Chapter Four

# Oceanography

**Chapter Concept**

- **Oceans**

The hydrosphere is the total mass of water on the surface of our planet. The Earth's oceans and seas cover more than 367 million sq km, that is twice the surface of Mars and nine times the surface of the Moon.

About 98% of the water is in the ocean; 2% is in streams, lakes, ground-water, and glaciers. Approximately 70.8% of the Earth is covered with water and 29.2 per cent is land area. Thus, it is for the good reason that Earth has been called *'the water planet'*. It has been estimated that if all the irregularities of the Earth's surface were smoothed out to form a perfect sphere, a global ocean would cover the Earth to a depth of *2.25 km*. It is this great water mass that makes the Earth unique. Water permitted life to evolve and flourish on the Earth and, therefore, every inhabitant on the Earth is directly or indirectly controlled by it.

Beneath the ocean waves lies the biggest and most unexplored landscape on the Earth. Here are coral reefs, enormous open plains, deep canyons, and the longest mountain range on the Earth – the *Mid-Atlantic Ridge*–which stretches almost from pole to pole.

## Oceans

Oceans water cover about 70.8 per cent of Earth's surface. There is only one world ocean, but the continents divide the ocean into five distinct parts, i.e. : (i) Pacific Ocean, (ii) Atlantic Ocean, (iii) Indian Ocean, (iv) Arctic Ocean, and (v) Southern Ocean (Antarctic Ocean).The greater parts of the oceans, the ocean basins, are relatively young having evolved within the last 80 million years. One of the most recent plate collision, between the Eurasian and African plates, created the present day arrangement of the continents and oceans. The main features of the Earth's solid surface as percentage of the planet's total surface have been shown in **Fig. 4.1**.

### Coasts

The total length of the Earth's coastlines is more than 500,000 km, that is the equivalent of 12 times around the globe. A high percentage of the world's population live in coastal zones. Of the ten most populated cities on the Earth, eight are situated on deltas, estuaries, or the coast.

## Ocean Relief or Major Features of Oceanic Lithosphere

The oceanic crust differs strikingly from the continental crust with respect to rock types, structure, landforms, age and origin. The major features of the ocean floor are: continental shelf (margin), (2) continental slope, (3) continental rise, (4) abyssal floor (deep ocean basins), (5) oceanic trenches, (6) oceanic ridges, and (7) seamounts.

### Continental Margin

The submerged part of the continent is known as continental margin. Geologically it is part of the continent and not part of the ocean basin. The continental margin includes (a) continental shelf and (b) continental slope.

#### *1. Continental Shelf*

It is the submerged margin of continental mass extending from the shore to the first prominent break in slope. Some shelves reach a depth of over 500 m, but 200 m is often conveniently used as a depth limit. The mean width is about 70 km, but there is a marked variation between different coasts. It is estimated that the continental shelves cover approximately 5 per cent of the Earth's surface. The vast majority of sea exploitation – including fishing and gas and oil-drilling – occurs on the continental shelf. Coastal areas are in the greatest danger of pollution.

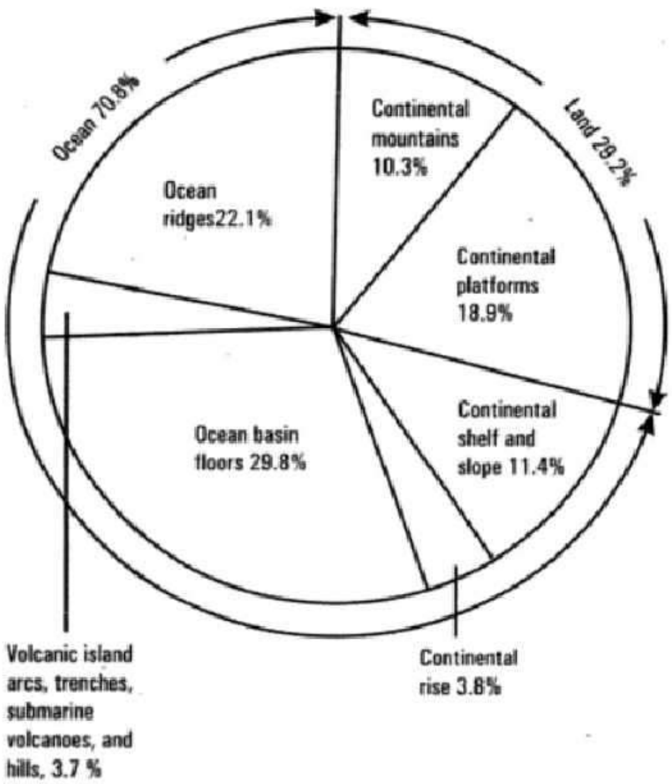


*Fig. 4.1 – Features of the Earth's solid surface, shown as percentages of the planet's total surface*

#### *2. Continental slope*

The slope that extends from the continental shelf down to the ocean deep is known as continental slope. In some areas, such as off eastern North America, the continental slope grades into the more gently sloping continental rise. At present continental shelves and continental slope constitute about 11.4 % of the Earth's solid surface out of which 6.4 per cent is the area of continental slope **(Fig. 4.1)**.

#### *Continental Rise*

This is the gently sloping seafloor lying at the foot of the continental slope and leading gradually into the abyssal plain. They cover 3.8 per cent of the total area of the oceans.

### Abyssal Floor

This is the large expanse of very smooth, flat ocean floor found at depths of 3000 to 5500 m. The abyssal plains cover from 80 to 85% of the floor of the Pacific Ocean. In fact, they are the most widespread landforms on the Earth **(Fig. 4.2)**.

### Oceanic Trench

The narrow, deep depression in the seafloor representing the line of subduction of an oceanic lithospheric plate beneath the margin of a continental lithospheric plate; often associated with an island arc. The ocean trenches are the lowest areas on Earth's surface. The Mariana Trench, in the Pacific Ocean, is the deepest part of the world's oceans –11022 m below sea level, and many other trenches are more than 8000m deep. Some of the important trenches of the oceans are given below **(Fig. 4.3)**.

### North Pacific Ocean

Mariana Trench (11022 m), Ramapo Deep or the Japan Trench (10,554 m), Aleutian Trench (10,498 m), Philippines Trench (10,475 m).

### South Pacific Oceanm

Kermadec-Tonga Trench (the steepest trench of the world), New Hebrides Trench, Peru-Chile or Atacama Trench (7635 m).

### North Atlantic

Puerto Rico Trench (8358 m), Romanche Trench (7631 m).

### Indian Ocean

The Sunda Trench (Sumatra) and Java Trench (7454 m).

### Oceanic Ridge

The oceanic ridge is perhaps the most striking and important feature on the ocean floor. They cover about 22.1 per cent of the surface of the oceans. Their total length is about 66 thousand kilometers. The oceanic ridge extends continuously from the Arctic basin, down the centre of the Atlantic Ocean, into the Indian Ocean, and across the South Pacific. The oceanic ridge is essentially a broad, fractured swell and generally more than 1400 km wide. Its higher peaks rise as much as 3000 m above the ocean floor. The Mid-Atlantic Ridge, having a length of about 14,450 km, extends from Iceland in the north to *Bouvet Island* in the south. The oceanic ridges are formed by lava which erupts beneath the sea and cools to form solid rock. This process mirrors the creation of volcanoes from cooled lava on the lava. The ages of the sea floor rocks increase in parallel bands outward from central ocean ridges. The major oceanic ridges of the world have been shown in **Fig. 4.4.**

### Island Arcs

These are curving chains of volcanic islands and seamounts that are always found paralleling the concave edge of trenches. They are formed by the tectonic activity of subduction. Some of the important island arcs are the Aleution Islands, the Lesser Antilles, and the Mariana Islands.

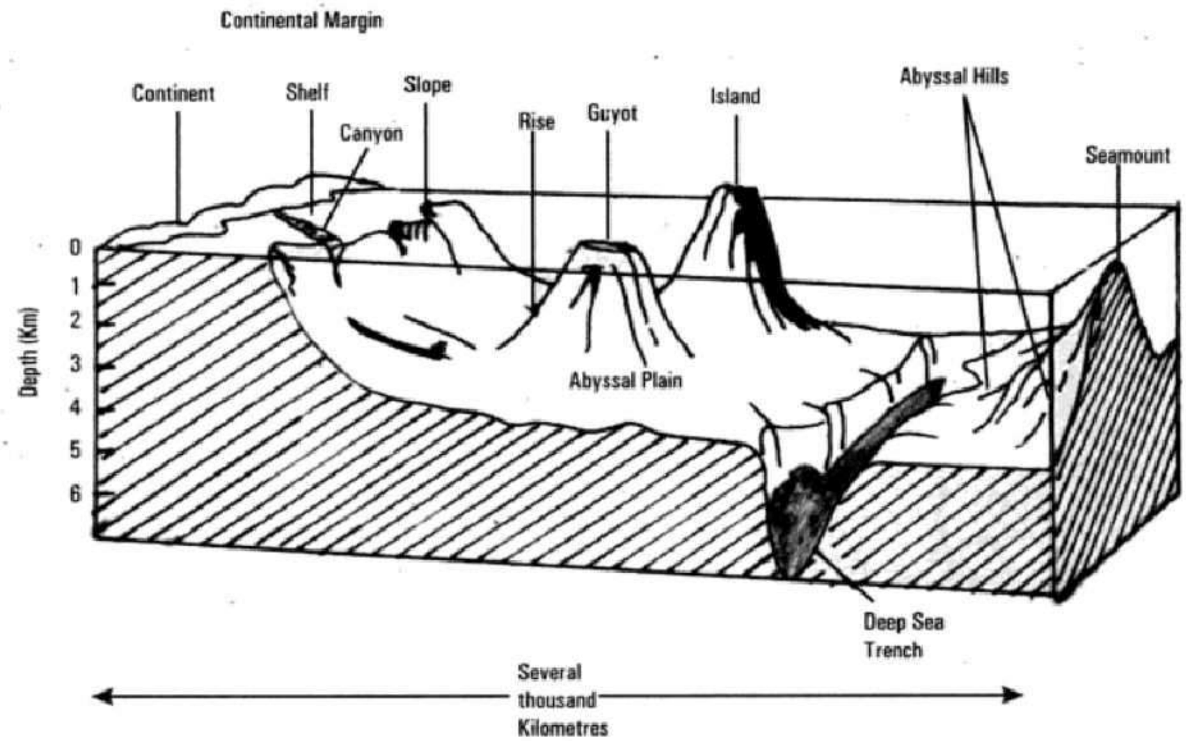


*Fig. 4.2 – Marine environment*

### Seamounts

It is circular or elliptical projection form the seafloor, more than one kilometer in height, with a relatively steep slope of 20° to 25° **(Fig. 4.2).**

### Guyot

Guyot is a flat topped, submerged, inactive volcano. They are tall enough to approach or penetrate the sea surface **(Fig. 4.2).** Generally they are confined to the west-central Pacific.

### Black Smokers

The black smokers are vents in the ocean floor which disgorge hot, sulfur-rich water from deep in the Earth's crust. Despite the great depths, a variety of life-forms have adapted to the chemical-rich environment which surrounds black smokers.

## Hypsographic Curve of the Earth Surface

This is a graph of the area of the Earth's surface above and given elevation or depth above or below the sea level. It may be observed from **Fig. 4.5** that the highest mountain peak (Mt. Everest) is 8848 m, while the greatest ocean depth is 11,022 m. The average elevation of the exposed land is 840 m and the average depth of the oceans is -3790 m.

## Temperature of the Oceans

Oceans absorb more than 80% of the solar radiation that reaches the Earth. Moreover, water has remarkable capacity for absorbing heat. The upper most 10 % of the oceans contain more heat than the entire atmosphere.

The temperature of the oceans is not uniform. It differs from latitude to latitude and from surface to bottom. The major determinants of oceans temperature are:

**(i) Latitude**: The surface temperature of the oceans declines from equator towards the pole as on equator the Sun's rays are vertical and slanting on the poles.

**(ii) Prevailing Winds**: Wind direction (trade and anti-trade winds) largely affects the surface distribution of temperature of the oceans.

**(iii) 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

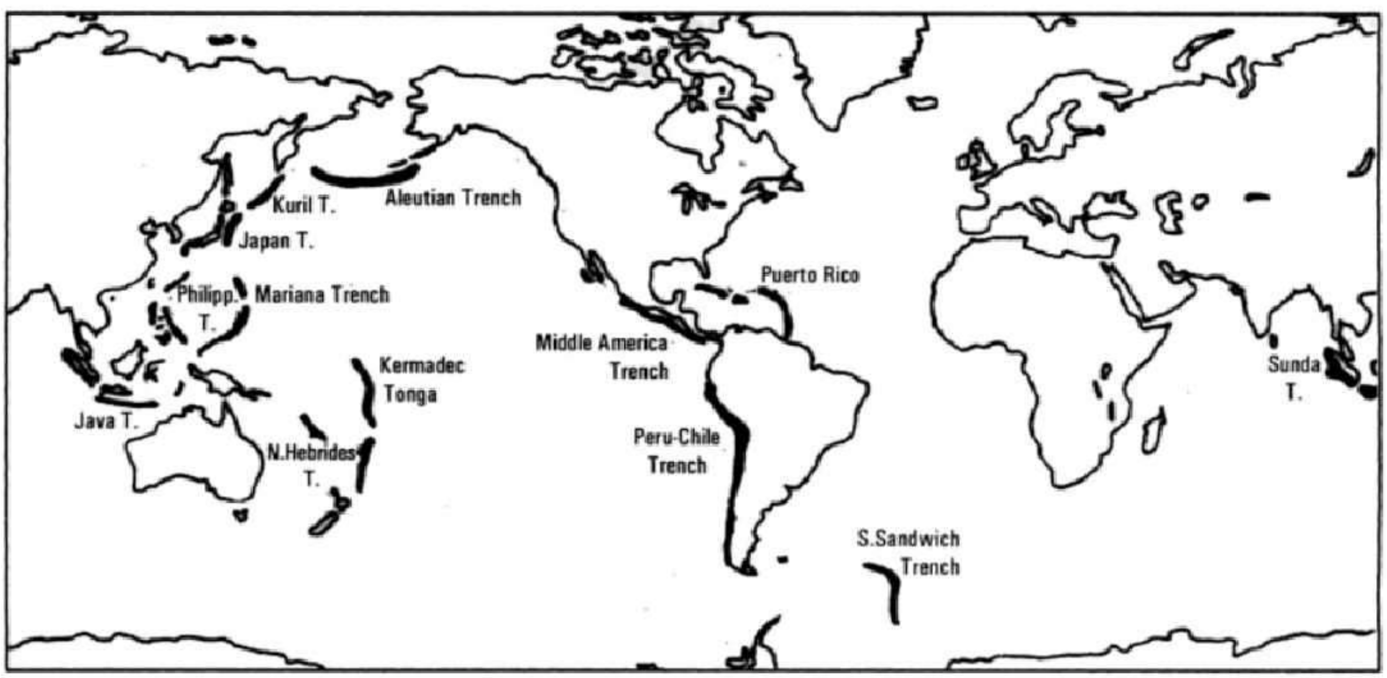


*Fig. 4.3 – Major ocean trenches of the world*

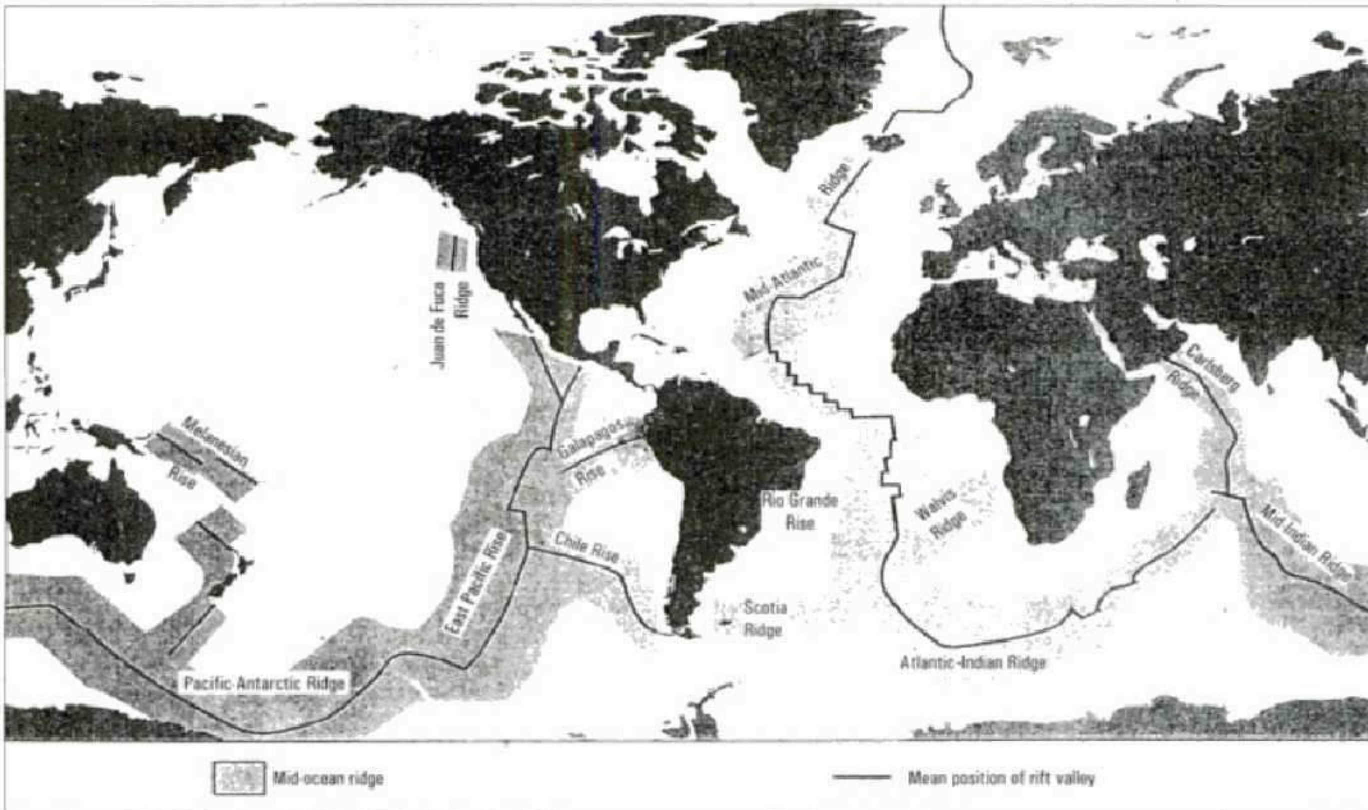


*Fig. 4.4 – The oceanic ridge system*

Hemisphere are warmer than that of the Southern Oceans.

**(iv) Evaporation Rate** : The volume of water that evaporates each year from the surface of ocean is equivalent to 350,000 cubic kilometers. The evaporation rate is however, not uniform in different latitudes.

**(v) Density of Water**: The density of water is mainly a function of its salinity and temperature. The density of water differs from latitude to latitude. In the areas of high salinity, there is relatively high temperature and vice-versa.

**(vi) Ocean Currents**: Surface temperature of the oceans are also controlled by warm and cold currents. The presence of a warm water current increases the temperature and the rate of evaporation. Consequently, the region records more rainfall, while the cold water current reduces the temperature of the moisture-laden wind. The coast along with a cold water current flows record more fog, but less precipitation.

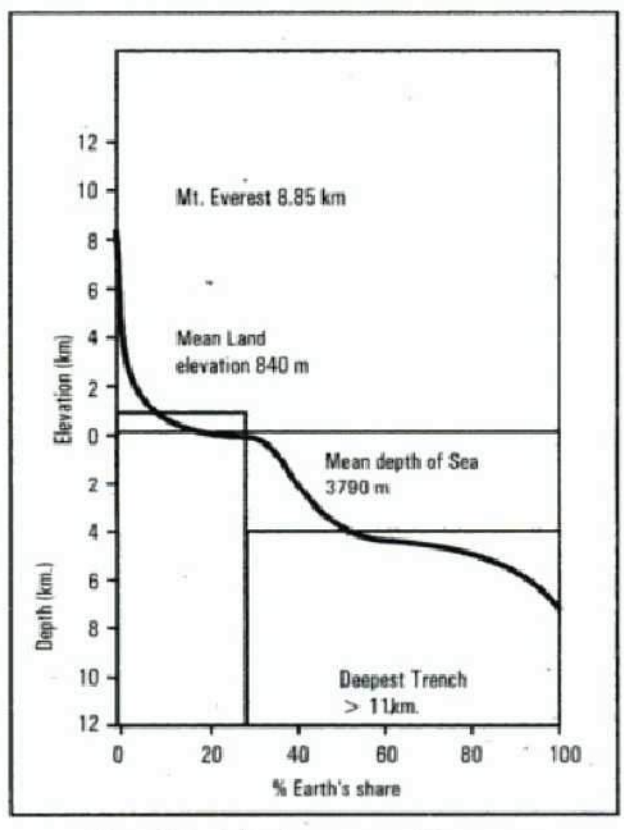


*Fig. 4.5 – The hypsographic curve*

**(vii) Local Factors**: Submarine ridges, local weather conditions like storms, cyclones, winds, fogs, cloudiness, rate of evaporation, lapse rate, condensation, and precipitation also affect the distribution of temperature of the oceans.

### Horizontal Distribution of Temperature

In general, the temperature of the surface water in the lower latitudes is about 26°C which decreases towards poles. The oceans of the Northern Hemisphere record an average temperature of 19.4°C. In the Northern Hemisphere the average temperature reads 22°C at 20° latitude, 14°C at 40° latitude, and 0°C near the poles. In the Southern Hemisphere, the average temperature is only 16.1°C. **(Fig. 4.6)**.

The maximum and minimum annual temperatures of ocean water in the Northern Hemisphere are in the months of August and February, respectively. The average annual range of temperature is about 12°C. The highest annual range of temperature is recorded in the North Atlantic Ocean. Moreover, the annual range of temperature is higher in the inland seas as compared to the open oceans.

### Vertical Distribution of Temperature

Both energy and sunlight decrease with depth in the oceans. Only about 45% of light energy striking the ocean surface reaches a depth of about one meter, and only 16% reaches 10 meter depth. On the basis of temperature the ocean depths may be divided into the following three zones:

**1. Surface Zone or Mixed Zone (Photic or Europhic Zone)**: It is the upper layer of the ocean. In this layer, the temperature and salinity are relatively constant. It contains about 2% of the total ocean volume of water, and its depth is only about 100 meter **(Fig. 4.7)**.

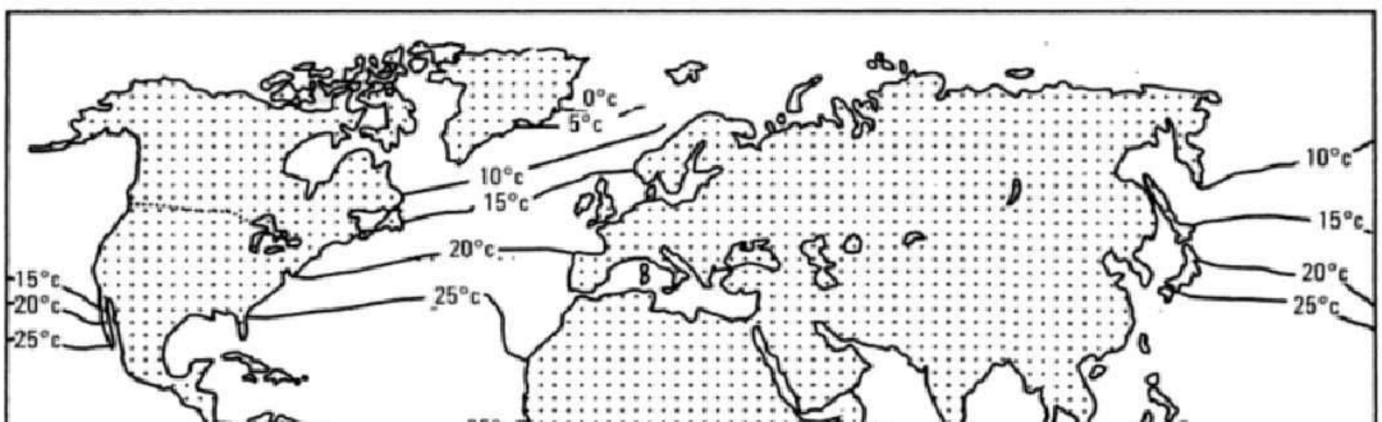


*Fig. 4.6 – Oceans: Horizontal distribution of temperature*

**2.Thermocline or (Pycnocline)**: It lies between 100 metres and 1000 metres. It contains about 18% of the total volume of oceanic water. There is a steep fall of temperature in this zone. The density of water increases with increasing depth.

**3.The Deep Zone**: This zone lies below 1000 meters in the mid-latitudes. The deep zone contains about 80% of the total volume of ocean water. Temperature near the bottom is always more than the freezing point – around one or two degree C.

## Salinity

Salinity is a measure of dissolved solids in seawater, usually expressed in grams per kilogram or parts per thousand by weight. The standard sea water has a salinity of 35% at 0°C (32°F). In water of the ocean, 96.5% is water, and 3.5% dissolved salts

The most common substance in the sea water is sodium chloride or salt. The chemical composition of salts of oceans is given in the **Table 4.1**.

***Table 4.1:*** *Chemical Composition of Sea Water*

| *Salt* | *Percentage* |
|---|---|
| Sodium chloride | 2.6 |
| Magnesium chloride | 0.3 |
| Magnesium sulphate | 0.2 |
| Calcium sulphate | 0.1 |
| Potassium chloride | 0.1 |
| Potassium bromide | 0.01 |
| Other elements | 0.01 |

## Sources of Salinity

Much of the dissolved materials (salts) of the seas/oceans originated from land which was carried to the oceans by rain, running water, ground water, wind, sea-waves and glaciers. Some of the salts, however, have their origin in the deeper layers of the Earth. The volcanic lava adds to the salinity of the oceans. In addition to these, the dead and decomposed organic life adds to the salinity of the oceans.

## Determinants of the Salinity of the Oceans

The distribution of salinity of the oceans depends on the rate of evaporation, temperature, precipitation, cloudiness, influx of fresh water, winds, and ocean currents:

**(i) Evaporation**: In general, higher the rate of evaporation, higher the salinity of oceans. The highest rate of evaporation is recorded along the Tropic of Cancer, especially in the Red Sea and the Persian Gulf. Consequently, these water bodies have one of the highest salinity in the world.

**(ii) Temperature**: There is a direct relationship between temperature and salinity of the oceans. In general, the higher, the temperature, the higher, the salinity of the oceans. The Torrid Zone has higher salinity as compared to the Frigid Zone of the world.

**(iii) Precipitation**: The amount of precipitation is inversely related to salinity. In general, the higher, the precipitation, the lower, the proportion of salinity. The oceans of the equatorial region, recording the heavy rainfall throughout the year, have relatively low salinity.

**(iv) Ocean Currents**: Ocean currents also affect the spatial distribution of salinity in the ocean

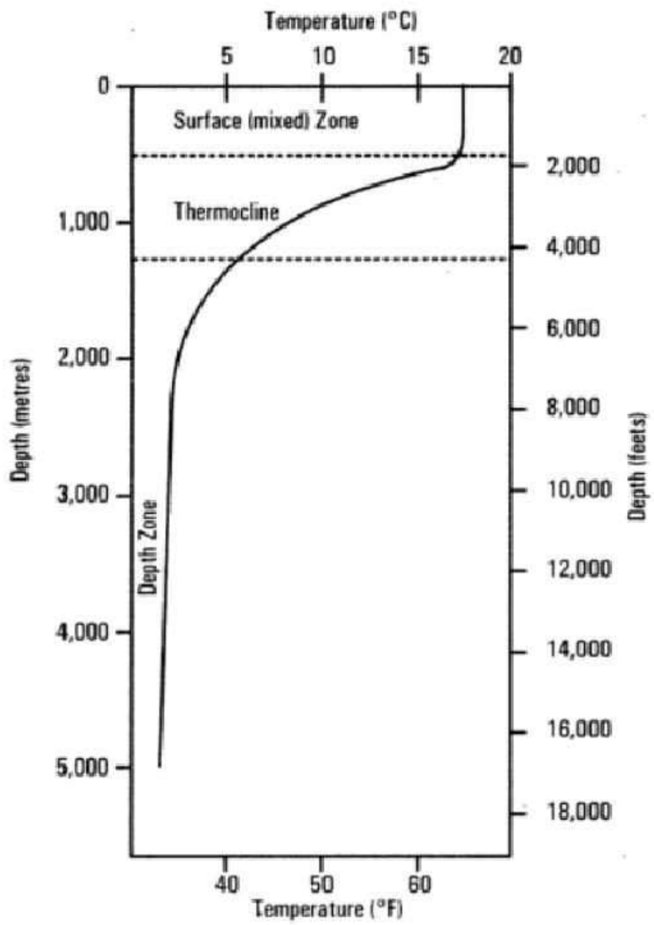


*Fig. 4.7 - Typical temperature variation with deep ocean at Mid-latitude*

bodies of the world. The equatorial warm water currents drive away salts from the eastern coastal areas and accumulate them along the western coastal areas of the oceans. The Gulf Stream and the North Atlantic Drift increase the salinity in the North Sea and the North east Atlantic Ocean.

**(v) Influx of Fresh (River) Water**: Comparatively low salinity is found along the mouth of the Amazon, Congo, and Ganga deltas mainly due to the influx of fresh water.

### Horizontal Distribution of Salinity

The salinity of the oceans decreases on both sides of the tropics. For example, the average salinity along the equator is about 35‰, while along the Tropic of Cancer, it is over 36‰.

On the basis of salinity, the oceans and seas of the world may be divided into the following categories:

**(i) Seas having Salinity above Normal**: The salinity of the Red Sea is about 39 to 41‰, Persian Gulf 38‰ and the Mediterranean Sea 37 to 39‰.

**(ii) Seas with Normal Salinity**: The Caribbean Sea, Gulf of Mexico, Gulf of California, and Yellow Sea have a salinity between 35‰ and 36‰.

**(iii) Seas having Salinity below Normal**: The Arctic Ocean, Antarctic Ocean, Bering Sea, Japan Sea, Baltic Sea, etc. have low salinity(21‰).

### Vertical Distribution of Salinity

So far as the vertical distribution of salinity is concerned, no definite trend is found and, therefore, no generalisation can be made. In general, with increasing depth of sea water, both the trends of increase and decrease of salinity are found. The vertical distribution of salinity is plotted on T-S Diagram, advocated by Helland-Hensen. The various patterns of salinity in the Halocline, Thermocline and Pycnocline have been shown in **Fig. 4.8**.

The characteristics of vertical distribution of salinity may be summarised as follows:

(i) The salinity of the oceans increases with increasing depth.

(ii) Salinity is low at the surface water in the equatorial water.

(iii) In the middle latitudes, the salinity increases with increasing depth.

## Ocean Deposits

The sediments, derived from various sources, deposited at the oceans floors are known as ocean deposits. The main sources of ocean deposits are:

**(i) Terrigenous**: Gravel, sand, silt, clay, mud, etc. Sediments derived from the land and

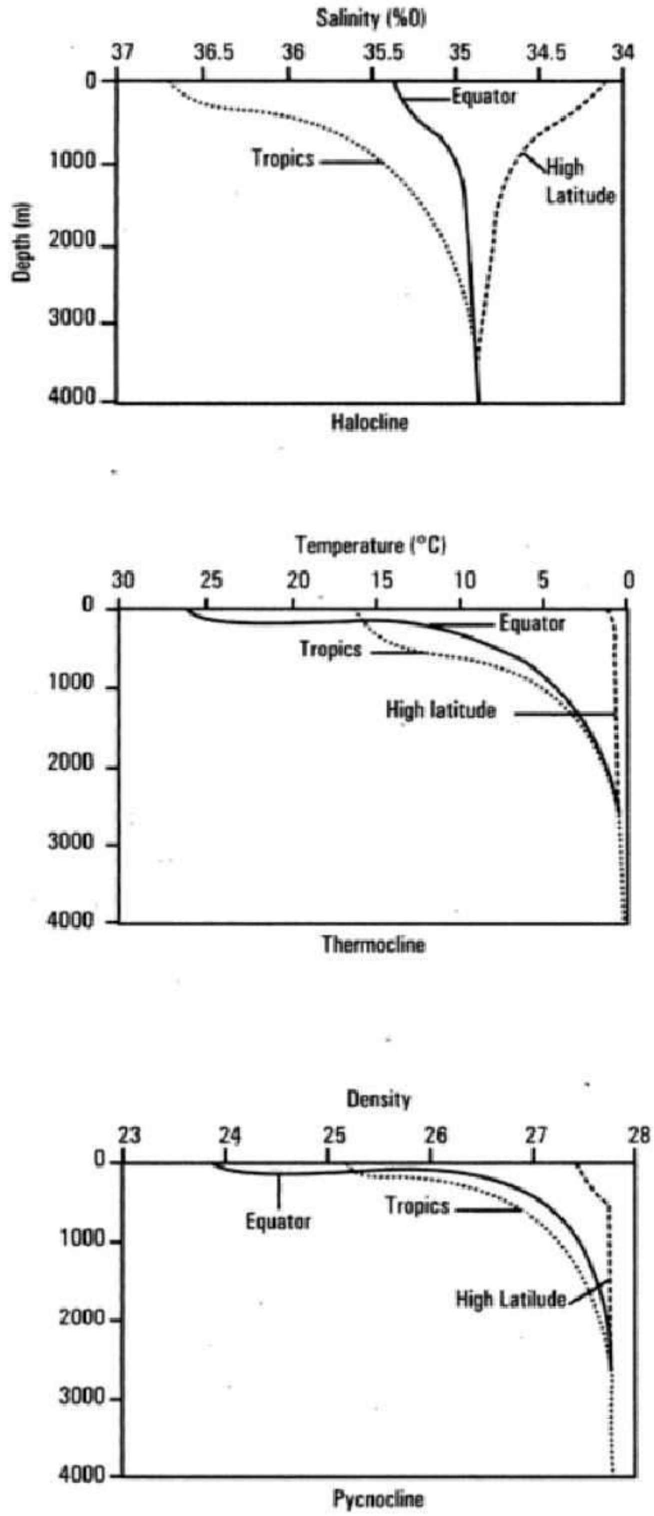


*Fig. 4.8 – Halocline, Thermocline and Pycnocline*

transported to the ocean by running water and wind, etc.

**(ii) Volcanic Deposits:** Ash, pumice, cinder, etc.

**(iii) Biotic Deposits**: Neretic deposits, pelagic deposits (ooze), globigerenia ooze, radiolarian ooze, red clay, etc. These deposits consist material mainly of marine organic origin, i.e. shells, skeletons of marine animals and plants. The most common of the biogenous sediments are calcareous ooze and siliceous ooze.

**(iv) Cosmogenous Deposits:** Dust, tektites and particles.

The general pattern of sediments on the ocean floor has been shown in **Fig. 4.9.**

## Ocean Currents

Surface ocean currents are driven by the prevailing winds and by the spinning motion of the Earth which drives the currents into circulating whirlpools, or gyres. Deep sea currents, over 100 m below the surface, are driven by differences in water temperature and salinity, which have an impact on the density of deep water and on its movement.

The main causes of ocean currents are:

1. Differential heating of the equatorial and polar oceans.
2. Trade and anti-trade winds.
3. Coriolis effect.
4. Variations in the salinity and temperature of the oceans.
4. Configuration of the coast line and ocean floor.

In general , warm ocean currents bring warm water from the equatorial regions to polar regions and cold ocean currents bring cold water from the polar regions to the equatorial regions. The major ocean currents have been shown in **Fig. 4.10.**

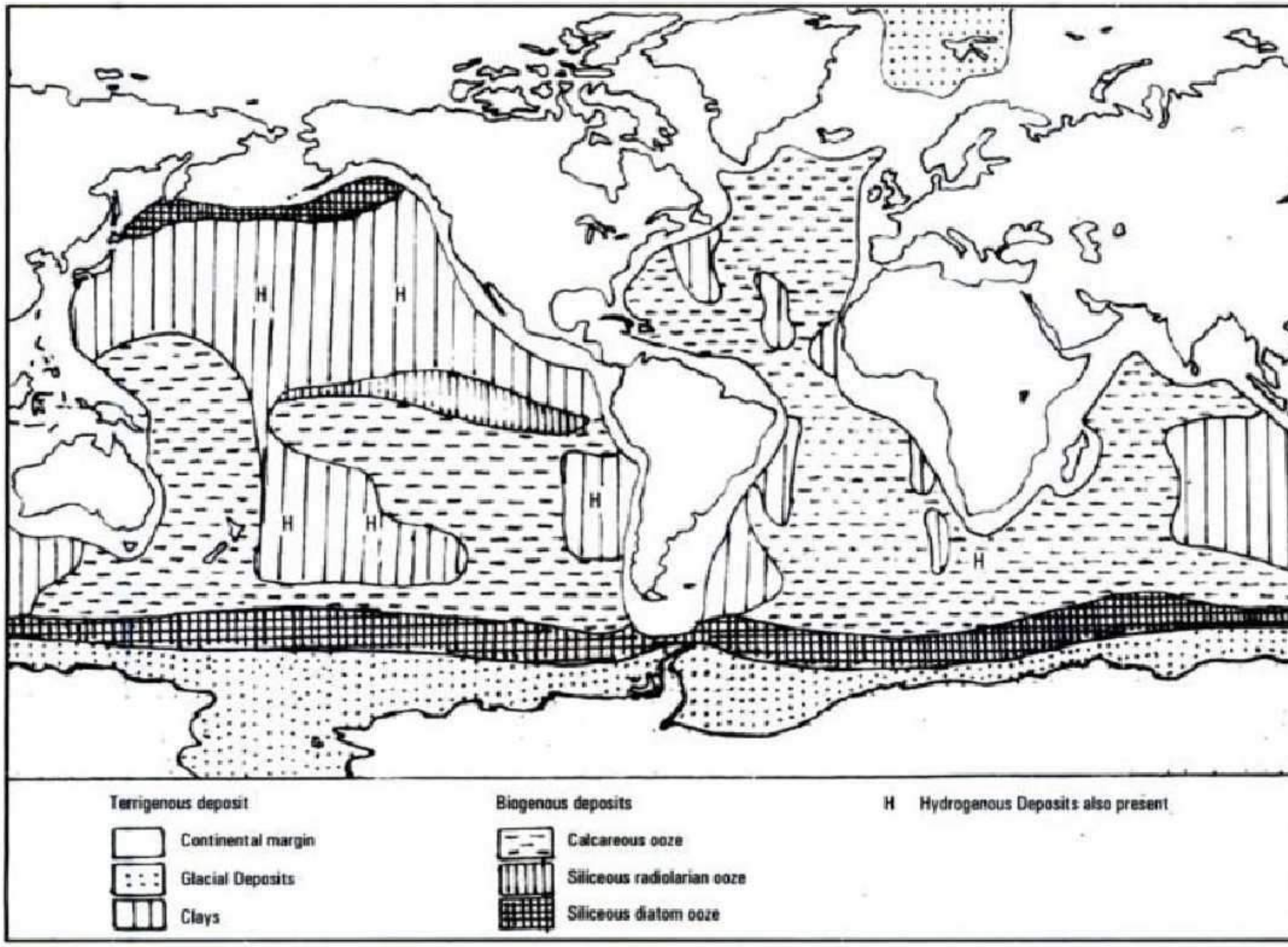


*Fig. 4.9 – Ocean deposits*

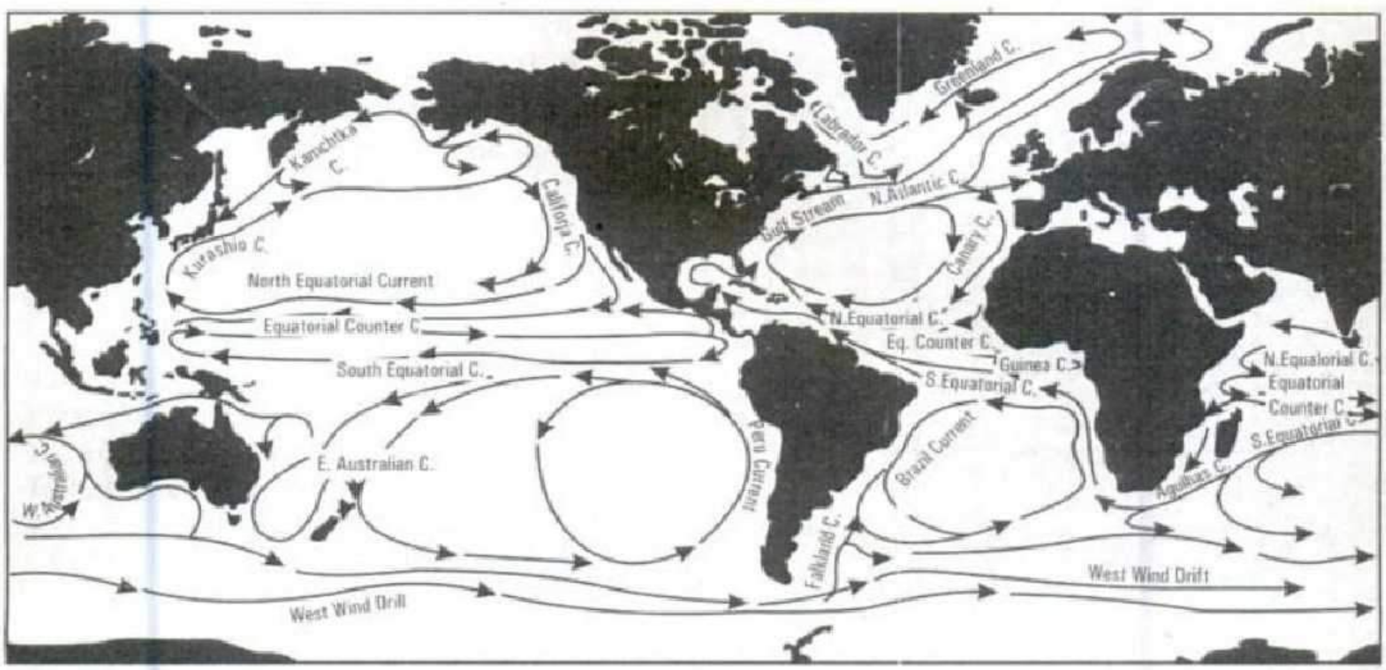


*Fig. 4.10 – Major surface ocean currents of the world*

***Table 4.2: Major Ocean Currents of the World***

| *Ocean* | *Name of the current* | *Nature* | *Effect* |
|---|---|---|---|
| North Atlantic Ocean | North Equatorial Current | Warm | Carries the warm water of the Gulf of Guinea towards South America. |
| | Antilles | Warm | Keeps the temperature of Antilles above 25°C throughout the year. |
| | Gulf Stream | Warm | Its confluence with the Labrador current produces heavy fog along the coasts of New Foundland. It is one of the important fishing grounds of the world. |
| | North Atlantic Drift | Warm | It keeps the ports of Norwegian Sea and Barents Sea like Murmansk and Severodvinsk (Russia) situated at higher latitudes ice-free throughout the year. |
| | Labrador | Cold | The confluence of Labrador and Gulf Stream produces heavy fog in the region of New Foundland which create conducive conditions for fishing. The fog creates obstacles in navigation. |
| | Canaries | Cold | Leads to fog along the western coast of North Africa. Helped in the genesis of Sahara Desert. |
| South Atlantic Ocean | South Equatorial Current | Warm | Carries warm water from the Gulf of Guinea towards Brazil. |
| | Brazilian Current | Warm | Keeps the eastern coast of South America warm. |
| | Benguela Current | Cold | Leads to foggy conditions along the coast of Namibia. Helped in the development of Namibian and Kalahari deserts. |
| North Pacific Ocean | North Equatorial Current | Warm | Carries heat from the eastern Pacific towards the East Indies. Carries warm water towards Alaska. |
| | Oyashio/Kurile Current | Cold | The confluence of Oyashio with Kuroshio produces heavy fog around Hokkaido. This confluence is conducive for the development of fisheries. |
| | Alaska Current | Warm | Keeps the seaports of Alaska open throughout the year. |

| | | | |
|---|---|---|---|
| | California Current | Cold | Leads to foggy conditions along the coast of California. It helped in the development of Arizona and Sonara deserts. |
| South Pacific Ocean | South Equatorial Current | Warm | Carries warm water from the eastern parts of the South Pacific towards New Guinea and eastern Australia. |
| | East Australian Current | Warm | Carries heat from the equatorial region towards the eastern coast of Australia. |
| | Peru/Humboldt Current | Cold | Helped in the desertification of the Atacama Desert. El-Nino effects the weather in western South America. It also affects the timely arrival of Indian Monsoon. |
| Indian Ocean | Mozambique Current | Warm | Carries heat from the equatorial region towards the eastern coast of Mozambique. |
| | Agulhas | Warm | Increases temperature along the eastern coast of South Africa. |
| | West Australian Current | Cold | Leads to foggy conditions along the western coast of Australia. It helped in the genesis of West Australian Desert. |

## Sea-waves

It is a ridge of water between two depressions. A wave approach, they curl into an arc and break. The energy of surface waves is responsible for the erosion of the coast. Waves also initiate currents which run along the coast and which are the moving force in long-shore drift. The height of a wave is generally proportional to the square of wind velocity.

## Tides

The periodic short-term rise and fall in the sea levels is known as tide. It is produced due to gravitational interaction of Earth, Moon and Sun. Moon exerts the strongest influence on tides because of its closeness to the Earth.

### Spring Tides

On the full moon and the new moon, the tides occur are the highest and known as the *Spring Tides*, while in the I$^{st}$ and 3$^{rd}$ quarters of a month, tides are lower than the usual, which is known as the *Neap Tides* **(Fig. 4.11)**.

The highest tides in the world occur in the *Bay of Funday*. The highest tides in India are recorded at *Okha*, Gujarat.

It takes 24 hours 50 minutes for the rotating Earth to bring the same meridian vertically below the Moon everyday. Hence, tides occur at regular intervals of 12 hours and 25 minutes. Generally, tides occur twice a day.

### Merits of Tides

Tides generally help in making some of the rivers navigable for ocean going ships. For example, London and Kolkata have become important ports owing to tidal nature of the mouths of Thames and Hooghly, respectively.

Tides also wash out the sediments brought by rivers and thus, retard the formation of deltas and help in cleaning the coastal regions.

The tidal force may also be used as a source for the generation of electricity. The generation of tidal energy was started by France, followed by Japan. India produces tidal energy in the Gulf of Khambat and Kachchh.

## Coral Reefs

Coral reef is a linear mass of calcium carbonate (aragonite and calcite) assembled from coral organism, algae, mollusks, worms, etc. Coral may contribute less than half of the reef material. In most reefs, the predominant organisms are stony corals that secrete calcium carbonate (limestone). The coral reefs are also referred as the '*Rainforests of the oceans*' because of their tremendous biodiversity.

The coral reefs may be broadly classified in the following categories:

**(i) Fringing Reef**: Reef that is directly attached to a shore or borders it with an intervening shallow channel or lagoon.

**(ii) Barrier Reef**: Reef separated from a mainland or island shore by a deep lagoon. The Great Barrier Reef lying to the east of Queensland is the largest living structure on the Earth. It extends for more than 2000 km.

**(iii) Atoll Reef**: A more or less circular or continuous barrier reef extending all the way around a lagoon without a central island.

**Distribution of Coral Reefs in the World :** Most of the coral reefs are found between 30° N and 30° S, where the average temperature of the sea surface is about 21°C.

According to one estimate coral reefs cover about 284,300 square kilometers, with the Indo-Pacific region (including the Red Sea, Indian Ocean, South East Asia and the Pacific) accounting for 92% of the total coral formations. The Caribbean coral reefs account for about 7.5% of the total coral formations of the world **(Fig. 4.12)**.

Coral reefs are almost absent from along the west coast of Americas and the west coast of Africa. Corals are also restricted from the coastline of South Asia from Pakistan to Bangladesh. They are also not found in the delta region of the Ganga-Brahmaputra river and the Amazon river due to the addition of vast quantities of fresh water.

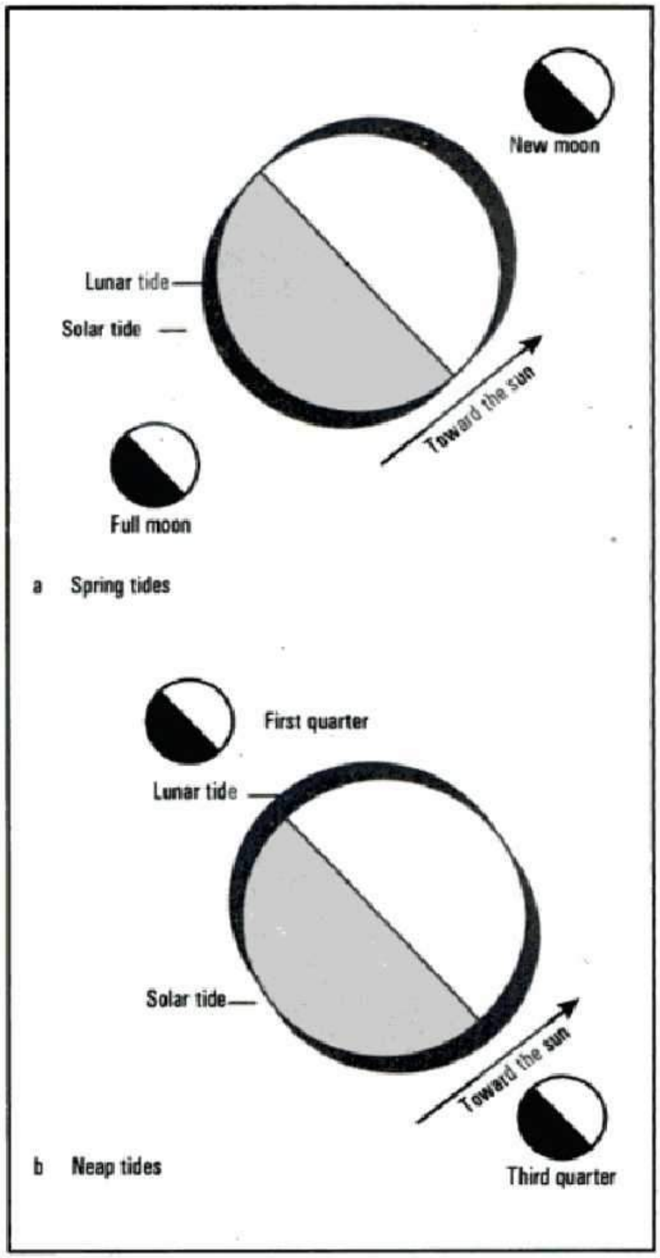


*Fig. 4.11 – Relative positions of the Sun, Moon, and Earth during spring and neap tides*

## Tsunami

The seismic waves, travelling through the ocean and sea water, result into high sea waves which are known as tsunamis. '*Tsunamis*' is a Japanese word which has been universally

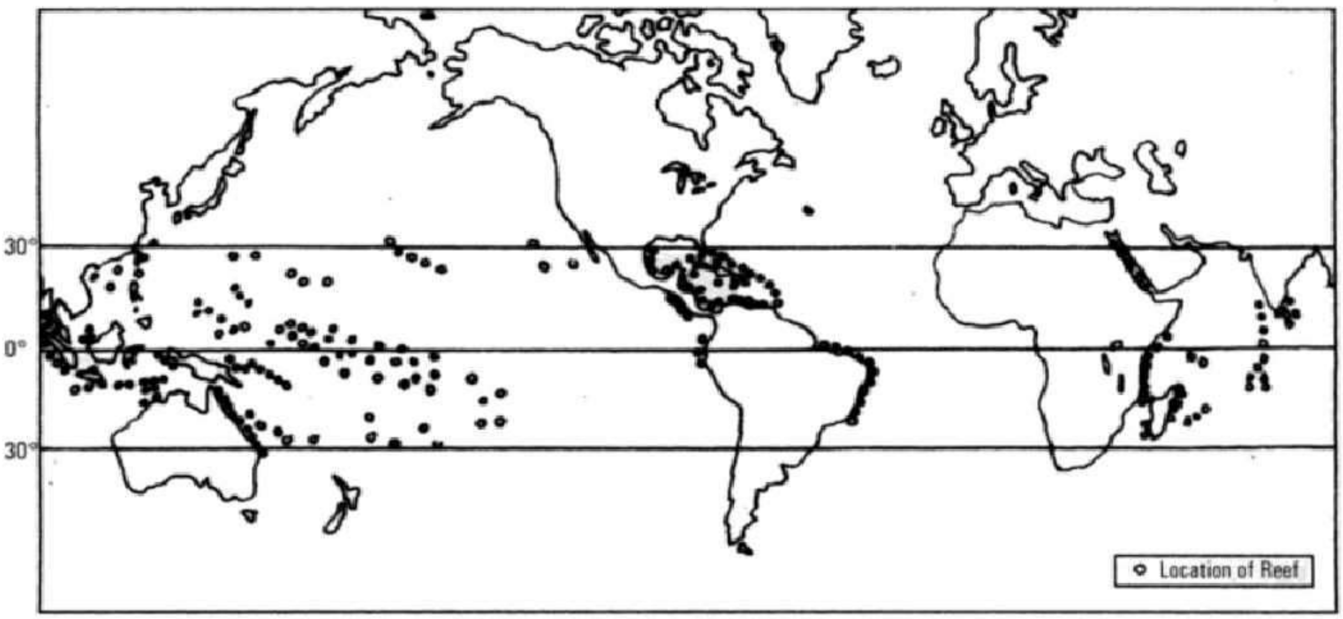


*Fig. 4.12 – Distribution of coral reefs*

adopted to describe the seismic sea waves. These waves are capable of causing considerable destruction in certain coastal areas, especially where submarine earthquakes occur. Once a tsunami is generated, its steepness (ratio of height to length) is extremely low. This lack of steepness, combined with wave's very long period (5 to 6 minutes), enables it to pass unnoticed beneath ship at sea. As the seismic sea wave approaches shore, the situation changes rapidly and often dramatically. While the period of the wave remains constant, velocity drops, and wave height greatly increases. As the crest arrives at coast, the water surges ashore in the manner of a very high, fast tide. In the vicinity of the epicenter of the earthquake, the tsunami waves can reach a height of over 30 metres (100 feet). The tsunami travels at a speed of 100 to 150 km per hour which may pick up to 650 to 950 km per hour. Likewise, it may travel considerable distance.

The tsunamis occur in or around the oceanic trenches. They are more frequent in the Pacific ocean. The other oceans like the Atlantic ocean and the Indian ocean, are, however, not free from the occurrence of seismic waves. On Ist April, 1946, a fracture along the Aleutian Trench, generated a tsunami that quickly engulfed the Scotch-Cap lighthouse in Unimark Island in the Aleutian. Trench The lighthouse was completely destroyed, and five coastguards working in the lighthouse were died.

Some of the greatest tsunamis of the recent past include the Japan tsunami (11$^{th}$ March 2011) which killed more than 25,000 people in and around Sendai city and ravaged the Fukushima nuclear plant. The nuclear radiation alarmed the population of Japan, China, North and South Koreas and as far as U.S.A. and Canada. Banda Aceh (Sumatra) seismic wave which occurred on 26$^{th}$ December, 2004 in the Sunda Trench and killed over two lakh people in the neighbouring countries. The impact of the tsunami was quite serious in Andaman and Nicobar Islands and the Tamil Nadu coast of India. Coastal areas of the distant countries like Sri Lanka, Maldives, Oman, and Somalia were also adversely affected resulting into human casualties and loss to property.

In 1703, at Awa (Japan) one lakh people died because of seismic waves of serious magnitude. On 27$^{th}$ August, 1883, the explosive volcanic eruption of Krakatoa in Indonesia generated 35 Meter high waves that destroyed 163 villages and killed more than 36,000 people. The Lisbon city of Portugal was inundated by tsunami (over 15 metres in height) in the earthquake of 1755 in which over 60,000 people were killed.

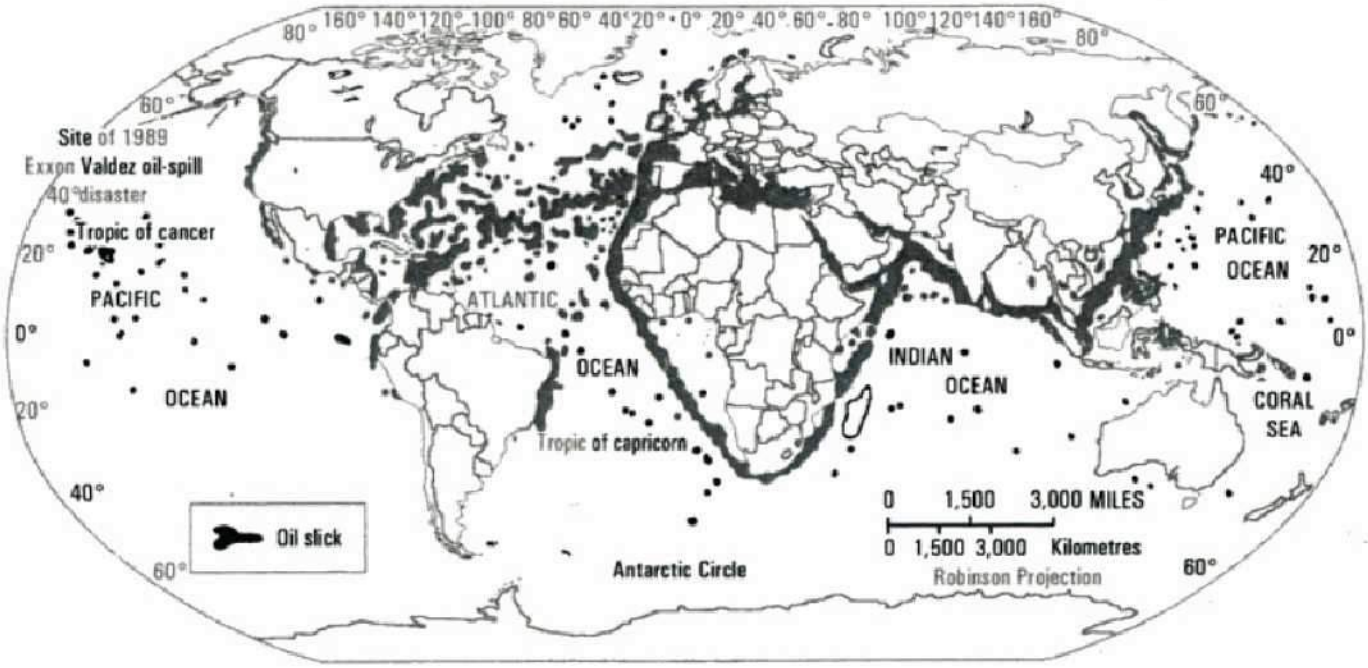


*Fig. 4.13 – Location of recent visible oil slicks worldwide. The location of the 1989 Exxon Valdez oil spill is noted on the map.[Data from Organisation for Economic Cooperation and Development, The State of the Environment.Paris:Organisation for Economic Cooperation and Development, 1985.] After Christopherson, R.W. Elemental Geosystem, 1995, p.533.*

Since 1948, an International Tsunami Warning Network has been in operation around the Pacific Ocean to alert the residents to possible danger. Its headquarters is at Honolulu. Much success has, however, not been achieved as the occurrence of earthquakes is sudden and the speed of the tsunami may be around one thousand km per hour. Tsunamis are thus a great natural hazard.

## Marine (Ocean) Pollution

With the increasing pressure of population and international trade, the sea-routes have become crowded. The excessive utilisation of ocean resources can result in the accidental (or unintentional) release of harmful substances. The marine pollution change the quality of the water or affect the physical and biological environment. The major causes of marine pollution are (i) volcanic eruption, (ii) oil-pollution–natural seeps, offshore-drilling, near shore refining, and accidents of tankers, (iv) spill of refined oil (v) dumping of wastes, etc.

The seriously polluted tracts of the oceans have been shown in **Fig.4.13**. It may be seen from this figure that the international sea-routes are seriously polluted. Out of all the oceans, the North Atlantic Ocean, Arabian Sea, Red Sea, Mediterranean Sea, North Sea, Baltic Sea, Strait of Malacca, China Sea are the most polluted regions of the world.

## Environmental Change

Environmental change is a continuous process that has been in operation since the Earth came into existence about 4600 million years ago. Earlier, there was a belief that man is the product of the Earth (Miss Semple), but now human beings are affecting the environment significantly.

At present the oil spill in the oceans and nuclear ration (Fukushima) are causing great damage to the ecosystems. The location of recent visible oil slicks worldwide have been shown in **(Fig. 4.13)**.

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