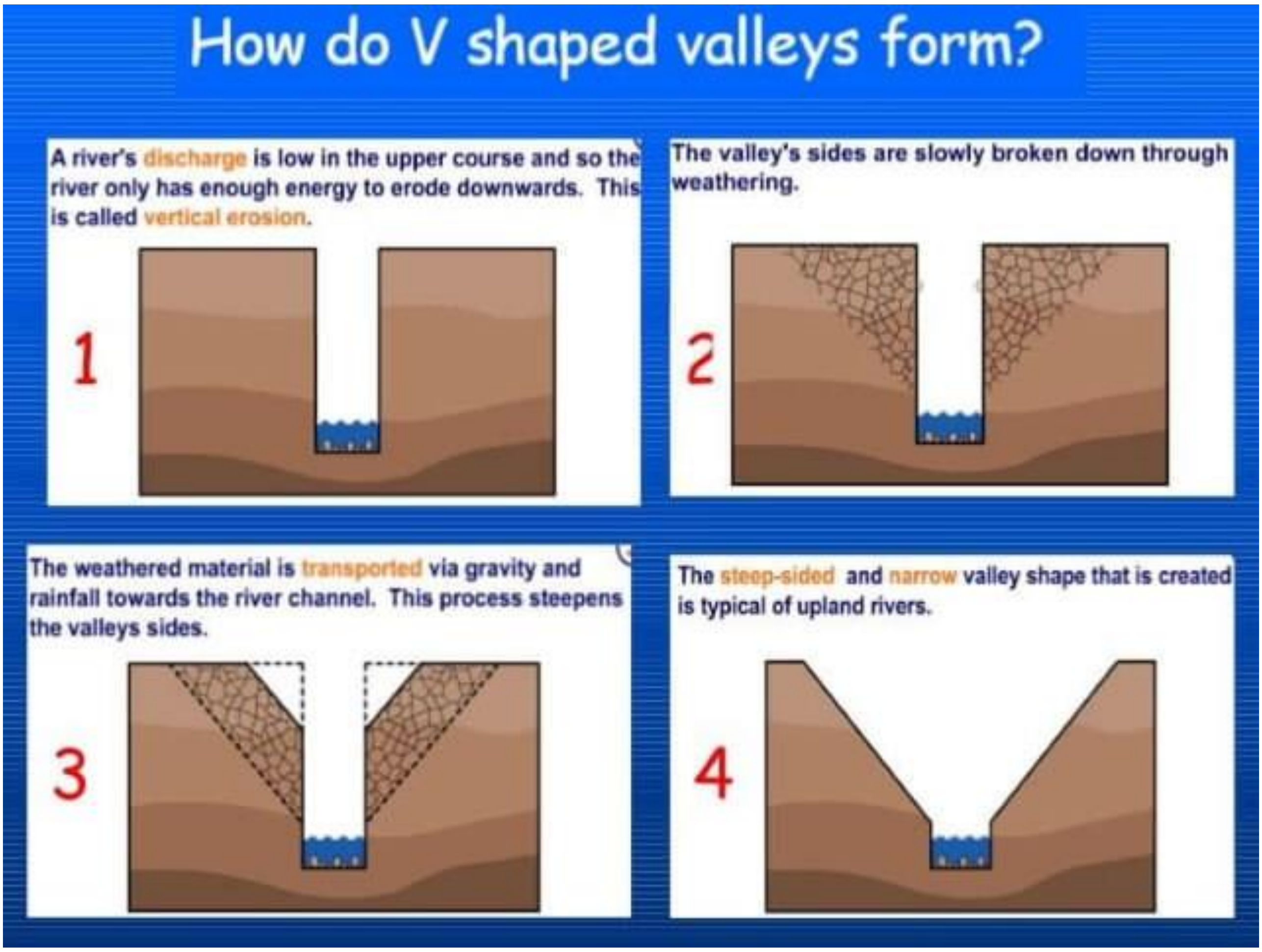


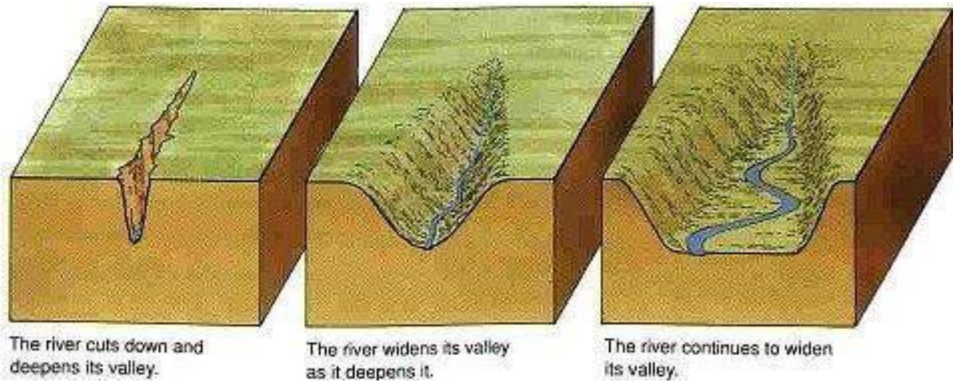
- **Braiding: the main water channel splitting into multiple, narrower channel. A braided river, or braided channel, consists of a network of river channels separated by small, and often temporary, islands called braid bars. Braided streams occur in rivers with low slope and/or large sediment load.**

RIVER VALLEY FORMATION

- The extended depression on the ground through which a stream flows is called a river valley.
- At different stages of the erosional cycle, the valley acquires different profiles.
- At a young stage, the valley is deep, narrow with steep wall-like sides and a convex slope.
- The erosional action here is characterized by predominantly **vertical downcutting** nature.
- The profile of valley here is typically 'V' shaped.
- A deep and narrow 'V' shaped valley is also referred to as **gorge** and may result due to downcutting erosion or because of the recession of a waterfall (the position of the waterfall receding due to erosive action).
- Most Himalayan rivers pass through deep gorges (at times more than 500 metres deep) before they descend to the plains.
- An extended form of the gorge is called a **canyon.** The Grand Canyon of the Colorado River in Arizona (USA) runs for 483 km and has a depth of 2.88 km.
- A tributary valley lies above the main valley and is separated from it by a steep slope down which the stream may flow as a waterfall or a series of rapids.

- As the cycle attains maturity, the **lateral erosion** (erosion of the walls of a stream) becomes prominent and the valley floor flattens out (attains a ‘V’ to ‘U’ shape).
- The valley profile now becomes typically ‘U’ shaped with a broad base and a concave slope.





River course

Youth

- Young rivers (A) close to their source tend to be fast-flowing, high-energy environments with rapid headward erosion, despite the hardness of the rock over which they may flow.
- Steep-sided **"V-shaped' valleys, waterfalls, and rapids** are characteristic features.
- E.g. Rivers flowing in the Himalayas.

Maturity

- Mature rivers (B) are lower-energy systems.
- Erosion takes place on the outside of bends, creating looping meanders in the soft alluvium of the river plain.
- Deposition occurs on the inside of bends and on the river bed.
- E.g. Rivers flowing in the Indo-Gangetic-Brahmaputra plain.

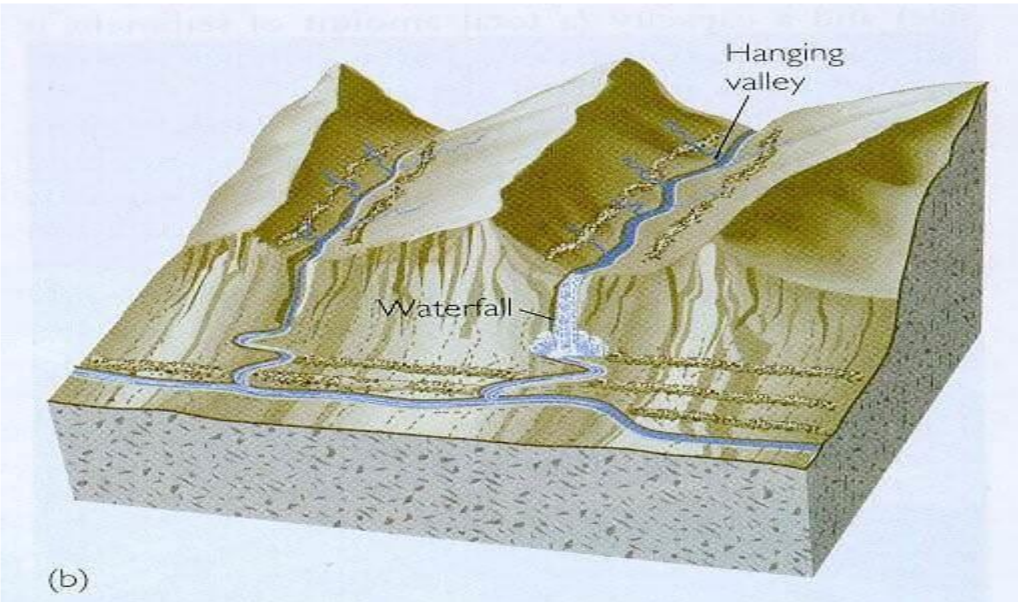
Old Age

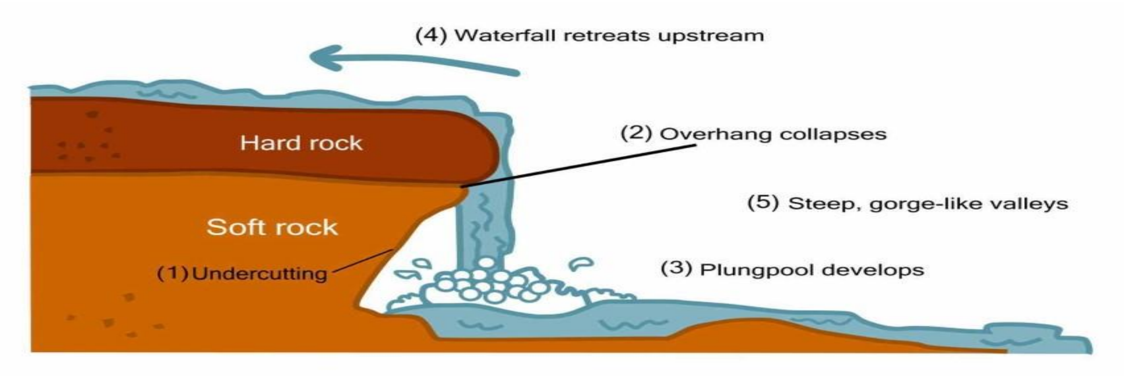
- At a river's mouth (C), sediment is deposited as the velocity of the river slows.
- As the river becomes shallower more deposition occurs, forming **temporary islands (Majuli, a river island in the Brahmaputra River, Assam is currently the world's largest river island)** and **braiding** (e.g. braided channels of Brahmaputra river flood plain in Assam) the main channel into multiple, narrower channels.

- As the sediment is laid down, the actual mouth of the river moves away from the source into the sea or lake, forming a **delta**.
- E.g. Ganga-Brahmaputra delta.

WATER FALLS

- A waterfall is simply the fall of an enormous volume of water from a great height.
- They are **mostly seen in** the **youth stage** of the river.
- Relative resistance of rocks, the relative difference in topographic reliefs, fall in the sea level and related rejuvenation, earth movements etc. are responsible for the formation of waterfalls.

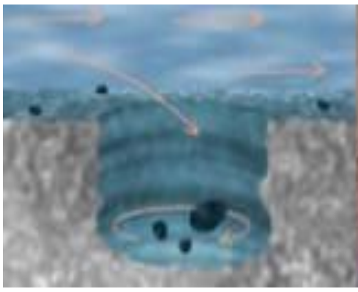




- **Kunchikal Falls (it is a cascade falls — falls with many steps) formed by Varahi river in Shimoga district, Karnataka is the highest waterfall in India (455 m).**
- **Nohkalikai Falls (340 m)** is the tallest plunge waterfall in India. The waterfall is located near Cherrapunji.
- **Jog or Gersoppa falls (253 m)** on Sharavati river (a tributary of Cauvery), Karnataka is the second-highest plunge waterfall in India.
- **Angel Falls** in Venezuela is the world's highest waterfall, with a height of 979 metres and a plunge of 807 metres.
- **Tugela Falls** (948 m) in the Drakensberg mountains, South Africa is the world's second highest waterfall.

Potholes

- The small cylindrical depressions in the rocky beds of the river valleys are called potholes.
- Potholing or pothole-drilling is the mechanism through which the fragments of rocks when caught in the water eddies or swirling water start dancing circularly and grind and drill the rock beds.
- They thus form small holes which are gradually enlarged by the repetition of the said mechanism.




Terraces

- Stepped benches along the river course in a flood plain are called terraces.
- Terraces represent the level of former valley floors and remnants of former (older) floodplains.

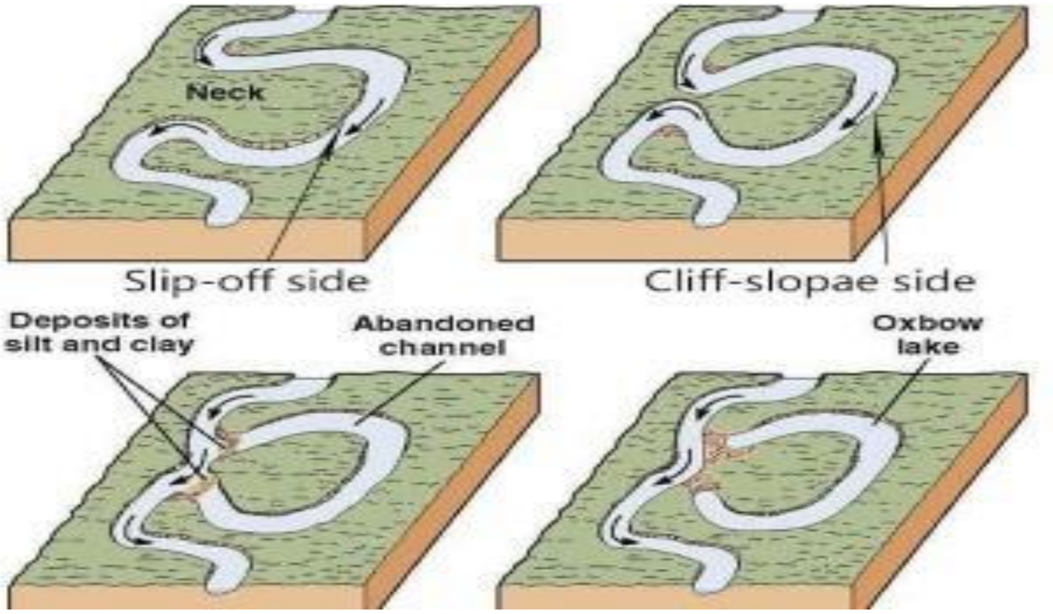
Gulleys/Rills

- Gulley is a water-worn channel, which is particularly common in semi-arid areas.
- It is formed when water from overland-flows down a slope, especially following heavy rainfall, is concentrated into rills, which merge and enlarge into a gulley.
- The **ravines of Chambal Valley** in Central India and the **Chos of Hoshiarpur** in Punjab are examples of gulleys.

Ravines of Chambal Valley in Madhya Pradesh

Meanders

- A meander is defined as a pronounced curve or loop in the course of a river channel.
- The outer bend of the loop in a meander is characterized by intensive erosion and vertical cliffs and is called the **cliff-slope side**. This side has a concave slope.
- The inner side of the loop is characterized by deposition, a gentle convex slope, and is called the **slip-off side.**
- The meanders may be wavy, horse-shoe type or oxbow type.



Oxbow Lake

- Sometimes, because of intensive erosion action, the outer curve of a meander gets accentuated to such an extent that the inner ends of the loop come close enough to get disconnected from the main channel and exist as independent water bodies called as oxbow lakes.
- These water bodies are converted into swamps in due course of time.

- In the Indo-Gangetic plains, southwards shifting of Ganga has left many oxbow lakes to the north of the present course of the Ganga.

Peneplane (Or peneplain)

- This refers to an undulating featureless plain punctuated with low-lying residual hills of resistant rocks. It is considered to be an **end product of an erosional cycle**.

Uluru or Ayers Rock in central Australia standing on a peneplane

- Fluvial erosion, in the course of geologic time, reduces the land almost to base level (sea level), leaving so little gradient that essentially **no more erosion could occur**.

FLUVIAL DEPOSITIONAL LANDFORMS CREATED BY THE DEPOSITIONAL ACTIVITY OF RIVERS.

FLUVIAL DEPOSITIONAL LANDFORMS

- The depositional action of a stream is influenced by stream velocity and the volume of river load.
- The decrease in stream velocity reduces the transporting power of the streams which are forced to leave some load to settle down.
- Increase in river load is effected through accelerated rate of erosion in the source catchment areas consequent upon deforestation.
- Various landforms resulting from fluvial deposition are as follows:

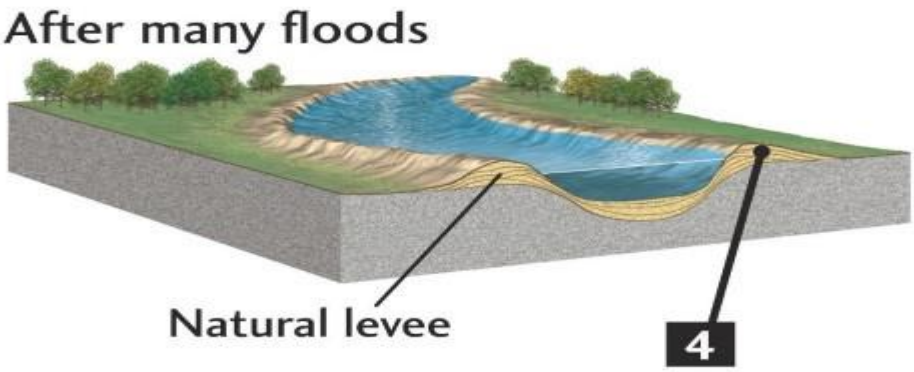
ALLUVIAL FANS & CONES

- When a stream leaves the mountains and comes down to the plains, its velocity decreases due to a lower gradient.
- As a result, it sheds a lot of material, which it had been carrying from the mountains, at the foothills.
- This deposited material acquires a conical shape and appears as a series of continuous fans. These are called alluvial fans.
- Such fans appear throughout the Himalayan foothills in the north Indian plains.

Alluvial Fans-Cones

Natural Levees

- These are narrow ridges of low height on both sides of a river, formed due to deposition action of the stream, appearing as natural embankments.
- These act as a natural protection against floods but a breach in a levee causes sudden floods in adjoining areas, as it happens in the case of the Hwang Ho river of China.



Delta

- A delta is a tract of alluvium at the mouth of a river where it deposits more material than can be carried away.
- The river gets divided into distributaries which may further divide and rejoin to form a network of channels.

A delta is formed by a combination of two processes:

1. load-bearing capacity of a river is reduced as a result of the check to its speed as it enters a sea or lake, and
2. clay particles carried in suspension in the river coagulate in the presence of salt water and are deposited.

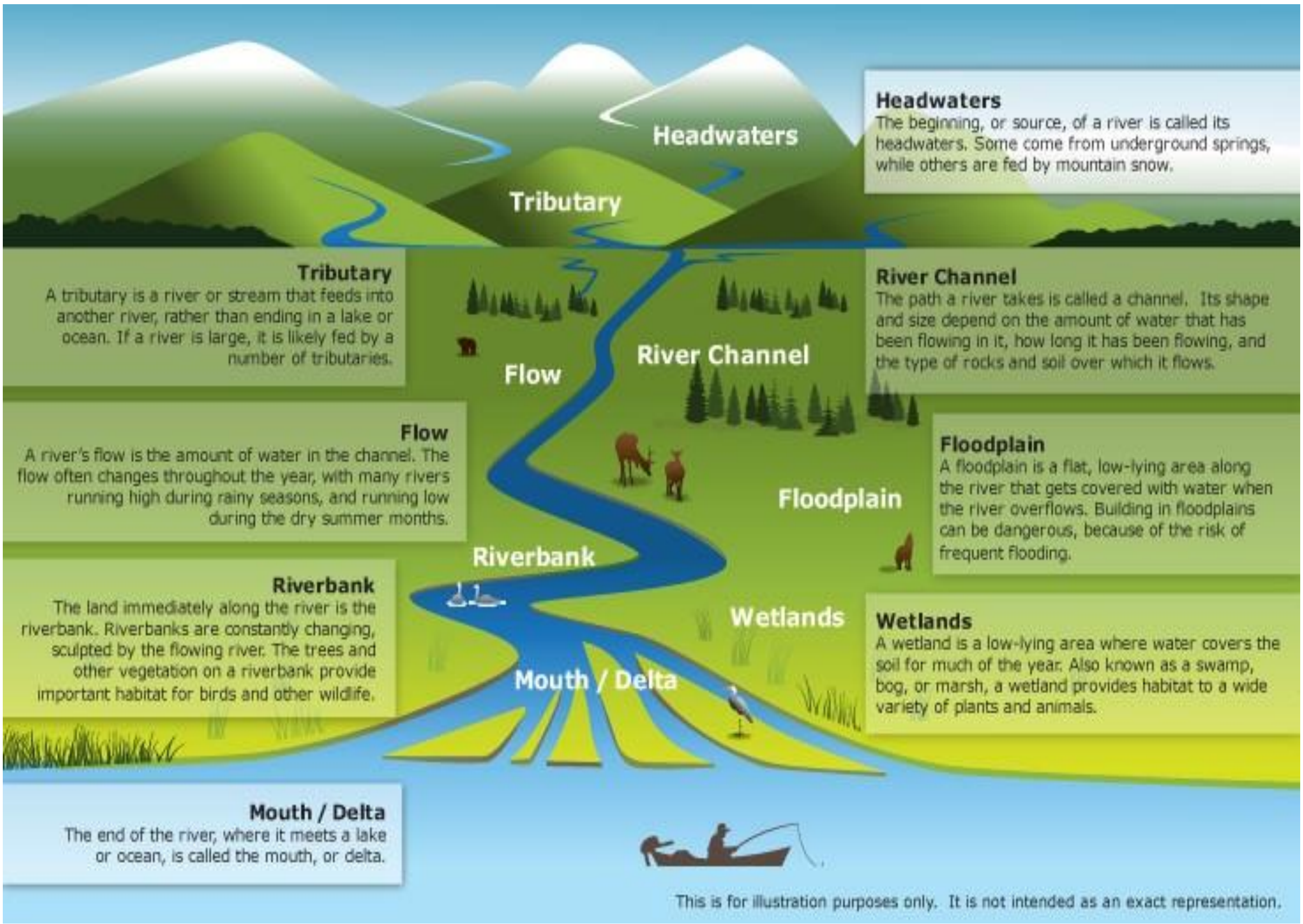
- The finest particles are carried farthest to accumulate as bottom-set beds.
- Depending on the conditions under which they are formed, deltas can be of many types.

Arcuate or Fan-shaped

- This type of delta results when light depositions give rise to shallow, shifting distributaries and a general fan-shaped profile. Examples: Nile, Ganga, Indus.

Bird's Foot Delta

- This type of delta emerges when limestone sediment deposits do not allow downward seepage of water.
- The distributaries seem to be flowing over projections of these deposits which appear as a bird's foot.
- The currents and tides are weak in such areas and the number of distributaries lesser as compared to an arcuate delta. Example: Mississippi river.

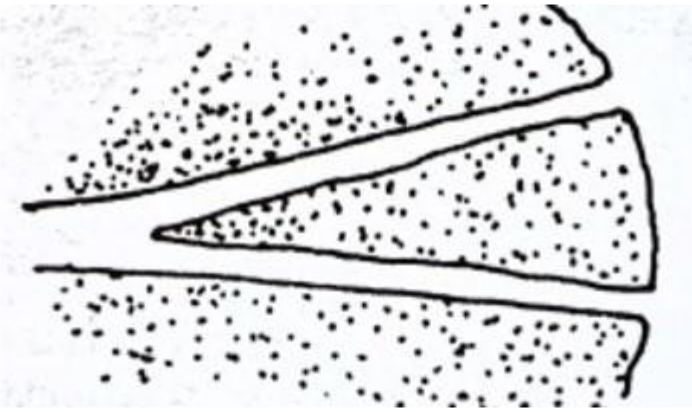


Estuaries

- Sometimes the mouth of the river appears to be submerged. This may be due to a drowned valley because of a rise in sea level.
- Here fresh water and the saline water get mixed. When the river starts 'filling its mouth' with sediments, mud bars, marshes and plains seem to be developing in it.
- These are ideal sites for fisheries, ports and industries because estuaries provide access to deep water, especially if protected from currents and tides. Example: Hudson estuary.

Cuspate Delta

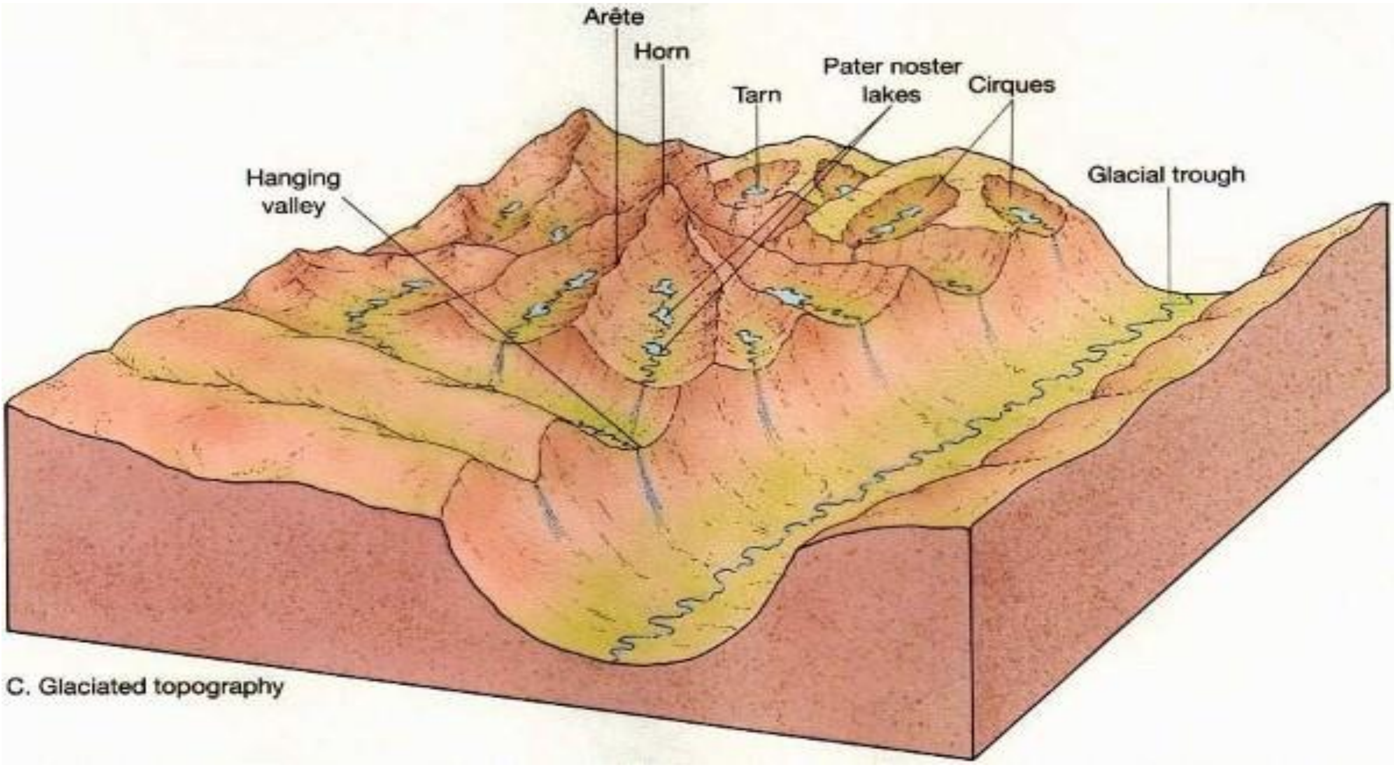
- This is a pointed delta formed generally along strong coasts and is subjected to strong wave action. There are very few or no distributaries in a cuspate delta.
- Example: Tiber river on west coast of Italy.



GLACIAL LANDFORMS AND CYCLE OF EROSION

- A glacier is a moving mass of ice at speeds averaging few meters a day.
- Types of Glaciers: continental glaciers, ice caps, piedmont glaciers and valley glaciers.
- The continental glaciers are found in the Antarctica and in Greenland. The biggest continental ice sheet in
- Ice caps are the covers of snow and ice on mountains from which the valley or mountain glaciers originate.
- The piedmont glaciers form a continuous ice sheet at the base of mountains as in southern Alaska.
- The valley glaciers, also known as Alpine glaciers, are found in higher regions of the Himalayas in our country and all such high mountain ranges of the world.
- The largest of Indian glaciers occur in the Karakoram range, viz. Siachen (72 km), while Gangotri in Uttar Pradesh (Himalayas) is 25.5 km long.
- A glacier is charged with rock debris which are used for erosional activity by moving ice.
- A glacier during its lifetime creates various landforms which may be classified into erosional and depositional landforms.

GLACIAL EROSIONAL LANDFORMS



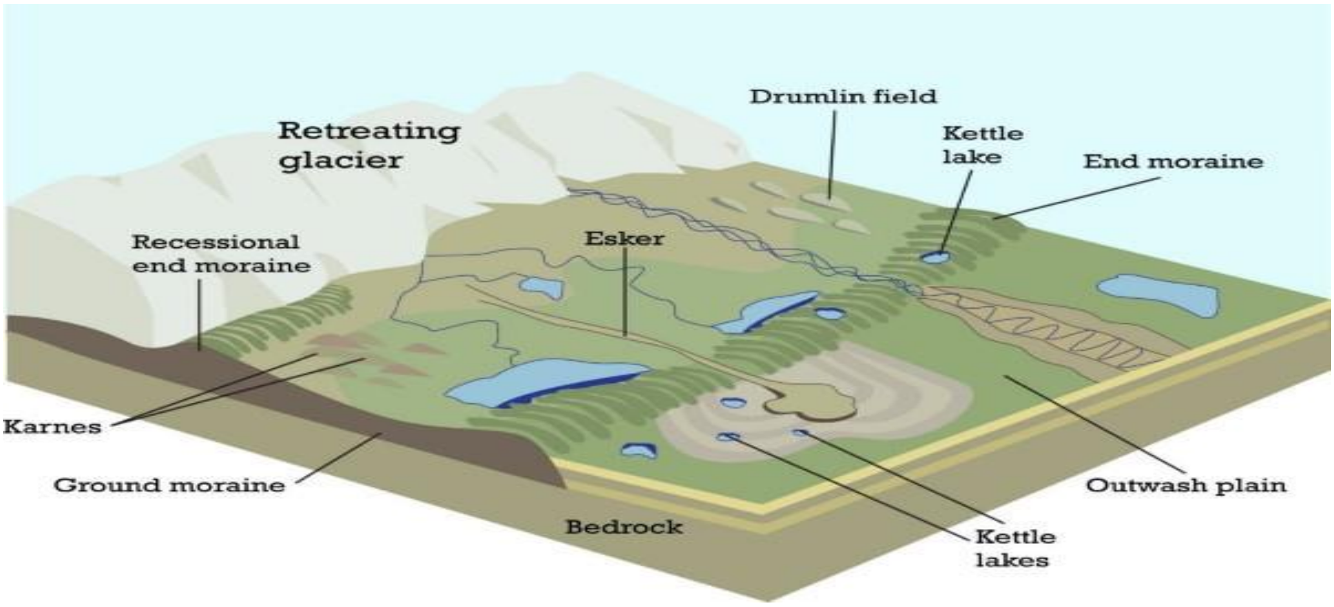
Cirque/Corrie	Hollow basin cut into a mountain ridge. It has steep sided slope on three sides, an open end on one side and a flat bottom. When the ice melts, the cirque may develop into a tarn lake.
Glacial Trough	Original stream-cut valley, further modified by glacial action. It is a 'U' Shaped Valley. It at mature stage of valley formation. Since glacial mass is heavy and slow moving, erosional activity is uniform – horizontally as well as vertically.

	A steep sided and flat bottomed valley results, which has a 'U' shaped profile.
Hanging Valley	Formed when smaller tributaries are unable to cut as deeply as bigger ones and remain 'hanging' at higher levels than the main valley as discordant tributaries. A valley carved out by a small tributary glacier that joins with a valley carved out by a much larger glacier.
Arete	Steep-sided, sharp-tipped summit with the glacial activity cutting into it from two
Horn	Ridge that acquires a 'horn' shape when the glacial activity cuts it from more than two sides.

D-Fjord

- Steep-sided narrow entrance-like feature at the coast where the stream meets the coast.
- Fjords are common in Norway, Greenland and New Zealand.

GLACIAL DEPOSITIONAL LANDFORMS



OUTWASH PLAIN	When the glacier reaches its lowest point and melts, it leaves behind a stratified deposition material, consisting of rock debris, clay, sand, gravel etc. This layered surface is called till plain or an outwash plain.
ESKER	Winding ridge of un-assorted depositions of rock, gravel, clay etc. running along a glacier in a till plain. The eskers resemble the features of an embankment and are often used for making roads.
KAME TERRACES	Broken ridges or un-assorted depositions looking like hump in a till plain.
DRUMLIN	Inverted boat-shaped deposition in a till plain caused by deposition.
KETTLE HOLES	Formed when the deposited material in a till plain gets depressed locally and forms a basin.
MORAINE	General term applied to rock fragments, gravel, sand, etc. carried by a glacier. Depending on its position, the moraine can be ground moraine and end moraine.

Glacial Cycle of Erosion

Youth

- The stage is marked by the inward cutting activity of ice in a cirque.
- Aretes and horns are emerging. The hanging valleys are not prominent at this stage.

Maturity

- Hanging valleys start emerging. The opposite cirques come closer and the glacial trough acquires a stepped profile which is regular and graded.

Old Age

- Emergence of a 'U'-shaped valley marks the beginning of old age.
- An outwash plain with features such as eskers, kame terraces, drumlins, kettle holes etc. is a prominent development.

Why are world's highest mountains at the equator?

- Ice and glacier coverage at lower altitudes in cold climates is more important than collision of tectonic plates. [Glacial erosion is very strong because of huge boulders of rocks carried by the glacial ice that graze the surface. Though ice moves only few meters a day, it can take along it huge rocks that can peal the outer layers.]
- Scientists have solved the mystery of why the world's highest mountains sit near the equator.
- Colder climates are better at eroding peaks. In colder climates, the snowline on mountains starts lower down, and erosion takes place at lower altitudes.
- In general, mountains only rise to around 1,500m above their snow lines, so it is the altitude of these lines — which depends on climate and latitude — which ultimately decides their height.
- At low latitudes, the atmosphere is warm and the snowline is high. Around the equator, the snowline is about 5,500m at its highest so mountains get up to 7,000m.

- There are a few exceptions [that are higher], such as Everest, but extremely few.
- When you then go to Canada or Chile, the snowline altitude is around 1,000m, so the mountains are around 2.5km.

MARINE LANDFORMS OR COASTAL LANDFORMS

1. Erosional Landforms: Chasms, Wave-Cut Platform, Sea Cliff, Sea Caves, Sea Arches, Stacks/Skarries/Chimney Rock, Blow Holes or Spouting Horns etc..
2. Depositional Landforms: Beach, Bar, Barrier, Spit and Hook, Tombolos etc..
3. Coastlines: Coastline of Emergence, Coastline of Submergence, Neutral coastline, Compound coastline and Fault coastline

MARINE LANDFORMS – CYCLE OF EROSION

- Sea waves, aided by winds, currents, tides and storms carry on the erosional and depositional processes.
- The erosive work of the sea depends upon size and strength of waves, slope, height of the shore between low and high tides, shape of the coast, composition of rocks, depth of water, human activity etc.
- The wave pressure compresses the air trapped inside rock fissures, joints, faults, etc. forcing it to expand and rupture the rocks along weak points. This is how rocks undergo weathering under wave action.
- Waves also use rock debris as instruments of erosion (glaciers are quite good at this). These rock fragments carried by waves themselves get worn down by striking against the coast or against one another.
- The solvent or chemical action of waves is another mode of erosion, but it is pronounced only in case of soluble rocks like limestone and chalk.

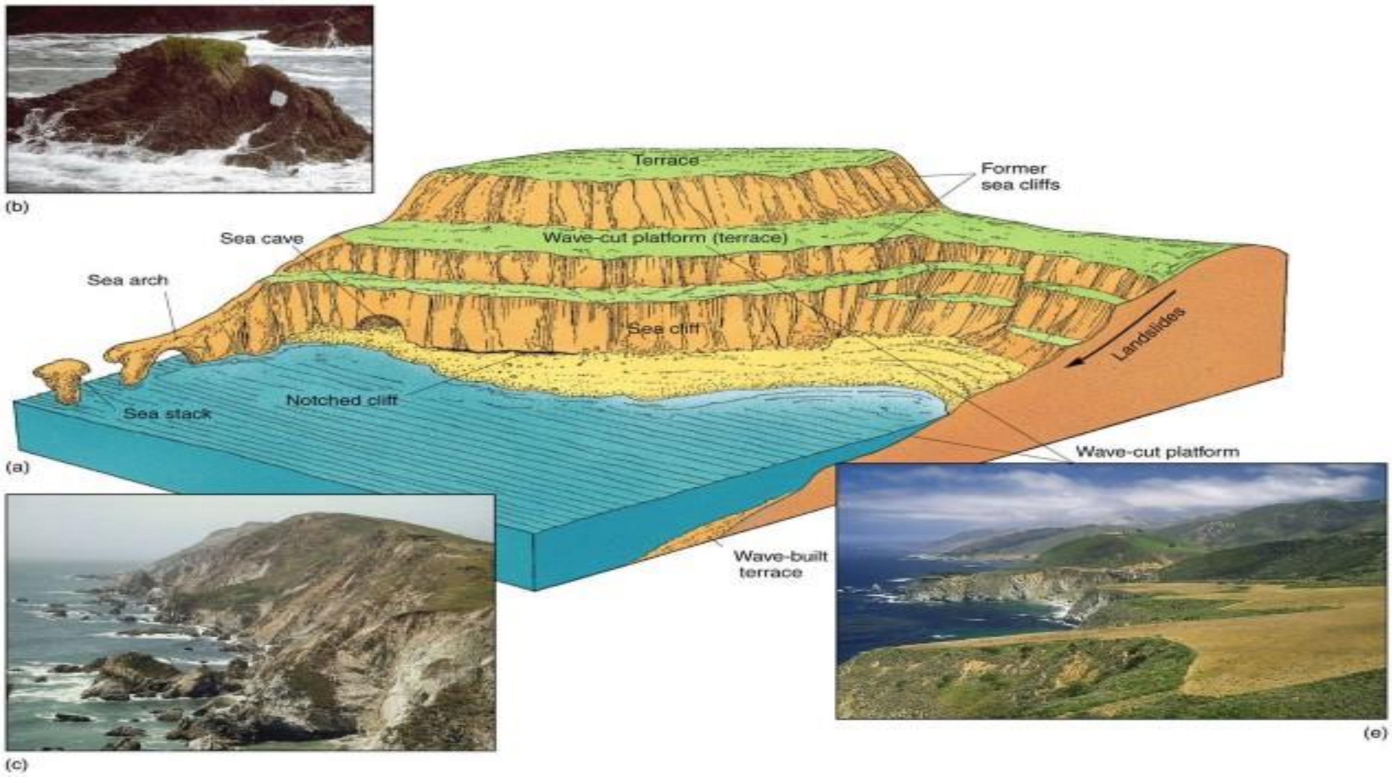
Chasms

- These are narrow, deep indentations (a deep recess or notch on the edge or surface of something) carved due to headward erosion (downcutting) through vertical planes of weakness in the rocks by wave action.
- With time, further headward erosion is hindered by lateral erosion of chasm mouth, which itself keeps widening till a bay is formed.

Wave-Cut Platform

- When the sea waves strike against a cliff, the cliff gets eroded (lateral erosion) gradually and retreats.

- The waves level out the shore region to carve out a horizontal plane or a wave-cut platform.
- The bottom of the cliff suffers the maximum intensive erosion by waves and, as a result, a notch appears at this position.



Sea Cliff

- Shoreline marked by a steep bank (escarpment, scarp).

Sea Caves

- Differential erosion by sea waves through a rock with varying resistance across its structure produces arched caves in rocks called sea caves.

Sea Arches

- When waves from opposite directions strike a narrow wall of rock, differential erosion of the rock leaves a bridge like structure called Sea arch.

Stacks/Skarries/Chimney Rock

- When a portion of the sea arch collapses, the remaining column-like structure is called a stack, skarry or chimney rock.

Hanging Valleys

- If the fluvial erosion of a stream at the shore doesn't match the retreat of the sea, the rivers appear to be hanging over the sea. These river valleys are called hanging valleys.

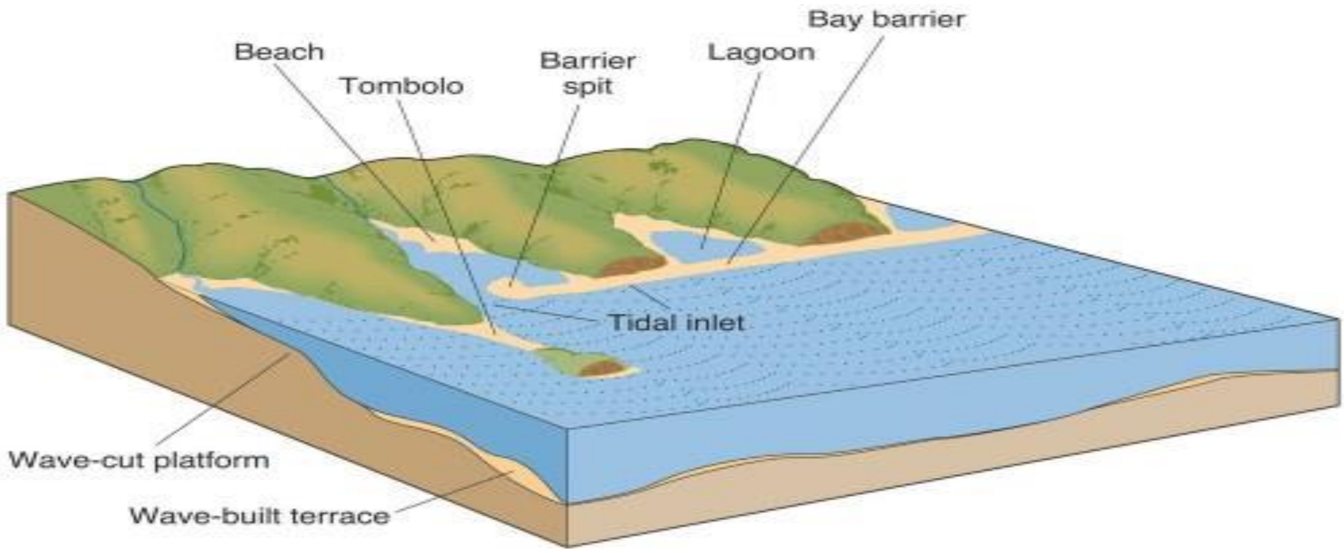
Blow Holes or Spouting Horns

- The burst of water through a small hole on a sea cave due to the compression of air in the cave by strong waves. They make a peculiar noise.

Plane of Marine Erosion/Peneplain

- The eroded plain left behind by marine action is called a plain of marine erosion. If the level difference between this plain and the sea level is not much, the agents of weathering convert it into a peneplain.

MARINE DEPOSITIONAL LANDFORMS



Beach	This is the temporary covering of rock debris on or along a wave-cut platform.
Bar	Currents and tidal currents deposit rock debris and sand along the coast at a distance from the shoreline. The resultant landforms which remain submerged are called bars. The enclosed water body so created is called a Barrier
Barrier	It is the overwater counterpart of a bar.
Spit and Hook	A spit is a projected deposition joined at one end to the headland, with the other end free in the sea. The mode of formation is similar to a bar or barrier. A shorter spit with one end curved towards the land is called a
Tombolos	Sometimes, islands are connected to each other by a bar called tombolo.

Marine Cycle of Erosion

Youth

- The waves are very active.
- Sea caves, arches and stalks begin to develop.
- Cliff undercutting is pronounced and wavecut platform begins to emerge due to wave erosion.
- By the end of youth, an irregular coastline remains.

Maturity

- The cliff and wave-cut platform are conspicuous.
- Stream deposition is taking place. These valleys may be normal or of the hanging type.
- Various landforms indicating continuous deposition are visible, such as bars, barriers and spits.

Old Age

- Irregularities, such as caves and arches disappear.

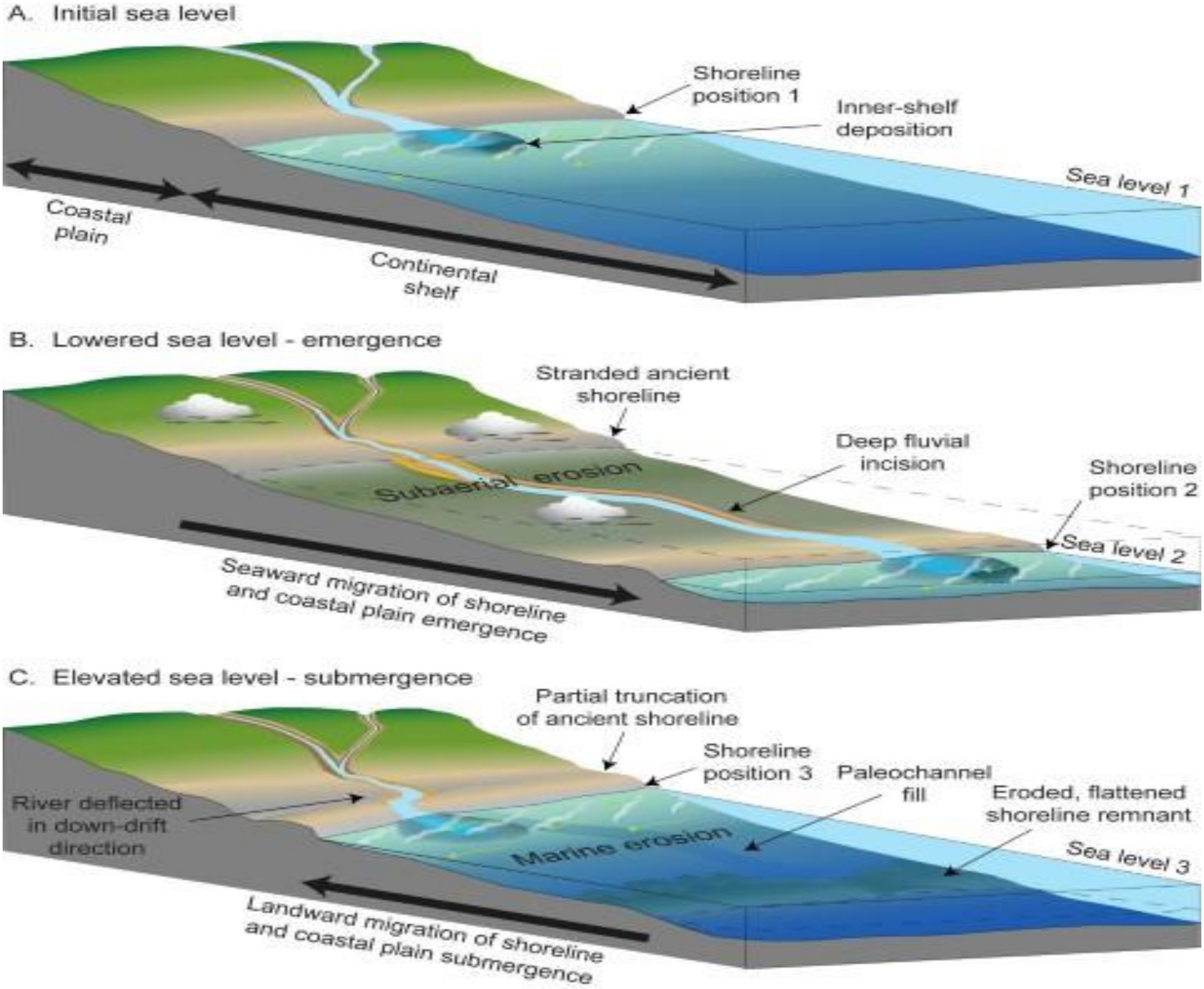
COASTLINES

- The boundary between the coast (the part of the land adjoining or near the sea) and the shore (the land along the edge of a sea) is known as the coastline.

Coastlines can be divided into the following classes:

1. Coastline of Emergence
2. Coastline of Submergence
3. Neutral coastline
4. Compound coastline
5. Fault coastline

- Coastline are modified either due to rise or fall in sea levels or upliftment or subsidence of land, or both.



Coastlines of Emergence

- These are formed either by an uplift of the land or by the lowering of the sea level.
- Bars, spits, lagoons, salt marshes, beaches, sea cliffs and arches are the typical features.
- The east coast of India, especially its south-eastern part (Tamil Nadu coast), appears to be a coast of emergence.

- The west coast of India, on the other hand, is both emergent and submergent. The northern portion of the coast is submerged as a result of faulting and the southern portion, that is the Kerala coast, is an example of an emergent coast.
- Coramandal coast == Tamil Nadu Coast == Coastline of emergence
- Malabar coast == Kerala Coast == Coastline of emergence
- Konkan coast == Maharashtra and Goa Coast == Coastline of submergence.

Coastlines of Submergence

- A submerged coast is produced either by subsidence of land or by a rise in sea level.
- Ria, fjord, Dalmatian and drowned lowlands are its typical features.

Ria

- When a region is dissected by streams into a system of valleys and divides, submergence produces a highly irregular shoreline called ria coastline.
- The coast of south-west Ireland is a typical example of ria coastline.

Fjord

- Some coastal regions have been heavily eroded by glacial action and the valley glacier troughs have been excavated below sea level.
- After the glaciers have disappeared, a fjord coastline emerges.
- These coasts have long and narrow inlets with very steep sides.
- The fjord coasts of Norway are a typical example.

Dalmatian

- The Dalmatian coasts result by submergence of mountain ridges with alternating crests and troughs which run parallel to the sea coast.
- The Dalmatian coast of Yugoslavia is a typical example.

Drowned lowland

- A drowned lowland coast is low and free from indentations, as it is formed by the submergence of a low-lying area.
- It is characterized by a series of bars running parallel to the coast, enclosing lagoons.
- The Baltic coast of eastern Germany is an example of this type of coastline.

Neutral Coastlines

- These are coastlines formed as a result of new materials being built out into the water.

- The word 'neutral' implies that there need be no relative change between the level of sea and the coastal region of the continent.
- Neutral coastlines include the alluvial fan shaped coastline, delta coastline, volcano coastline and the coral reef coastline.

Compound Coastlines

- Such coastlines show the forms of two of the previous classes combined, for example, submergence followed by emergence or vice versa.
- The coastlines of Norway and Sweden are examples of compound coastlines.

Fault Coastlines

- Such coastlines are unusual features and result from the submergence of a downthrown block along a fault, such that the uplifted block has its steep side (or the faultline) standing against the sea forming a fault coastline.

ARID LANDFORMS

- Water Eroded Arid Landforms – Rill, Gully, Ravine, Badland Topography, Bolsons, Playas, Pediments, Bajada etc..
- Wind Eroded Arid Landforms – Deflation basins, Mushroom rocks, Inselbergs, Demoiselles, Demoiselles, Zeugen , Wind bridges and windows.
- Depositional Arid Landforms – Ripple Marks, Sand dunes, Longitudinal dunes, Transverse dunes, Barchans, Parabolic dunes, Star dunes and Loess.

Arid Landforms and Cycle of Erosion

- Arid regions are regions with scanty rainfall. Deserts and Semi-arid regions fall under arid landforms.

Water Eroded Arid Landforms

Rill

- In hill slope geomorphology, a rill is a narrow and shallow channel cut into soil by the erosive action of flowing water.

Gully

- A gully is a landform created by running water. Gullies resemble large ditches or small valleys, but are metres to tens of metres in depth and width.

Ravine

- A ravine is a landform narrower than a canyon and is often the product of stream cutting erosion. Ravines are typically classified as larger in scale than gullies, although smaller than valleys.

Badland Topography

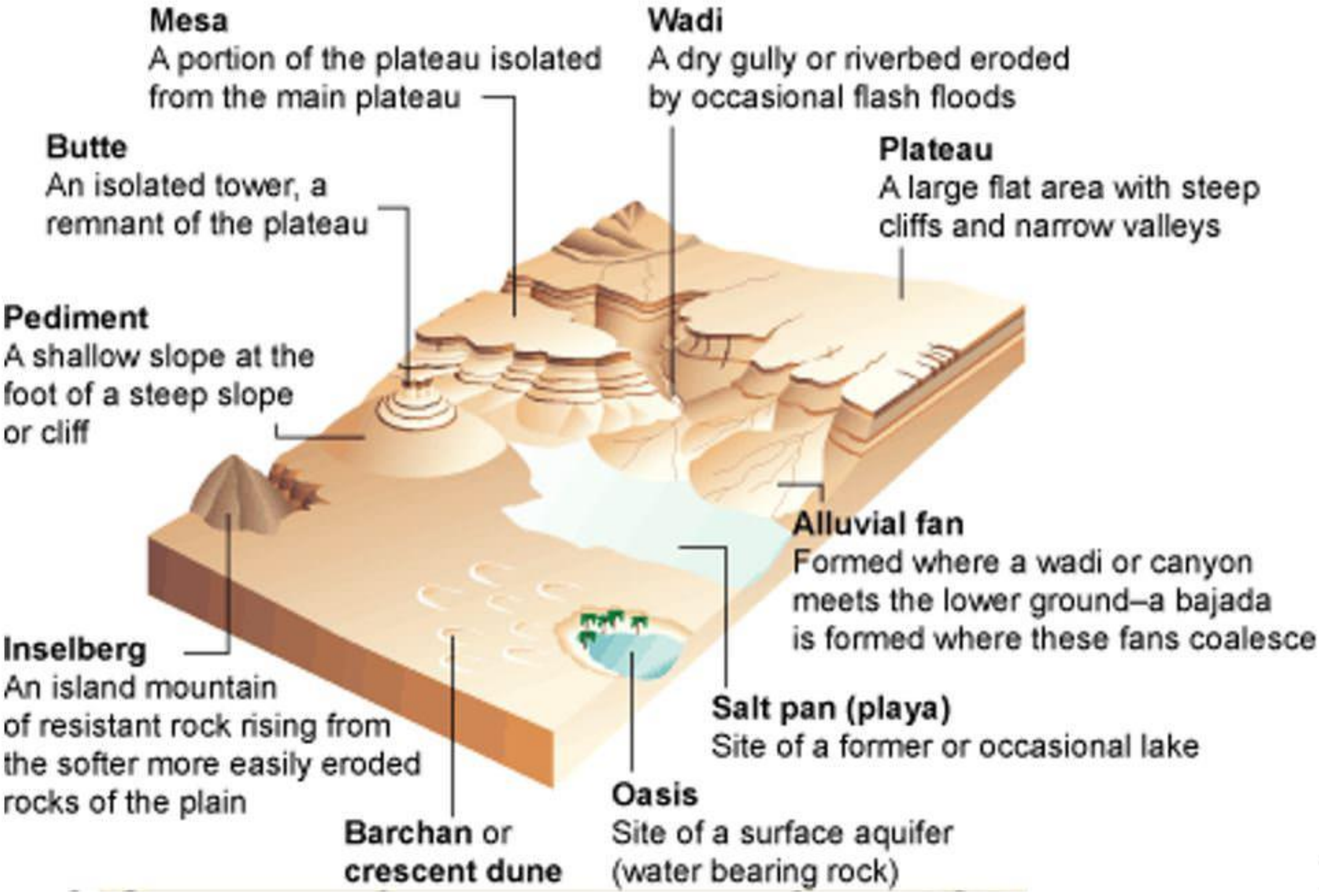
- In arid regions occasional rainstorms produce numerous rills and channels which extensively erode weak sedimentary formations.
- Ravines and gullies are developed by linear fluvial erosion leading to the formation of badland topography.
- Example: Chambal Ravines.

Bolsons

- The intermontane basins in dry regions are generally known as bolsons.

Playas

- Three unique landforms viz. pediments, bajadas and playas are typically found in bolsons.
- Small streams flow into bolsons, where water is accumulated. These temporary lakes are called playas.
- After the evaporation of water, salt-covered playas are called salinas.



Pediments

- In form and function there is no difference between a pediment and an alluvial fan; however, pediment is an erosional landform while a fan is a constructional one.
- A true pediment is a rock cut surface at the foot of mountains.

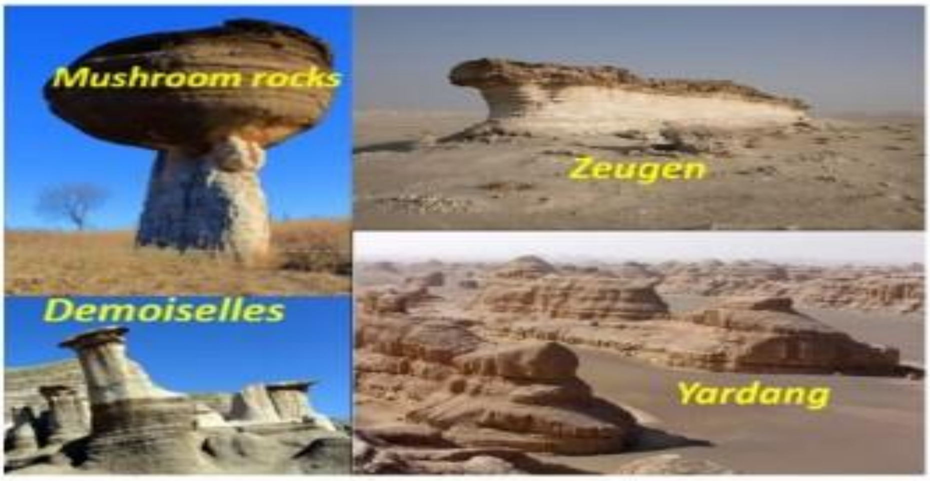
Bajada

- Bajadas are moderately sloping depositional plains located between pediments and playa.
- Several alluvial fans coalesce to form a bajada.

WIND ERODED ARID LANDFORMS

- The wind or Aeolian erosion takes place in the following ways, viz. deflation, abrasion, and attrition.
- Deflation == removing, lifting and carrying away dry, unsorted dust particles by winds. It causes depressions known as blow outs.
- Abrasion == When wind loaded with sand grains erodes the rock by grinding against its walls is called abrasion or sandblasting.
- Attrition == Attrition refers to wear and tear of the sand particles while they are being transported.

Following are the major landforms produced by wind erosion.



Deflation basins

- Deflation basins, called blowouts, are hollows formed by the removal of particles by wind. Blowouts are generally small, but may be up to several kilometers in diameter.

Mushroom rocks

- A mushroom rock, also called rock pedestal or a pedestal rock, is a naturally occurring rock whose shape, as its name implies, resembles a mushroom.
- The rocks are deformed in a number of different ways: by erosion and weathering, glacial action, or from a sudden disturbance. Mushroom rocks are related to, but different from, yardang.

Inselbergs

- A monadnock or inselberg is an isolated hill, knob, ridge, outcrop, or small mountain that rises abruptly from a gently sloping or virtually level surrounding plain.

Demoiselles

- These are rock pillars which stand as resistant rocks above soft rocks as a result of differential erosion of hard and soft rocks.

Zeugen

- A table-shaped area of rock found in arid and semi-arid areas formed when more resistant rock is reduced at a slower rate than softer rocks around it.

Yardangs

- Ridge of rock, formed by the action of the wind, usually parallel to the prevailing wind direction.

Wind bridges and windows

- Powerful wind continuously abrades stone lattices, creating holes. Sometimes the holes are gradually widened to reach the other end of the rocks to create the effect of a window—thus forming a wind window. Window bridges, are formed when the holes are further widened to form an arch-like feature.

Arid Depositional Landforms

- Landforms are also created by the depositional force of wind. These are as follows.

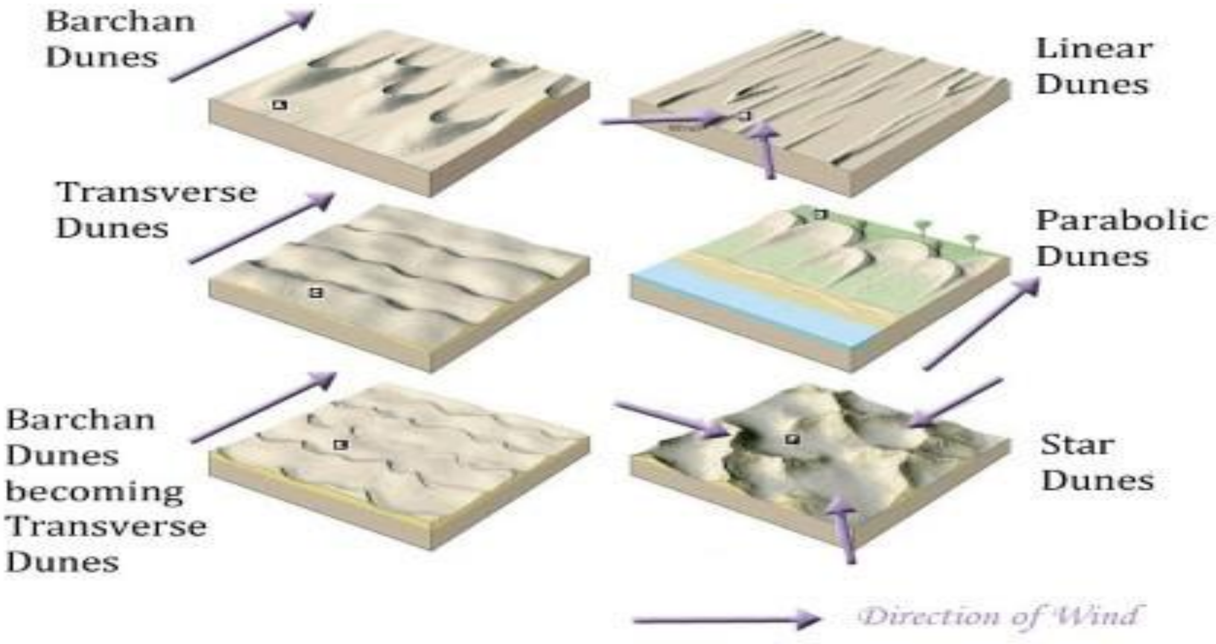
Ripple Marks

- These are depositional features on a small scale formed by saltation (he transport of hard particles over an uneven surface in a turbulent flow of air or water).

Sand dunes

- Sand dunes are heaps or mounds of sand found in deserts. Generally their heights vary from a few metres to 20 metres but in some cases dunes are several hundred metres high and 5 to 6 km long.

Some of the forms are discussed below:



Longitudinal dunes

- Formed parallel to the wind movement. The windward slope of the dune is gentle whereas the leeward side is steep. These dunes are commonly found at the heart of trade-wind deserts like the Sahara, Australian, Libyan, South African and Thar deserts.

Transverse dunes

- Dunes deposited perpendicular (transverse) to the prevailing wind direction.

Barchans

- Crescent shaped dunes. The windward side is convex whereas the leeward side is concave and steep.

Parabolic dunes

- They are U-shaped and are much longer and narrower than barchans.

Star dunes

- Have a high central peak, radically extending three or more arms.

Loess

- In some parts of the world, windblown dust and silt blanket the land. This layer of fine, mineral-rich material is called loess.
- Extensive loess deposits are found in northern China, the Great Plains of North America, central Europe, and parts of Russia and Kazakhstan.
- The thickest loess deposits are near the Missouri River in the U.S. state of Iowa and along the Yellow River in China.
- Loess accumulates, or builds up, at the edges of deserts. For example, as wind blows across the Gobi, a desert in Asia, it picks up and carries fine particles. These particles include sand crystals made of quartz or mica. It may also contain organic material, such as the dusty remains of skeletons from desert animals.
- Loess often develops into extremely fertile agricultural soil. It is full of minerals and drains water very well. It is easily tilled, or broken up, for planting seeds.

- Loess usually erodes very slowly – Chinese farmers have been working the loess around the Yellow River for more than a thousand years.

KARST LANDFORMS AND CYCLE OF EROSION

- Karst is a landscape which is underlain by limestone which has been eroded by dissolution, producing towers, fissures, sinkholes, etc.
- It is so named after a province of Yugoslavia on the Adriatic sea coast where such formations are most noticeable.
- Karst topography is a landscape formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum.
- It is characterized by underground drainage systems with sinkholes, caves etc..

Conditions Essential for Full Development of Karst Topography

- Presence of soluble rocks, preferably limestone at the surface or sub-surface level.
- These rocks should be dense, highly jointed and thinly bedded.

Cavern

- This is an underground cave formed by water action by various methods in a limestone or chalk area.

Arch/Natural Bridge

- When a part of the cavern collapses the portion which keeps standing forms an arch.

Sink Hole/Swallow Hole

- Sink holes are funnel-shaped depressions having an average depth of three to nine metres.
- These holes are developed by enlargement of the cracks found in such rocks, as a result of continuous solvent action of the rainwater.
- The surface streams which sink disappear underground through swallow holes.

Karst Window

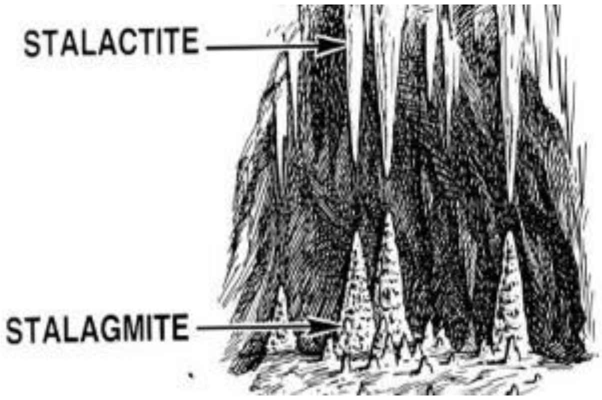
- When a number of adjoining sink holes collapse, they form an open, broad area called a karst window.

Sinking Creeks/Bogas

- In a valley, the water often gets lost through cracks and fissures in the bed. These are called sinking creeks, and if their tops are open, they are called bogas.

Stalactite and Stalagmite

- The water containing limestone in solution, seeps through the roof in the form of a continuous chain of drops.
- A portion of the roof hangs on the roof and on evaporation of water, a small deposit of limestone is left behind contributing to the formation of a stalactite, growing downwards from the roof.
- The remaining portion of the drop falls to the floor. This also evaporates, leaving behind a small deposit of limestone aiding the formation of a stalagmite, thicker and flatter, rising upwards from the floor.
- Sometimes, stalactite and stalagmite join together to form a complete pillar known as the column.



LAKES

- A lake is a body of water of considerable size, localized in a basin, that is surrounded by land apart from a river or other outlet that serves to feed or drain the lake.
- Lakes lie on land and are not part of the ocean, and therefore are distinct from lagoons, and are also larger and deeper than ponds.
- Natural lakes are generally found in mountainous areas, rift zones, and areas with ongoing glaciation.
- Most lakes have at least one natural outflow in the form of a river or stream, which maintain a lake's average level by allowing the drainage of excess water
- Other lakes are found in endorheic basins. Some lakes do not have a natural outflow and lose water solely by evaporation or underground seepage or both. They are termed endorheic lakes.
- The majority of lakes on Earth are fresh water, and most lie in the Northern Hemisphere at higher latitudes. Canada, Finland and Siberia contain most of the fresh water lakes.

CLASSIFICATION OF LAKES

Temporary lakes

- Lakes may exist temporarily filling up the small depressions of undulating ground after a heavy shower.
- In this kind of lakes, Evaporation > Precipitation.
- Example: Small lakes of deserts.

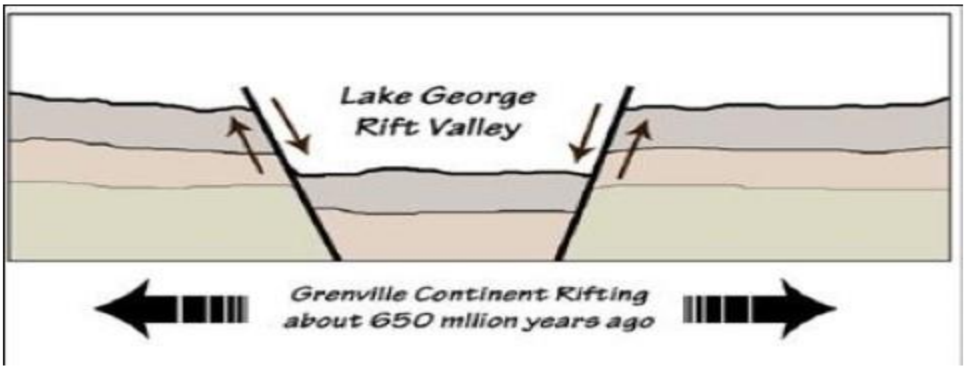
Permanent lakes

- In this kind of lakes, Evaporation < Precipitation.
- These lakes are deep and carry more water than could ever be evaporated.
- Example: Great Lakes of North America, East African Rift Lakes.

Fresh water lakes	Most of the lakes in the world are fresh-water lakes fed by rivers and with out-flowing streams e.g. Great Lakes of North America.
Saline lakes	Salt lakes (also called saline lakes) can form where there is no natural outlet or where the water evaporates rapidly and the drainage surface of the water table has a higher-than-normal salt content. Because of the intense evaporation (negative freshwater balance == more water is lost in evaporation than gained from rivers) these lakes are saline. Examples of salt lakes include Great Salt Lake, the Aral Sea and the Dead Sea. For example the Dead Sea has a salinity (salt content) of 250 parts per thousand, and the Great Salt Lake of Utah, U.S.A. has a salinity of 220 parts per thousand. Playas or salt lakes, are a common feature of deserts (recall desert landforms).

Lakes Formed by Earth Movement

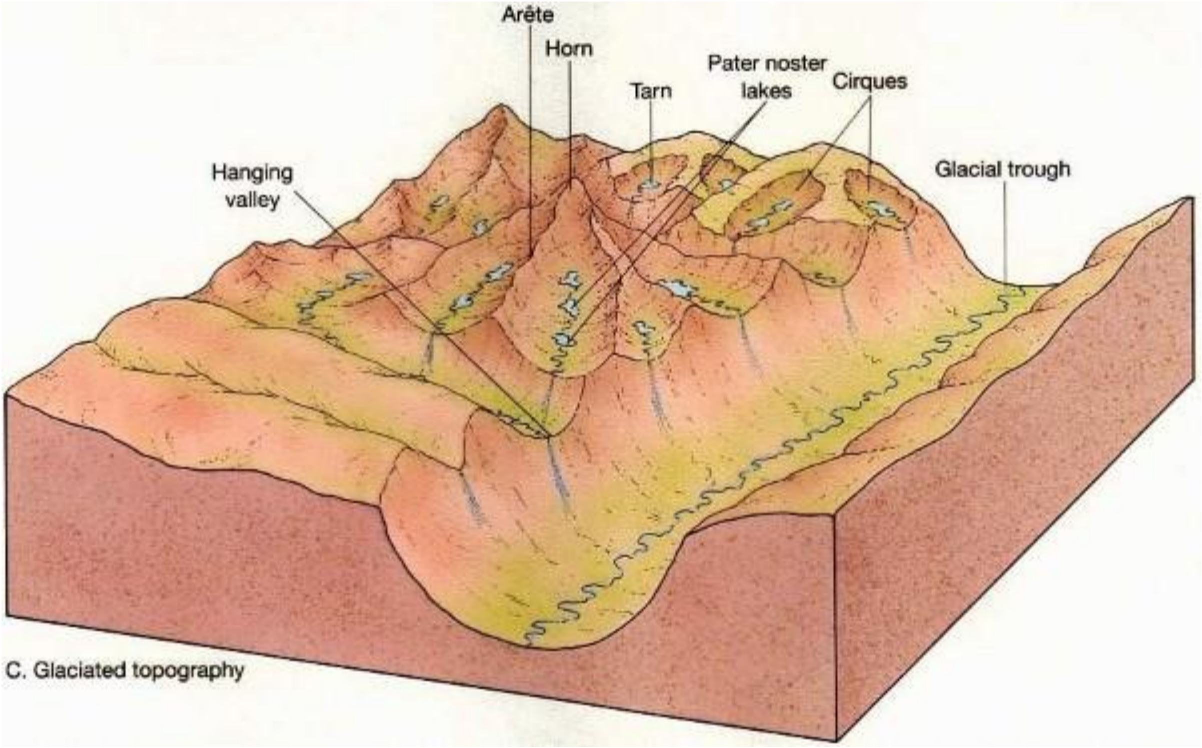
TECTONIC LAKES	Due to the warping (simple deformation), subsidence (sliding downwards), bending and fracturing (splitting) of the earth's crust, tectonic depressions occur. (We have studied all these terms in previous posts) Such depressions give rise to lakes of immense sizes and depths. They include Lake Titicaca, and the Caspian Sea.
RIFT VALLEY LAKES	A rift valley is formed when two blocks of earth move apart letting the 'in between' block slide downwards. Or, it's a sunken land between two parallel faults. Rift valleys are deep, narrow and elongated. Hence the lakes formed along rift valleys are also deep, narrow and very long. Water collects in troughs (Valley in the rift) and their floors are often below sea level. The best known example is the East African Rift Valley which runs through Zambia, Malawi, Tanzania, Kenya and Ethiopia, and extends along the Red Sea to Israel and Jordan over a total distance of 3,000 miles. It includes such lakes as Lakes Tanganyika, Malawi, Rudolf, Edward, Albert, as well as the Dead Sea 1,286 feet below mean sea level, the world's lowest lake.



Lakes Formed by Glaciation

Cirque lakes or tarns

- Cirque is a hollow basin cut into a mountain ridge. It has steep sided slope on three sides, an open end on one side and a flat bottom.
- When the ice melts, the cirque may develop into a tarn lake.



C. Glaciated topography

Rock-hollow lakes

- The advance and retreat of glaciers can scrape depressions in the surface where water accumulates; such lakes are common in Scandinavia, Patagonia, Siberia and Canada.
- These are formed by ice-scouring (eroding) when ice sheets scoop out (dig) hollows on the surface.
- Such lakes of glacial origin are abundant in Finland – Land of Lakes. It is said that there are over 35,000 glacial lakes in Finland.

Lakes due to morainic damming of valleys

- Valley glaciers often deposit morainic debris across a valley so that lakes are formed when water accumulates behind the barrier.

LAKES FORMED BY VOLCANIC ACTIVITY

Crater and caldera lakes

- During a volcanic explosion the top of the cone may be blown off leaving behind a natural hollow called a crater.
- This may be enlarged by subsidence into a caldera.
- In dormant or extinct volcanoes, rain falls straight into the crater or caldera which has no superficial outlet and forms a crater or caldera lake.
- Examples: Lonar in Maharashtra and Krakatao in Indonesia.

Others are Lava-blocked lakes and Lakes due to subsidence of a volcanic land surface.

LAKES FORMED BY EROSION

Karst lakes

- The solvent action of rain-water on limestone carves out solution hollows. When these become clogged with debris lakes may form in them.
- The collapse of limestone roofs of underground caverns may result in the exposure of long, narrow-lakes that were once underground.

Karst Landforms – Cavern, Bogas, Stalactite, Stalagmite

Wind-deflated lakes

- The winds in deserts creates hollows. These may reach ground water which seeps out forming small, shallow lakes. Excessive evaporation causes these to become salt lakes and playas. Example: Great Basin of Utah, U.S.A.

Lakes Formed by Deposition

Lakes due to river deposits

- Ox-bow lake, e.g. those that occur on the flood-plains of Lower Mississippi, Lower Ganges etc..

Fluvial Depositional Landforms – Alluvial Fan – Levee – Delta Types

Lakes due to Marine deposits

- Also called Lagoons.
- Example: Lake Chilka

Marine Landforms – Erosional and Depositional – Coastines

Lakes due to damming of water

- Lakes formed by these processes are also known as barrier lakes. Landslides, avalanches may block valleys so that rivers are dammed. Such lakes are short-lived.
- Example: Lakes that are formed in Shiwaliks (Outer Himalayas). Dehradun (all Duns) were lakes few centuries ago.

Man-made lakes

- Besides the natural lakes, man has now created artificial lakes by erecting a concrete dam across a river valley so that the river water can be kept back to form reservoirs.
- Example: Lake Mead above the Hoover Dam on the Colorado River, U.S.A.
- Man's mining activities, e.g. tin mining in West Malaysia, have created numerous lakes. Inland fish culture has necessitated the creation of many fishing-lakes.

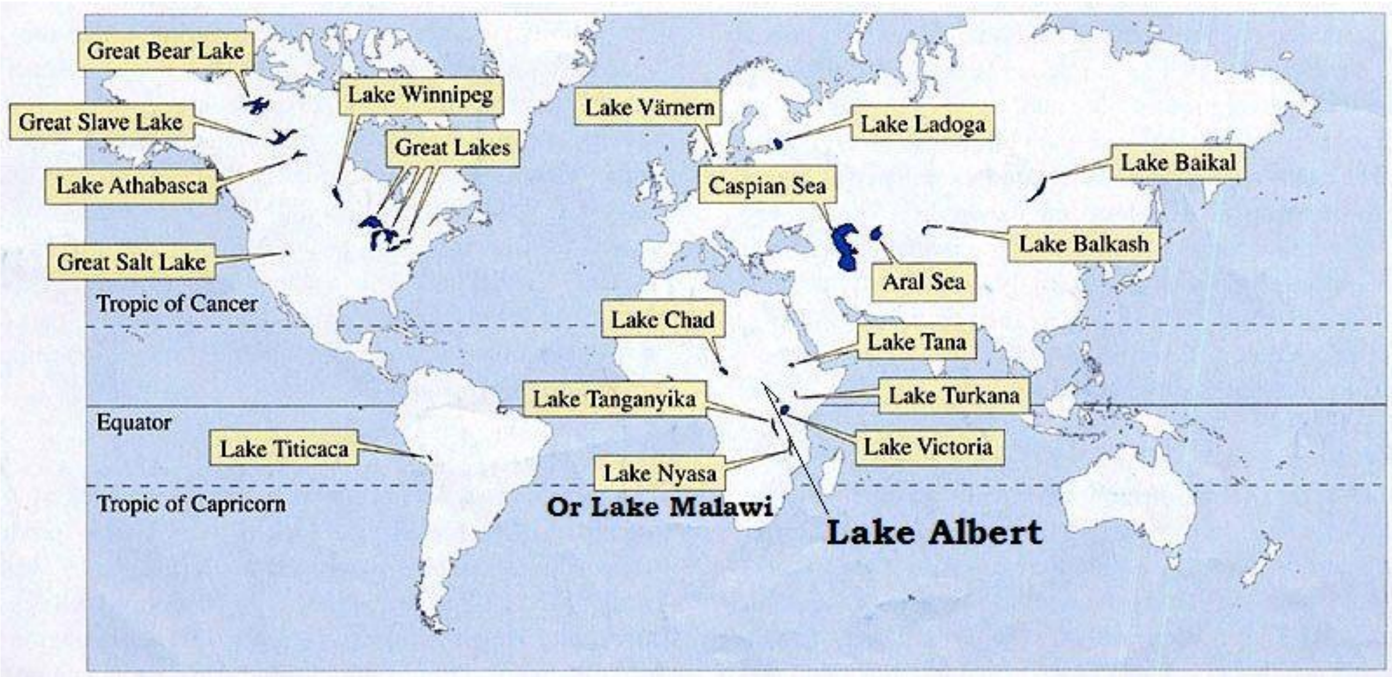
Lakes and Man

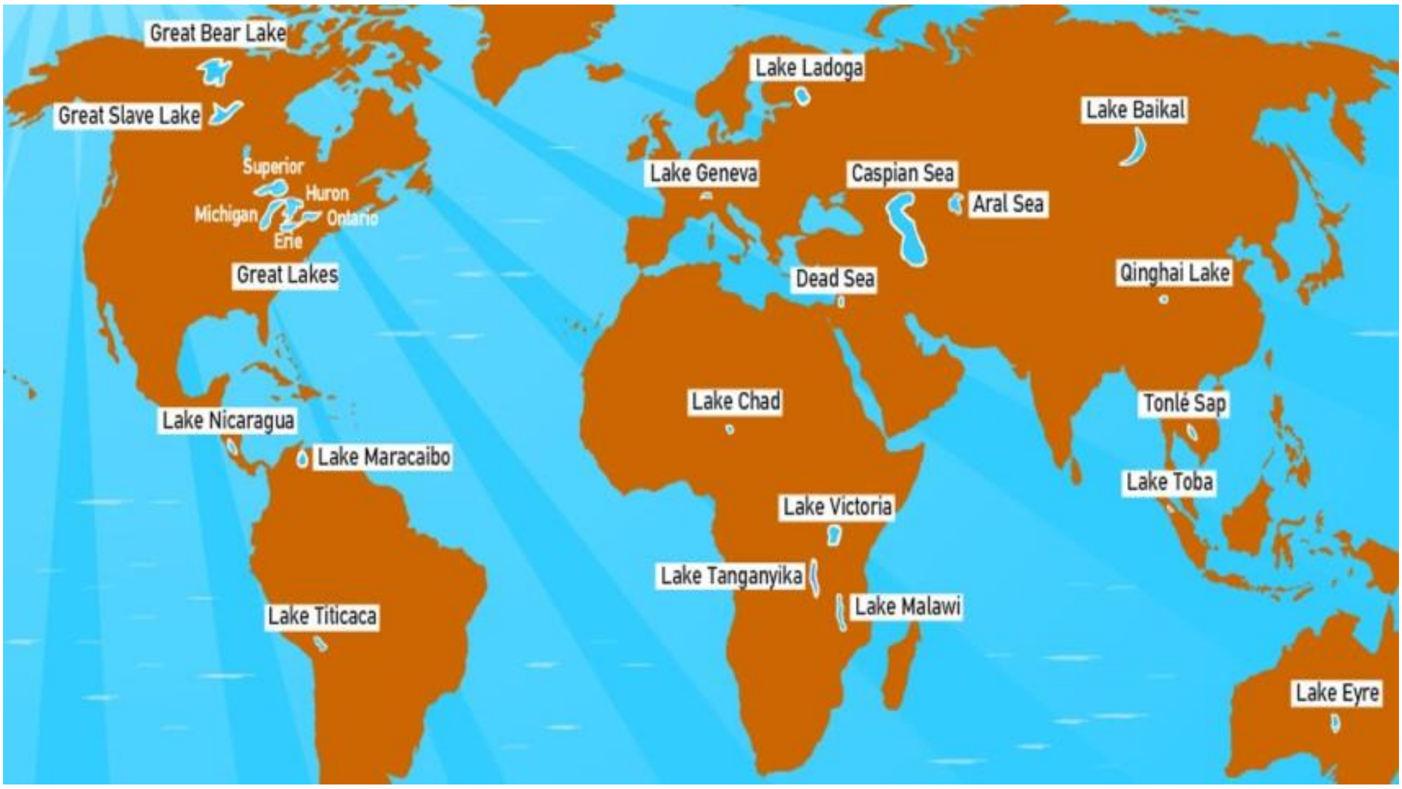
- In countries where they are found in abundance, such as Finland, Canada, U.S.A., Sweden and the East African states, lakes are used as inland waterways.

Means of communication	Large lakes like the Great Lakes of North America provide a cheap and convenient form of transport for heavy and bulky goods such as coal, iron, machinery, grains and timber. The Great Lakes-St. Lawrence waterways penetrate more than 1,700 miles into the interior. They are thus used as the chief arteries of commerce.
Economic and industrial development	The Great Lakes-St. Lawrence waterways were responsible for the development of the interior wheat farms and lakeside industries.
Water storage	Example: Kolleru lake in Andhra Pradesh.
Hydro-electric power generation	Artificial lakes like Hirakud.
Agricultural purposes	Many dams are built across artificial lakes. Bhakra Nangal Dam. Its reservoir, known as the "Gobind Sagar Lake" and Hirakud Dam (Madhya Pradesh) on the Mahanadi in India.
Regulating river flows	Hoover Dam on the River Colorado and the Bhakra and Nangal Dams on the Sutlej in India. The Hirakud dam was originally conceived as a flood control measure. But the project is criticized for doing more damage than good.
Source of food	Many large lakes have important supplies of protein food in the form of freshwater fish. Sturgeon is commercially caught in the Caspian Sea, salmon and sea trout in the Great Lakes
Source of minerals	Salt lakes provide valuable rock salts. In the Dead Sea, the highly saline water is being evaporated and produces common salt. Borax is mined in the salt lakes of the Mojave Desert.
Tourist attraction and health resorts	Lake Chilka, Leh, Dead Sea etc..

No lake is permanent over geologic time	Lakes are only temporary features of the earth's crust; they will eventually be eliminated by the double process of draining and silting up. The process of lake elimination may not be completed within our span of life, it takes place relatively quickly in terms of geological time.

Important Lakes on Earth





FACT CORNER

Note 1: Black Sea is not a lake since Bosporus and Dardanelles Straits connect it to the Mediterranean Sea. Many big rivers fall into the Black Sea, making the salinity of its surface water half that of the ocean: 17‰.

Note 2: Caspian Sea and Dead Sea are lakes. The surface and shores of the Dead Sea are 423 metres below sea level, making it Earth's lowest elevation on land.

Note 3: While writing facts about lakes, people ignore Caspian Sea because for them it is too big to be considered a lake. But it is still a lake.

Note 4: Just like everybody else, even I have ignored Caspian Sea while stating the below facts.

Lake Baikal – Deepest Lake

- Located in Siberia, Russia.
- The deepest lake in the world [1,637 metres deep]
- It is the world's largest lake by volume.
- It is the second longest.

Lake Tanganyika – Longest Lake

- The longest lake in the world. [660 kilometres long]
- It is also the second largest by volume.
- It is the second deepest lake in the world, after lake Baikal.

World's Highest and Lowest Lakes

- The world's highest lake, if size is not a criterion, may be the crater lake of Ojos del Salado, at 6,390 metres. It is in Andes.
- The highest large lake in the world is the Pumoyong Tso (Pumuoyong Tso), in the Tibet Autonomous Region of China. [5,018 metres above sea level]
- The world's highest commercially navigable lake is Lake Titicaca in Peru and Bolivia border at 3,812 m. It is also the largest lake in South America.
- The world's lowest lake is the Dead Sea, bordering Israel and Jordan at 418 metres below sea level. It is also one of the lakes with highest salt concentration.

The Largest Lakes (surface area) by Continent

- Australia – Lake Eyre (salt lake)
- Africa – Lake Victoria, also the third-largest freshwater lake on Earth. It is one of the Great Lakes of Africa.
- Antarctica – Lake Vostok (subglacial)
- Asia – Lake Baikal (if the Caspian Sea is considered a lake, it is the largest in Eurasia, but is divided between the two geographic continents)
- Europe – Lake Ladoga, followed by Lake Onega, both located in northwestern Russia.
- North America – Lake Superior.
- South America – Lake Titicaca, which is also the highest navigable body of water on Earth at 3,812 metres above sea level. The much larger Lake Maracaibo is a contiguous body of water with the sea, so it is ignored. ,

Great Lakes

- Great Lakes of North America are a series of interconnected freshwater lakes which connect to the Atlantic Ocean through the Saint Lawrence Seaway.

- Consisting of Lakes Superior, Michigan, Huron, Erie, and Ontario [in the order of west to east]. Superior, Huron, Michigan, Erie, and Ontario [In the order of largest to smallest].
- Lake Superior is the largest continental lake in the world by area, and Lake Michigan is the largest lake that is entirely within one country.

Shipping

- The Great Lakes are today used as a major water transport corridor for bulk goods.
- The Great Lakes Waterway connects all the lakes; the smaller Saint Lawrence Seaway connects the lakes to the Atlantic oceans.

Dead Sea

- Also called the Salt Sea.
- Lake bordering Jordan to the east, and Palestine and Israel to the west.
- It Earth's lowest elevation on land.

Aral Sea

- It was a lake lying between Kazakhstan in the north and Uzbekistan, in the south.
- Aral Sea has been steadily shrinking since the 1960s after the rivers that fed it were diverted by Soviet irrigation projects.

The Aral Sea in 1989 (left) and 2008 (right)

African Great Lakes

- Series of lakes constituting the part of the Rift Valley lakes in and around the East African Rift.
- They include Lake Victoria, the second largest fresh water lake in the world, and Lake Tanganyika, the world's second largest in volume as well as the second deepest.

Largest Lakes by Surface Area

[Caspian Sea Excluded in all facts]

1. Lake Superior – North America
2. Lake Victoria – Africa
3. Lake Huron – North America
4. Lake Michigan – North America

Largest Lakes by Volume

1. Baikal – Asia
2. Tanganyika – Africa
3. Superior – North America

Deepest Lakes in the World

1. Lake Baikal – Asia
2. Lake Tanganyika

PLATEAU

- A plateau is a flat-topped table land.
- Plateaus occur in every continent and take up a third of the Earths land.
- They are one of the four major landforms, along with mountains, plains, and hills.
- Plateaus, like mountains may be young or old. The Deccan plateau in India is one of the oldest plateaus.
- Valleys form when river water cuts through the plateau. The Columbia Plateau, between the Cascade and Rocky mountains in the northwestern United States, is cut through by the Columbia River.
- Sometimes, a plateau is so eroded that it is broken up into smaller raised sections called Many outlier plateaus are composed of very old, dense rock formations. Iron ore and coal often are found in plateau outliers.
- Plateaus are very useful because they are rich in mineral deposits. As a result, many of the mining areas in the world are located in the plateau areas.

Plateau Formation	Tectonic plateaus are formed from processes that create mountain ranges – volcanism (Deccan Plateau), crustal shortening (thrusting of one block of crust over another, and folding occurs. Example: Tibet), and thermal expansion (Ethiopian Highlands).
Thermal expansion	Thermal expansion of the lithosphere means the replacement of cold mantle lithosphere by hot asthenosphere). Those caused by thermal expansion of the lithosphere are usually associated with hot spots. The Yellowstone Plateau in the United States, the Massif Central in France, and the Ethiopian Plateau in Africa are prominent examples. When the lithosphere underlying a broad area is heated rapidly – e.g., by an upwelling of hot material in the underlying asthenosphere – the consequent warming and thermal expansion of the uppermost mantle causes an uplift of the overlying surface. The high plateaus of East Africa and Ethiopia were formed this way.
Hotspot Volcanism – Hawaiian and Reunion Crustal shortening	The great heights of some plateaus, such as the Plateau of Tibet is due to crustal shortening. Crustal shortening, which thickens the crust as described above, has created high mountains along what are now the margins of such plateaus. Plateaus that were formed by crustal shortening and internal drainage lie within major mountain belts and generally in arid climates. They can be found in North Africa,

	Turkey, Iran, and Tibet, where the African, Arabian, and Indian continental masses have collided with the Eurasian continent.
Volcanic Flood Basalts – Traps	Volcanism Types – Exhalative, Effusive, Explosive, Subaqueous Volcanic Landforms – Extrusive and Intrusive Volcanism – Andesitic, Basaltic-Geyser,Hot Water Spring A third type of plateau can form where extensive lava flows (called flood basalts or traps) and volcanic ash bury preexisting terrain, as exemplified by the Columbia Plateau in the northwestern United States, Deccan Traps of peninsular India, Laurentian plateau or The Canadian Shield and the Siberian Traps of Russia. Volcanic plateaus are commonly associated with eruptions that occurred during the Cenozoic or Mesozoic. Eruptions on the scale needed to produce volcanic plateaus are rare, and none seems to have taken place in recent time. The volcanism involved in such situations is commonly associated with hot spots. The lavas and ash are generally carried long distances from their sources, so that the topography is not dominated by volcanoes or volcanic centers. The thickness of the volcanic rock can be tens to even hundreds of metres, and the top surface of flood basalts is typically very flat but often with sharply incised canyons and valleys.

Others

- Some plateaus, like the Colorado Plateau, the Ordos Plateau in northern China, or the East African Highlands, do not seem to be related to hot spots or to vigorous upwelling in the asthenosphere but appear to be underlain by unusually hot material. The reason for localized heating beneath such areas is poorly understood, and thus an explanation for the distribution of plateaus of that type is not known.
- There are some plateaus whose origin is not known. Those of the Iberian Peninsula and north-central Mexico exhibit a topography that is largely high and relatively flat.

Plateau Types

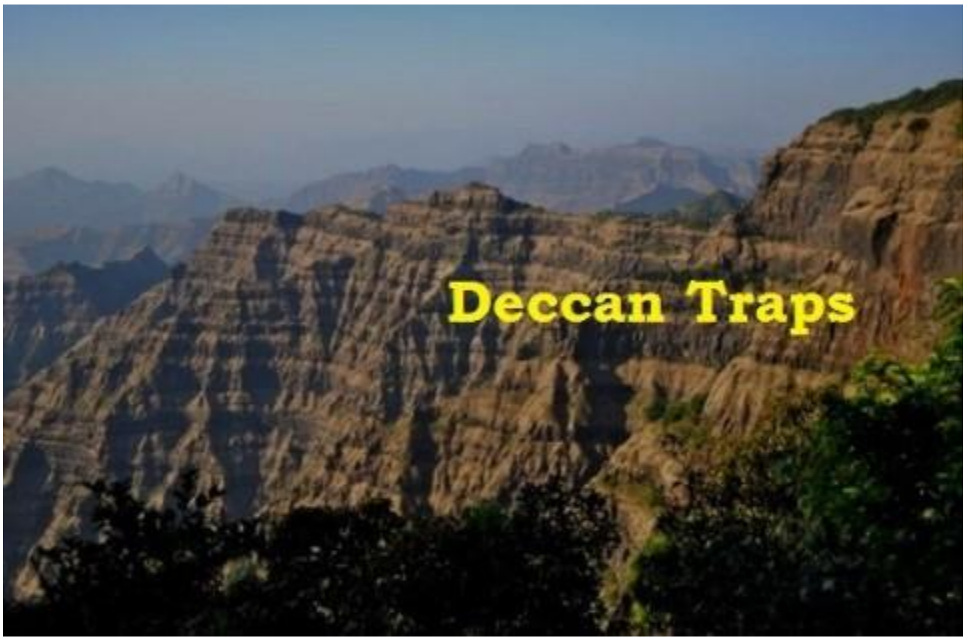
- There are two kinds of plateaus: dissected plateaus and volcanic plateaus.

Dissected plateau

- A dissected plateau forms as a result of upward movement in the Earth's crust.
- The uplift is caused by the slow collision of tectonic plates. The Colorado Plateau, in the western United States, Tibetan plateau etc. are examples.

Volcanic plateau

- A volcanic plateau is formed by numerous small volcanic eruptions that slowly build up over time, forming a plateau from the resulting lava flows.
- The Columbia Plateau in the northwestern United States of America and Deccan Traps are two such plateaus.



Others

- Intermontane plateaus are the highest in the world, bordered by mountains. The Tibetan Plateau is one such plateau.
- Continental plateaus are bordered on all sides by the plains or seas, forming away from mountains.

Major plateaus of the World

Tibetan Plateau	Highest and largest plateau in the world and hence called the 'roof of the world'. Formed due to collision of the Indo-Australian and Eurasian tectonic plates. The plateau is sufficiently high enough to reverse the Hadley cell convection cycles and to drive the monsoons of India towards the south. [We will learn this in future posts] It covers most of the Autonomous Tibetan Region, Qinghai Province of Western China, and a part of Ladakh in Jammu and Kashmir. It is surrounded by mountains to the south by the Himalayan Range, to the northeast by the Kunlun Range, and to the west by the Karakoram Range.
Columbia – Snake Plateau	River Columbia and its tributary Snake meet in this plateau. It is bordered by the Cascade Range and Rocky Mountains and divided by the Columbia River. This plateau has been formed as the result of volcanic eruptions with a consequent coating of basalt lava (Flood Basalt Plateau).
Colorado Plateau	It is lying to western part of U.S.A. It is the largest plateau in America. It is divided by the Colorado River and the Grand Canyon. This plateau is an example of intermontane plateau. Mesas and buttes are found here at many places [Arid Landforms]. The plateau is known for the groundwater which is under positive pressure and causes the emergence of springs called Artesian wells.
Deccan Plateau	Deccan Plateau is a large plateau which forms most of the southern part of India. It is bordered by two mountain ranges, the Western Ghats and the Eastern Ghats. The plateau includes the Deccan Traps which is the largest volcanic feature on Earth. Made of multiple basalt layers or lava flows, the Deccan Traps covers 500,000 square kilometers in area. The Deccan Traps are known for containing some unique fossils. The Deccan is rich in minerals. Primary mineral ores found in this region are mica and iron ore in the Chotanagpur region, and diamonds, gold and other metals in the Golconda region
Kimberley Plateau	Lies in the northern part of Australia. This plateau is made of volcanic eruption. Many minerals like iron, gold, lead, zinc, silver and diamond are found here. Diamond is also found here.
Katanga Plateau	It is lying in Congo. It is famous for copper production. Other minerals like Cobalt, Uranium, Zinc, Silver, Gold and Tin are also mined here.
Mascarene Plateau	Plateaus also form in the ocean, such as the Mascarene Plateau in the Indian Ocean. It extends between the Seychelles and Mauritius Islands.
Laurentian Plateau	Lying in the eastern part of Canada, it is a part of Canadian Shield. Fine quality of iron-ore is found here.

Mexican Plateau	It is called as 'Mineral Store'. Different types of metallic minerals like silver, copper etc. are obtained from here. World's biggest silver mine Chihuahua is situated in the plateau.
Patagonian Plateau	It is a Piedmont plateau (Arid Landforms) lying in southern part of Argentina. It is a rain shadow desert plateau. It is an important region for sheep rearing.
Altiplano Plateau or Bolivian Plateau	It is an intermontane plateau which is located between two ranges of Andes Mountain. It is a major area of Tin reserves
Massif Central	This plateau lies in the central France. It is famous for Grapes cultivation.
Anatolian Plateau	Also known as Asia Minor, most of Turkey lies on this plateau. It is an intermontane plateau lying between Pontiac and Taurus Mountain ranges. Tigris – Euphrates Rivers flow through this plateau. Precious wool producing Angora goats are found here.

Others

- Spanish Plateau or Iberian Plateau: It is situated in the middle of Spain. It is a lava plateau. It is rich in minerals like Iron.
- Loess Plateau: It is in China. The soil here is made of fine particles brought by the wind. This fine loamy soil is extremely productive. Crops grown in this soil along the Yellow River give great yields.

Arid Landforms – Erosional, Depositional – Wind, Water Eroded

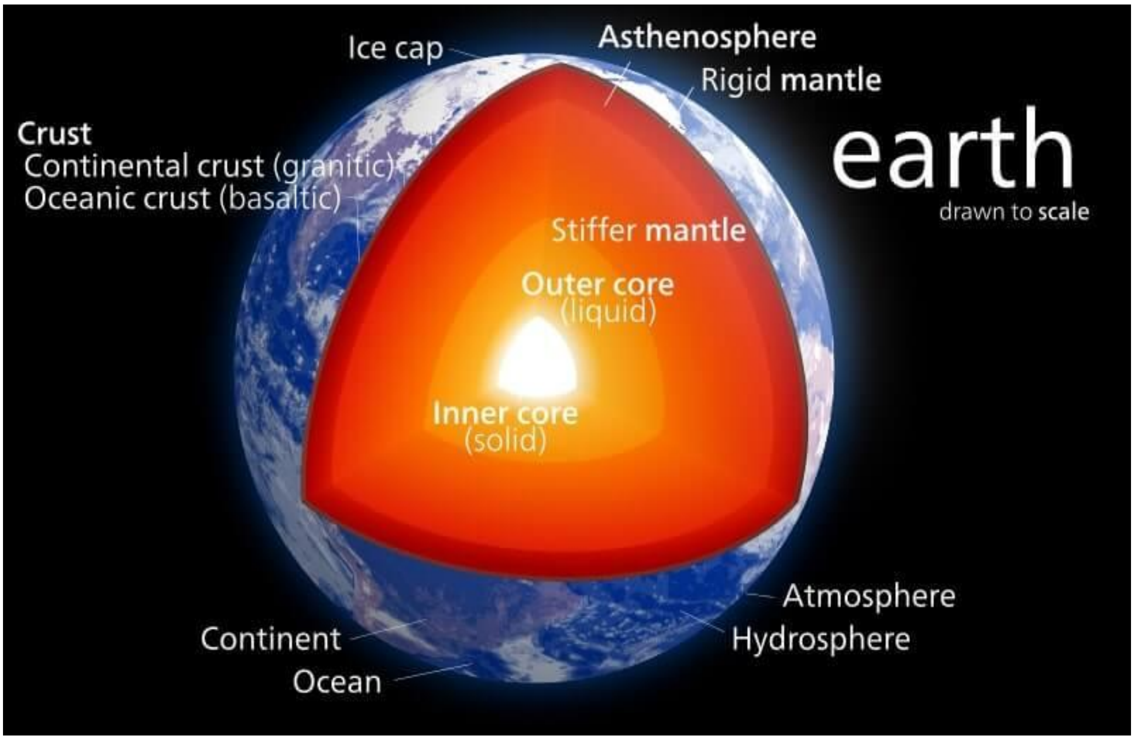
- Potwar Plateau: It is situated in northern plateau (Punjab) region of Pakistan. Its average 'Salt Range' is located to the south-west of the plateau.
- Bavarian Plateau: Southern part of Germany.
- Ahaggar Plateau: A small plateau located in Algeria, Sahara.

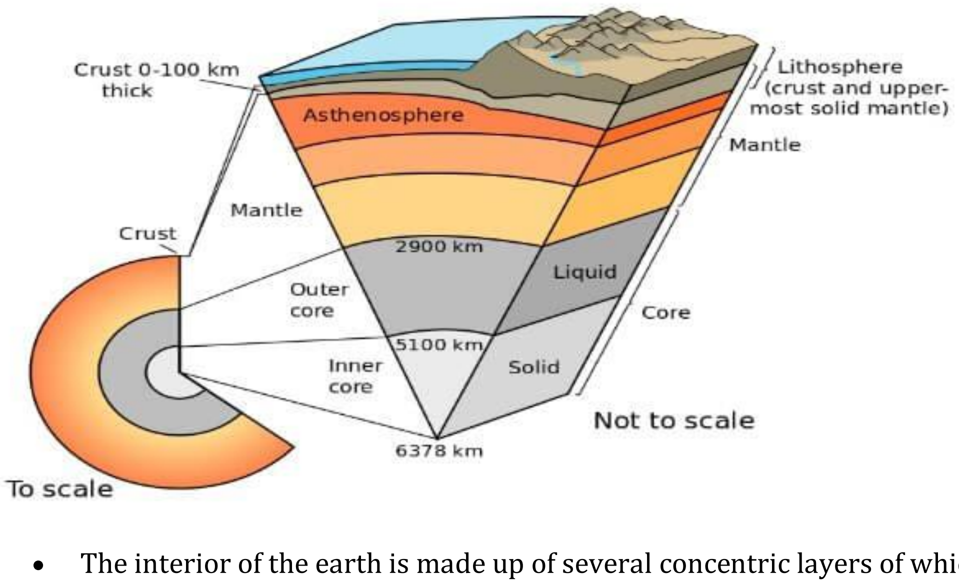
IMPORTANCE OF UNDERSTANDING THE INTERIOR OF THE EARTH

Understanding the structure of the earth's interior (crust mantle, core) and various forces (heat, seismic waves) emanating from it is essential to understand

- the evolution of the earth's surface, its current shape and its future.
- the geophysical phenomenon like volcanism, earthquakes, etc.
- earth's magnetic field
- the internal structure of various solar system objects
- the evolution and present composition of the atmosphere
- for mineral exploration

Earth's Layers (The internal structure of the Earth)





- The interior of the earth is made up of several concentric layers of which the crust, the mantle, the outer core and the inner core are significant because of their unique physical and chemical properties.

- The crust is a silicate solid, the mantle is a viscous molten rock, the outer core is a viscous liquid, and the inner core is a dense solid.
- Mechanically, the earth's layers can be divided into **lithosphere, asthenosphere, mesospheric mantle** (part of the Earth's mantle below the lithosphere and the asthenosphere), **outer core**, and **inner core**.
- Chemically, Earth can be divided into the **crust, upper mantle, lower mantle, outer core, and inner core**.

THE CRUST

- The crust is the outermost layer of the earth making up **0.5-1.0 per cent of the earth's volume** and **less than 1 per cent of Earth's mass**.
- Density increases with depth, and the average density is about **2.7 g/cm³** (average density of the earth is 5.51 g/cm³).
- The thickness of the crust varies in the range of range of **5-30 km in case of the oceanic crust** and as **50-70 km in case of the continental crust**.
- The continental crust can be thicker than 70 km in the areas of major mountain systems. It is as much as 70-100 km thick in the Himalayan region.
- The temperature of the crust increases with depth, reaching values typically in the range from about 200 °C to 400 °C at the boundary with the underlying mantle.
- The temperature increases by as much as 30 °C for every kilometre in the upper part of the crust.
- The outer covering of the crust is of **sedimentary material** and below that lie crystalline, igneous and metamorphic rocks which are acidic in nature.
- The lower layer of the crust consists of basaltic and ultra-basic rocks.
- The continents are composed of lighter silicates — **silica + aluminium** (also called **sial**) while the oceans have the heavier silicates — **silica + magnesium** (also called **sima**) [Suess,1831–1914 — this classification is now obsolete (out of date)].
- The continental crust is composed of lighter (**felsic**) **sodium potassium aluminium silicate** rocks, like **granite**.
- The oceanic crust, on the other hand, is composed of dense (**mafic**) **iron magnesium silicate** igneous rocks, like **basalt**.

In geology, felsic refers to igneous rocks that are relatively rich in elements that form feldspar and quartz.

It is contrasted with mafic rocks, which are relatively richer in magnesium and iron.

Felsic refers to rocks which are enriched in the lighter elements such as silicon, oxygen, aluminium, sodium, and potassium.

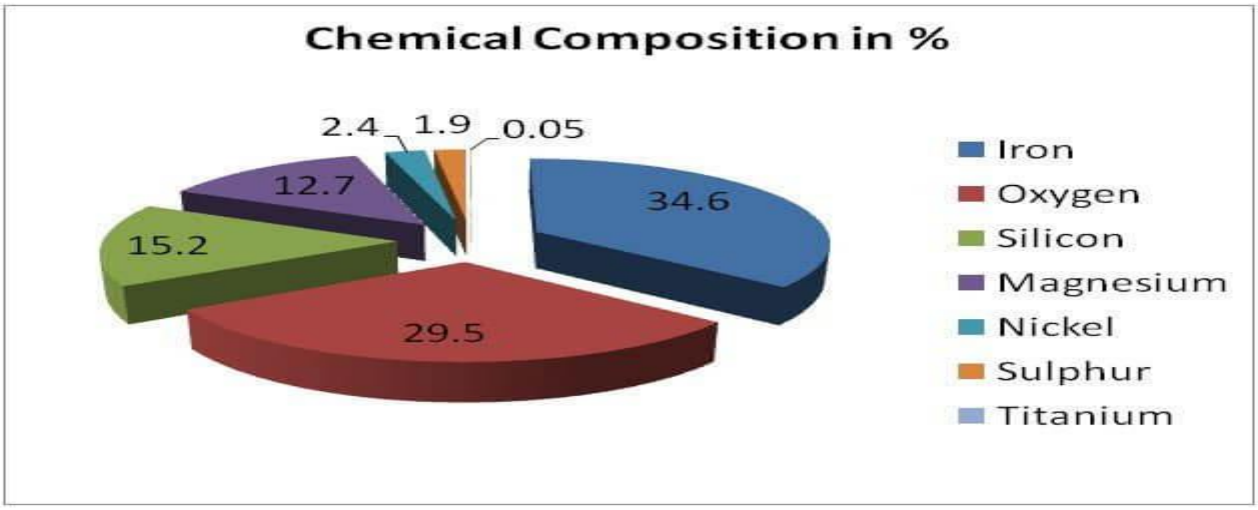
Most Abundant Elements of the Earth's Crust

	Element	Approximate % by weight
1	Oxygen (O)	46.6
2	Silicon (Si)	27.7

3	**Aluminium (Al)**	**8.1**
4	**Iron (Fe)**	**5.0**
5	**Calcium (Ca)**	**3.6**
6	Sodium (Na)	2.8
7	Potassium (K)	2.6
8	Magnesium (Mg)	1.5

OS CIA

Most Abundant Elements of the Earth



Most Abundant Elements of the Earth's Crust ==> **OS CIA**

Most Abundant Elements of the Earth ==> **iOS**

THE MOHOROVICIC (MOHO) DISCONTINUITY	Mohorovicic (Moho) discontinuity forms the boundary between the **crust** and the **asthenosphere** (upper reaches of the mantle) where there is a discontinuity in the seismic velocity. It occurs at an average depth of about 8 kilometres beneath the ocean basins and 30 kilometres beneath continental surfaces. The cause of the Moho is thought to be a change in rock composition from rocks containing **feldspar** (above) to rocks that contain no feldspars (below).
LITHOSPHERE	The lithosphere is the rigid outer part of the earth with thickness varying between 10-200 km.

	It is includes the **crust and the upper part of the mantle**. The lithosphere is broken into **tectonic plates (lithospheric plates),** and the movement of these tectonic plates cause large-scale changes in the earth's geological structure (folding, faulting). The source of heat that drives plate tectonics is the **primordial heat** left over from the planet's formation as well as the **radioactive decay of uranium, thorium, and potassium in Earth's crust and mantle**.
THE MANTLE	It forms about **83 per cent of the earth's volume and holds 67% of the earth's mass**. It extends from Moho's discontinuity to a depth of 2,900 km. The density of the upper mantle varies between **2.9 g/cm^3 and 3.3 g/cm^3**. The lower mantle extends beyond the **asthenosphere**. It is in a solid state. The density ranges from **3.3 g/cm^3** to **5.7 g/cm^3** in the lower mantle. The mantle is composed of **silicate rocks that are rich in iron and magnesium** relative to the overlying crust. Regarding its constituent elements, the mantle is made up of **45% oxygen, 21% silicon,** and **23% magnesium (OSM)**. In the mantle, temperatures range from approximately 200 °C at the upper boundary with the crust to approximately 4,000 °C at the core-mantle boundary. Because of the temperature difference, there is a **convective material circulation** in the mantle (although solid, the high temperatures within the mantle cause the silicate material to be sufficiently ductile). Convection of the mantle is expressed at the surface through the motions of tectonic plates. High-pressure conditions ought to inhibit seismicity in the mantle. However, in subduction zones, earthquakes are observed down to 670 km (420 mi).
ASTHENOSPHERE	The upper portion of the mantle is called as asthenosphere (astheno means weak). It lies **just below the lithosphere** extending up to **80-200 km**. It is **highly viscous, mechanically weak and ductile** and its density is higher than that of the crust. These properties of the asthenosphere **aid in plate tectonic movement and isostatic adjustments** (the elevated part at one part of the crust area is counterbalanced by a depressed part at another). It is the **main source of magma** that finds its way to the surface during volcanic eruptions.
THE OUTER CORE	The outer core, surrounding the inner core, lies between 2900 km and 5100 km below the earth's surface. The outer core is composed of **iron mixed with nickel** (**nife**) and trace amounts of lighter elements. The outer core is **not under enough pressure to be solid**, so it is liquid even though it has a composition similar to the inner core. The density of the outer core ranges from **9.9 g/cm^3** to **12.2 g/cm^3**. The temperature of the outer core ranges from 4400 °C in the outer regions to 6000 °C near the inner core. Dynamo theory suggests that **convection in the outer core, combined with the Coriolis effect**, gives rise to **Earth's magnetic field**.

THE INNER CORE	The inner core extends from the centre of the earth to 5100 km below the earth's surface. The inner core is generally believed to be composed primarily of **iron (80%) and some nickel** (**nife**). Since this layer can transmit shear waves (transverse seismic waves), it is solid. (When P-waves strike the outer core – inner core boundary, they give rise to S-waves) Earth's inner **core rotates slightly faster** relative to the rotation of the surface. The solid inner core is too hot to hold a permanent magnetic field. The density of the inner core ranges from **12.6 g/cm^3** to **13 g/cm^3**. The core (inner core and the outer core) accounts for just about **16 per cent of the earth's volume but 33% of earth's mass**. Scientists have determined the temperature near the Earth's centre to be 6000° C, 1000° C hotter than previously thought. At 6000°C, this iron core is as hot as the Sun's surface, but the **crushing pressure caused by gravity prevents it from becoming liquid**.
SEISMIC DISCONTINUITIES	Seismic discontinuities are the regions in the earth where seismic waves behave a lot different compared to the surrounding regions due to a marked change in physical or chemical properties.

Remember: when ambient pressure increases the melting point of solid increases, and vice versa. One exception is Ice. In the case of ice increase in ambient pressure will lower its melting point.

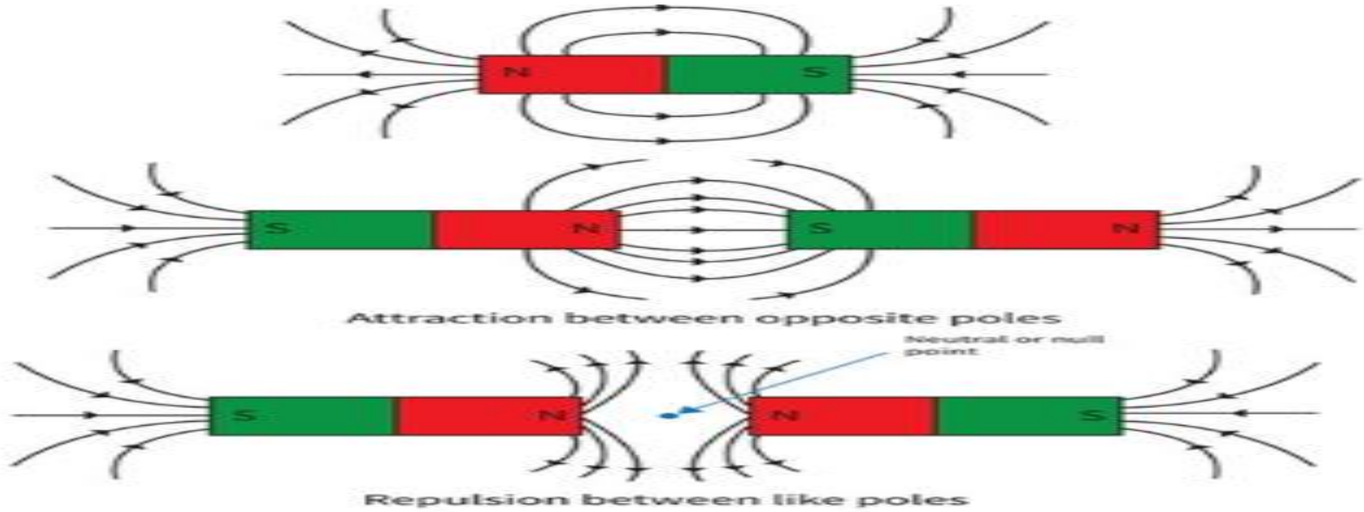
- **Mohorovicic Discontinuity (Moho): separates the crust from the mantle.**
- **Asthenosphere: highly viscous, mechanically weak and ductile part of mantle.**
- **Gutenberg Discontinuity: lies between the mantle and the outer core.**

MAGNETIC FIELD

- A 'field' is a region in which a body experiences a force owing to the presence of other bodies. Earth's Magnetic Field is one such field.
- Gravitational fields determine how bodies with mass are attracted to each other.
- In electric fields, objects that have an electric charge are attracted or repelled from each other.
- Magnetic fields determine how electric currents that contain **moving electric charges** exert a force on other electric currents.

Dynamo theory: Generation of Earth's Magnetic Field and Sustaining it

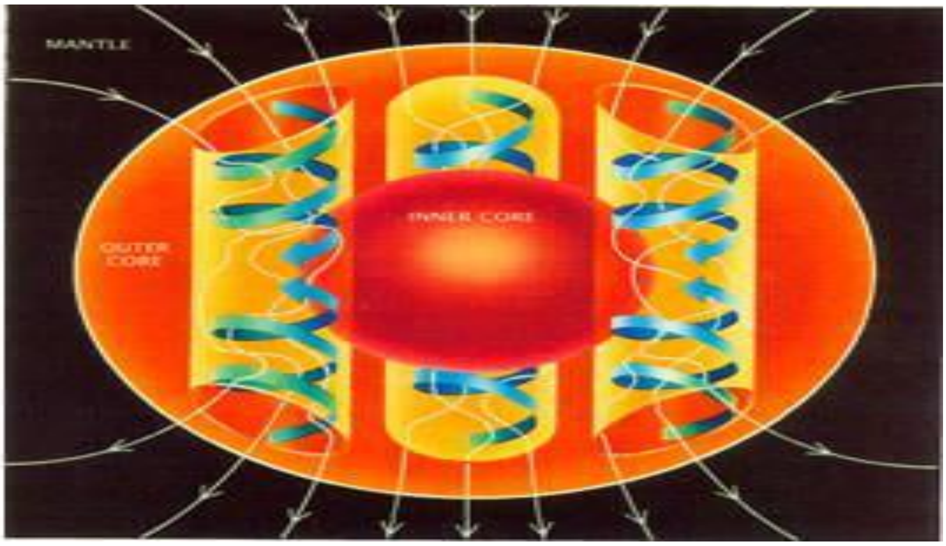
- **Dynamo theory** proposes a mechanism by which a celestial body such as Earth or a star generates a magnetic field and sustains it over astronomical time scales (millions of years).
- Dynamo theory suggests that **convection in the outer core, combined with the Coriolis effect** (caused due to the rotation of the earth), gives rise to **self-sustaining (geodynamo)** Earth's magnetic field.



MECHANISM

- Earth's magnetic field is generated in the **earth's outer core**.
- Lower pressure than the inner core means the metal in the outer core is **fluid**.
- The temperature of the outer core ranges from 4400 °C in the outer regions to 6000 °C near the inner core.
- Heat sources include energy released by the compression of the core, energy released at the inner core boundary as it grows (latent heat of crystallisation), and radioactivity of potassium, uranium and thorium.
- The differences in temperature, pressure and composition within the outer core cause **convection currents** in the molten iron of the outer core as cool, dense matter sinks while warm, less dense matter rises.
- This **flow of liquid iron** generates **electric currents**, which in turn produce **magnetic fields**.
- Charged metals passing through these fields go on to create electric currents of their own, and so the cycle continues. This **self-sustaining loop** is known as the **geodynamo**.

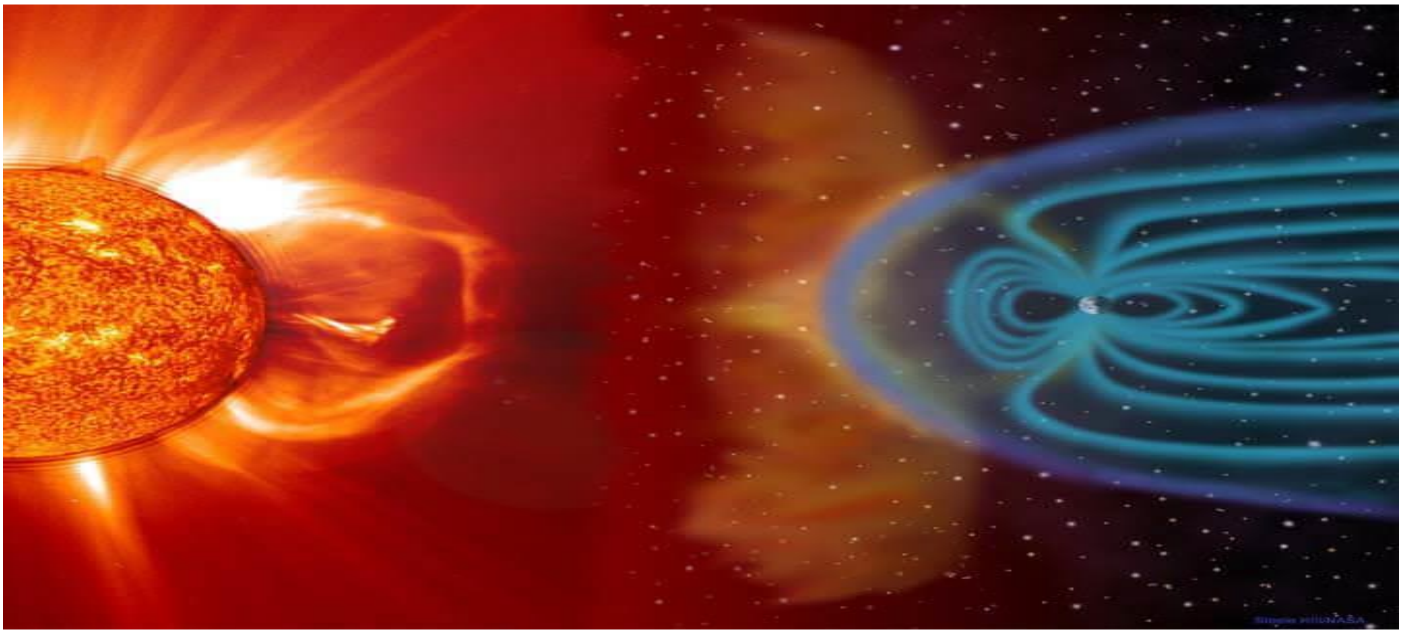
- The **spiral movement** of the charged particles caused by the **Coriolis force** means that separate magnetic fields created are roughly aligned in the same direction, their combined effect adding up to produce one vast magnetic field of the planet.



Convection currents in the outer core. Spiral motion is caused due to the Coriolis Effect

MAGNETOSPHERE

- The magnetosphere is the region above the ionosphere that is **defined by the extent of the Earth's magnetic field in space**.
- It extends several tens of thousands of kilometres into space, **protecting the Earth from the charged particles of the solar wind and cosmic rays** that would otherwise strip away the upper atmosphere, **including the ozone layer** that protects the Earth from harmful ultraviolet radiation.
- Many cosmic rays are kept out of the Solar system by the **Sun's magnetosphere called heliosphere**.



Earth's magnetosphere

MAGNETOPAUSE

- Earth's magnetic field, predominantly dipolar at its surface, is distorted further out by the **solar wind**.
- The solar wind exerts a pressure. However, it is kept away by the pressure of the Earth's magnetic field.

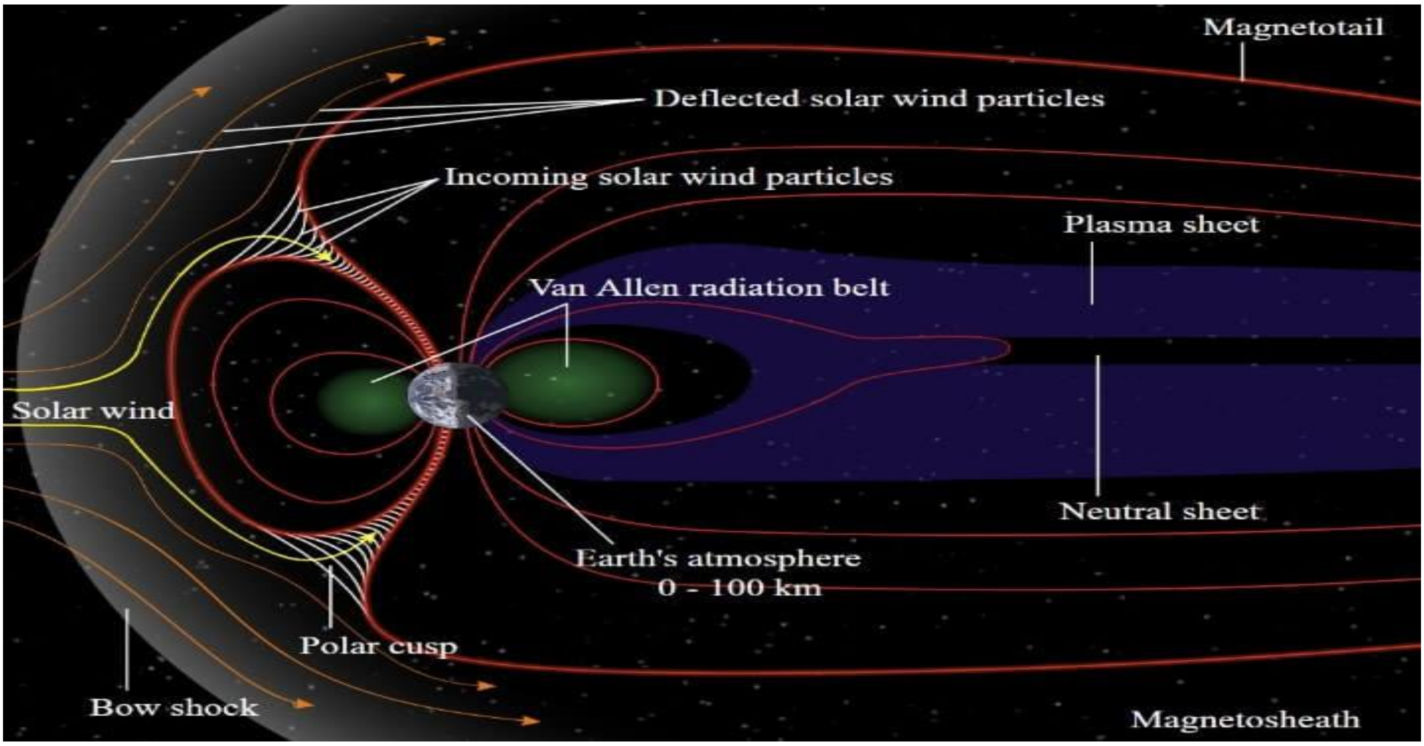
- The **magnetopause**, the **area where the pressures balance**, is the boundary of the magnetosphere.
- Despite its name, the magnetosphere is asymmetric, with the sunward side being about 10 Earth radii out but the other side stretching out in a magnetotail that extends beyond 200 Earth radii.

MAGNETOSHEAT

- The turbulent magnetic region just outside the magnetopause is known as the magnetosheath.

BOW SHOCK

- Sunward of the magnetopause is the **bow shock**, the area where the **solar wind slows abruptly**.



Earth's magnetosphere (Original bitmap from NASA. SVG rendering by Aaron Kaase,)

PLASMA SPHERE

- Inside the magnetosphere is the plasmasphere, a region containing **low-energy charged particles**.
- This region begins at the height of 60 km, extends up to 3 or 4 Earth radii, and includes the **ionosphere**.
- This region rotates with the Earth.

AURORA'S

- Aurora is the name given to the luminous glow in the upper atmosphere of the Earth which is produced by charged particles (solar wind) descending from the planet's magnetosphere.
- Positive ions slowly drift westward, and negative ions drift eastward, giving rise to a **ring current**. This current **reduces the magnetic field at the Earth's surface**.
- Some of these particles penetrate the ionosphere and collide with the atoms there.
- This results in an **excitation of the oxygen and nitrogen molecular electrons**. The molecules get back to their original state by emitting photons of light which are the aurorae.
- The charged particles follow magnetic field lines which are oriented in and out of our planet and its atmosphere near the magnetic poles. Therefore, aurorae mostly are seen to occur at **high latitudes**.

GEOMAGNETIC STROMS

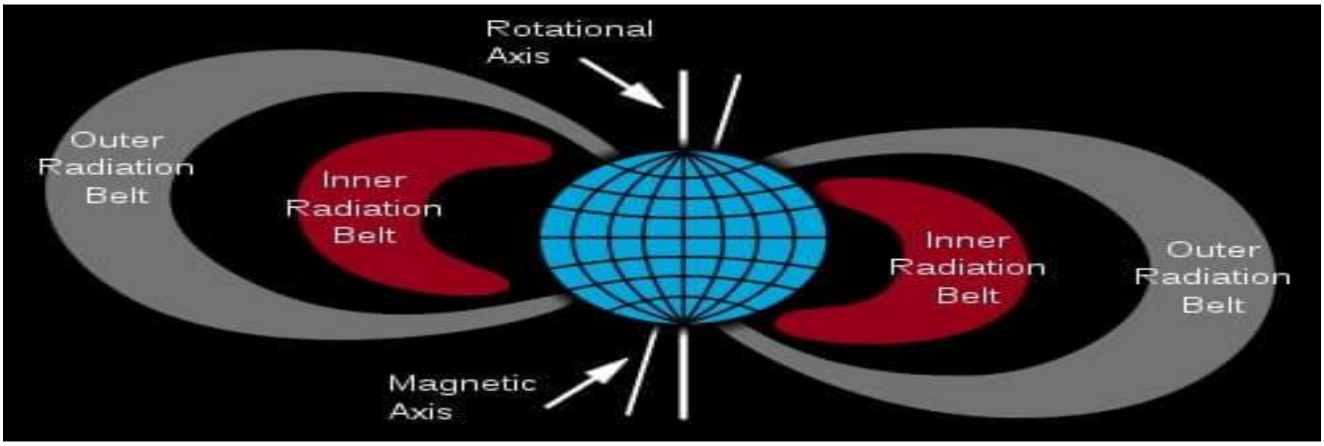
- The varying conditions in the magnetosphere, known as space weather, are largely driven by **solar activity**.
- If the solar wind is weak, the magnetosphere expands; while if it is strong, it compresses the magnetosphere and more of it gets in.
- Periods of intense activity, called geomagnetic storms, can occur when a **coronal mass ejection erupts** above the Sun and sends a shock wave through the Solar System. It takes just two days to reach the Earth.
- At the Earth's surface, a magnetic storm is seen as a **rapid drop in the Earth's magnetic field strength**.
- **Ring Current**: Ring current is the name given to the large electric current that circles the Earth above its equator during magnetic storms.

EFFECTS

- The **ionosphere gets heated and distorted**, which means that **long-range radio communication that is dependent upon sub-ionospheric reflection can be difficult**.
- Ionospheric expansion can increase **satellite drag,** and it may become difficult to control their orbits.
- Geomagnetic storms disrupt satellite communication systems like GPS.
- Astronauts and high-altitude pilots would face high radiation levels.
- Electric power grids would see a high increase in voltage that would cause blackouts.
- Geomagnetic storms disrupt satellite communication systems like GPS.

VAN ALLEN RADIATION BELT

- A Van Allen radiation belt is a **zone of energetic charged particles**, most of which originate from the solar wind, that are **captured by and held around a planet by that planet's magnetic field**.
- There are two such concentric tire-shaped regions. The inner belt is 1–2 Earth radii out while the outer belt is at 4–7 Earth radii.
- By trapping the solar wind, the belts deflect the energetic particles and **protect the atmosphere**.
- The **belts endanger satellites**, which must have their sensitive components protected with adequate shielding if they spend significant time near that zone.
- Spacecraft travelling beyond low Earth orbit enter the zone of radiation of the Van Allen belts. Beyond the belts, they face additional hazards from cosmic rays and solar particle events.



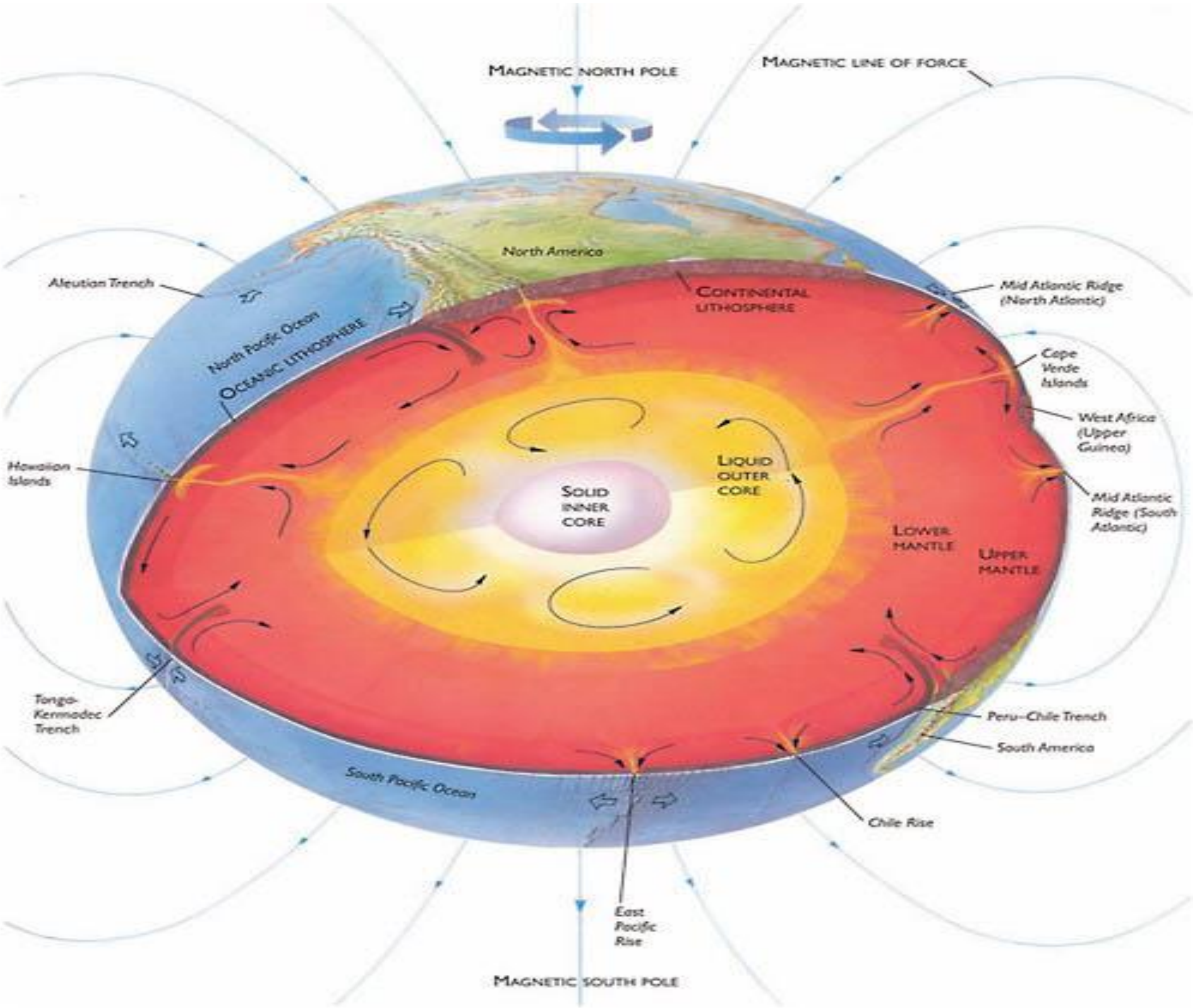
Van Allen Belts (Booyabazooka

Magnetic field of other solar system objects

MOON	The magnetic field of the Moon is very weak in comparison to that of the Earth and doesn't have a magnetic dipole. It is not strong enough to prevent atmospheric stripping by the solar wind.
MERCURY	Mercury's magnetic field is approximately a magnetic dipole (meaning the field has two poles) and is just 1.1% that of Earth's magnetic field. Its proximity to the sun makes it next to impossible to sustain an atmosphere.
MARS	Mars does not have an intrinsic global magnetic field, but the solar wind directly interacts with the atmosphere of Mars, leading to the formation of a magnetosphere. The **lack of a significant magnetosphere** is thought to be one reason for Mars's thin atmosphere
VENUS	Venus **lacks a magnetic field**. Its ionosphere separates the atmosphere from outer space and the solar wind. In spite of the absence of a magnetic field, **Venus's atmosphere is one of the densest among the terrestrial planets**.
JUPITER	Jupiter has the **largest magnetic field and a thick atmosphere**.
SATURN	Saturn's magnetosphere is the second largest of any planet in the Solar System after Jupiter. Uranus and Neptune too have a significant and similar magnetic field

Magnetic Poles

- A magnet's North pole is thought as the pole that is attracted by the Earth's North Magnetic Pole when the magnet is suspended so it can turn freely.
- Since opposite poles attract, **the North Magnetic Pole of the Earth is the south pole of its magnetic field**.



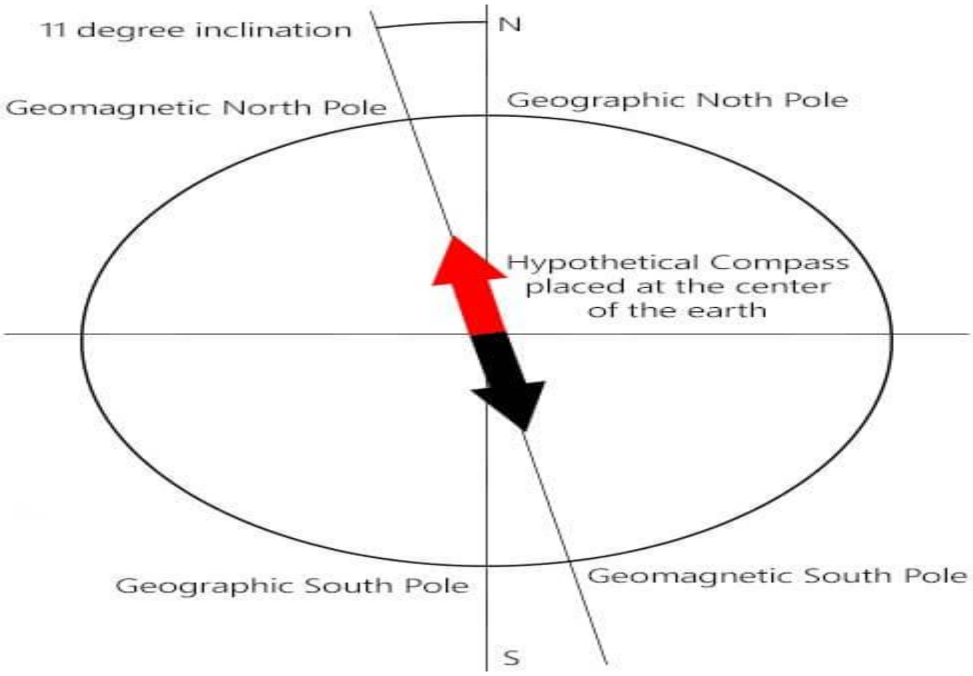
- Magnetic dipole field (simple north-south field like that of a simple bar magnet) is usually aligned fairly closely with the Earth's rotation axis; in other words, the magnetic poles are usually **fairly close to the geographic poles (earth's axis passes through these poles), which is why a compass works**.
- However, the dipole part of the field **reverses** after a few thousand years **causing the locations of the north and south magnetic poles to switch**.

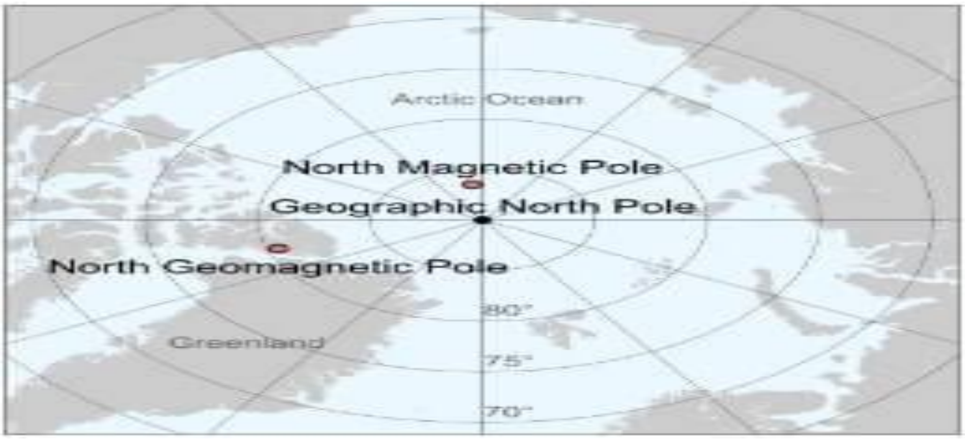
The terms magnetic north and magnetic south are not to be confused with geographic north and geographic south, and geomagnetic north and geomagnetic south.

GEOMAGNETIC POLES

- The Geomagnetic poles (dipole poles) are the **intersections of the Earth's surface and the axis of a bar magnet hypothetically placed at the centre the Earth**.
- There is such a pole in each hemisphere, and the poles are called as "the geomagnetic north pole" and "the geomagnetic south pole", respectively.
- Approximately, geomagnetic dipole is currently tilted at an angle of about **11 degrees** to Earth's rotational axis.
- On the other hand, the magnetic poles (the magnetic north pole and the magnetic south pole) are the points at which **magnetic needles become vertical**.

- The difference in the position of magnetic poles and geomagnetic poles is due to the uneven and complex distribution of the earth's magnetic field.



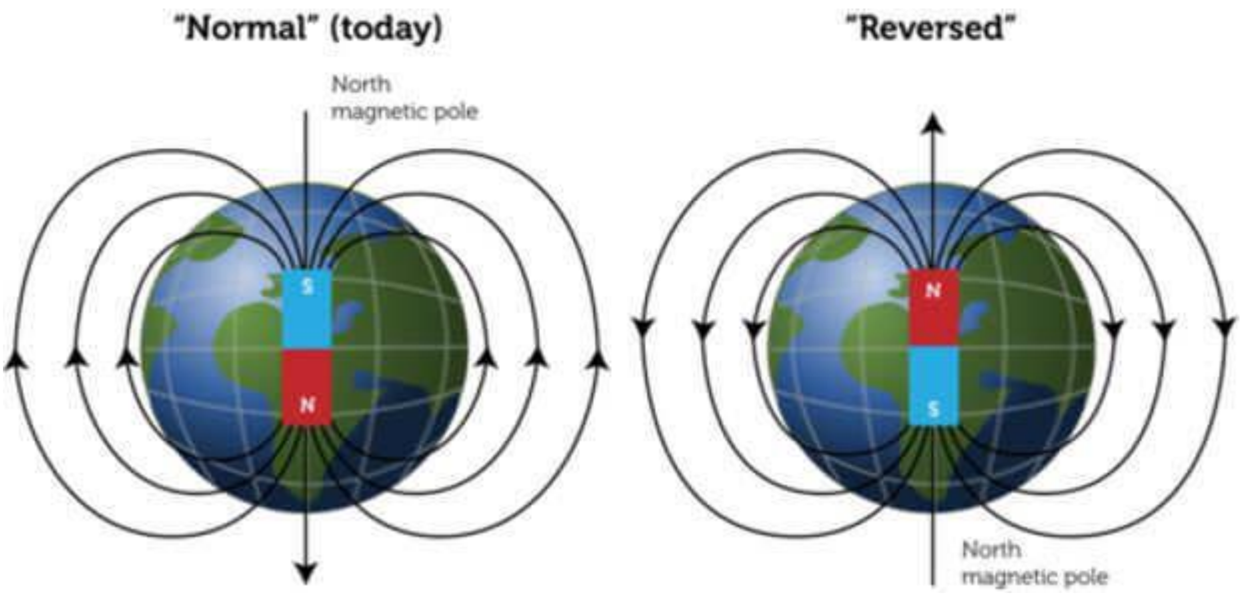


GEO MAGNETIC REVERSAL

- A geomagnetic reversal or a reversal in earth's magnetic field is a change in a planet's magnetic field such that the **positions of magnetic north and magnetic south are interchanged**.
- Based on **palaeomagnetism** (magnetism in rocks that was induced by the earth's magnetic field at the time of their formation), it is observed that over the last 20 million years, magnetic north and south have flipped roughly every 200,000 to 300,000 years.
- **The reversal is not literally 'periodic' as it is on the sun, whose magnetic field reverses every 11 years**.
- The time between magnetic reversals on the Earth is sometimes as short as 10,000 years and sometimes as long as 25 million years.
- And the time it takes to reverse could be about a few hundred or a few thousand years.
- The magnetic poles emerge at odd latitudes throughout the process of the reversal.

NORMAL & REVERSED FIELD

- The Earth's field has alternated between periods of **normal polarity, in which the predominant direction of the field was the same as the present direction**, and reverse polarity, in which it was the opposite.



Normal and Reversed field (The bar magnet at the centre represents earth's magnetic field)

In Normal Polarity, Earth's North Magnetic Pole is the South Pole of its Magnetic Field.

In Reverse Polarity, Earth's North Magnetic Pole is the North Pole of its Magnetic Field.

The current location of the Magnetic Poles

- The North and South Magnetic Poles wander (Polar Shift Theory) due to changes in Earth's magnetic field.
- The North Magnetic Pole (86° N, 172° W) lie to the north of Ellesmere Island in northern Canada and is rapidly drifting towards Siberia.
- The location of the South Magnetic Pole is currently off the coast of Antarctica and even outside the Antarctic Circle.
- Scientists suggest that the north magnetic pole migrates about 10 kilometres per year.
- Lately, the speed has accelerated to about 40 kilometres per year and could reach Siberia in a few decades.
- Since the Earth's magnetic field is not exactly symmetrical, the North and South Magnetic Poles are **not antipodal** (a straight line drawn from one to the other does not pass through the centre of the Earth).
- The Earth's North and South Magnetic Poles are also known as **Magnetic Dip Poles** because of the vertical "dip" of the magnetic field lines at those points.
- That is, if a magnetic compass needle is suspended freely at the magnetic poles then it will point **straight down** at the north magnetic pole (south pole of earth's magnetic field) and **straight up** at the south magnetic pole (north pole of earth's magnetic field).

COMPASS

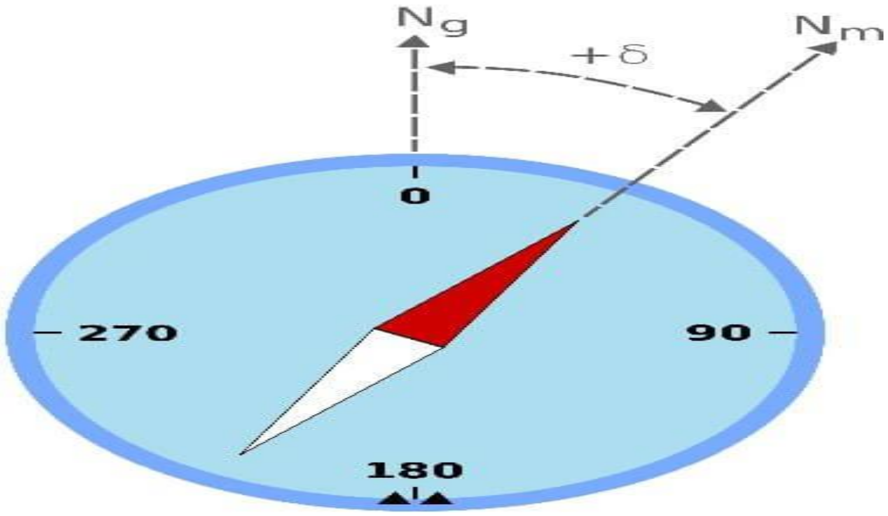
- A compass point north because all magnets have two poles, a north pole and a south pole, and the north pole of one magnet is attracted to the south pole of another magnet.
- The Earth is a magnet that can interact with other magnets in this way, so the north end of a compass magnet is drawn to align with the Earth's magnetic field.
- Because the Earth's Magnetic North Pole attracts the "north" ends of other magnets, **it is technically the "South Pole" of our planet's magnetic field**.

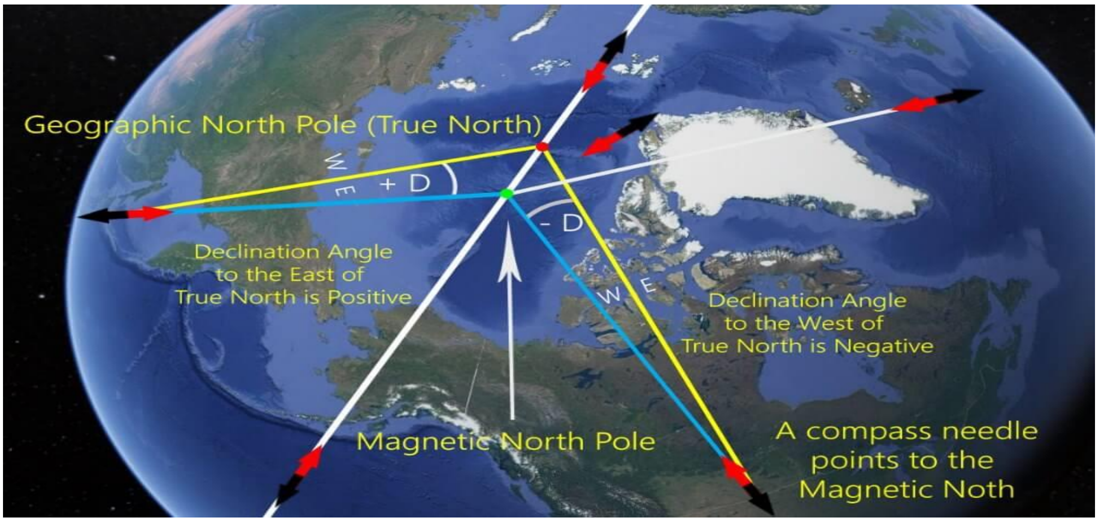
- While a compass is a great tool for navigation, it doesn't always point exactly north. This is because the Earth's magnetic North Pole is not the same as "true north (Earth's Geographic North Pole)."
- Although the **magnetic declination** (deviation from true north) does shift with time, this wandering is slow enough that a simple compass remains useful for navigation.

Using magnetoreception various organisms, ranging from some types of bacteria, sea turtles, some migratory birds, pigeons, etc. use the Earth's magnetic field for orientation and navigation.

MAGNETIC DECLINATION

- **Magnetic declination is the angle between magnetic north and true north**.
- It is positive when the angle derived is east of the true north, and it is considered negative when the angle measured is west of the true north.
- In which direction would a compass needle point if you were standing on the true North Pole?





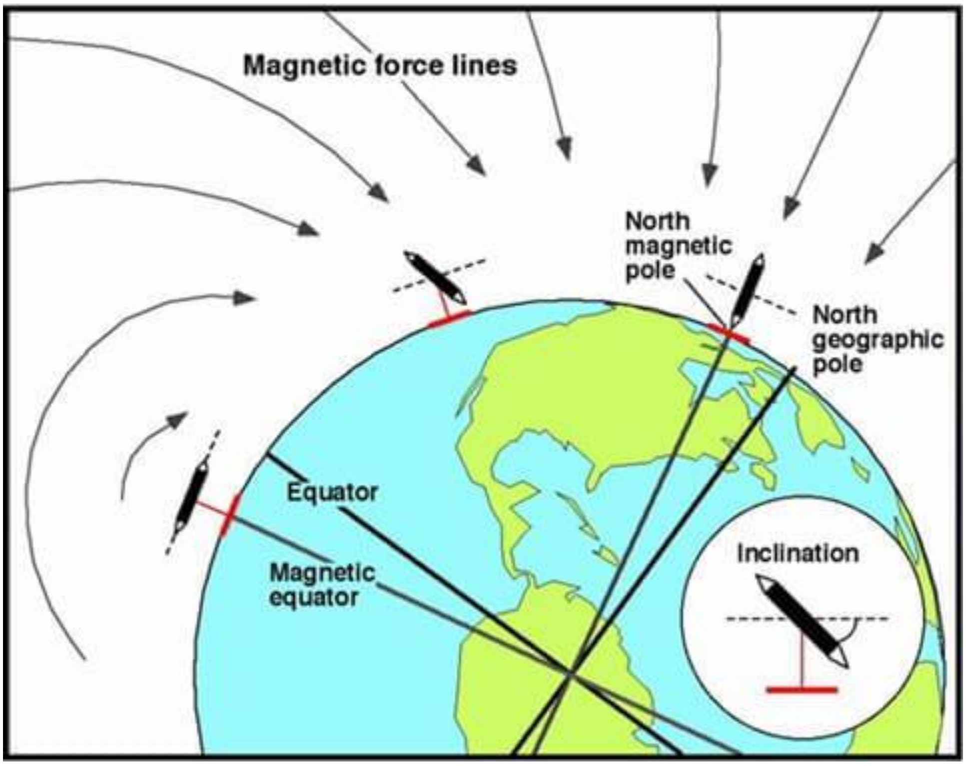
Magnetic Declination

- Importance: Ships and other long-distance means of transport that rely on the compass for navigation should do necessary corrections to account for magnetic declination at different latitudes and longitudes to stay in the right course.

Magnetic deviation is the error of a compass needle due to the influence of nearby metallic objects.

MAGNETIC INCLINATION

- Magnetic dip, dip angle, or magnetic inclination is the **angle made with the horizontal by the Earth's magnetic field lines**.
- In simple terms, magnetic inclination is the angle made by a compass needle when the compass is held in a **vertical** orientation.
- The magnetic equator is the irregular imaginary line, passing round the earth near the equator, on which a **magnetic needle has no dip** (because magnetic field lines are parallel to the horizontal at the equator).
- Again, the magnetic equator, like the magnetic field and poles, is **not fixed**.



- **Magnetic dip at the magnetic equator is 0°, and at the magnetic poles, it is 90°.**
- Importance: The phenomenon of magnetic dip is important in aviation, as it causes the aeroplane's compass to give erroneous readings during banked turns and airspeed changes. Necessary corrections need to be made to the compass reading to stay in the right course.
- Earth's crust and its surface are constantly evolving (changing) due to various forces emanating from below (**endogenic forces**) as well as above the surface of the earth (**exogenic forces**).
- These forces cause physical and chemical changes to the geomorphic structure (earth's surface).
- Some of these changes are imperceptibly slow (e.g. weathering, folding), some others are gradual (e.g. erosion) while the remaining are quite sudden (earthquakes, volcanic eruptions).
- **Geomorphic:** relating to the form of the landscape and other natural features of the earth's surface.
- **Geomorphic agents:** mobile medium (like running water, moving ice masses or glaciers, wind, waves, currents etc.) which removes, transports and deposits earth materials.
- **Geomorphic processes:** physical and chemical processes that take place on the earth's surface (folding, faulting, weathering, erosion, etc.) due to endogenic and exogenic forces.
- **Geomorphic movements:** large scale physical and chemical changes that take place on the earth's surface due to geomorphic processes.

PLATE TECTONICS

- **During WW II, it was discovered that the ocean floor had some unique relief features like ridges, trenches, seamounts, shoals etc.**
- **Ridges and trenches gave insights into natural boundaries between various lithospheric plates (tectonic plates). These important discoveries led to the field of tectonics in geology.**
- **Tectonics is the scientific study of forces (convection currents in the mantle) and processes (collisions of the lithospheric plates, folding, faulting, volcanism) that control the structure of the Earth's crust and its evolution through time.**
- **It is basically about understanding the large-scale deformation of the lithosphere (crust and upper mantle above asthenosphere) and the forces that produce such deformation.**
- **It deals with the folding and faulting associated with mountain building; the large-scale, gradual upward and downward movements of the crust (epeirogenic movements); the growth and behaviour of old cores of continents known as cratons; and sudden horizontal displacements along faults.**

Important concepts that tried to explain the tectonic processes

CONTINENTAL DRIFT THEORY (CDT)	Continental drift refers to the movement of the continents relative to each other.
POLAR WANDERING (SIMILAR TO CONTINENTAL DRIFT THEORY)	Polar wandering is the relative movement of the earth's crust and upper mantle with respect to the rotational poles of the earth
SEAFLOOR SPREADING THEORY (SFST)	Seafloor spreading describes the movement of oceanic plates relative to one another.
PLATE TECTONICS (PT)	Plate tectonics is the movement of lithospheric plates relative to each other
CONVECTION CURRENT THEORY (CCT)	Convection current theory forms the basis of SFST and PT. It explains the force behind plate movements

Continental Drift Theory (Alfred Wegener, 1922)

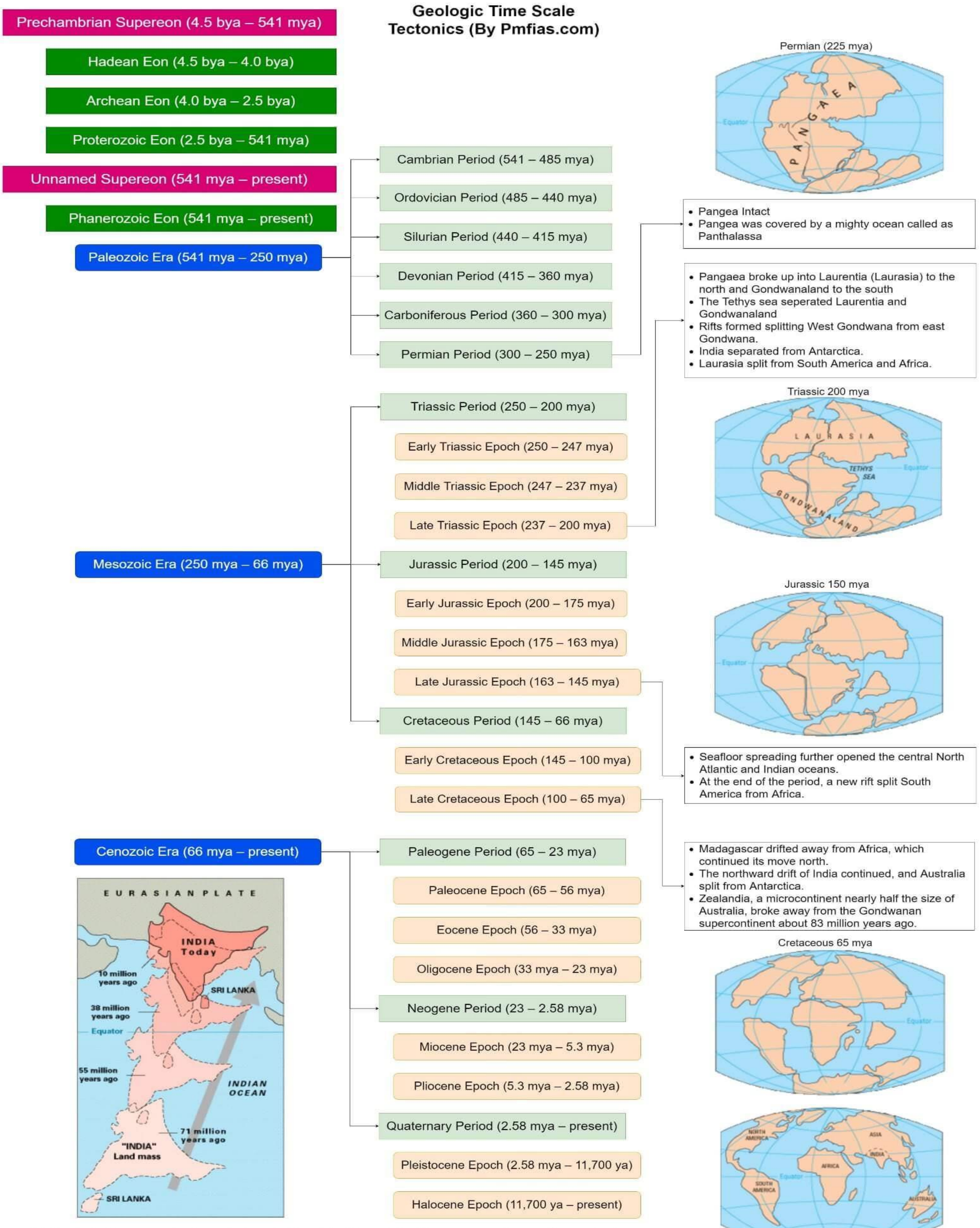
Forces behind the drifting of continents, according to Wegener

- According to Wegener, the drift was in two directions:

1. equator wards 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), and
2. westwards 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).

- Wegener suggested that tidal force (gravitational pull of the moon and to a lesser extent, the sun) also played a major role.
- The polar-fleeing force 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.

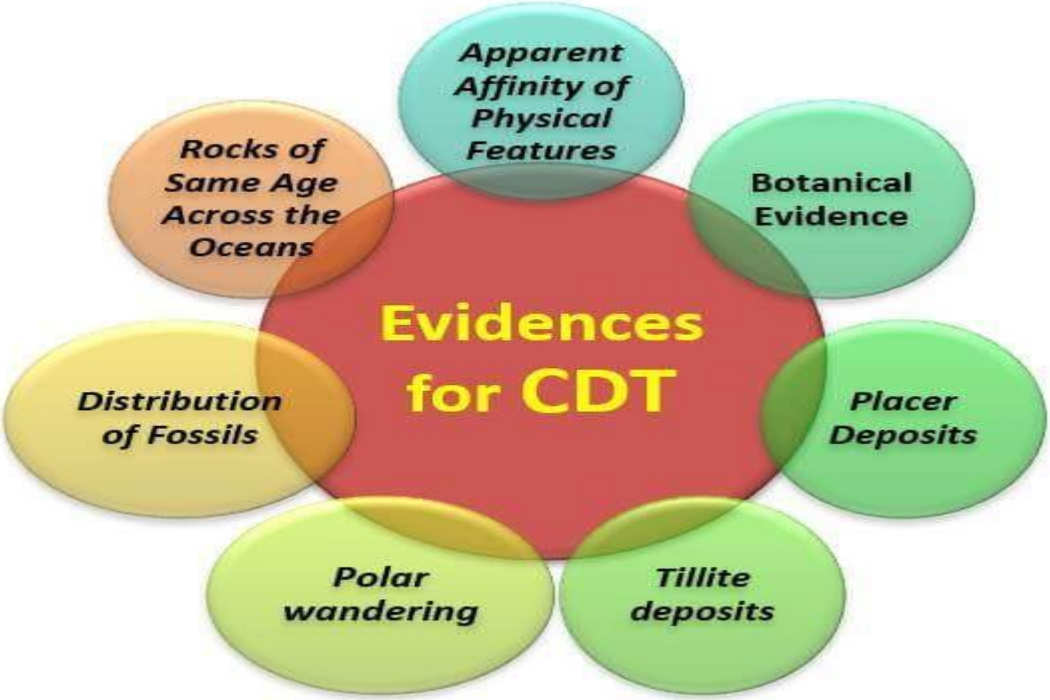


Tertiary is the former term for the geologic period from 66 million to 2.58million years ago. The term is now obsolete.

PLATE TECTONICS – BREAK UP OF PANGEA

- Alfred Wegener suggested continental Drift Theory in the 1920's.
- According to Continental Drift Theory there existed one big landmass which he called **Pangaea** which was covered by one big ocean called **Panthalassa**.
- A sea called **Tethys** divided the Pangaea into two huge landmasses: **Laurentia (Laurasia)** to the north and **Gondwanaland** to the south of Tethys.
- Drift started around 200 million years ago (Mesozoic Era, Triassic Period, Late Triassic Epoch), and the continents began to break up and drift away from one another.

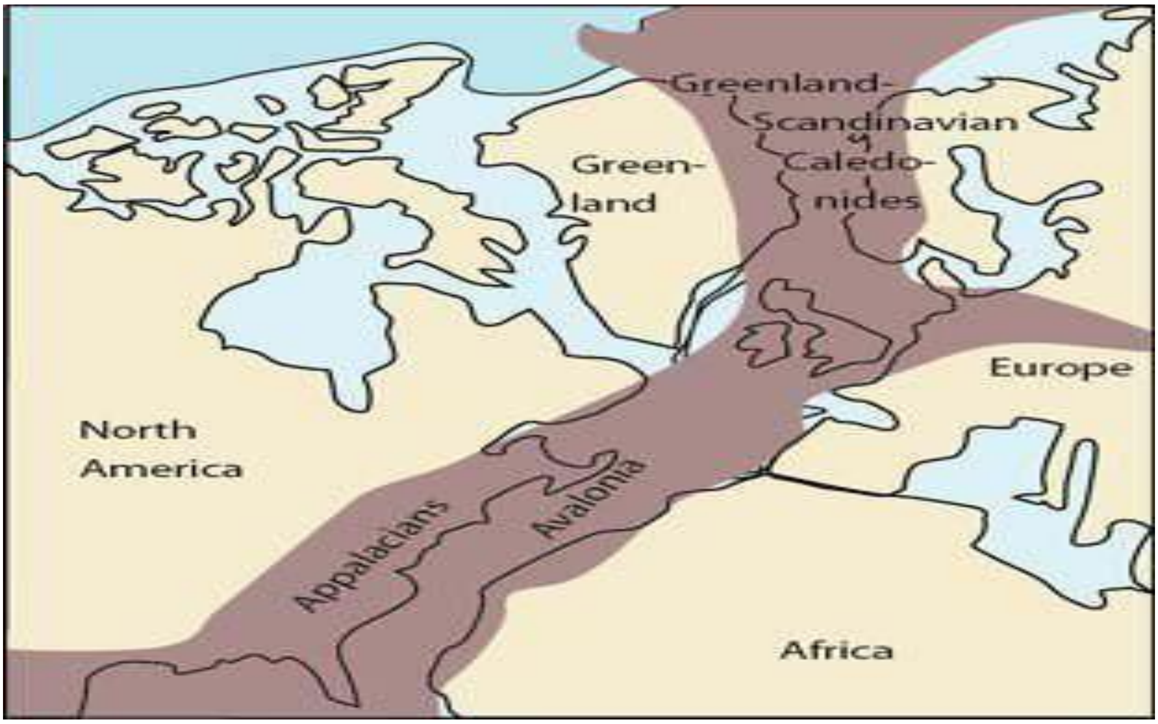
EVIDENCE – CONTINENTAL DRIFT THEORY



Apparent Affinity of Physical Features

Apparent Affinity of Physical Features

- The bulge of Brazil (South America) seems to fit into the Gulf of Guinea (Africa).
- Greenland seems to fit in well with Ellesmere and Baffin islands of Canada.
- The west coast of India, Madagascar and Africa seem to have been joined.
- North and South America on one side and Africa and Europe on the other fit along the mid-Atlantic ridge.
- The Caledonian and Hercynian mountains of Europe and the Appalachians of USA seem to be one continuous series.



Continuous Very Old Fold Mountain Chain

Criticism

- Coastlines are a temporary feature and are liable to change.
- Several other combinations of fitting in of unrelated landforms could be attempted.
- Continental Drift Theory shifts India's position too much to the south, distorting its relationship with the Mediterranean Sea and the Alps.
- The mountains do not always exhibit geological affinity.

Causes of Drift

- The gravity of the earth, the buoyancy of the seas and the tidal currents were given as the main factors causing the drift, by Wegener.

Criticism

- This is illogical because for these factors to be able to cause a drift of such a magnitude, they will have to be millions of times stronger.

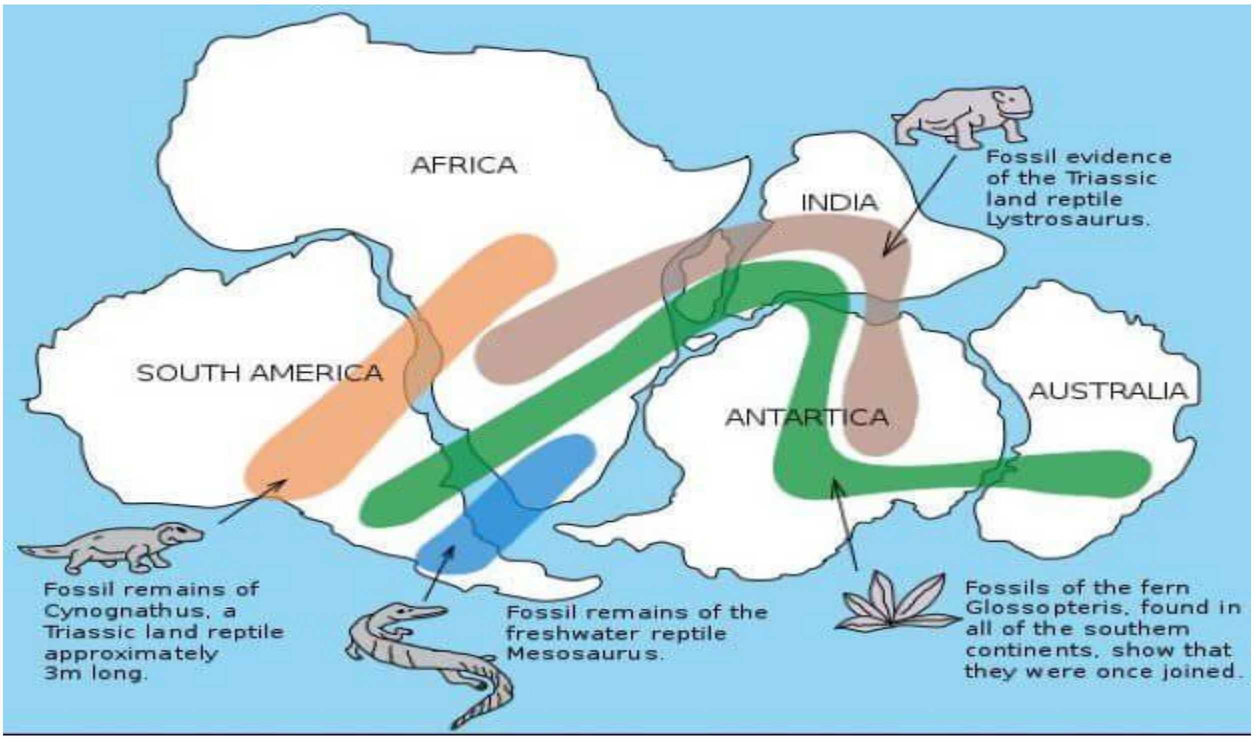
Polar wandering (Shifting of Poles)

- The position of the poles constantly drifted (due to plate tectonics).

Criticism

- Poles may have shifted, not necessarily the continents.

Botanical Evidence



Distribution of Fossils across the Gondwanaland

- 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.

Criticism

- Similar vegetation is found in unrelated parts of the world like Afghanistan, Iran and Siberia.

Distribution of Fossils

- The observations that Lemurs occur in India, Madagascar and Africa led some to consider a contiguous landmass "Lemuria" linking these three landmasses.
- Mesosaurus was a small reptile adapted to shallow brackish water. The skeletons of these are found only in South Africa and Brazil. The two localities presently are 4,800 km apart with an ocean in between them.

Rocks of Same Age Across the Oceans

- The belt of ancient rocks of 2,000 million years from Brazil coast matches with those from western Africa.

Criticism

- Rocks of the same age and similar characteristics are found in other parts of the world too.

Tillite deposits

- **Tillite deposits** are **sedimentary rocks formed out of deposits of glaciers**.
- The Gondwana system of sediments are found in India, Africa, Falkland Island, Madagascar, Antarctica and Australia (all were previously part of Gondwana).

- Overall resemblance demonstrates that these landmasses had remarkably similar histories.

Placer Deposits

- Rich **placer deposits of gold** are found on the Ghana coast (West Africa) but the source (gold-bearing veins) are in Brazil, and it is obvious that the gold deposits of Ghana are derived from the Brazil plateau when the two continents lay side by side.

Drawbacks of Continental Drift Theory

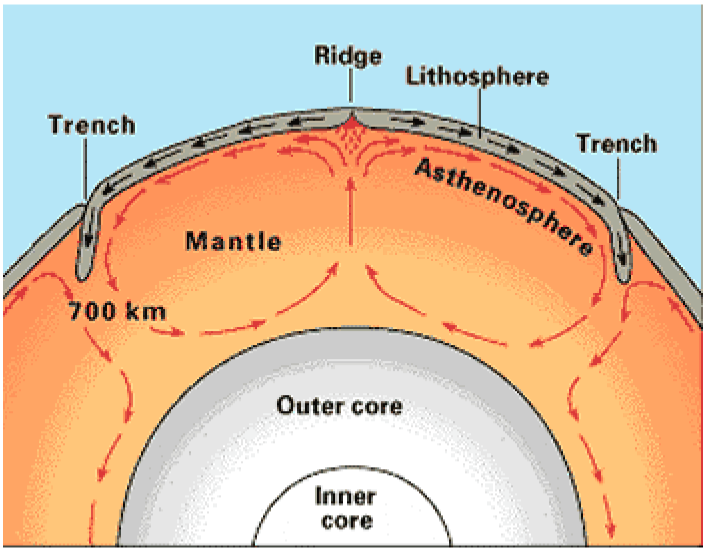
- Wegener failed to explain why the drift began only in Mesozoic era and not before.
- The theory doesn't consider oceans.
- Proofs heavily depend on assumptions that are generalistic.
- Forces like buoyancy, tidal currents and gravity are too weak to be able to move continents.
- Modern theories (Plate 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.

- To understand the concept of Seafloor Spreading, we must first understand some basic concepts that form the cornerstones for the concept of Seafloor Spreading. These cornerstones are **Convectional Current Theory** and **Paleomagnetism**.

CONVECTION CURRENT THEORY

- Convection Current Theory is the soul of Seafloor Spreading Theory.
- **Arthur Holmes** in 1930s discussed the possibility of **convection currents in the mantle**.
- These currents are generated due to **radioactive elements causing thermal differences** in the mantle.



Convection currents in the mantle

- According to this theory, the intense heat generated by radioactive substances in the mantle (100-2900 km below the earth surface) seeks a path to escape and gives rise to the formation of convection currents in the mantle.

- Wherever **rising limbs of these currents meet, oceanic ridges are formed** on the seafloor due to the **divergence** of the lithospheric plates (tectonic plates), and wherever the **failing limbs meet, trenches are formed** due to the **convergence** of the lithospheric plates (tectonic plates).
- **The movement of the lithospheric plates is caused by the movement of the magma in the mantle**.

PALEOMAGNETISM

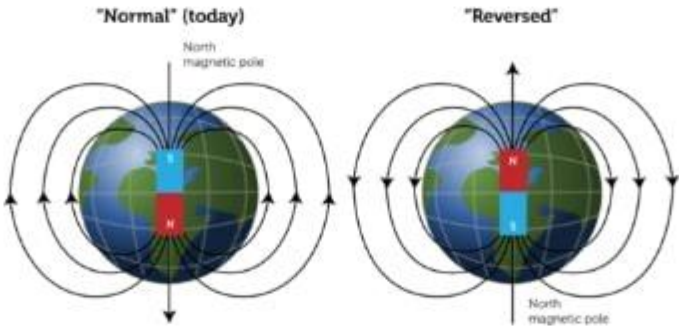
- Paleomagnetism is the study of the **record of earth's magnetic field** with the help of **magnetic fields recorded in rocks, sediment**, or archaeological materials.
- The polarity of the Earth's magnetic field and magnetic field reversals are thus detectable by studying the rocks of different ages.
- Rocks formed from underwater volcanic activity are mainly **basaltic** (low silica, iron-rich) that makes up most of the ocean floor.
- **Basalt contains magnetic minerals, and as the rock is solidifying, these minerals align themselves in the direction of the magnetic field.**
- This locks in a record of which way the magnetic field was positioned at the time.
- Paleomagnetic studies of rocks have demonstrated that the orientation of the earth's magnetic field has **frequently alternated (geomagnetic reversal)** over geologic time.

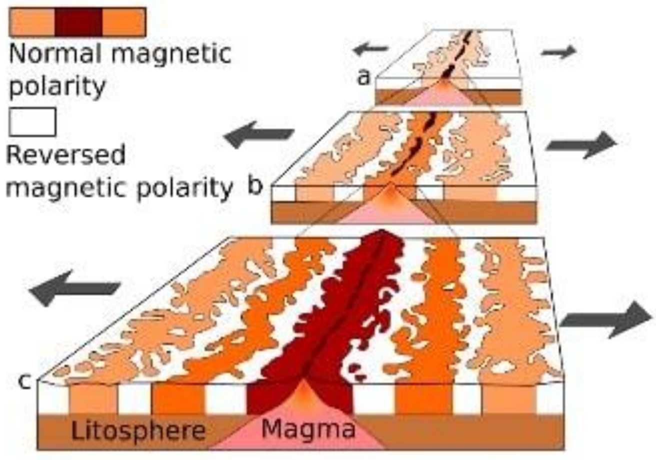
Paleomagnetism: Strong evidence of Seafloor Spreading and Plate Tectonics

- **Paleomagnetism** led the revival of the continental drift hypothesis and its transformation into theories of Sea Floor Spreading and Plate Tectonics.
- The regions that hold the unique record of earth's magnetic field lie along the **mid-ocean ridges** where the sea floor is spreading.
- On studying the **paleomagnetic rocks** on either side of the oceanic ridges, it is found that **alternate magnetic rock stripes were flipped** so that one stripe would be of normal polarity and the next, reversed.
- Hence, paleomagnetic rocks (paleo: denoting rocks) on either side of the mid-ocean or submarine ridges provide the **most important evidence to the concept of Sea Floor Spreading**.
- Magnetic field records also provide information on the **past location of tectonic plates**.

Explanation

- These oceanic ridges are boundaries where tectonic plates are **diverging** (moving apart).
- The fissure or vent (in between the ridge) between the plates allowed the magma to rise and harden into a long narrow band of rock on either side of the vent.
- Rising magma **assumes the polarity of Earth's geomagnetic field at the time** before it solidifies on the oceanic crust.
- As the conventional currents pull the oceanic plates apart, the solidified band of rock moves away from the vent (or ridge), and a new band of rock takes its place a few million years later when the magnetic field was reversed. This results in this **magnetic striping** where the **adjacent rock bands have opposite polarities**.
- This process repeats over and over giving rise to a series of narrow parallel rock bands on either side of the ridge and **alternating pattern of magnetic striping on the seafloor.**



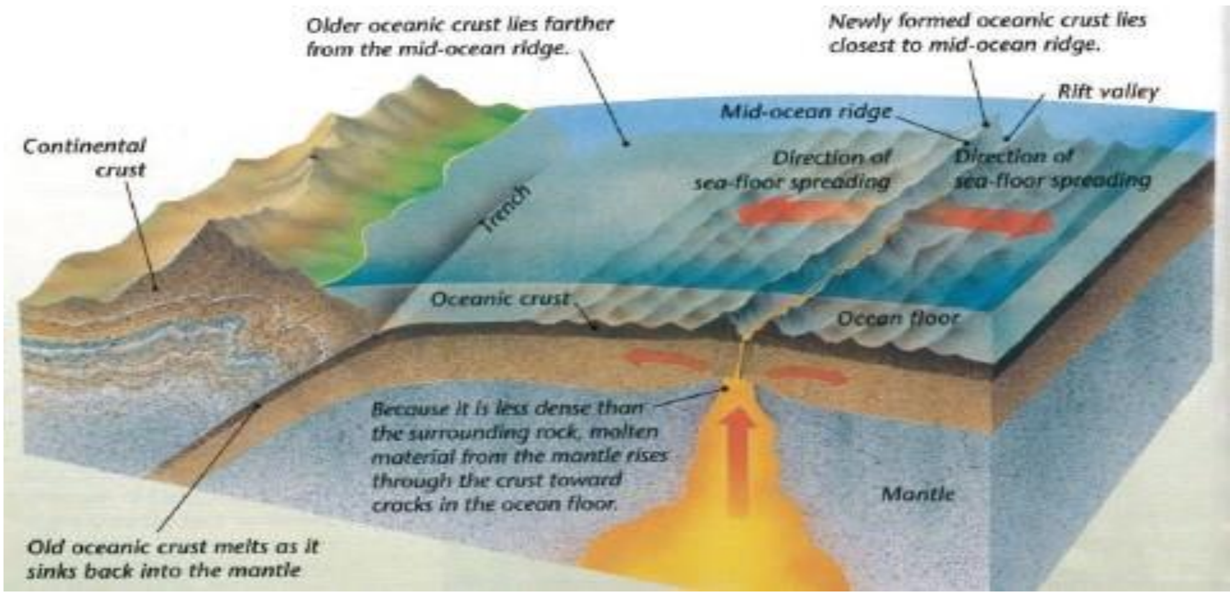


The alternating pattern of magnetic striping on the seafloor

THE CONCEPT OF SEA FLOOR SPREADING

- **Harry Hess proposed the idea of See Floor Spreading.**
- When oceanic plates diverge, tensional stress causes fractures to occur in the lithosphere.
- **Basaltic magma** rises from the fractures and cools on the ocean floor to form **new seafloor**.
- The newly formed seafloor (oceanic crust) then **gradually moves away** from the ridge, and its place is taken by an even newer seafloor and the cycle repeats.
- With time, **older rocks are spread farther away from the spreading zone** while **younger rocks will be found nearer to the spreading zone**.

Seafloor spreading helps explain continental drift in the theory of plate tectonics.



Seafloor Spreading

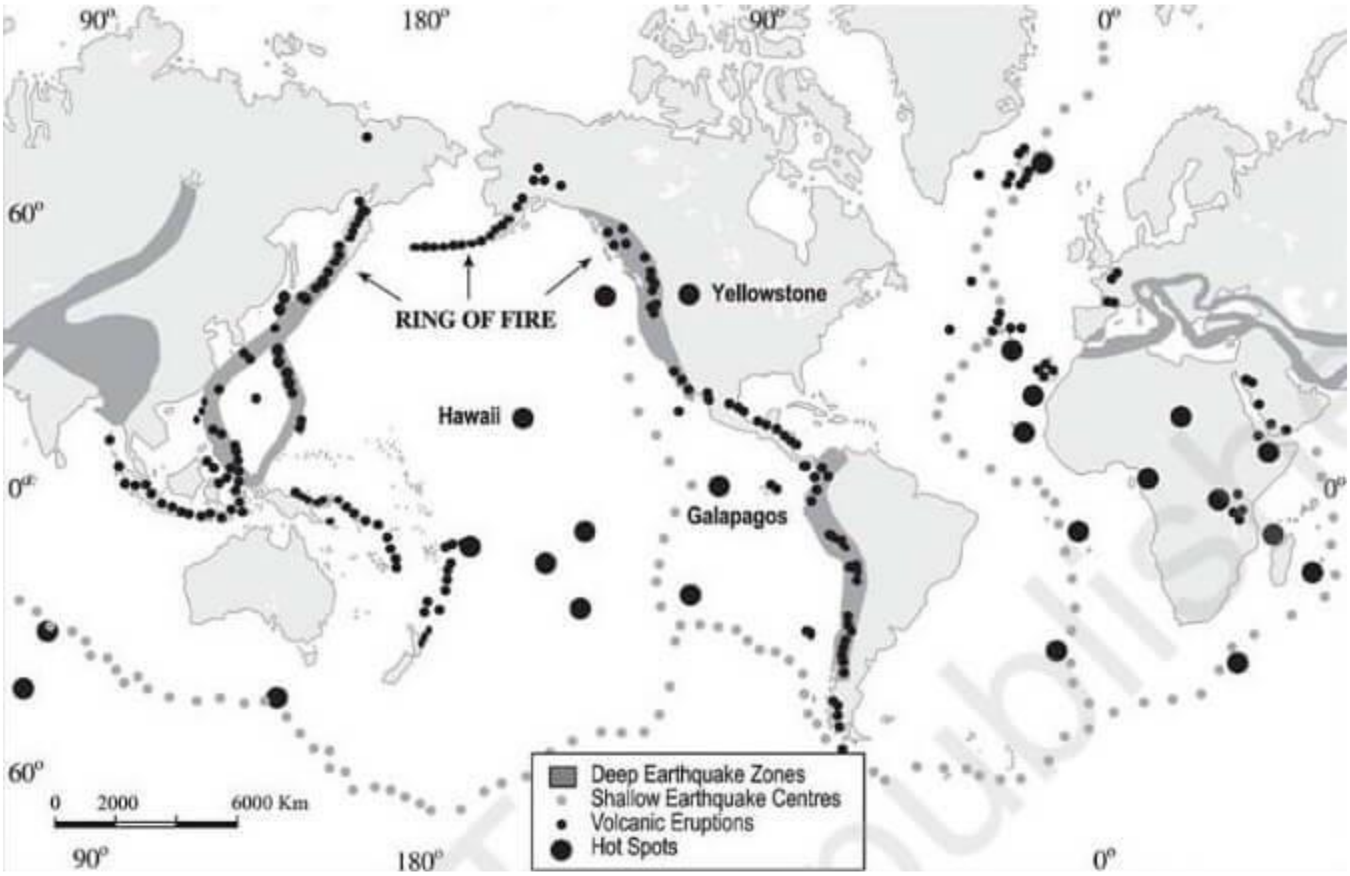
EVIDENCE – FOR SEA FLOOR SPREADING

Nature of oceanic rocks around mid-ocean ridges

- Rocks on either side of the crest of oceanic ridges having equidistant locations from the crest were found to have similarities both in terms of their constituents, their age and magnetic orientation.
- Rocks closer to the mid-oceanic ridges have normal polarity and are the youngest and the age of the rocks increases as one moves away from the crest (ridge).

- The **rocks of the oceanic crust near the oceanic ridges are much younger than the rocks of the continental crust**.

Distribution of Earthquakes and Volcanoes along the mid-ocean ridges



- The normal temperature gradient on the sea floor is 9.4° C/300 m, but near the ridges it becomes higher, indicating an upwelling of magmatic material from the mantle.
- Dots in the central parts of the Atlantic Ocean and other oceans are almost parallel to the coastlines. This indicates that the seafloor has widened with time.
- In general, the foci of the earthquake in the areas of mid-oceanic ridges are at shallow depths whereas, along the Alpine-Himalayan belt as well as the rim of the Pacific, the earthquakes are deep-seated ones.

PLATE TECTONICS

- It was from the continental drift theory, convection current theory and the theory of seafloor spreading, the theory of **Plate Tectonics** was formulated.
- In 1967, **McKenzie and Parker** suggested the theory of plate tectonics. Morgan later outlined the theory in 1968.
- According to the theory of plate tectonics, the **earth's lithosphere is broken into distinct plates** which are floating on a **ductile layer called asthenosphere** (upper part of the mantle).
- Plates move horizontally over the **asthenosphere** as rigid units.
- The lithosphere includes the **crust** and **top mantle** with its thickness range varying between **5-100 km in oceanic parts and about 200 km in the continental areas**.
- The oceanic plates contain mainly the **Simatic crust** and are relatively thinner, while the continental plates contain **Sialic material** and are relatively thicker.

- Lithospheric plates (**tectonic 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).
- The movement of these crustal plates (due to convection currents in the mantle) causes the formation of various landforms and is the principal cause of all earth movements.

Force for plate movement

- Convection currents in the mantle that are generated due to thermal gradients.

Rates of Plate Movement

- The Arctic Ridge has the slowest rate (less than 2.5 cm/year), and the East Pacific Rise in the South Pacific (about 3,400 km west of Chile), has the fastest rate (more than 15 cm/year).

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.

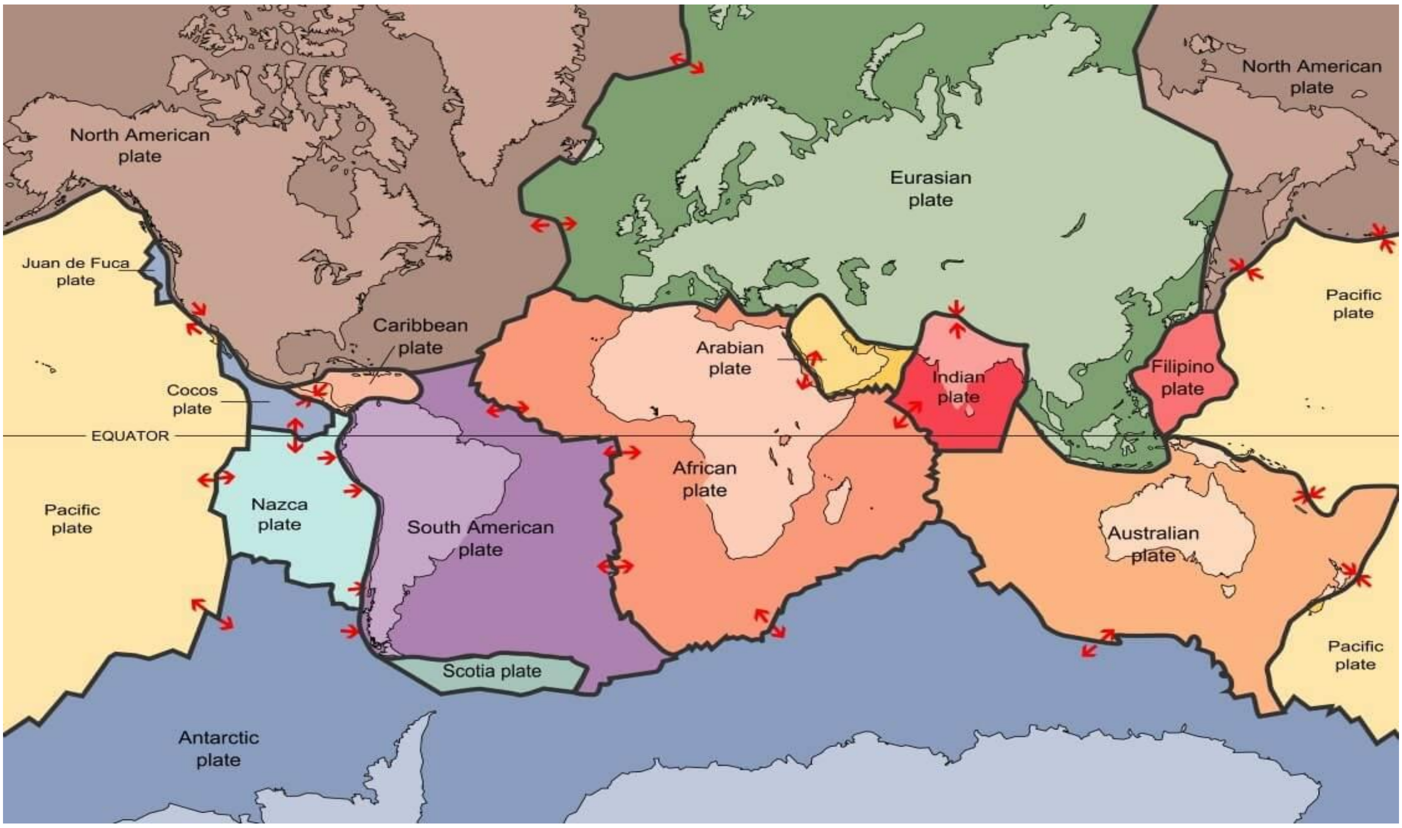
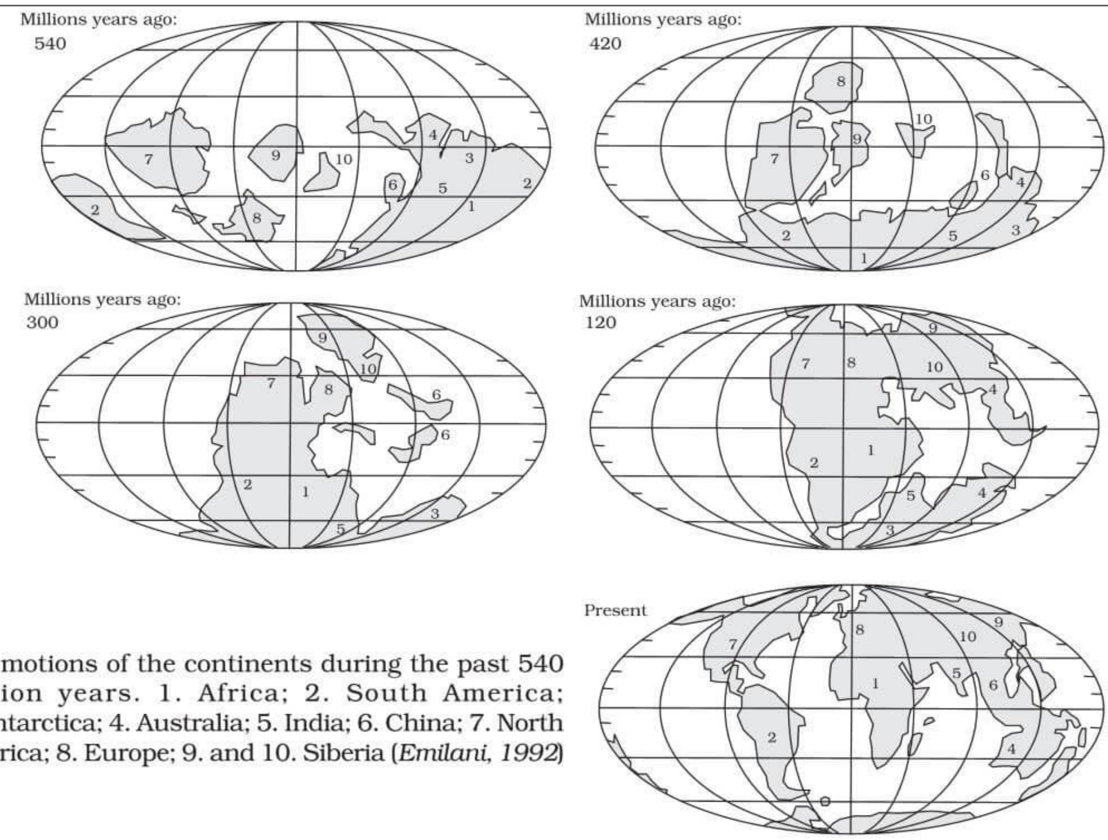


Plate Boundaries

The figure below shows the changes in landform with time due to the interaction of various plates.



The motions of the continents during the past 540 million years. 1. Africa; 2. South America; 3. Antarctica; 4. Australia; 5. India; 6. China; 7. North America; 8. Europe; 9. and 10. Siberia (*Emilani, 1992*)

The position of the continents through geologic past

Watch the video for quick and better understanding

EVIDENCE – IN SUPPORT OF PLATE TECTONICS

- Evidence for both See Floor Spreading and Plate tectonics are **complimentary** (almost same evidences).

Paleomagnetism

- **Paleomagnetic rocks** are the most important evidence. The orientation of iron grains on older rocks shows an orientation which points to the existence of the South Pole, once upon a time, somewhere between present-day Africa and Antarctica (polar wandering).

Older rocks form the continents while younger rocks are present on the ocean floor

- On continents, rocks of up to 3.5 billion years old can be found while the oldest rock found on the ocean floor is not more than 75 million years old (western part of Pacific floor).
- As we move, towards ridges, still younger rocks appear. This points to an effective spread of seafloor (See floor spreading is almost similar to plate tectonics except that it examines the interaction between oceanic plates only) along oceanic ridges which are also the plate margins.

Gravitational anomalies

- In trenches, where subduction has taken place (convergent edge), the value of gravitational constant 'g' is less. This indicates a loss of material.
- For instance, gravity measurements around the Indonesian islands have indicated that large gravity anomalies are associated with the oceanic trench bordering Indonesia.

Earthquakes and Volcanoes

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

The significance of Plate Tectonics

- Almost all major landforms formed are due to plate tectonics.
- New minerals are thrown up from the core with the magmatic eruptions.
- Economically valuable minerals like copper and uranium are found near the plate boundaries.
- From present knowledge of crustal plate movement, the shape of landmasses in future can be predicted.
- For instance, if the present trends continue, North and South America will separate. A piece of land will separate from the east coast of Africa. Australia will move closer to Asia.

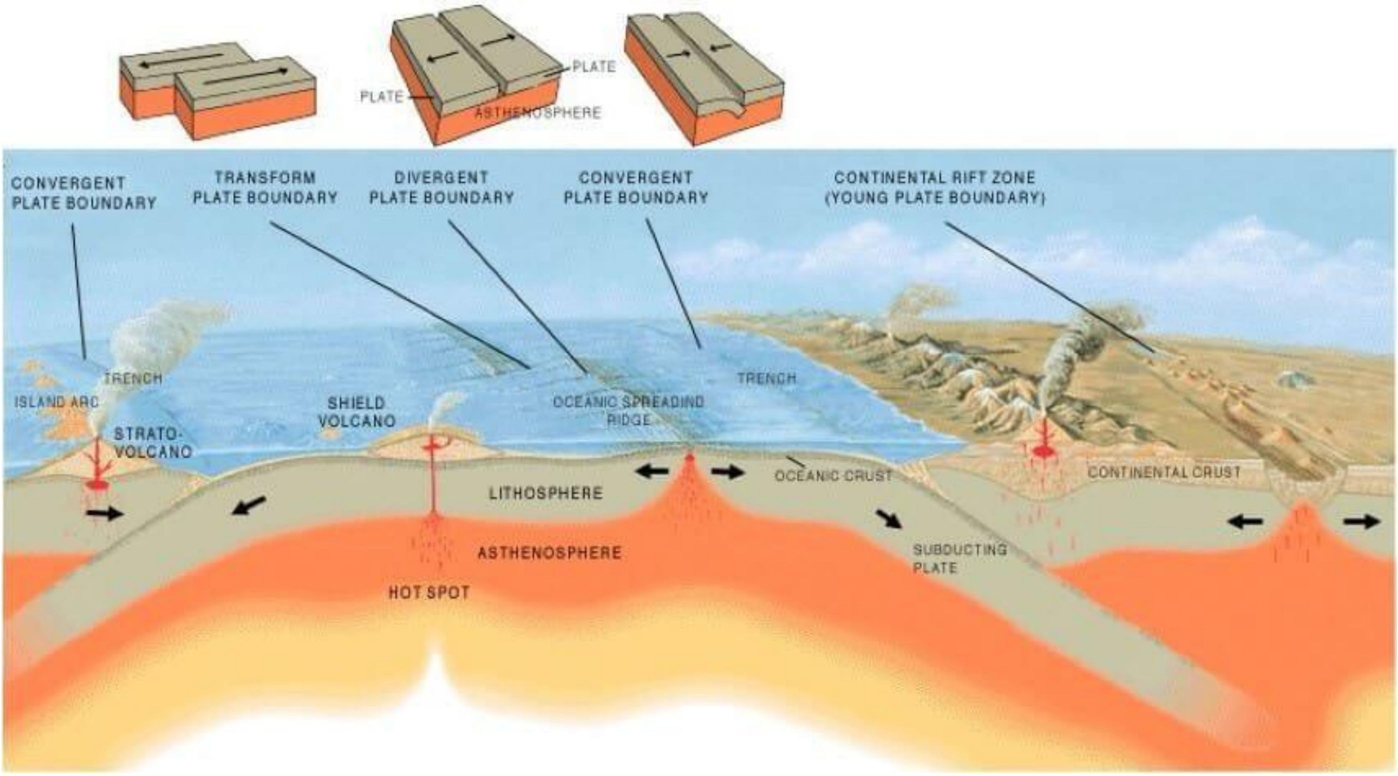
Comparison: Continental Drift – See Floor Spreading – Plate Tectonics

	Continental Drift	See Floor Spreading	Plate Tectonics
Explained by	Put forward by **Alfred Wegener** in 1920s	**Arthur Holmes** explained Convectional Current Theory in the 1930s. Based on convection current theory, **Harry Hess** explained See Floor Spreading in the 1940s	In 1967, McKenzie and Parker suggested the theory of plate tectonics. Morgan later outlined the theory in 1968

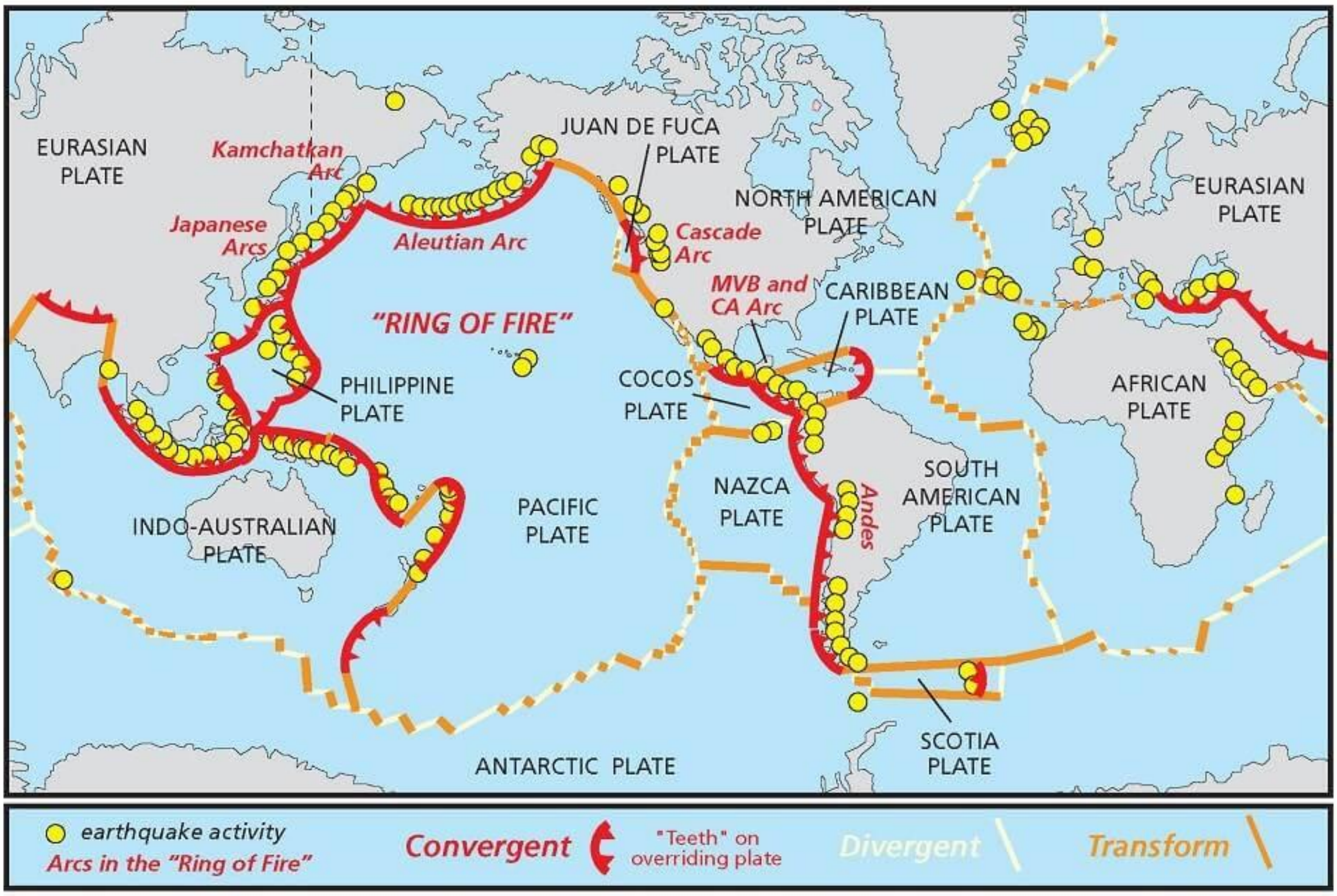
Theory	Explains the Movement of Continents only	Explains the Movement of Oceanic Plates only	Explains the Movement of Lithospheric plates that include both continents and oceans.
Forces for movement	Buoyancy, gravity, pole-fleeing force, tidal currents, tides,	Convection currents in the mantle drag crustal plates	Convection currents in the mantle drag crustal plates
Evidence	Apparent affinity of physical features, botanical evidence, fossil evidence, Tillite deposits, placer deposits, rocks of same age across different continents etc.	Ocean bottom relief, Paleomagnetic rocks, distribution of earthquakes and volcanoes etc.	Ocean bottom relief, Paleomagnetic rocks, distribution of earthquakes and volcanoes, gravitational anomalies at trenches, etc.
Drawbacks	Too general with silly and sometimes illogical evidence.	Doesn't explain the movement of continental plates	————————
Acceptance	Discarded	Not complete	Most widely accepted
Usefulness	Helped in the evolution of convection current theory and seafloor spreading theory	Helped in the evolution of plate tectonics theory	Helped us understand various geographical features.

Interaction of Tectonic Plates

- Major geomorphological features such as fold and block mountains, mid-oceanic ridges, trenches, volcanism, earthquakes etc. are a direct consequence of the interaction between various Tectonic Plates (lithospheric plates).
- There are three ways in which the plates interact with each other.



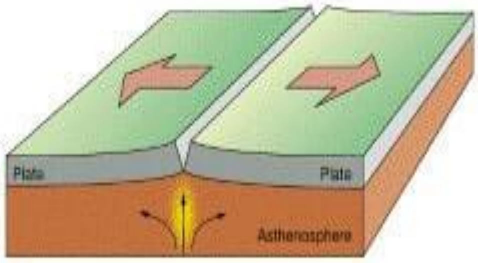
Types of Tectonic Plate Boundaries (Jose F. Vigil. USGS, via Wikimedia Commons)



Tectonic Plates: Divergent, Convergent and Transform Boundaries (nps.gov R.J. Lillie. 2005. Parks and Plates)

DIVERGENCE FORMING DIVERGENT EDGE OR THE CONSTRUCTIVE EDGE

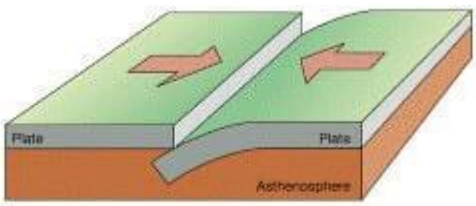
- In this kind of interaction, the plates diverge (**move away** from each other).
- **Mid-ocean ridges** (e.g. Mid-Atlantic Ridge) are formed due to this kind of interaction.
- Here, the basaltic magma erupts and moves apart (seafloor spreading).
- On continents, **East African Rift Valley** is the most important geomorphological feature formed due to the divergence of **African and Somali plates**.
- Divergent edges are sites of earth **crust formation** (hence the name **constructive edge**), and volcanic earth forms are common along such edges.
- Earthquakes (shallow focus) are common along divergent edges.



Divergent Boundary

CONVERGENCE FORMING CONVERGENT EDGE OR DESTRUCTIVE EDGE

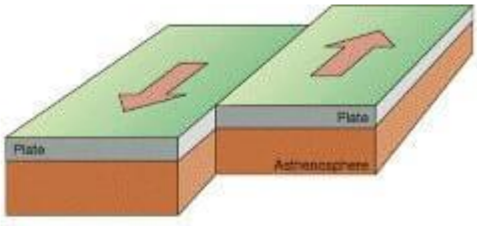
- In this kind of interaction, two lithospheric plates **collide** against each other.
- The zone of collision may undergo crumpling and folding, and folded mountains may emerge (**orogenic collision**). **Himalayan Boundary Fault** is one such example.
- **When one of the plates is an oceanic plate, it gets embedded in the softer asthenosphere of the continental plate, and as a result, trenches are formed at the zone of subduction.**
- **Near the convergent edge a part of the** crust **is destroyed, hence the name Destructive Edge.**
- The subducted material gets heated, up and is thrown out forming **volcanic island arc and continental arc systems** and a dynamic equilibrium is achieved.

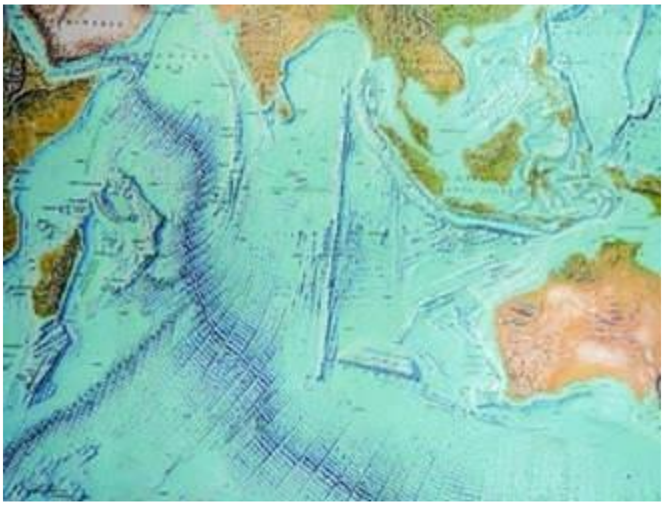


Convergent Boundary

TRANSCURRENT EDGE OR CONSERVATIVE EDGE OR TRANSFORM EDGE

- In this kind of interaction, two plates slide past against each other, and there is **no creation or destruction of landform** but **only deformation** of the existing landform.
- In oceans, **transform faults** are the planes of separation generally perpendicular to the mid-oceanic ridges.
- **San Andreas Fault** (Silicon Valley lies dangerously close to the faultline) along the western coast of USA is the best example for a transcurrent edge on continents.





Transform Edge

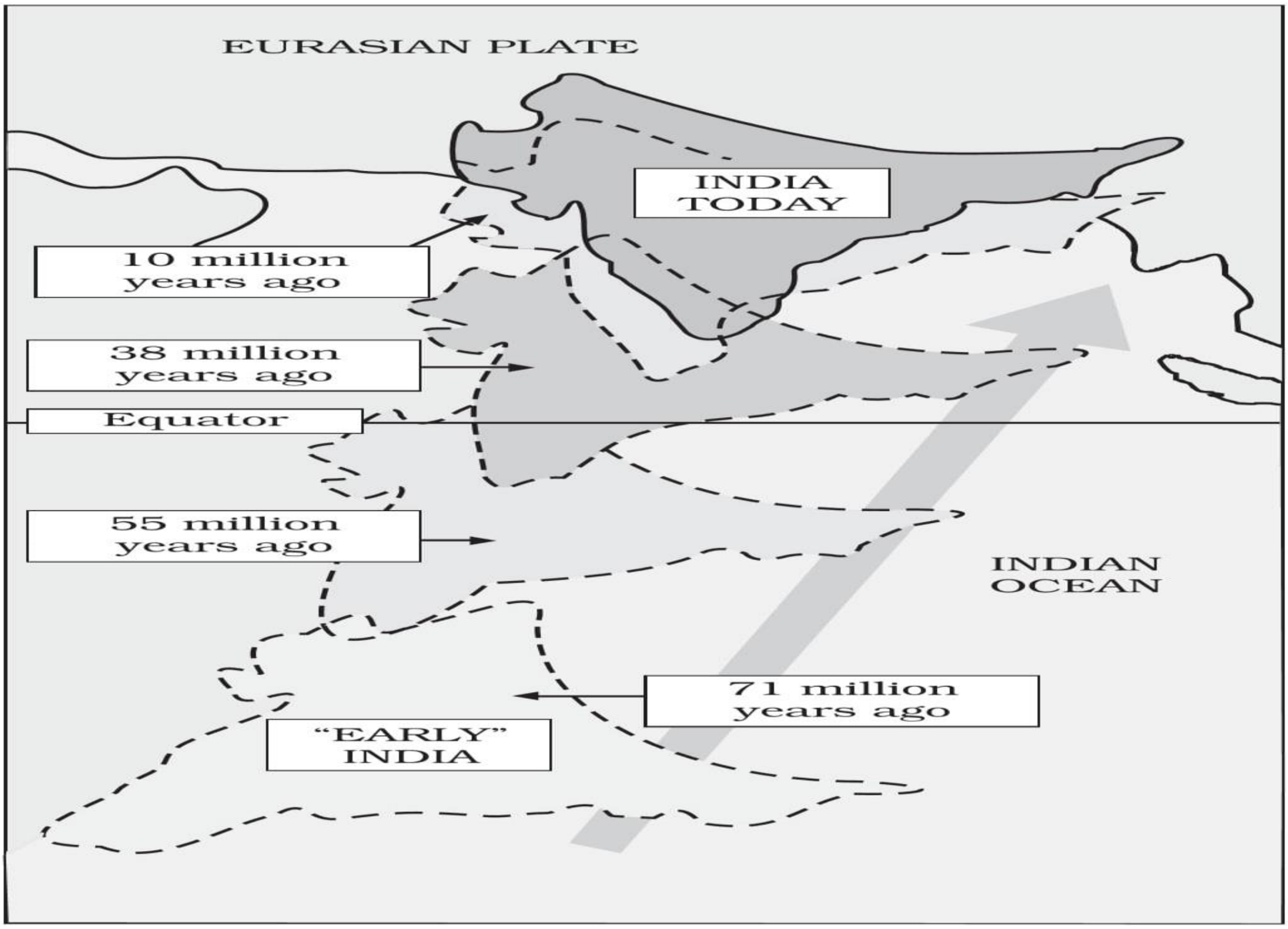
Movement of The Indian Tectonic Plate

- The Indian plate includes Peninsular India and the Australian continental portions.
- The subduction zone along the **Himalayas** forms the northern plate boundary in the form of continent-continent convergence.
- In the east, it extends through Rakinyoma Mountains (Arakan Yoma) of Myanmar towards the island arc along the Java Trench.
- The eastern margin is a spreading site lying to the east of Australia in the form of an oceanic ridge in SW Pacific.
- **The Western margin follows Kirthar Mountain of Pakistan. It further extends along the Makrana coast (Pakistan and Iranian coasts) and joins the spreading site from the Red Sea rift (Red Sea rift is formed due to the divergence of Somali plate and Arabian plate) south-eastward along the Chagos Archipelago (Formed due to hotspot volcanism).**
- **The boundary between India and the Antarctic plate is also marked by an oceanic ridge (divergent boundary) running in roughly W-E direction and merging into the spreading site, a little south of New Zealand.**

Movement

- India was a large island situated off the Australian coast. The **Tethys Sea** separated it from the Asian continent till about 225 million years ago.
- India is supposed to have started her northward journey about 200 million years (**Pangaea** broke).
- About 140 million years ago, the subcontinent was located as south as 50 ° S latitude.
- The Tethys Sea separated the Indian plate and the Eurasian plate.
- The Tibetan block was a part of the Asiatic landmass.
- India collided with Asia about **40-50 million years ago** causing rapid uplift of the Himalayas (the Indian plate and the Eurasian plate were close to the equator back then).
- It's thought that India's coastline was denser and more firmly attached to the seabed, which is why Asia's softer soil was pushed up rather than the other way around.
- The process is continuing, and the **height of the Himalayas is rising** even to this date.

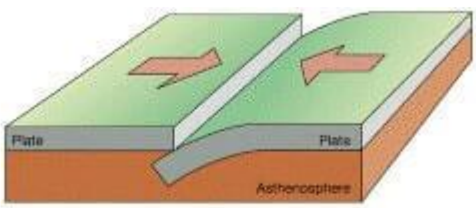
- The northward movement of the Indian tectonic plate pushing slowly against the Asiatic plate is evident by the **frequent earthquakes** in the region.
- During the movement of the Indian plate towards the Asiatic plate, a major event that occurred was the outpouring of lava and formation of the **Deccan Traps (shield volcano)**.
- The shield volcanism started somewhere around **60 million years ago** and continued for a long period.



OCEAN-OCEAN CONVERGENCE AND VOLCANIC ISLAND ARC FORMATION

Convergent Boundary

- Along a convergent boundary two lithospheric plates **collide** against each other.
- **When one of the plates is an oceanic plate, it gets embedded in the softer asthenosphere of the continental plate, and as a result, trenches are formed at the zone of subduction.**



Convergent Boundary

In convergence there are subtypes namely:

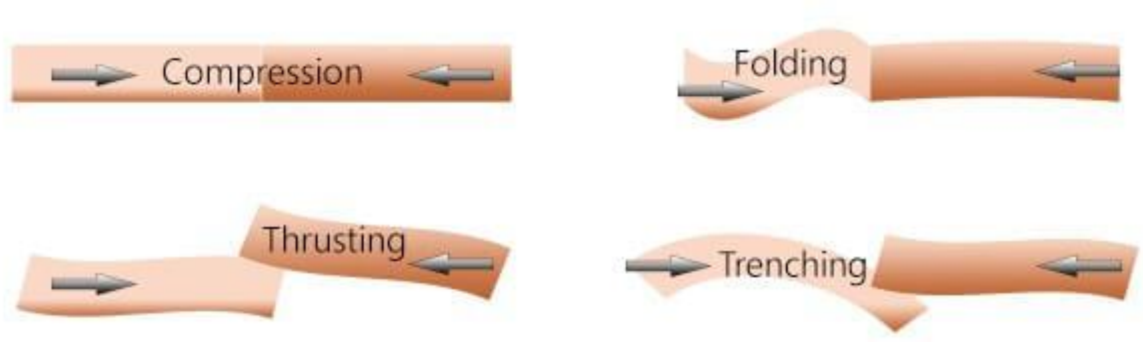
1. **Collision of oceanic plates or ocean-ocean convergence (formation of volcanic island arcs).**

2. **Collision of continental and oceanic plates or ocean-continent convergence (formation of continental arcs and fold mountains).**
3. **Collision of continental plates or continent-continent convergence (formation of fold mountains)**
4. **Collision of continent and arc, or continent-arc convergence.**

Ocean-Ocean Convergence or The Island-Arc Convergence

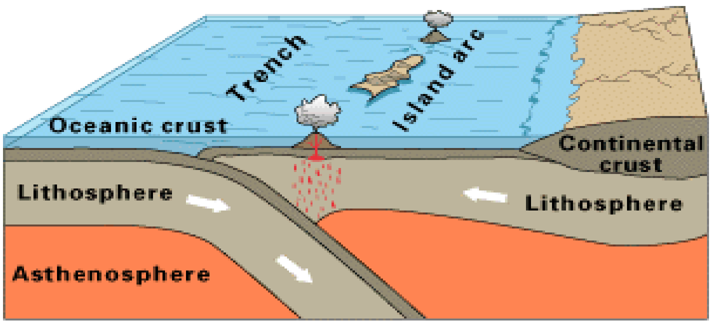
- **The concept of Ocean-Ocean Convergence helps us understand the formation of Japanese Island Arc, Indonesian Archipelago, Philippine Island Arc and Caribbean Islands.**
- **Archipelago:** an extensive group of islands.
- **Island arc:** narrow chain of islands which are volcanic in origin. An island arc is usually curved.

Basics



In all types of convergence, the **denser plate subducts,** and the less dense plate is either **up thrust or folded or both** (upthrust and folded).

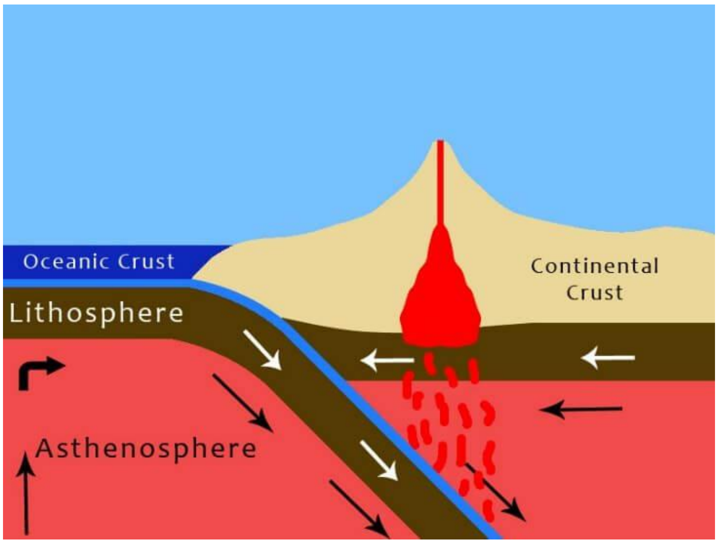
- In Ocean-Ocean Convergence, a **denser oceanic plate** subducts below a **less dense oceanic plate** forming a **trench** along the boundary.



Oceanic-oceanic convergence

Ocean – Ocean Convergence

- As the ocean floor crust (oceanic plate) loaded with sediments **subducts** into the softer **asthenosphere**, the rocks in the subduction zone become **metamorphosed (alteration of the composition or structure of a rock)** under high pressure and temperature.
- After reaching a depth of about 100 km, the plates melt. Magma (**metamorphosed sediments and the melted part of the subducting plate**) has lower density and is at high pressure.
- It rises upwards due to the **buoyant force** offered by surrounding denser medium.
- The magma flows out to the surface. A continuous upward movement of magma creates constant volcanic eruptions at the ocean floor.



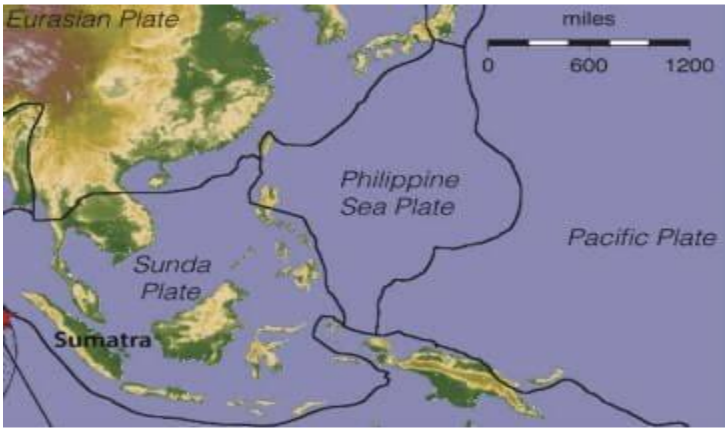
Subduction Zone Illustration

- Constant volcanism above the subduction zone creates layers of rocks. As this process continues for millions of years, a volcanic landform is created which in some cases rises above the ocean waters.
- Such volcanic landforms all along the boundary form a **chain of volcanic islands** which are collectively called as **Island Arcs** (Indonesian Island Arc or Indonesian Archipelago, Philippine Island Arc, Japanese Island Arc etc.).
- Orogenesis (mountain building) sets in motion the process of **building continental crust by replacing the oceanic crust** (this happens at a much later stage. For example, new islands are born around Japan in every few years. After some million years, Japan will be a single landmass because continental crust formation is constantly replacing the oceanic crust).

This explanation is common for all the island arc formations (ocean-ocean convergence). We only need to know the plates involved with respect to each island formation.

Formation of the Philippine Island Arc System

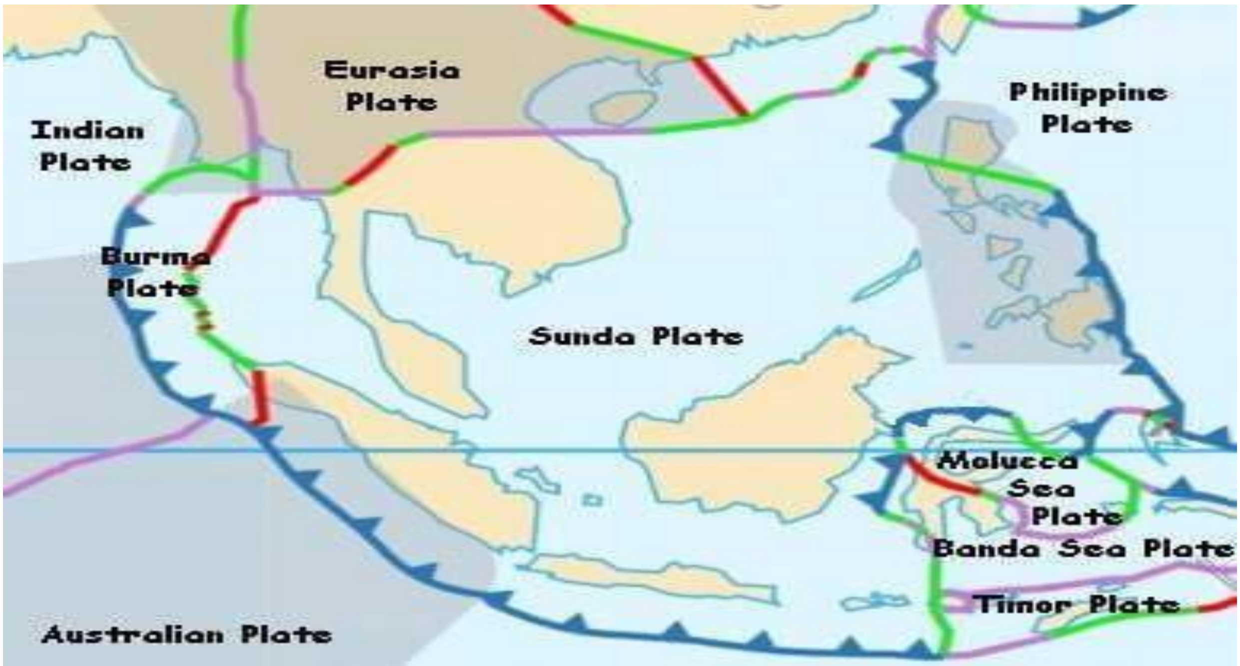
- Philippine Island Arc system is formed due to subduction of **Philippine Sea plate** under the **Sunda Plate** (major continental shelf of the **Eurasian plate**). The trench formed here is called **Philippine Trench**.
- **Sunda Shelf: The extreme south-eastern portion of the Eurasian plate, which is a part of Southeast Asia, is a continental shelf. The region is called the Sunda Shelf. The Sunda Shelf and its islands is known as the Sundaland block of the Eurasian plate.**

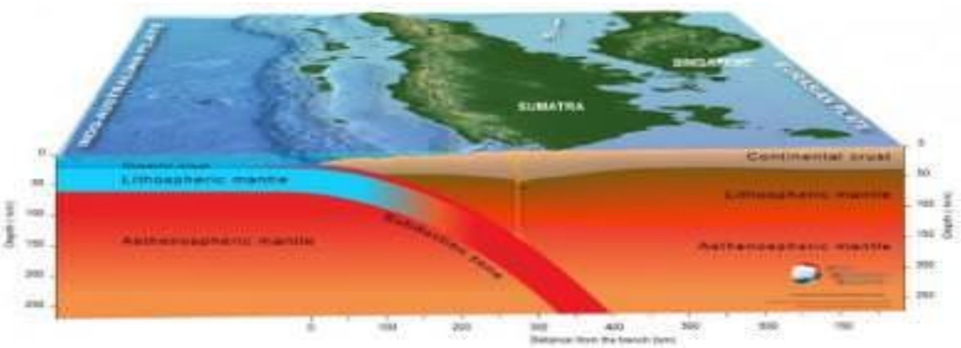


Minor plates in the Southeast Asia

Formation of the Indonesian Archipelago

- **In the case of Indonesian Archipelago, the Indo-Australian plate is subducting below Sunda Plate (part of Eurasian Plate). The trench formed here is called Sunda trench (Java Trench is a major section of Sunda trench).**



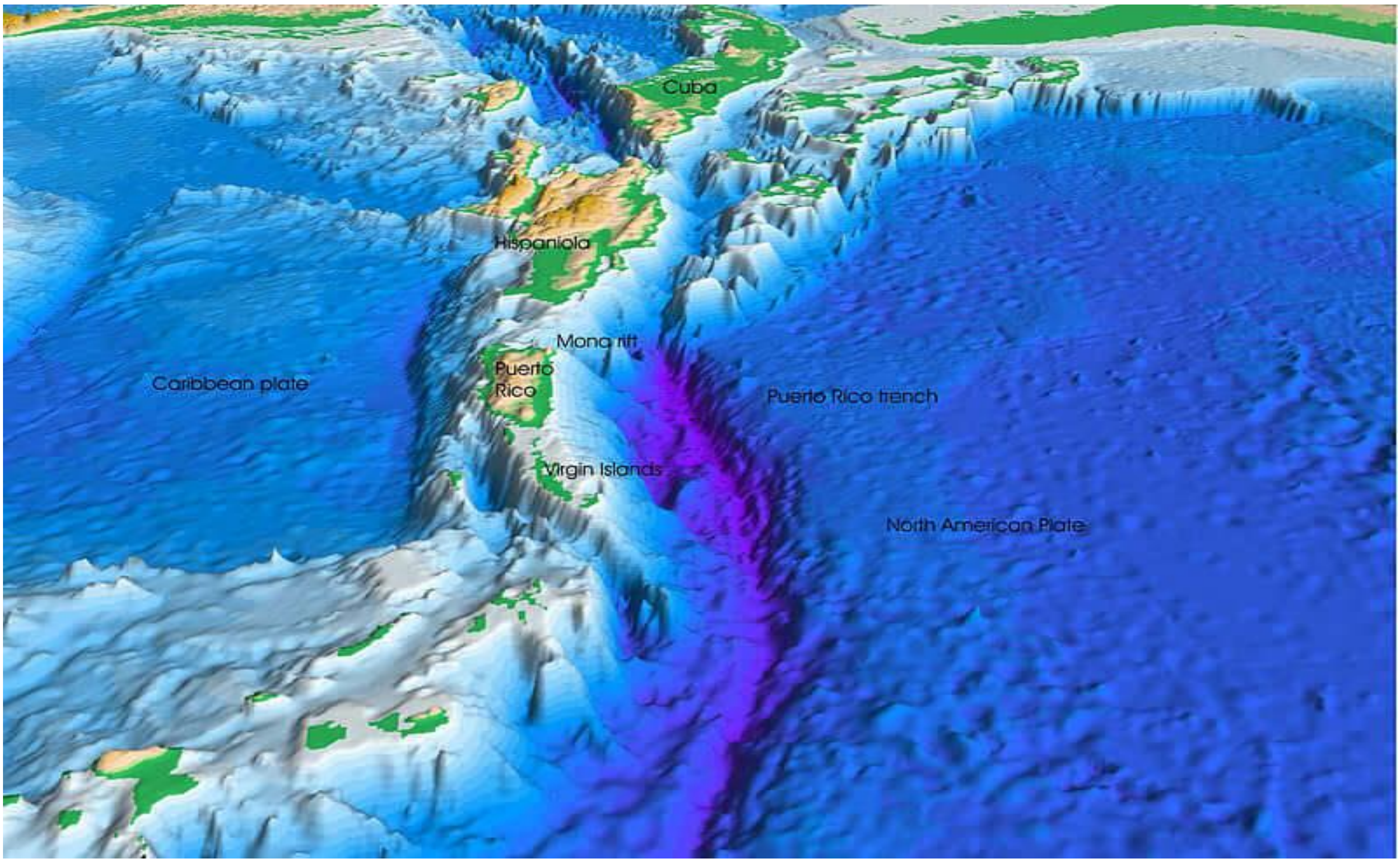


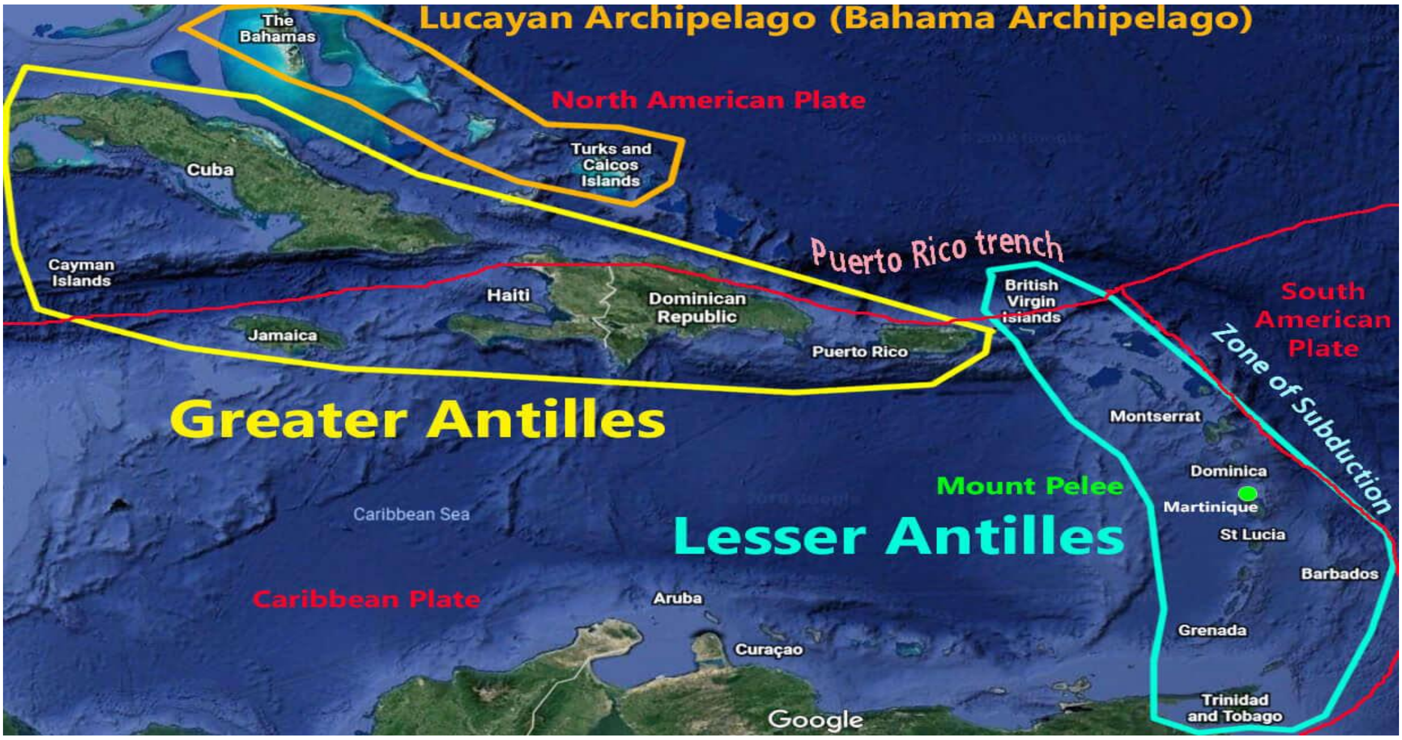
- **Anak Krakatau (child of Krakatau)** volcano lies close to the Java Trench. It is situated in the **Sunda Strait** between the Indonesians Islands of **Java** and **Sumatra**.
- Underwater land shifting on the Anak Krakatau volcano in December 2018 triggered a Tsunami that killed more than 400 people.

Formation of the Caribbean Islands

- The Caribbean Plate is a mostly oceanic tectonic plate. The northern boundary with the North American plate is a **transform or strike-slip boundary** (more about this in the subsequent chapters).
- The Caribbean Plate is moving to the east while the North American Plate is moving to the west.
- The **Puerto Rico Trench** is located at a boundary between the two plates that pass each other along a **transform boundary with only a small component of subduction**.
- The boundary between the two plates in the past has been convergent, and most of the **Greater Antilles** group of islands are formed due to the complex interaction between the two plates.
- The eastern boundary of the Caribbean Plate is a subduction zone, the **Lesser Antilles subduction zone**, where oceanic crust of the South American Plate is being subducted under the Caribbean Plate.

- This subduction zone explains the presence of **active volcanoes along the Lesser Antilles**.
- **Mount Pelée** is an active volcano at the northern end of Martinique Island (French overseas department) in the Lesser Antilles island arc of the Caribbean.
- The volcano is famous for its eruption in 1902. The eruption killed about 30,000 people. Most deaths were caused by pyroclastic flows which destroyed the city of Saint-Pierre.

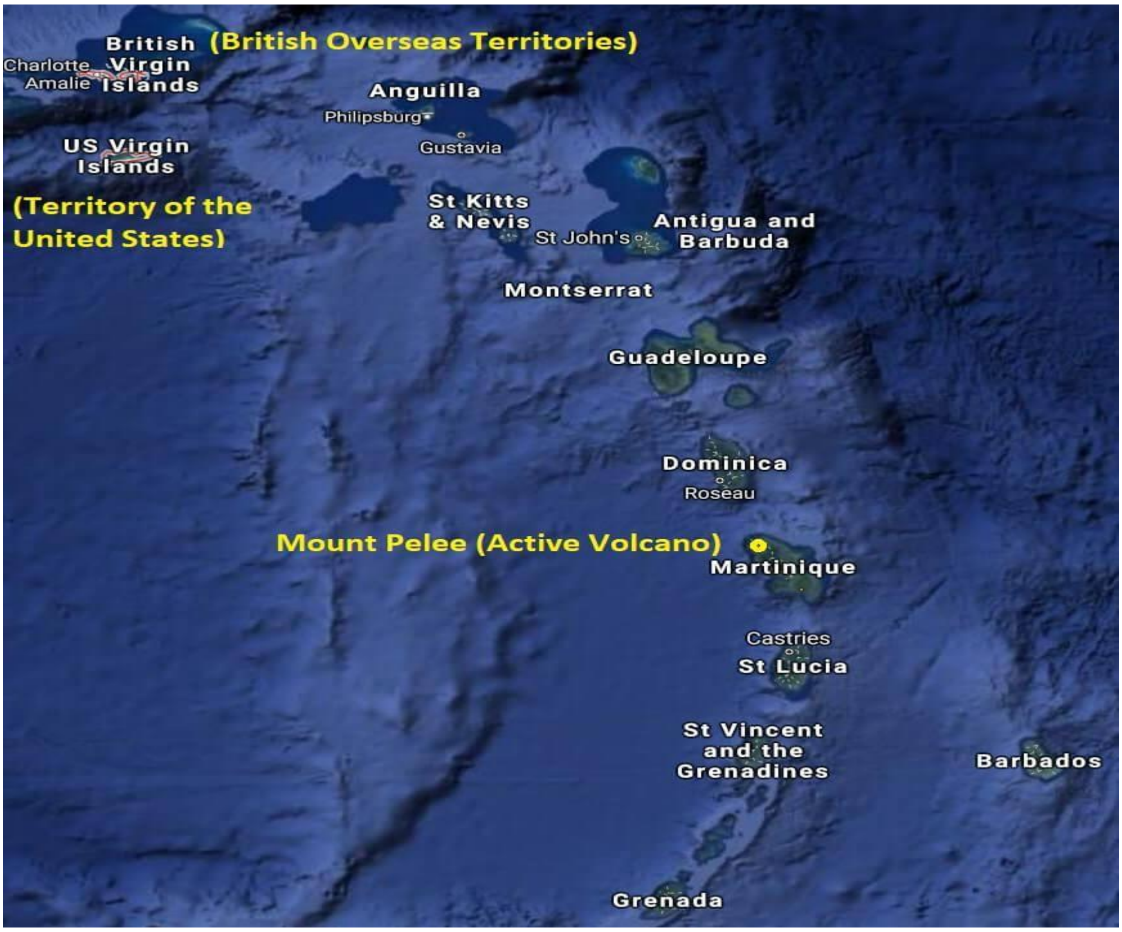




The Greater Antilles and Lesser Antilles Island Arcs (Map from Google Earth)

The island groups in the Caribbean Sea

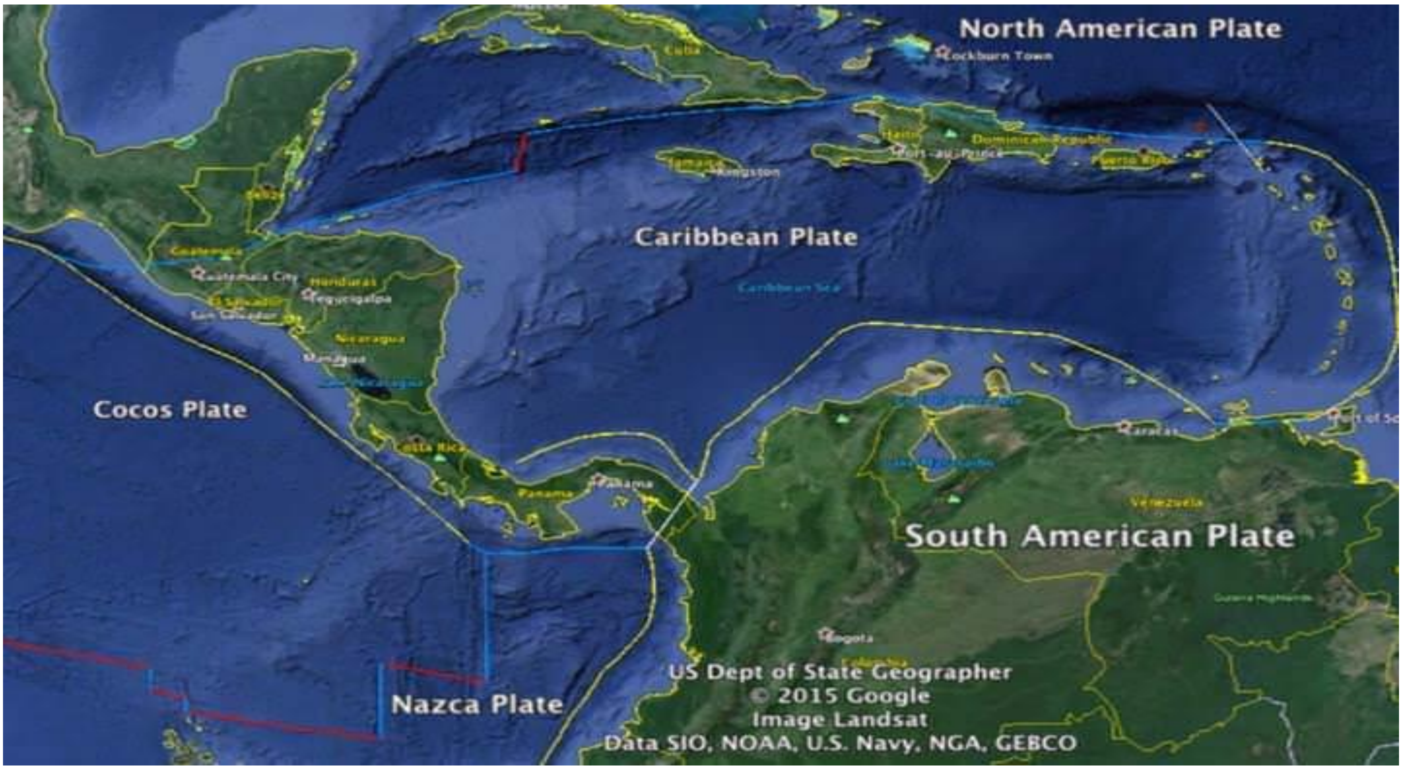
- The Greater Antilles is a grouping of the **larger islands** in the Caribbean Sea: Cuba, Hispaniola (containing Haiti and the Dominican Republic), Puerto Rico, Jamaica, and the Cayman Islands.
- Together, the **Lesser Antilles** and the **Greater Antilles** compose the Antilles (or the **Caribbean islands**).
- When combined with the **Lucayan Archipelago (Bahama Archipelago)**, all three are known as the **West Indies**.
- Lucayan Archipelago is an island group comprising the Commonwealth of The Bahamas and the British Overseas Territory of the Turks and Caicos Islands.



Islands in the Lesser Antilles Island Arcs (Map from Google Earth)

Formation of Isthmus of Panama

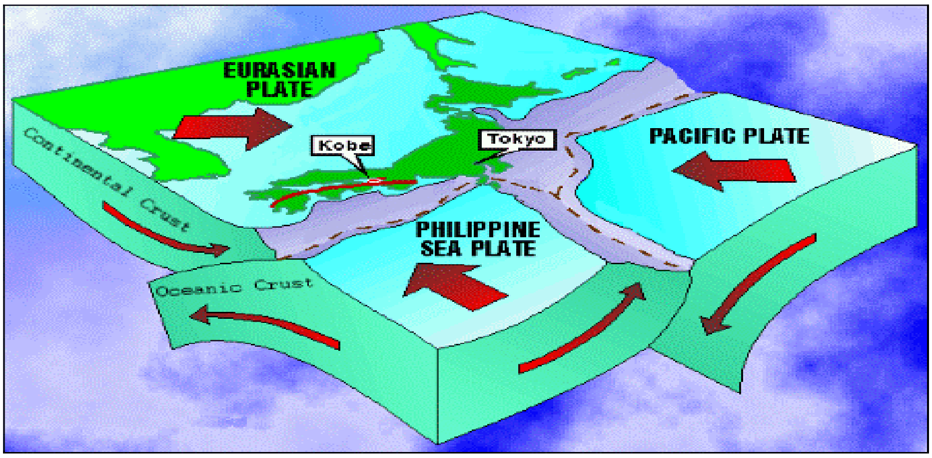
- Formation of the Isthmus of Panama involved subduction of the **Pacific-Farallon Plate** beneath the **Caribbean and South American plates**, forming a volcanic arc on the edge of the Caribbean Plate.
- The remains of the ancient Farallon Oceanic Plate are the Juan de Fuca Plate, parts of the North American Plate and the South American Plate, the Cocos Plate and the Nazca Plate.
- This initial Panama Arc began to form as the Caribbean Plate moved eastward.
- The North and South American plates continued to move westward past the Caribbean Plate.
- In addition to their east-west (strike-slip) motion, the plates also acquired a north-south component of convergence, leading to the collision of the Panama Arc with South America.
- This collision drove uplift in both the Northern Andes and the Panama Arc, forming the Isthmus of Panama.

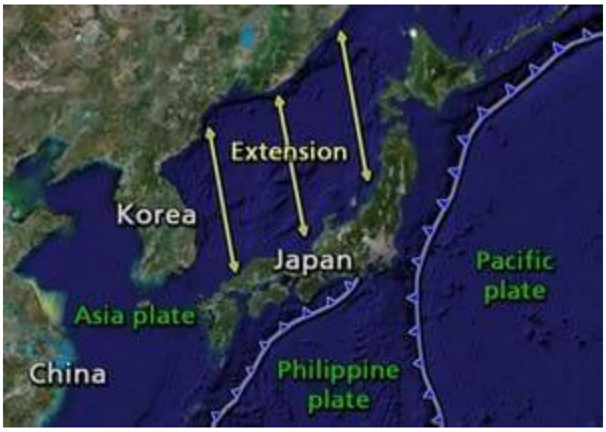


Plates in the region of Isthmus of Panama

Formation of the Japanese Island Arc

- Japan's volcanoes are part of three volcanic arcs.





Triple Junction of the plates

- The arcs meet at a triple junction on the island of Honshu.

- Northern arc is formed due to the subduction of the **Pacific Plate** under the **Eurasian Plate**. The trench formed is **Japan Trench.**
- Central arc is formed due to the subduction of the **Pacific Plate** under the **Philippine Plate** (island formation is not significant along this arc). The trench formed is **Izu Trench.**
- Southern Arc is formed due to the subduction of the **Philippine Plate** under the **Eurasian Plate.** The trench formed is **Ryukyu Trench.**
- Japanese island arc was very close to the mainland.
- The force exerted by the Pacific plate and the Philippine plate tilted the arc towards its east giving rise to the **Sea of Japan.**

The Mariana Trench or Marianas Trench

- The Mariana Trench or Marianas Trench, the **deepest trench**, is located in the western Pacific Ocean.
- The Mariana Trench is formed due to the subduction of the **Pacific Plate** below the **Mariana Plate**.
- The maximum known depth is between 10,994 & 11,034 metres in its floor known as the **Challenger Deep**.

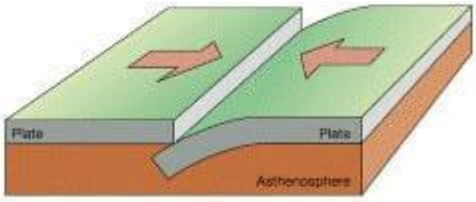
The Mariana trench is not the part of the seafloor closest to the centre of the Earth. This is because the Earth is not a perfect sphere (its Geoid); its radius is about 25 kilometres smaller at the poles than at the equator.

As a result, parts of the **Arctic Ocean seabed** are at least 13 kilometres closer to the Earth's centre than the Challenger Deep seafloor.

CONTINENT-OCEAN CONVERGENCE, FORMATION OF FOLD MOUNTAINS

Convergent Boundary

- Along a convergent boundary two lithospheric plates **collide** against each other.
- **When one of the plates is an oceanic plate, it gets embedded in the softer asthenosphere of the continental plate, and as a result, trenches are formed at the zone of subduction.**



Convergent Boundary

In convergence there are subtypes namely:

1. **Collision of oceanic plates or ocean-ocean convergence (formation of volcanic island arcs).**
2. **Collision of continental and oceanic plates or continent-ocean convergence (formation of continental arcs and fold mountains).**
3. **Collision of continental plates or continent-continent convergence (formation of fold mountains)**
4. **Collision of continent and arc, or continent-arc convergence.**

Continent-Ocean Convergence or The Cordilleran Convergence

- The concept of Continent-Ocean Convergence is important to understand the formation of **the Rockies**, **the Andes** and other similar **fold mountain systems**.
- Continent-Ocean Convergence is also called **Cordilleran Convergence** because this kind of convergence gives rise to extensive mountain systems.
- A cordillera is an extensive chain of mountains or mountain ranges. Some mountain chains in North America and South America are called cordilleras.
- Continent-Ocean Convergence is similar to ocean-ocean convergence. One important difference is that in continent-ocean convergence **mountains are formed instead of islands**.
- When oceanic and continental plates collide or converge, the oceanic plate (denser plate) subducts or plunges below the continental plate (less dense plate) forming a **trench** along the boundary.
- The **trenches formed here are not as deep as those formed in ocean-ocean convergence**.
- As the ocean floor crust (oceanic plate) loaded with sediments subducts into the softer asthenosphere, the rocks on the continental side in the subduction zone become **metamorphosed** under high pressure and temperature (metamorphism: alteration of the composition or structure of rock by heat, pressure).

Formation of Continental Arcs due to Continent-Ocean Convergence

- After reaching a certain depth, plates melt. Magma (metamorphosed sediments and the melted part of the subducting plate) has lower density and is at high pressure.
- It rises due to the **buoyant force** offered by surrounding denser medium. The magma flows out, sometimes violently to the surface.
- A continuous upward movement of magma creates constant volcanic eruptions at the surface of the continental plate along the margin.

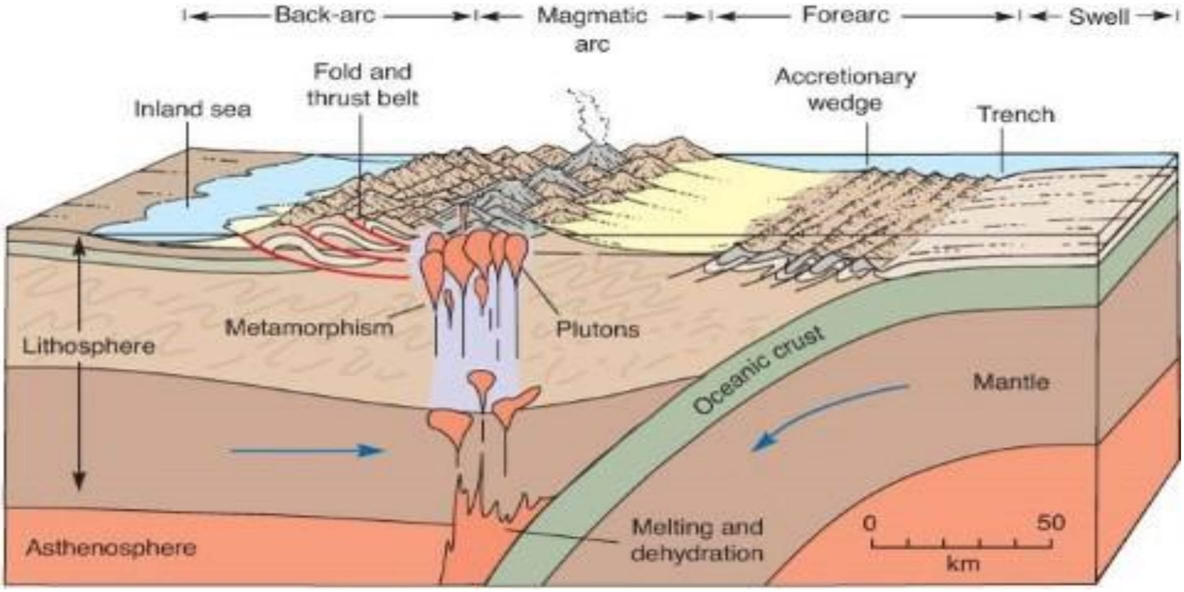
- Such volcanic eruptions all along the boundary form a chain of volcanic mountains which are collectively called as a **continental arc**. E.g. the **Cascade Range (parallel to the Rockies), the Western Chile range (parallel to the Andes)**
    - **Arc:** narrow chain of volcanic islands or mountains.
    - **Island arc:** A narrow chain of volcanic islands (Japanese Islands).
    - **Continental arc:** A narrow chain of volcanic mountains on continents (Cascade Range).
    - **Accretionary wedge:** As the oceanic plate subducts, the sediments brought by it accumulates in the trench region. These accumulated sediments are called as **accretionary wedge**.
    - The accretionary wedge is compressed into the continental margin leading to **crustal shortening**.
    - **Convergence ==> Crustal Shortening**
    - **Divergence ==> Crustal Widening**
    - **Crustal Shortening at one place is compensated by Crustal Widening in some other place**.

FORMATION OF FOLD MOUNTAINS (OROGENY)

Orogeny (Geology) is a process in which a section of the earth's crust is **folded** and deformed by **lateral compression** (force acting sideways) to form a mountain range.

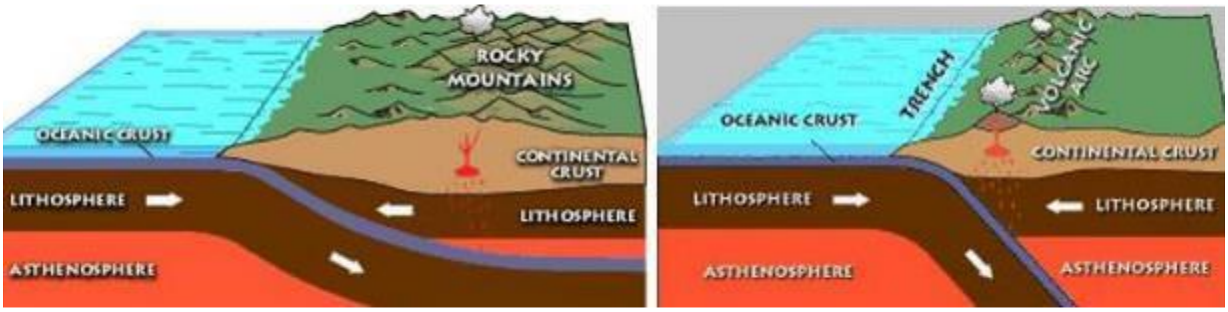
Orogenic movements are 'Tectonic movements' of the earth involve the **folding of sediments**, **faulting** and **metamorphism** (rocks that have transformed by heat, pressure).

- Continental margins are filled with **thick sediments** brought by the rivers.
- As a result of convergence, the buoyant granite of the continental crust overrides (is placed above) the oceanic crust (continental crust in **upthrust** by the oceanic crust).
- As a result, the edge of the deformed continental margin is thrust above sea level.
- The advancing oceanic plate adds more compressive stress on the upthrust continental margin and leads to its **folding** creating a **fold mountain system (orogenic belt)**.
- In some cases, the advancing oceanic plate compresses the **orogenic belt** leading to its folding **(Rockies and Andes).**
- With the formation of the orogenic belt (fold mountain belt), resistance builds up which effectively stops convergence. Thus, the subduction zone progresses seaward.
- With the culmination of compression, erosion continues to denude mountains. This results in **isostatic adjustment** (denser regions sink, and less denser regions rise) which causes the ultimate exposure of the roots of mountains.
- Examples are found in the **Rockies**, deformed in the late Mesozoic and early Tertiary period, and the **Andes**, where the deformation began in the Tertiary Period is still going on.



Continent-Ocean Convergence

Formation of the Andes	The Andes are formed due to convergence between **Nazca plate** (oceanic plate) and the **South American plate** (continental plate). **Peru-Chile trench** is formed due to subduction of Nazca plate. The Andes are a continental arc (narrow, continental volcanic chain) formed due to the volcanism above the subduction zone. The pressure offered by the **accretionary wedge** folded the volcanic mountain, raising the mountains significantly. The folding process is continuing, and the mountains are constantly rising. Volcanism is still active. **Ojos del Salado active volcano** on the Argentina-Chile border is the **highest active volcano** on earth at 6,893 m. (**Olympus Mons** on Mars is the highest volcano in the solar system. It is 26 – 27 km high) **Mount Aconcagua** (6,960 m, Argentina) in the Andes is the highest peak outside the Himalayas and the highest peak in the western hemisphere. It is an **extinct volcano**.
Western Chile Range (Chilean Coast Range)	The range was separated from the Andes during the Tertiary rise of the Andes due to the subsidence of the Intermediate Depression.
Formation of the Rockies	The **North American plate** (continental plate) moved westwards while the **Juan de Fuca plate** (minor oceanic plate) and the **Pacific plate** (major oceanic plate) moved eastwards. The convergence gave rise to a series of parallel mountain ranges. Unlike the Andes, the Rockies are formed at a distance from the continental margin due to the **less steep subduction by the oceanic plates**. **Trenching is less conspicuous** as the boundary is filled with accretionary wedge and there are a series of fault zones (San Andreas Fault) that make the landform different from the Andes.

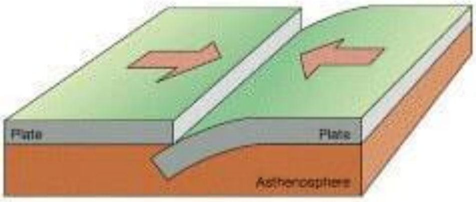


Left: Formation of the Rockies (less steep subduction); Right: Formation of the Andes

Continent-Continent Convergence, Formation of the Himalayas

Convergent Boundary

- Along a convergent boundary two lithospheric plates **collide** against each other.
- **When one of the plates is an oceanic plate, it gets embedded in the softer asthenosphere of the continental plate, and as a result, trenches are formed at the zone of subduction.**



Convergent Boundary

In convergence there are subtypes namely:

1. **Collision of oceanic plates or ocean-ocean convergence (formation of volcanic island arcs).**
2. **Collision of continental and oceanic plates or ocean-continent convergence (formation of continental arcs and fold mountains).**
3. **Collision of continental plates or continent-continent convergence (formation of fold mountains)**
4. **Collision of continent and arc, or continent-arc convergence.**

Continent-Continent Convergence or The Himalayan Convergence

Understanding Continent-Continent Convergence is important to understand the Formation of the Himalayas, the Alps, the Urals and the Atlas Mountains.

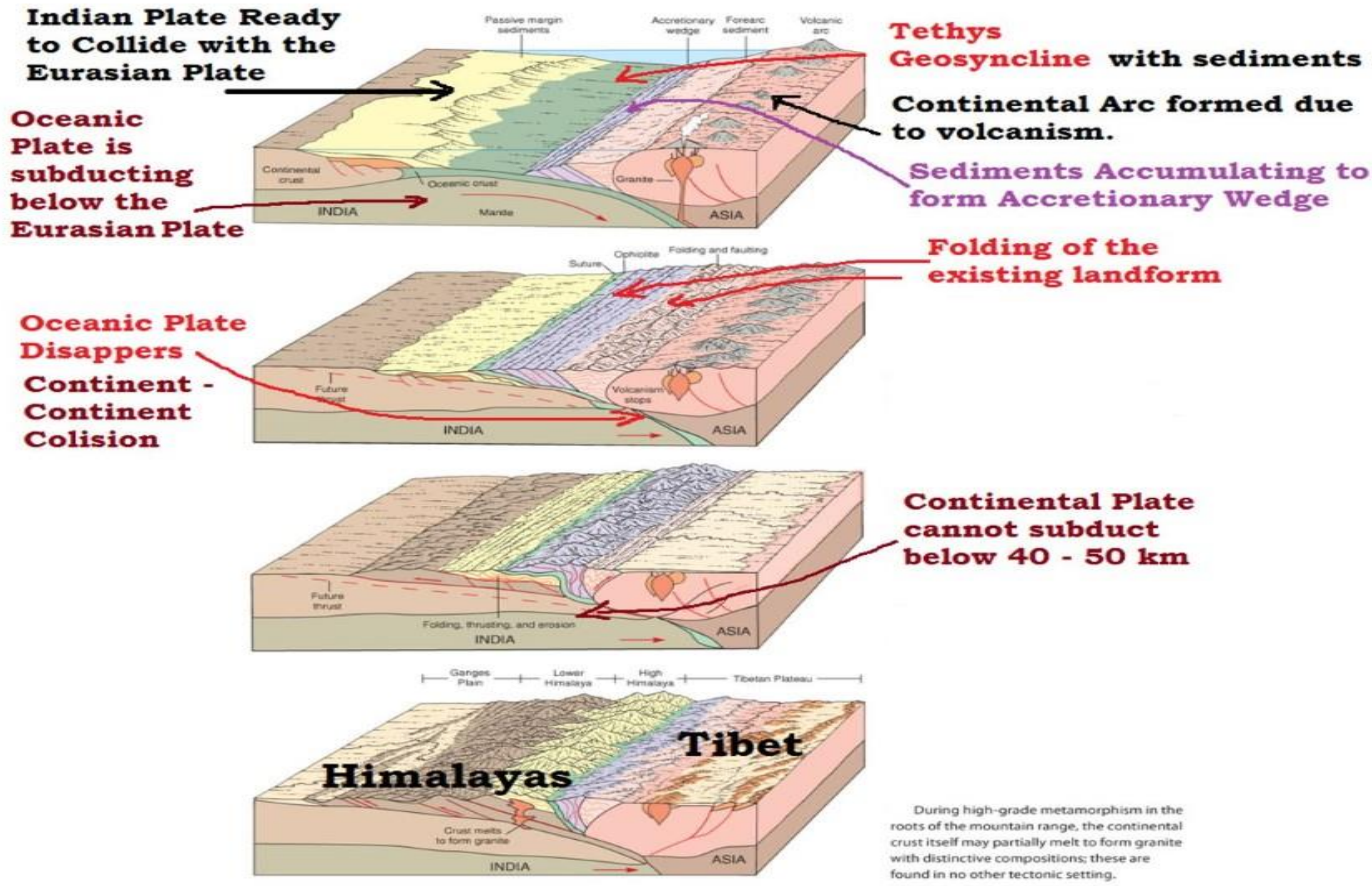
- In ocean-ocean convergence and continent-ocean convergence, **at least one of the plates is denser** and hence the subduction zone is **quite deep** (few hundred kilometres).
- In Continent-Continent Convergence, at continent-continent convergent margins, due to **lower density**, both of the continental crustal plates are too light (buoyant) to be carried downward (subduct) into a trench.
- In most cases, neither plate subducts or even if one of the plates subducts, the **subduction zone will not go deeper than 40 – 50 km**. The two plates converge, buckle up (**suture zone**), fold, and fault.
- As the continental plates converge, the ocean basic or a sedimentary basin (geoclinal or geosynclinal sediments found along the continental margins) is squeezed between the two converging plates.
- Huge slivers of rock, many kilometres wide are thrust on top of one another, forming a towering mountain range.

- With the building up of resistance, convergence comes to an end. The mountain belt erodes, and this is followed by **isostatic adjustment**.
- As two massive continents weld, a single large continental mass joined by a mountain range is produced.
- **Examples: The Himalayas, Alps, Urals, Appalachians and the Atlas Mountains.**

Suture zone: The subduction of the continental crust is not possible beyond 40 km because of the normal buoyancy of the continental crust. Thus, the fragments of oceanic crust are plastered against the plates causing welding of two plates known as **suture zone**. Example: The Indus-Tsangpo suture zone.

Formation of the Himalayans and the Tibetan Plateau due to Continent-Continent Convergence

- The Himalayas are the **youngest mountain chain** in the world.
- Himalayan mountains have come out of a **great geosyncline** called the **Tethys Sea** and that the uplift has taken place in different phases.
- During **Permian Period (250) million years ago**, there was a supercontinent known as **Pangaea.**
- Its northern part consisted of the present-day North America and Eurasia (Europe and Asia) which is called as **Laurasia or Angaraland or Laurentia**.
- The southern part of Pangaea consisted of present-day South America, Africa, South India, Australia and Antarctica. This landmass was called **Gondwanaland.**
- In between Laurasia and Gondwanaland, there was a long, narrow and shallow sea known as the **Tethys Sea** (all this was explained earlier in Continental Drift Theory).
- There were many rivers which were flowing into the Tethys Sea (**some of the Himalayan rivers were older than the Himalayas themselves**. We will study this in Antecedent and Subsequent Drainage).
- Sediments were brought by these rivers and were deposited on the floor of the Tethys Sea.
- These sediments were subjected to powerful compression due to the northward movement of the Indian Plate. This resulted in the folding of sediments.
- An often-cited fact used to illustrate this process is that the **summit of Mount Everest is made of marine limestone** from this ancient ocean.
- Once the Indian plate started plunging below the Eurasian plate, these sediments were further folded and raised. This process is still continuing (India is moving northwards at the rate of about **five cm per year** and crashing into rest of Asia).
- And the folded sediments, after a lot of erosional activity, appear as the present-day Himalayas.
- Tibetan plateau was formed due to **upthrusting** of the southern block of the Eurasian Plate.
- The Indo-Gangetic plain was formed due to the consolidation of alluvium brought down by the rivers flowing from the Himalayas.
- The curved shape of the Himalayas convex to the south is attributed to the maximum push offered at two ends of the Indian Peninsula during its northward drift.



Phases of formation

- The Himalayas do not comprise a single range but a series of at least three ranges running more or less parallel to one another.
- Therefore, the Himalayas are supposed to have emerged out of the Himalayan Geosyncline, i.e. the Tethys Sea in **three different phases** following one after the other.
- The first phase commenced about **50-40 million years ago** when the **Great Himalayas** were formed. The formation of the Great Himalayas was completed about 30 million years ago.
- The second phase took place about **25 to 30 million years ago** when the **Middle Himalayas** were formed.
- The **Shiwaliks** were formed in the last phase of the Himalayan orogeny — say about **two million to twenty million years ago**.
- Some of the fossil formations found in the Shiwalik hills are also available in the Tibet plateau. It indicates that the past climate of the Tibet plateau was somewhat similar to the climate of the Shiwalik hills.

Recent studies have shown that convergence of the Indian plate and the Asian plate has caused a **crustal shortening** of about 500 km in the Himalayan region. This shortening has been compensated by seafloor spreading along the oceanic ridge in the Indian Ocean.

Evidence for the rising Himalayas

- Today's satellites that use high precision atomic clocks that can measure accurately even a small rise of one cm. The heights of various places as determined by satellites indicate that the Himalayas rise by few centimetres every year. The present rate of uplift of the Himalayas has been calculated at 5 to 10 cm per year.

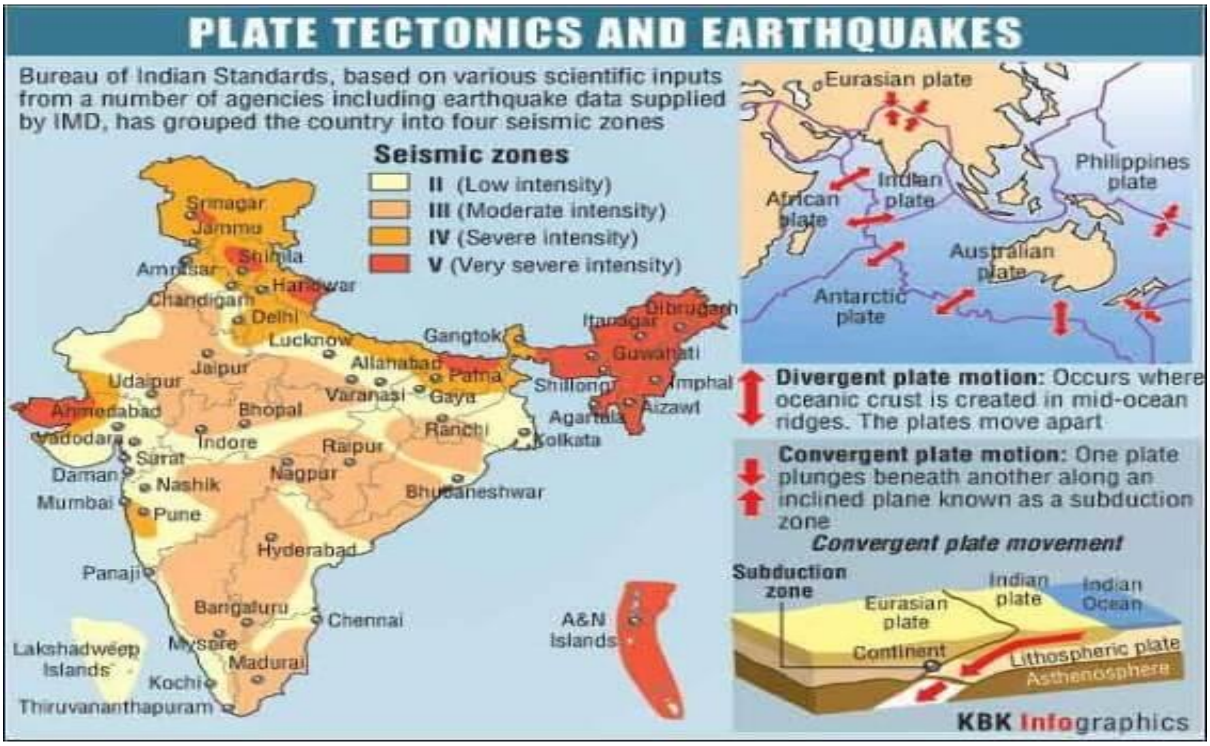
- Due to uplifting, lakes in Tibet are desiccated (lose water) keeping the gravel terraces at much higher levels above the present water level. This could be possible only in the event of uplift of the region.
- The frequent tectonic activity (occurrence of earthquakes) in the Himalayan region shows that the Indian plate is moving further northwards and plunging into the Eurasian plate.
- This means that the Himalayas are still being raised due to compression and have **not yet attained isostatic equilibrium**.
- The Himalayan rivers are in their youthful stage and have been rejuvenated (make or cause to appear younger) in recent times. This shows that the Himalayan Landmass is rising, keeping the rivers in youth stage since a long time.

Formation of Alps, Urals, Appalachians and the Atlas Mountains

- The formation of each of these mountains is similar to the formation of the Himalayas.
- **The Alps** are **young fold mountains** which were formed due to the collision between **African Plate** and the **Eurasian Plate**.
- **The Atlas Mountains** are also **young folded mountains** which are still in the process of formation. They are also formed due to the collision between **African Plate** and the **Eurasian Plate**.
- **The Urals** are **very old fold mountains** which were formed even before the breakup of Pangaea. They were formed due to the collision between Europe and Asia.
- **The Appalachians** are also **very old fold mountains** which were formed even before the breakup of Pangaea. They were formed due to the collision between North America and Europe.

Volcanism and Earthquakes in Continent-Continent Convergence

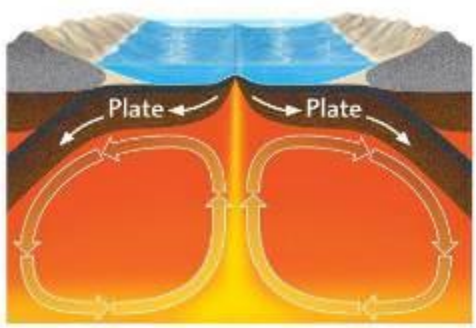
- Oceanic crust is only 5 – 30 km thick. But the continental crust is 50 – 70 km thick. Magma cannot penetrate this thick crust, so there are **no volcanoes**, although the magma stays in the crust.
- **Metamorphic rocks** are common because of the stress the continental crust experiences.
- With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and **large earthquakes** (Earthquakes in Himalayan and North Indian Region, Kachchh region).



Divergent Boundary, The Great Rift Valley (African Rift Valley)

Divergent Boundary

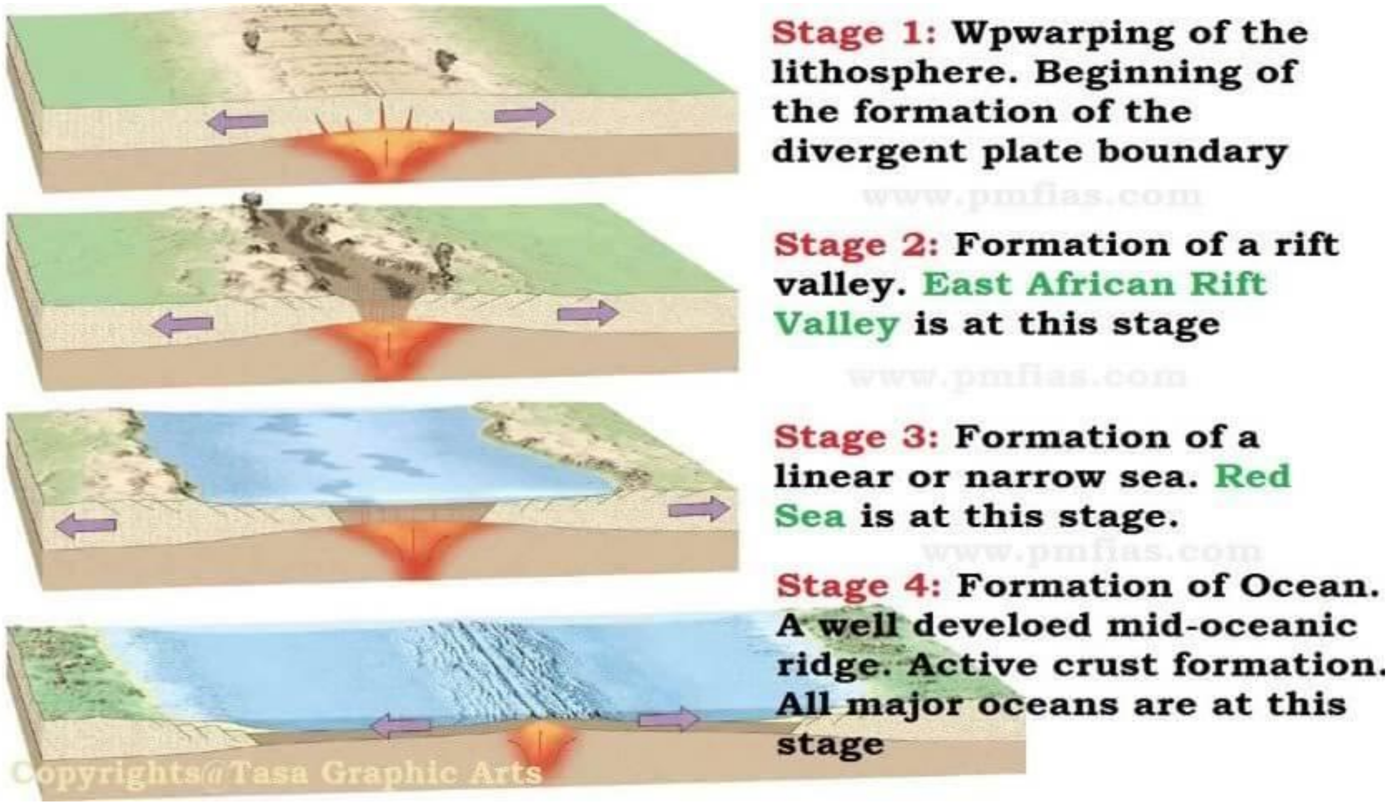
- In the Seafloor Spreading Theory, we have studied how divergent boundaries below the oceans are responsible for the spreading of the seafloor.
- In Plate Tectonics, we have learnt about the major and minor lithospheric plates and how these plates moved through the geological past.
- We have studied about **convection currents** in the mantle which are the primary reason behind plate movements — divergence and convergence of the lithospheric plates.
- The horizontal limbs of the convection currents, just below the lithosphere, drag the plates horizontally.
- The falling limbs of the convection currents create a negative pressure on the lithosphere, and this negative pressure (pulling force) is responsible for the formation of the convergent boundary.
- The **rising limbs**, on the other hand, create positive pressure on the lithosphere, and this positive pressure (pushing force) creates a divergent boundary.
- Divergence (divergent boundary) is responsible for the **evolution and creation of new seas and oceans** just like convergent boundaries are responsible for the formation of **fold mountains, volcanic arcs**.



EVOLUTION OF A DIVERGENT BOUNDARY – FORMATION OF RIFT VALLEYS, RIFT LAKES, SEAS & OCEANS

- The formation of atmosphere and the oceans took millions of years. They were formed due to continuous 'degassing' of the Earth's interior.
- After the Earth's surface temperature came down below the boiling point of water, rain began to fall.
- Water began to accumulate in the hollows and basins, and the primeval (earliest) water bodies were formed.
- The primeval water bodies evolved to form seas and oceans.

- The process of formation of a new sea **begins with the formation of a divergent boundary**.
- **New lithosphere is created at the divergent boundary and old lithosphere is destroyed somewhere else at the convergent boundary**.



Basic Terms:

- **Upwarp:** a broad elevated area of the earth's surface.
- **Plume:** a column of magma rising by convection in the earth's mantle.
- **Rift Valley:** a linear-shaped lowland (graben) between several highlands (horst) or mountain ranges created by the action of a geologic rift or fault.

Stage 1: Upwarping, fault zones

- Rising limbs of the convection currents create a **plume** that tries to escape to the surface by upwarping the lithosphere (doming the lithosphere upwards).
- During upwarping, a series of faults are created. Both normal and thrust faults (reverse fault) occur during upwarping. The divergence of plates begin.

Stage 2: Rift Valley Formation

- Faulting due to divergence creates extensive rift system (fault zones, rift valleys).
- The lithosphere is subject to a horizontal extensional force, and it will stretch, **becoming thinner (E.g. The crust above Yellowstone hotspot is thinning because of mantle plume)**.

Eventually, it will rupture, leading to the formation of a rift valley.

- This process is accompanied by surface manifestations along the rift valley in the form of volcanism and seismic activity.
- Rifts are the initial stage of a continental break-up and, if successful, can lead to the formation of a new ocean basin.

- An example of a place on Earth where this has happened is the South Atlantic Ocean, which resulted from the breakup of South America and Africa around 138m years ago.
- The East African Rift is described as an active type of rift. Beneath this rift, the **rise of a large mantle plume** is doming the lithosphere upwards (Ethiopian Highlands), causing it to weaken.
- The rifting started in the **Afar region** in northern Ethiopia at around 30 million years ago and propagating southwards towards Zimbabwe. (It's unzipping Africa!)
- Rifting is followed by **flood basalt volcanism** in some places that spread around the rift creating plateaus and highlands (Ethiopian Highlands, Kenya Dome).

Backdrop: In early 2018, a large crack made a sudden appearance in south-western Kenya adding fuel to the debate on the breakup of Africa.

Narmada and Tapti Rift Valleys (fault zones) are formed from a mechanism different from the one explained above. They are formed due to the bending of the northern part of the Indian plate during the formation of Himalayas.

Stage 3: Formation of Linear Sea or Rift Lakes

- Rift valley deepens due to further divergence and makes way for ocean waters.
- If the rift valleys are formed deeper within the continents, rains waters accumulate forming rift lakes.
- Rift lakes form **some of the largest freshwater lakes** on earth.
- Rift valleys evolve into a volcanic vent. Block mountains on either side of the rift evolve into oceanic ridges.
- Successive volcanism and seafloor spreading create spreading sites where new crust is formed (divergent boundary is also called a **constructive edge**).
- Oceanic crust starts to replace continental crust. This stage is the formation of linear seas. Example: **Red Sea**.

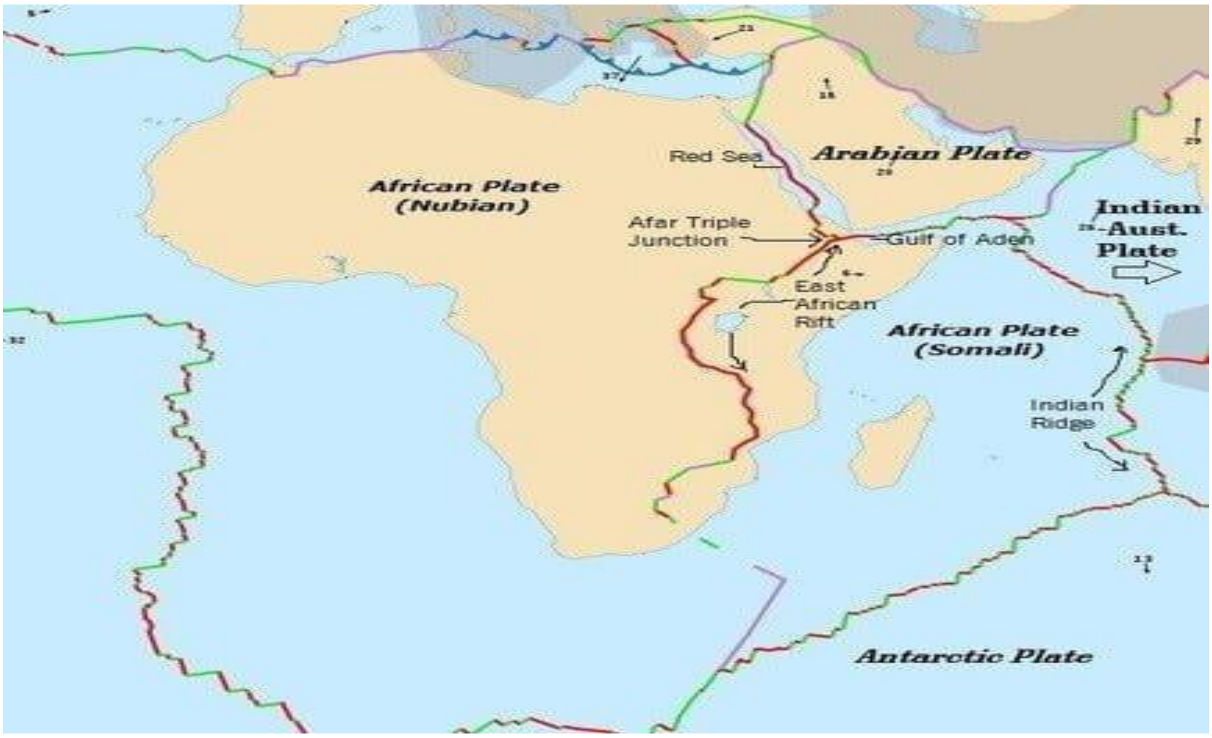
Stage 4: Linear Sea transforms into Ocean

- The intense outpouring of basaltic magma accentuates **see floor spreading** and **oceanic crust formation**.
- Oceanic crust replaces the continental crust, and a mighty ocean is formed.
- **Crust formation along the mid-oceanic ridge (divergent boundary) is compensated by crust destruction (crustal shortening) along the convergent boundary (destructive Edge). This is how the continents and oceans get transformed.**

Great Rift Valley (The Best Example of a Divergent Boundary)

- The Great Rift Valley is a geographical feature running north to south for around 6,400 kilometres from northern Syria to central Mozambique in East Africa.
- The northernmost part of the Rift forms the Beqaa Valley in **Lebanon**.
- Farther south, the valley is the home of the **Jordan River** which continues south through the Jordan Valley into the **Dead Sea** on the Israeli-Jordanian border.
- From the Dead Sea southward, the Rift is occupied by the **Gulf of Aqaba** and the **Red Sea**.
- The **Afar Triangle of Ethiopia and Eritrea** is the location of a triple junction.
- The Gulf of Aden is an eastward continuation of the rift, and from this point, the rift extends south-eastward as part of the mid-oceanic ridge of the Indian Ocean.

- In a southwest direction, the fault continues as the Great Rift Valley, which split the older **Ethiopian highlands** into two halves.
- In eastern Africa, the valley divides into the Eastern Rift and the Western Rift. The Western Rift, also called the **Albertine Rift** contains **some of the deepest lakes in the world**.

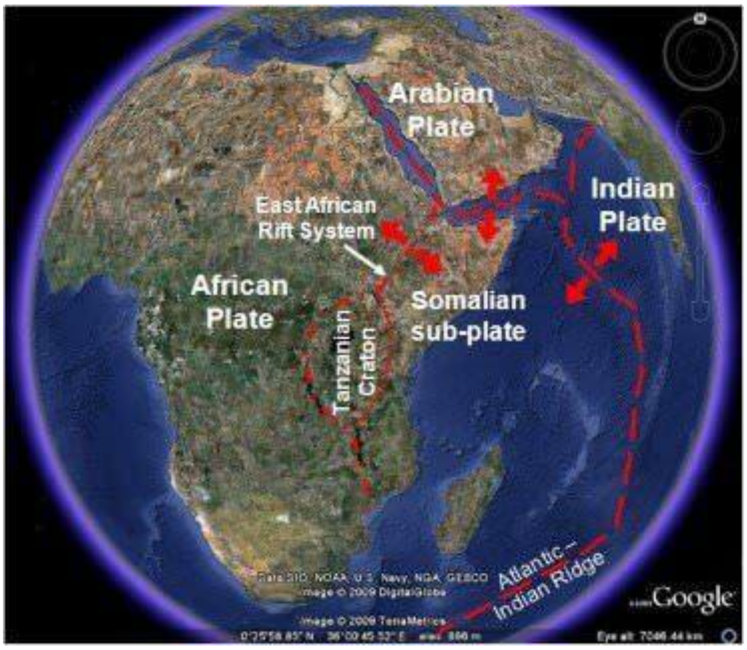


East African Rift Valley

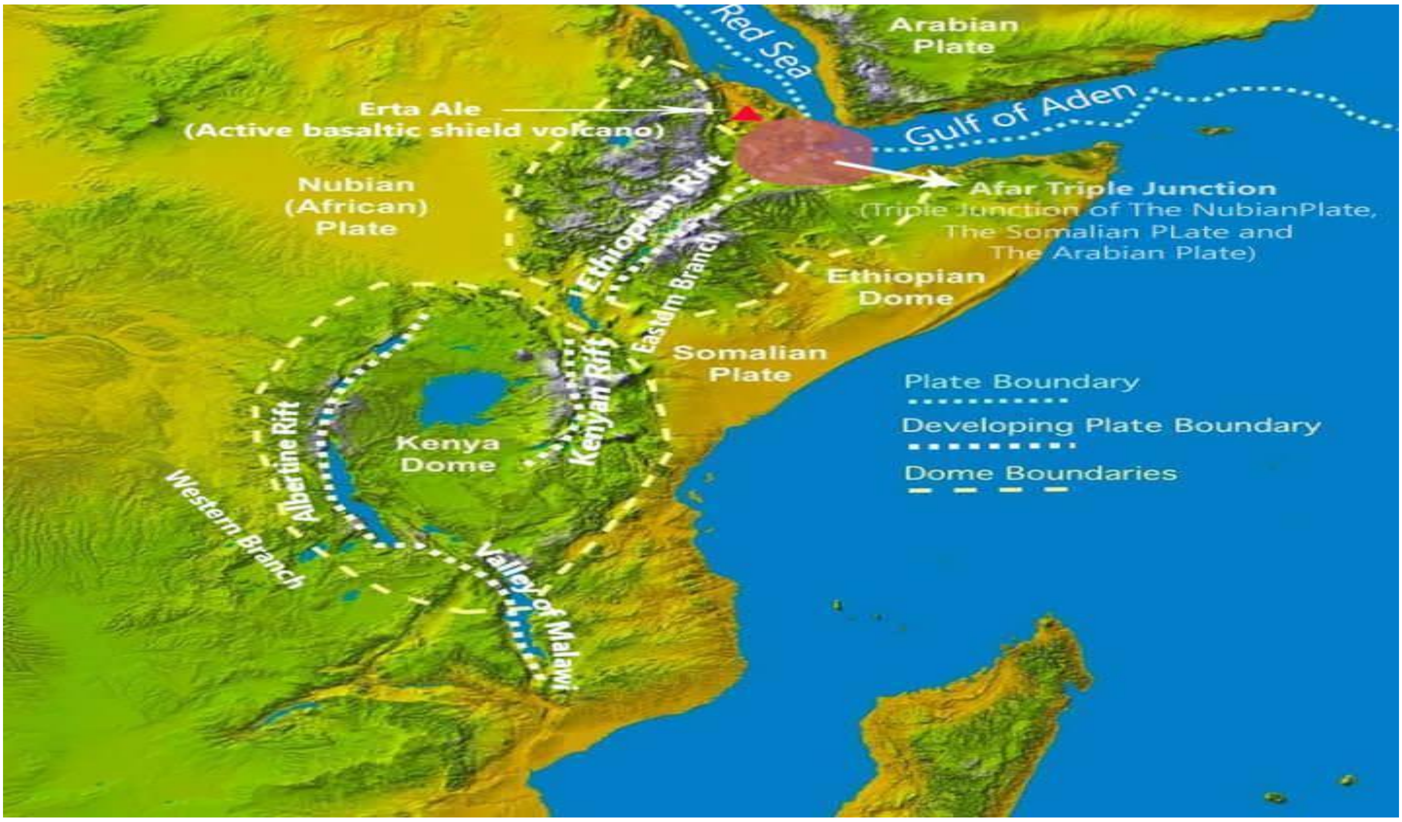
- The Eastern Rift Valley (also known as **Gregory Rift**) includes the main **Ethiopian Rift**, running eastward from the **Afar Triple Junction**, which continues south as the **Kenyan Rift Valley**.
- The Western Rift Valley includes the **Albertine Rift**, and farther south, the valley of **Lake Malawi**.
- To the north of the **Afar Triple Junction**, the rift follows one of two paths: west to the **Red Sea Rift** or east to the **Aden Ridge in the Gulf of Aden**.
- The EAR transects through Ethiopia, Kenya, Uganda, Rwanda, Burundi, Zambia, Tanzania, Malawi and Mozambique.
- Before rifting, enormous continental flood basalts erupted on the surface and uplift of the **Ethiopian, Somalian, and East African plateaus** occurred.

Breaking up of Africa

- The East African Rift (EAR) is an **active continental rift zone** in East Africa.
- The EAR began developing around the onset of the Miocene, **22-25 million years ago**.
- In the past, it was considered to be part of a larger Great Rift Valley.
- The EAR is subjected to different stages of rifting along its length. To the **south, where the rift is young**, extension rates are low, and faulting occurs over a wide area. Volcanism and seismicity are limited.
- Towards the **Afar region**, however, the entire rift valley floor is covered with volcanic rocks.
- This suggests that, in this area, the **lithosphere has thinned almost to the point of complete break-up**.



- The rift is a narrow zone that is a developing divergent tectonic plate boundary, in which the African Plate is in the process of splitting into two tectonic plates, called the **Somali Plate** and the **Nubian Plate (African Plate)**, at a rate of 6–7 mm annually.
- As extension continues, **lithospheric rupture** will occur within 10 million years, the Somalian plate will break off, and a new ocean basin will form.



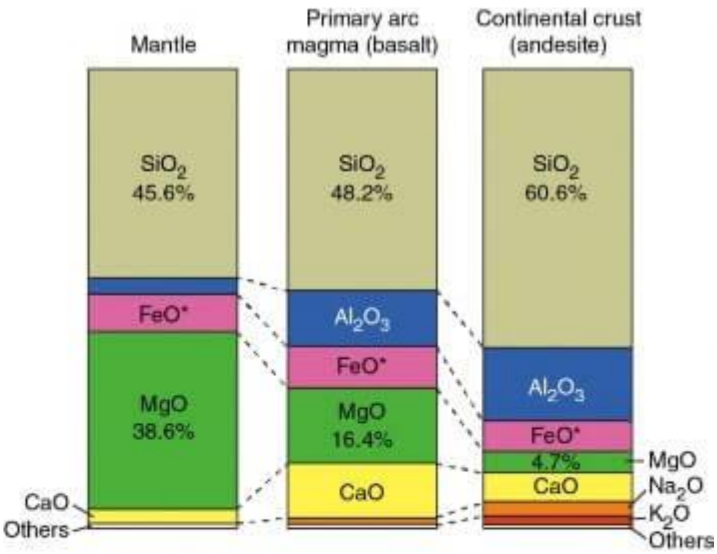
Volcanism and seismicity along East African Rift Valley

- The East African Rift Zone includes many active as well as dormant volcanoes.
- **Mount Kilimanjaro** (it has three volcanic cones), is a **dormant** stratovolcano in Tanzania, **Mount Kenya** is an extinct stratovolcano.
- Although most of these mountains lie outside of the rift valley, the EAR created them.

- The EAR is the **largest seismically active rift system** on Earth today.
- The majority of earthquakes occur near the Afar Depression, with the largest earthquakes typically occurring along or near major border faults.

How come Mount Kilimanjaro and Mount Kenya that formed close to the divergent boundary are stratovolcanoes when the magma that flows out at the divergent boundary is basaltic?

- The formation of stratovolcano and shield volcano depends on the silica content of the magma.
- **Shield volcanoes** are formed from magma that contains a low proportion of silicates (**magma coming from the mantle, like in divergent boundary**).
- Stratovolcanoes are formed from magma that contains a high proportion of silicates (**magma formed due to the melting of crustal plates, like in convergent boundary**).
- Mt Kilimanjaro is a stratovolcano. It was formed during the process of formation of the African rift valley.
- During the formation of the African rift valley, there was a lot of faulting. The stress caused in the crustal plates led to the melting of the subsurface layer into magma, and the volcanism around Kilimanjaro occurred due to this magma (high proportion of silicates).
- Take a look at the picture below to know the proportion of silicon content in mantle and crust.



Silicon content in the mantle, oceanic crust (mafic) and the continental crust (felsic)

- Majority of the stratovolcanoes occur along the convergent boundary, but there is no fixed rule that they should occur only along convergent boundaries. It all depends on the nature of magma that flows out.

CLASSIFICATION OF MOUNTAINS ON THE BASIS OF LOCATION, ORIGIN

Classification of mountains on the basis of location	Continental mountains Oceanic mountains
Continental mountains	Coastal mountains Inland mountains
Coastal mountains	The Rockies, The Appalachians, The Alpine mountain chains, The Western Ghats and The Eastern Ghats (India);
Inland mountains	The Vosges and the Black Forest (Europe), The Kunlun, Tienshan, Altai mountains of Asia, The Urals of Russia, the Aravallis, The Himalayas, the Satpura, and the Maikal of India
Oceanic mountains	Oceanic mountains are found on continental shelves and ocean floors. If the height of the mountains is considered from the ocean floor, **Mauna Kea (9140 m)**, would be the highest mountain. It is a dormant volcanic mountain in the Hawaii hotspot volcanic chain.

Mauna Kea, a dormant volcano in the island of Hawaii

Classification of mountains on the basis of the period of origin

- A total of nine orogenic or mountain building movements have taken place so far.
- Some of them occurred in Pre-Cambrian times between 600-3,500 million years ago.
- The three more recent orogenies are the **Caledonian, Hercynian and Alpine**.

PRECAMBRIAN MOUNTAINS	They belong to the Pre-Cambrian period, a period that extended for more than 4 billion years.

	The rocks have been subjected to upheaval, denudation and metamorphosis. So, the remnants appear as **residual mountains.** Some of the examples are Laurentian mountains, Algoman mountains etc.
CALEDONIAN MOUNTAINS	They originated due to the great mountain-building movements and associated tectonic movements of the late Silurian and early Devonian periods (approximately 430 million years and 380 million years ago). Examples are the **Appalachians, Aravallis, Mahadeo** etc
HERCYNIAN MOUNTAINS	These mountains originated during the upper Carboniferous to Permian Period in Europe (approximately 340 million years and 225 million years ago). Some examples are the mountains of **Vosges and the Black Forest, Altai, Tien Shan mountains of Asia, Ural Mountains etc**.
ALPINE MOUNTAIN SYSTEM	Has its origin in the **Tertiary Period** (**65 million years to 7 million years ago)**. Examples are • **the Rockies of North America, the Alpine mountains of Europe,** • **the Atlas Mountains of north-western Africa,** • **the Himalayas of the Indian subcontinent** • **the mountains radiating from Pamir knot like Pontic, Taurus, Elburz, Zagros and Kunlun etc.** • Being the most recently formed, these ranges, such as the Alps, Himalayas, Andes and Rockies are the **loftiest with rugged terrain**.

Classification of mountains on the basis of mode of origin

1. Original or Tectonic mountains
2. Circum-erosional or Relict or Residual mountains

ORIGINAL / TECTONIC MOUNTAINS

- Original or Tectonic mountains are the product of tectonic forces.
- The tectonic mountains may be categorized into
- **fold mountains (the Himalayas, the Rockies, the Andes),**
- **block mountains (Vosges mountains in France, the Black Forest in Germany, Vindhya and Satpura in India) and**
- **volcanic mountains (Cascade Range in the USA, Mount Kenya, Mount Kilimanjaro, Mount Fujiyama)**.

VOLCANIC MOUNTAINS

- Volcanic mountains are formed due to volcanic activity.
- Mount Aconcagua, Mount Kilimanjaro, Mount Mauna Kea and Mount Fujiyama are examples of such mountains.
- These are, in fact, volcanoes which are built up from material ejected from fissures in the earth's crust.
- The materials include molten lava, volcanic bombs, cinders, ashes, dust and liquid mud.
- They fall around the vent in successive layers, building up a characteristic volcanic cone.
- Volcanic mountains are often called **mountains of accumulation**.
- They are common in the Circum-Pacific belt.

Circum-erosional or Relict or Residual mountains

- Circum-erosional or Relict or Residual mountains (**Aravallis in India, Urals in Russia**) are the remnants of old fold mountains derived as a result of **denudation** (strip of covering).
- Residual mountains may also evolve from plateaus which have been dissected by rivers into hills and valleys.
- Examples of **dissected plateaux**, where the down-cutting streams have eroded the uplands into mountains of denudation, are the Highlands of Scotland, Scandinavia and the **Deccan Plateau**.

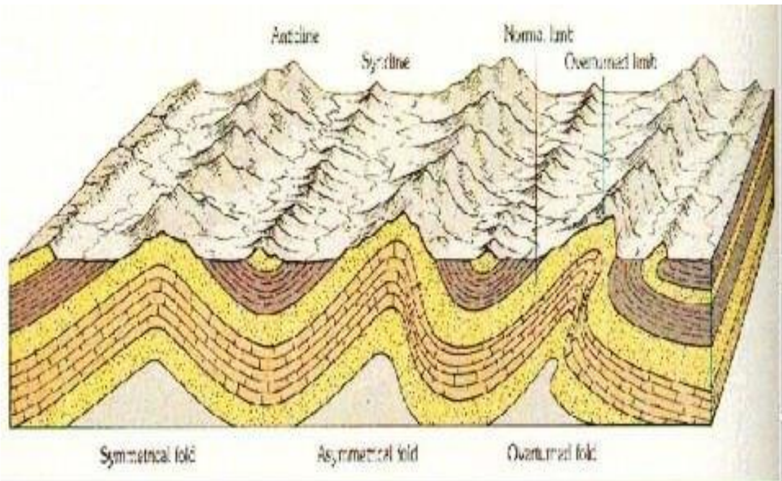
FOLD MOUNTAINS

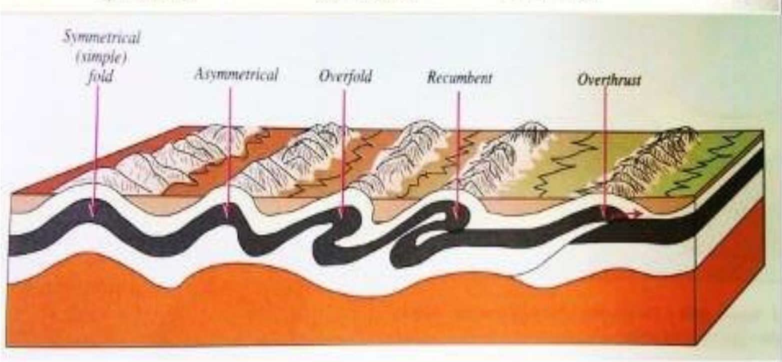
- Fold mountains are formed when sedimentary rock strata in **geosynclines** are subjected to compressive forces.
- They are the **loftiest** mountains, and they are generally concentrated along continental margins.

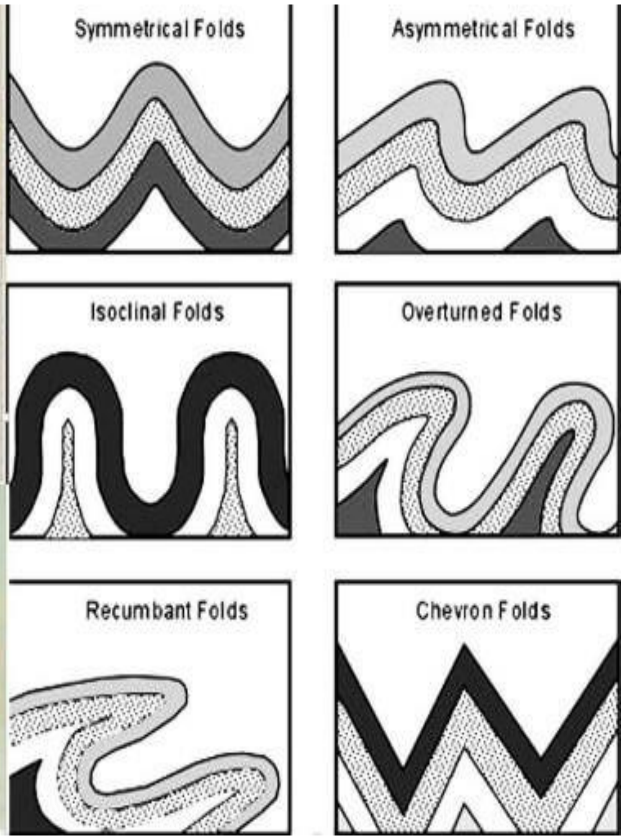
Geosyncline: a large-scale depression in the earth's crust containing very thick deposits. E.g. Tethys geosyncline.

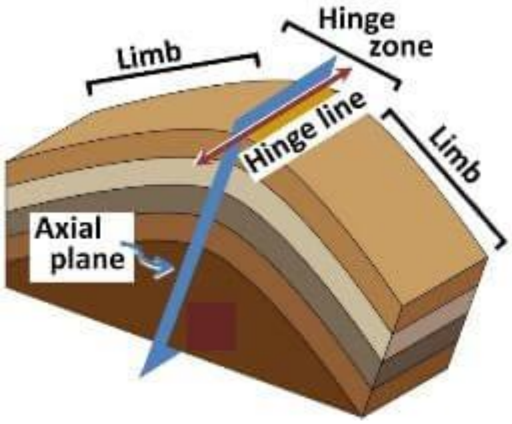
'Fold' in geology

- A fold is an undulating structure (wave-like) that forms when rocks or a part of the earth's crust is folded (deformed by bending) under compressional stress. The folds are made up of **multiple strata** (rock layers).
- The folds that are upwardly convex are called as **anticlines**. The core (centre) of an anticline fold consists of the older strata, and the strata are progressively younger outwards.
- In contrast, the folds that are downwardly convex are called **synclines**. The core of a syncline fold consists of the younger strata, and the strata are progressively older outwards.









- **Limbs:** The limbs are the flanks of the fold.
- **Hinge line:** the where the flanks join together (the line of maximum curvature).
- **Axial plane:** plane defined by connecting all the hinge lines of stacked folding surfaces (the plane in which hinge lines of various strata lie).

Types of folds

- A **symmetrical fold** is one in which the axial plane is vertical.
- An **asymmetrical fold** is one in which the axial plane is inclined.
- An **isoclinal fold** has limbs that are essentially parallel to each other and thus approximately parallel to the axial plane.
- An **overturned fold** has a highly inclined axial plane such that the strata on one limb are overturned.
- A **recumbent fold** has an essentially horizontal axial plane.

CLASSIFICATION OF FOLD MOUNTAINS

On the basis of period of origin	On the basis of the period of origin, fold mountains are divided into very old fold mountains, old fold mountains and Alpine fold mountains.
Very Old Fold Mountains	They are more than 500 million years old. They have rounded features (due to denudation). They are of low elevation. Some of the examples are Laurentian mountains, Algoman mountains, etc
Old Fold Mountains	Old fold mountains had their origin before the Tertiary period (tertiary period started 66 million years ago). The fold mountain systems belonging to **Caledonian** and **Hercynian** mountain-building periods fall in this category. The **Appalachians** in North America and the **Ural Mountains** in Russia are the examples. They are also called **thickening relict fold mountains** because of lightly rounded features and medium elevation. Top layers are worn out due to erosional activity. Example: **Aravalli Range** in India. The **Aravalli Range** in India is the **oldest fold mountain systems in India**. The range rose in post-Precambrian event called the **Aravalli-Delhi orogeny.**

Alpine or young fold mountains	Alpine fold mountains belonging to the Tertiary period (66 million years ago to present) can be grouped under the new fold mountains category since they originated in the Tertiary period. Examples are the **Rockies, the Andes, the Alps, the Himalayas**, etc.

Characteristics

- Rugged relief.
- Imposing height (lofty).
- High conical peaks.

On the basis of the nature of folds

Simple fold mountains

- Simple fold mountains with open folds in which **well-developed systems of synclines and anticlines** are found, and folds are of wavy patterns.

Complex fold mountains

- Complex fold mountains in which the rock strata are intensely compressed to produce a complex structure of folds.
- In the Himalayas, over folds and recumbent folds are often found detached from their roots and carried a few hundred kilometres away by the tectonic forces. These detached folds are called '**nappe**.'

Characteristics of Fold Mountains

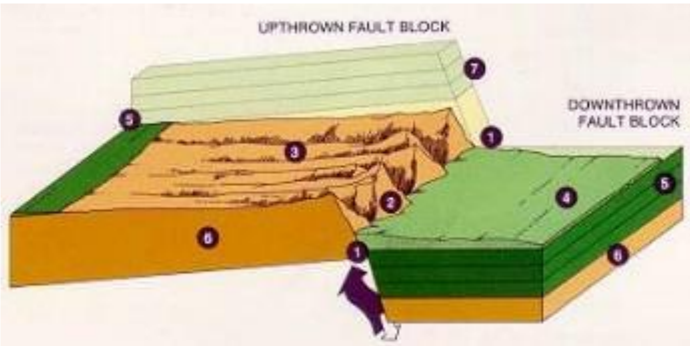
- Fold mountains belong to the group of **youngest mountains of the earth**.
- The presence of fossils suggests that the **sedimentary rocks** of these folded mountains were formed after accumulation and consolidation of silts and sediments in a marine environment.
- Fold mountains extend for **great lengths** whereas their **width is considerably small**.
- Generally, fold mountains have a concave slope on one side and a convex slope on the other.
- Fold mountains are mostly found along continental margins facing oceans (C-O Convergence).
- Fold mountains are characterized by **granite intrusions** (formed when magma crystallises and solidifies underground to form intrusions) on a massive scale.
- **Recurrent seismicity** is a common feature in folded mountain belts.
- High heat flow often finds expression in **volcanic activity** (Himalayas is an exception, because of C-C convergence).
- These mountains are by far the most widespread and also the most important.
- They also contain rich mineral resources such as **tin, copper, gold** etc.

BLOCK MOUNTAINS

- Block mountains are created because of faulting on a large scale (when large areas or blocks of earth are broken and **displaced vertically or horizontally**).
- The uplifted blocks are termed as **horsts,** and the lowered blocks are called **graben**.
- The **Great African Rift Valley (valley floor is graben)**, The **Rhine Valley (graben)** and the **Vosges mountain (horst)** in Europe are examples.
- Block mountains are also called **fault-block mountains** since they are formed due to faulting as a result of tensile and compressive forces.

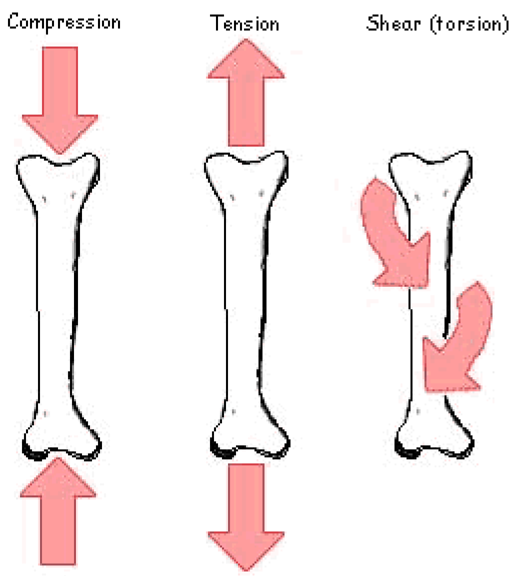
There are two basic types of block mountains:

1. **Tilted block** mountains have one steep side contrasted by a gentle slope on the other side.
2. **Lifted block mountains** have a flat top and extremely steep slopes.



'Fault' in Geology

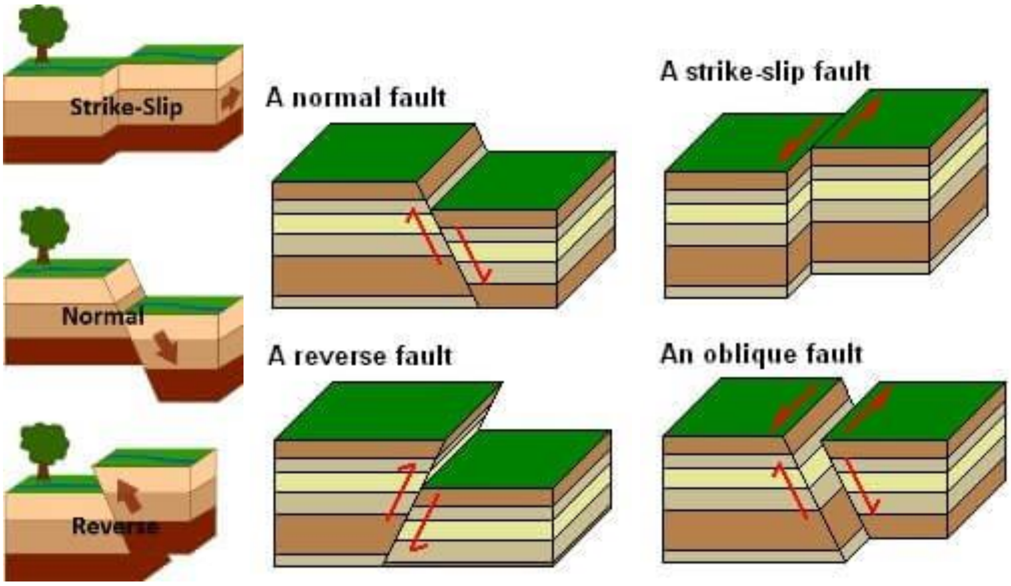
- When the earth's crust bends folding occurs, but when it cracks, faulting takes place.
- A fault is a planar fracture (crack) in a volume of earth's crust, across which there has been significant displacement of a block/blocks of crust.
- The **faulted edges are usually very steep**, e.g. the Vosges 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 faults



Types of faults

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**).

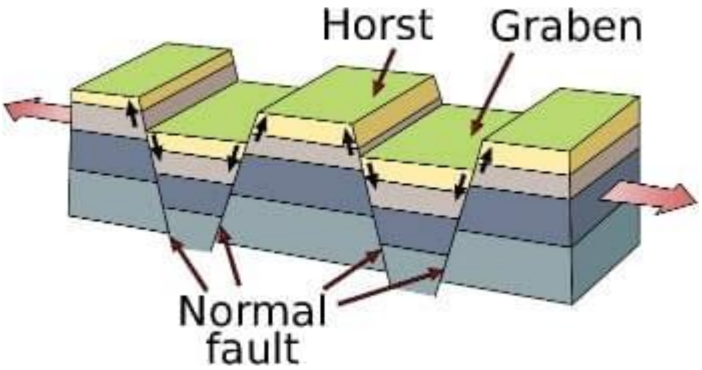
Transform fault

- 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.

Major Mountain Ranges of the World, Highest Mountain Peaks

Basics

Ridge

- Mountain ridges refer to mountains which originate as a result of local folding and faulting.
- Generally, the slope of one side of the ridge is steep in contrast to the moderate slope on the other side (**in case of Himalayas, the southern slope is steeper compared to the northern slope**).
- In some cases, a ridge may have a symmetrical slope on both sides.

Mountain range

- It refers to a series of ridges which originated in the same age and underwent the same processes.
- The most prominent or characteristic feature of mountain ranges is their long and narrow extension.

- Example: the Himalayas is a mountain range with Himadri ridge, Himachal ridge and Shiwalik ridge.

Mountain System

- A group of mountain ranges formed in a single period, similar in their form, structure and extension, is termed a mountain system.
- Examples are the Basin Range of Nevada (USA), the Rocky mountain system of North America and the Appalachian.

Mountain Chain

- It consists of mountain ranges which differ in size and period of formation.

Cordillera

- Cordillera is a community of mountains which includes ridges, ranges, mountain chains and mountain systems.
- The best example is the Western Cordillera in the western part of North America.

Longest Mountain Ranges

1. The Andes – 7,000 km
2. The Rockies – 4,830 km
3. The Great Dividing Range – 3,500 km
4. The Transantarctic Mountains – 3,500 km
5. The Ural Mountains – 2,500 km
6. The Atlas Mountains – 2,500 km
7. The Appalachian Mountains – 2,414 km
8. The Himalayas – 2,400 km
9. The Altai Mountains – 2,000 km (1,243 mi)
10. The Western Ghats – 1,600 km
11. The Alps – 1,200 km
12. Drakensberg – 1,125 km
13. The Aravalli Range – 800 km

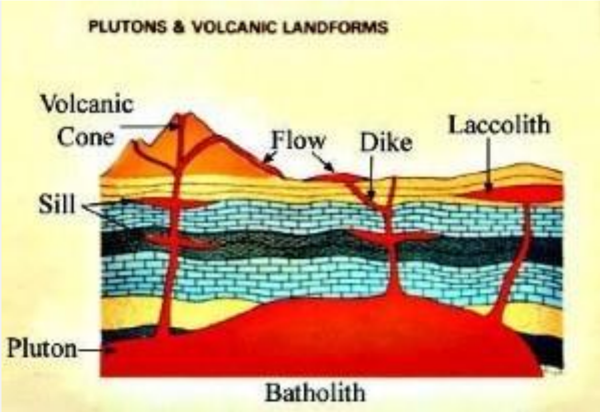
ROCK SYSTEM

Igneous, Sedimentary & Metamorphic Rocks, Rock cycle

- Rocks are an aggregate of one or more minerals held together by chemical bonds.
- **Feldspar** and **quartz** are the most common minerals found in rocks.
- The scientific study of rocks is called **petrology**.
- Based on the mode of formation three major groups of rocks are defined: igneous, sedimentary, and metamorphic.
- **Igneous Rocks** — solidified from magma and lava.
- **Sedimentary Rocks** — the result of deposition of fragments of rocks.
- **Metamorphic Rocks** — formed out of existing rocks undergoing recrystallisation.

IGNEOUS ROCKS – PRIMARY ROCKS

	The solidification of magma formed the first rocks on earth. Rocks formed out of solidification of magma (molten rock below the surface) and lava (molten rock above the surface) and are known as **igneous or primary rocks**. Having their origin under conditions of high temperatures the igneous rocks are **unfossiliferous**. **Granite, gabbro, basalt,** are some of the examples of igneous rocks. **There are three types of igneous rocks based on place and time taken in cooling of the molten matter, plutonic rocks, volcanic rocks and intermediate rocks.** There are two types of rocks based on the presence of acid-forming radical, silicon, **acidic rocks** and **basic rocks.**
INTRUSIVE IGNEOUS ROCKS (PLUTONIC ROCKS)	If magma cools slowly at great depths, mineral grains formed in the rocks may be **very large**. Such rocks are called **intrusive rocks or plutonic rocks (e.g. Granite).** These rocks appear on the surface only after being uplifted and denuded.
EXTRUSIVE IGNEOUS ROCKS (LAVA OR VOLCANIC ROCKS)	Sudden cooling of magma just below the surface or lava above the surface results in small and smooth grains in rocks as rapid cooling prevents crystallisation, as a result, such rocks are fine-grained. Such rocks are called **extrusive rocks or volcanic rocks (e.g. Basalt)**. The Deccan traps in the Indian peninsular region is of basaltic origin. Basic rocks contain a greater proportion of **basic oxides**, e.g. of iron, aluminium or magnesium, and are thus **denser and darker in colour**.
HYPABYSSAL OR DYKE ROCKS OR INTERMEDIATE ROCKS	These rocks occupy an intermediate position between the deep-seated plutonic bodies and the surface lava flows. Dyke rocks are semi-crystalline in structure.

	
ACIDIC ROCKS	Acidic rocks are characterised by high content of silica (quartz and feldspar) — up to 80 per cent. The rest is divided among aluminium, alkalis, magnesium, iron oxide, lime etc. These rocks have a lesser content of heavier minerals like iron and magnesium. Hence, they are less dense and are lighter in colour than basic rocks. These rocks constitute the sial portion of the crust. Due to the excess of silicon, **acidic magma cools fast,** and it does not flow and spread far away. **High mountains** are formed of this type of rock. Add rocks are hard, compact, massive and resistant to weathering. **Granite, quartz** and **feldspar** are typical example
BASIC ROCKS	These rocks are poor in silica (about 40 per cent); magnesia content is up to 40 per cent, and the remaining is spread over iron oxide, lime, aluminium, alkalis, potassium etc. Due to low silica content, the parent material of such rocks **cools slowly and thus, flows and spreads far away**. This flow and cooling give rise to plateaus. Presence of heavy elements imparts to these rocks a dark colour. **Not being very hard, these rocks are weathered relatively easily**. **Basalt**, **gabbro** and **dolerite** are typical examples.

Economic Significance of Igneous Rocks

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

SEDIMENTARY ROCKS – DETRITAL ROCKS

- Sedimentary rocks are formed by **lithification** — consolidation and compaction of sediments.
- Hence, they are layered or stratified of varying thickness. Example: **sandstone, shale** etc.
- Sediments are a result of denudation (weathering and erosion) of all types of rocks.

- These types of rocks cover 75 per cent of the earth's crust but volumetrically occupy only 5 per cent (because they are available only in the upper part of the crust).
- Ice deposited sedimentary rocks are called **till or tillite**. Wind-deposited sediments are called **loess**.

Depending upon the mode of formation, sedimentary rocks are classified into:

1. mechanically formed — **sandstone, conglomerate, limestone, shale, loess**.
2. organically formed — **geyserite, chalk, limestone, coal**.
3. chemically formed — **limestone, halite, potash**.

Mechanically Forme	They are formed by mechanical agents like running water, wind, ocean currents, ice, etc. Arenaceous sedimentary rocks have more sand and bigger sized particles and are hard and **porous**. They form the **best reservoirs for liquids like groundwater and petroleum**. E.g. sandstone. Argillaceous rocks have more clay and are fine-grained, softer, **mostly impermeable** (mostly non-porous or have very tiny pores). E.g. claystone and shales are predominantly argillaceous
Chemically Formed	Water containing minerals evaporate at the mouth of springs or salt lakes and give rise to Stalactites and stalagmites (deposits of lime left over by the lime-mixed water as it evaporates in the underground caves).
Organically Formed	The remains of plants and animals are buried under sediments, and due to heat and pressure from overlying layers, their composition changes. **Coal and limestone** are well-known examples. Depending on the predominance of calcium content or the carbon content, sedimentary rocks may be calcareous **(limestone, chalk, dolomite)** or **carbonaceous (coal)**.

Chief Characteristics of Sedimentary Rocks

- They are **stratified** — consist of many layers or strata.
- They hold the most informative geological records due to the marks left behind by various geophysical (weather patterns, wind and water flow) and biological activities (fossils).
- They are **fossiliferous** — have fossils of plants and animals.
- These rocks are **generally porous and allow water to percolate** through them.

The spread of Sedimentary Rocks in India

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

Economic Significance of Sedimentary Rocks

- Sedimentary rocks are not as rich in minerals of economic value as the igneous rocks.

- But important minerals such as hematite iron ore, phosphates, building stones, coals, petroleum and material used in the cement industry are found.
- The decay of tiny marine organisms yields petroleum. Petroleum occurs in suitable structures only.
- Important minerals like bauxite, manganese, tin, are derived from other rocks but are found in gravels and sands carried by water.
- Sedimentary rocks also yield some of the richest soils.

METAMORPHIC ROCKS

- The word metamorphic means '**change of form**'.
- Metamorphism is a process by which **recrystallisation and reorganisation of minerals** occur within a rock. This occurs due to pressure, volume and temperature changes.
- When rocks are forced down to lower levels by tectonic processes or when molten magma rising through the crust comes in contact with the crustal rocks, metamorphosis occurs.
- In the process of metamorphism in some rocks grains or **minerals get arranged in layers or lines**. Such an arrangement is called **foliation or lineation**.
- Sometimes minerals or materials of different groups are arranged into alternating thin to thick layers. Such a structure in is called **banding**.
- **Gneissoid, slate, schist, marble, quartzite** etc. are some examples of metamorphic rocks.

Causes of Metamorphism	**Orogenic (Mountain Building) Movements:** Such movements often take place with an interplay of folding, warping and high temperatures. These processes give existing rocks a new appearance. **Lava Inflow:** The molten magmatic material inside the earth's crust brings the surrounding rocks under the influence of intense temperature pressure and causes changes in them. **Geodynamic Forces:** The omnipresent geodynamic forces such as plate tectonics also play an important role in metamorphism. On the basis of the agency of metamorphism, metamorphic rocks can be of two types
Thermal Metamorphism	The change of form or re-crystallisation of minerals of sedimentary and igneous rocks under the influence of high temperatures is known as thermal metamorphism. A magmatic intrusion causing thermal metamorphism is responsible for the **peak of Mount Everest** consisting of **metamorphosed limestone**. As a result of thermal metamorphism, **sandstone changes into quartzite and limestone into marble**.
Dynamic Metamorphism	This refers to the formation of metamorphic rocks under high pressure. Sometimes high pressure is accompanied by high temperatures and the action of chemically charged water. The combination of directed pressure and heat is very powerful in producing metamorphism because it leads to more or less complete recrystallisation of rocks and the production of new structures. This is known as dynamo thermal metamorphism. Under high pressure, **granite is converted into gneiss; clay and shale are transformed into schist**.

Some examples of Metamorphosis

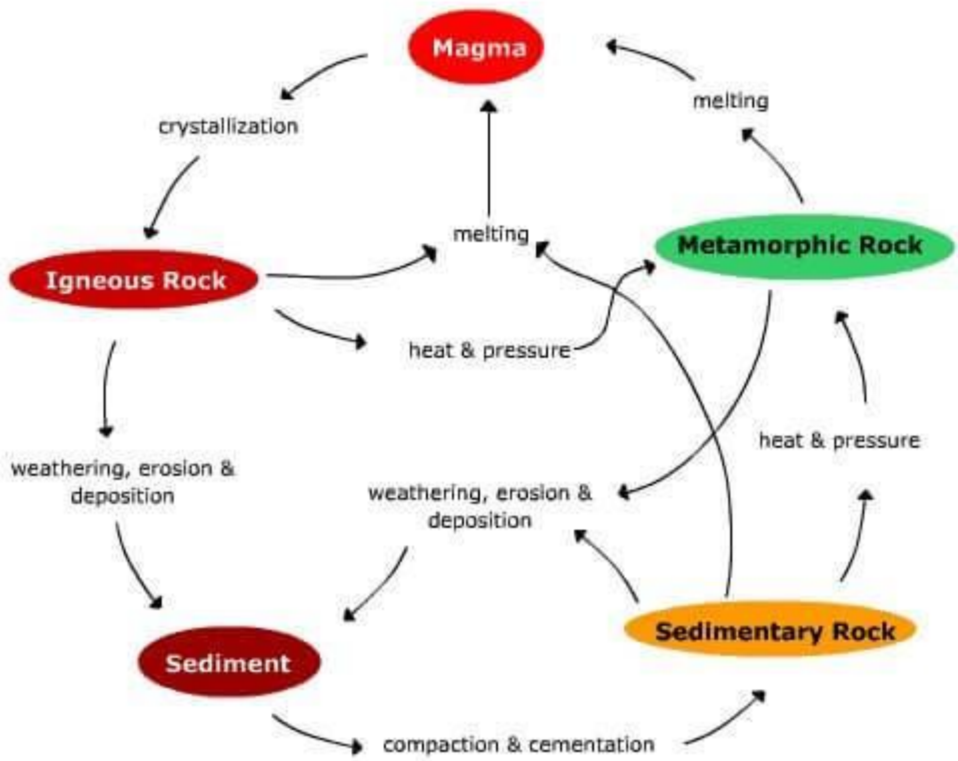
Igneous or Sedimentary rock	Influence	Metamorphosed rock
Granite	Pressure	Gneiss
Clay, Shale	Pressure	Schist
Sandstone	Heat	Quartzite
Clay, Shale	Heat	Slate ==> Phyllite
Coal	Heat	Anthracite ==> Graphite
Limestone	Heat	Marble

Metamorphic Rocks in India

- The gneisses and schists are commonly found in the Himalayas, Assam, West Bengal, Bihar, Orissa, Madhya Pradesh and Rajasthan.
- Quartzite is a hard rock found over Rajasthan, Bihar, Madhya Pradesh, Tamil Nadu and areas surrounding Delhi.
- Marble occurs near Alwar, Ajmer, Jaipur, Jodhpur in Rajasthan and parts of Narmada Valley in Madhya Pradesh.
- Slate, which is used as a roofing material and for writing in schools, is found over Rewari (Haryana), Kangra (Himachal Pradesh) and parts of Bihar.
- Graphite is found in Orissa and Andhra Pradesh.

ROCK CYCLE

- Rock cycle is a continuous process through which old rocks are transformed into new ones.
- **Igneous rocks are primary rocks**, and other rocks form from these rocks.
- Igneous rocks can be changed into **sedimentary or metamorphic rocks**.
- The fragments derived out of igneous and metamorphic rocks form into sedimentary rocks.
- **Sedimentary and igneous rocks themselves can turn into metamorphic rocks.**
- The crustal rocks (igneous, metamorphic and sedimentary) may be carried down into the mantle (interior of the earth) through subduction process and the same meltdown and turn into molten magma, the source for igneous rocks



Some Rock-Forming Minerals

- **Feldspar:** Half the crust is composed of feldspar. It has a light colour, and its main constituents are silicon, oxygen, sodium, potassium, calcium, aluminium. It is used for **ceramics and gloss making**.
- **Quartz:** It has two elements, silicon and oxygen. It has a hexagonal crystalline structure. It is uncleaved, white or colourless. It cracks like glass and is present in sand and granite. It is used in the manufacture of **radio and radar**.
- **Bauxite:** A hydrous oxide of aluminium, it is the **ore of aluminium**. It is non-crystalline and occurs in small pellets.
- **Cinnabar (mercury sulphide):** Mercury is derived from it. It has a brownish colour.
- **Dolomite:** A double carbonate of calcium and magnesium. It is used in cement and iron and steel industries. It is white.
- **Gypsum:** It is hydrous calcium sulphate and is used in cement, fertiliser and chemical industries.
- **Haematite:** It is a red ore of iron.
- **Magnetite:** It is the black ore (or iron oxide) of iron.
- **Amphibole:** It forms about 7 per cent of the earth's crust and consists mainly of aluminium, calcium, silica, iron, magnesium, etc. It is used in the **asbestos industry**.
- **Mica:** It consists of potassium, aluminium, magnesium, iron, silica, etc., and forms 4 % of the earth's crust. It is generally found in igneous and metamorphic rocks and is mainly used in **electrical instruments**.
- **Olivine:** The main elements of olivine are magnesium, iron and silica. It is normally a greenish crystal.
- **Pyroxene:** It consists of calcium, aluminium, magnesium, iron and silica. It is of green or black colour.
- Other minerals like chlorite, calcite, magnetite, hematite, bauxite, barite, etc., are also present in rocks.