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Introduction

Ocean is the principal component of Hydrosphere. They are major bodies of saline water and 71% of earth's surface is covered by Ocean i.e. a continuous body of water. It can be divided into several principal oceans and smaller seas.

- Surface area of earth is 510,072,000 km^2
- It comprises of 148,940,000 km^2 land (29.2 %) & 361,132,000 km^{2}water (70.8 %).
- Half of this more than 36 Crore Square Kilometers of total area under oceans is deeper than 3000 meters.
- The Average salinity of the oceans is 3.5% or 35ppt i.e. parts per thousand.
- The volume of all oceans is around 1.3 billion Km^3.
- Average depth is 3790 meters.
- Maximum Depth is 10923 meters.

- Total mass of ocean water is 1.4 x 10^{21} kilograms. It is 0.023% of Earth's total mass.
- Less than 3% of water available on earth is Fresh water, rest is saline water

Color of Oceans

Color of the Oceans is slightly blue because of the primary fact that:

1. It shows reflection of sky
2. It absorbs all the wavelengths of light except blue.
3. It absorbs red color of light.
4. Because it has impurities such as Cu++

Answer of the above question is 3. Please note that Ocean is blue because sky is blue is a misconception. The primary cause of ocean bodies being slightly blue is because water shows slightly blue color and that is because of the fact that it absorbs the Red photons of the light. Because the absorption which gives water its color is in the red end of the visible spectrum, one sees blue, the complementary color of red, when observing light that has passed through several meters of water.

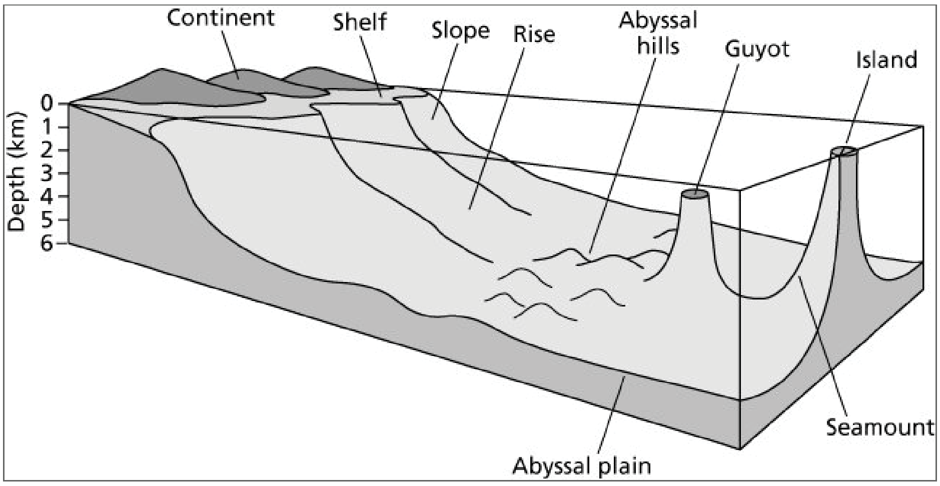
Some Extreme Points

- The deepest point in the ocean is the Mariana Trench, located in the Pacific Ocean near the Northern Mariana Islands.
- Its maximum depth has been estimated to be 10,971 meters (plus or minus 11 meters).
- British naval vessel, **Challenger II** surveyed the trench in 1951 and named the deepest part of the trench, the "Challenger Deep".
- In 1960, the Trieste successfully reached the bottom of the trench, manned by a crew of two men.

Types of Oceanic landforms

The ocean relief can be divided into the following parts as shown in the graphics:

1. Continental shelves
2. Continental Slope
3. Continental Rise or Foot
4. Deep Ocean basins
5. Abyssal plains & Abyssal Hills
6. Oceanic Trenches
7. Seamounts
8. Guyots.



Continental Shelf

Continental Shelf is the submerged edge of a continent. It is a gently sloping plain that extends into the Ocean. The typical gradient is less than 1°. Taken together, total area of the continental shelves is 18% of earth's dry land area. Continental shelf is made up of Granite rock overlain by the sediments. Because of the gentle slope, the continental shelf is influenced by the changes in the sea level.

Continental Slope

Continental slope is relatively steep descent from the shelf break to the deep sea floor. It is the transition between the granite of the continent and basalt of the sea bed. Inclination of the typical continental slope is around 4° and usually between 2° to 5°. Shelf break is almost constant all over the globe and is around 150 meters, except the Antarctica and Greenland continental slopes. The slope plunges down at least 1 kilometer and usually 2-3 kilometers.

Continental Rise or Continental Foot

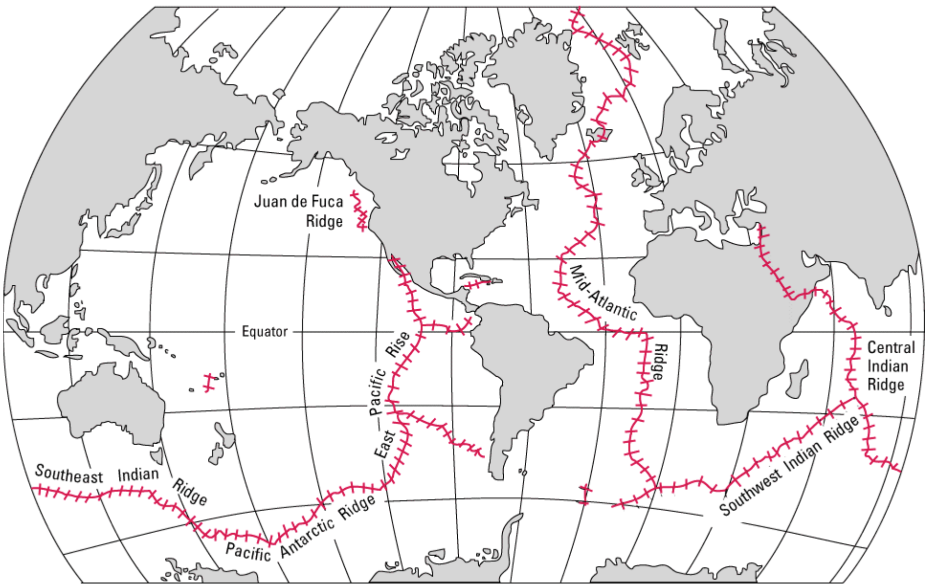
It connects that Continental slope to the deep sea or abyssal plain. Its width is around 100-1000 kilometers. Slope is gradual and around l/8th of the continental slope.

Deep Ocean basin

This is the layer or sea bed, which is lowest layer in the ocean. The sea floor is like a covering of sediments over a basalt rock which may be up to 5 kilometers thick.

Oceanic Ridges

Oceanic ridges are most commonly found in young seabed and refer to the boundary between the diverging plates. They are also known as mid oceanic ridges. The oceanic ridges present a mountainous chain of young rocks which stretch around 65000 kilometers, i.e. 1.5 times of the earth's circumference. Oceanic ridges are made up of basalt rocks, , are geologically active as the new magma constantly emerging onto the ocean floor accumulates in the crust at and near rifts along the ridge axes. The following graphic shows distribution of some Oceanic Ridges around the world.



Location of some important Oceanic Ridges:

1. **Aden Ridge:** Gulf of Aden and Indian Ocean along the southeastern coastline of the Arabian Peninsula.
2. **Explorer Ridge:** Located 240 km west of Vancouver Island, British Columbia, Canada.
3. **Gorda Ridge:** off the coast of Oregon and northern California north of Cape Mendocino
4. **Juan de Fuca Ridge:** off the coasts of the state of Washington in the United States

5. **Cocos Ridge:** Its is a Volcanic hotspot. Also known as **Galapagos hotspot** located in East Pacific Ocean responsible for the creation of the Galapagos Islands as well as three major seismic ridge systems. Carnegie, Cocos and Malpelso.
6. **Gakkel Ridge:** located in the Arctic Ocean between Greenland and Siberia, and has a length of about 1,800 kilometers. It is **slowest known spreading ridge** on the earth.
7. **Pacific-Antarctic Ridge:** located in South Pacific Ocean
8. **Southeast Indian Ridge:** It is located in the Indian Ocean and separates the Indo Ocean plate from the Antarctic plate.
9. **Carlsberg Ridge:** Located in the Indian Ocean.

Abyssal Plain

Abyssal plain is flat, cold and sediment covered ocean floor. Abyssal plains are more extensive in Atlantic and Indian Oceans and less extensive in pacific Ocean. Abyssal plain is found at an average depth between 3000 and 6000 meters. They are among the flattest, smoothest and least explored regions on earth.

Oceanic Trench

An elongated through or Deep in the ocean floor is called ocean trench. It is more or less a U shaped valley. Most of world's trenches are in Pacific Ocean. Trenches are most active geological features on earth where great earthquakes are Tsunamis are born. Here is a brief info about important trenches:

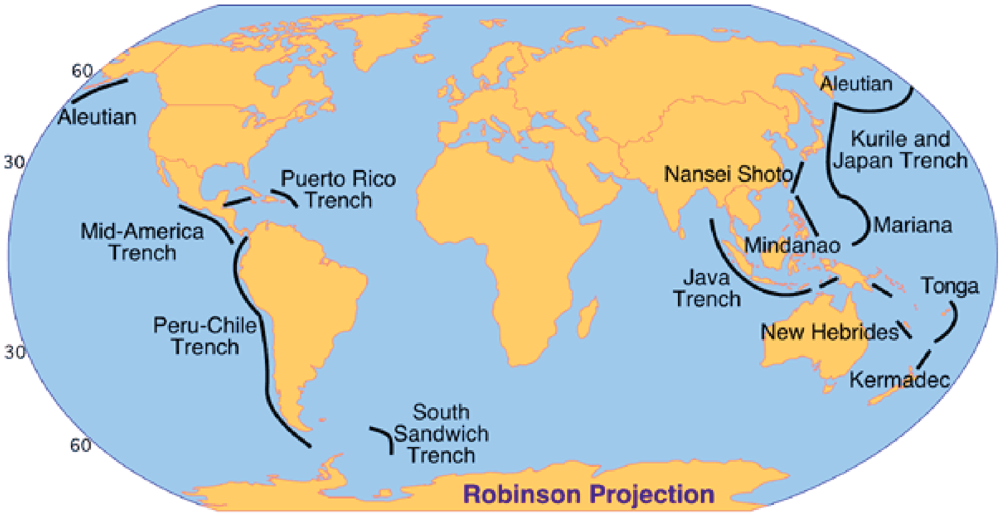
- ✓ **Mariana Trench:** Mariana Trench is the deepest part of the world's oceans. It is located in the western Pacific Ocean, east of the Mariana Islands. The trench is about 2,550 kilometers long but has a mean width of only 69 kilometers. The maximum known depth is 11.03 kilometers at the Vityaz-l Deep and about 10 91 kilometers at the Challenger Deep.
- ✓ **Tonga Trench:** Tonga Trench us located in South Pacific Ocean and is second deepest trench. Its deepest point is called Horizon Deep. It is Steepest Trench of the World.

Factbox: Tonga Trench and Apollo 13

Apollo 13 was the third Apollo mission which was launched to land on the Moon. It was successfully launched toward the Moon, but the landing had to be aborted after an oxygen tank ruptured. It was launched on April 11, 1970 and subsequently failed. Its lunar module reentered earth's surface on April 17. 1970 and was targeted over the pacific Ocean to reduce the contamination from the Radioisotope Thermoelectric Generator (RTG) on board, which would have provided energy to the mission. This RTG was landed in the Tonga Trench. The RTG will remain active for next 2000 years. It has 3.9 kilogram of radioactive plutonium.

- ✓ **Puerto Rico Trench:** Puerto Rico Trench is located on the boundary between the Caribbean Sea and the Atlantic Ocean. The trench is 800 kilometers long and has a maximum depth of 8,605 meters at Milwaukee Deep. which is the deepest point in the Atlantic Ocean.

Location of some Mid-Oceanic Trenches in Oceans



Source: Physicalgeography.net

North Pacific Ocean

- ✓ Mariana Trench (Vityaz-l Deep and Challenger Deep)
- ✓ Japan Trench (**Ramapo Deep**)
- ✓ Aleutian Trench
- ✓ Kurile Trench
- ✓ Philippine Trench
- ✓ Atacama Trench

South Pacific Ocean

- ✓ Tonga Trench (Horizon Deep)
- ✓ New Hebrides Trench
- ✓ Peru trench
- ✓ Plate Tectonics

North Atlantic

- ✓ Puerto-Rico trench
- ✓ Romanche trench

Indian Ocean

- ✓ Sunda Trench also known as Java Trench.

Seamounts

Seamounts are elliptical projections from the sea floor which look like mountains and have a steep slope of around 22° to 24°.Half of the world's total seamounts arc in Pacific Ocean.

Guyots

They are basically inactive volcanoes which are flat topped. Some of them are tall enough to approach or even penetrate the sea surface. Guyots are confined to Central Pacific Ocean.

Rift valleys

A rift valley is linear-shaped lowland between highlands or mountain ranges created by the action of a geologic rift or fault in opposite or parallel. The result is the formation of a long steep sided, flat floored valley. **World's largest Fresh water lakes are typical rift valleys.** Examples are Lake Baikal in Siberia, Lake Tanganyika, Lake Superior, Lake Vostok, Lake Nipissing and Lake Timiskaming. **Jordan Rift Valley**, which is lowest land elevation on earth is located in the Dead Sea and is 760 meters below the surface of the Mediterranean Sea. **Gulf of Aqaba** in the Red Sea is also a rift valley.

Lake Baikal

Lake Baikal, also known as "Pearl of Siberia" is located in Siberia and is second most voluminous lake in the world after the Caspian Sea. It is also world's oldest and deepest lake. It's a Rift valley, created by the Baikal Rift Zone, and a World Heritage site declared in 1996. Lake Baikal is home to **Buryats , the largest ethnic minority group** and a tribe in Siberia. It was referred as North Sea by ancient Chinese writers.

Lake Tanganyika

After lake Baikal, Lake Tanganyika is second deepest lake in the world. It is world's longest Lake spanning in 4 countries of Africa viz. Burundi, Tanzania, Congo and Zambia. This lake is a Rift Valley and largest rift lake in Africa.

Lake Superior

Lake Superior is largest lake of North America, shared by Canada as well as USA. It is largest freshwater lake in the world by surface area if lake Michigan and lake Huron are NOT considered one.

Lake Vostok

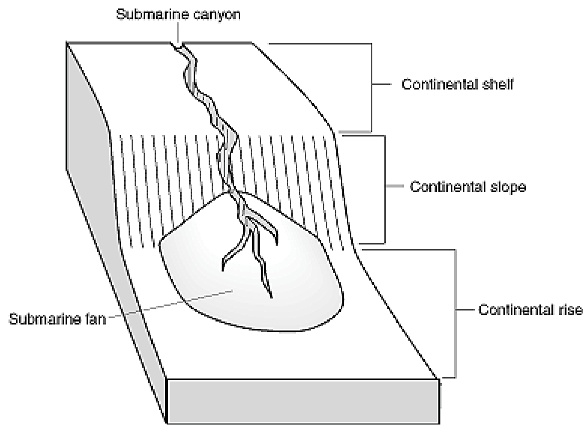
Lake Vostok is in Antarctica and is a Sub Glacial lake. It is located below the Vostok Station of Russia in Antarctica.

Lake Nipissing

Lake Nipissing is located in Canada. It's one of the shallowest lakes of Canada.

Abyssal Fans

Abyssal fans are also known as **deep-sea fans**, **underwater deltas,** and **submarine fans**. They are delta like structures formed at the deep sea surfaces.



Abyssal plain

Abyssal plain is found at the depths between 3000 and 6000 meters. Abyssal plains cover more than 50% of Earth's total surface. They are considered to be major reservoir of biodiversity.

Archipelago

Archipelago refers to a cluster of islands which are formed tectonically. This term was initially used for Aegean Islands located in the Aegean Sea between Greece and Turkey. Indonesia is often referred to as the world's largest archipelago; however, this means that it is largest by area and not by number of islands. Indonesia has 17,500 islands which span more than 5000 km^2. World's largest archipelago by number of Islands is Archipelago Sea which is located Baltic Sea between the Gulf of Bothnia and the Gulf of Finland. It has 50,000 Islands. Top 5 archipelagoes in the world by number of Islands are as follows:

1. Archipelago Sea (Finland) 50,000
2. Canadian Arctic Archipelago 36.563
3. Stockholm Archipelago 24,000
4. Indonesian Archipelago 17.508
5. Philippine Archipelago 7.107

Lagoon

Lagoon is a shallow body of sea water or brackish water separated from the sea by some form of barrier. The biggest lagoon in the world is located in New Caledonia, in southwest pacific. In India, **Chilika Lake** in Orissa and the **Vembanad Lake** in Kerala are both connected to the Bay of Bengal and the Arabian Sea respectively through a narrow channel and they are typical lagoons.

Chilika lake

Chilika Lake is a Brackish water lagoon spanning in 3 districts of Puri, Khurda and Ganjam of Orissa. It is largest Coastal lagoon in India. The lake is an ecosystem with large fishery resources and supports 1.5 Lkh fishermen. Chilka lake has the distinction of being India's First Wetland of International Importance under the Ramsar Convention. Chilika Development Authority (CDAl is monitoring the water quality of the lagoon every month from 30 different Stations for various physico-chemical parameters, which are said to be within the permissible limits.

Vembanad Lake

Vembanad Lake located in Kerata is India's longest lake, bordered by 3 districts of Kerala viz. Alappuzha, Kottayam, and Ernakulam. Its length is 96.5 kilometers and widest width is 14 kilometers.

Coral Reefs

- ✓ Coral reefs, which are also called as "rainforests of the sea", are underwater reefs made by calcium carbonate secreted by Corals.
- ✓ Coral is the hard exoskeleton of the polyps.
- ✓ Coral Reefs grow best in **warm, shallow, clear, sunny and agitated** waters.
- ✓ Coral reefs are some of the most diverse ecosystems on earth which despite of covering less than 10% of world ocean surface (284,300 km^2) provide home to 25% of marine species including fishes, mollusks etc.
- ✓ Coral Reefs are very fragile ecosystem and are **susceptible to "Surface Temperature"** of the oceans.
- ✓ They are threatened by the climate change, ocean acidification, **blast fishing**, **cyanide fishing** for aquarium fish, overuse of reef resources, and harmful land-use practices.

Blast Fishing & Cyanide Fishing

Blast fishing refers to using the explosives to kill schools of Fishes for easily collection. The underwater shockwaves produced by the blast made by dynamite or a bomb causes the swim bladder of the fish rupture and leave them dead. The practice is Illegal. It is most common in Tanzania and Indonesia.

Cyanide fishing refers to capturing the fishes using Sodium Cyanide to kill the schools of the fishes. The fish killed are put in fresh water for 10 days and then supplied to the markets for consumption.

- ✓ The Indian Ocean and Pacific Ocean region including the Red Sea, Indian Ocean, Southeast Asia and the Pacific account for 91.9% or total Coral reefs in the world.
- ✓ Southeast Asia accounts for 32.3%, while the Pacific including Australia accounts for 40.8%. Atlantic and Caribbean coral reefs only account for 7.6%.

Great Barrier Reef

Largest Coral reef in the world is Great Barrier Reef. It is located in the Coral Sea, off the coast of Queensland in north-east Australia. It is composed of over 2,900 individual reefs and 900 islands stretching for over 2,600 kilometers. This reef can be seen from outer space and is the world's biggest single structure made by living organisms. It is a World Heritage Site (1981). It is also a state icon of Queensland, made by Queensland National Trust. A large part is protected by the Great Barrier Reef Marine Park, established by Government of Australia through **Great Barrier Reef Marine Park Act 1975**.

Belize Barrier Reef

Belize Barrier Reef is world's second largest Coral Reef which is a part of 900 kilometer Mesoamerican Barrier Reef System. It was described by Charles Darwin in 1842 as "the most remarkable reef in the West Indies".

Pulley Ridge

Pulley Ridge is located off the coast of Florida, United States. It is deepest photosynthetic coral reef known so far

Raja Ampat Islands & Coral Triangle

Raja Ampat Islands, largest marine national park in Indonesia are located in Indonesia and New Guinea and comprise 1,500 small islands .It is known for highest recorded marine biodiversity on Earth. It makes the Coral Triangle which is a triangular shaped area of the tropical marine waters of Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands and Timor-Leste. These waters contain at least 500 species of reef-building corals in each ecoregion. **Coral Triangle** as well as **Raja Ampat Islands** is considered to be the global epicenters of marine biodiversity. INWF considers the region as a top priority for marine conservation and has launched the Coral Triangle Program in 2007

Beach

Beach is the shoreline of an ocean, sea or lake which consists of loose particles such as sand, gravel. pebbles etc. They are formed as a result of wave action by which waves or currents move sand or other loose sediments.

- ✓ **Cox's Bazaar:** Cox's Bazaar sandy beach in Bangladesh's Chittagong is considered to be world's longest natural sandy beach. It has an unbroken length of 120 kilometers.
- ✓ **Marina Beach:** Marina Beach is located in India's Chennai and is one of the largest beaches of India.

Continental Drift

The first thing we should note is that the Lithosphere of our earth is always in a state of work in progress. The changing surfaces create opportunities as well as threats for the people and animals. The changing surfaces means the surface is in motions. The earthquakes make us remind this eternal fact.

In 1912, a German geologist named **Alfred Wegener** came up with an outlandish theory known as **continental drift,** after noting the jigsaw puzzle–like geometry of Africa's west coast and South America's east coast. Apart from this what he noticed was:

- Presence of coal fields in the temperate regions, while they could only be formed in the Tropical regions.

- Evidences of the Glacial flow of the past.
- Similarity in the rock structure on opposite sides of the Atlantic.

So, **Wegener** proposed that the present continents were once joined in a super continent named **Pangaea** and later the drifted apart.

Wegener proposed that the **Pangaea** broke into continents and the new continents drove away themselves in two directions viz. Equatorward and Westward movements. He said that the movements towards the equators were because of the gravitational differential forces and force of buoyancy. The Westward movement occurred because of the tidal force of sun and moon.

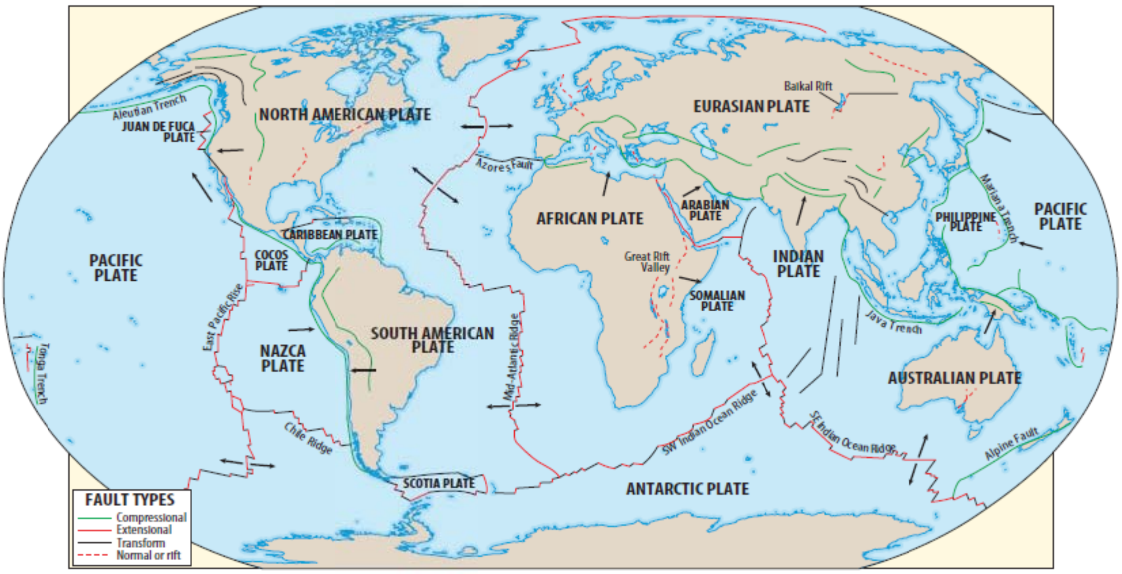
He proposed that the Pangaea began to separate into the **Gondwanaland** and **Angaraland** in the Carboniferous period and the space between the two was filled with water that was called **Tethys Sea**. Later the Gondwanaland disrupted during the Cretaceous period and with this, the Indian subcontinent (peninsula) , Madagaskar, Australia and Antarctica broke away from the Gondwanaland. Similarly the North America broke away from the **Angaraland** and drifted westward due to Tidal forces. He went on further proposing that South America broke way from Africa and moved westwards due to Tidal forces.

This theory was interesting and thrilling but Wegener was unable to explain what the forces behind this drift were.

So, the result was that **Alfred Wegener** was derided by the scientific community; his proposal was called "geopoetry"☺. However, the later discoveries in deep-sea science led Wegener's basic proposition to be accepted as fact, and today a good deal is known about how the continental drift occurs.

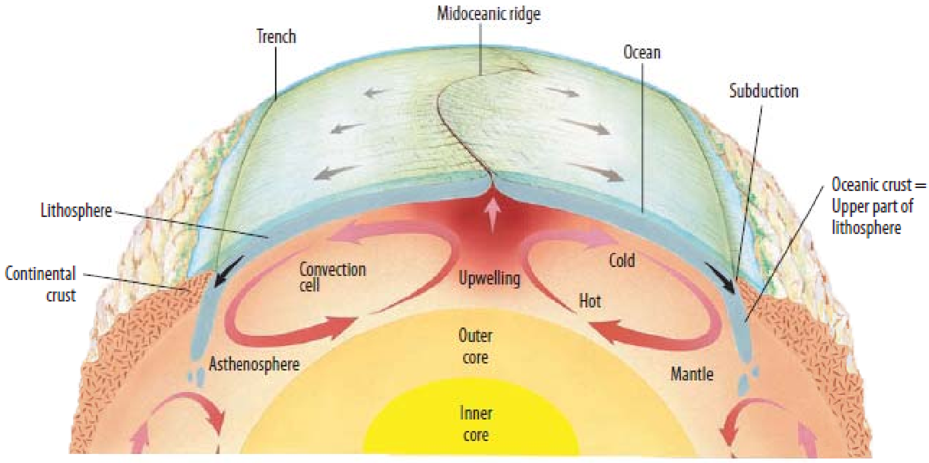
Plate Tectonics and Seafloor Spreading

Today, we know that the Earth's lithosphere is made up of about a dozen giant and several smaller sections called plates, and these move in various directions in processes known collectively as plate tectonics. The following graphics shows the plates.



The above graphic shows the major tectonic plates and their general direction of movement. Earthquakes, volcanoes, and other geologic events are concentrated where plates separate, collide, or slide past one another. Where they separate, rifting produces very low land elevations (e.g. well below sea level at the

Dead Sea of Israel and Jordan) or the emergence of new crust on the ocean floor (e.g. in the middle of the Atlantic Ocean). Now, before we move ahead, please look at this generalized cross section of Earth.



The central item in the above graphics is Mid-Oceanic Ridge. A mid-ocean ridge (MOR) refers to an **underwater mountain system** that consists of various mountain ranges (chains), typically having a valley known as a rift that runs along its spine, formed by **plate tectonics.**

This type of oceanic ridge is characteristic of what is known as an oceanic spreading center, which is responsible for seafloor spreading. The mid-ocean ridges of the world are connected and form a single global mid-oceanic ridge system that is part of every ocean, making the mid-oceanic ridge system the longest mountain range in the world. The continuous mountain range is 65,000 km (40,400 mi) long and the total length of the oceanic ridge system is 80,000 km (49,700 mi) long.

When the ocean floors such as Mid-Atlantic Ridge and the East Pacific Rise, new lithosphere is "born" as molten material rises from the earth's mantle and cools into solid rock. Plate tectonics are often explained by the useful analogy of a "conveyor belt" (the convection cell shown in above graphics) in constant motion. On either side of the long, roughly continuous ridges, the two young plates move away from one another, carrying islands with them; this process is called **seafloor spreading.**

Seafloor spreading has few impacts on us, but when the earth's plates collide, there is cause for great concern: tectonic forces are among the planet's greatest natural hazards. The seismic activity (seismic refers to earth vibrations, mainly earthquakes) that causes earthquakes and tsunamis (tidal waves) and the volcanism (movement of molten earth material) of volcanoes and related features are the most dangerous tectonic forces.

Movements of the Plates – Subduction

The Plates collide and converge in different ways and with different consequences. On some parts of the earth one plate "dives" below another in a process known as **subduction**. The descending lithosphere is melted again as it dives into the earth's mantle along a deep linear feature known as a trench (such as the Mariana Trench off Japan). Subduction is another stage along the "conveyor belt" process that will eventually see this material recycled as newborn lithospheric crust. This subduction process releases enormous amounts of energy. The great stress of one plate pushing beneath another is released in the form of an earthquake. The world's largest recorded earthquakes—registering 9.5 (Chile, 1960), 9.2 (United

States, 1964), and 9.1 (Indonesia, 2004), respectively, on the Richter scale, which measures the strength of the earthquake at its source—struck along these subduction zones. This sudden displacement of a section of oceanic lithosphere is also what triggers a tsunami and the attendant loss of life and property such a powerful wave can cause. Here, we should note that **Volcanism generally occurs at places near the subduction zones.**

Movement of Plates – Faulting

In some other places, the lithospheric plates **grind and slide along one another.** The processes of rock crowding together or pulling apart along these **fracture lines** is known as **faulting. The** movement along various kinds of faults causes earthquakes, the emergence of new landforms, and other consequences.

Ocean Temperature

The temperature of the oceanic water is important phytoplankton as well as zooplanktons. The temperature of sea water also affects the climate of coastal lands and plants and animals. The study of both, surface and subsurface temperature of sea water is significant.

The first question arises is that how we measure the temperature of the Seawater? Standard type of thermometer is used to measure the surface temperature while reversing thermometers and **thermograph**s are used to measure the subsurface temperature. These thermometers record the temperature up to the accuracy of ±0.02° centigrade. With respect to temperature, there are three layers in tile oceans from surface to the bottom in the tropics as follows:

1. The first layer represents the top-layer of warm, oceanic water and is 500m thick with temperature ranging between 20° and 25°C. This layer is present within the tropics throughout the year but it develops in mid· latitudes only during summer.
2. The **thermocline layer** represents vertical zone of oceanic water below the first layer and is characterized by rapid rate of decrease of temperature with increasing depth,
3. The third layer is very cold and extends upto the deep ocean floor. The polar areas have only one layer of cold water from surface (sea level) to the deep ocean floor.

As we all know the Oceans absorb more than 80% of the solar radiation and water which has highest specific heat is the remarkable capacity of storing the heat. The uppermost 10% of the oceans has more heat than the entire atmosphere of earth!

The radiant energy transmitted from the photosphere of the sun in the form of electromagnetic short waves and received at the ocean surface is called **insolation**. Besides, some energy, though insignificant, is also received from **below the bottom and through the compression of sea water**. The amount of insolation to be received at the sea surface depends on the angle of sun's rays, length of day, distance of the earth from the sun and effects of the atmosphere. The mechanism of the heating and cooling of ocean water differs from the said mechanism on land because besides horizontal and vertical movements of water, the evaporation is most active over the oceans.

Daily Range of Temperature

The difference of maximum and minimum temperature of a day (24 hours) is known as daily range of temperature.

- ✍ The daily range of temperature of surface water of the oceans is **almost insignificant** as it is around 1°C only.

✍ The daily range of temperature is usually 0.3°C in the low latitudes and 0.2° to 0.3°C in high latitudes.

The diurnal range depends on the

1. Conditions of sky (cloudy or clear sky),
2. Stability or instability of air and
3. stratification of seawater.

The heating and cooling of ocean water is rapid under clear sky (cloudless) and hence the diurnal range of temperature becomes a bit higher than under overcast sky and strong air circulation. The high density of water below surface water causes very little transfer of heat through conduction and hence the diurnal range of temperature becomes low.

Annual Range of Temperature

The maximum and minimum annual temperatures of ocean water are recorded in August and February respectively (in the northern hemisphere). Usually, the average annual range of temperature of ocean water is -12°C (10°F) but there is a lot of regional variation which is due to regional variation in insolation, nature of seas, prevailing winds, location of seas etc.

Annual range of temperature is higher in the enclosed seas than in the open sea (Baltic Sea records annual range of temperature of 4.4°C or 40°F). The size of the oceans and the seas also affects annual range of temperature e.g., bigger the size, lower the annual range and vice versa. The Atlantic Ocean records relatively higher annual range of temperature than the Pacific Ocean.

Distribution Pattern of Temperature

The distributional pattern of temperature of ocean water is studied in two ways viz.

1. **Horizontal distribution** (temperature of surface water) and
2. Vertical distribution (from surface water to the bottom).

Since the ocean has three dimensional shape, the **depth of oceans, besides latitudes,** is also taken into account in the study of temperature distribution.

The following factors affect the distribution of temperature of ocean water.

1. **Latitudes:** The temperature of surface water decreases from equator toward the poles because the sun's rays become more and more slanting and thus the **amount of insolation decreases pole ward** accordingly.
   - ✍ The temperature of surface water between 40°N and 40°S is lower than air temperature but it becomes higher than air temperature between 40th latitude and the poles in both the hemispheres.
2. **Unequal distribution of land and water:** The temperature of ocean water varies in the northern and the southern hemispheres because of dominance of land in the former and water in the latter.
   - ✍ The oceans in the northern hemisphere receive more heat due to their contact with larger extent of land than their counterparts in the southern hemisphere and thus the temperature of surface water is comparatively higher in the former than the latter.
   - ✍ The isotherms are not regular and do not follow latitudes in the northern hemisphere because of the existence of both warm and cold landmasses whereas they (isotherms) are regular and follow latitudes in the southern hemisphere because of the dominance of water.

- ✍ The temperature in the enclosed seas in low latitudes becomes higher because of the influence of surrounding land areas than the open seas e.g., the average annual temperature of surface water at the equator is 26.7°C whereas it is 37.8°C in the Red Sea and 34.4°C (94°F) in the Persian Gulf.

3. **Prevailing wind:** Wind direction largely affects the distribution of temperature of ocean water.
    - ✍ The winds blowing from the land towards the oceans and seas (e.g., offshore winds) drive warm surface water away from the coast resulting into upwelling of cold bottom water from below.
    - ✍ Thus, the replacement of warm water by cold water introduces longitudinal variation in temperature.
    - ✍ Contrary to this, the onshore winds pile up warm water near the coast and thus raise the temperature.
    - ✍ For example, trade winds cause low temperature (in the tropics along the eastern margins of the oceans or the western coastal regions of the continents) because they blow from the land towards the oceans whereas these trade winds raise the temperature in the western margins of the oceans or the eastern coastal areas of the continents because of their onshore position. Similarly, the eastern margins of the oceans in the middle latitudes (western coasts of Europe' and North America) have relatively higher temperature than the western margins of the oceans because of the onshore position of the westerlies.
4. **Ocean currents:** Surface temperatures of the oceans are controlled by warm and cold currents. Warm currents raise the temperature of the affected areas whereas cool currents lower down the temperature.
5. **Other factors:** Other factors include the following:
    1. Submarine ridges
    2. Local weather conditions such as storms, cyclones, hurricanes, fog, cloudiness, evaporation and condensation
    3. **Location and Shape of area:** The enclosed seas in the low latitudes record relatively higher temperature than the open seas whereas the enclosed seas have lower temperature than the open seas in the high latitudes.

Horizontal Distribution of Temperature

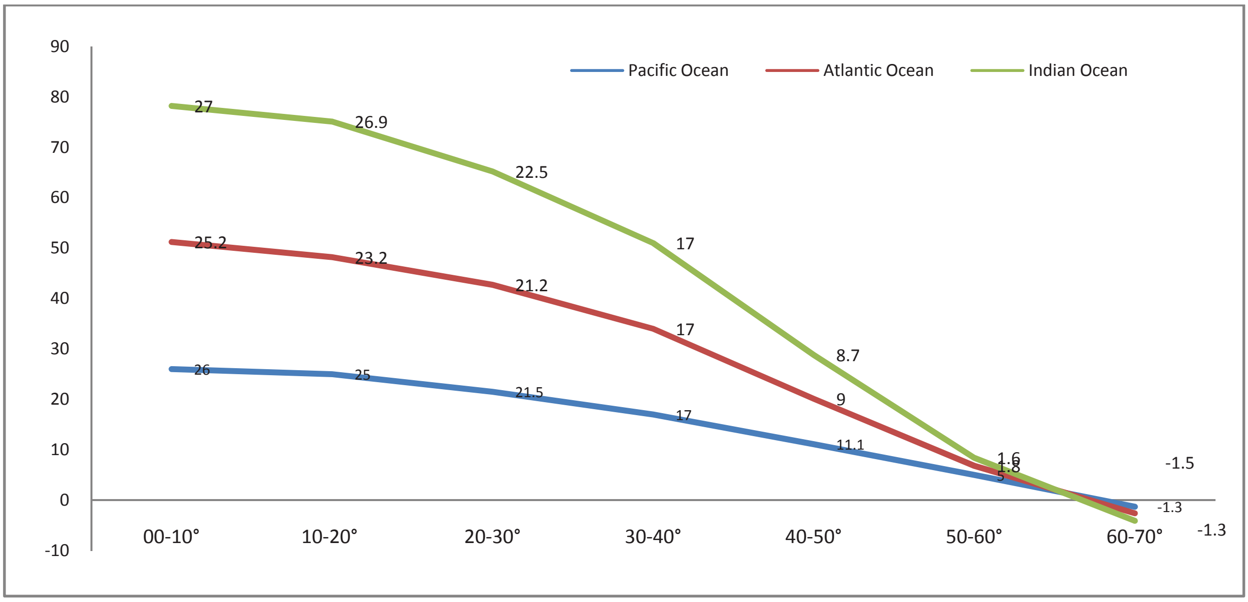
Average temperature of surface water of the oceans is 26.7°C and the temperature gradually decreases from equator towards the poles.

- The rate of decrease of temperature with increasing latitudes is generally 0.5°C per latitude.
- The average temperatures become 22°C at 20° latitude, 14°C (57°F) at 40° latitude, and 0°C (32°F) near the poles.
- The oceans in the northern hemisphere record relatively higher average temperature than in the southern hemisphere.
- Please note that the highest temperature is not recorded at the equator rather it is a bit north of it.

Also we should note that the average annual temperature of all the oceans is 17.2°C. The average annual temperatures for the northern and southern hemispheres are 19.4°C and 16.1°C respectively. The variation of temperatures in the northern and southern hemispheres is because of unequal distribution of land and water as Northern hemisphere is made up of more land, while the southern hemisphere is made up of more oceans.

In Northern Atlantic, there is a **very low decrease of temperature** with increasing latitudes towards north. This is because of the Gulf Stream currents which are warm currents. However, in southern Atlantic, the decrease of temperature with increasing latitude is more pronounced.

The follows graphics shows the variations of three major oceans:



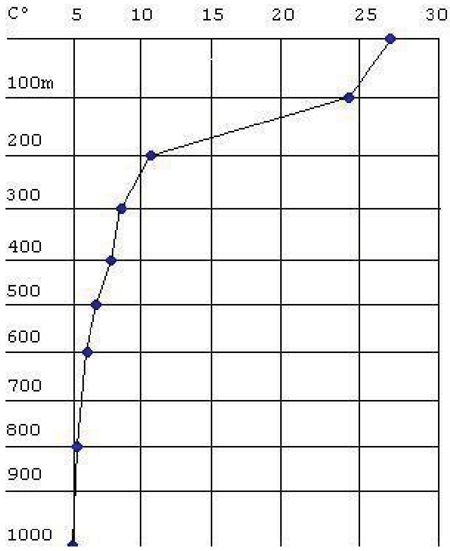
Latitudes	Pacific Ocean	Atlantic Ocean	Indian Ocean
00-10°	26	25.2	27
10-20°	25	23.2	26.9
20-30°	21.5	21.2	22.5
30-40°	17	17	17
40-50°	11.1	9	8.7
50-60°	5	1.8	1.6
60-70°	-1.3	-1.3	-1.5

Vertical Distribution of Temperature

We know that the maximum temperature of the oceans is always on the surface because it directly receives the insolation. The heat is transmitted to the lower sections of the oceans through the mechanism of conduction. Solar rays very effectively penetrate up to 20m depth and they seldom go beyond 200m depth. Consequently, the temperature decreases from the ocean surface with increasing depth but please note that the rate of decrease of temperature with increasing depth is not uniform everywhere. The temperature falls very rapidly up to the depth of 200m and thereafter the rate of decrease of temperature is slowed down. From this stand point the oceans are vertically divided into three zones as follows:

1. **Photic Zone or Euphotic Zone:** This is the upper layer of the ocean. The temperature is relatively constant and is 100 meters deep.

2. **Thermocline:** Thermocline or **Pycnocline** lies between 100-1000 meters. There is a steep fall in the tempereature. The following graph shows the thermocline.



3. **Deep Zone:** Below 1000 meters is the deep zone. Here, the temeperature is near zero °C. Please note that near bottom, the tempereture of water never goes to 0°C. It is always 2-3°C.

Here, we should note the following points:

- Sea temperature decreases with increasing depth but the rate of decrease of temperature is not uniform.
- The change in sea temperature below the depth of 1000m is negligible. The maximum change in temperature is between 100-1000 meters (Thermocline)
- Diurnal and annual ranges of temperature cease after a depth of 30 feet and 600 feet respectively.
- The rate of decrease of temperature with increasing depth from equator towards the poles is not uniform.
- **Temperature of Ocean bottom is uniform from Equator to Poles**.

Salinity of Ocean Water

Salinity of the ocean water is between 3.3-3.7 percent. The maximum amount of salt is common salt i.e. Sodium Chloride, which is followed by Magnesium Chloride. The major salts are as follows:

Salt	‰ (parts per thousand)
Sodium Chloride	2.6
Magnesium Chloride	0.3
Magnesium Sulphate	0.2
Calcium Sulphate	0.1
Potassium Chloride	0.1
Potassium Bromide	0.001
Others	0.001

Most of the salinity of the sea comes from the dissolved material that originates from land and was carried by the rain, running water, ground water, wind, sea waves, glaciers etc. Some of the salts come from the deeper layers of earth. Volcanic lava, dead organic matters also contribute.

The salinity of the ocean water depends upon the following:

1. **Evaporation:** Higher the rate of evaporation, higher is salinity. The Highest evaporation has been recorded along the tropic of Cancer and that is why the region of Red Sea and Persian Gulf has one of the highest salinity.

2. **Temperature:** There is a direct relationship between ocean temperature and salinity. So the warmer parts are more saline and frigid parts are less saline.
3. **Precipitation:** Precipitation is inversely related to salinity. Higher is the precipitation, lower is the proportion of salinity. The equatorial region records highest rainfall and that it is why it has low salinity in comparison to those which are near to tropics.
4. **Influx of Freshwater:** Low salinity will be found at the mouth of rivers. This salinity is minimum in the raining season.
5. **Atmospheric Pressure:** High pressure areas have high salinity and vice versa.
6. **Circulation of Ocean water:** Ocean currents play a major role in distribution of salinity.

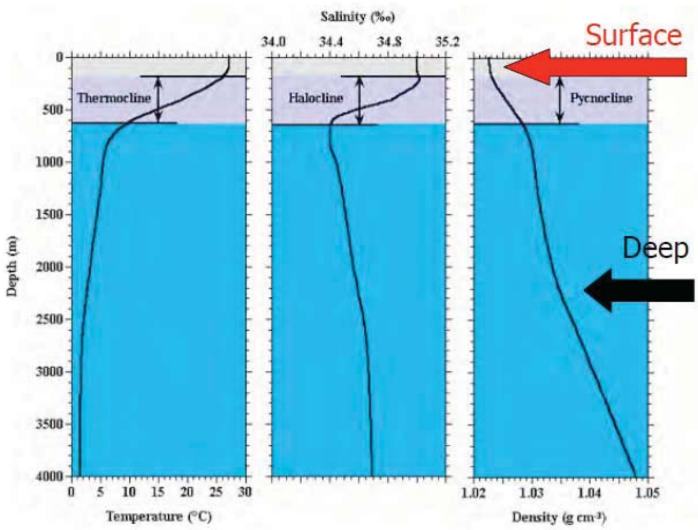
Horizontal Distribution of Salinity of Ocean Water

Please note that generally, the salinity of the Oceans decreases on both sides from the tropic of Cancer. This means that highest salinity of the seawater is between 20°N to 40°N. The average salinity of the Northern and southern hemisphere is 3.5 and 3.4 $\%_0$ respectively.

Vertical Distribution of Salinity

There is no definite trend in the vertical distribution of salinity in the oceans, so there are no generalizations. However, it has been noted that the salinity of the ocean increases with increasing depth in the higher latitudes and polar areas. In the middle latitudes also, the same trends is seen but ONLY up to a depth of 370 meters after that it decreases with increasing depth.

The following graphics shows the variation of temperature, salinity and density of ocean water with depth:



Ocean Currents

Ocean current is the general movement of a mass of oceanic water in a definite direction, which is more or less similar to water streams flowing on the land surface of the earth. Ocean currents are most powerful of all the dynamics of oceanic waters because these drive oceanic waters for thousands of kilometers away. Ocean currents are divided on the basis of temperature into warm currents and cold currents. On the basis of velocity, dimension and direction, they can be divided into drifts, currents and streams. The forward movement of surface water of the oceans under the influence of prevailing winds is called drift whereas the ocean current involves the movement of Oceanic water in a definite direction with greater velocity. Ocean stream involves movement of larger mass of ocean water like big rivers of the continent in a definite direction with greater velocity than the drifts and currents such as in Gulf Stream.

How currents originate in Oceans?

The currents in the oceans are originated due to combined effects of several internal as well as external factors, which control the origin and other characteristics of ocean current. They are related to different characteristics of ocean waters, rotational mechanism of the earth, external factors or atmospheric factors, topographic characteristics of the coasts and ocean basins. Besides, there are some factors which can modify the ocean currents.

- ✍ The factors relating to the earth's nature and its rotation include the gravitational force and deflective force by earth's rotation also known as **Coriolis Force**.
- ✍ Oceanic factors include the pressure gradient, temperature variations and salinity differences. Ex-oceanic factors are atmospheric pressure and winds, evaporation and precipitation.
- ✍ The factors that can modify the currents are direction and shape of coastlines, bottom reliefs of the ocean basins, seasonal variations and rotation of the earth.

Impact of Rotation of the Earth: Coriolis force

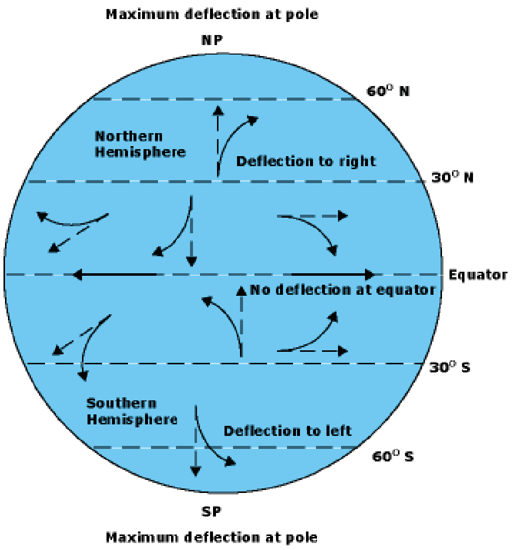
The rotation of the earth on its axis from west to east results in the genesis of deflective force or **Coriolis force** which deflects the general direction of ocean currents. For example, the currents flowing from equator towards the North Pole and from North Pole towards the equator are deflected to their right while the currents flowing north-south and south-north in the southern hemisphere are deflected towards their left.

The rotational force of the earth causes movement of ocean water near the equator in opposite direction to 'the west to east rotation of the earth and thus equatorial currents are generated. These currents flow from east to west. Some ocean water moves in the direction of the rotation of the earth i.e. from west to east and thus counter equatorial currents are formed.

Please note that the magnitude of the deflection, or "Coriolis effect," varies significantly with latitude. The **Coriolis Effect is zero at the equator** and **increases to a maximum at the poles**. The effect is proportional to wind speed; that is, deflection increases as wind strengthens. The resultant balance between the pressure force and the Coriolis force is such that, in the absence of surface friction, air moves parallel to isobars (lines of equal pressure). This is called the the geotropic wind.

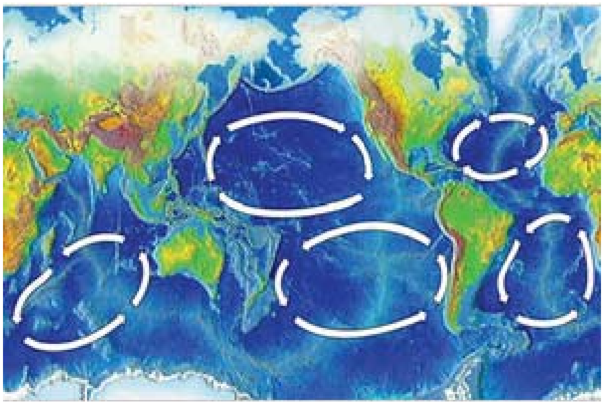
The Coriolis force explains why winds circulate around high and low pressure systems as opposed to blowing in the direction of the pressure gradient.

The following figure shows how wind is deflected in each hemisphere.



Ocean gyre

A gyre is any large system of rotating ocean currents, particularly those involved with large wind movements. Gyres are caused by the Coriolis Effect; planetary vorticity along with horizontal and vertical friction, which determine the circulation patterns from the wind curl (torque). The term gyre can be used to refer to any type of vortex in the air or the sea, even one that is man-made, but it is most commonly used in oceanography to refer to the major ocean systems, as shown in the following figure:



Impact of Physical Properties of Ocean on Ocean Currents

Local variations in the physical properties of the ocean such as pressure gradient, temperature differences, salinity differences, density variations etc. generate ocean currents.

- ✓ The amount of insolation received at the earth's surface and consequent temperature decreases from equator towards the poles.
- ✓ Due to high temperature in the equatorial region the water density decreases because of greater expansion of water molecules whereas the density of sea water becomes comparatively greater in the polar areas.
- ✓ Consequently water moves due to expansion of volume from equatorial region (of higher temperature) to polar areas (colder areas) of relatively very low temperature.

- There is movement of ocean water below the water surface in the form of subsurface current from colder polar areas to warmer equatorial areas in order to balance the loss of water in the equatorial areas.
- Thus, the poleward surface current and Equatorward subsurface currents form a complete circulatory system of ocean water. The Gulf Stream and Kuroshio warm currents moving from equator towards north are examples of such currents.

Oceanic salinity affects the density of ocean water and density variation causes ocean currents.

- Salinity increases the density of ocean water. If two areas having equal temperature are characterized by varying salinity, the area of high salinity will have greater density than the area of low salinity.
- The denser water sinks and moves as subsurface current whereas less saline water moves towards greater saline water as surface current. In other words, ocean currents on the water surface are generated from the areas of less salinity to the areas of greater salinity. Such system of surface and subsurface currents caused by salinity variation is originated in open and enclosed seas. For example, the current flowing from the Atlantic Ocean to the Mediterranean Sea via Gibraltar Strait is caused because of the difference in salinity.
- The salinity of the Mediterranean Sea is much higher than the adjoining Atlantic Ocean. Consequently, water sinks in the Mediterranean Sea. In order to compensate the loss of water Atlantic water flows as surface current into the Mediterranean Sea. The sinking water in the Mediterranean Sea moves as subsurface current towards the Atlantic Ocean. Similarly, such system of surface and subsurface currents is generated between the RedSea and the Arabian Sea via Babel Mandeb Strait.

The salinity of the Baltic Sea is lowered due to the flow of fresh water by the rivers but the level of water is raised. With the result water moves northward as a surface current into the North Sea and subsurface current moves from the North Sea to the Baltic Sea.

Impact of Air Pressure and Winds on Ocean Currents

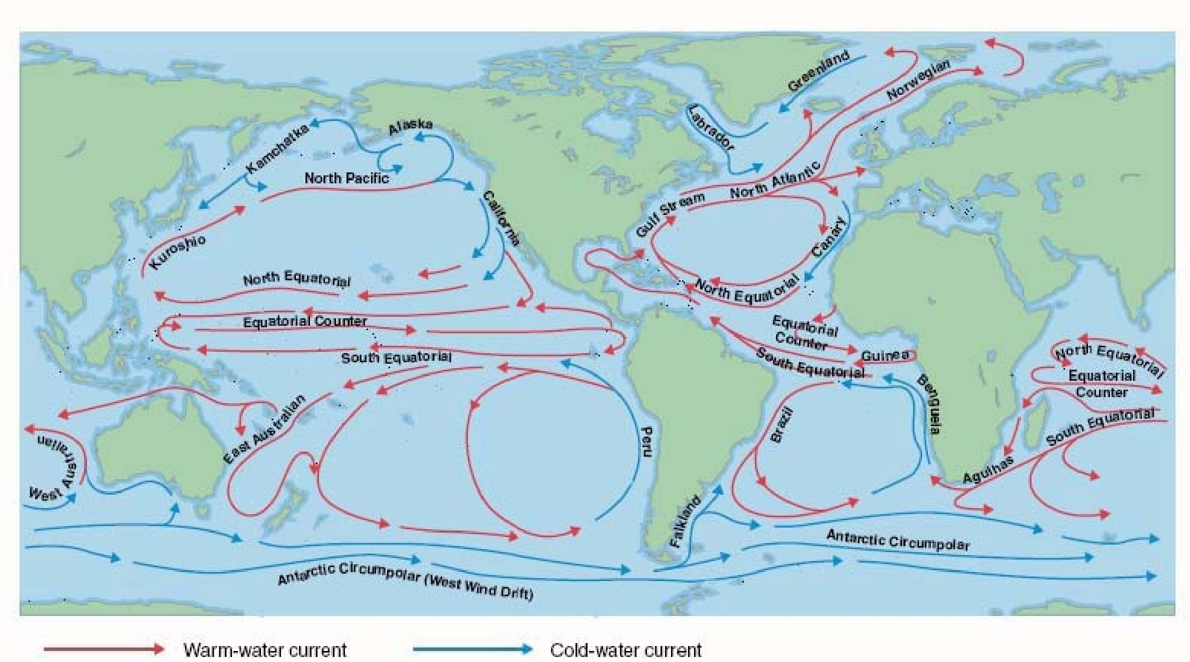
Air pressure on the oceanic water causes ocean currents through density variations. The areas of high atmospheric pressure are characterized by low volume of water and thus lowering of water level. Contrary to this the areas of low atmospheric pressure record higher volume of water and higher water level. Thus, water moves as surface current from the areas of higher water level (Low pressure areas) to low water level areas (high pressure areas).

Prevailing or planetary winds (e.g., trade winds, westerlies and polar winds) play major roles in the origin of ocean currents. The wind blowing on the water surface also moves water in its direction due to its friction with the water. Most of the ocean currents of the world follow the direction of prevailing winds. For example, equatorial currents flow westward under the influence of N.E. and S.B. trade winds. The Gulf Stream in the Atlantic and the Kuroshio in the Pacific move in northeastern direction under the influence of the westerlies. There is seasonal change in the direction of currents in the Indian Ocean twice a year (after every 6 months) due to seasonal change in the direction of monsoon winds. Friction caused by the wind sets the sea water in motion.

Types of Oceanic Currents

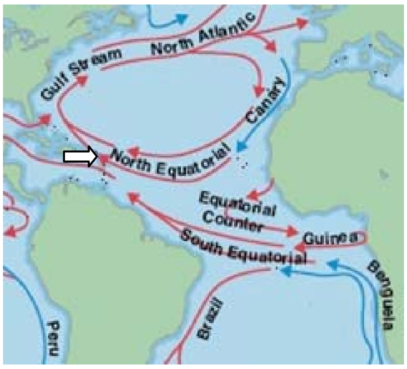
Ocean currents are of two type's viz. **Surface Currents** and **Deep Currents**. Surface currents affect surface water above the **pycnocline** (<10% of ocean water). These currents are driven by major wind belts. The Deep currents affect deep water below pycnocline (90% of ocean water) and are driven by density differences. The deep currents are larger and slower than surface currents.

The stress of wind blowing across the sea causes a surface layer of water to move. Due to the low viscosity of water, this stress is not directly communicated to the ocean interior, but is balanced by the Coriolis force within a relatively thin surface layer, 10-200m thick. **This layer is called the Ekman layer and the motion of this layer is called the Ekman transport**. Because of the deflection by the Coriolis force, the Ekman transport is not in the direction of the wind, but is 90° to the right in the Northern Hemisphere and 90° toward the left in the Southern Hemisphere. The amount of water flowing in this layer depends only upon the wind and the Coriolis force and is independent of the depth of the Ekman layer and the viscosity of the water. The major surface currents are shown below:



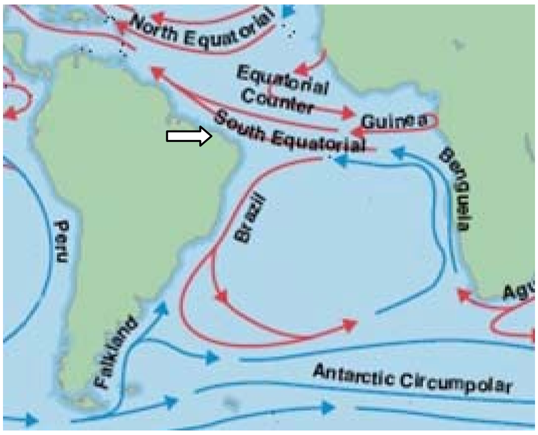
CURRENTS OF THE ATLANTIC OCEAN

North Equatorial Current (warm)



North equatorial current is a significant Pacific and Atlantic Ocean current that flows east-to-west between about 10° north and 20° north. This current is generated because of upwelling of cold-water near the west coast of Africa. This warm current is also pushed westward by the cold Canary current. On an average, the north equatorial warm current flows from east to west but this saline current is deflected northward when it crosses the mid-Atlantic Ridge near 15°N latitude. It again turns southward after crossing over the ridge. This current, after being obstructed by the land barrier of the east coast of Brazil, is bifurcated into two branches viz. Antilles current and Caribbean current. The Antilles current is diverted northward and flows to the east of West Indies islands, and helps in the formation of Sargass Sea eddy while the second branch known as the Caribbean current enters the Gulf of Mexico and becomes Gulf Stream.

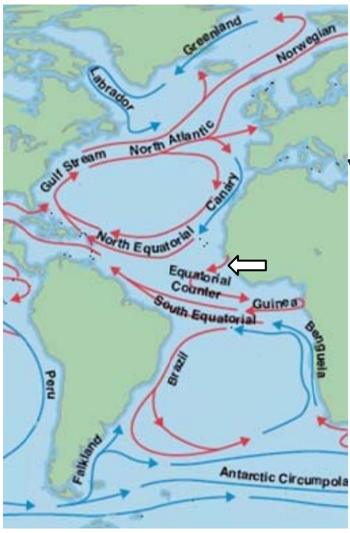
South Equatorial Current (warm)



The South Equatorial Current is a significant Pacific, Atlantic, and Indian Ocean current that flows east-to-west between the equator and about 20 degrees south. In the Pacific and Atlantic Oceans, it extends across the equator to about 5 degrees north. South equatorial current flows from the western coast of Africa to the eastern coast of South America between the equator and 20°S latitude. This current is more constant, stronger and of greater extent than the north equatorial current. In fact, this current is the continuation of the cold **Benguela current.** This warm current is bifurcated into two branches due to obstruction of land barrier in the form of the east coast of Brazil. The northward branch after taking north-westerly course merges with the north equatorial current near Trinidad while the second branch turns southward and continues as Brazil warm current parallel to the east coast of South America. This current is basically originated under the stress of trade winds.

Equatorial Counter Current

Equatorial Counter Current is a significant ocean current in the Pacific and Indian oceans that flows west-to-east at approximately five degrees north. The Counter Currents result from balancing the westward flow of water in each ocean by the North and South Equatorial currents.



✓ In El Niño years, this current intensifies in the Pacific Ocean.

The Equatorial Counter current flows from west to east in between the westward flowing strong north and south equatorial currents. This currents is less developed in the west due to stress of trade winds. In fact, the counter current mixes with the equatorial currents in the west but it is more developed in the east where it is known as the Guinea Stream. The Equatorial Counter current carries relatively higher temperature and lower density than the two equatorial currents. Several ideas have been put forth to explain the origin of the Equatorial Counter current. According to some scientists this current is originated because of the influence of the westerlies which blow from west to east in the calm zone of the doldrums or in the convergence zone of the north east and south east trade winds.

Gulf Stream

The Gulf Stream is a system of several currents moving in north-easterly direction. This current system originates in the Gulf of Mexico around 20°N latitude and moves in north easterly direction along the eastern coast of North America and reaches the western coasts of Europe near 70°N latitude. This system,named Gulf Stream because of its origin in the Mexican Gulf, consists of

1. Florida current from the strait of Florida to Cape Hatteras,

2. Gulf Stream from Cape Hatteras to the Grand Bank, and
3. North Atlantic Drift (current) from Grand Bank to the Western European coast.

North Equatorial Current flows westward off the coast of northern Africa. When this current interacts with the northeastern coast of South America, the current forks into two branches. One passes into the Caribbean Sea, while a second, the Antilles Current, flows north and east of the West Indies.T hese two branches rejoin north of the Straits of Florida. Thus, Florida current is in fact, the northward extension of the north equatorial current. This current flows through Yucatan channel into the Gulf of Mexico, thereafter the current moves forward through Florida Strait and reaches 30°N latitude. Thus, the Florida warm current contains most of the characteristics of the equatorial water mass.

The trade winds blow westward in the tropics, and the westerlies blow eastward at mid-latitudes. This wind pattern applies a stress to the subtropical ocean surface with negative curl across the North Atlantic Ocean. The resulting Sverdrup transport is Equatorward. Because of conservation of potential vorticity caused by the northward-moving winds on the subtropical ridge's western periphery and the increased relative vorticity of northward moving water, transport is balanced by a narrow, accelerating poleward current, which flows along the western boundary of the ocean basin, outweighing the effects of friction with the western boundary current known as the Labrador Current. The conservation of potential vorticity also causes bends along the Gulf Stream, which occasionally break off due to a shift in the Gulf Stream's position, forming separate warm and cold eddies. This overall process, known as western intensification, causes currents on the western boundary of an ocean basin, such as the Gulf Stream, to be stronger than those on the eastern boundary.

As a consequence, the resulting Gulf Stream is a strong ocean current. It transports water at a rate of 30 million cubic meters per second through the Florida Straits. As it passes south of Newfoundland, this rate increases to 150 million cubic meters per second.

The average temperature of water at the surface is 24°C while the salinity is 3.6%. The temperature never falls below 6.5°C . The current becomes narrow while passing through the Florida strait but thereafter its width increases and current flows close to coast.

Canary Current (Cold)

The Canary current, a cold current, flows along the western coast of north Africa between Maderia and Cape Verde. In fact, this current is the continuation of North Atlantic Drift which turns sout.hward near the Spanish coast and flows to the south along the coast of Canaries Island. The average velocity of this current is 8 to 30 nautical miles per day. This current brings cold water of the high latitudes to the warm water of the low latitudes and finally merges with the north equatorial current. The Canary cold current ameliorates the otherwise hot weather conditions of the western coasts of North Africa.'

Labrador Current (Cold)

The Labrador Current, an example of cold current, originates in the Baffin Bay and Davis Strait and after flowing through the coastal waters of Newfoundland and Grand Bank merges with the Gulf Stream around 50°W longitude. The flow discharge rate of the current is 7.5 million ml of water per second. This current brings with it a large number of big icebergs as far south as Newfoundland and Grand Bank. These icebergs present effective hindrances in the oceanic navigation. Dense fogs are also produced due to the convergence of the Labrador cold current and the Gulf Stream near New-foundland.

Brazil Current (Warm)

The Brazil current is characterized by high temperature and high salinity. This current is generated because of the bifurcation of the south equatorial current because of obstruction of the Brazilian coast near Sun Rock. The northern branch flows northward and merges with the north equatorial current while the southern branch known as the Brazil current flows southward along the east coast of South America up to 40°S latitude. Thereafter it is deflected eastward due to the deflective force of the rotation of the earth and flows in easterly direction under the influence of westerlies. The Falkland cold current coming from south merges with Brazil current at 40° S.

Falkland Current (Cold)

The cold waters of the Antarctic Sea flows in the form of Falkland cold current from south to north along the eastern coast of South America up to Argentina. This current becomes most extensive and developed near 30°S latitude. This current also brings numerous icebergs from the Antarctic area to the South American coast.

South Atlantic Drift (Cold)

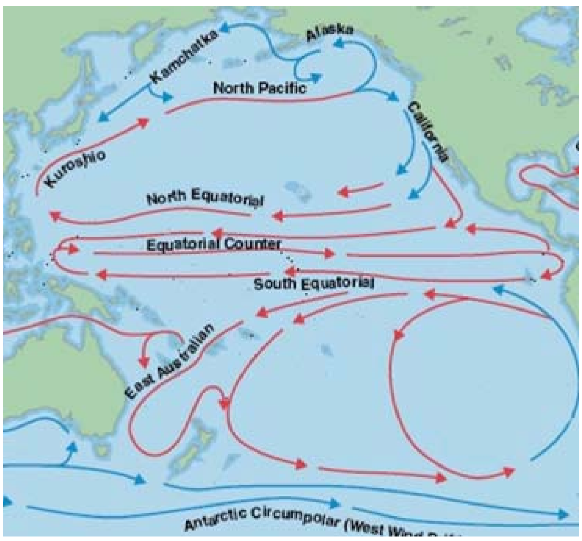
The eastward continuation of the Brazil current is called South Atlantic Drift. This current is originated because of the deflection of the Brazil warm current eastward at 40°8 latitude due to the deflective force of the rotation of the earth. The South Atlantic Drift, thus, flows eastward under the influence of the westerlies. This current is also known as the Westerlies Drift or the Antarctic Drift.

Benguela Current (Cold)

The Benguela current, a cold current, flows from south to north along the western coast of south Africa. In fact, the South Atlantic Drift turns northward due to obstruction caused by the southern tip of Africa. Further northward, this current merges with the South Equatorial Current.

CURRENTS OF THE PACIFIC OCEAN

North Equatorial Current (Warm)



The north equatorial current originates off the western coast of Mexico and flows in westerly direction and reaches the Philippines coast after covering a distance of 7500 nautical miles. This current is originated because of the Californian current and north-east monsoon. The volume of water continuously increases westward because numerous minor branches join this current from the north. A few branches also come out of the main current and turn towards -north and south. One branch emerges from the north equatorial current near Taiwan and flows northward to join **Kuroshio current** while the southern branch turns eastward to form counter equatorial current. It is significant to note that north equatorial current flows as a continuous current i n the north Pacific Ocean but there are seasonal variations in its northern and southern marginal areas. The velocity of the current ranges between 12 and 18 nautical miles per day. With the northward (northern summer) and southward (south northward and southward but it always remains to the north of equator.

South Equatorial Current (Warm)

The south equatorial current is originated due to the influence of south-east trade winds and flows from east to west. This current is stronger than the north equatorial current. The average velocity is 20 nautical miles per day while the maximum velocity becomes 100 nautical miles a day. Numerous minor currents join this current. from the left and thus. the volume of water continuously increases west-ward, The current is bifurcated into northern and southern branches near New Guinea. The northern branch turns eastward and flows as counter equatorial current w rule the southern branch –moves towards the northern and north-eastern coasts of Australia.

Counter Equatorial Current (Warm)

The current flowing west to east between the north and south equatorial currents is termed counter equatorial current. Because of trade winds immense volume of water is piled up in the western marginal parts of the ocean, with the result there is general slope gradient of water surface from west to east. This higher water level in the west and descending slope gradient of water surface from west to east make the oceanic water flow in easterly direction in the name of counter equatorial current which is the most developed counter current in the Pacific Ocean. This counter equatorial current is extended up to the Panama Bay.

Kuroshio System (Warm)

The Kuroshio System consists of several currents and drifts is similar to the Gulf Stream system of the Atlantic Ocean. This system runs from Taiwan to the Bering Strait and consists of the Kuroshio current, the Kuroshio extension, the north Pacific drift, the Tsushima current and the counter Kuroshio current.

Oyashio Current (Cold)

The Oyashio cold current is also known as Kurile cold current. This cold current flows through the Bering Strait in southerly direction and thus transports cold water of the Arctic Sea into the Pacific Ocean. Near 50°N latitude this current is bifurcated into two branches. One branch turns east-ward and merges with the Aleutian and Kuroshio currents. The second branch moves upto the Japanese coasts. This current is comparable to the cold **Labrador Current** of the North Atlantic Ocean. The convergence of cold Oyashio (Kurile) and warm Kuroshio Current causes dense fogs which become potential hazards for navigation.

California Current (Cold)

The California current, an example of cold current, is similar to the Canary cold current of the Atlantic Ocean in most of its characteristics. In fact, this current is the eastward extended portion of the North Pacific drift. The cold California current is generated because of the movement of oceanic water along the Californian coast from north to south in order to compensate the loss of water which is caused due to large-scale transport of water off the coast of Mexico under the influence of trade winds in the form of the north equatorial current. This current after reaching the Mexican coast turns west-ward and merges with the north equatorial current.

Peru Current (Cold)

The cold current flowing along the western coast of South America from south to north is called Peru current or Humboldt current. This current is known as Peru coastal current near the coast w bile it is called Peru oceanic current off the coast. Mean annual temperature ranges between 14°C and 17°C and the average velocity of moving water is 15 nautical miles (27km) per day. The temperature of sea water increases from the coast towards the ocean.

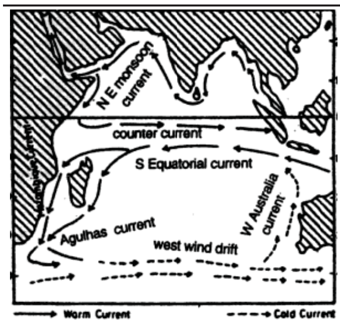
East Australia Current (Warm)

South equatorial current is bifurcated near the Australian coast into northern and southern branches. The southern branch flows as east Australia current from north to south along the eastern coasts of Australia. New Zealand is surrounded by this current. It is deflected eastward near 40°S latitude due to deflective force of the earth and flows in easterly direction under the influence of the westerlies. This is a warm and more consistent current. It raises the temperature of east Australian coast for considerable distance southward.

CURRENTS OF THE INDIAN OCEAN

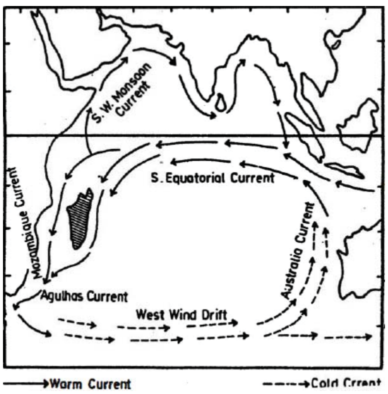
The current systems of the Indian Ocean are largely controlled and modified by landmasses and monsoon winds. Indian Ocean being surrounded by the Indian subcontinent, Africa and Australia does not present most favourable conditions for the development of consistent system of ocean currents. The currents in the northern Indian Ocean change their flow direction twice a year due to north-east and south-west monsoon winds.

North-East Monsoon Current (Warm)



North-east monsoon winds blow from land to the ocean during winter season in the northern hemisphere and thus westward blowing north-east monsoon currents are produced in Indian Ocean. This current flows to the south of 5°N latitude. Besides, some independent currents originate in the Bay of Bengal and Arabian sea and flow in south-westerly direction.

S.W. Monsoon Current (Warm)



There is complete reversal in the direction of monsoon winds during summer season. The north-easterly direction of winter monsoon winds becomes south-westerly during summer season in the northern hemisphere. This reversal of direction of monsoon winds also reverses the direction of ocean currents of Indian Ocean during summer season. North-east monsoon ocean currents disappear and south-west monsoon ocean currents are developed. The general direction of monsoon currents is from south-west to north-east but several minor branches emerge from the main branch and move in the Bay of Bengal and Arabian Sea. The Indian counter current developed during winter season disappears due to this current.

Tides

Before we move ahead, lets discuss some basic things

At which of the following places water would boil at lowest temperature?

1. Delhi 2. Shimla 3. Kochi 4. Jodhpur

We all know that water gets boiled at a lower temperature at Shimla, as compared to Kochi, Jodhpur or Delhi. This is because; Shimla is at a higher sea level. With the sea level getting high, the atmospheric pressure decreases. The decrease in the atmospheric pressure tends the water molecules to release themselves from the liquid easily. In other words, the vapor pressure at higher levels gets equal to the atmospheric pressure at a comparatively lower temperature.

In a pressure cooker, the atmospheric pressure inside the cooker gets high and this makes the water boil at higher temperatures than 100 degree centigrade. This is the fundamental principle of working of a pressure cooker.

Hypsometry & Bathymetry

The principle that water boils at different temperatures at different sea levels or altitudes can be used to determine the sea level. This is called Hypsometry.

☑ A hypsometer is an instrument used in hypsometry, which estimates the elevation of a particular place by boiling water.

If Hypsometry is measurement of land elevation relative to sea level, then what about the land elevation below sea level?

The underwater equivalent of Hypsometry is called **Bathymetry.** *Bathos* is a Greek word which means deep. The instrument is Bathometer.

☑ Large mass of intrusive igneous rocks, which are believed to have solidified deep within the earth, are called plutons. The other word for plutons is batholiths. The word "Pluton" derives from Pluto.

Bathymetry is possible on planets which have oceans and water bodies. On a planet such as Mars, which has no ocean, we cannot use bathometer.

☝ Can you define Paleobathymetry? [1]

Initially the bathymetry used pre-measured heavy rope or cable lowered over a ship's side. But this technique was not efficient because either the ship could move or the current moved the rope or cable out of line. Further, the earlier techniques of bathymetry could only ascertain the depth at a particular point only at a particular point. This was not a good idea to create **bathymetric maps.**

Today, we have Digital Terrain Models (DTMs), also known as **Digital elevation model** developed with highly efficient techniques.

[1] Understanding the past of underwater depths.

One of the efficient techniques of Bathymetry is **LIDAR.** LIDAR and LADAR are synonymous. LIDAR is Light Detection And Ranging. It is different from RADAR (Radio Detection And Ranging). RADAR is a term used first by US Navy in 1940.

- ☑ LIDAR: Light Detection And Ranging
- ☑ LADAR: Laser Detection and Ranging
- ☑ RADAR : Radio Detection And Ranging

Laser and Light come within the ambit of LIDAR & LADAR, but Radio waves and microwaves come under the ambit of RADAR.

Consider the following statements:

1. Both Radar and Laser Radar can use Microwaves
2. Both Laser Radar and Radar can be used in military.

Can you bring out the correct statements?

Laser Radar is another name of LADAR. We now know that microwaves are used in RADAR, so first statement is incorrect. LADAR is mainly used in military context, so both LADAR and RADAR come under the ambit of the military –army, navy or air force. So statement 2 is correct.

LIDAR works on the principle of Optical Remote Sensing technology and measures the properties of the scattered light. It's used in Geomatics, geology, seismology and remote sensing. One application of LIDAR is ALSM (Airborne Laser Swath Mapping). LIDAR can be used in Atmospheric physics also. It can used in measuring the incoming wind at the wind farms and used in saving the instruments from turbulent air winds coming up.

What are Tides?

Moon, the only natural satellite, [2] of Earth is at 384403 kilometers average distance from her. This distance is approximately 30 times of the diameter of earth. Please note that like earth revolving around Sun in elliptical path, Moon also revolves around Earth in an elliptical path and the nearest and farthest points are called Perigee (363,300 km) and Apogee (405,500 km).

- ☑ The mean radius of Moon is 1,737.10 km, which is 0.273 of Earth's mean Radius. Mass of moon is 7.3477×10^{22} Kg which is 0.0123 or $\frac{1}{81}$ of Earth's mass.
- ☑ Moon is Fifth largest satellite in the solar system.
- ☑ **Ganymede** of Jupiter is the largest satellite in the solar system. Second largest is **Titan of Saturn**, Third largest is **Callisto of Jupiter** and fourth largest is **Lo of Jupiter**. After moon, Europa is largest and it is a natural satellite of Jupiter.

The gravitation pull of Moon is 1/6 as compared to Earth, so an object weighing 1 Kg on earth would weigh 166 gms on moon. A person who can high jump 1 meter would be able to jump 6 meters on Moon.

[2] Some quasi-satellites have been proposed, but none of them has been verified. For example, 3753 Cruithne is "glibly" called Earth's second moon, but so far, it is not correct to call it earth's second moon. Some other quasisatellites proposed are 54509 YORP, (85770) 1998 UP1, 2002 AA29, 2000 PG5, 2000 WN10.

The size is considerable.

This considerable size of moon pulls Earth towards it and Earth pulls Moon towards herself. Besides, there is Sun's gravitational force.

The gravitation pull is evident as rise and fall of sea levels, which are called tides. Tides are a result of gravitational pull by both Sun and Moon , but the pull exerted by Sun is apparently weak. This is because of the larger distance as the gravitational force is inversely proportional to the square of the distance.

The gravitational attraction force between two point masses is directly proportional to the product of their masses and inversely proportional to the square of their separation distance. The force is always attractive and acts along the line joining them – Inverse Square Law.

☑ The alignment of Sun and moon affects the size of the tides.

Earliest geographer to state that the tides are caused by moon was Pytheas, an early Greek geographer around 300 BC. Pytheas also described polar ice. But he could not understand what the reason was. Newton's analysis of gravitation explained the phenomenon.

It's worth note that man, since times unknown must have observed the tides. In the Indus Valley Civilization, we have studied that a dockyard was found in Lothal in Gujarat.

The 4 walls of this dock towards the estuary are made up of kiln burnt bricks, which prove that these people not only observed but also understood and created structures as per the phenomena & impact of tides.

It's worth note that in Rig-Veda there was no record about Tides, but in Samveda Chapter 10, Part II, 20, mentions *Soma….samudravardhanam,* links moon to tides.

Stages of Tides

There are 4 distinct stages of tides:

☑ Stage I: Sea level rises over several hours, covering the intertidal zone and this is called flood tide.
☑ Stage II: The water rises to its highest level, known as high tide.
☑ Stage III: Sea level falls over several hours, revealing the intertidal zone. This is called ebb tide.
☑ Stage IV: The water stops falling, this is called low tide.

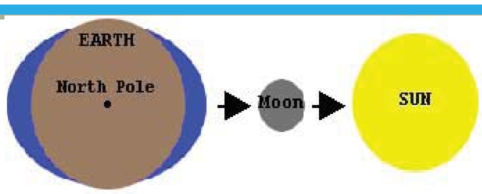
In general the rising tides are called *flood tides* and falling tides are called *ebb tides* and they are known as Jwar & Bhata in Hindi respectively.

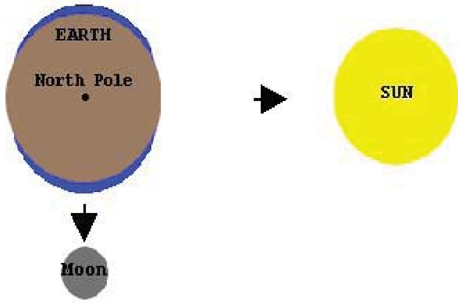
In astronomy, the alignment of three or more celestial bodies in the same gravitational system along a line is called **Syzygy** and eclipses occur at the time of Syzygy. Syzygy also affects tides in the form of variations between the High tides and Low Tides.

Spring Tides and Neap Tides

☑ When there is greatest variation between the high tides and low tides, it is called Spring Tides. **Gulf of Fundy** is known for highest tides in the world (approximately 50 meters). At spring tide, Sun, Moon and Earth are in a line.

☑ When there is smallest difference between high and low a tide, it is called Neap tide. It occurs when Sun, moon and Earth are at right angles.





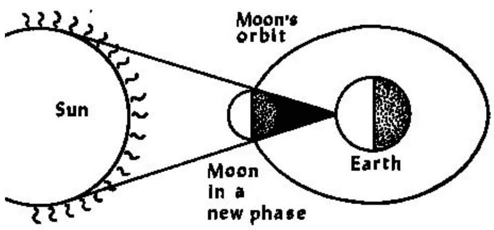
Consider the following Options:

A. January 3, New Moon
B. January 3, Moon in second quarter
C. July 6, Full Moon
D. December 21, New moon

On which of the above dates, the **amplitude of the tides would be maximum**?

This is an interesting question. We know that a Syzygy is a time, when Earth, Moon and Sun are in same line, either in conjunction or in opposition.

Following graphic shows the New Moon:

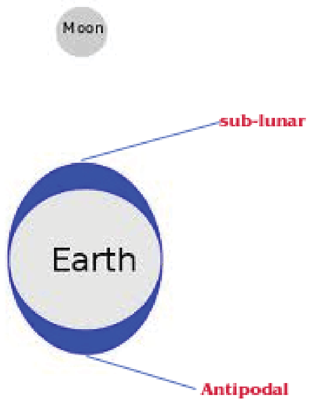


Of course we can understand that on New Moon the tides will have higher amplitude. In the given dates, on January 3, Earth is at perihelion. This means that Earth on January 2 0r 3 is at closest distance from Sun. So, the tide would be highest in the year on Perihelion-New Moon. This spring tide would be the highest in the entire year.

Tide Pattern

Now let's understand the daily frequency of tides. We know that earth rotates around its own axis and it takes 24 hours to finish its rotation. The direction of Earth rotation is the same in which Moon revolves around earth.

The gravitational attraction moon raises the water on two opposite sides of Earth, these points are called Sub-lunar and antipodal points.



But, why on both sides?

The tidal bulge shown above follows the revolution of the moon, and the earth rotates eastward through the bulge once every 24 hours and 50 minutes. (This is because, of the relative distance covered by moon in its orbit). This tidal bulge shows that the water of the entire world ocean is pulled by the moon's gravity.

On the opposite side of the earth simultaneously there is a high tide. This high tide is due to inertia of the ocean water and because the earth is being pulled toward the moon by its gravitational field and the ocean water remains left behind. This means that Earth is pulled little away from the water. This creates a high tide on the side of the earth opposite the high tide caused by the direct pull of the moon.

Duration and Frequencies of Tides

Most coastal areas experience two high and two low tides per day. One of these high tides is at the point on the earth which is closest to the moon (sub lunar) and other high tide is at the opposite point on the earth (antipodal).

One tidal cycle comprises two high tides and two low tides. One tidal cycle completes in 24 hours and 50.4 minutes. This is because of the revolution of Moon around the earth and both earth's rotation and moon revolution are in same direction. (Moon is not stationary, so there is a difference, if moon were stationary the high tides would have occurred exactly in 12 hours)

☑ The high tides occur at an interval of 12 hours and 25.2 minutes. This means that if there is a high tide is at 7.00 am, next high tide would be at 7.25 pm and next would be at 7.50 am, and so on.
☑ The time difference between two high tides is 12 hours 25.2 minutes. This time difference is called "Tidal Interval".
☑ The tidal cycle in this pattern is called **semidiurnal.**

But most of the enclosed water bodies or away from the open ocean such as Caribbean sea or Caspian Sea, there are only one high tide and one low tide. This pattern is called **Diurnal tides.**

At the coast of the oceans, there may be two high tides, of unequal length. This is called **Mixed Tides.**

Various Concepts related to Tides

1. **Tidal datum:** A chart obtained from the long period of a tidal record is called tidal datum.
2. **Tidal Flat:** The sands uncovered by the low tides is called tidal flat
3. **Tidal range:** Tidal range is the difference between the height of water at low and high tides.

4. **Tidal Bore:** Tidal bore is a Tidal phenomenon in which the leading edge of the incoming tide forms a wave (or waves) of water that travel up a river or narrow bay against the direction of the river or bay's current.

5. **Intertidal Zone:** Intertidal zone is sometimes known as littoral zone and it is that area of the sea shore or shore of water body such as open ocean, which is exposed to air at low tides and water at high tides. The examples are rocky cliffs, sandy beaches, or wetlands.

☑ **Bay of Fundy is an excellent Intertidal Zone Ecosystem.**

6. Apogean Tides and perigean tides: When moon is at closest point to Earth during its revolution around earth it is called Perigee. The high tides are higher than usual and low tides are lower than usual at this point. When moon is farthest, it is called apogee and the high tides are lower than usual and low tides are higher than usual at this point of time.

7. Tidal Power: Power can be generated exploiting the huge energy of the tides. This can be done by making dams and the tidal zones where best tides occur and allowing the water to enter and exit through a turbine. However, this is a complicated work and not much success as been achieved as of now.

World's first Tidal Power Station is Rance Tidal Power Station, located on the estuary of the Rance River, in Brittany, France. It is also world's largest tidal power station which started working in 1966. Its annual output is 600 GWh.

8. **Earth's tides:** Earth's tides, also known as terrestrial tides affect the entire Earth's mass. This involves the movement of Earth's crust in all directions, due to solar and lunar gravitation.

Please note that Earth's tide amplitude can reach about 55 centimeters at the equator. 15 centimeters is due to the Sun and this calculation needs to be kept while doing GPS calibration and Very Long Baseline Interferometry measurements. The tidal forces generate currents in conducting fluids in the Earth's interior and they affect the Earth's magnetic field.

The Tides Which Are Not Tides

Consider the following:

1. Storm Tides
2. Rip Tides
3. Tsunamis

Which among the above come within the definition of Tides?

The answer is **none of them.**

The tide suffix has been used for various phenomena. Some of them are not at all related to the tides. The following are a few:

☑ **Storm Tides:** Storm tides is the name given to the offshore rise of water associated with a low pressure weather system. Wind causes the water to pile up higher than the ordinary sea level and they are nowhere related to the tides.

☑ **Rip Tides:** Rip tides are strong channel of water flowing seaward from near the shore, typically through the surf line. They are again caused by the winds and not related to Tides.

☑ **Tsunami:** Tsunamis are called 'harbor wave', and they are result of displacement of a large volume of a body of water, usually an ocean due to Earthquakes, volcanic eruptions and other underwater explosions.