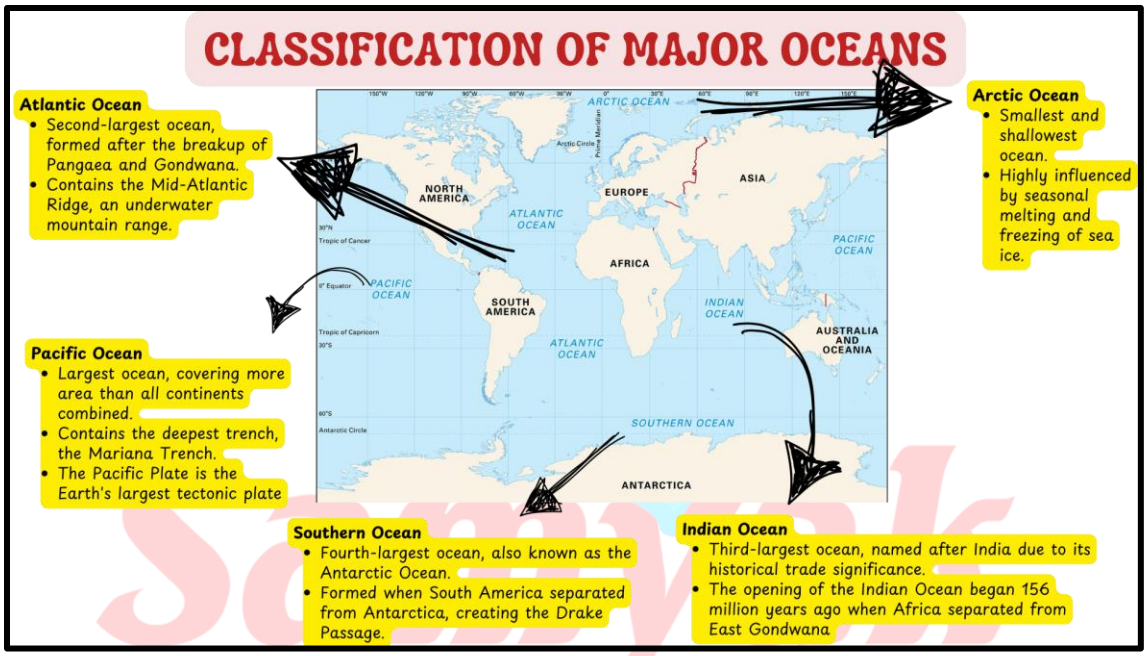
LECTURE 6 and 7 – OCEANOGRAPHY

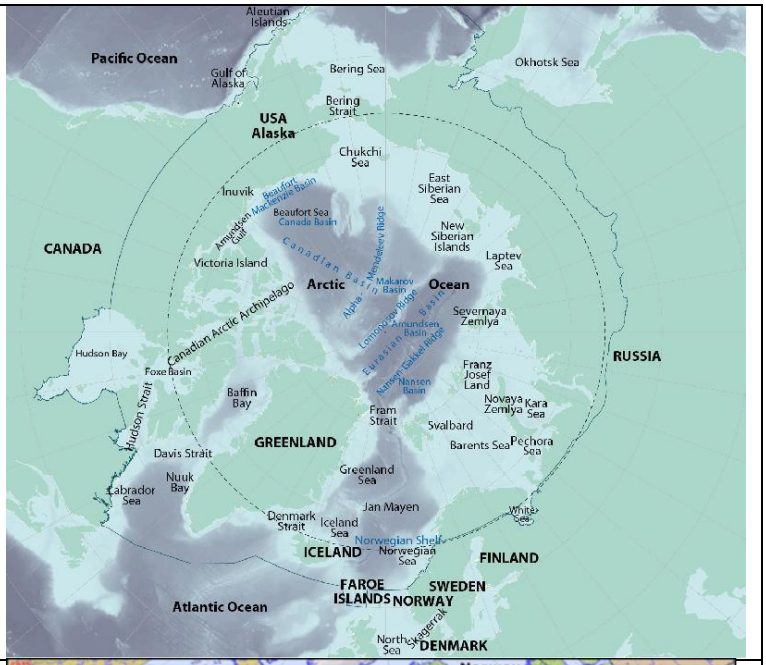
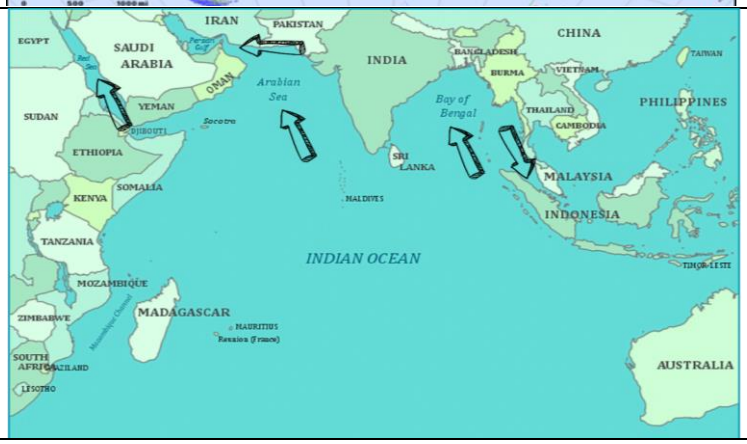
- Oceanography is the scientific study of the world's oceans, encompassing submarine relief, physical and chemical properties, and marine biodiversity.
- The oceans form a single, vast body of water, covering approximately 71% of the Earth's surface and playing a critical role in regulating global climate, weather patterns, and water balance.

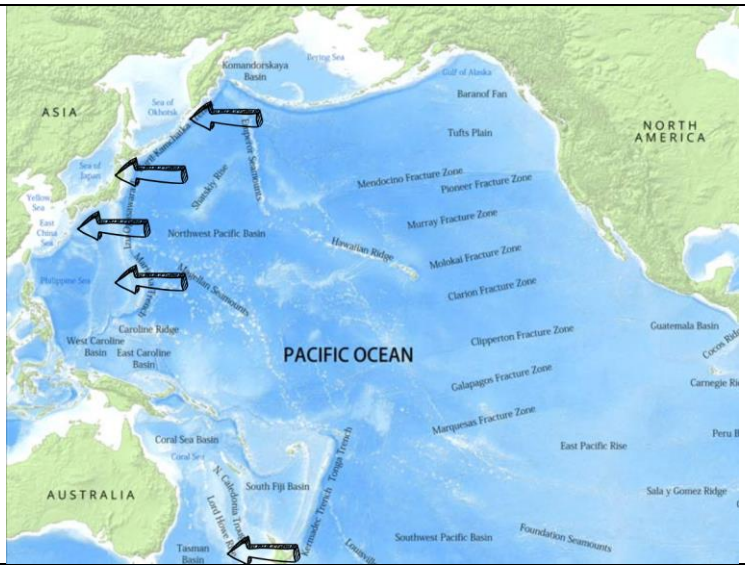


MARGINAL SEAS

- A marginal sea is a partially enclosed body of water, located near a landmass, often bordered by islands, peninsulas, or archipelagos. These seas are distinct from open oceans due to their shallower depths and greater exposure to land-based influences such as climate, river runoff, and human activities.

OCEANS	ASSOCIATED MARGINAL SEAS
Mediterranean Region	

Arctic Ocean	
Atlantic Ocean	
Indian Ocean	

Pacific Ocean	

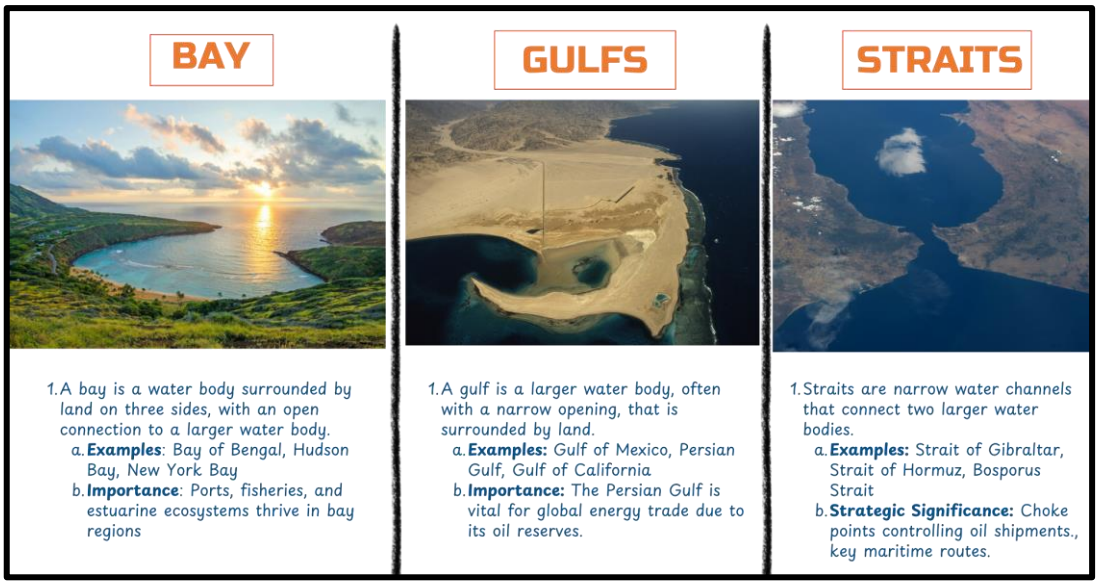
MARGINAL SEAS DIFFER FROM OPEN OCEANS IN THE FOLLOWING WAYS:

- **Proximity to Land:** Closer to coastlines, influenced by river runoff and human activities
- **Depth:** Generally shallower than open oceans
- **Water Circulation:** Influenced by freshwater inflow, evaporation, and salinity variations
- **Ecological Sensitivity:** More vulnerable to pollution, climate change, and overfishing

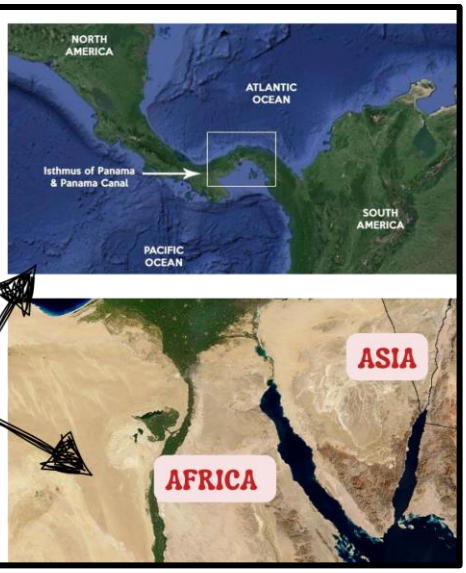
BIOMASS PRODUCTION AND PRIMARY PRODUCTIVITY

- Primary productivity in marginal seas is driven by sunlight availability, dissolved nutrients (nitrates, phosphates), and water mixing.
- **Highest productivity:** Found in coastal upwelling regions where nutrient-rich deep waters rise.
- **Intermediate productivity:** Occurs in marginal seas.
- **Lowest productivity:** Found in open ocean waters due to nutrient scarcity.

BAYS, GULFS, AND STRAITS



ISTHMUS



- An **isthmus** is a narrow strip of land connecting two larger landmasses, often separating two water bodies.
- **Examples:**
  - **Isthmus of Panama:** Connects North and South America, hosting the Panama Canal.
  - **Isthmus of Suez:** Connects Africa and Asia, hosting the Suez Canal, a crucial global shipping route.

HYDROLOGICAL CYCLE

The hydrological cycle describes the movement of water on, in, and above the Earth.

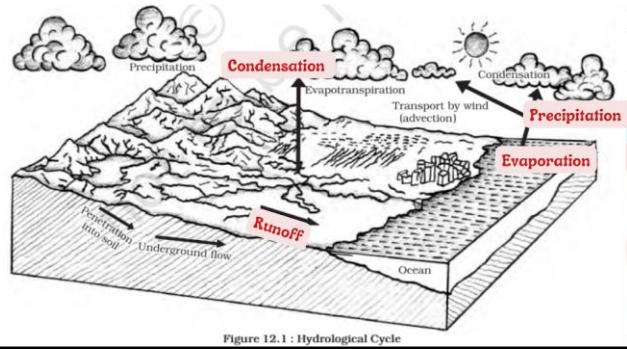


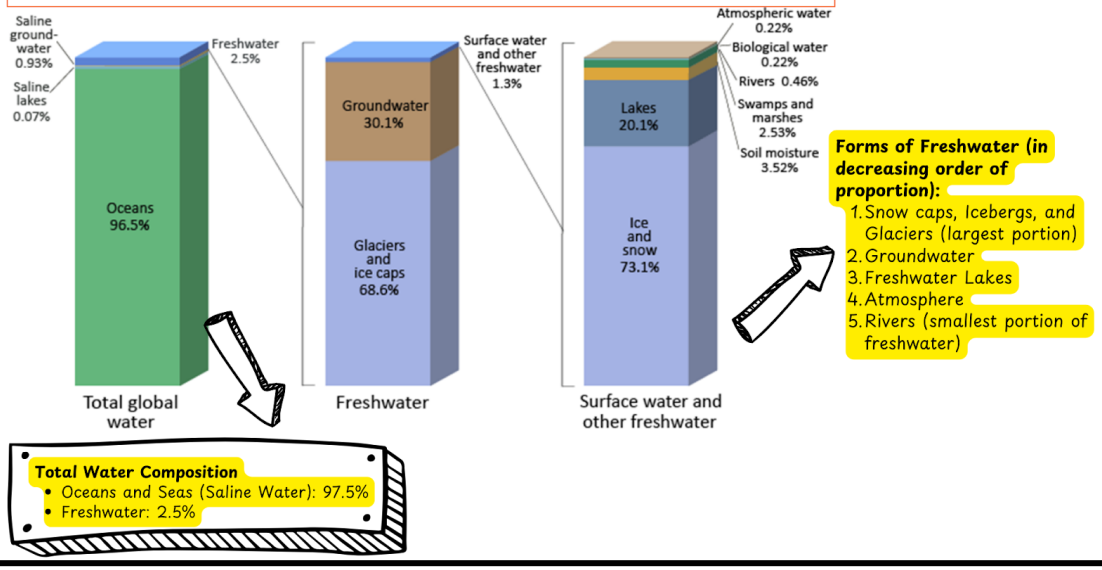
Figure 12.1 : Hydrological Cycle

Table 12.1 : Components and Processes of the Water Cycle

Components	*Processes*
Water storage in oceans	Evaporation Evapotranspiration Sublimation
Water in the atmosphere	Condensation Precipitation
Water storage in ice and snow	Snowmelt runoff to streams
Surface runoff	Stream flow freshwater storage infiltration
Groundwater storage	Groundwater discharge springs

WATER DISTRIBUTION ON EARTH

WATER DISTRIBUTION ON EARTH



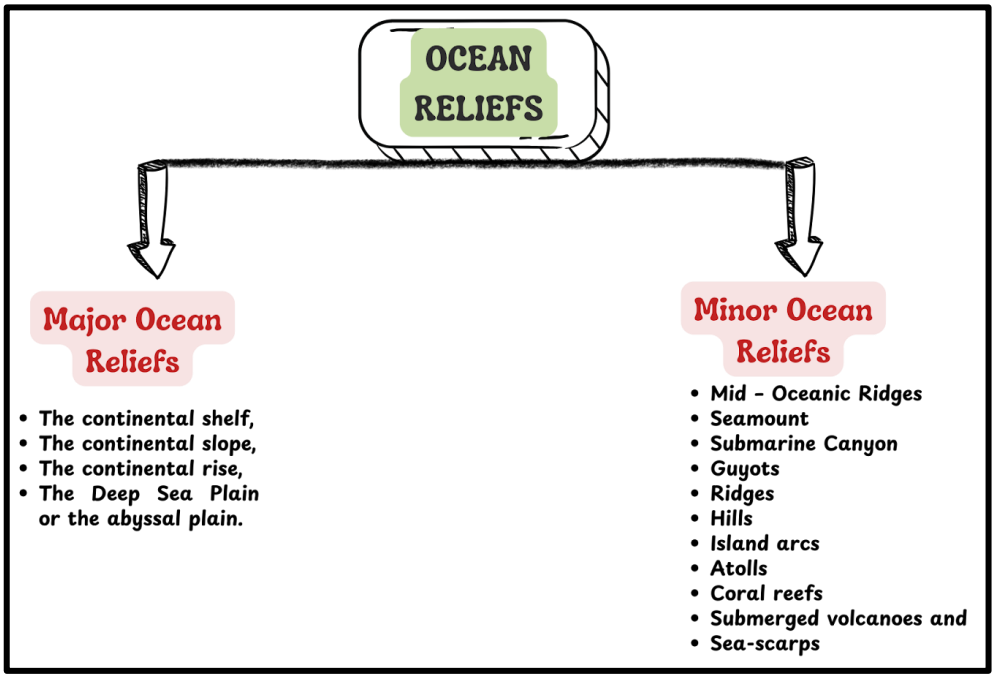
Forms of Freshwater (in decreasing order of proportion):

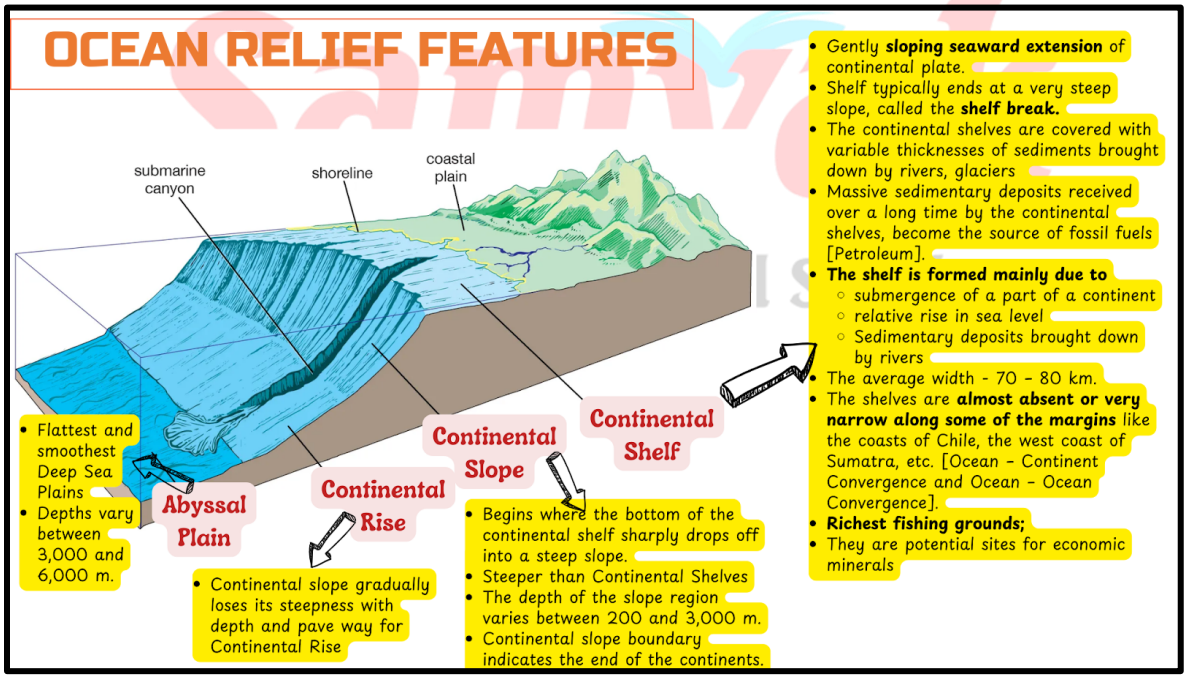
1. Snow caps, Icebergs, and Glaciers (largest portion)
2. Groundwater
3. Freshwater Lakes
4. Atmosphere
5. Rivers (smallest portion of freshwater)

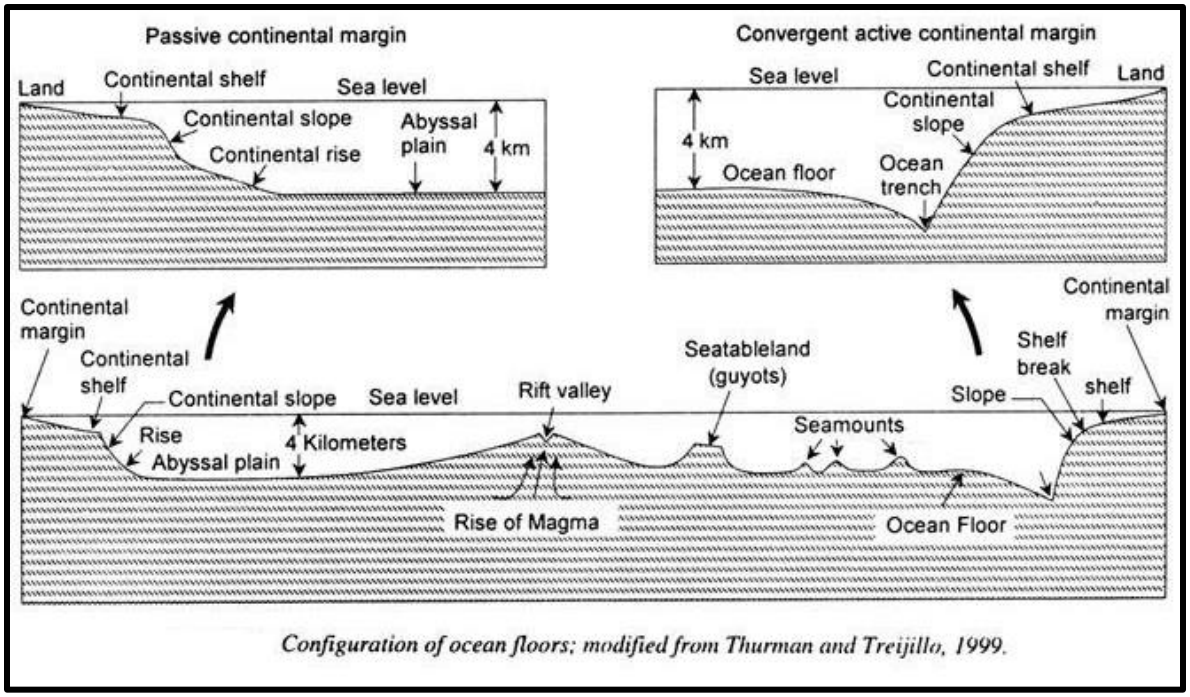
Total Water Composition

- Oceans and Seas (Saline Water): 97.5%
- Freshwater: 2.5%

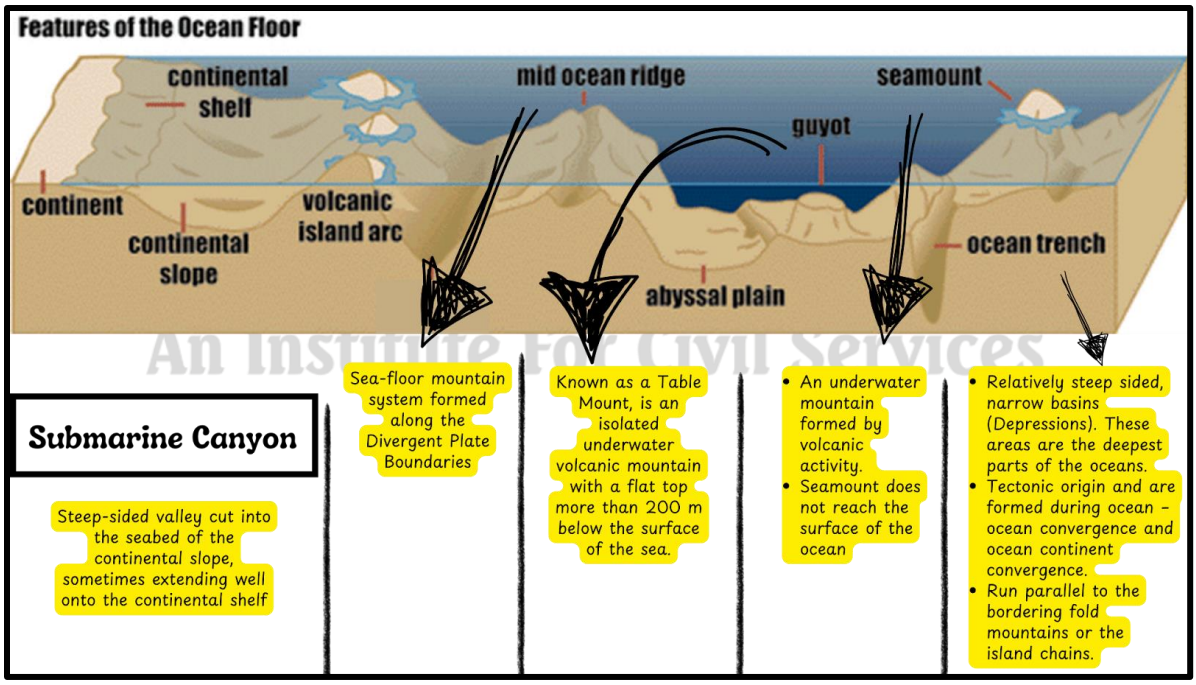
OCEAN RELIEF FEATURES







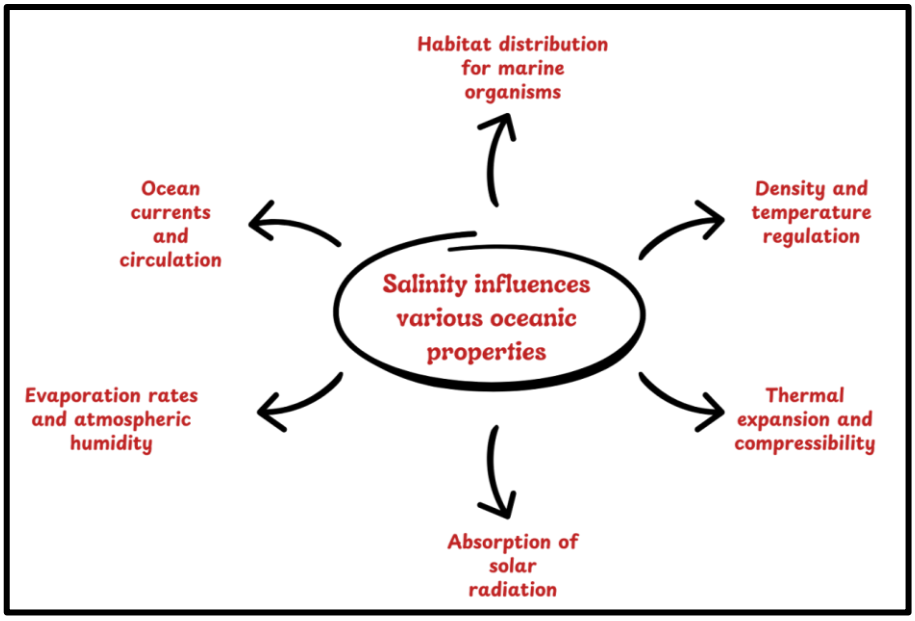
Configuration of ocean floors; modified from Thurman and Treijillo, 1999.



SALINITY OF OCEANS

- **Salinity** refers to the total concentration of dissolved salts in seawater.
- It is measured in **grams of salt per 1,000 grams (1 kg) of seawater** and expressed as **parts per thousand (ppt)**.
- Water with a salinity level **above 24.7 ppt** is classified as saline, whereas levels below this threshold indicate **brackish water**.

Component in seawater	Percentage (%)
Sodium chloride	77.7
Magnesium chloride	10.9
Magnesium sulfate	4.7
Calcium sulfate	3.6
Potassium sulfate	2.5



FACTORS AFFECTING SALINITY

FACTORS	EFFECTS ON SALINITY
Evaporation	➢ Where the **evaporation is greater, the salinity is higher**, for example, Mediterranean sea.
Freshwater Influx	➢ Where the **freshwater flow into the oceans is greater, the salinity is lower**. Example – Mouths of Rivers or Melting of Glaciers ➢ Freezing of Ocean water leads to increase in Salinity
Temperature and Density	➢ Regions with **high temperatures are also regions with high salinity (**Sub-Tropical Regions)
Ocean Currents	➢ Play role in the spatial distribution of dissolved salts in ocean waters. ➢ The **warm currents near the equatorial region push away the salts from the eastern margins of the oceans and accumulate them near the western margins.** ➢ Gulf Stream in the North Atlantic Ocean increases the salinity of ocean waters along the western margins of the Atlantic Ocean.
Atmospheric Pressure	➢ **Anti-cyclonic conditions with stable air and high temperature increase salinity of the surface water of oceans** ➢ Winds help is redistribution of salinity, as they drive away saline waters to less saline areas resulting into decrease of salinity in the former and increase in the latter
Precipitation	➢ Regions with **higher levels of precipitation have lower levels of salinity**. (Equatorial Regions)

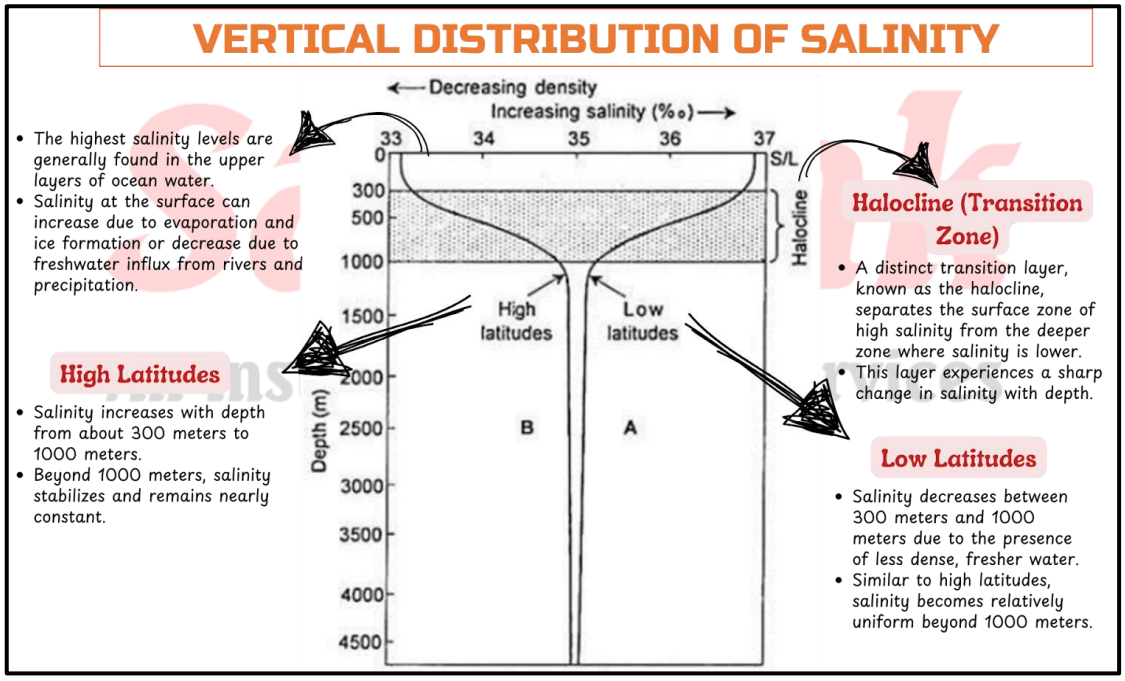
HORIZONTAL DISTRIBUTION OF SALINITY

➢ On an average, **salinity decreases from equator towards the poles**.

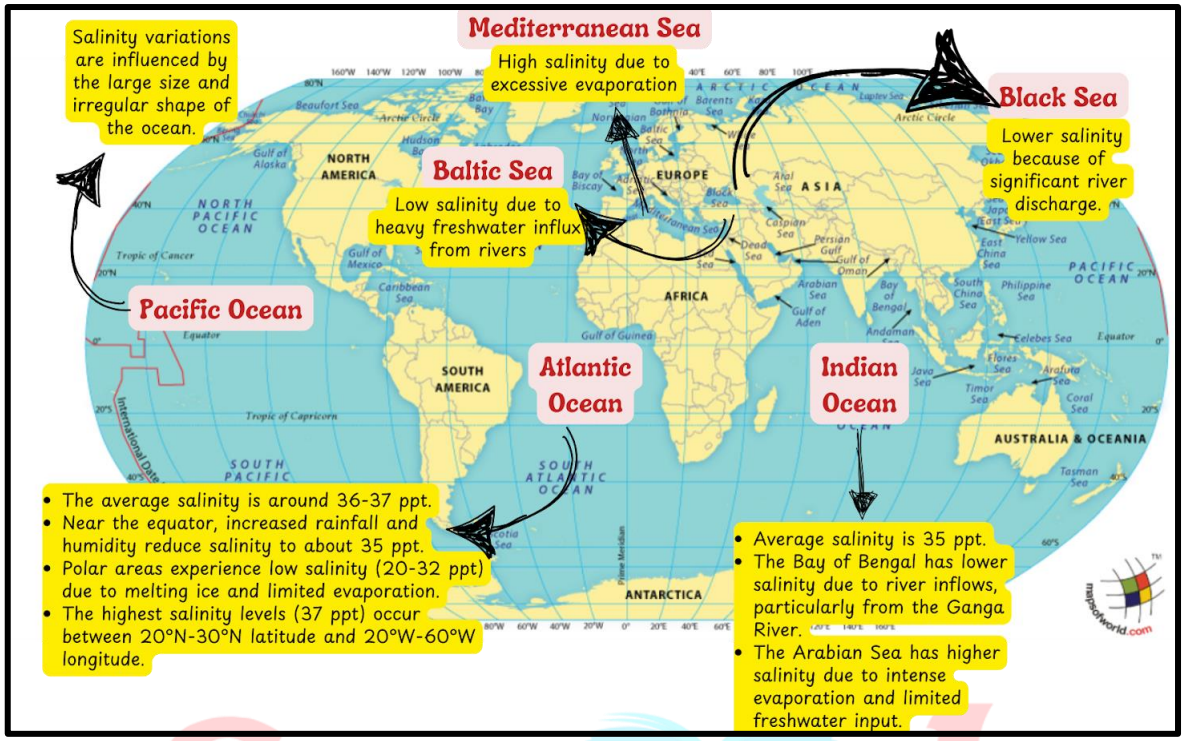
- On the basis of **latitudinal distribution of salinity** four zones of oceanic salinity may be identified
  - **Equatorial zones** of relatively low salinity (due to excessive rainfall),
  - **Tropical zone of maximum salinity** (due to low rainfall and high evaporation),
  - **Temperate zone of low salinity**, and
  - **Sub-polar and polar zone of minimum salinity.**
- On an average, the northern and the southern hemispheres record average salinity of 35‰ and 34‰ respectively.

- The **open ocean** generally has salinity levels between **33 and 37 ppt**
- The **Red Sea** has a salinity of **41 ppt** due to limited freshwater inflow and high evaporation.
- **Landlocked water bodies** in hot, arid regions can reach **70 ppt** or more.
- **Estuaries and Polar Regions** – Salinity fluctuates between **0 and 35 ppt**, depending on seasonal freshwater inflow from melting ice and river discharge.

VERTICAL DISTRIBUTION OF SALINITY



REGIONAL DISTRIBUTION OF SALINITY



- **North Sea**: In spite of its location in higher latitudes, it records **higher salinity** due to more saline water brought by the North Atlantic Drift.
- **Inland seas and lakes:** The **salinity of the inland Seas and lakes is very high**
- **Highest Salinity:** Lake Van Turkey (Highest) > Dead Sea > Great Salt Lake (USA)

TEMPERATURE DISTRIBUTION

RANGE OF OCEAN TEMPERATURE

- The **oceans and seas get heated and cooled slower than the land surfaces.**
- The process of heating and cooling of the oceanic water is slower than land due to **vertical and horizontal mixing** and **high specific heat of water**.

FACTORS AFFECTING DISTRIBUTION OF TEMPERATURE

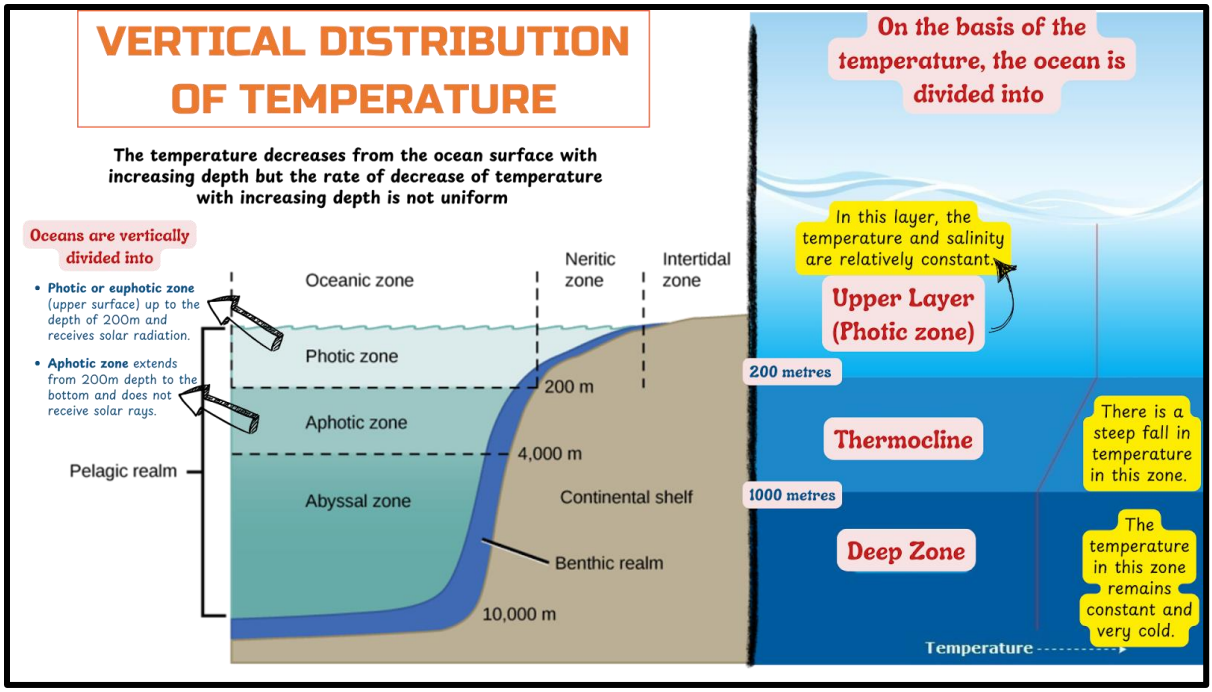
FACTORS	EFFECTS
Latitude	➢ Surface temperature of the oceans **declines from the equator towards the poles**
Prevailing Winds	➢ Direction of the prevailing winds such as the Trade Winds, Westerlies etc., determines the surface temperature of ocean waters at a point. ➢ For instance, **eastern edges of the ocean along the trade wind belt have cooler waters due to the pushing of the warm waters by the trade winds away from the coast causing the**

	upwelling of bottom waters.
Unequal distribution of Land and Water	➢ The Northern Hemisphere has more land area than that of the Southern Hemisphere. Consequently, the **oceans of the Northern are warmer than that of the Southern Oceans.**
Ocean Currents	➢ **The presence of warm water increases the temperature and consequently the rate of evaporation**. Consequently, the region records more rainfall ➢ The cold current reduces the temperature of the moisture-laden wind. ➢ The coast along which a cold water current flows records more fog, but less precipitation.
Enclosed Seas	➢ The enclosed seas (Marginal Seas – Gulf, Bay etc.) in the low latitudes record relatively higher temperature than the open seas ➢ Whereas the enclosed seas in the high latitudes have lower temperature than the open seas.
Other Factors	➢ Submarine ridges, local weather conditions like storms, cyclones, winds, fogs, cloudiness, the rate of evaporation, lapse rate, condensation, and precipitation

HORIZONTAL TEMPERATURE DISTRIBUTION OF OCEANS

- **General Temperature Pattern:**
  - The average surface temperature of ocean water is approximately 27°C.
  - Temperature gradually decreases from the equator towards the poles due to reduced solar radiation.
- **Variation in Temperature Across Hemispheres:**
  - The highest ocean temperature is not found exactly at the equator but slightly north of it due to the influence of ocean currents and land distribution.
  - The northern hemisphere records higher average ocean temperatures compared to the southern hemisphere because of greater landmass, which absorbs and retains heat more effectively.
- **Impact of Ocean Currents:** In the **northern Atlantic Ocean**, the decline in temperature with increasing latitude is relatively slow due to the presence of **warm ocean currents** that transport heat towards higher latitudes.
- **Isothermal Lines:** The horizontal distribution of ocean temperature is represented using **isothermal lines**, which connect locations with the **same temperature** on a map.
- **Formation of Sea Fogs:**
  - **Sea fogs** occur when **warm air passes over cold ocean waters** that are below the **dew point** of the air. This leads to **cooling from below**, resulting in the condensation of moisture and the formation of fog.

VERTICAL DISTRIBUTION OF TEMPERATURE



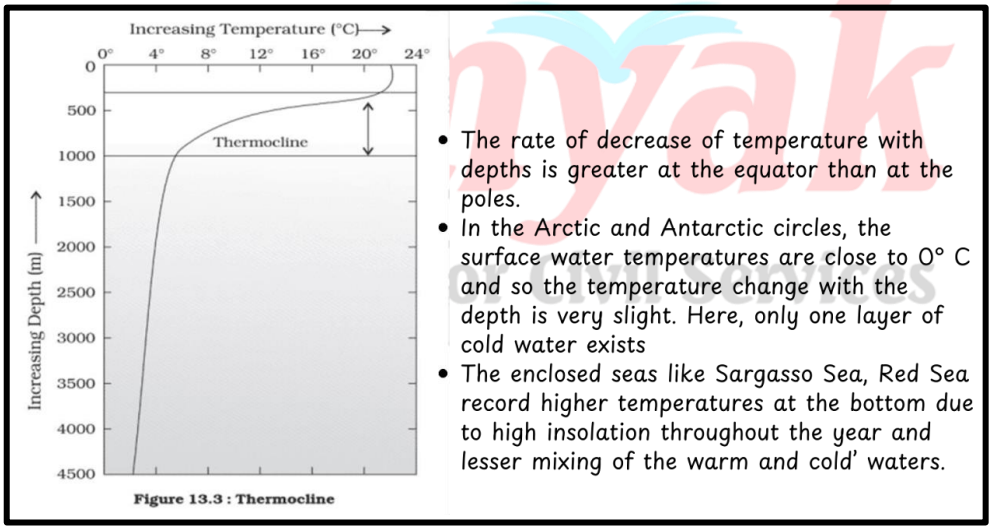
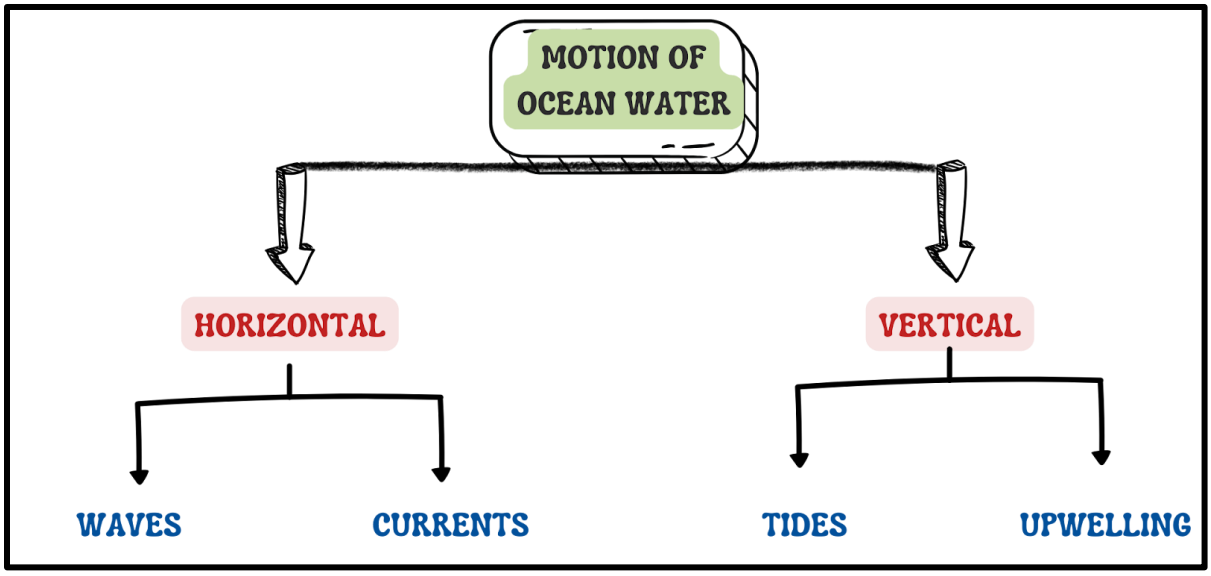


Figure 13.3 : Thermocline

- The rate of decrease of temperature with depths is greater at the equator than at the poles.
- In the Arctic and Antarctic circles, the surface water temperatures are close to 0° C and so the temperature change with the depth is very slight. Here, only one layer of cold water exists
- The enclosed seas like Sargasso Sea, Red Sea record higher temperatures at the bottom due to high insolation throughout the year and lesser mixing of the warm and cold' waters.

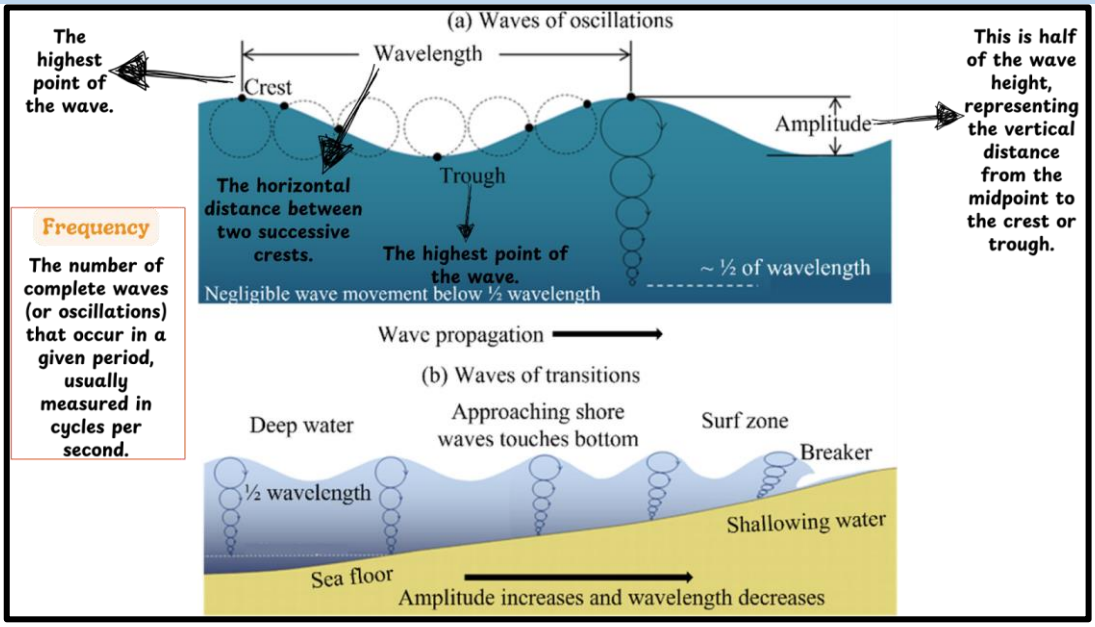


HORIZONTAL MOTION

OCEAN WAVES

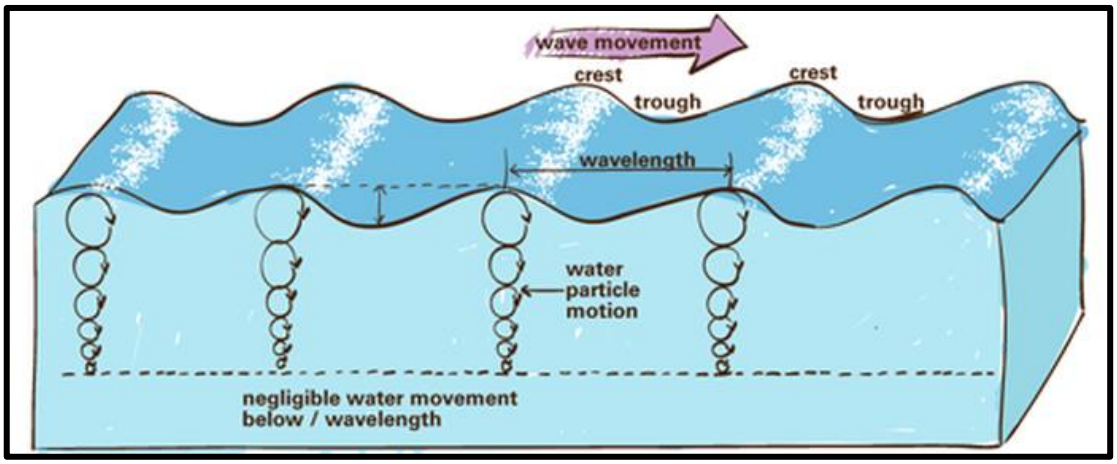
- Ocean waves are a dynamic phenomenon resulting from the transfer of energy across the water's surface, primarily driven by wind.
- These waves involve rhythmic, oscillatory movements that cause the rise and fall of the water's surface, but it's important to note that the movement of water itself is not the primary transfer; rather, it is the energy that propagates across the ocean.
- Waves are a form of horizontal movement of ocean water. The energy for these waves is supplied by the wind, which creates friction with the water surface. As the wind's velocity increases, the wave's wavelength, height, and period all grow as well.

KEY CONCEPTS



WAVE MOTION:

- Water particles move in an orbital pattern as a wave passes. The shape of the motion varies with depth, with particles moving in increasingly smaller circles as they go deeper beneath the surface. The diameter of these orbits increases with the wave size and decreases with depth. This orbital movement is crucial in understanding how waves propagate.



WAVE BREAKING:

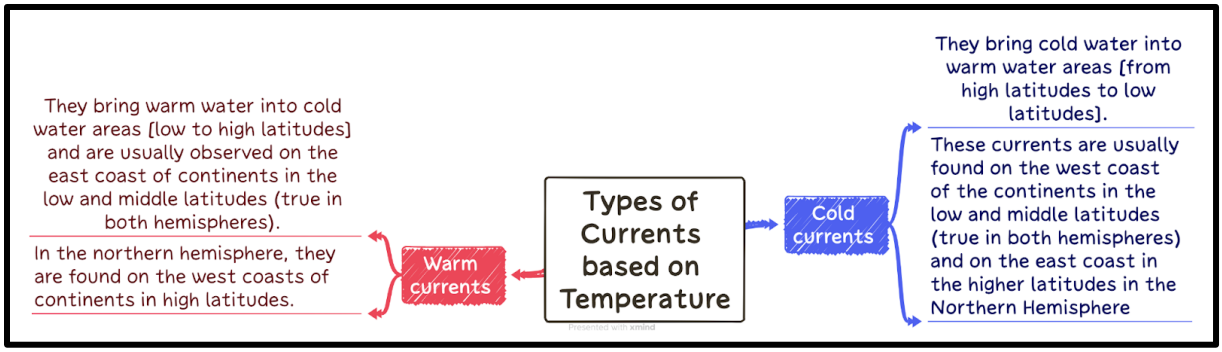
- As waves travel closer to shore and encounter friction with the ocean floor, they slow down. This causes the crest to advance faster than the trough, bringing the crest and trough closer together. Eventually, the wave "breaks," where the crest topples over and crashes into the shore.
- **Wave Types:**
  - **Wind-generated Waves**: The most common type, caused by the wind's friction with the water's surface.
  - **Wave Types Based on Speed and Formation**: Vary depending on wind speed, duration, and fetch (distance over which the wind blows).

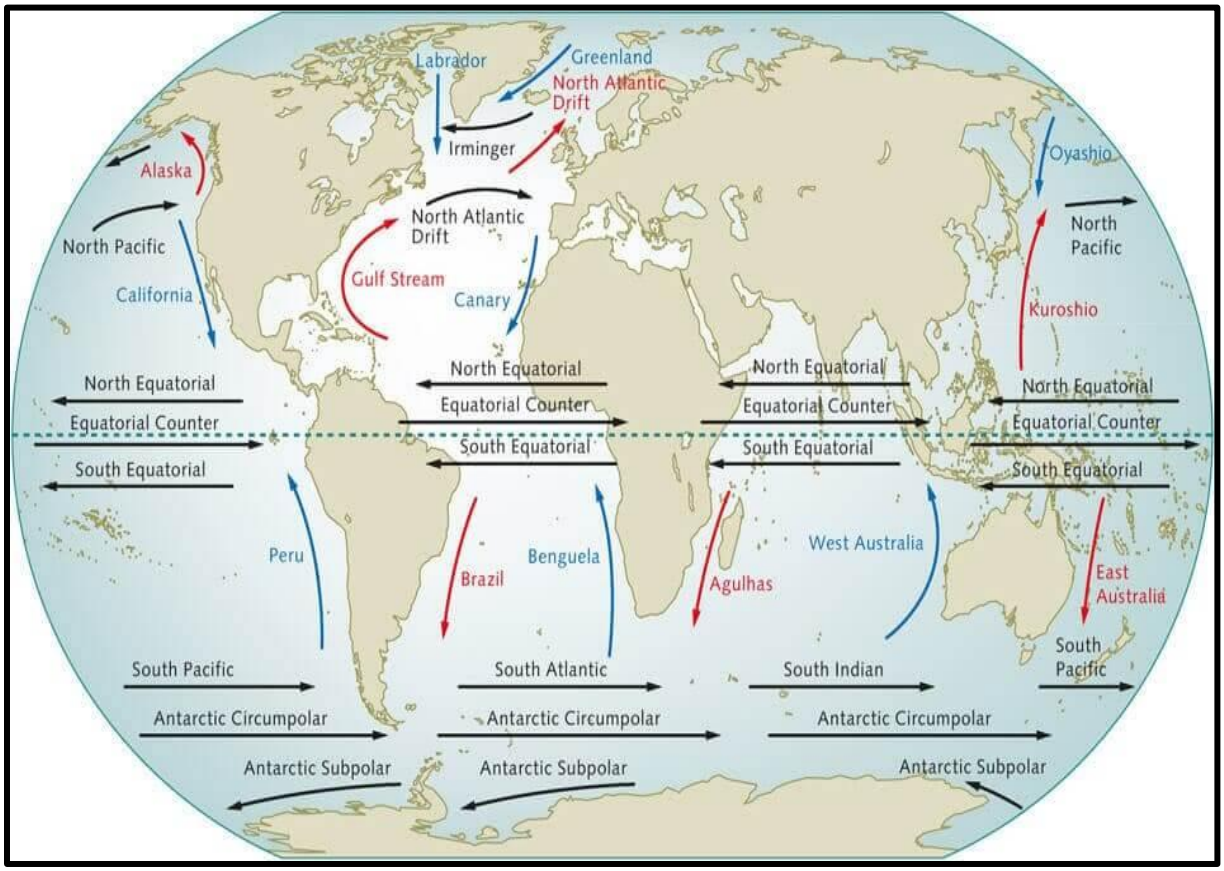
WAVE CUT ACTION:

- Waves can also erode coastal areas through a process known as wave cut action, where the force of the breaking waves erodes the land, often creating features like cliffs and shore platforms.

OCEANS CURRENTS

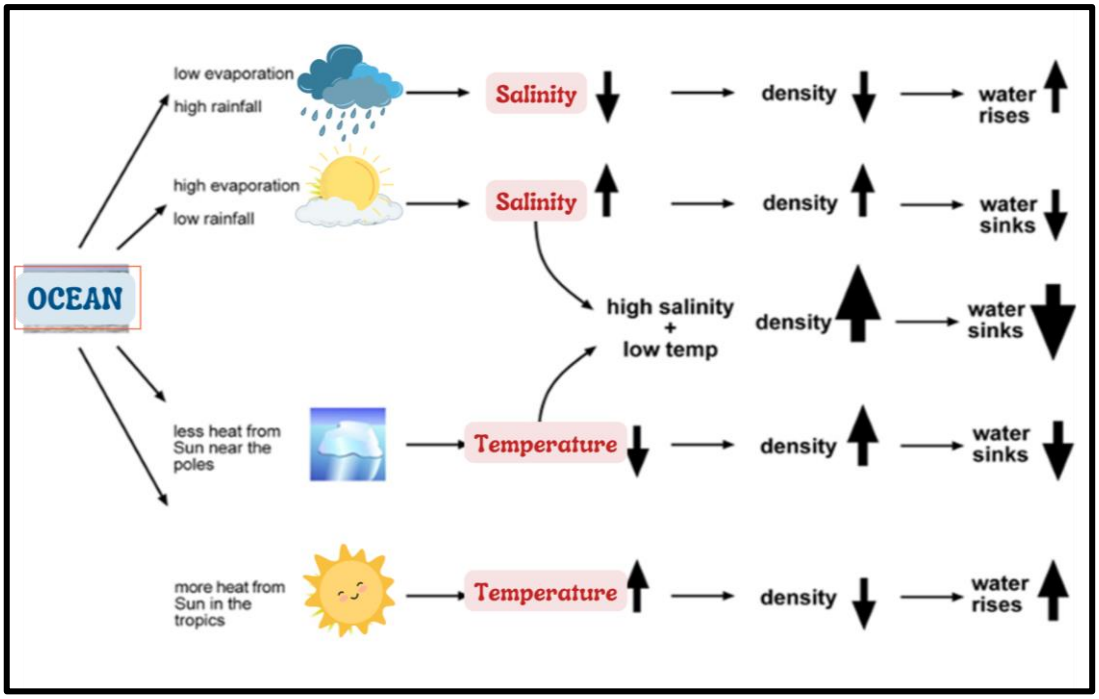
- Ocean currents are the **massive, continuous, predictable, directional movement of seawater.**
- Ocean water moves in two directions: horizontally and vertically.
  - Horizontal movements are referred to as currents.
  - Vertical changes are called upwelling or downwelling.



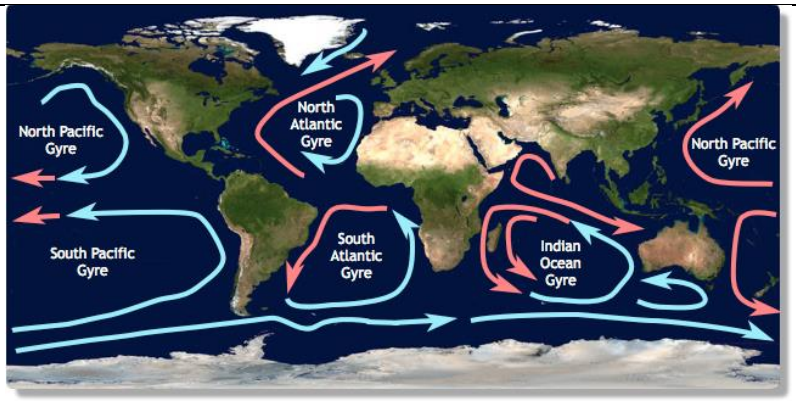


CAUSES	EXPLANATIONS
Prevailing Winds	➢ **Drag the surface water due to the force of friction**. This leads to the formation of ocean currents. ➢ **Equatorial currents** - flow westward under the influence of northeast and southeast trade winds. ➢ **The North Atlantic Drift** in the Atlantic and **the North Pacific current** in the Pacific move in the northeast direction under the influence of westerlies. ➢ **Monsoon winds** are responsible for the seasonal reversal of ocean currents in the Indian ocean.
Temperature	➢ **Higher Temperature leads to expansion of volume of water and thus decreases in density**. This leads to formation of Ocean Currents. Example – **Equatorial Regions**
Salinity	➢ Ocean currents on the water surface are generated **from the areas of low salinity (Low Density) to the areas of high salinity (High Density)**
Rotation	➢ The earth rotates on its axis from west to east.

	➢ **The Rotation is the cause of deflective force known as Coriolis force** which deflects the general direction of the winds and that of the ocean currents. ➢ For example, **the currents flowing from the Equator towards the North and South Poles are deflected to their right in the Northern Hemisphere and towards their left in the Southern Hemisphere.**
Configuration of the coastline	➢ **Have influence on the direction and movement of the ocean currents.** ➢ For example, the equatorial current after being obstructed by the Brazilian coast is bifurcated into two branches. The Northern Branch is called the **Caribbean current** while the Southern branch is called the **Brazilian current.** ➢ **In the Indian Ocean, the monsoon currents closely follow the coastlines.**
Precipitation	✓ **High Rainfall leads to decrease in density** and thus results in formation of currents. ✓ Example – Equatorial Regions



Ocean Gyres: Large rotating ocean current systems formed by wind, coriolis force and landmasses.



EFFECTS OF OCEAN CURRENTS

DESERT FORMATION

- Cold ocean currents have a direct effect on **desert formation** in west coast regions of the **tropical and subtropical continents**.
- There is **fog** and most of the areas are **arid due to desiccating effect (loss of moisture).**

RAINS

- Warm ocean currents bring rain to coastal areas and even interiors. Example: Summer Rainfall in **British Type climate**.

MODERATING EFFECT

- They are responsible for moderate temperatures at coasts. **[North Atlantic Drift brings warmness to England**. Canary cold current brings cooling effect to Spain, Portugal]

FISHING

- **Mixing of cold and warm ocean currents bear richest fishing grounds in the world.**
- The mixing of warm and cold currents help to replenish the oxygen and favour the growth of **planktons**, the primary food for fish population
- Example: **Grand Banks around Newfoundland**, Canada and North-Eastern Coast of Japan.

DRIZZLE AND FOG

- ✓ **Mixing of cold and warm ocean currents create foggy weather where precipitation occurs in the form of drizzle** [Example - Newfoundland].

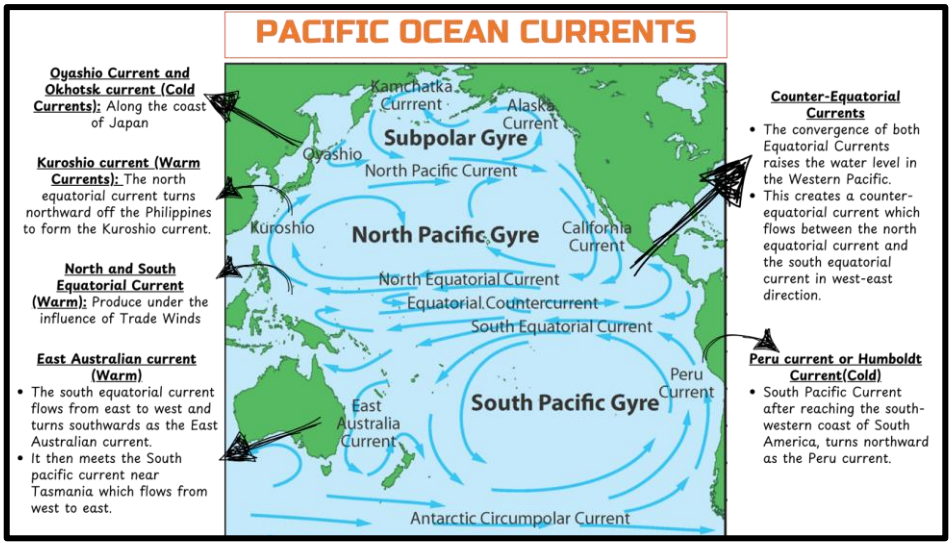
TROPICAL CYCLONES

- ✓ They pile up warm waters in tropics and this warm water is the major force behind tropical cyclones.

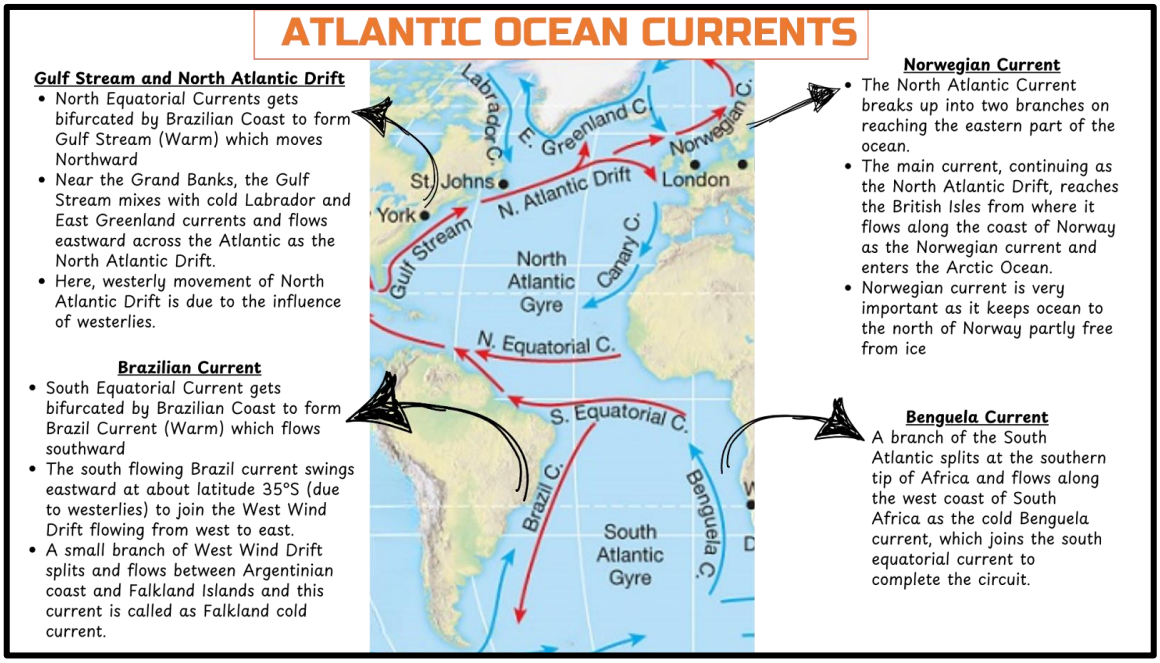
NAVIGATION

- ✓ Ships usually follow routes which are aided by ocean currents and winds.

PACIFIC OCEAN CURRENTS



ATLANTIC OCEAN CURRENTS

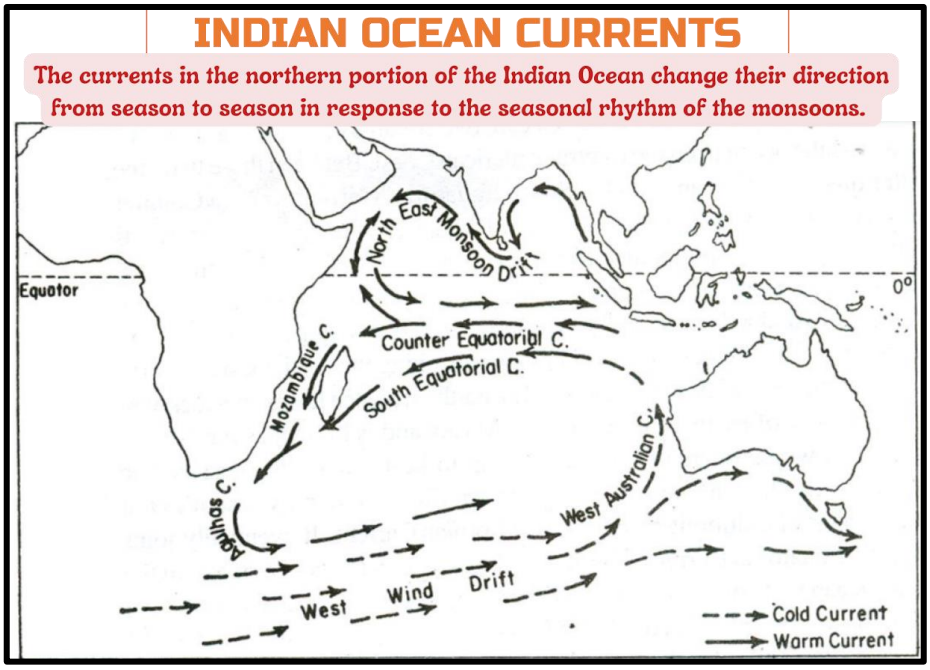


SARGASSO SEA

- The Sargasso Sea is entirely within the Atlantic Ocean and is the only sea without a land boundary.
- Named after *Sargassum*, a type of golden drift algae that forms extensive floating mats.
- It is an open-ocean ecosystem surrounded by currents in the North Atlantic subtropical gyre.
- **Boundaries:**
  - **Western Boundary:** Defined by the Gulf Stream.
  - **Northern Boundary:** Defined by the North Atlantic Current.
  - **Eastern Boundary:** Defined by the Canary Current.
  - **Southern Boundary:** Defined by the North Atlantic Equatorial Current.
- Supports a variety of flora and fauna, providing habitats, spawning areas, migration routes, and feeding grounds.

INDIAN OCEAN AND ITS CURRENTS

- The currents in the northern portion of the Indian Ocean change their direction from season to season in response to the **seasonal rhythm of the monsoons**.



WINTER CIRCULATION

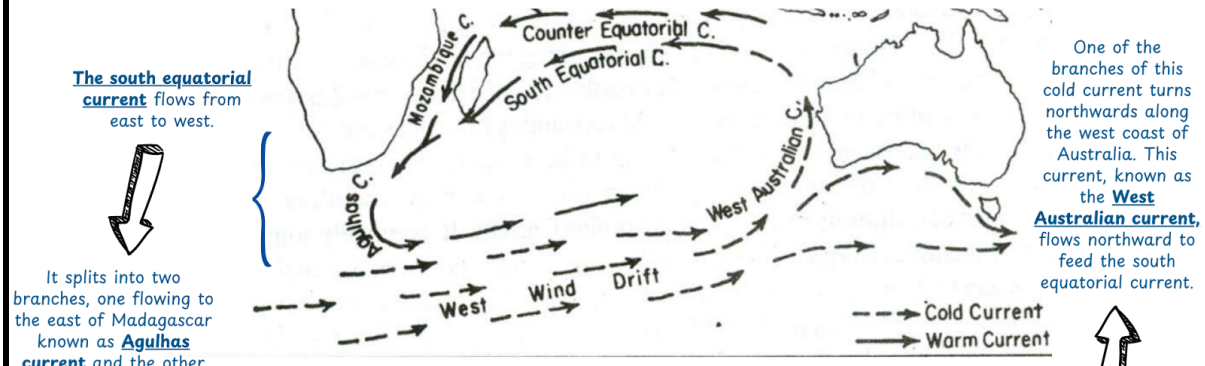
- Under the influence of **prevailing trade winds [easterly trade winds]**, the north equatorial current and the south equatorial current start from the south of Indonesian islands, moving from east to west.
- This raises the level of western Indian (south-east of horn of Africa) ocean And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.
- The north-east monsoons drive the water along the coast of Bay of Bengal to circulate in an **anti-clockwise** direction.
- Similarly, the water along the coast of Arabian Sea also circulate in an **anti-clockwise** circulation.

SUMMER CIRCULATION – NORTH EQUATORIAL CURRENT COUNTER-EQUATORIAL CURRENT ARE ABSENT

- In summer, due to the effects of the strong south-west monsoon and the absence of the north-east trades, strong current flows from west to east, which completely ***obliterates the north equatorial current***. Hence, there is ***no counter-equatorial current as well.***
- Thus, the circulation of water in the northern part of the ocean is **clockwise** during this season.

SOUTHERN INDIAN OCEAN CURRENTS

The general pattern of circulation in southern part of the Indian Ocean is quite similar to that of southern Atlantic and Pacific oceans. It is less marked by the seasonal changes.



The south equatorial current flows from east to west.

It splits into two branches, one flowing to the east of Madagascar known as **Agulhas current** and the other between Mozambique and Western Madagascar coast known as **Mozambique current.**

At the southern tip of Madagascar, these two branches mix and are commonly called as the **Agulhas current.** It still continues to be a warm current, till it merges with the **West Wind Drift.**

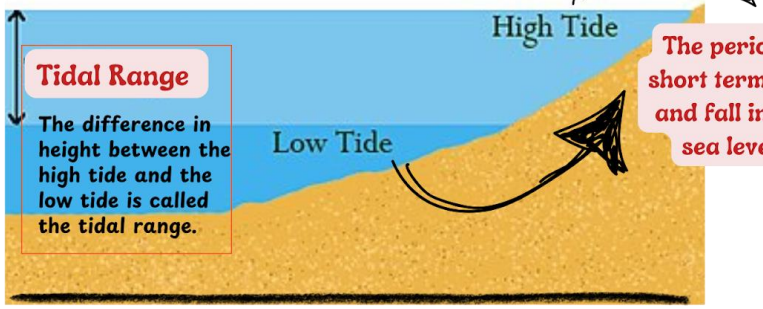
The West Wind Drift, flowing across the ocean in the higher latitudes from west to east, reaches the southern tip of the west coast, of Australia.

One of the branches of this cold current turns northwards along the west coast of Australia. This current, known as the **West Australian current,** flows northward to feed the south equatorial current.

VERTICAL MOTION

TIDES

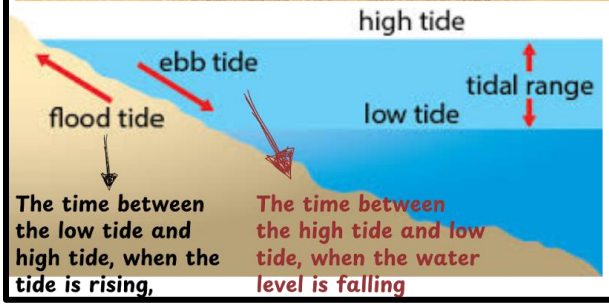
TIDES



Tidal Range

The difference in height between the high tide and the low tide is called the tidal range.

The periodic short term rise and fall in the sea level



The time between the low tide and high tide, when the tide is rising,

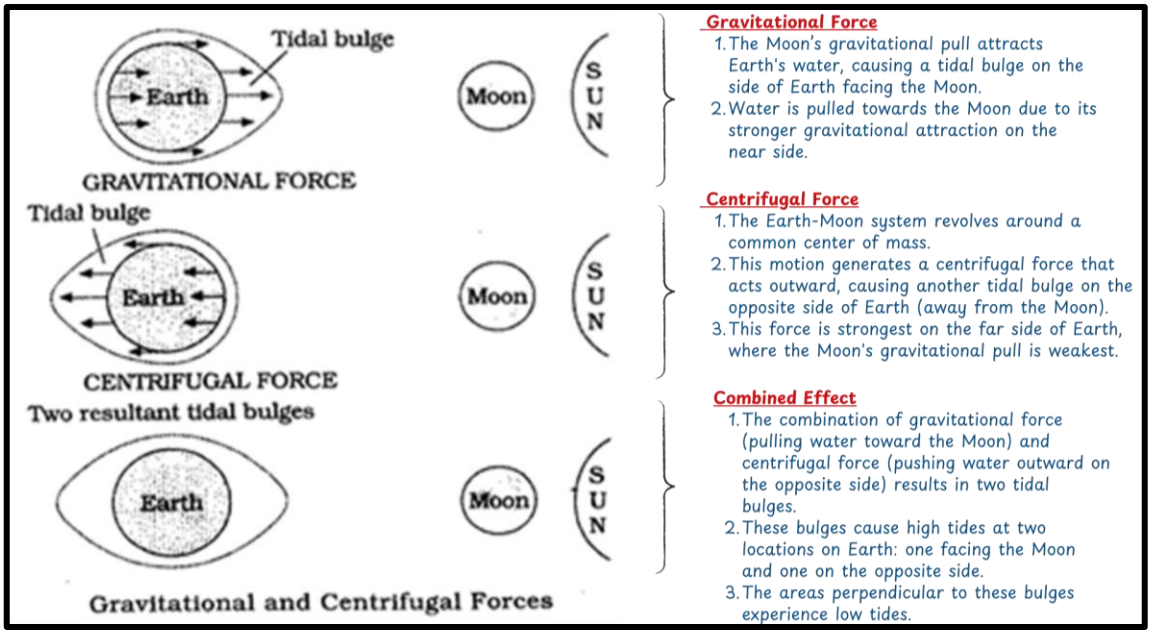
The time between the high tide and low tide, when the water level is falling

It is caused by the combined effects of

- The gravitational force exerted on Earth by the Sun
- The gravitational force exerted on Earth by the Moon
- Centrifugal Force

The Highest

- The highest tide in the World occurs in the Bay of Funday (Canada).
- The highest tide in India is recorded at Okha, Gujarat.
- The greatest tidal range in the world is found at Bay of Fundy in eastern Canada.

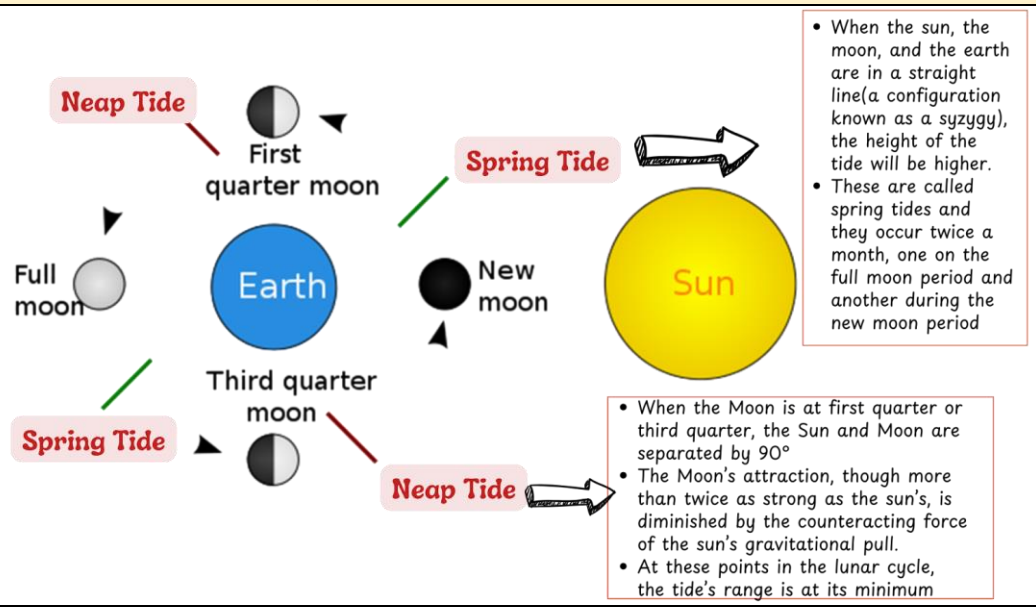


Gravitational Force
1. The Moon's gravitational pull attracts Earth's water, causing a tidal bulge on the side of Earth facing the Moon.
2. Water is pulled towards the Moon due to its stronger gravitational attraction on the near side.

Centrifugal Force
1. The Earth-Moon system revolves around a common center of mass.
2. This motion generates a centrifugal force that acts outward, causing another tidal bulge on the opposite side of Earth (away from the Moon).
3. This force is strongest on the far side of Earth, where the Moon's gravitational pull is weakest.

Combined Effect
1. The combination of gravitational force (pulling water toward the Moon) and centrifugal force (pushing water outward on the opposite side) results in two tidal bulges.
2. These bulges cause high tides at two locations on Earth: one facing the Moon and one on the opposite side.
3. The areas perpendicular to these bulges experience low tides.

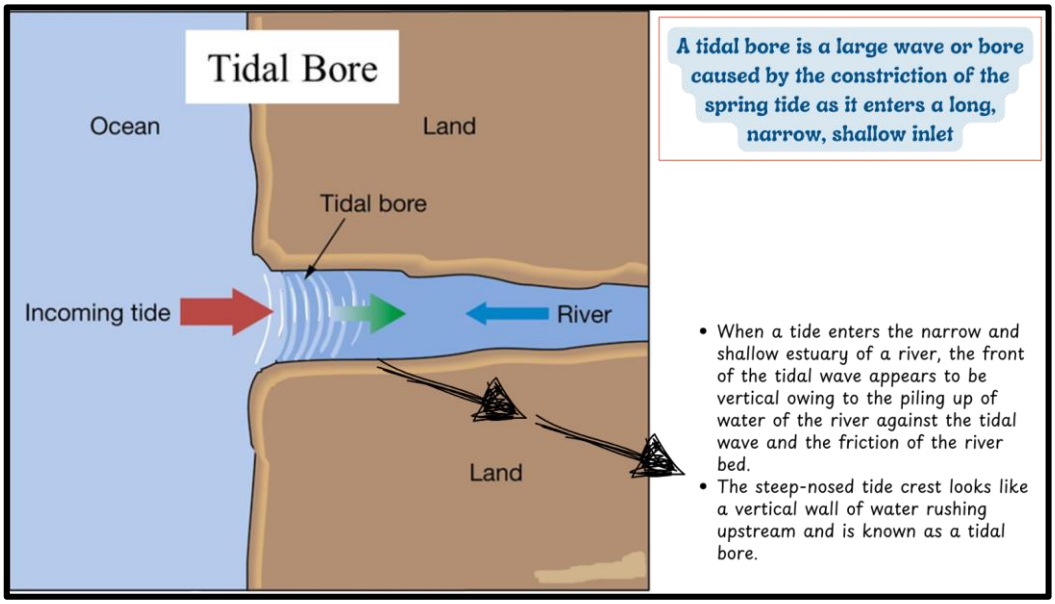
TYPES OF TIDES

BASED ON FREQUENCY	
Semi-Diurnal	➢ **Two high tides and two low tides each day** ➢ Although tides occur twice a day, their interval is not exactly 12 hours. Instead, **they occur at regular intervals of *12 hours and 25 minutes*.** ➢ This is because the moon revolves around the earth from west to east, and each day it moves a bit to the east if observed from the same place on earth at the same time on two consecutive days.
Diurnal Tide	➢ There is **only one high tide and one low tide during each day**
BASED ON THE SUN, MOON AND THE EARTH POSITIONS	
Spring Tide and Neap Tide	

- When the sun, the moon, and the earth are in a straight line(a configuration known as a syzygy), the height of the tide will be higher.
- These are called spring tides and they occur twice a month, one on the full moon period and another during the new moon period

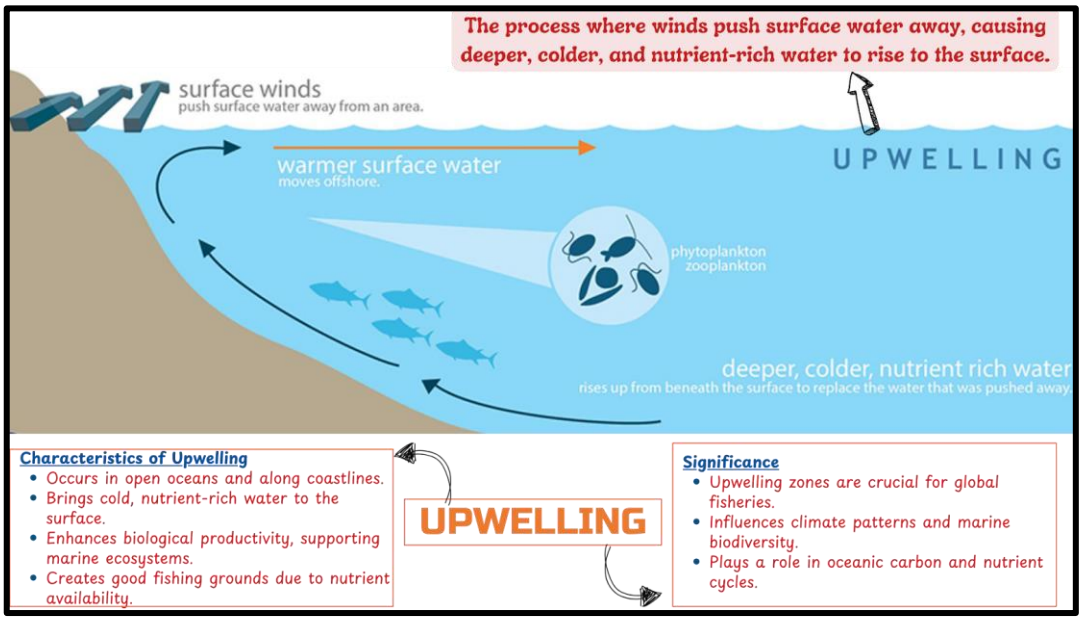
- When the Moon is at first quarter or third quarter, the Sun and Moon are separated by 90°
- The Moon's attraction, though more than twice as strong as the sun's, is diminished by the counteracting force of the sun's gravitational pull.
- At these points in the lunar cycle, the tide's range is at its minimum

TIDAL BORE



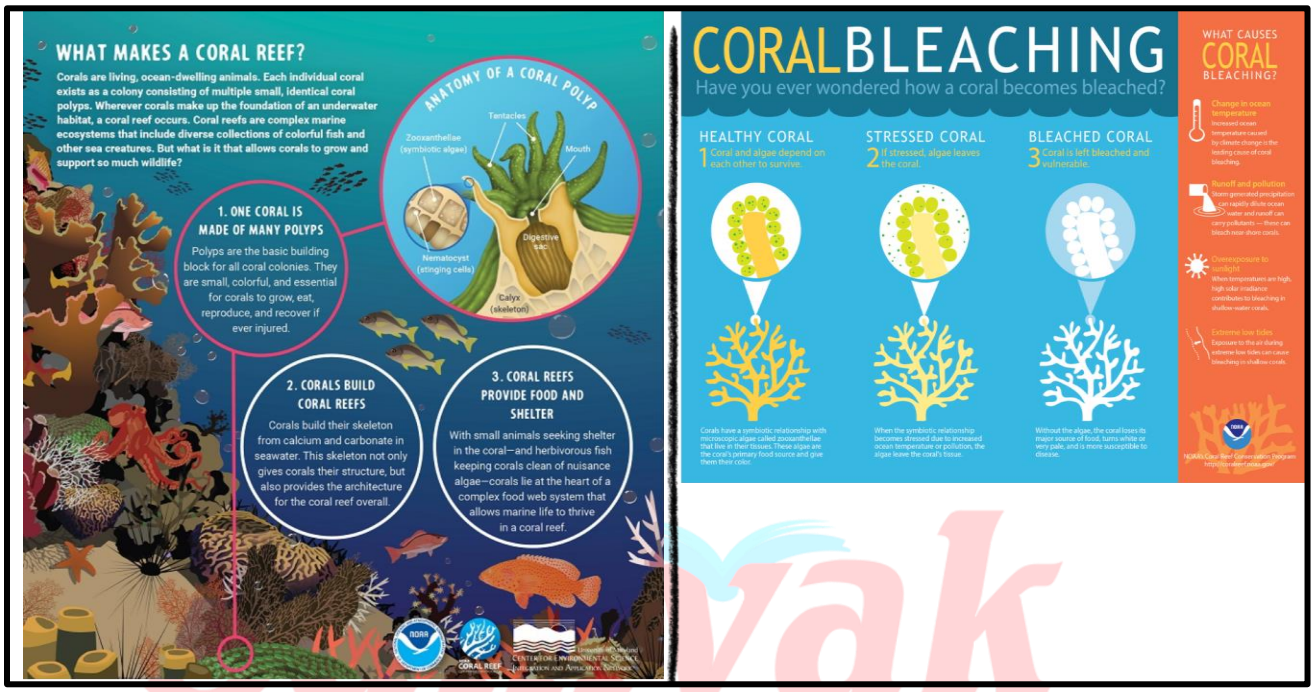
EXAMPLES
➢ There are exceptions – the **Amazon River** is the largest river in the world. It empties into the Atlantic Ocean. ➢ The mouth of the Amazon is not narrow but the river still has a strong tidal bore. A tidal bore develops here because the mouth of the river is shallow and dotted by many low-lying islands and sand bars.
➢ In **India**, tidal bores are common in the Hooghly River.

UPWELLING

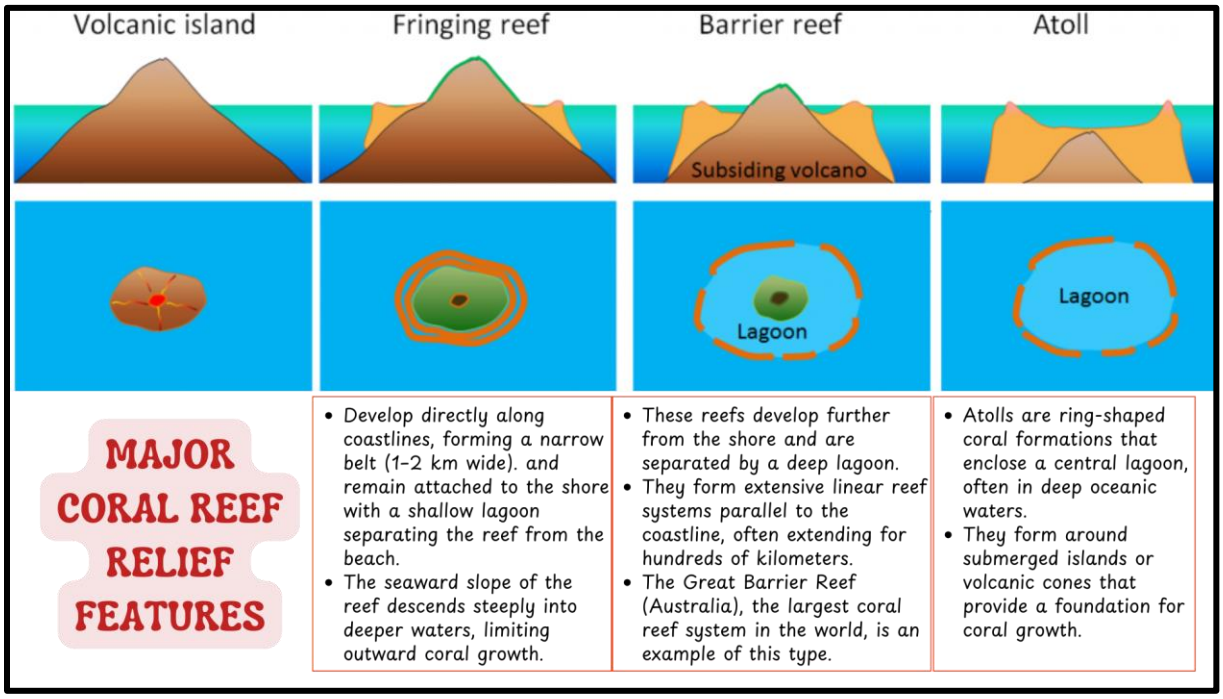


CORAL REEFS

- Coral reefs are unique marine structures formed by the accumulation of calcium carbonate secreted by coral polyps, tiny marine organisms related to jellyfish and anemones. These ecosystems are among the most diverse and productive on Earth, supporting a wide range of marine life.



EVOLUTION OF CORAL REEFS (DARWIN'S THEORY OF CORAL REEF DEVELOPMENT)



- Charles Darwin proposed a **three-stage evolutionary process** for coral reefs, explaining their transformation over time:
  - **Fringing Reef Formation:** Coral reefs begin to develop in shallow coastal waters around an emerging volcanic island.
  - **Barrier Reef Formation:** As the island subsides, coral growth keeps pace with the changing water level, resulting in a barrier reef that moves away from the original landmass.
  - **Atoll Formation:** With continued subsidence, the island completely submerges, leaving only a ring-shaped coral reef enclosing a lagoon.

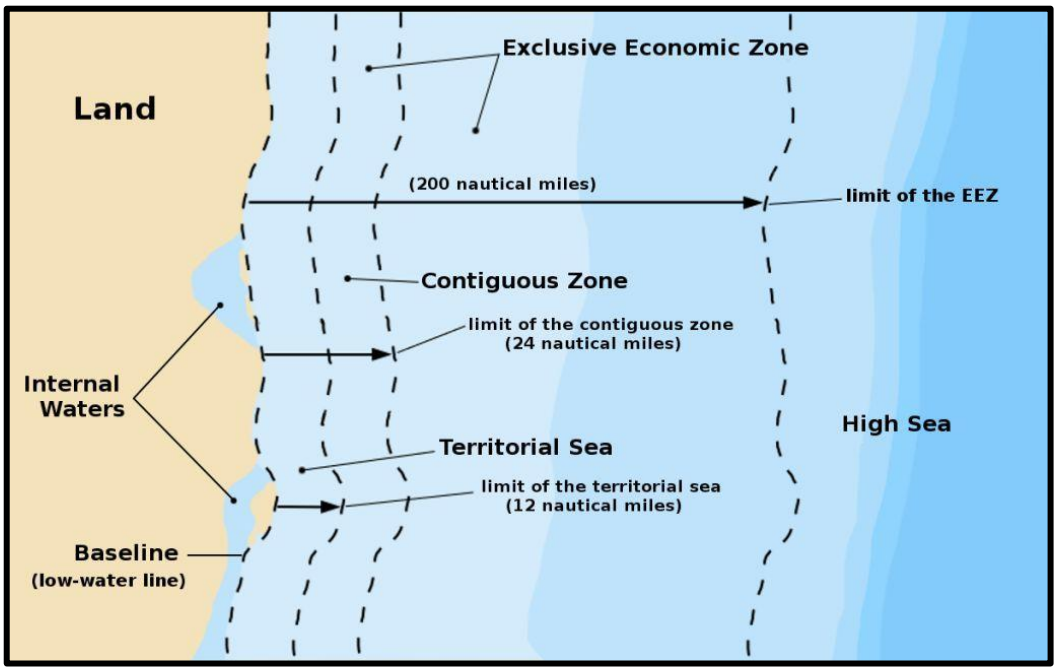
FORMATION OF LAKSHADWEEP ISLANDS (HOTSPOT THEORY)

- The Lakshadweep Islands are an example of atoll formation driven by volcanic hotspot activity.
- The Indian Ocean Hotspot led to the emergence of volcanic islands.
- As these islands gradually submerged, coral reefs developed into atolls.
- Over time, sedimentation and wave action transformed these atolls into coral islands.

UNITED NATIONS CONVENTION ON THE LAW OF THE SEA (UNCLOS)

- The United Nations Convention on the Law of the Sea (UNCLOS), also referred to as the Law of the Sea Treaty, serves as a comprehensive legal framework governing the use of the world's oceans.
- It outlines the rights and responsibilities of nations concerning maritime activities, ensuring peaceful and lawful utilization of oceanic resources.
- The convention also facilitates international cooperation and dispute resolution regarding marine boundaries, resource exploitation, and environmental protection.

KEY FEATURES OF UNCLOS



- **Exclusive Economic Zone (EEZ):**
  - Nations have special economic rights within a **200-nautical mile** zone from their coastline.
  - Countries can explore and exploit marine resources, both living and non-living, in this designated area.
- **Territorial Waters and Contiguous Zone:**
  - A 12-nautical mile zone from the baseline where the coastal state has sovereignty.
  - Beyond this, the Contiguous Zone extends another 12 nautical miles, allowing limited jurisdiction over security, taxation, customs, and immigration.
- **Continental Shelf Rights:**
  - Coastal nations can claim natural extensions of their landmass up to 200 nautical miles or more if geological conditions support it.
  - This allows countries to exploit seabed resources, including oil and gas reserves.
- **Freedom of Navigation and Innocent Passage:**
  - Foreign vessels can pass through territorial waters under the "right of innocent passage."
  - Military activities such as weapon exercises or espionage are restricted in these waters.
- **Environmental Protection and Sustainable Use:**
  - Encourages responsible exploration and exploitation of marine resources while ensuring environmental protection.
  - Supports conservation of marine biodiversity and sustainable fisheries management.

MAJOR INITIATIVES UNDER UNCLOS

- Following the adoption of UNCLOS, several international bodies were established to ensure its effective implementation:
- **International Tribunal for the Law of the Sea (ITLOS):** Established in **1994** to resolve disputes related to UNCLOS provisions.
- **International Seabed Authority (ISA):**
  - Regulates **deep-sea mining** beyond national jurisdictions.
  - Ensures **equitable sharing** of marine resources among nations.
- **Commission on the Limits of the Continental Shelf (CLCS):** Helps nations define their **extended continental shelf claims** beyond 200 nautical miles.

UNCLOS AND INDIA

- India played an active role in the negotiations leading to the adoption of UNCLOS in 1982 and ratified the treaty in 1995. As a maritime nation, India benefits from UNCLOS in several ways:
- **Strategic and Economic Importance**
  - India enjoys sovereign rights over EEZ spanning approximately 2.37 million square kilometers.
  - Has exclusive access to oil, gas, and polymetallic nodules in its continental shelf region.
  - Actively involved in deep-sea exploration for rare minerals and hydrocarbons.
  - India has initiated projects in deep-sea mining for polymetallic nodules, cobalt-rich crusts, and hydrothermal sulfides.
  - Developing technological capabilities for sustainable exploitation of marine resources.