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Indira Gandhi National
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BGGCT-131
PHYSICAL GEOGRAPHY

Block

4

HYDROSPHERE

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CONTENTS

BLOCK 4: HYDROSPHERE

In the previous block, you have studied about atmosphere. So now, you are aware of the composition and structure of the atmosphere. You learnt about the processes related with heating and cooling of atmosphere and earth. You have been acquainted with the global distribution of surface pressure systems and winds. You also know about atmospheric moisture and humidity conditions and the reasons behind its uneven distribution. Lastly, you have learnt that our earth has varied climatic conditions. In this regard, you have studied climatic classification of koeppen.

In this block you will learn about hydrosphere which accounts for the total amount of water on planet earth including the water in its atmosphere. This block is divided into five units in which the first unit gives you a brief introduction to hydrosphere. Since oceans account for 97.5% of the total volume of hydrosphere, the remaining four units are dedicated to the study of oceans. So you will study about the bottom reliefs of oceans, temperature and salinity of oceans, oceanic circulations, as well as ocean deposits.

Unit 15 introduces you to the Hydrosphere. Apart from oceans, hydrosphere comprises of cryosphere, surface waters as well as underground waters. You will learn that water exists in different physical states on earth that is solid (ice), liquid (water) and gaseous state which are all connected together in a hydrological cycle.

Unit 16 familiarises you with the relief features of ocean floor. You will get acquainted with features like continental shelf, continental slope, continental rise etc. which occupies the transitional area between the continents and oceans and features like mid-oceanic ridges, trenches, seamounts etc. which occupy the deep sea plains. In this unit, you will also study in detail the relief features of the major oceans of the world.

Unit 17 emphasises on the two physical properties of ocean water, i.e. temperature and salinity. The variations in these physical properties not only affect other properties of ocean water like density, pressure etc. but also bring about movement of huge volumes of ocean water. They are also important for the survival of varied oceanic life forms.

Unit 18 introduces you to various oceanic circulations like waves, tides and ocean currents. It is important to study these oceanic circulations as they affect the coastal climatic conditions and can also produce energy if tapped economically.

Lastly **Unit 19** acquaints you with ocean deposits, the unconsolidated layer of sediments lying on the ocean floor. Its study is important as oceans are the final repository of all the debris from land.

Objectives

After studying this block, you should be able to:

- define and describe hydrosphere;
- discuss about different relief features of the oceans;
- correlate with different physical properties of oceans specially temperature and salinity;
- differentiate between different oceanic circulations like waves, tides and currents; and
- elaborate on oceanic deposits.

So we wish you good luck for studying this block.

UNIT 15

INTRODUCTION TO HYDROSPHERE

Structure

15.1 INTRODUCTION

In the previous units of this course, you have studied about geo-tectonics, lithosphere and atmosphere. In this block you will learn about hydrosphere. Hydrosphere can be defined as the total amount of water on the earth which forms a discontinuous layer that can be in all the three states, that is, solid ice, liquid water and in gaseous form as water vapour. It includes the water in the oceans, lakes, rivers, swamps; all underground water; frozen water in the form of ice, snow and high-cloud crystals; water vapour in the atmosphere as well as the moisture temporarily stored in plants and animals. Oceans account for 97% of the total volume of water on earth and spreads over three-fourths of the surface area of earth. So, in the next four units you will study about oceans. However, we have kept the block name as hydrosphere, so that it is in coherence with the earlier blocks on lithosphere (Block 2) and atmosphere (Block 3).

Sec. 15.2 gives a brief introduction to the distribution of water on earth. You will study hydrological cycle in Sec. 15.3 where you will learn about the movement of water in different realms or different spheres and in different physical states. The next four sections, that is, Sec. 15.4, Sec. 15.5, Sec. 15.6 and Sec.15.7 gives the description of water in different realms, that is, Oceans, Cryosphere, Surface water and Underground water respectively.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define hydrosphere and mention its relevance;
- state the distribution of water on earth;
- explain hydrological cycle in greater detail;
- describe the oceans of the world;
- elaborate about cryosphere, surface waters and underground water.

In the next unit, you will learn in detail about different relief features of the oceans.

15.2 THE DISTRIBUTION OF WATER

Water is the most abundant substance found on earth and covers about 70% of earth's surface. About 1.4 billion cubic kilometers (326 million cubic miles) of water in liquid and frozen form make up the oceans, lakes, streams, glaciers, and groundwaters. Of the water covering the earth's surface, 97.5% is in the oceans (as saltwater) and only 2.5 % is in glaciers, groundwater, lakes and streams (as fresh water). Amongst fresh water, 68.7 % is in the form of ice and permanent snow in polar and mountainous regions. 29.9 % of fresh water exists in the form of groundwater. The remaining 0.26 % of fresh water is the only water which is accessible and includes water of rivers, lakes, reservoirs, etc.

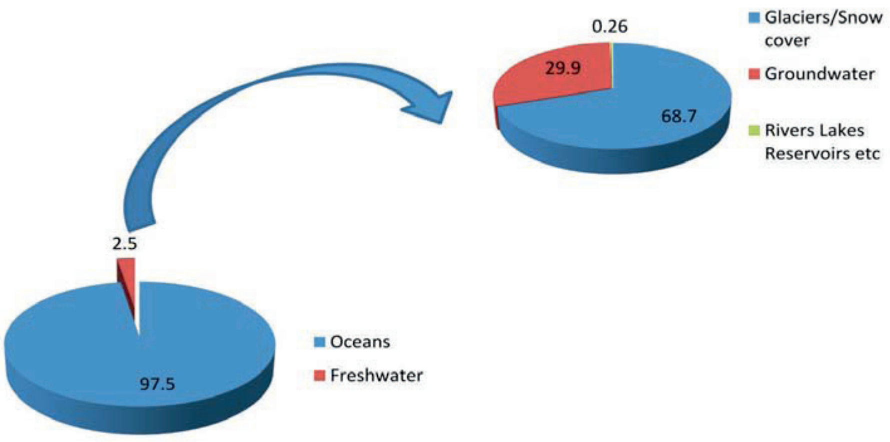

Fig. 15.1: Water Distribution in different Realms on Earth.

The hydrosphere significantly overlaps other spheres and is the least well defined of all the four spheres. Lithosphere has the presence of water in all the three states, that is, liquid water, solid ice and even water vapour. Similarly, water exists in atmosphere in the form of water vapour as well as water and ice crystals in the cloud. Water is an important constituent of all living organisms present in the biosphere and its percentage ranges from 60 percent to even 95 percent in some organisms.

In the unit on "Humidity and Precipitation", we have already dealt with the physical properties of water. We have also discussed hydrological cycle in brief there. In this unit we shall focus on geography of water in greater detail and also study the hydrological cycle more elaborately.

15.3 THE HYDROLOGICAL CYCLE

So by now, you should know that, there is very uneven distribution of water on earth. Also a very small amount of fresh water is available for use though water appears everywhere on earth, that is in air, in land and in every living being. It also exists on earth in all the three states, that is, solid, liquid and gaseous state. The different physical states of water is in fact very important as they are all connected to the hydrological cycle.

The key phenomena in water cycle are evaporation, condensation, precipitation, run-off, sublimation, transpiration and evapotranspiration. You have already studied about these processes in unit 13. Here we will focus on how these processes transfer water from one realm to another.

A. Movement of Water from Surface to Air

Since oceans occupy 71 % area of the earth's surface, they undergo maximum amount of evaporation and provide a major portion of moisture to the atmosphere. Oceans are estimated to provide about 86% of total moisture to the atmosphere. The remaining 14% moisture comes from land sources which undergoes not only evaporation but also transpiration to provide moisture to the atmosphere. The movement of water vapour in the atmosphere is either horizontal or vertical. Horizontally it occurs through advection with the help of winds and vertically through convection. Water vapour stays in atmosphere for a shorter duration ranging from a few hours to few days.

> You have already studied the terms like advection convection etc. in the previous block.

B. Movement of Water from Air to Surface

Water vapour either condenses to form the liquid water or undergoes deposition to form solid ice which becomes the basis of cloud formation. This way movement of water from air to surface begins. You may recall that clouds may precipitate under favourable circumstances. Precipitation can occur in several forms like rain, snow, sleet or hail. Source of water for precipitation comes from evaporation and transpiration. So you may reason out that precipitation should be equal to evaporation cum transpiration. Though overall they are equal but they vary in different realms. Oceans undergo 86 % of the total evaporation but receive only 78 % of the total precipitation. On the other hand, continents undergo only 14 % of evaporation but receive 22 % of precipitation.

C. Movement of Water on the Surface and Beneath

In spite of the fact that Oceans receive lesser percentage of precipitation compared to evaporation, they do not face any dearth of water. Similarly, continents receive greater percentage of precipitation compared to evaporation; they do not face abundance of water or flooding. Can you reason out why?

This is because the slope of the continents is eventually towards the oceans. So whatever water that fall on land areas, fills up the streams, lakes, reservoirs and other water bodies there and some also percolate into the ground and become a part of underground water and the rest of water runs off towards the oceans. This runoff water towards the oceans compensates about 8 percent of dearth of precipitation that the ocean receives. You can get a better understanding of this from Fig. 15.2 which explains the hydrological cycle.

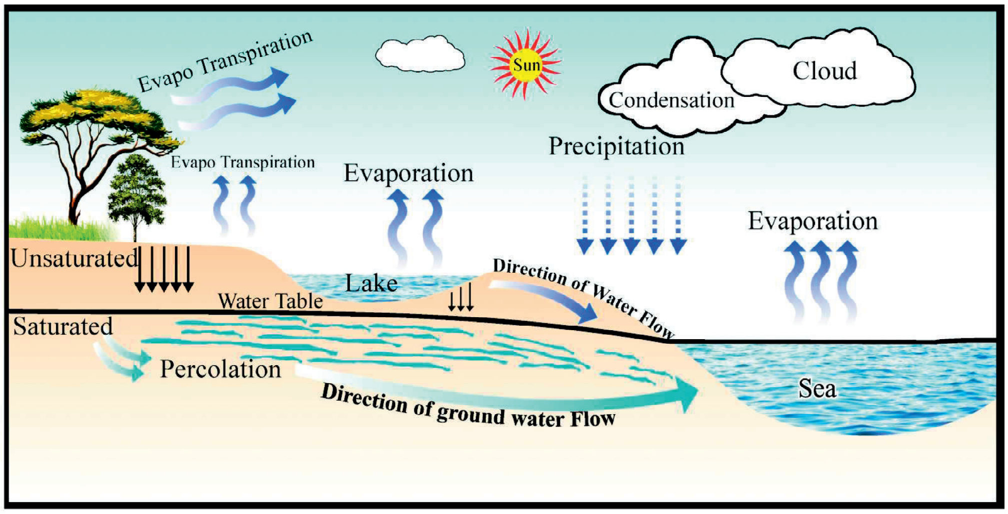

Fig. 15.2: The Hydrological Cycle

15.4 THE OCEANS

You now know that oceans account for about 97% of the total volume of water on earth and spreads over three-fourths of the surface area of earth. Freshwater accounts for only about 3% of water on earth. So Oceans account for a much greater portion of hydrosphere. However, they are not evenly distributed with respect to the equator. Northern Hemisphere accounts for two-thirds of the earth's land area. About 80% of the Southern Hemisphere is ocean. They play a crucial role in regulating our climate and atmosphere. In spite of the vast expanse of oceans, our knowledge about them seems to be limited and very recent with the development of modern equipments so as to discover the details regarding it.

The world ocean is traditionally classified into four major basins; the Pacific, the Atlantic, The Indian and the Arctic Oceans. The Pacific Ocean is the deepest and largest, almost as large as all the others combined. The Atlantic Ocean is a little larger than the Indian Ocean, but the two are similar in terms of average depth. The Arctic is the smallest and shallowest of these four major oceans. One interesting fact regarding these oceans is that they happen to be interconnected and there is no clear boundary between them. Apart from these major oceans, other water bodies include seas, gulfs, bays etc. which are relatively smaller in nature.

Now let us know some basics about the major oceans. The relief features of these oceans would be dealt with in the next unit. Refer to Fig. 15.3 to get a picture of these oceans before we start the content part.

A. Pacific Ocean

Pacific Ocean is the largest and deepest ocean occupying about one-third of the total area of the globe. It extends from Arctic Circle in the north to a few degrees beyond Antarctic circle in the south and is widest along the equatorial region. Its greatest width is between Isthmus of Panama and Malay Peninsula. The ocean in the western part has several volcanoes and is known as **"*Pacific Ring of Fire*"**. It is connected to the Arctic ocean by Bering strait and with Atlantic ocean by strait of Magellan, Panama canal and Drakes passage. It is connected to the Indian Ocean by Malay Archipelago and passages between Australia and Antarctica. The ocean has a number of islands, the important ones being the New Zealand, Japan and the Malayan Archipelagos. Some of the major rivers drain into the ocean like Hwang Ho and Yangtze from Asiatic landmass and Columbia from North America. The average depth of Pacific Ocean is 4,300 m. The deepest point is the Mariana trench which is about 11,022 m deep.

The eastern Pacific has narrow and deep continental shelf as the coast rises abruptly to mountainous heights that are in the form of Rockies and Andes mountains. Contrary to this, the western coast, that is, along Asia is characterized by low, highly indented and wider continental shelf. In the next unit, you will study in detail about the bottom reliefs of Pacific Ocean. Let us now know about other oceans.

B. Atlantic Ocean

The Atlantic Ocean is slightly less than half of the size of Pacific Ocean and occupies a relatively narrow body of water which appears to be s-shaped and curves between almost two parallel continental masses covering about 21% of the earth's total surface area. The north-south stretch of the ocean is roughly the same as that of the Pacific but the east-west extent is almost half of the Pacific. This ocean contains most of the shallow seas of the earth like the Caribbean, Mediterranean, Baltic, Black, North sea and the Gulf of Mexico. However, it has fewer islands compared to the Pacific. As the continents on both sides of Atlantic slopes towards it, it receives waters of some of the major rivers of the world and has the largest drainage area. Some of the rivers that drain into it are St. Lawrence, the Mississippi, the Orinoco, the Amazon, the Rio de la Plata, the Congo, the Niger, the Loire, the Rhine, the Elbe, and also the rivers draining into the Mediterranean, Black, and Baltic seas. The average depth of the Atlantic Ocean (including its adjacent seas) is about 3300 meters. The deepest point of the ocean is 8,376 meters which is at Puerto Rico Trench. The mid-Atlantic ridge, running roughly down the center of this ocean region, separates the Atlantic Ocean into two large basins. We will study about the bottom reliefs of Atlantic Ocean in detail in the next unit.

> Malay peninsula comprises the south east portion of Myannar, the south west portion of Thailand, Peninsular Malaysia and Singapore. It is also known as "Kra Peninsula".

> Sunda islands includes the greater Sundas (Sumatra, Java, Borneo, celebes and adjacent smaller islands) and Lesser Sundas (Bali, Lombok, Sumbawa, Sumba and Flores, Timor, Alor and adjacent smaller islands).

C. Indian Ocean

The Indian ocean covers about 14% area of the earth and is slightly smaller than the Atlantic ocean. It is the smallest, geologically youngest, and physically the most complex of the world's three major oceans. It is surrounded by huge continental masses of Africa, Asia, and Australia on three sides and nine-tenths of its area is to the south of equator. The countries that border the ocean are Pakistan, India, and Bangladesh to the north; the Malay Peninsula, Sunda Islands of Indonesia, and Australia to the east; Antarctica to the south; and Africa and the Arabian Peninsula to the west. In the south-west it connects with the Atlantic Ocean along the southern tip of Africa, and to the east and south-east its waters mingle with those of the Pacific Ocean. The southern limit of the Indian ocean is not well defined. Average depth of the ocean is 3,900 m, the

Fig. 15.3: Oceans and Seas of the World.

deepest point being the Java trench which is at a depth of 7,450 m deep. Compared to Atlantic ocean, lesser number of streams drain into this ocean. Also continental shelf areas are quite narrow. Some of the major rivers that drain into the Indian Ocean are rivers Zambezi, Shatt-al-Arab, Indus, Ganges, Brahmaputra and Irrawaddy. Sea water salinity ranges between 32 and 37 parts per 1000. A greater percentage of Indian Ocean lies within the tropics, due to which, this basin has the warmest surface ocean temperatures.

D. Arctic Ocean

Arctic Ocean is the smallest ocean bound on all sides by continents and is roughly circular in shape. It is connected to Atlantic Ocean and Pacific Ocean through Baffin Bay and Bering Sea respectively. The floor of the Arctic Ocean is divided by three submarine ridges, that is, Alpha ridge, Lomonosov ridge, and Arctic mid-oceanic ridge. Arctic Ocean remains frozen for most of the time of the year to the extent that it was also called Frozen Ocean. However since 1980, the volume of summer ice is greatly reduced. Due to frozen conditions, exploration of the ocean with the help of sounding technique is difficult. With the development of satellite technology for mapping and echo-sounders for measuring depths, research work in the ocean has become easier. Some of the marginal seas of the ocean are Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea, Barents Sea, White Sea, Greenland Sea and Beaufort Sea.

15.5 CRYOSPHERE

Cryosphere is the frozen water part or the solid portion of the hydrosphere. The word "cryosphere" comes from the Greek word for cold that is "kryos". When we talk about cryosphere, we mean the places where water is in its solid form, where temperatures are extremely low that water is frozen into ice. As you have learnt in the beginning of this unit, in terms of percent distribution of water, it stands second to the world oceans. Cryosphere is divided into two types, that is, the ice found on land areas and the other one is occupying the oceans. Those occupying land are higher in percentage and are found as continental ice sheets found in Greenland and Antarctica, as well as mountain glaciers, ice caps and areas of snow and permafrost. Thus they occur in areas of high altitude as well as in areas of high latitudes. Now do you know what glaciers are?

Glaciers cover about 10% of earth's land area and are thick masses of ice on land that move downhill under the impact of gravity. They have accumulated over many seasons of snowfall and act as huge reserves of freshwater. They carve various ladscapes wherever they form and flow. You must have read about these ladscapes in Block 2 of this course. Now let us learn about oceanic ice.

Oceanic ice exist as ice pack, ice shelf, ice floe and iceberg. Let us get acquainted with these terms.

Ice pack is a massive mass of floating ice. The largest ice pack covers most of the Arctic Ocean in the polar region. Similarly, along Antarctica on the opposite side of globe ice pack occurs along the fringes of the continent. However due to increase in temperatures globally nowadays the size of these ice masses, have been decreasing continuously.

Ice shelf is a portion of continental ice that projects over the sea. It is also massive in size. Ice shelves are mostly found in Antarctica and Greenland, as well as in Arctic region near Canada and Alaska. One of the most prominent ice shelf found in Antarctica is the Ross Ice Shelf which is spread over an area of 100,000 km^2. Again due to global warming, many ice shelves are disintegrating or decreasing in their size. One such ice shelf was Larsen-B Ice shelf in Antarctica which showed signs of disintegration in the year 2002. Later in 2008 another one from Antarctica itself, that is, Wilkins Ice Shelf showed similar impact of rising temperatures.

Ice floe is a huge body of ice that has broken from a still bigger mass of ice and is floating independently.

Lastly, ***Iceberg*** is a floating mass of ice that has broken from an ice shelf or glacier. Both ice shelf and iceberg raise the level of sea only when they first leave land and push into the water, but not when they melt in water. With the rise in temperature they will break off and melt. They support biodiversity as they provide shelter for krill, small fish, penguins, seals, whales, and sea birds. So you might now understand, that cryosphere also influences our world's climate and is central to the daily lives of the people, plants, and animals that inhabit it. Refer to Fig. 15.4, Fig. 15.5, Fig. 15.6 to see an example of an ice shelf, ice floe and an iceberg.

Cryosphere is also subject to expansion during the winter months. You should also remember one important point that inspite of the fact that oceanic water is saline, all forms of oceanic ice is composed of freshwater.

You should also be acquainted with another realm of world's ice, that is, beneath the land surface. Frozen ground occurs when the ground contains water, and the temperature of the ground goes down below 0°C (32° Fahrenheit). It exists mostly in the Arctic and Antarctic, that is high latitudes and also at high altitudes. More than half of the land in the northern hemisphere freeze and thaw every year and is called seasonally frozen ground. One-fourth

Fig 15.4: Ice Shelf in Antarctica (Picture Credit: Geo Swan, 2008, CC BY 2.0)
(Source: https://commons.wikimedia.org/wiki/File:Ice_Shelf_Antarctica_13.jpg)

Fig. 15.5: Ice Floe (Source: https://pixabay.com/photos/ice-floe-winter-water-cold-3196055/)

Fig 15.6: An Iceberg
(*Source*: **https://www.maxpixel.net/Solar-Sea-Water-Iceberg-Nature-Mirroring-471549**)

of the land in the northern hemisphere has an underground layer that stays frozen all year long. Ground that stays frozen for at least two years in a row is called ***permafrost*** having permanently frozen sub-soil. At some places, entire towns are built on ground that stays frozen all year around. People there rely on the hard frozen ground under their houses. Under these conditions even animals and plants have adapted themselves to take advantage of the frozen ground. Frozen ground creates hurdles for construction of roads or houses because the hardness of the soil can change once the frozen ground thaws due to which the structures can experience a shift or fracture. Frozen ground around the world is connected to earth's climate. Due to increase in temperatures across the globe, it has begun to melt.

SAQ 1

Spend 5 min

a) Can you reason out why oceanic ice is composed of freshwater and is not saline like the oceanic water?

b) What is the difference between snow and ice?

Now let us learn about another realm of water, that is, surface water which though accounts for only about 0.02 % of the world total water but considered the most important for the human beings. So let us know about them.

15.6 SURFACE WATERS

So far, we have learnt that water is in a constant state of motion, moving from surface to air, from air to surface and from surface to beneath the earth. It also stays in all the three states, that is, solid, liquid and gaseous states which are connected together in a hydrological cycle. The key processes are like evaporation, condensation, precipitation, run-off (both surface run-off and sub-surface infiltration), sublimation, transpiration and evapotranspiration. We have also studied about oceans and cryosphere. "Surface water" as the name suggests is the water on the earth's surface, including rivers, lakes, swamps, marshes and other wetlands. Surface water is essential, not only to human beings but to all life forms on earth. The most important use of surface water is for drinking purposes. Other uses include irrigating the agricultural land, generating hydroelectric power and other public uses. Surface water mostly comes from rainfall runoff. However, not all runoff goes into rivers. Some goes into vegetation, some seeps into the ground and recharges ground water systems, some even evaporates and a portion also seeps into river beds. At a certain depth below the land surface, called the water table the ground becomes saturated with water. If a river happens to cut into this saturated layer, then water will seep out of the ground into the river.

So, surface water can be classified into three types.

- Permanent,
- Semi-Permanent, and
- Man-made

Let us get familiar with them.

Permanent surface waters

These are actually perennial having water throughout the year. Examples of these include rivers, lakes, springs, swamps etc. The perennial characteristics are maintained due to water coming from groundwater during dry spells when there is scarcity of water.

Semi Permanent Surface Waters

These water bodies are seasonal in nature as they hold water only for a part of the year. These are actually low lying areas, waterholes, small creeks or lagoons, which get filled with water temporarily.

Man-Made Structures

At times, Surface waters can be stored in man-made structures ranging from lakes, dams, artificial swamps, sewage treatment plants etc.

Surface water is replenished by precipitation and by accretion from ground water. It is lost through evaporation, seepage into the ground where it becomes a part of ground water or used by plants for transpiration, extracted by humans for a variety of uses like agriculture, industry etc. or finally gets discharged into the sea to become a part of saline water.

> The total land area that contributes surface runoff to a river or lake is called a watershed, drainage basin, or catchment area.

Now let us take a close look at some of the important rivers, lakes etc.which though contain a very small proportion of the world's water at any given time are very important for living organisms.

A. Rivers

Rivers are extremely dynamic component of hydrological cycle. Since the rivers are freshwater and not saline like oceans, they provide a good source of drinking water and is also used for irrigation purposes so that we grow our food. Rivers also help in renewing the nutrients of soil thereby making it fertile. It also helps as a cheap source of transportation. Undoubtedly, rivers have been the settling place of several ancient civilizations because of the benefits provided by them which is very essential for the very survival of all living organisms.

Sometimes the term stream is used interchangeably with rivers. However, they seem to be a little smaller compared to the rivers. Let us take a quick look at some of the major rivers of the world listed in Table 15.1.

Refer to Fig. 15.7 to get an idea of location of these important rivers of the world.

B. Lakes

Lake is a large body of water occupying an inland basin and surrounded by land. There is ambiguity regarding the size of lakes however they can be differentiated from ponds in being relatively larger compared to them. Lakes can further be differentiated from rivers and streams or swamps and marshes. Do you know how? Rivers or streams are relatively fast moving but lakes are slowly moving or a sort of standing water that occupies an inland basin area. Swamps and marshes have greater proportion of grasses, trees and shrubs.

Although lakes are distributed all over the world, but the continents of North America, Africa and Asia account for about 70 % of the total lakes of the world. Lakes can be either freshwater or saline. Freshwater lakes constitute only about 0.009 percent of all free water while saline lakes and inland seas contain another 0.0075 percent of all free water. If a lake has no drainage outlet, either as a surface stream or as a sustained sub-surface flow, it is bound to become saline. Lake Baykal in Siberia is the world's largest freshwater lake in terms of volume of water. It is also the deepest lake in the world (1742 m deep) and contains more water than the combined volume of waters of all five Great lakes in Central United States. Some lakes contain water only for a short time in a

Table 15.1: List of Some Major Rivers of the World- Their Length, Source, Outflow and the countries along their Basin

Serial No.	Name of Rivers	Length (Km)	Source of Origin	Outflow	Countries Along the Drainage Basin
1.	Nile	6650	Tributaries of Lake Victoria	Mediterranean Sea (Africa)	Ethiopia, Eritrea, Sudan, Uganda, Tanzania, Kenya, Rwanda, Burundi, Egypt, Democratic Republic of the Congo, South Sudan
2.	Amazon	6400	Glacier-fed lakes in Peru	Atlantic Ocean	Brazil, Peru, Bolivia, Colombia, Ecuador, Venezuela, Guyana
3.	Yangtze	6300	Tibetan plateau, China	China Sea	China
4.	Mississippi-Missouri	6000	Source of Red Rock, Montana	Gulf of Mexico	United States, Canada
5.	Congo	4700	Confluence of Lualab and Luapula rivers in Congo	Atlantic Ocean	Democratic Republic of the Congo, Central African Republic, Angola, Republic of the Congo, Tanzania, Cameroon, Zambia, Burundi, Rwanda
6.	Mekong	4350	Tibetan Highlands	South China Sea	China, Myanmar, Laos, Thailand, Cambodia, Vietnam
7.	Volga	3645	Valdai Plateau, Russia	Caspian Sea	Russia
8.	Zambezi	3540	Black wetland in north-western Zambia	Mozam-bique Channel	Zambia, Angola, Namibia, Botswana, Zambia, Zimbabwe, Mozambique
9.	Indus	2,897	Himalayas	Arabian Sea	Pakistan, India, China
10.	Danube	2842	Black Forest in Germany	Black Sea	Romania, Hungary, Austria, Serbia, Germany, Slovakia, Bulgaria, Croatia
11.	Ganges	2510	Western Himalayas in India	Bay of Bengal	India, Bangladesh, Nepal, China

Note: The length of the rivers are given approximately as they vary in different data sources.

year, while it remains dry during most of the time. This is because they are situated in arid regions where inflow of water to the lake is less. Such lakes are also mentioned as ephemeral lakes. You should know that there are two conditions necessary for the origin of lakes and their continuous existence. The first one is that there should be presence of a basin or depression having restricted outlet and the second one is related to its water source which should be regular at least to keep it partly filled. These basins or depressions are either of glacial origin or may have resulted due to faulting. The lakes of North America are especially of glacial origin. The lakes of eastern and central Africa were resulted due to faulting. Several lakes are found in limestone regions due to dissolution of sinkholes like the ones found in Florida. Some lakes are also created by human beings artificially which are better called as reservoirs. Water gets collected in these reservoirs by building dams across some rivers and blocking their flow. This water is used for several purposes and hydroelectric power is also generated from these multipurpose river valley projects.

However, lakes around the world face the problem of siltation due to silt deposited by the inflowing streams. So in course of time lakes become shallow and tend to disappear.

Let us now go through Table 15.2 to get a clear idea of some of the important lakes of the world.

Table 15.2: List of Some Major Lakes of the World- Their Area, Water Quality and the Countries Located along them

Serial No.	Name of Lakes	Area (Km^2)	Water	Countries Located along the Lake
1.	Caspian Sea	3,86,400	Salty	Turkmenistan, Kazakhstan, Russia, Azerbaijan, Iran
2.	Lake Superior	82,100	Freshwater	Canada, United States
3.	Lake Victoria	69,485	Freshwater	Kenya, Tanzania-Uganda
4.	Lake Huron	59,600	Freshwater	Canada, United States
5.	Lake Michigan	57,800	Freshwater	United States
6.	Aral Sea	33,800	Salty	Kazakhstan, Uzbekistan
7.	Lake Tanganyika	32,900	Freshwater	Burundi, Tanzania, Congo (Dem. Rep.), Zambia
8.	Great Bear Lake	31,153	Freshwater	Canada
9.	Lake Malawi (Nyasa)	29,604	Freshwater	Malawi, Mozambique, Tanzania
10.	Great Slave Lake	28,570	Freshwater	Canada
11.	Lake Erie	25,667	Freshwater	Canada, United States
12.	Lake Winnipeg	24,390	Freshwater	Canada
13.	Lake Ontario	19,010	Freshwater	Canada, United States
14.	Lake Chad	17,800	Freshwater	Cameroon, Chad, Niger, Nigeria

Note: The area of the lakes are given approximately as they vary in different data sources.

Fig. 15.7: Some of the Major Rivers and Lakes of the World.

Refer to Fig. 15.7 to see the location of some important lakes of the world.

Now let us explore another important relam of water, that is, underground water in the next section.

15.7 UNDERGROUND WATER

As the name suggests, this realm of water happens to be under the land surface. However, it is more widespread compared to surface waters. This is because underground water is found everywhere on earth beneath the surface. What differs is the depth at which it is found. Surface waters like rivers, streams, lakes are quite localised. More than half of the world's underground water is found upto a depth of about 800 m from the surface. The source of underground water is from the surface. Either it comes from precipitation, where soil absorbs the moisture which percolates downwards or it comes from surface waterbodies from where the water seeps below. The percolation of water beneath the surface depends on the spaces between the sub-surface soil particles or rock fragments which is called as porosity of the material. In fact the ability to transmit underground water is termed as permeability of the sub-surface materials that depends not only on the amount of porosity of the material but also how these pores are interconnected so that water can traverse through the pores.

Underground water is stored in and moves through aquifers which are typically made up of gravel, sand, sandstone, or fractured rock, like limestone. Water can move through these aquifers because they have large connected spaces which make them permeable. We can thus define ***aquifer*** as a unit of rock or an unconsolidated deposit which can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the ***water table***. Heavy rains or melting of snow may cause the water table to rise and heavy pumping of groundwater supplies may cause the water table to fall.

Let us now get acquainted with vertical sub-surface cross section of hydrologic zones without which the study of underground water is not complete. These layers are arranged vertically from top to bottom in the following order:

- Zone of Aeration;
- Zone of Saturation; and
- Zone of Confined Water
- Waterless Zone

Let us now understand each of these zones briefly.

A) Zone of Aeration

This is the topmost zone immediately underlying the surface of earth. It is composed of a mixture of solids, water and air. Here the pore spaces between the particles are partially filled with water and partially filled with air. In this layer the water content is subject to a lot of fluctuation. Can you reason out why? This is because huge amount of water accumulates during the rainy season

Confined aquifer is a permeable layer (such as sandstone) between layers of impermeable material (such as clay or mudstone, called ***aquitards***. A completely impermeable aquitard is called an ***aquiclude*** or ***aquifuge***.

just after rains. The interspaces becomes saturated with rain water. Ultimately it percolates downwards into the next layer but a considerable amount is absored by plants and vegetation and some also gets evaporated.

B) Zone of Saturation

This zone is immediately below the zone of aeration where the pores are totally filled with water or saturated with water. That is why it is called the zone of saturation. The moisture in this layer is called groundwater which slowly seeps downwards under the impact of gravity. Its movement is based on the alignment of rocks and interconnectedness of spaces between them. The surface separating the zone of aeration from the zone of saturation is called as water table. The elevation of water table varies in response to local topography and climatic conditions. Groundwater returns to the surface through aquifers when the water table intersects with the earth's surface. Eventually, it empties itself into lakes, rivers and oceans. Sometimes perched water table is found which is the localised zone of saturation above main water table.

Well is an artificial opening cut down from the surface into the zone of saturation or into a confined aquifer. If a well is pumped heavily and water is taken out of the ground faster than it can be replenished (recharged), a ***cone of depression*** results which lowers the water table to a considerable extent over a large area. Refer to Fig. 15.8 to understand these zones in a better way.

Further downward movement of underground water is hindered by the presence of impermeable rock material or clay which is so dense that the pores do not allow water to traverse through them. They are called ***aquicludes***. Let us now study the next zone of underground water, that is, the zone of confined water.

C) Zone of Confined Water

This is the third hydrological zone of water which is found beyond the zone of saturation separted by impermeable rocks. This zone of confined water has aquicludes both above and below them where water has somehow percolated from a distant aquifer where no aquiclude existed. Also an aquifer in confined zone is sloping in such a way that it reaches to the surface from where it gets recharged with infiltrating water. This zone of confined water provides an important source of water in arid and semi-arid regions where water is in dearth.

D) Waterless Zone

This is the last zone where as the name suggests, it is devoid of water. At greather dephs the pressure of overlying rocks is such that density of rocks is increased to the extent that it becomes devoid of any pores. If porosity is nil, water cannot be absorbed in it neither it can traverse through it.

SAQ 2

What is the difference between aquifers and aquicludes?

Spend 5 mins

There are also some issues related to groundwater. We have already discussed that if groundwater is extracted more than its recharge or

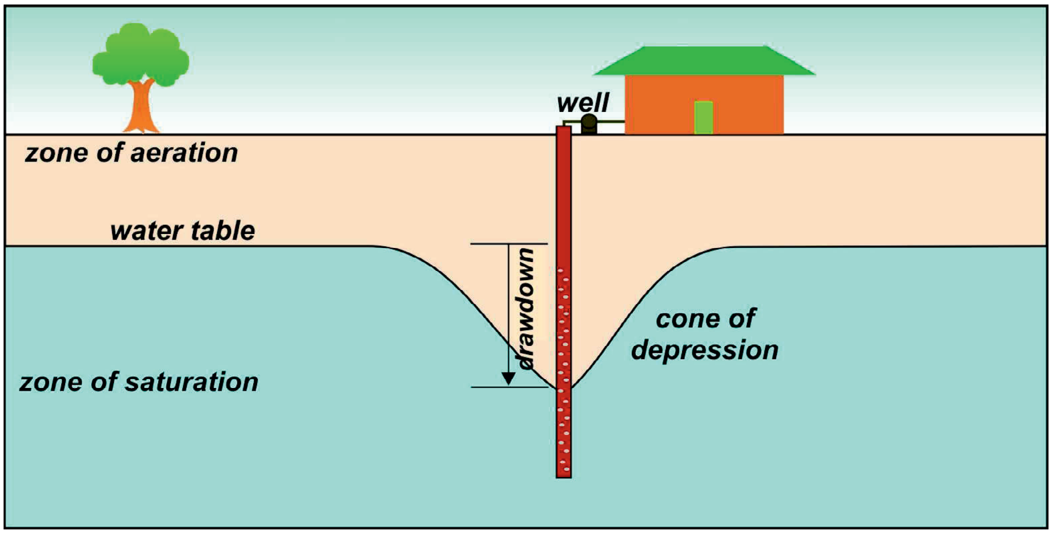

Fig. 15.8: Vertical Sub-Surface Cross Section of Hydroloical Zones.

replenishment rate then there can be a crisis. You are already familiar with the cone of depression that develops when water is taken out from a well at a much higher rate. It also results in decrease in water table to the extent that the overlying land surface would subside. Other problems associated with groundwater is, saltwater influx, groundwater contamination etc. which you will study at higher levels.

Let us now sum up what we have learnt so far in this unit.

15.8 SUMMARY

Water covers about 70% of earth's surface. Of the total water 97.5% is in the oceans (as saltwater) and only 2.5 % is in glaciers, groundwater, lakes and streams (as fresh water). Amongst fresh water, 68.7 % is in the form of ice and permanent snow in the polar and mountainous regions. 29.9 % of fresh water exists in the form of groundwater. The remaining 0.26 % of fresh water is the only water which is accessible and includes water of rivers, lakes, reservoirs, etc. Water exists on the earth in all the three states and they are all connected to the hydrological cycle where the key phenomena are evaporation, condensation, precipitation, run-off, sublimation, transpiration and evapotranspiration.

The world ocean is traditionally classified into four large basins, the Pacific, the Atlantic, the Indian and the Arctic Oceans of which the Pacific Ocean is the deepest and the largest. Cryosphere is the frozen water part or the solid portion of the hydrosphere. Cryosphere is divided into two types, that is, the ice found on land areas and the other one occupying the oceans. Ground that stays frozen for at least two years in a row is called permafrost having permanently frozen sub-soil. Surface water includes rivers, lakes, swamps, marshes and other wetlands. Underground water happens to be under the land surface. The vertical sub-surface cross section reveals the presence of four hydrological zones, that is the zone of aeration, zone of saturation, the zone of confined water and finally the waterless zone.

15.9 TERMINAL QUESTIONS

1. Give an account of cryosphere?
2. Explain sub-surface vertical distribution of underground water with the help of a diagram?
3. Write short notes on:
   i) Hydrological cycle
   ii) Surface waters
   iii) Oceans of the world

15.10 ANSWERS

Self-Assessment Questions

1. a) Oceanic ice is composed of freshwater and is not saline like oceanic water because the freezing process does not incorporate the salts present in oceanic water in the ice crystals.

   b) Snow is a form of precipitation which is actually made up of ice crystals. Ice forms when temperatures drop below the freezing point and liquid water becomes a solid, creating a tightly bonded substance.

   Snow crystals form when cold temperature is accompanied by high humidity levels. As long as air temperature remains below freezing, the crystals will fall to the earth as snow. So, ice is an ingredient of snow as well as glaciers, sea ice, ice shelves, icebergs, and frozen ground.

2. Aquifers are permeable materials composed of gravel, sand, sandstone, or fractured rocks like limestone that freely carries groundwater while aquicludes are impermeable materials composed of components like clay or dense unfractured rocks which prevents the passage of water through them.

Terminal Questions

1. First define cryosphere. Explain how it is divided into two types, that is, those occupying land areas (high latitudes and high altitudes or mountainous glaciers) and other occupying oceans. Then explain the terms glaciers, ice floe, iceberg etc.as given in Sec. 15.5.

2. First define underground water and explain all the four vertical sub-surface layers, that is, zone of aeration, zone of saturation, zone of confined water and waterless zone. Enhance your answer by a figure. Refer to Sec. 15.7.

3. (i) Define hydrological cycle and explain briefly with the help of a figure. Refer to Sec. 15.3 (For detail answer on Hydrological Cycle, you can explain the terms like evaporation, condensation etc. as given in unit

13 of previous block. Also include the movement of water in different realms with figure as in sec. 15.3 of this unit).

(ii) Define surface waters and give its percentage distribution on earth. Give examples of surface waters like rivers, lakes etc.and also mention some important rivers and lakes very briefly. Refer to Sec. 15.6

(iii) Refer to Sec. 15.4 and bring out the importance of oceans and give a short mention of different oceans of the world.

15.11 REFERENCES/FURTHER READING

Hess, D. (2012), Physical Geography: A Landscape Appreciation, PHI Learning Pvt. Ltd. New Delhi.

https://www.britannica.com/science/hydrosphere

http://www.britannica.com/place/Atlantic-Ocean

http://curry.eas.gatech.edu/Courses/6140/ency/Chapter1/Ency_Oceans/Origin_Oceans

https://nsidc.org/cryosphere/allaboutcryosphere.html

https://denr.nt.gov.au/__data/assets/pdf_file/0005/269339/factsheet-what-is-surface-water.pdf.pdf

https://www.usgs.gov/special-topic/water-science-school/science/surface-water-information-topic?qt-science_center_objects=0#qt-science_center_objects

https://www.infoplease.com/world/world-geography/principal-rivers-world

https://www.touropia.com/most-important-rivers-in-the-world/

https://www.britannica.com/science/lake

https://www.infoplease.com/world/world-geography/large-lakes-world

UNIT 16

OCEAN FLOOR AND RELIEF FEATURES

Structure

16.1 INTRODUCTION

In the previous unit of this block you have read about the hydrosphere. So now you know that hydrosphere is the aqueous envelope of the earth and includes the entire mass of water found on, under and over the surface of earth. Thus, it includes all liquid and frozen surface waters, groundwater held in soil and rock, and also atmospheric water vapour. In this unit, as well as in the next three units of this block, we are concentrating mainly on the oceans. However, we have kept the block name as hydrosphere, so that it is in coherence with the earlier blocks on lithosphere (Block 2) and atmosphere (Block 3).

In this unit Sec. 16.2 familiarises you with the oceans in brief. You will be acquainted with the depths of the oceans, hypsographic curve in Sec 16.3. Like continents, oceans too have relief features which you will learn in Sec. 16.4. In the remaining portion of the unit, that is in Sec.16.5, Sec. 16.6, and Sec. 16.7, you will be taught about bottom reliefs of all major oceans that is, Altantic, Indian and Pacific Oceans respectively.

In the next unit, you will read about temperature and salinity of the oceans.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define oceans and describe all major oceans of the world;
- define and distinguish between different relief features of the oceans;
- summarise the bottom reliefs of the major oceans of the world; and
- compare the bottom reliefs of the major oceans of the world.

Now let us get familiar with oceans in the beginning.

16.2 FAMILIARISING THE OCEANS

You may recall that oceans are large depressions or basins on the surface of solid earth containing saline water and covers 71% of the earth's surface and about 97% of the earth's water. Some of the major oceans of the world are Pacific Ocean, Atlantic Ocean, Indian Ocean, Arctic Ocean and Antarctic Ocean or Southern Ocean. Of these, the first four oceans have well-defined boundaries excepting the Southern Ocean which is often considered to be a continuity of its northern counterparts that is, the Pacific Ocean, the Atlantic Ocean and the Indian Ocean. Some important seas are Mediterranean Sea, Bering Sea, Japan Sea, Okhotsk Sea, Yellow Sea etc.(see Fig. 16.1). Oceans play an integral part in determining the earth's climatic system and daily weather pattern.

Titan is the largest moon of Saturn and the second largest moon of our solar system after Jupiter's Ganymede. It is supposed to have dense atmosphere and large stable bodies of surface liquid as well as liquid ocean beneath its surface.

According to the astronomers, earth is the only planet in our solar system to have oceans on its surface. Earlier it was opined that Mars and moon had huge volumes of water, but they disappeared in course of time due to some probable reasons like greenhouse effect, influence of comet etc. Recently some researches have confirmed the existence of stable bodies of extraterrestrial surface liquids in the form of lakes of Titan. Some more discoveries or researches could confirm the presence of extraterrestrial water in course of time.

This unit introduces you to the relief features of the oceans. Three major oceans, that is, Atlantic, Indian and Pacific are taken separately for the detailed study of oceanic relief features. Let us first learn about the depths of the oceans, hypsographic curve and nomenclature of oceanic features.

16.3 DEPTHS OF THE OCEANS AND THE HYPSOGRAPHIC CURVE

Oceanic dimensions include length and breadth of oceans which is regarded as the horizontal dimension while depth of the oceans is included under its vertical dimension. Let us get acquainted with the methods employed by the oceanographers to reveal the secrets underlying these oceans.

A. Measuring the Depths of the Oceans

Deep sounding line techniques were adopted to find the depths of the oceans. The earlier types were hand line and lead, armed with tallow that was

Fig. 16.1: Oceans and seas of the World.

used by ordinary sailors. Later, ***Lieutenant Brooke*** devised an improved sounding machine. ***Challenger expedition*** used a hemp line for sounding. Sounding techniques further improved with the use of fine wire with which the machine recorded the depth automatically at the moment when the sinker struck the bottom. Later on, sound and echo recording instrument further improved the method of measuring the depths of the oceans. ***Echo- Sounders*** transmits pulses of sound of frequency about 10-30 KHz and calculates the time interval taken between transmission of sound pulses and the reception of its echo. We already know the velocity of sound in water and by multiplying it with time interval taken, we can get twice the depth of oceans. Acoustic echo-sounders have been in use for mapping the oceans and its accuracy is about ± 1%.

By combining data from echo-sounders and satellite altimeters (Seasat and ERS-1) Smith and Sandwell produced maps of sea floor in 1997 with an average depth accuracy of ± 100m.

Nowadays, we also make use of data from satellite altimeters to know the shape of ocean surface as well as its floor with greater accuracy. ***Satellite altimeters*** have radar that measures the altitude of satellite from the sea surface and a tracking system that determines the height of satellite in geocentric coordinates. Thus the height of sea surface with respect to centre of mass of earth is measured. This gives the shape of the sea surface. Some of the popular satellite altimeters include Seasat (1978), GEOSAT (1985-88), Jason (2002) and Envisat (2002).

SAQ 1

What is the difference between Oceans and Seas?

Spend 5 min

B. Hypsographic Curve

In simple words, you can understand that hypsographic or hypsometric curve is the representation of different relief features of the lithosphere and hydrosphere with respect to sea level in the form of cumulative height-frequently curve (refer to Fig. 16.2). The relative proportions of elevations and depressions in terms of area and height are perfectly represented in this curve. However, this curve does not represent location of different elevations and

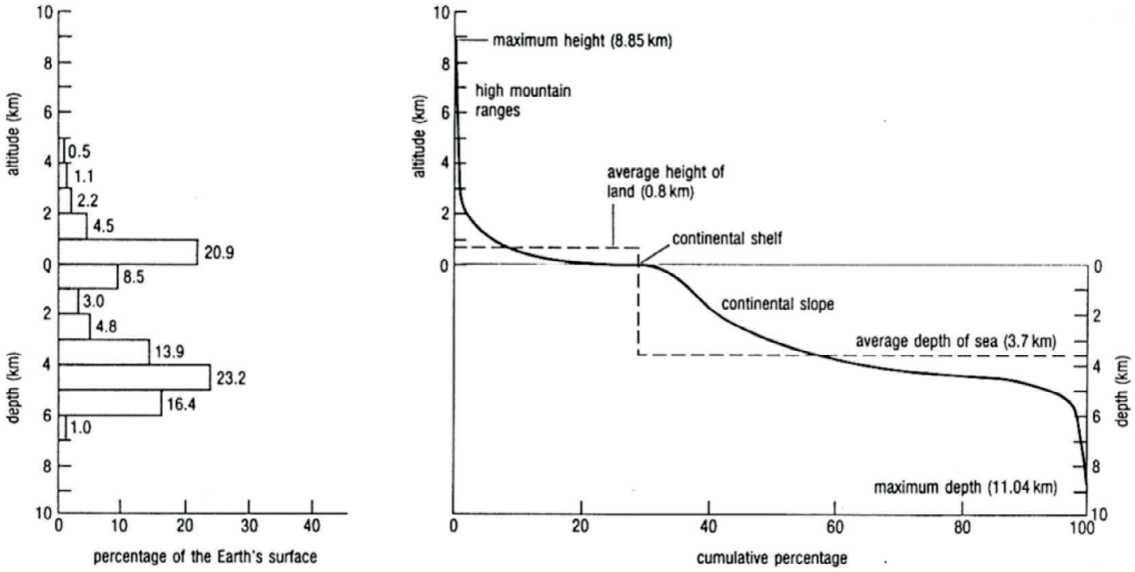

Fig. 16.2: Hypsographic Curve.
(Source: https://commons.wikimedia.org/wiki/File:EarthHypso.png)

depressions. So it cannot be taken as the average profile of earth's land-sea surface. It was first prepared by Kossinna in 1921 and was modified by Sverdrup in the year 1942.

Please refer to Fig. 16.2 to have a better understanding of hypsographic curve.

Have a look at Table 16.1 which gives the distribution of ocean floor of all major oceans at various depth zones in percentage. What do you interpret from the table?

Table 16.1: Distribution of Ocean Floor of the Major Oceans at Various Depth Zones in Percentage (Along With Adjoining Seas)

Depth Interval (m)	Atlantic	Pacific	Indian	All Oceans
0-200	13.3	5.7	4.2	7.6
200-1000	7.1	3.1	3.1	4.3
1000-2000	5.3	3.9	3.4	4.2
2000-3000	8.8	5.2	7.4	6.8
3000-4000	18.5	18.5	24.0	19.6
4000-5000	25.8	35.2	38.1	33.0
5000-6000	20.6	26.6	19.4	23.3
6000-7000	0.6	1.6	0.4	1.1
Above 7000	…	0.2	…	0.1

Now let us study different relief features of the oceans.

16.4 FEATURES OF THE OCEAN FLOOR

One fathom is equal to 6 feet or 1.8288 m. This unit is very often used for measuring depth of water especially oceanic depth and was used mainly in old imperial and US customary systems.

Just as we see the relief features on continental blocks, like mountains, plains plateaus, valleys etc, oceans too have characteristic relief features. Continents form a major lateral boundary to the oceans. The transitional area between the continents and oceans is occupied by features starting from land in order like shore, continental shelf, continental slope and rise. The features of deep sea plain or abyssal plains are mid-oceanic ridges, trenches, island arcs, sea mounts which are supposed to be the result of plate tectonics (refer to Fig. 16.3). Let us study them separately.

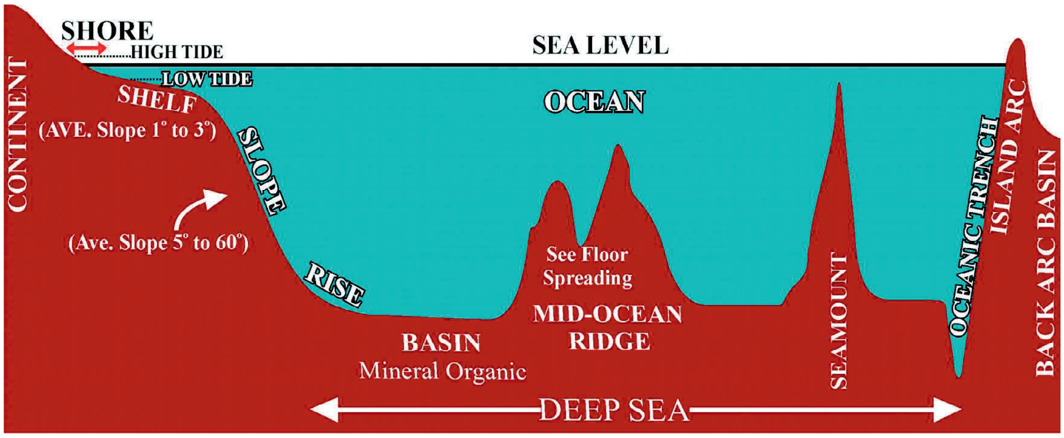

Fig. 16.3: Schematic Section through Ocean Floor Showing Principal Features.

A. Continental Shelf

Continental shelf is the continuation of coastal land or continental margins and slopes gently towards the sea with an average gradient of ***1 in 500*** (1° to 3°or 17 feet per mile). It has an average depth of ***100 fathoms***. Its outer limit is set where the gradient increases to an average of about 1 in 20, which marks the beginning of continental slope area and is referred to as shelf break. Average width of the continental shelves for the entire world is about 65 km (67 km or 42 miles as per Sheppard). However there are some regional variations regarding the width of continental shelves like they are wider along the river mouths while narrow in regions where mountains appear parallel to the coastal area.

The origin of continental shelves is due to various complex processes and different views regarding their origin exists and you should get a brief idea of this. There formation may be due to:

- sediments brought by rivers and sea waves;
- simple faulting along continental margins;
- negative change in sea level (e.g., during glaciation) leading to the formation of extensive continental platforms as a result of glacial erosion or other agents of marine erosion;
- abrasion work of sea waves leading to the formation of extensive wave- cut platforms; and
- submergence of continental lands due to the tilting of lands towards the sea.

B. Continental Slope

The region extending between continental shelf and deep sea plain is known as continental slope. It has a steeper slope compared to continental shelf and ranges between 5° to 60° and has regional variations. In hypsographic curve it falls between 200-2000 m depth (at some places even up to 3000 m) and covers about 8.5% of total area of ocean basins. Important physical features found here are submarine canyons and oceanic trenches. However due to its steep slope, the region is devoid of ocean deposits which accumulates at the bottom of slope, or even if they collect at few places in slope, they collect as very thin deposits.

The lower part of the continental slope where it merges into deep sea plain is referred to as continental rise (refer to Fig. 16.3). It is supposed to be the major depositional zone of the oceans as deposits accumulates here from the steep continental slopes.

C. Submarine Canyons

Submarine Canyons are relatively narrow, deep valleys with vertical side walls and steep slopes resembling the land valleys and are found in continental shelf and slope area. They are usually found either in front of large rivers and may have been carved by them which in course of time got submerged into the sea. Submarine canyons are usually associated with straight coasts rather than indented ones. The slope of the canyons show regional variations, the average slope being 1.7%. Submarine canyons found around the islands have very steep slope generally of the order of 13.8%. They are rarely found on coasts having faulted scarps or oceans studded with many islands. They are found in abundance along the eastern coast of America extending from Canada to Cape Hatteras. There are many theories related to the origin of submarine canyons and its distribution which you will study at higher levels.

D. Deep Sea Plains

Deep sea plains are extensive, flat plains found between continental slope and oceanic abyss. It accounts for 82.7% of the total oceanic area and covers the portion of ocean falling between 2000-6000 m depth. The vast monotony of featureless deep sea plains is broken by the presence of features like ridges, guyots etc.as already mentioned. Earlier it was believed that deep sea plains were completely flat, apart from having the few relief features. However, oceanic expedition of Albatross discovered that deep sea plains of Atlantic and Pacific oceans are highly rugged. However, in case of Indian Ocean, deep sea plains were found to be highly levelled perhaps due to its formation from hard lava extending over hundreds of kilometres here.

E. Mid-Oceanic Ridge

Mid-Oceanic Ridges are found along diverging plate boundaries where plates move away from each other and the gap is filled up by upwelling magma which solidifies to form a new crust and its accretion results in the formation of a ridge like structure. That is why the plate margin is called constructive plate margin because there is addition or accretion of crust in this case. You must have read about different plate margins in Unit 6 of this course, where you learnt about plate tectonics.

Seamounts also affect oceanic circulation like ocean currents and waves and also refract tsunamis

F. Seamounts and Guyots

Sea mounts are undersea mountains formed by volcanic activity that rise hundreds or thousands of feet from the sea floor. They are found near plate boundaries and also at mid-plates. As you know that at mid-oceanic ridges, plates are spreading apart, and magma rises to fill the gaps. Near subduction zones, the denser plate gets subducted and melts, and magma rises buoyantly towards the surface and erupts to form volcanoes and seamouts. Seamounts are widely scattered in the oceans and is easily distinguished from the abyssal plains. Guyots are seamounts that have reached to the surface or sea level. In course of time they have been eroded by waves and their tops have been worn out resulting in a flattened shape. Due to the movement of the ocean floor away from oceanic ridges, the sea floor gradually sinks and the flattened guyots are submerged to become undersea flat-topped peaks. As the plates move across the hotspots, chains of seamounts are formed, for example, Hawaiian Islands, Polynesian Islands etc.

Oceanic deeps are known as ***Tiefe*** in Germany and in France they are known as ***Fosse***.

G. Oceanic Trenches and Deeps

Oceanic trenches are long, narrow and deep depressions of the sea floor, with relatively steep sides. You might know that along the edges of destructive plate margins, one plate which is denser subducts below the other plate and deep trenches are formed along these subduction zones. Deeps are the deepest parts of these trenches ranging approximately from 7,300 m to more than 11,000 m. Most of the oceanic trenches are found along the Circum-Pacific belt like Kurile trench, Tonga trench, Phillipines trench etc. ***Mariana Trench*** is the deepest of all such trenches with its deepest part reaching up to a depth of 11,034 m which is known as the ***Challenger Deep***. Most of these trenches are shaped like an arc of a circle with an island arc on the other side. This is because of the fact that the subducted plate begin to melt on account of high temperatures prevailing at such depths and molten magma from here reaches to the surface through fractures or weaker portions of the crust in the form of volcanoes. These form volcanic islands and are also known as Island Arcs. Examples are Aleutian Arc, Kurile Arc, Japan Arc, Ryukyu Arc, Philippine Arc etc. (Refer to Fig. 16.4 and 16.5 to understand in a better way.

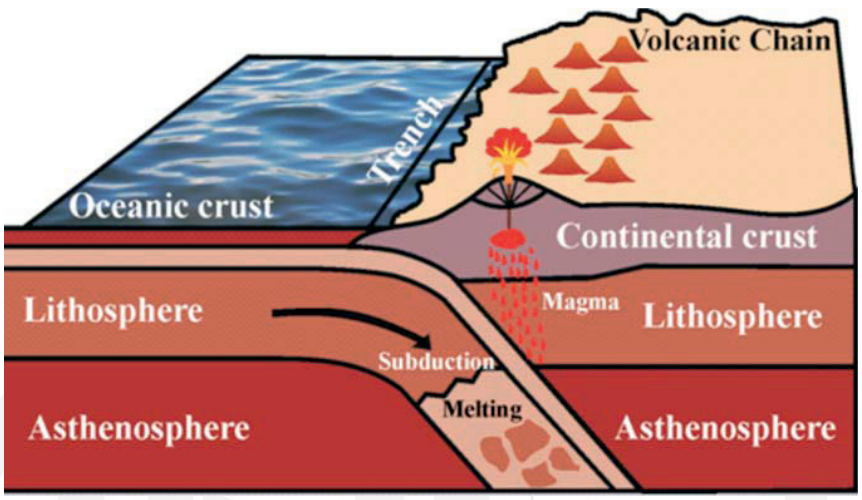

Fig. 16.4: Formation of Oceanic Trenches.

SAQ 2

What is the difference between the following?

a) Sea Mounts and Guyots

b) Trenches and Deeps

c) Continental Rise, Mid-Oceanic Ridges and Mid-Oceanic Rises

Spend 5 mins

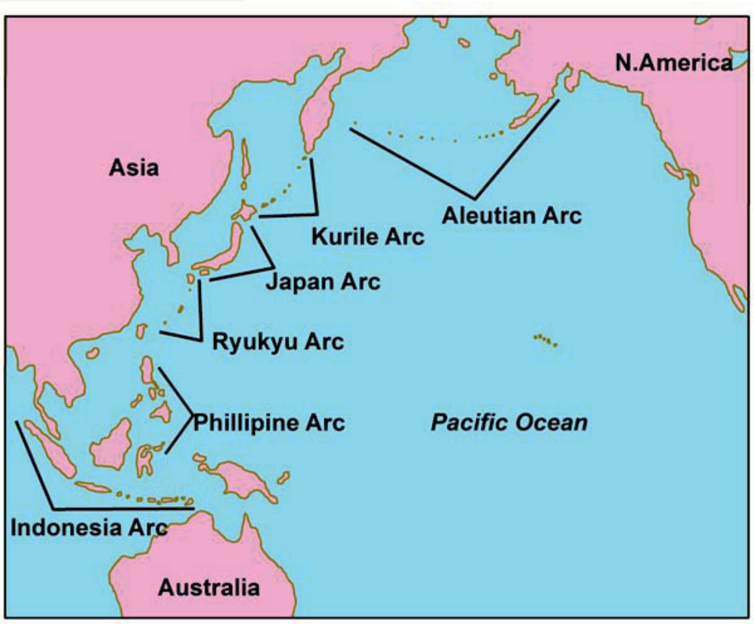

Fig. 16.5: Island Arcs.

In the subsequent sections of this unit you will study in detail about the bottom reliefs of Atlantic, Indian and Pacific Ocean.

16.5 BOTTOM RELIEFS OF ATLANTIC OCEAN

The name Atlantic Ocean is derived from Greek mythology, means the "Sea of Atlas".

The Atlantic Ocean is located between North and South America in the west and Europe and Africa in the east and covers an area of 82 million sq km. It is 1/6th of the geographical area of the globe and half of the area of Pacific Ocean. The S-shape of the ocean suggests that the landmasses on both sides of the ocean once formed a contiguous part. This ocean was formed as a result of plate tectonics due to drifting of North and South Americas to the west. It connects with Arctic Ocean in the north and Southern Ocean in the south and hence it is open both in the northern and southern parts. Atlantic Ocean has several marginal seas like Mediterranean Sea, Weddell Sea, Nordic Sea etc. The east-west extent of the ocean varies considerably. It is much wider at 35°S latitude (5950 km) and narrows down towards equator (2575 km) and widens again in the north about 40°N latitude (4800 km). About 24% of the Atlantic Ocean is less than 915 m deep.

Norwegian Sea, Greenland and Iceland Seas are collectively known as Nordic Sea.

A. Continental Shelf of the Atlantic Ocean

A continental shelf of less than 200 meters depth is found all along the Atlantic coastline. However, its width varies between 2 km to 80 km and at few places it even exceeds 400 km depending on the nature of the coast. Extensive shelves have been found around Newfoundland, Greenland, Iceland and between Bahia Blanca to Antarctica. The shelf is however narrow along coasts where mountains are found in vicinity, for example, along the African coasts between Bay of Biscay and Cape of Good Hope and Brazilian shelves between 5-10° S latitudes. Many marginal seas and islands are found on the continental shelves of Atlantic. Marginal seas include Hudson Bay, Baltic sea, the North Sea, Davis strait, Denmark Strait, Gibraltar Strait, Mediterranean Sea, Caribbean Sea, Gulf of Mexico etc. Important islands found here are Azores, Ascension, Tristan da Cunha, Falkland, Shetland, St. Helena and many more.

Sea mounts are also present in Atlantic Ocean, e.g. ***Pico island*** of Azores (8,229.6m above sea floor and 213.36m above the sea-level) is found here. Several fracture zones like ***Gibbs*** Fracture Zone, ***Atlantic*** Fracture Zone, ***Oceanographic*** Fracture Zone, ***Kane*** Fracture Zone, ***Vema*** Fracture Zone, ***Romancha*** Fracture Zone etc.are found here.

B. Mid Atlantic Ridge of the Atlantic Ocean

The most striking feature of Atlantic is the mid-Atlantic ridge representing the zone of divergent or constructive plate margins and extending from Iceland in the north to Bouvet island in the south. It covers a distance of 14,450 km. It is known as Dolphin Rise in the north and Challenger Rise to the south of equator. It is known as Wyville Thompson Ridge between Iceland and Scotland while it is called Telegraphic Plateau to the south of Greenland and Iceland at about 55° N latitude where the ridge widens. This is because the first telegraphic cables were laid down in this area. The main ridge is further divided into a number of branches running to the east and west of the main ridge. Those branches are supposed to have emerged either due to intra-plates movements or due to geographical extension of continental rise which is due to mud and clay deposits at the bottom of continental slopes.

Let us study some of the important branches of the central ridge of the Atlantic. While doing so, please refer to Fig. 16.6 to see the location of these ridges on the map.

Fig. 16.6: Bottom Reliefs of Atlantic Ocean.

- **Newfoundland Rise:** It emerges from the central ridge to the west of Tele graphic plateau at about 40° N and continues up to Newfoundland.
- **Azores Rise:** It comes out from the main ridge to the south of 40° N and extends upto Azores islands.
- **Sierra Leone Rise:** It emerges near the equator from the central ridge and extends in north-eastern direction.
- **Para Rise:** This also emerges from the equatorial portion of central ridge and continues towards the north-western direction.
- **Guinea Rise:** It emerges from the central ridge at about 10° S latitudes and runs in the north-eastern direction towards the Guinea Coast of Africa.
- **Walvis Ridge:** It emerges from the central ridge at about 40° S latitudes and extends in north-easterly direction and merges with the African continental shelf.
- **Rio Grande Rise:** It also emerges along with Walvis ridge but extends towards South American coast.

C. Basins of the Atlantic Ocean

North American Basin is also called North-Western Atlantic Basin.

The mid-Atlantic ridge divides the Atlantic Ocean into two major basins, that is, East and West Atlantic basins. The vast ocean floor is occupied by ocean basins or deep sea plains. Geographical continuity of such basins is interrupted by ridges and continental rises. Consequently deep sea plains are subdivided. Western Atlantic basin is divided into 4 basins while the eastern Atlantic basin is divided into 8 sub-basins.

Let us discuss the Western Atlantic Basins first.

- **Labrador Basin:** It is located between continental shelf of Greenland and Newfoundland Rise and covers a latitudinal extent of 40° N- 50° N where the depth of ocean is roughly 4000 m.
- **North America Basin:** This is supposed to be the biggest basin of the Atlantic and extends between 12° N to 40° N latitudes. Its depth is approximately 5,200 m.

Spanish Basin is also called North-East Atlantic Basin.

- **Brazilian Basin:** It is confined between equator and 30°S latitude and the east coast of Brazil in the west to Para rise in the east. The depth here is 6000m.
- **Argentina Basin:** This basin is circular in shape and extends from the coast of Argentina up to south Atlantic ridge between 35°- 50° S. The average basin depth is 5000 m and reaches even up to 7000 m on its southern part.

Eastern Atlantic basin is subdivided into 8 sub-basins. Let us get acquainted with them.

- **Spanish Basin:** It extends from 38° N to 50° N latitude and is located between mid-Atlantic ridge and Iberian Peninsula. Its average depth is 5000 m.
- **Canary Basin:** It is found to the west of Canary Islands and is 5000 m deep.

- **Cape Verde Basin:** It is located between mid-Atlantic Ridge and Western African coast and extends from 10° N to 38° N latitude. Average depth of the basin is 6000 m.
- **Guinea Basin:** It is elongated in shape and extends between Guinea ridge and Sierra Leone rise and has an average depth of 6000 m.
- **Angola Basin:** It is located from equator to 30° S latitude and is North of Walvis ridge. It is wider towards the African coast and gets narrow towards south-west. Its average depth is about 5000 m.
- **Cape Basin:** It extends between 28°-41° S to the west of Africa.
- **Agulhas Basin:** It extends between 40°-50° S latitude to the south of Cape of Good Hope.
- **Atlantic Indian Antarctic Basin:** It is a contiguous and irregular east west depression and extends to the north of Antarctic continent along 60° S latitude.

Puerto Rico Deep is the deepest trench of Atlantic Ocean having a depth of 8376 m.

D. Atlantic Deeps

Due to lack of any recent folding activity, Atlantic Ocean has fewer or less prominent deeps. Murray has reported19 deeps in the Atlantic located at depths below 5000 m. You should know the names of some important deeps in the ocean, that is, Nares Deep, Puerto Rico Deep, Romancha Deep etc.

Now let us get familiar with the bottom reliefs of the Indian Ocean.

16.6 BOTTOM RELIEFS OF INDIAN OCEAN

The Indian Ocean is unique amongst the three major oceans of the world as it is blocked on the three sides by continents of Africa, Asia and Australia. It is smaller in area and relatively warm extending only till 25° N latitude, that is, having no high northern latitudes. It is connected to the Pacific Ocean through Indonesian Archipelago. The average depth of the ocean is 4000 m. Some important marginal seas are Mozambique Channel, Arabian Sea, Bay of Bengal, Andaman Sea, Red Sea, Persian Gulf etc. The ocean has a great variety of islands, that is, the large islands of Madagascar and Srilanka and the small ones like Socotra, Zanzibar, Comoro, Andaman and Nicobar islands, Kerguelen , Mauritius and Reunion islands.

Indian Ocean was relatively unexplored for a long time. During the International Indian Ocean Expedition (1962-65), major collection of data was done. During the 1980's and 90's international exploration of Indian Ocean was carried out as a part of major World Ocean Circulation Experiment (WOCE)

One interesting feature about Indian Ocean is that it can be divided into three distinct regions or zones which you should know.

i) The first one is the ***Western zone*** which includes the area between mid-oceanic ridge and the African coast. This region has fewer number of islands like Seychelles, Madagascar etc.and has depth of less than 6000 m.

ii) The second one is the ***Eastern zone*** which is relatively deeper and has narrow continental shelf.

iii) The third zone includes the elevated portion near the mid-oceanic ridge and includes several ***island groups*** and depth of 4000 m or even less.

Now let us study the bottom reliefs of Indian Ocean in detail.

A. Continental Shelf of Indian Ocean

Continental shelf of Indian Ocean is quite varied. Extensive shelves are found along the margins of Arabian Sea and Bay of Bengal (about 640 km wide) and along eastern of coast of Africa around Madagascar. On the other hand continental shelves are narrow (160 km) along the coast of Java and Sumatra and along Australia as well as along the northern coast of Antarctica.

B. Mid Oceanic Ridge of Indian Ocean

Islands like Laccadive, Maldives, Chagos, New Amsterdam, St. Pauls, Kerguelen, Seychelles etc.are situated on the Central ridge of Indian Ocean. Prince Edward Crozet Islands are situated on Southern Madagascar Ridge.

The central ridge of Indian Ocean is about 9000 km long and is not a longitudinal ridge touching the two ends of a meridian because northern part is blocked by continents. However, the ridge has a north-south extent and divides the ocean into two major basins on the either side. Secondly, the ridge is relatively wider and is not so sharply turned into S-shape as in case of Atlantic Ocean. Another interesting feature of the ridge is that, it is divided in the southern part. Mid-Indian Oceanic ridge here too has similar process of origin and has been characterised by branch ridges or off-shoot ridges. You should now get acquainted with them.

The central ridge starts from the continental shelf of Indian subcontinent with an average width of 320 km and is known as ***Laccadive-Chagos Ridge*.** Further south, that is between 0°-30° S, the ridge is known as ***Chagos-St. Paul Ridge***. Between 30° S to 50° S, the ridge further widens to about 1600 km and is called ***Amsterdam-St. Paul Plateau***. South of 50° S, the central ridge divides into two branches. The Western branch is called ***Kerguelen-Gaussberg Ridge*** (aligned from north-east to south-west) and the eastern branch is known as ***Indian-Antarctic Ridge***, which merges with the Antarctic continental shelf.

The central ridge also has several branches spread over the entire Ocean. Let us study them too.

- **Socotra Chagos Ridge:** It originates near 5°S and extends in north-westerly direction upto Gardaful peninsula of North-East Africa.
- **Seychelles Mauritius Ridge:** It is nearly parallel Socotra Chagos Ridge and comes out from the central ridge at about to 18°S latitude near Mauritius Island and as the name suggests, it reaches up to Seychelles making an arc.
- **Madagascar Ridge:** It extends from the southern tip of Madagascar to 40°S latitude.
- **Prince Edward Crozet Ridge:** It comes after Madagascar ridge from 40°S-50°S latitude and here the ridge widens. In fact, it is the widest part of all the ridges in the world. Here the depth is shallow and is only about 1000 m.
- **Cape Rise:** It is a circular ridge situated to the north-west of Prince Edward Crozet Ridge. It reaches a depth of 2000 m.
- **Andaman and Nicobar Ridge:** This ridge extends from the mouth of river

- **Andaman and Nicobar Ridge:** This ridge extends from the mouth of river Irrawaddy to Nicobar Islands in the Bay of Bengal. It runs almost parallel to 90°E longitude and hence it is also called Ninety East Ridge.
- **Carlsberg Ridge:** This ridge divides the Arabian Sea into two portions and it widens towards Chagos Ridge.
- **Murray Ridge:** It is located near 62°E and 22°S and goes towards east.

Some of the ridges can be located in Fig. 16.7 while studying the ridges and basins of Indian Ocean

C. Basins of the Indian Ocean

The central ridge of Indian Ocean divides it into two major basins while other ridges further divide these into various sub-basins. Altogether nine basins are found here of which six basins are on the western side and three basins on eastern side.

a) Western Side

- **Oman Basin:** As the name suggests it is found near the Gulf of Oman where the continental shelf is much wider. The depth here is about 4000 m.
- **Arabian Basin:** It is a circular basin and is located between Laccadive Chagos Ridge and Socotra Chagos Ridge and has an average depth of 2000-4000m.
- **Somali Basin:** It is bordered by Socotra Chagos Ridge in the north, St. Pauls Ridge in the east and by Seychelles ridge in the south. Its depth is greater than 4000 m and Carlsberg ridge separates it from Arabian basin.
- **Mauritius Basin:** This basin extends longitudinally from 10°-15° S latitudes between Madagascar and St Paul's Ridge.
- **Natal Basin:** It is bordered by Madagascar ridge in north and north-east, Prince Edward Crozet Ridge in the east and south-east, African coast in the west and north-west. It has an average depth of 3,600 m.
- **Agulhas Basin:** This basin is in continuation of Agulhas Basin of Atlantic Ocean and reaches a depth of 6000 m.

b) Eastern side

- **Andaman Basin:** It is a shallow basin of about 2000 m depth along the eastern coast of Andaman.
- **Cocos Keeling Basin:** This is the very massive basin and extends from 10° N to 50° S latitude with a depth reaching up to 4000 m. Only along the trenches its depth exceeds 4000 m.
- **Atlantic-Indian-Antarctic Basin:** This is an eastward extension of Atlantic-Antarctic basin of the Atlantic Ocean and is found to the south of Prince Edward Crozet Ridge.
- **Eastern-Indian-Antarctic Basin:** This basin is found south of 50°S latitude and is surrounded by the central ridge on all sides in the form of a curve.

Fig. 16.7 Bottom Reliefs of Indian Ocean.

D. Deeps of the Indian Ocean

There is only one major deep in the Indian Ocean, that is, Sunda deep or trench which is about 7450 m deep and is situated along the fold mountains south of Java island of Indonesia.

After studying the bottom reliefs of Atlantic and Indian Ocean, now let us study about the relief features of the world's largest body of water, that is, Pacific Ocean.

> The East-West extent of Pacific Ocean is 16,000 km while its North-South extent is 14,480 km and covers one-third area of the globe.

16.7 BOTTOM RELIEFS OF PACIFIC OCEAN

The Pacific Ocean is the largest of the three major oceans of the world. It is connected to Indian Ocean through Indonesian Archipelago and is connected to Arctic Ocean through a very shallow Bering Strait. It is also connected to Atlantic waters through the Strait of Magellan. It extends from Asian coast in the west to American coast in east and from Bering Strait in the north to Antarctica in the south. Along the western side, the Ocean has numerous marginal seas like the Sea of Japan, Okhotsk Sea, Celebes Sea, Coral Sea, East China Sea, Yellow Sea etc. Average depth of the ocean is about 5000 m. The Pacific Ocean is the freshest of the three major oceans.

> Solomons, New Hebrides and Fizi are islands of Melanesia while Marshalls, Carolines, Gilbert and Ellice are Micronesian island groups. Examples of Polynesian islands are Society, Cook, Tuamoto.

Apart from marginal seas, the Ocean is studded with thousands of islands which can be broadly grouped into three categories described below:

(1) **Large Continental islands:** They have geomorphological resemblance to the mainland and have been separated by the mainland due to some tectonic activity, e.g., Aleutian islands, British Columbian islands, Chilean islands etc.

(2) **Island Arcs and Festoons:** These have arisen due to plate movements along destructive plate margins where the lighter plate is squeezed into fold mountains with volcanic intrusions. Such island examples are Kuriles, Japanese Archipelago, Philippines and Indonesian islands

(3) **Small Scattered Islands:** These islands are further subdivided into small groups of islands on the basis of races e.g., **Melanesia**, **Micronesia and Polynesia.** Some island groups are also formed of **volcanic material** like Hawai, while there are also examples of **coral islands** like Ellice, Fizi, Faunafuti etc.

Pacific Ocean has been divided into Northern, Central, South-west and South-eastern zones by Johnstone. ***Northern zone*** is the region touching Arctic Ocean and has abundance of trenches thus making its average depth very high. The ***Central zone*** has abundance of islands and sea mounts. ***South-Western zone*** has numerous marginal seas along with islands. Marginal seas are missing in the ***South-Eastern zone***, where there is prominence of a ridge that is East Pacific Ridge which you would study in this section while studying ridges of the Pacific Ocean

> Pacific Ocean has some east- west fracture zones. Their names in the order from north to south are ***Mendocino*** Fracture Zone at 40°N, ***Murray*** Fracture Zone at 30°N, ***Molokai*** Fracture Zone 25°N, ***Clarion*** Fracture Zone 20°N, ***Clipperton*** Fracture Zone 10°N, ***Eastern Island Fracture*** Zone 30°S, ***Challenger Fracture*** Zone 40°S etc.

A. Continental Shelf of Pacific Ocean

The continental shelf is quite extensive in the western Pacific Ocean along Japanese and Indonesian Archipelago and along the eastern coast of Australia. Here the width of continental shelf reaches even about 1600 km and the average depth is only about 1000 m. The island groups found along this part of the ocean encloses several marginal seas like Bering Sea, Sea of Japan, Yellow Sea etc. as already discussed. Contrary to this, the eastern Pacific (along the western coast of Americas) is characterised by very narrow continental shelf where the average width is only about 80 km and at few places it is even 45 km wide.

B. Ridges of the Pacific Ocean

One unique feature of Pacific Ocean is that, it is devoid of any central ridge. Instead, there are few ridges scattered along the ocean, of which the most prominent one is the ***East Pacific Ridge.*** This ridge extends from California in the west to New Zealand in the east and is also called ***Albatross Plateau.*** Another important ridge is the ***Cocos Ridge*** which is supposed to be the projection of Albatross Plateau in the north-eastern direction. Cocos ridge gets divided near 2°S latitude into two parts, the eastern part being known as ***San Felix-Juan Fernandes ridge*** which is parallel to the coast of Chile. The western part of Cocos ridge is known as ***South Eastern Pacific Plateau*** which broadens in the form of plateau between 20°-40° S latitudes. Another significant ridge of the Pacific Ocean is the ***Hawaiian Ridge*** between 35°-17°N latitudes. This ridge has locational importance as it hosts the islands of Hawaii and Honolulu. Another ridge known as ***Marcus Necker Rise*** exists in vicinity. The depth of water in these two ridges is between 2000-3000 m.

There are only a few ridges of importance in the western Pacific along the western coast of New Zealand and south of Tasmania known as ***Chatham Rise*** and ***South Tasmania Ridge*** respectively. ***Lord Howe Rise*** and ***Norfolk Island Ridge*** exists between Australia and Fiji basin. Tasmania Ridge further merges into Indian-Antarctic ridge. ***Eauripik-New Guinea Rise*** and ***Caroline Soloman Ridge*** are located near New Guinea and Solomon islands as their name suggests.

C. Basins of the Pacific Ocean

Due to the absence of central ridge there is no division of basins into eastern and western parts in the Pacific Ocean as in the other two oceans discussed here. Instead the basins or depressions are found all over the ocean. Some of the major basins of the Pacific are important for you to know. They are Philippine Basin, Fiji Basin, Aleutian Basin, West Caroline Basin and East Caroline Basin, East-Australian and South-Australian Basin, South-Western Pacific Basin and South-Eastern Pacific Basin and Pacific Antarctic basin. The depth of all these basins range between 4000 m to 6000 m. West Caroline Basin and East Caroline Basins are separated by Eauripik -New Guinea Rise. Pacific Antarctic basin extends to the south-west of Chile. All these basins are named as per their location.

D. Pacific Deeps

There are a number of deeps or trenches found in the Pacific Ocean of which 32 are more significant ones. The deepest oceanic trench of the world that is, ***Mariana trench*** is found here. The deepest point of this trench is called the ***Challenger deep***. In fact five deepest trenches of the world are located in this

Fig. 16.8: Bottom reliefs of Pacific Ocean.

ocean. Other important trenches of Pacific are Tonga trench, Philippine trench, Kurile-Kamchatka trench, Kermadec trench etc. Please refer to Table 16.2 to know about some of the important trenches in the Pacific Ocean and their depths.

TABLE 16.2: Major Trenches of the Pacific Ocean

Trenches	Depth in meters	Trenches	Depth in meters
Mariana	11,022	Middle American	6,562
Tonga	10,882	Ryukyu	6,395
Kurile	10,498	Bonin	-
Philippine	10,475	Yap Palau	-
Japan	10,375	Soloman	-
Kermadec	10,047	New Britain	-
Peru-Chile	8,025	New Hebbrides	-

16.8 SUMMARY

The major oceans of the world are Pacific Ocean, Atlantic Ocean, Indian Ocean, Arctic Ocean and Antarctic Ocean or the Southern Ocean. Currently echo-sounders and satellite altimeters are in use for making maps of the ocean floor. Hypsographic or hypsometric curve is the representation of different relief features of the lithosphere and hydrosphere with respect to sea level in the form of a cumulative height-frequently curve. The transitional area between the continents and oceans is occupied by features starting from land in order like shore, continental shelf, continental slope and rise. The features of deep sea plain or abyssal plains are mid-oceanic ridges, trenches, island arcs, sea mounts, etc.which are supposed to be the result of plate tectonics. All the relief features for Atlantic, Pacific and Indian oceans have been discussed in detail in this unit.

16.9 TERMINAL QUESTIONS

1. Explain with suitable figure the mid-oceanic ridges and basins of Atlantic Ocean.
2. Give an account of bottom reliefs of Pacific Ocean.
3. What are the different relief features of the oceans. Enhance your answer with suitable figures.

16.10 ANSWERS

Self-Assessment Questions

1. The term sea is sometimes used interchangeably with the oceans. However seas are smaller in area compared to the oceans and are partly or fully enclosed by land areas.

2. a) Sea mounts are isolated or comparatively isolated elevations rising 1000 m or more from the sea floor and with small summit area while guyots are seamounts that have reached to the surface or sea level and their tops have become flattened due to erosion by waves. Both are formed by volcanic activity under the sea.

   b) Oceanic trenches are long, narrow, and deep depressions of the sea floor, with relatively steep sides while deeps are the deepest parts of these trenches.

   c) Continental rise is the lower part of the continental slope where it merges into deep sea plain and it becomes a major depositional zone of the oceans as deposits accumulates here from the steep continental slopes. Mid-Oceanic Ridges are found along diverging plate boundaries where the gap is filled up by upwelling magma which solidifies to form a new crust or ridge like structure. Mid-Oceanic Rises also forms in the similar way and represents underwater mountain chains like ridges but their slopes are gentler and they lack a central rift valley found in ridges

Terminal Questions

1. First define mid-oceanic ridges and give the salient features of mid-oceanic ridges of Atlantic Ocean and after giving a rough sketch explain all the branch ridges. Same to do with basins. Refer to Sec. 16.5 B and 16.5 C of the unit.
2. This would cover all islands, shelf, ridges, basins and deeps of Pacific Ocean as given in Sec. 16.7 of the unit.
3. Your answer should contain all the relief features like continental shelf, slope, mid-oceanic ridges, deep sea plains, oceanic deeps etc. Define all the features and give a short description with figure as given in Sec. 16.4 of the unit.

16.11 REFERENCES/FURTHER READING

Sharma, R. C. and Vatal, M. (1993). Oceanography for Geographers, Chaitanya Publishing House, Allahabad.

Singh, S. (2003). *Physical Geography*, Prayag Pustak Bhawan, Allahabad.

Talley, L.D. Pickard, G.L. Emery, W.J. Swift, J. H. (2011). *Descriptive Physical Oceanography*: *An Introduction*, Elsevier, USA.

Murray, J. and Hjort, J. (1912). *Depths of the Oceans*, Macmillan and Co Ltd., London.

Stewart, R.H. (2008). *An Introduction to Physical Oceanography*, Texas A& M University (http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html)

UNIT 17

DISTRIBUTION OF TEMPERATURE AND SALINITY IN THE OCEANS

Structure

17.1 INTRODUCTION

In the previous unit, you have studied about ocean floor and its relief features. So now you can differentiate between continental shelf and slope, mid-oceanic ridges and trenches. You can also describe the bottom reliefs of all major oceans of the world. In this unit, you will get a detailed discussion about the physical properties of sea water especially temperature and salinity. Temperature of the oceans is discussed in Sec. 17.2 and distribution of temperature of the oceans forms the subject matter of study in Sec. 17.3. You will study both horizontal and vertical distribution of temperature of the oceans. Sea water is the mixture of 96.5 per cent pure water and 3.5 per cent of materials like salts and dissolved gases, organic substances and undissolved particles. Although the physical property of fresh water is usually determined by temperature and pressure variables, but due to dissolve salts in sea water, its case is a bit different. So, a third variable, that this, salinity is also added in its case which is introduced in Sec. 17.4. Distribution of salinity in oceans, again both horizontal and vertical distribution is explained in Sec. 17.5. Temperature and salinity together determine the density of sea water. A preliminary knowledge of all these physical properties of sea water is important in the study of oceanography which would be discussed in this unit.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define the properties of sea water;
- discuss the process related to heating of oceans;
- distinguish between horizontal and vertical distribution of temperature of the oceans;
- describe salinity of the oceans; and
- explain horizontal, vertical and regional distribution of oceanic salinity.

Let us now start our study with the temperature of the oceans.

17.2 TEMPERATURE OF THE OCEANS

You have already studied about atmospheric temperature and know about its horizontal and vertical variations. The temperature of oceans is also of significance because it supports all life-forms, their types and distribution at various depths in the oceans. Temperature also controls the movement of large volumes of ocean water. So measuring of oceanic temperature both surface and sub-surface forms a challenging task for oceanographers. There are three types of thermometers used for measuring temperatures of ocean water. ***Standard Type Thermometers*** are used for measuring the surface temperature while ***Reversing Thermometers and Thermographs*** are used for measuring sub-surface temperatures of the oceans. The accuracy of these thermometers is of the order of 0.01°C. Sampling of water is required for measuring sub-surface temperature and is done through devices like Petterson-Nansen water bottle and Ekman bottle.

You know that sun is the major source of temperature of the ocean water. It heats up the ocean through the process of insolation in which shortwave electromagnetic radiation emanated from the sun is received at the ocean surface. Heating of ocean water also occurs due to a number of processes apart from insolation and you should be familiar with them too. Heat is also received from the interior of earth near the ocean bottom which is distributed through convection currents to the upper layers of ocean. Heating of ocean is also due to chemical processes, convection of sensible heat from atmosphere, condensation of water vapour and transformation of kinetic energy (due to vertical and horizontal movements of ocean water) into heat energy. Compression of sea water at a greater depth also generates some heat but it is very insignificant.

Now let us get familiar with the daily and annual temperature range of the oceans.

A. Daily Temperature Range

The difference between the maximum and minimum temperatures of the oceans of a day is known as daily range of temperature. In other words, you can also say that it is a balance between incoming solar radiation and outgoing terrestrial radiation. This range of temperature at sea surface is very insignificant, that is, hardly 1°C. Maximum temperature is reached at about 2 p.m. and minimum temperature at about 5 a.m. It depends on a number of factors like sky conditions, stability or instability of air, nature of sea surface etc. Let us get acquainted with them in brief.

- When the sky is clear, greater amount of insolation would reach the sea surface during the day and at the same time greater amount of heat is also lost to the atmosphere at night. This would result in greater heating and cooling of the sea surface and hence higher diurnal range of temperature.
- On the other hand, if the sky is cloudy, lesser amount of insolation would reach the earth and so the outgoing radiation would also be lesser. This would result in lower range of temperature.
- If the atmosphere is calm and stable, there would be lesser mixing of air and hence the diurnal range of temperature would be high.
- Regarding sea conditions, stratification of sea water also affects the diurnal range of temperature. The high density water found below the sea surface at greater depths reduces conduction of heat and hence the range of temperature becomes low.

Schott and Wegemann recorded the diurnal range of temperature in tropical ocean waters which you can see in Table 17.1. You can interpret from the table that range of temperature increases in case of clear sky compared to overcast sky. Also range of temperature is higher during calm atmospheric conditions compared to conditions when it is breezy.

Table 17.1: Range of Diurnal Variation of Sea Surface Temperature in the Tropics

	Wind and Cloudiness	Temperature Range, ^{0}C		
		Average	Maximum	Minimum
1.	Moderate to Fresh Breeze			
(a)	Sky Overcast	0.39	0.6	0.0
(b)	Sky Clear	0.71	1.1	0.3
2.	Calm or Very Light Breeze			
(a)	Sky Overcast	0.93	1.4	0.6
(b)	Sky Clear	1.59	1.9	1.2

Source: Vattal, M. and Sharma, R.C. (1993)

B. Annual Temperature Range

The difference between the annual highest and lowest temperatures of the ocean waters is called annual temperature range. As sea water is heated and cooled very slowly, so the annual temperature range is not very high. It is of the order of 10°F. Maximum and minimum temperatures are recorded in August and February respectively in northern hemisphere and vice-versa in southern hemisphere. The annual range of temperature of the oceans depends on annual variation of incoming solar radiation, nature of ocean currents and prevailing winds. Smaller landlocked seas have higher annual temperature range. Mediterranean Sea records an annual temperature range of 20°F, while that for Baltic Sea is 40°F.

SAQ 1

Spend 5 mins

a) What are the factors affecting the daily range of temperature?

b) Why August and February isotherms are taken for the study of horizontal distribution of temperature of the oceans, while for the same study in case of land areas, July and January isotherms are taken?

17.3 DISTRIBUTION OF TEMPERATURE IN THE OCEANS

You all know the fact that ocean is a three-dimensional body. So the depths of oceans have to be taken into consideration regarding the distribution of temperature in the oceans. Hence, the distribution of temperature of oceans is studied in terms of both horizontal and vertical distribution. Let us discuss them separately.

17.3.1 Horizontal Distribution of Temperature

The average temperature of surface water of the ocean is 26.7°C. Several factors like amount of insolation received, ocean currents, prevailing winds, etc affect the distribution of temperature of the oceans. Let us get familiar with them.

Factors Affecting the Horizontal Distribution of Temperature of the Oceans

> The average annual temperature of all the oceans is 17.2° C. The average annual temperatures for oceans in northern and southern hemispheres are 19.4° C and 16.1° C respectively.

i) The amount of insolation decreases from equator towards the poles. Hence the temperature of surface water decreases from equator towards poles.

ii) The location and shape of the sea also controls the temperature conditions and its distribution. Oceans in northern hemisphere receive more heat due to their contact with huge land masses compared to the oceans located in southern hemisphere where there is dominance of water with greater uniformity. Even the isotherms in southern hemisphere follow a more regular path compared to those in northern hemisphere.

iii) Prevailing winds and ocean currents also affect the temperature of the oceans. Onshore winds pile up warm water near the coast while offshore winds drive warm surface water away from the coast resulting into upwelling of cold water from below. Hence the temperature rises and falls accordingly along the coasts having onshore and offshore winds respectively. Trade winds blowing along the western coastal regions are offshore and hence reduce the temperature along the adjoining coasts while trade winds blowing along the eastern coastal areas are onshore and hence they raise the temperature of those coastal regions. Similar is the case with ocean currents where warm ocean currents raise the temperature of the adjoining coastal area and cold ocean currents reduces the temperature of coastal area visited by them.

iv) Local variations in weather conditions like storms, cyclones etc also affect the ocean temperature.

v) Submarine ridges too affect the temperature of oceans as there is lesser mixing of water on the opposite side of the ridges.

As already mentioned, there is a gradual decrease of temperature from equator towards the poles. However, this rate of decrease of temperature is generally of the order of 0.5°F per latitude. Still, the highest value of surface temperature is found to the north of equator as thermal equator is most probably located to the north of equator. This is because the maximum amount of radiation is received a little north of equator. Also, the oceans in northern hemisphere record a slightly higher temperature than the oceans in southern hemisphere. This is again due to dominance of land areas over oceans in the nouthern hemisphere compared to the southern hemisphere. Now let us study the horizontal distribution of temperature in major oceans of the world.

A. Horizontal Distribution of Temperature in Atlantic Ocean

In Atlantic Ocean the decrease of temperature with increasing latitudes is relatively low because of the presence of warm ocean currents that is Gulfstream which transports plenty of warm water to higher latitudes. Here the highest temperature is recorded at 5° North latitude and lowest temperature is recorded between 80° North and North Pole and between 75° South and South Pole. So the decrease of temperature is more pronounced in the southern hemisphere.

B. Horizontal Distribution of Temperature in Pacific Ocean

The average annual temperature of Pacific Ocean is slightly higher than the Atlantic Ocean (16.91°C) and the Indian Ocean (17°C). The lowest and highest temperature of 3.3° C and 32.2° C is recorded near New Scotland and in the western Pacific Oceans respectively. In the North Pacific ocean, the isotherms are almost parallel to lines of latitudes (see Fig. 17.1 and Fig. 17.2) except at few places where due to effect of warm Kuroshio current the isotherms tend to make minor loops and become more intensified due to cold Oyashio current. Even in the southern hemisphere the isotherms in the Pacific ocean runs parallely except at places where they deviate slightly due to effect of cold

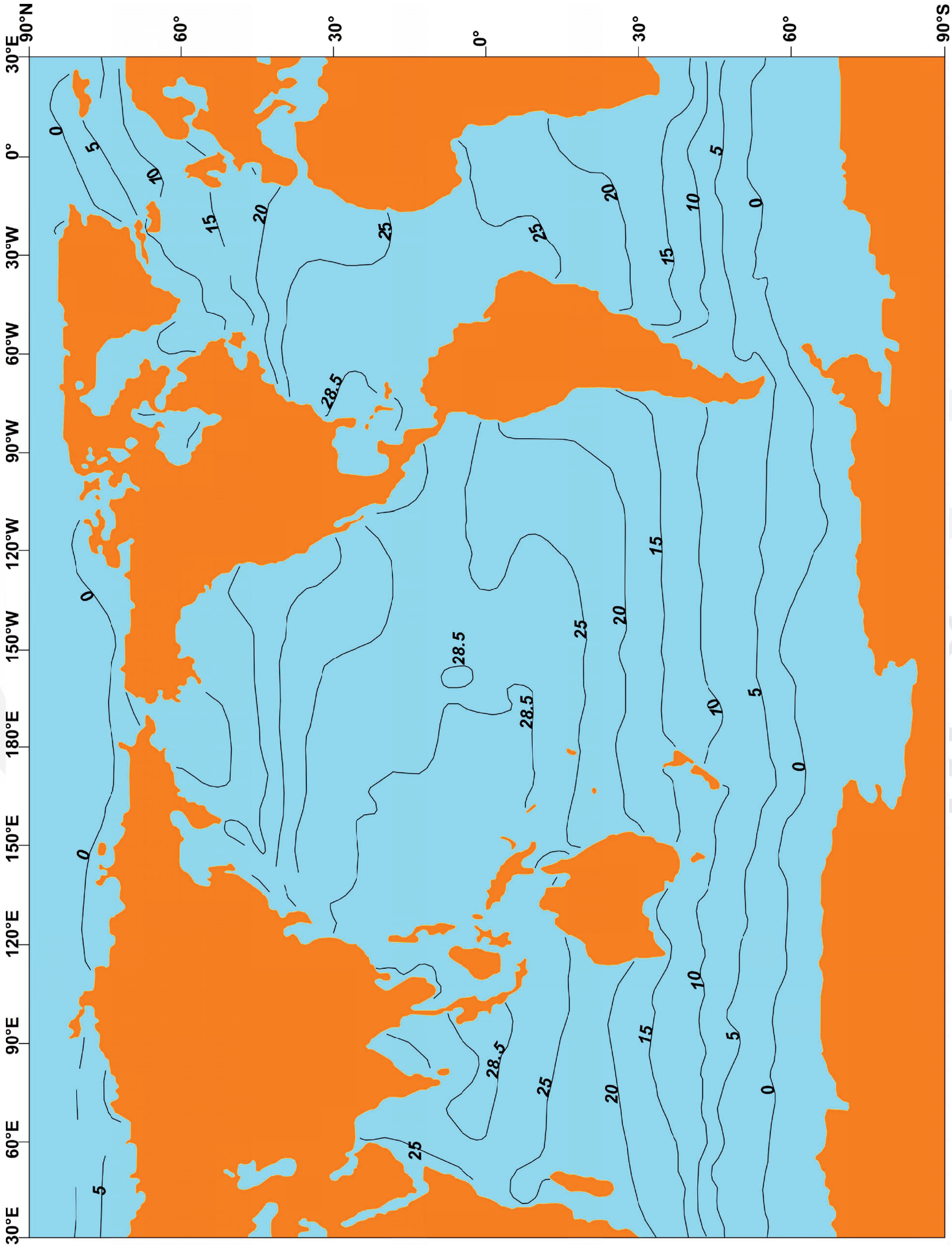

Fig. 17.1: Horizontal Distribution of Temperatures of the Oceans in the Month of August (°C).

(Redrawn from Source: http://www.nodc.noaa.gov/cgi-bin/OC5/WOA09F/woa09f.pl)

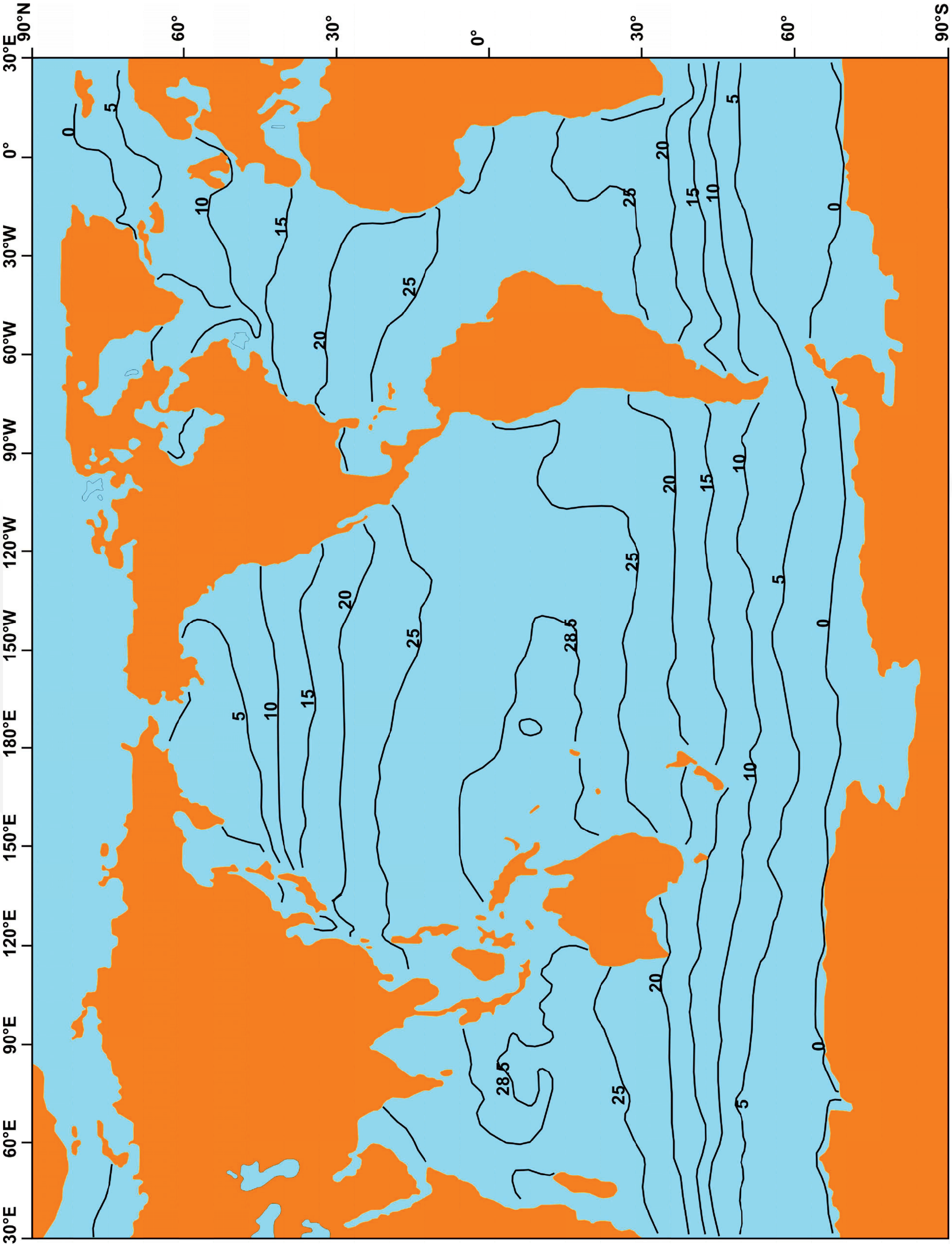

Fig. 17.2: Horizontal Distribution of Temperatures of the Oceans in the Month of February (°C).

(Redrawn from Source: http://www.nodc.noaa.gov/cgi-bin/OC5/WOA09F/woa09f.pl)

currents. So we see that ocean currents play a major role in the distribution of temperature in oceans.

(C) Horizontal Distribution of Temperature in Indian Ocean

The highest temperature of Indian Ocean is 28°C and is recorded in the Arabian Sea as well as Bay of Bengal. However some of the enclosed seas of the Ocean record still higher temperatures. For example, Red Sea records 30°C and Persian Gulf attains a maximum of 33°C. These enclosed seas show higher temperatures compared to the open seas during the summers and lesser temperature than open seas during the winters. In the southern part, the isotherms become almost parallel to the lines of latitudes.

If the temperature of surface water of oceans is higher than the air above it, there is transfer of heat from the ocean surface to the atmosphere. This difference in the ocean surface temperature and the air above it sometimes results in fogs over seas and oceans. This also happens when warm air passes over cool sea surface.

Table 17.2: Surface Water Temperature of the Oceans in Northern Hemisphere (in °C)

Latiudes	Pacific Ocean	Atlantic Ocean	Indian Ocean
70-60	-	5.60	-
60-50	5.74	8.66	-
50-40	9.94	13.16	-
40-30	18.62	20.40	-
30-20	23.38	24.16	26.14
20-10	26.42	25.81	27.23
10-0	27.20	26.66	27.88

Source: Sverdrup, H.U. (1942)

Table 17.3: Surface Water Temperature of the Oceans in Southern Hemisphere (in °C)

Latiudes	Pacific Ocean	Atlantic Ocean	Indian Ocean
0-10	26.01	25.18	27.14
10-20	25.11	23.16	25.85
20-30	21.53	21.20	22.53
30-40	16.98	16.90	17.00
40-50	11.16	8.68	8.67
50-60	5.00	1.76	1.63
60-70	1.30	-1.30	-1.50

Source: Sverdrup, H.U. (1942)

Now let us study about the vertical distribution of temperature of the Oceans.

17.3.2 Vertical Distribution of Temperature

As the Ocean surface receives direct insolation from the sun, so the temperature of surface water is higher than the temperature of water at increasing depths from the ocean-surface. However this rate of decrease of temperature of the oceans is not uniform. There are some basic characteristics of vertical distribution of temperature of the oceans which you should get acquainted with.

i) It has been observed in subsequent oceanic expeditions that sun's rays can penetrate effectively only up to a depth of 20 m from the surface and they are hardly noticeable beyond a depth of 200 m. So vertically oceans can be divided into two zones, that is, Photic or Euphotic zone (from sea surface to 200 m depth) and Aphotic zone (from 200 m to the bottom surface).

ii) The rate of decrease of temperature with depth can be seen efficiently up to 2000 m. Thereafter this rate almost becomes stagnant. You can understand this from the table given below which compiles the data collected from Challenger Expedition of Murray.

Table 17.4: Temperature of Oceans at Varying Depths

Depth in fathoms	Temperature (O° F)	Depth (fathoms)	Temperature (O° F)
100	60.7	1,000	36.5
200	50.1	1,500	35.3
500	40.1	2,200	35.2

Source: Vattal, M. and Sharma, R.C. (1993)

(iii) The rate of decrease of temperature with increasing depths also varies from equator to the poles. It is more rapid near equator than at poles. This may be also due to the fact that with increasing latitudes, surface temperature of the oceans also decreases and the bottom temperature remains almost the same. You will understand this with the help of the Table 17.5.

iv) Upwelling of water from below also affects the rate of vertical decrease of temperature of the ocean. You should be knowing that onshore winds piles up the water near the coast and also record relatively high temperature at the surface contrary to the offshore winds which remove water away from the coast resulting into upwelling of water from below the ocean surface which is at the relatively lower temperature. Hence the rate of decrease of temperature of the oceans vertically down is high in case of onshore winds compared to offshore winds.

v) Enclosed seas record exceptionally high temperatures even at greater depths compared to the open oceans and seas. You must be familiar with

Table 17.5: Latitudinal and Vertical Decrease of Temperature of the Ocean

Latitudinal Zones	0-10°	10-20°	20-30°	30-40°	40-50°	50-60°	60-70°
Surface Temperature (0 °C)	26.83	25.60	23.90	20.30	12.94	8.94	4.26
Depth in metres	0	100	200	400	800	1000	
Temperature (0° C)	26.86	18.57	10.71	7.70	5.13	4.81	

Source: Jenkins (1921)

the names of enclosed seas like Red Sea, Mediterranean Sea etc. At a depth of 1829 m Mediterranean Sea records a temperature of 24.4°C. However at the same depth Indian Ocean records a much lower temperature of about 1.1°C. Another interesting fact about enclosed seas is that they show a reversal of temperature conditions at higher latitudes. This means that the surface temperatures of these enclosed seas is relatively lower than the temperature of sub-surface water which is denser and more saline and has higher temperature.

vi) There exists a submarine barrier between open oceans and enclosed seas which prevents the mixing of water on both sides. Henceforth the temperature conditions vary in both the cases.

In this unit, so far, you have had a brief discussion about the temperature conditions prevailing in the oceans and its distribution both horizontally and vertically. In the coming section, let us now get familiar with salinity of the oceans which is an important physical property of the oceans.

17.4 SALINITY IN OCEANS

Have you ever wondered why ocean water is salty? From where, this salt comes? The answer to this is that, the salt actually comes from land. We all know that rainwater, river water and streams wash up the land surface and contain dissolved salts. Compared to the oceans, they however contain much lesser amount of salt and hence the characteristic salty feature is not present in fresh waters. So we can conclude that oceans contain unacceptable amount of dissolved salts and chemicals which bring out there inherent salty feature which is also called salinity. It is too salty for human consumption compared to the river water or other freshwater systems.

Salinity is the ratio between the weight of dissolved material and the weight of a sample of sea water. Hence it is defined as the total amount of solid materials in grams (g) contained in 1 kg of sea water and is expressed as parts per thousand (‰). As for example salinity of 20 ‰ expresses the fact that 20 g of salt is present in 1000 g of sea water.

Every year river deposits millions of tonnes of dissolved solids into the oceans. The primeval seas must have been only slightly salty. Ever since rains descended upon the earth, rivers have been formed and they have been transporting dissolved minerals into the sea. So salinity of the oceans is gradually increasing every year. According to the estimates of Joly, Murray and

Clark, the total salt in oceans and seas is about 50 billion tonnes, 5 billion tonnes and 2.7 billion tonnes respectively. Joly states that if all the salts of the oceans are dried up and spread over the globe it will form a layer of about 45.72 m. Evaporation of sea water as well as formation of sea ice also increases the salinity. However this is compensated by continuous influx of freshwater from the rivers, rain, snowfall, melting of ice etc.

Salinity is one of the most important physical properties of the ocean as it affects other properties like density, temperature, pressure, waves, current etc. The freezing point of sea water also depends on salinity. Greater the amount of salinity, lower is the freezing point. Also higher the salinity, lower would be the evaporation rate. Salinity also increases the temperature of the oceans by scattering the solar radiation received at the ocean surface. It also increases the density of ocean water.

Spend 5 mins

SAQ 2

Why is boiling point of saline water higher than freshwater?

17.4.1 Sea Water Composition

Dittmar during his Challenger expedition confirmed the presence of 47 different salts in the sea. Amongst the various methods for calculating the amount of salts in the sea, the titration method and the hydrometer method has been the most popular ones. Average salinity of different oceans and seas varies between 33 %o to 37 %o. Sodium Chloride or NaCl is the most important constituent of sea water. Other important elements are silicon, nitrogen, phosphorus etc. which form respective salts like silicates, nitrates, phosphates etc. These salts act as nutrients and support various life forms in the oceans directly or indirectly. Refer to Table 17.6, to get an idea of percentage of different salts present in sea water.

Table 17.6: Percentage of Different Salts in the Sea water

Sl.No.	Salts	Amout ‰	Percentage
1.	Sodium Chloride	27.213	77.8
2.	Magnesium Chloride	3.807	10.9
3.	Magnesium Sulphate	1.658	4.7
4.	Calcium Sulphate	1.260	3.6
5.	Potassium Sulphate	0.863	2.5
6.	Calcium Carbonate	0.123	0.3
7.	Magnesium Bromide	0.076	0.2
		35.000	100.0

17.4.2 Factors Affecting Salinity

There are several factors which control the amount and distribution of salinity in the oceans. You should get familiar to them. They are listed below.

- Evaporation
- Precipitation
- Influx of Freshwater from Rivers
- Atmospheric Pressure and Wind Direction
- Oceanic Circulation or Movement of Ocean Water

According to Wust, the average evaporation from all oceans is about 93 cm per year.

Now let us discuss them.

A. Evaporation

There exists a positive correlation between the rate of evaporation and amount of salinity. Greater is the rate of evaporation, higher is the salinity of oceans and vice versa. Due to evaporation, water content is lost and salts are left behind, which in turn increases salinity. Both equator and tropics have higher rate of evaporation but still tropical regions have higher salinity due to comparatively low humidity ratio near the tropics. Equatorial regions have high relative humidity which reduces the salinity of these regions compared to tropical regions.

B. Precipitation

There exists a negative correlation between precipitation and salinity of the oceans. Higher the precipitation, lower is the salinity and vice versa. Consequently the equatorial regions as discussed above receive high rainfall throughout the year have lower salinity compared to the regions of lower rainfall in subtropical high-pressure belts. Similarly oceans in polar and sub-polar regions also have low salinity because of high amount of precipitation in the form of snow which further adds freshwater into the oceans thereby reducing salinity.

C. Influx of Freshwater from Rivers

Influx of freshwater from voluminous rivers like Ganges, Congo, Amazon etc reduces salinity at places where these rivers enter the sea, that is, at their mouth. Though rivers bring huge amount of salts into the ocean but they also pour immense volumes of water due to which the salinity is decreased to a great extent at the mouth of these voluminous rivers. This effect is more pronounced in enclosed seas like Black Sea, Baltic Sea etc. compared to the open oceans. However in enclosed seas itself, if the rate of evaporation is higher than the rate of influx of fresh river water, then salinity would be high. An example of this can be seen in Mediterranean Sea which records are high salinity of about 40 %o.

D. Atmospheric Pressure and Wind Direction

Atmospheric pressure and prevailing winds also have a great impact on the salinity of the oceans. Subtropical high-pressure belts experiencing anticyclonic conditions with stable air and high-temperature has higher salinity. Prevailing winds also pile-up water from one part of the ocean to the other thereby changing and redistributing salinity. For example trade winds pile up saline water from eastern margins of oceans to the western margins thereby reducing the salinity in the eastern part and increasing it in the western part.

E. Oceanic Circulation or Movement of Ocean Water

Oceanic circulation in the form of ocean currents and tides play a major role in the distribution of salinity by thorough mixing of sea water. For example equatorial warm current brings saline water from western coastal areas of the continents to eastern coastal areas thereby reducing salinity in the former and increasing it in the latter part. The vertical movement of ocean water lifts up water from the bottom to the surface parts thereby mixing water and redistributing salinity.

There are also periodical variations of salinity related to different seasons which affects the rate of precipitation and evaporation and in-turn salinity. There are also diurnal variations of salinity which is hardly noticeable.

17.5 DISTRIBUTION OF SALINITY IN THE OCEANS

Till now you have got familiar with the terms like salinity and factors influencing oceanic salinity. Now, it is equally important for you to study the distribution of salinity in oceans worldwide which is subject to spatial and temporal variations. Let us discuss both horizontal and vertical variants of salinity.

17.5.1 Horizontal Distribution of Salinity

Horizontal distribution of salinity can be studied both in terms of latitudinal distribution as well as regional distribution considering major oceans as separate regions as well as some enclosed seas which can be treated as separate entities where salinity conditions are unique and worth studying.

a) Latitudinal Distribution

Latitudes show a decreasing trend in salinity from equator to the poles. Equatorial regions have high temperature throughout the year but high salinity is not found in the equatorial zone. This is because of the excessive rains which overtakes the rate of evaporation in this zone. Higher salinity is in fact recorded in the tropical zones having high temperature coupled with high evaporation which exceeds precipitation. The salt left behind attributes to high salinity in the oceans of this zone. The highest salinity in the northern hemisphere is recorded between 20-40° N latitude which accounts to about 36 %o. In the southern hemisphere maximum salinity is recorded between 10-30 °N latitude. Salinity again has a decreasing trend beyond these latitudes in both hemispheres. Thereafter, in Polar regions salinity further decreases due to abundance of freshwater in the oceans which results from the melting of snow. On an average salinity of the oceans of northern hemisphere has been found to be 34 %o and that of the southern hemisphere is 35 %o. This is due to the fact that southern hemisphere has lesser land mass and more of oceans compared to the northern hemisphere. Due to less land areas, less amount of freshwater is brought from the rivers in the southern hemisphere.

You can understand this from Table 17.7 which itself expresses the salinity trends of oceans for different latitudinal zones.

Table 17.7: Distribution of Salinity in Different Latitudinal Zones

Latitudinal Zones	Salinity (‰)
70-50°N	30-31
50-40°N	33-34
40-15°N	35-36
15°N- 10°S	34.5-35
10 -30°S	35-36
30-50°S	34-35
50-70°S	33-34

Source: Johnstone, J.(1928), An Introduction to Oceanography

Isohalines are the imaginary lines on the map of oceans connecting all points of equal salinity.

b) Regional Distribution

Regional distribution of salinity is expressed in the form of Isohalines drawn on a map. Isohalines are imaginary lines drawn on maps joining places of equal salinity. We can study the regional distribution of salinity considering individual oceans separately or we can form a few ranges of salinity and group different oceans coming within that range. Let us study the salinity of some major oceans like Atlantic Ocean, Indian Ocean and Pacific Ocean.

Atlantic Ocean

Average salinity of Atlantic Ocean is about 36.67 %o. The highest salinity is not recorded at the equatorial latitudes but about 15° N of it where salinity becomes 36%o. In the southern hemisphere at similar latitudes a little higher salinity is recorded which is about 37.77 %o. Salinity in Atlantic Ocean is also affected by the presence of ocean currents like warm Gulfstream which transports saline water from the western margin of Atlantic Ocean and increases the salinity along its eastern margin. This is why greater salinity of about 35%o is recorded along the eastern margin even up to 70°N latitudes along north-west Europe. Similarly Labrador cold current reduces the salinity along the western margins of North Atlantic Ocean. Trade winds also lowers salinity along the western coast or Guinea Coast of Africa by transporting warm saline water to the western margins of Atlantic Ocean due to which there is upwelling of cold water along the Guinea Coast from below the ocean surface. However Atlantic Ocean in the southern hemisphere shows more parallel isohalines due to regularity of ocean masses over land masses in the southern hemisphere. Refer to Fig. 17.3 to learn better.

The mouth of rivers records very low salinity due to influx of freshwater into the ocean. For example mouth of St. Lawrence records 31%o, that of Amazon records 15%o, along Congo river mouth it is 34%o and along river Niger it is 20%o.

Inland seas and lakes have excessively high salinity due to high evaporation and absence of any outlet. Lake Van in Turkey for example has a very high salinity of about 330%o and that of Dead Sea is to 240%o and Great Salt Lake in America has a salinity of 220%o.

In enclosed or semi-enclosed seas salinity is high or low due to the conditions prevailing there. For example in North Sea salinity is increased due to saline water brought by North Atlantic drift while in Baltic sea, it is reduced due to influx of fresh river water. Similarly Mediterranean Sea experiences high salinity due to greater rate of evaporation and salinity is increased in Gulf of Mexico due to saline water brought by North equatorial current.

Indian Ocean

Indian Ocean shows more complex salinity conditions due to the presence of Indian subcontinent and monsoons. You can see from the Fig. 17.3 that 35 %o isohalines divide the ocean into eastern and western parts. The eastern part of Indian Ocean has comparatively low salinity especially towards Bay of Bengal due to influx of enormous volumes of freshwater by giant rivers like Ganga, Mahanadi, Godavari, Krishna etc. However western part has relatively high salinity. Arabian Sea records higher salinity due to less influx of freshwater from the rivers and arid conditions prevailing there. Similarly in southern Indian Ocean maximum salinity is found along the western coast of Australia due to arid conditions prevailing there.

Partially enclosed seas like Red Sea records are high salinity of about 36.5%o along Babel-Mandeb and 41%o along Gulf of Suez. Persian Gulf records a salinity of 37%o at its head and 40%o at its interior parts.

Pacific Ocean

Salinity conditions in the Pacific Ocean is quite varied due to its vastness and its unique shape. Between 15°-20° N latitudes salinity recorded is about 35%o. In the southern hemisphere along the same latitudes it is a bit higher than 36%o. From Fig. 17.3 you can see that in the north salinity decreases along the Okhotsk Sea, where it becomes 31%o because of the cold Oyashio current which brings fresh water from the melting of snow from the Bering Strait. Low salinity is also found along the California coast due to upwelling of cold water from below the ocean surface and the transfer of warm water by ocean currents and prevailing winds. The river mouths are again characterised by low salinity for example, along the mouths of Hwang Ho (30%o), Yangtzekiang (23%o) etc low salinity is recorded. In southern Pacific Ocean, high salinity zone is found at 20° S and 120° W longitude as you can see in this in Fig. 17.3.

17.5.2 Vertical Distribution of Salinity

Several studies have been conducted regarding vertical distribution of salinity of the oceans. The data collected however suggests that there is no regular trend of increase or decrease of oceanic salinity with depth. The oceanographers have found out some specific characteristics related to the vertical distribution of salinity of the oceans which is discussed below:

i) Salinity increases with depth in high latitudes due to the presence of dense water at the bottom.

(ii) In mid-latitudes salinity increases with increasing depth up to 200 fathoms and thereafter it starts declining.

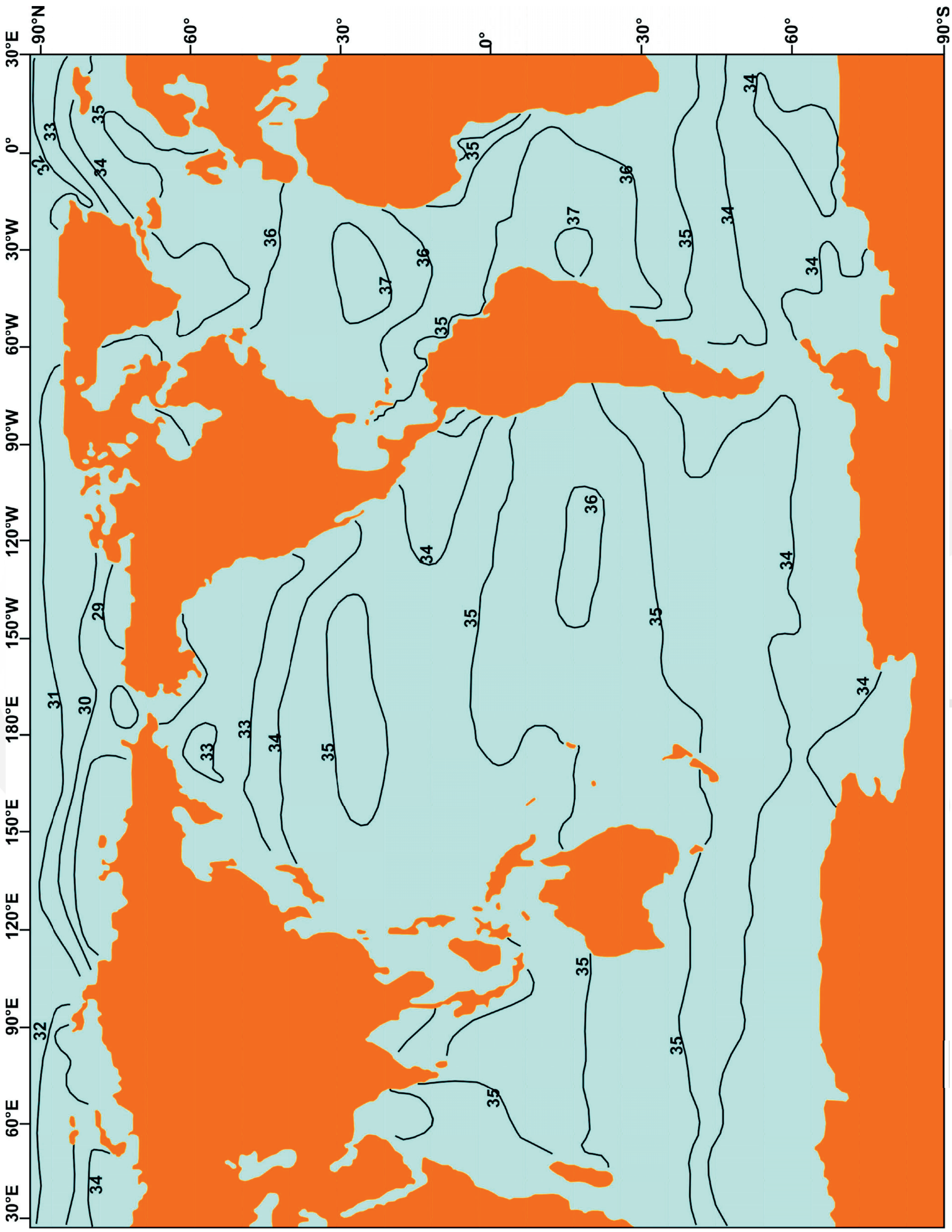

Fig. 17.3: Horizontal Distribution of Salinity of the Oceans.
(Redrawn from Source: http://www.nodc.noaa.gov/cgi-bin/OC5/WOA09F/woa09f.pl)

(iii) Equatorial regions as you know experience plenty of rains. So these regions are characterised by low salinity at the surface of ocean which increases just below the ocean surface and again starts decreasing towards the bottom of the ocean.

17.6 SUMMARY

Temperature and pressure variables and salinity are important physical properties of oceans. Sea water is a mixture of 96.5 per cent water and 3.5 per cent of materials like salts and dissolved gases. Salinity is defined as the total amount of solid materials in grams contained in 1 kg of sea water and is expressed as parts per thousand (%o). Sea water has 77.8 per cent sodium chloride and 10.9 per cent magnesium chloride and other salts like calcium sulphate, potassium sulphate, calcium carbonate etc. Various factors like evaporation, precipitation, influx of freshwater, atmospheric pressure, wind direction, oceanic circulation etc affect salinity of oceans. Average salinity of different oceans varies between 33%o to 37 %o.

The difference between maximum and minimum temperatures of the oceans of a day is known as daily range of temperature while the difference between annual highest and lowest temperatures of the ocean waters is called annual temperature range. Average temperature of surface water of oceans is 26.7°C. Several factors like insolation, location of sea, prevailing winds, ocean currents etc play a major role in the horizontal distribution of temperature of the oceans. Photic or Euphotic zone is from sea surface to 200 m depth, beyond which sun's rays is hardly noticeable and that is called Aphotic zone.

17.7 TERMINAL QUESTIONS

1. Discuss the factors affecting horizontal distribution of temperature of the oceans.
2. Discuss the vertical distribution of temperature of oceans in general.
3. Discuss the factors affecting salinity of the oceans. How inland seas and lakes have high salinity?

17.8 ANSWERS

Self-Assessment Questions

1. a) The factors affecting the daily temperature range of oceans are sky conditions, stability or instability of air, sea conditions etc. Clear sky enables greater amount of insolation to reach the oceans compared to cloudy sky. Instability of air leads to greater amount of mixing of air in the atmosphere and hence reduces the daily temperature range. Sea waves and currents also piles up some warm water from one place to another thus affecting the temperature range of the oceans.

   b) In case of land areas, July and January are considered to be the hottest and coldest months of northern hemisphere while coldest and warmest month of southern hemisphere. So July and January isotherms are used for studying horizontal distribution of temperature of land areas of the world. In case of oceans, maximum and minimum temperatures are slightly delayed as water takes more time to get heated or cooled. So August and February are taken to be the hottest and coolest months for studying horizontal distribution of temperature of the oceans in northern hemisphere and coolest and warmest months for the oceans of southern hemisphere.

2. Saline water contains dissolved salts mainly sodium chloride (NaCl). When some salt is added to water, it disrupts the hydrogen bonding and another type of bonding which is even stronger is formed. Na^+ ions from salt and O^- ions from water align themselves. The same thing occurs with Cl^- ions which align themselves with the positive ends of water molecules (H^+). So, saline water needs higher temperature or higher boiling point compared to freshwater to get evaporated from the surface.

Terminal Questions

1. Discuss all the factors affecting the horizontal distribution of temperature of oceans in very brief as given in Sub-sec. 17.3.1.
2. Refer to Sub-sec. 17.3.2 and describe the trends of vertical distribution of temperature of oceans. Also explain photic and aphotic zones
3. First list and then explain all factors affecting the salinity of oceans as given in Sub-sec. 17.4.2. In the next part explain why inland seas and lakes have high salinity as given in Sub-sec. 17.5.1 (b).

17.9 REFERENCES/FURTHER READING

Sharma, R. C. and Vatal, M. (1993), *Oceanography for Geographers*. Chaitanya Publishing House, Allahabad.

Singh, S. (2003), *Physical Geography*. Prayag Pustak Bhawan, Allahabad.

Sverdrup, H.U. (1942), *Oceanography for Meteorologists*, Prentice Hall Inc., New York.

Johnstone, J. (1928), *An Introduction to Oceanography*, University press of Liverpool, London.

Jenkins, J.T. (1921), *A Textbook of Oceanography*, Constable, London.

http://www.nodc.noaa.gov/cgi-bin/OC5/WOA09F/woa09f.pl

http://www.nodc.noaa.gov/cgi-bin/OC5/WOA09F/woa09f.pl

http://www.nodc.noaa.gov/cgi-bin/OC5/WOA09F/woa09f.pl

Stewart, R.H. (2008), *Introduction to Physical Oceanography*,

http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html

Talley, D. Pickard, G.L. Emery, W.J. Swift, J.H. (2011), *Descriptive Physical Oceanography*, Elsevier Ltd., CA, USA.

UNIT 18

TIDES AND CURRENTS

Structure

18.1 INTRODUCTION

In the previous units of this block, you have had a brief introduction about hydrosphere and oceans in particular, its bottom reliefs and features like temperature and salinity of oceans. In this unit, you will get introduced to the movements in oceanic waters, which play a significant role in maintaining equilibrium in earth's system. So, various oceanic circulations like waves, periodic rise and fall of ocean water (tides) and horizontal movement of ocean water (ocean currents) etc have been introduced in Sec. 18.2. The next section, that is, Sec. 18.3 deals with tides in detail, its origin and its types. Ocean currents have been discussed in Sec. 18.4. Here you will get acquainted with factors that lead to ocean currents and its general pattern and direction. A basic knowledge about the effect of these movements, have been highlighted in Sec. 18.5. It is important to understand the movements of oceanic circulations both scientifically and strategically for continuous monitoring of sea water at different levels and intervals.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define movements of ocean waters;
- describe different types of tides and currents;
- explain forces producing tides and factors behind ocean currents;
- visualise variation in tides and movement of ocean currents in different oceans; and
- recognise some useful measures to harness the potential of tides and currents.

18.2 OCEANIC CIRCULATIONS

Have you ever gazed carefully at movements of water in the oceans? Continuous motion of water at a large-scale and fluctuations along the coastlines are a common sight of all oceanic waters. Wind speed and direction, temperature, salinity level, disturbances underneath the sea, gravitational effect of sun and moon - all affect movements of ocean water. Waves of different heights, tides and currents are the most important phenomena that influence the hydrosphere. Now you will get a brief overview of basics of wave, followed by tides and currents.

A. Waves

Waves represent undulations of sea surface having crest (highest point) and trough (lowest point) in succession without actual movement of water. Thus waves transmit energy not water across the ocean. Each wave is characterised by ***wave height*** which is the distance from the highest point on the crest to lowest point on trough; ***amplitude*** which is half of wave height; ***wavelength*** which is the distance between successive crests or troughs; and ***wave period*** representing time required to complete one cycle of wavelength. Refer to Fig. 18.1(a) to understand better. Water particles rotate in circular orbit beneath each wavelength with diameter equal to wave height. Waves are mostly caused by wind. Pinnet's (1992) classification of waves based on their period is useful for understanding of basic characteristics of physical oceanography. Wave periods can range from less than one second for capillary waves generated by local winds to the order of tens of minutes for tsunamis (earthquake waves) and hours in case of tides (refer to Fig.18.1b). A natural standing wave in a basin or harbour is called seiche whereas internal submarine sea wave progresses energy along different densities.

B. Tides

Have you ever watched the sea-shore carefully for daily rise and fall of sea at regular intervals and time of moon and sun crossing that meridian? If yes, then difference between tides and other waves can be distinguished easily. Tides are rise and fall of sea water or waves with regular period produced by gravitational forces of sun and moon. You will get a greater understanding of the tidal phenomena in this unit. Tides are important amongst different oceanic

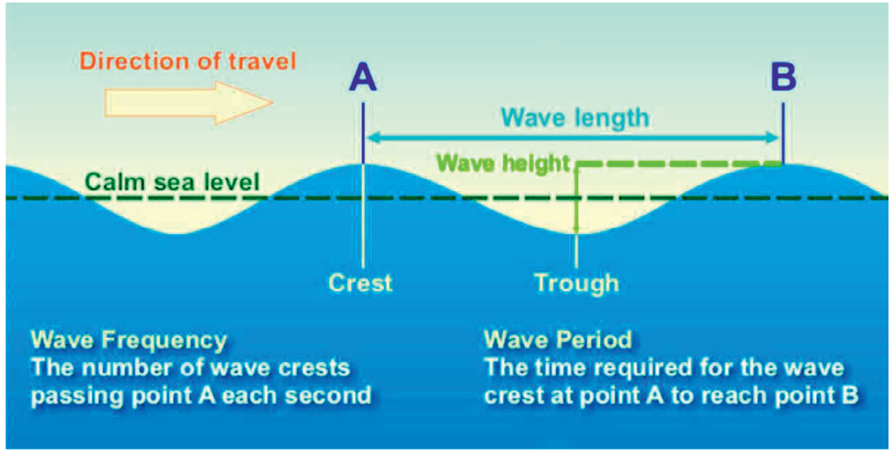

Fig.18.1(a): Components of Sea Waves.
(Source: https://commons.wikimedia.org/wiki/File:Water_Wave_diagram.jpg

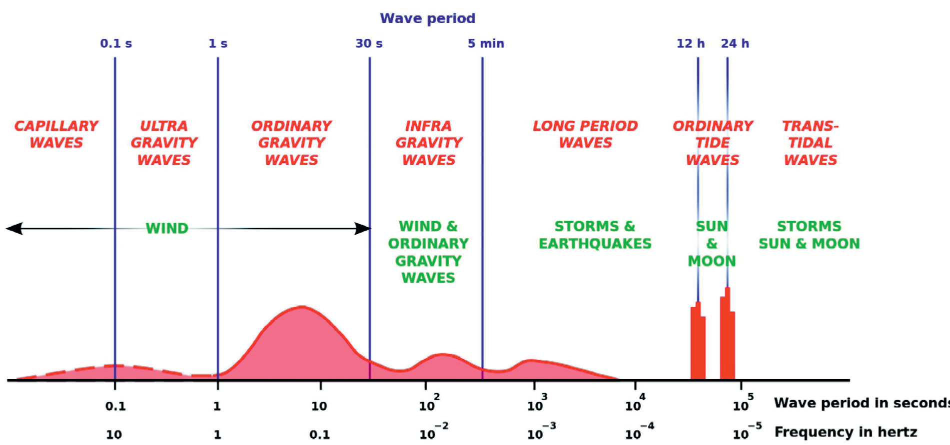

Fig.18.1(b): Different types of Waves.
(Source: https://en.wikimedia.org/wiki/File:Munk_ICCE_1950Fig1.svg)

circulations because tidal currents affect the whole water mass of oceans, that is, from surface to bottom.

C. Currents

Ocean currents are a horizontal movement of a mass of oceanic water in a definite direction. Currents are important because they are able to drive oceanic waters to thousands of kilometres. Energy is transferred through mixing and transportation of waters of different temperatures and densities. Often, currents are wind induced. Rotation of earth further deflects them. Directional changes take place in each ocean in accordance with coastal and bottom topography. The resultant current flows under the influence of several factors which you will study later in this unit.

Spend 5 mins

SAQ 1

What is the difference between tides and ocean currents?

18.3 TIDES

In this section we would discuss about the origin of tides, different types of tides and theories related to the origin of tides. Tides are waves with regular periodicity undergoing rhythmic rise and fall of water under the impact of varying gravitational forces of moon and sun. The rise of sea water leads to high water level and is called high tide water whereas a fall in sea water results in low water level and is called low tide water. Tidal range is the difference between high tide and succeeding low tide. It varies and accordingly macrotidal, mesotidal, and microtidal coasts have been mentioned by Pinnet (1992). Macrotidal coasts have a tidal range of more than 10m, while Mesotidal varies between 2-10m and microtidal has a tidal range less than 2m. Effect of earth's rotation, revolution, declination of its axis and moon's revolution around the earth, all produces a lot of variations in tidal range.

Sun's tidal pull on the earth is less than half (about 46%) of the moon's tidals pull.

18.3.1 Origin of Tides

Tides are produced by gravitational forces of attraction between earth and sun or between earth and moon. But the relative effect of moon is more as compared to sun due to lesser distance of moon from earth in spite of its smaller mass. As the larger component of earth's surface is water, so the effect of gravitational pull is observed more on oceans in the form of tidal bulge on the side facing these celestial bodies.

You must have studied at earlier levels that the gravitational force of attraction between two bodies is directly proportional to the product of their masses and inversely proportional to the square of distance between them. So the surface of earth facing the moon experiences maximum gravitational force of attraction of moon compared to the centre of earth. Besides, the side exactly opposite to the surface of earth facing moon experiences minimum gravitational force of moon. So, the oceanic water facing the moon is attracted and pulled towards the moon and high tide occurs.

Another tidal bulge takes place on the opposite side of earth due to centrifugal force (reactionary force of centripetal or gravitational force) that operates outwards from earth's centre equally in all directions. Refer to Fig. 18.2 to understand better.

The distance between earth, sun and moon varies in different seasons as the common centre of mass of earth and moon revolves around sun in an elliptical plane. The plane of earth's equator is inclined at an angle of 23.5° to the plane of the ellipse and the plane of moon's orbit round the earth is inclined at an angle of 5° to the plane of the ellipse. Thus position of earth, sun and moon along with their declinations produce significant effect on tidal range.

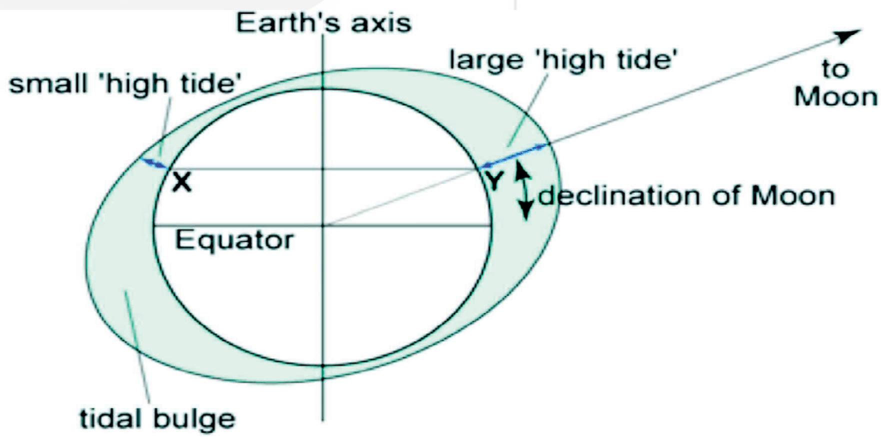

Fig. 18.2: Tidal Bulge. (Redrawn from *Source*: **http://www.oc.nps.edu/nom/day1/tidal_bulge.gif)**

So every place experiences two high tides in a day. One during the time it faces the moon and the other one after 12 hours when it is exactly opposite to the side facing the moon. However it takes 12 hours 25 minutes to receive the second high tide. This time lag of 25 minutes is due to the combined effect of earth's rotation and moon's revolution round the earth. Let us understand this with the help of Fig. 18.3.

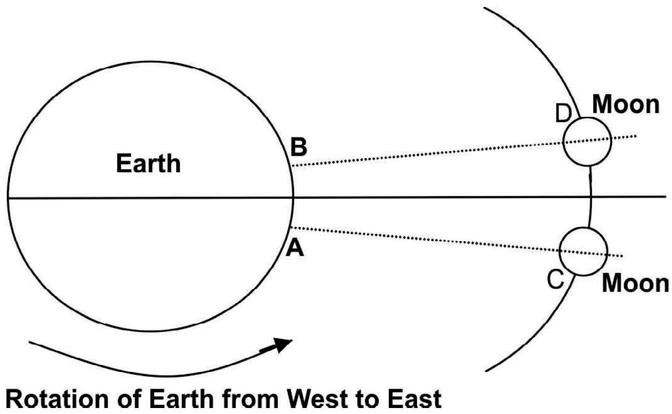

Fig. 18.3: Time of Tides.

Suppose a place 'A' experiences high tide at 2 p.m. Then after 24 hours it should come back again under the moon. However, by this time moons also travels 'CD' distance in its course of revolution around the earth. So the place 'A' has to travel 'AB' distance to come exactly under moon and this takes an additional 50 minutes. So it takes 24 hours 50 minutes for a place 'A' to come again under the moon. But this place 'A' receives second high tide when it reaches the opposite side in 12 hours 25 minutes. So it will receive second high tide at 2.25 a.m. and another at 2.50 p.m. and so on. Let us now study about different types of tides.

18.3.2 Types of Tides

Effects of rotation, revolution and declination of earth, sun and moon produce short-term and long-term variations in tidal forces. Let us now get acquainted with these variations and resultant tides.

A. Daily Variation

B. Fortnightly Variation

C. Monthly Variation

D. Yearly Variation

E. Long-Term Variation

Synodic month is of 29.5 days during the time when moon completes its northward and southward position with respect to equator. Spring tides occur twice every month when the moon's declination reaches maximum to the north (at Tropic of Cancer) and to the south (at Tropic of Capricorn)

(A) Daily Variation

Based on the tidal frequency in a day, three types of tides have been observed in different parts of world as the earth rotates. You can see this in Fig. 18.4.

Diurnal Tides: Tides occurring at an interval of 24 hours 50 minutes are called diurnal tides. One high tide and one low tide take place with a daily periodicity of 24 hr 50 minutes in high latitudes. Refer to Fig. 18.4(a).

Semi-Diurnal Tides: Tides occurring at an interval of 12 hours 25 minutes are called semi-diurnal tides. Two high and two low tides occur after 12 hr 25 minutes and they are found in low latitude equatorial zone (see Fig. 18.4(b)).

Mixed Tides: They are most frequent type of tides especially in mid-latitude regions where high and low tides alternate with unequal wave height and period. (see Fig. 18.4(c)).

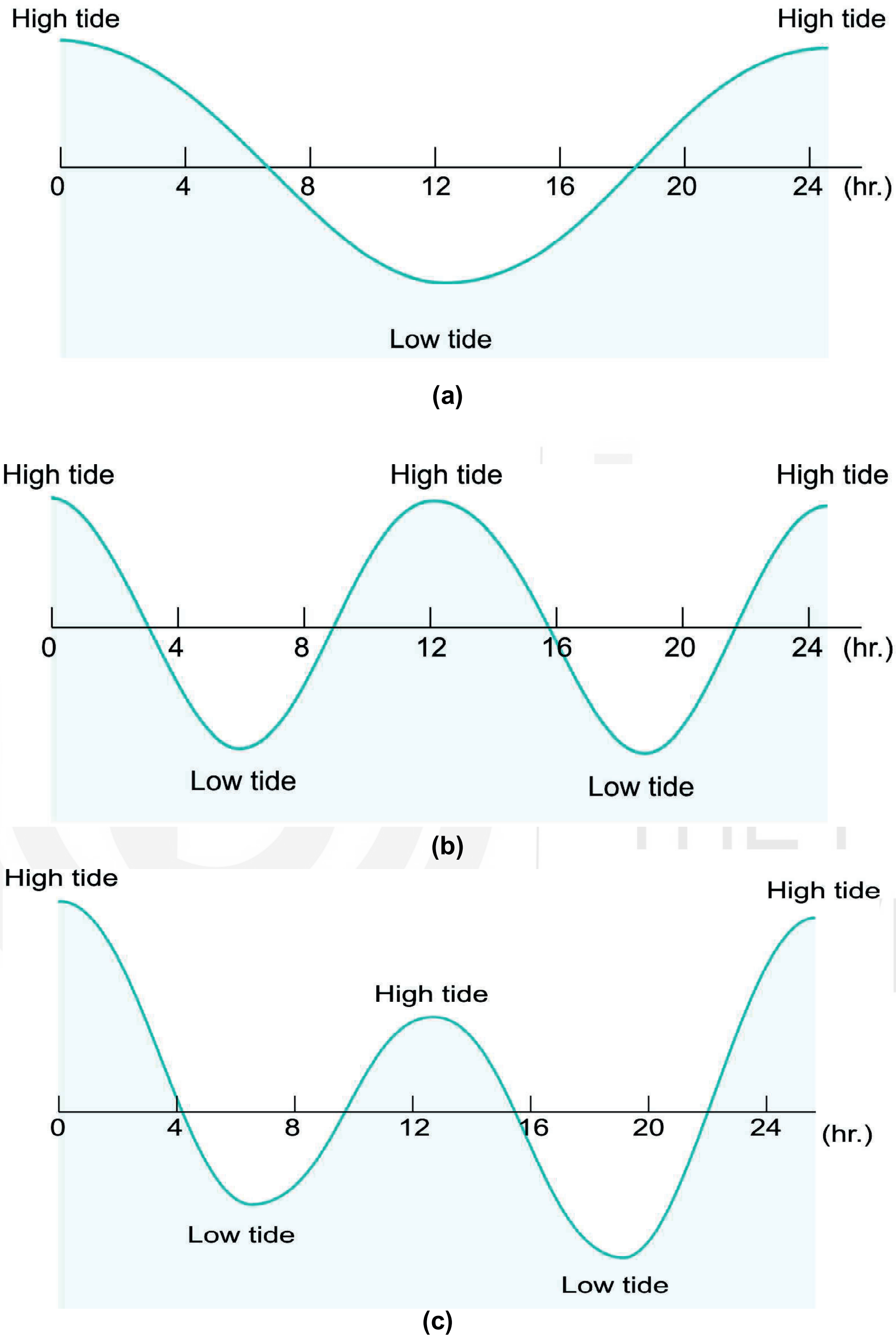

Fig. 18.4: Daily Variation (a) Diurnal Tide (b) Semi-Diurnal Tide (c) Mixed Tide
(Redraw from Source: http://oceanmotion.org/images/background/tides/7-9.gif)

(B) Fortnightly Variation

As Moon completes one cycle around earth in 29.5 days, the position of earth changes with respect to different phases of moon (Refer to Fig. 18.5). Thus moon's tidal force varies in the following manner in a month.

Spring Tides*: ** Earth, sun and moon align themselves along a line twice in a month on a new moon and a full moon day. So, the combined gravitational force of sun and moon produce higher tides almost 20 per cent higher than the normal tides. This position of sun, moon and earth in a straight line is called ***syzygy. When sun and moon are in one side of earth (that is in solar eclipse position), the position is called ***conjuction***. However when earth is between sun and moon, the position is called ***opposition***. During both conjuction and opposition positions, the resultant tides are spring tides.

Neap Tides*: ** When the moon reaches in the first and third quarter of its cycle, its position becomes perpendicular to sun. This alignment of sun, earth and moon is called ***Quadrature. In this case, the tidal bulge is lower on both sides facing sun and moon as the gravitational forces of sun and moon work against each other. This too happens twice in a month, that is, during the first and the third quarter of lunar phase.

Syzygy is the position of sun, moon and earth in the same straight line. It happens during the time of full moon and new moon.

Quadrature is a position when earth, sun and moon are at right angles. It happens during the first and third quarter of lunar phase.

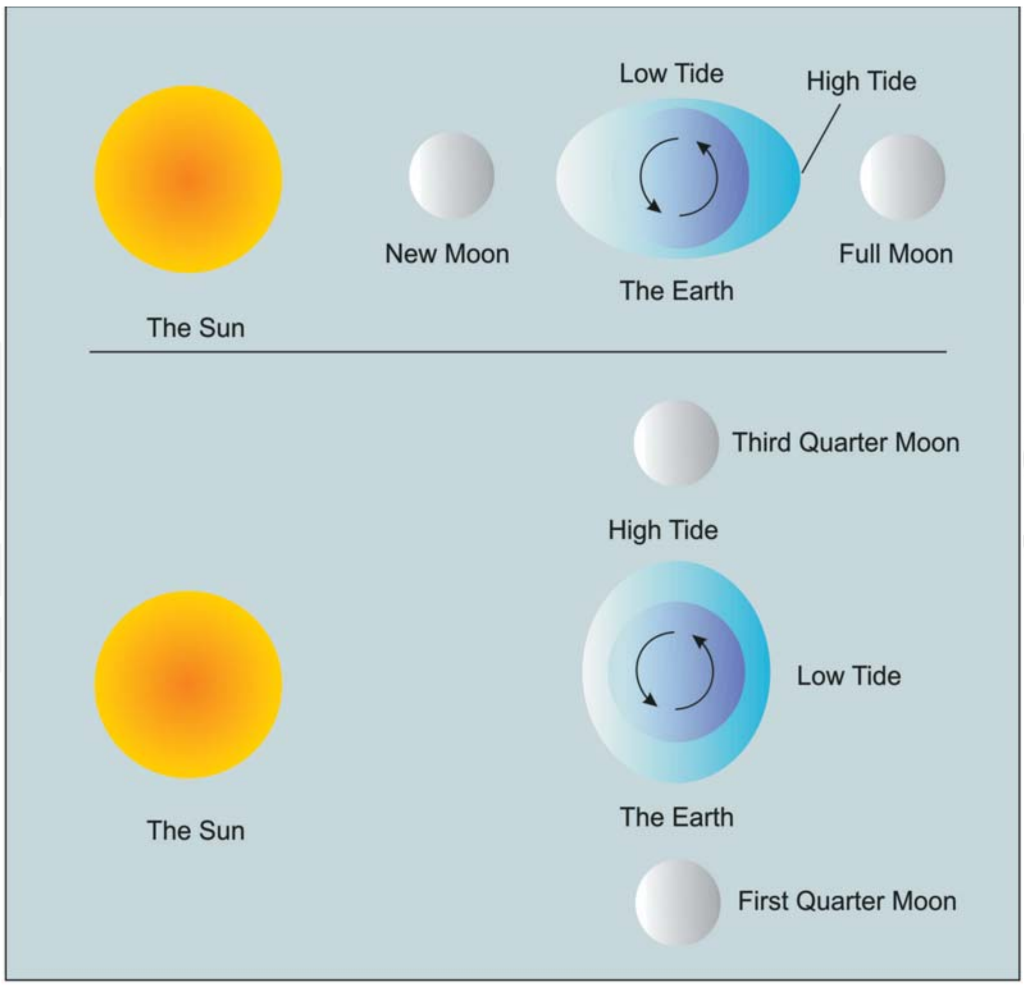

Fig. 18.5: Moon in Conjunction and Quadrature.
(Redrawn from Source:http://www.lcsd.gov.hk/CE/Museum/Space/EducationResource/Universe/framed_e/lecture/ch06/imgs/tides.jpg)

(C) Monthly Variation

You should know that moon is revolving around the earth on an elliptical orbit. In each synodic month, distance between earth and moon on the elliptical plane becomes smallest and largest. It affects the gravitational force on these days and in turn the tidal range varies.

***Perigean Tides*:** At Perigee, the moon is closest to the earth (356,000 km) and this accounts for higher gravitational force and higher than normal tides (almost 15 to 20 per cent higher).

***Apogean tides*:** At Apogee, moon becomes farthest from earth once in month (407,000 km) which accounts for lower gravitational force as compared to perigee. Hence, Apogean tides are 20 per cent lower than normal tides.

(D) Half-Yearly Variation

Declination of sun varies from 0° at equator to a maximum at 23.5° North and South of it in different seasons. Tilt of earth's axis and declination of the sun produces half yearly variation in tidal force in each hemisphere and the resultant tides are as follows:

Declination of a celestial body is its angular distance from the celestial equator, on a celestial sphere. Celestial sphere is an imaginary sphere (around the earth) on the surface of which stars appear to be studded to an observe stationed on earth.

***Equinoctial Tide*:** During both spring and autumn equinoxes on 21st March and 23rd September respectively, sun's rays are overhead at equator due to which tidal bulge at equator becomes stronger and the resultant tides are called equinoctial tides.

***Solstice*:** During winter solstice (22nd December) and Summer Solstice (21st June), sun's rays are overhead at Tropic of Capricorn and Tropic of Cancer respectively. Hence tidal bulge gets tilted in the direction of maximum declination of Sun twice in a year.

(E) Yearly Variation

While revolving round the sun, variation in distance from earth results into larger and smaller solar component of tidal force and the following tides result.

***Perihelion*:** On January 3, when earth comes closest to the sun (147 million km) tide generating forces also multiply.

***Aphelion*:** On July 4, earth gets farthest from the sun (152 million km) and the tidal force is lesser in comparison to perihelion.

(F) Long-Term Variation

Besides declination and revolution effect, axis of rotation of earth and moon also precede after 18.6 and 8.8 years respectively, whereby perfect alignment condition reaches after a long gap. Absolute maxima reaches once in about 1600 years when earth, sun and moon are in conjunction and moon is in perigee, sun is in perihelion and axes intersect with zero declination. Tidal force is phenomenal in such position that is estimated to take place now in 3300 A.D.

Now let us get familiar with different theories related to the origin and movement of tides.

18.3.3 Theories of Origin of Tides

Different theories have been put forward to explain the tidal force and movement of oceanic water. Although gravitational force is the most important cause behind tides but tidal waves are quite complex that cannot be fully explained mathematically. Four most popular theories of tides have been discussed here.

1. Equilibrium Theory

After Newton's laws of gravitation (1687), this theory became quite popular in the understanding of tides. You have already learnt about the origin of tides in Sec. 18.2.1 of this unit. The equilibrium theory can be taken in continuation with that. It explains the equilibrium maintained in tidal bulge due to gravitational and centrifugal forces with the following assumptions:

i) Earth is covered entirely by ocean;

ii) Water moves freely in all oceans having equal depth and having no barriers; and

iii) Tidal wave progresses with predictable time having no standing wave component.

Tidal bulge is created on the side facing the moon (due to centripetal or gravitational force) and the side exactly opposite to it (due to centrifugal force). Gravitational and centrifugal forces balance each other along the line joining both the poles resulting in a force which is directed towards the centre of earth. This force causes lowering of sea level or low tide perpendicular to the places mentioned above experiencing high tides. Thus, all places lying under moon's meridian should have equal timings for high and low tides. Tide tables were also produced in this manner after observing tides for some time.

Progression of tidal wave generated by both the force can be explained as harmonic wave with solar and lunar component. But difference in tide timings on same meridian, complexities introduced by shape of coastal line, latitudinal diurnal inequality of tidal wave height could not be satisfactorily explained by equilibrium theory.

Some other theories were given to solve these complexities. Let us learn about them.

2. Dynamic Theory

Laplace in 1755 produced mathematical explanation of tidal waves after taking into account both vertical and horizontal movement of water. As the earth rotates, tidal bulge generated by gravitational force starts moving horizontally towards the side of ocean facing the moon and thereby giving rise to the bulge of water. Thereafter, as a result of pressure gradient it moves in opposite direction that gets further deflected by Coriolis force (Fig.18.6) and thus a bulge with tilt is formed on the side opposite to moon.

3. Progressive Wave Theory

William Whewell in 1833 explained that tides occur at different times on the same meridian due to progression of tidal wave which is generated in southern ocean. G.B. Airy in 1842 also expressed similar views about tides. According to this theory, tides originating under the gravitational force of moon in the southern ocean in Southern hemisphere take the form of primary waves that progresses towards west as forced wave due to the rotation of earth. Shape of continents further channelises its movement towards north in the form of secondary waves. Time lag due to progression of this wave accounts for difference in timings of tides on the same meridian.

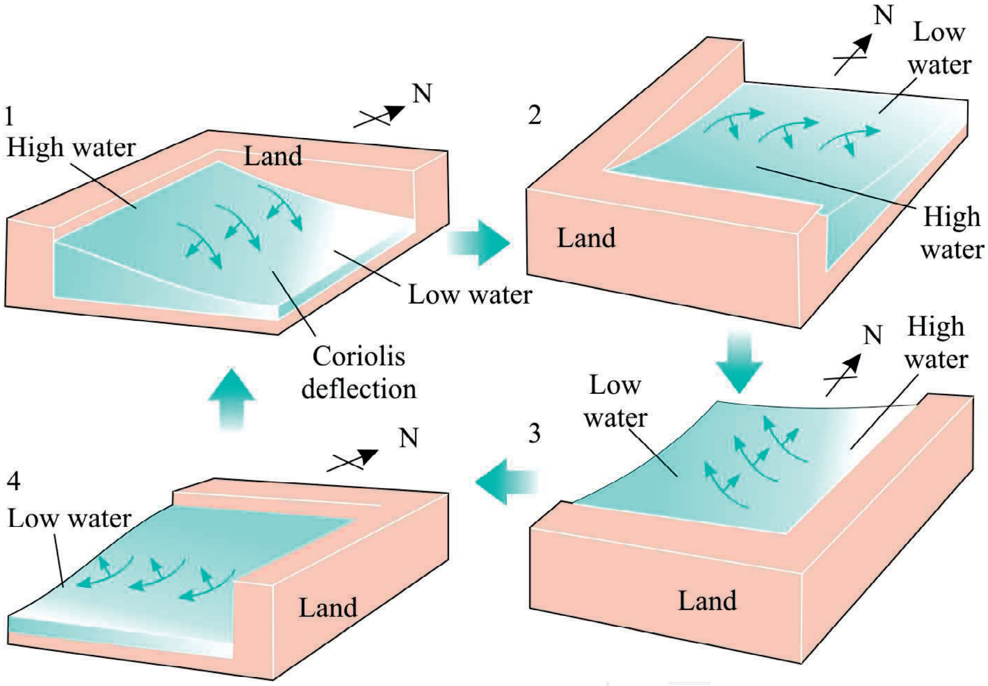

Fig. 18.6: Dynamic Theory of Tides: Stages in Rotary Flow

(Redrawn from Source:**http://www.geo.arizona.edu/geo4xx/geos412/OcSci07.Tides.pdf)**

However, it has been observed in Atlantic Ocean that there is no significant difference in timing of spring tide from Cape Horn to Greenland. Further, different types of tides suggest tides as a result of regional or local effect rather than global wave originating from southern ocean.

Let us now understand the next theory, which is the stationary wave theory regarding tides which tries to remove all these shortcomings.

4. Stationary Wave Theory

R. A. Harris put forward his theory to explain the local differences in timings and types of tides. Once oscillation in water is set by tide producing forces, then water starts moving in each ocean like in a big tank. It results into amphidromic points around which water oscillates and water movement is nil in the centre. This is called nodal point which has zero wave height, just like the middle point in *sea-saw jhula*. From here water moves to a maximum level which is called the antinodal point. Once equilibrium is established, water moves up and down diagonally in open ocean (Fig.18.7). All places along these diagonals are called

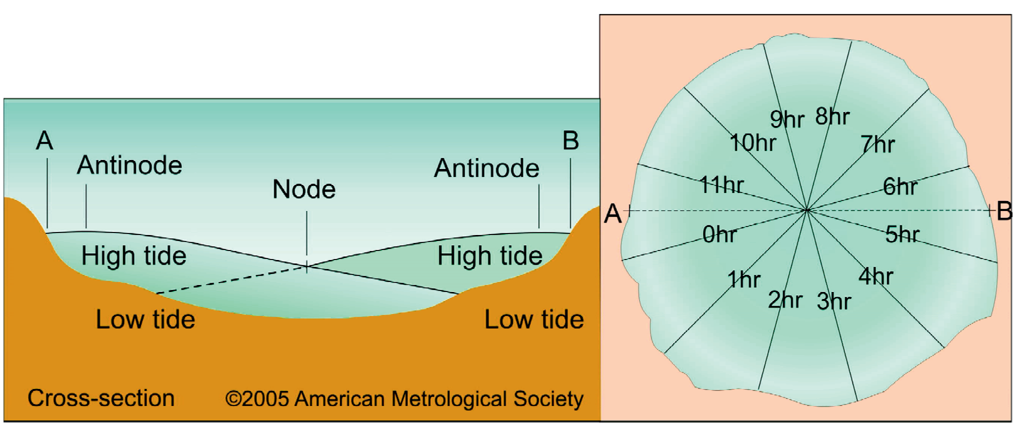

Fig 18.7: Amphidromic point and Cotidal Lines

(Redrawn from Source:http://oceanmotion.org/images/background/tides/07-11.png)

cotidal lines that experience high and low tides at similar times. Amplitude and timings of tide are affected by local phenomena like depth of ocean, coastal and bottom topography resulting into several amphidromic points in each ocean.

Hence, both stationary and progressive wave components are important to understand variation in tides. Progression of water from the amphidromic point can be predicted along each meridian and water height increases towards coast and gets modified by coastal topography resulting into different tidal ranges as explained earlier.

Spend 5 mins

SAQ 2

Name the important theories related to the origin of tides?

18.4 OCEAN CURRENTS

You have already been introduced to ocean currents in section 18.2 of this unit. In this section, you will study factors affecting ocean currents and the general circulation pattern of currents in different oceans of the world.

18.4.1 Factors Affecting Ocean Currents

The flow of ocean currents depends upon external factors like general circulation pattern of winds in atmosphere, pressure and internal factors like temperature and salinity of oceans. Now we shall study the role played by each factor regarding direction and speed of circulation pattern of currents.

1. Wind Stress

Wind is the most important factor influencing direction as well as speed of ocean currents. It exerts stress on ocean surface due to which the water is dragged. According to Pinnet (1992), effect of stress is directly proportional to square of wind speed and resultant current speed is 3-4% of that of the wind. Take for example, if the wind is blowing at 50 km/hr then the speed of the ocean current will be 1.5-2.0 km/hr.

Direction of ocean current is aligned as per planetary wind belt as volumes of water get transported from eastern shores to western shores of oceans in Trade wind zone and *vice-versa* in Westerly wind belt. Temperature of air mass and sea surface also get affected by overlying winds.

2. Pressure Gradient

Difference in water level of sea surface at two places produces pressure gradient force. A steeper pressure gradient produces current with greater speed and its direction obviously will be from low pressure area (high water level) to high-pressure area (low water level). These differences may be due to *atmospheric pressure, precipitation and melting of ice*. Higher pressure of air column over sea surface can lower its level and in turn lower pressure areas have higher sea level to compensate it. Similarly, areas having more rainfall will have higher water level while evaporation leads to lowering of water level.

Melting of snow in higher latitudes results into more flow of water in the oceans that again gets lowered in case of freezing.

3. Coriolis Force

Due to rotation of earth, moving objects like wind and water in the oceans get deflected towards right in northern hemisphere and towards left of its direction of motion in southern hemisphere. This Coriolis force being little along equator deflects less water in lower latitudes as compared to mid latitudes where it becomes stronger. In the previous block on atmosphere, you have already learnt about Coriolis force in detail while studying about global pressure belts and wind movements.

4. Temperature

Temperature affects the surface and sub-surface movements of oceanic waters. Due to high temperature of oceanic water along equatorial and tropical regions, water expands and becomes less dense. Contrary to this, density of water increases in polar regions. Consequently water moves from equatorial regions to polar regions along the surface while sub-surface movement of water is seen from polar areas to equatorial areas. Warm ocean currents like Gulfstream and Kuroshio are examples of this.

5. Salinity

Salinity affects the density of water making it denser in case of cold water. Warm water is lighter but, if saline, it again becomes denser than fresh melt water. Due to these differences, sub-surface currents are affected as the denser water sinks and moves as sub-surface current whereas less saline water moves towards greater saline water as surface current. So, on the surface, ocean currents move from areas of low salinity to areas of high salinity.

6. Coastal Topography and Bottom Reliefs

Shape of coastline and bottom topography particularly mid-oceanic ridges affects not only direction of currents but also mixing of energy of warm and cold water.

So these were the factors affecting ocean currents. Now, let us learn about general circulation pattern of ocean currents.

18.4.2 General Circulation Pattern of Ocean Currents

The combined effect of all the factors discussed above produces a general circulation pattern of ocean currents. Large-scale circulation in each hemisphere results in the formation of oceanic gyres. ***Oceanic gyres*** are large system of rotating ocean currents and are caused mainly by Coriolis effect and large wind movements. They are represented by different names in different oceans for their northern, southern, eastern and western arms running clockwise in northern hemisphere and anti-clockwise in southern hemisphere. Upwelling of water takes place on the eastern shores and along the equator in the divergence zone between the two gyres of each hemisphere. Contrary to this, downwelling i.e. sinking of water occurs in the middle of converging currents of gyre and on western shores in lower latitudes. Refer to Fig. 18.8 to see how it happens.

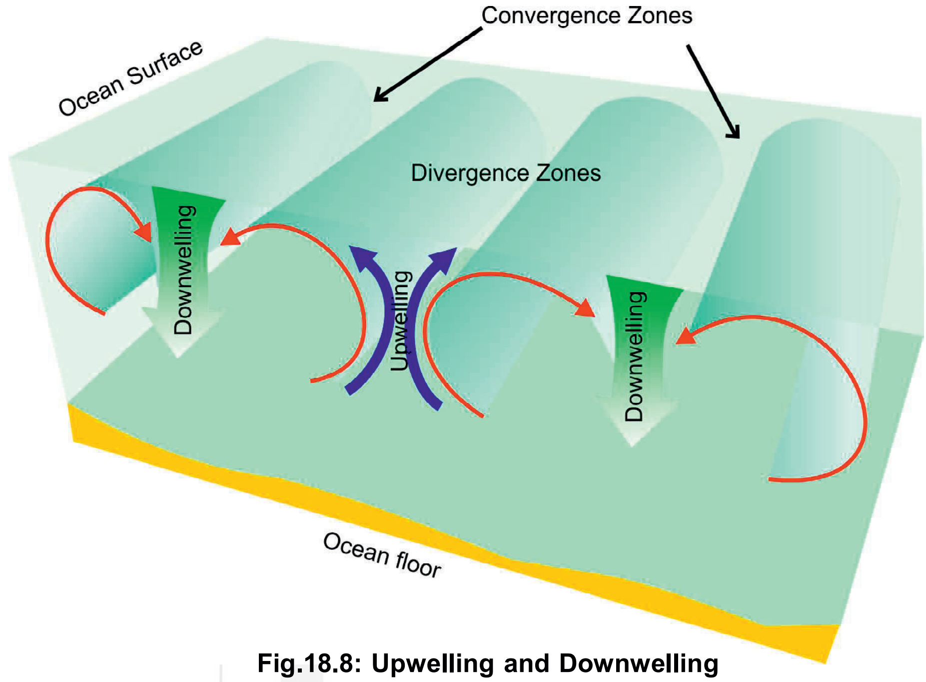

Fig.18.8: Upwelling and Downwelling

(Redrawn from Source:**https://www.e-education.psu.edu/earth103/files/earth103/module06/url-1.jpg)**

From the large-scale circulation pattern of ocean currents, deviations may take place in the form of *eddies* of both warm and cold currents. They help in transfer of energy across different latitudinal zones.

18.4.3 Distribution of Surface Currents

Although pattern of circulation of ocean currents maintains more or less similarity in direction in different oceans but nomenclature and speed varies in each ocean. Hence, individual description of currents in each ocean is necessary to understand movement of water in oceans. We shall begin our discussion with currents in lower latitudes of each hemisphere. Please refer to Fig. 18.9 to understand this.

In northern hemisphere, *North Equatorial Warm Current* flows in Atlantic and Pacific Ocean towards west under the influence of trade winds. In Indian Ocean, it re-curves northward along monsoon drift. This equatorial current, after reaching the coast, is termed as *Gulf Stream* around Mexico region in North Atlantic. It is a very strong warm current with great speed. It moves northward and gets deflected in mid-latitude region in Westerlies belt, from where it moves as *North Atlantic Drift* towards west European Coast making the coastal areas warmer during winters. In case of North Pacific, *Kuroshio Warm Current* flows along Japan and Phillipines Coast and it gets deflected as North Pacific drift to reach the eastern Pacific along the westerlies belt, just as in Atlantic Ocean. Eastward arm of northern gyre is cold current which happens due to upwelling of cold water from below. They are known as *Canary Cold Current* in Atlantic and *Californian Cold Current* in eastern Pacific. However, gyre is asymmetrical towards western side with narrow and stronger movement as compared to wide and lighter movement on eastern side. Around equator, in zone of calm winds, a *Counter Equatorial Warm Current* flows from west to east of the oceans and an Equatorial undercurrent is also found here just below it to balance the flow.

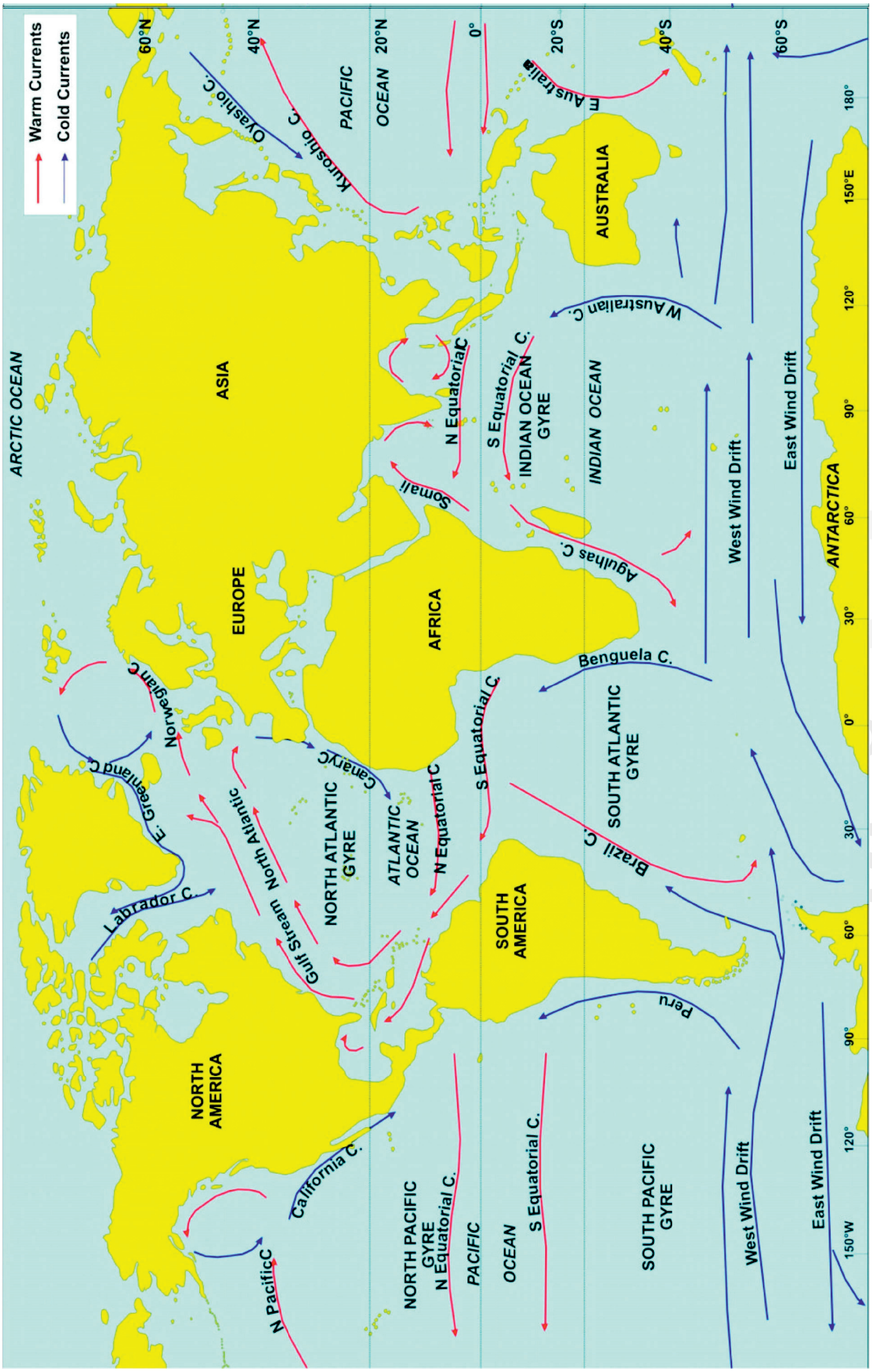

Fig. 18.9: Ocean Currents.

In southern hemisphere, a similar gyre is formed in each ocean with *South Equatorial Warm Current* as westward current. After that it gets deflected to the left as *Brazilian* Warm Current in South Atlantic, *Agulhas* Current in Indian Ocean and *East Australian Current* in South West Pacific. Again they deflect to their left along the western zone in southern hemisphere and are called west wind drift in all oceans as it drifts from west to east and is a very strong wind. Eastward arm of these west wind drifts are *Beneguela* cold currents in south-eastern Atlantic, *Peru* cold current in south-eastern Pacific, West Australian Current in Indian Ocean.

In higher latitudes, a reverse pattern of currents is found. Cold currents like *Labrador* and *East Greenland* Current in North Atlantic, *Oyashio* Current in North Pacific, flow from Polar area towards mid-latitudes along the western shores of oceans. North Atlantic Drift continues in higher latitudes as well towards eastern shores in Atlantic Ocean. The pattern becomes complicated there with no proper gyre formation. In southern hemisphere, a circumpolar *Antarctic Current* flows from west to east under the influence of West Wind Drift. West Wind Drift is the largest ocean current in the world. Further southwards is the East Wind drift current which happens to be the southernmost current of the world and is also called Antarctic Coastal current which flows west wards parallel to Antarctic coastline.

18.4.4 Sub-Surface Ocean Currents

Oceans also have sub-surface currents that run beneath the surface currents likeand travel at a much slower speed. They originate mainly in response to internal factors of oceans mainly due to difference in temperature and salinity levels. So, it is also called *thermohaline circulation*. Near the surface, sea water begins its travel deep into the ocean in North Atlantic. The downwelling of this water is caused by high levels of evaporation which cools and increases the salinity of the sea water located there. The high levels of evaporation take place in between northern Europe and Greenland and just north of Labrador. This sea water then moves south along the coast of North and South America until it reaches Antarctica. At Antarctica, the cold and dense sea water then travels eastward joining another deep current that is created by evaporation occurring between Antarctica and the southern tip of South America. Slightly into its eastward voyage the deep cold flow splits off into two currents, one of which moves northward. In the middle of the North Pacific and in Indian Ocean (off the east coast of Africa), these two currents move from the ocean floor to its surface creating upwelling. The current then becomes near surface moving eventually back to the starting point in the North Atlantic or creating a shallow warm flow that circles around Antarctica. One complete circuit of this flow of sea water is estimated to take about 1,000 years. Refer to Fig. 18.10 to understand sub-surface currents. The currents which are near to surface are shown in ***red*** while ***blue*** ones depict the deeper and colder currents. You can very well understand from the figure that water is moving continuously from surface to greater depths within the oceans and back to the top of the ocean.

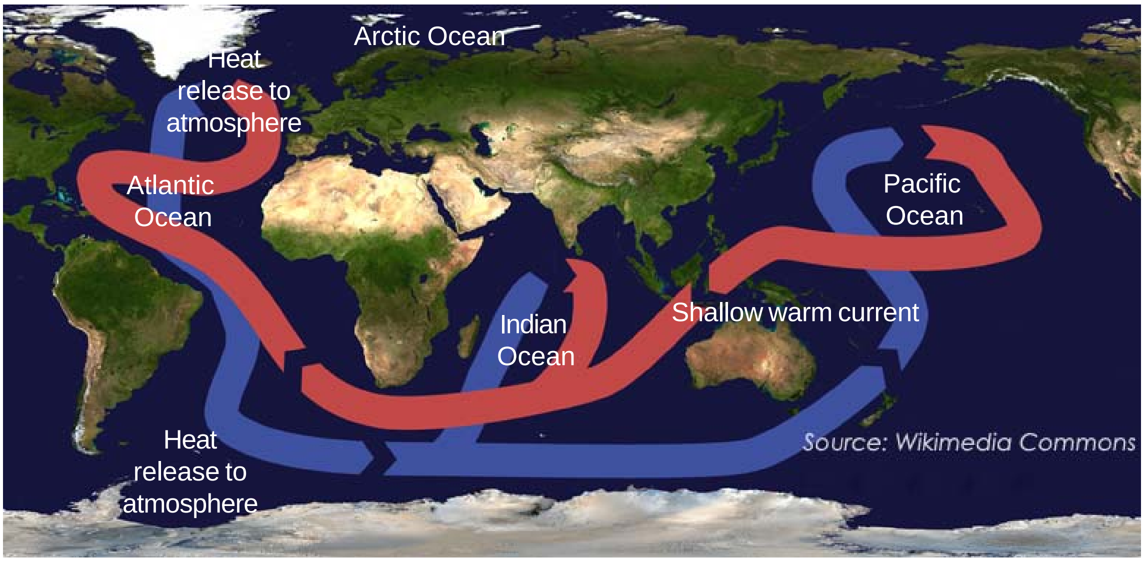

Fig. 18.10: Thermohaline Circulation

(Source: https://commons.wikimedia.org/wiki/File:Granda_rubokirlo_en_Pacifiko.jpg))

SAQ 3

What do you understand by thermohaline circulation?

Spend 5 mins

18.5 EFFECTS OF TIDES AND CURRENTS

Both tides and currents provide large-scale mechanism for the transfer of energy in oceanic waters. Tides are good source of renewal energy in coastal areas having large tidal range. Tidal currents represent movement of water towards the coast at the time of high and low tide. At the mouths of rivers, estuaries, bays, they act as forced tidal waves having great height depending upon basin geometry and depth of water. For example, Bay of Fundy, along the eastern coast of USA experiences very high tides. At the time of high tide when water enters into inlet, it is called *flood current* and receding water during low tide creates *ebb current*. They help immensely in the movement of ships towards the harbour.

Tidal currents (a horizontal motion) are a result of the rise and fall of the water level due to tides (a vertical motion). The effect of tidal currents on the movement of water in and out of bays and harbors is important.

Ocean currents can also be harnessed for the production of electricity with the help of hydro turbines, windmills etc. Gulf Stream current is the powerful source of energy for Florida's needs of electricity. Downwelling and upwelling of surface and sub-surface waters helps in the maintenance of temperatures of marine life. Fishing industry and ports derive great advantage of favourable ocean currents. For example North Atlantic drift raises the temperatures of entire north-west European coastal area where some of the important ports of Norway (Hammerfest), Russia (Murmansk), Sweden (Goteborg) etc remains open throughout the year. However, areas in the interiors of Europe remain frozen along the same latitudinal belt. North Atlantic warm current also brings sufficient rainfall along these coastal areas. Benguela cold current and Canary cold current are responsible for the extension of Kalahari and Sahara deserts respectively up to the coastal area. Mixing of warm and cold ocean currents for example Gulf stream warm current and Labrador cold current along

Warm ocean currents bring rainfall to the coastal regions visited by them as the air in contact with them picks up moisture. Contrary to this, air blowing over cold ocean currents are dry and hence desert like situations emerge wherever they visit.

Newfoundland and Oyashio cold current and Kuroshio warm current along the eastern coast of Japan causes fog like situations in these areas which disturbs sea navigation.

Now let us recapitulate what we have learnt in this unit.

18.6 SUMMARY

To summarise, movements in oceanic circulations mean transfer of energy either by wave in the form of rotary motion of water particles or by actual displacement of water in the form of ocean currents. Waves represent undulations in water surface that may be regular or irregular. Waves with regular periodicity are called tides which are generated by gravitational force of sun and moon. It can be seen from gravitational calculations that tidal force produced by moon is higher than that of sun due to its lesser distance from the earth. Solar component is only 46% of lunar component in tide generating force. Tidal bulge on earth's surface represents horizontal movement of water on two sides by gravitational force on the side facing moon or sun and by centrifugal force on the opposite side. The relative alignment of earth, sun and moon produces differential force during spring and neap tides. Effect of revolution and declination introduces further variations in tidal force at different latitudes. *Equilibrium theory* of tides explains tide generating forces whereas *Dynamic theory* helps in the explanation of movement of tidal wave. Time lag in progression of wave in each ocean is explained by progressive wave theory. Stationary wave theory takes into account standing wave component that gets modified by coastal topography in different basins.

Effect of general circulation pattern of wind can be best seen in the direction of ocean currents. Oceanic gyres are effective mechanism of energy transfer from lower latitudes to higher latitudes and *vice-versa*. This Geostrophic flow of ocean currents is balanced by Coriolis force and pressure gradient and gets further modified not only by coastal topography but also by bottom topography as in the case of sub-surface currents in the form of thermohaline circulation. Besides thermohaline circulation, upwelling and downwelling of currents due to divergence and convergence of currents is important mechanism of mixing of oceanic waters upside down. Last, but not the least, both tides and currents provide good source of energy for commercial purposes if tapped economically.

18.7 TERMINAL QUESTIONS

1. Describe the role of different types of water movements in oceans.
2. Compare between spring and neap tides.
3. Discuss various factors affecting ocean currents with examples of ocean currents.
4. Explain the variation in tidal range.
5. Explain the following:

   a) Oceanic Gyres

b) General Circulation pattern of ocean currents in Atlantic Ocean.

c) Effect of Ocean Currents on coastal climatic condition.

18.8 ANSWERS

Self-Assessment Questions

1. Tides are vertical rise and fall of sea water under the impact of gravitational forces of sun and moon and have regular periodicity. On the other hand ocean currents are horizontal movement of a mass of oceanic water in a definite direction even up to thousands of kilometres under the impact of several factors like temperature, salinity of oceans, prevailing winds, coastal topography, bottom reliefs of oceans etc.

2. Some important theories related to the origin of tides are Equilibrium Theory of Newton (1687), Dynamic Theory by Laplace (1755), Progressive Wave Theory by William Whewell (1833) and Stationary Wave Theory by R.A. Harris.

3. Thermohaline circulation is the sub-surface circulation of ocean waters driven by density differences in ocean waters due to differences in temperature (thermo) and salinity (haline). Currents driven by thermohaline circulation occur at both deep and shallow oceans and move much slower than tidal or surface currents.

Terminal Questions

1. Give a brief introduction of waves, tides and ocean currents as given in Sec. 18.2.

2. Explain the terms conjuction, opposition and quadrature and then explain spring and neap tides. Enhance your answer with a figure (Fig. 18.5) as given in Sec. 18.3.2 B.

3. List and elaborate all factors affecting the ocean currents as in Section 18.4.1. In the next part give examples of ocean currents resulting from those factors.

4. First define tides and then explain the variations in tides as given in Sec. 18.3.2 .

5. a) Define ocean gyre and explain just in one paragraph with the help of a simple figure. Refer to Sub-sec. 18.4.2.

   b) With the help of a figure explain only the currents of Atlantic Ocean. Refer to Sub-sec. 18.4.3.

   c) Refer to Sec. 18.5 and explain in general the effects of ocean currents and then take examples of few currents which have a remarkable impact on coastal climatic condition.

18.9 REFERENCES/FURTHER READING

Sharma, R. C. and Vatal, M. (1993). *Oceanography for Geographers*. Chaitanya Pub House. Allahabad.

Thurman, H. V. (1990). *Essentials of Oceanography*. Merrill Pub Company, U.S.A.

Pinnet, P. R. (1992). *Oceanography*: *An Introduction to Planet Oceanus*. USA: West Pub Company, U.S.A.

Met Education online video of tides and currents

Eclipse Pictures and Map of Currents from Atlas

physicalgeography.net/fundamentals/8q.html

All online references cited in figures.

UNIT 19

OCEAN DEPOSITS

Structure

19.1 INTRODUCTION

In the previous units of this block, you have learnt about almost all the major portions of Oceanography. So now, you must be well acquainted with the terms like continental shelf, continental slope, mid-oceanic ridges, tides, currents, temperature and salinity of oceans. Now you should also study about ocean deposits, which is an important topic of study regarding oceans. They are the unconsolidated layer of sediments lying on the ocean floor. The study of ocean deposits is important as oceans are the final repository of all debris from the land. Their study can also reveal earth's history as these must have been deposited in several layers since the beginning of the origin of earth. You must have already read in unit 6 of this course, how oceanic sediments were lifted and squeezed into fold mountains (which mainly consists of sedimentary rocks that were lithified out of marine or oceanic sediments).

In this unit, you will study about different types of ocean deposits on the basis of their area of occurrence in Sec. 19.2. You will also learn about different types of ocean deposits based on their source and composition in Sec. 19.3. These ocean deposits are widely distributed in all the oceans of the world. In Sec. 19.4 distribution of ocean deposits in terms of both horizontal and vertical distribution is dealt with. Ocean deposits are also transported from one place to another in the oceans by waves, currents, tides, rivers and other agents of erosion. Transportation and deposition of ocean deposits is discussed in Sec. 19.5.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define ocean deposits and explain its importance in the study of Oceanography;
- classify ocean deposits on the basis of its location;
- identify different sources of ocean deposits as well as its composition and distinguish between them; and
- compare the distribution of ocean deposits both horizontally and vertically in the oceans.

One ***fathom*** is equal to 6 feet or 1.8288 m. This unit is very often used for measuring depth of water especially oceanic depth and was used mainly in old imperial and US customary systems.

19.2 CLASSIFICATION OF OCEAN DEPOSITS ON THE BASIS OF AREA OF OCCURRENCE

Since Ocean deposits are unconsolidated, they are not a part of crust and hence they are not lithified. Their thickness ranges from a few meters to about 700m to750m at different places in different oceans. Ocean deposits are classified on the basis of their location or area of occurrence and also on the basis of their source and composition. The major sources of ocean deposits are continents and oceans itself. The deposits from continents mainly comprises of sediments brought by rivers, glaciers, winds and other agents of erosion. The coarser deposits are found near the continental margins while deeper ones comprises of finer deposits. Various studies regarding ocean deposits have been conducted by oceanographers like ***Captain Phipps, John Murray*** etc. Some of the earliest attempts at deep-sea sounding were made by Captain Phipps, the deepest sounding being 683 fathoms, from which depth he brought up a sample of Blue mud. In 1780 ***Saussure*** determined the temperature of the Mediterranean at depths of 300 fathoms and 600 fathoms by protected thermometers. In 1782 when Six's maximum and minimum thermometer was invented, subsequent use was made by ***Krusenstern*** in 1803, by ***Kotzebue*** in 1815, by ***Sir John Ross*** accompanied by ***Sir Edward Sabine*** in 1818, by ***Parry*** in 1819, and by ***Dumont d'Urville*** in 1826. The challenger expedition of Murray conducted between1872-76 has been the basis of several unknown secrets of oceans. The first world map of ocean deposits was indeed prepared on the basis of results obtained through challenger expedition.

In this section, we would study about the types of ocean deposits on the basis of their location. ***Murray*** has classified ocean deposits as Terrigenous and

Pelagic. ***Jetkins*** on the other hand, has classified ocean deposits as (a) Deep sea deposits (beyond 100 fathoms), (b) Shallow sea deposits (up to 100 fathoms) and (c) Littoral deposits (between high tide and low tide).

So, on the basis of area of occurrence, we broadly divide ocean deposits into three types:

- Continental or terrigenous deposits
- Neritic deposits
- Pelagic deposits

Now let us know about each one of them.

A. Continental or Terrigenous Deposits

Terrigenous is a Latin word which means "derived from the earth". **"*Terra*"** means earth and **"*generare*"** means produce. So these sediments include continental rocks which after getting disintegrated are carried by agents of erosion to the sea. These deposits include both ***littoral*** and ***shallow water deposits***. As already mentioned, littoral deposits extends between high tide and low tide while shallow water deposits mainly occurs from the seashore up to 100 fathoms. Shallow water deposits are coarser in nature compared to the deeper deposits and mostly consist of boulders, sand and gravel collected from nearby continental areas. As the carrying capacity of the waves decreases away from the coast, so the coarser deposits are found near to the coast and finer ones are deposited at greater depths. So a kind of gradation is formed from coarser to finer deposits in case of shallow water deposits. ***Quartz*** is the most dominant element for both littoral and shallow water deposits. In the littoral areas, a lot of organisms are found. So apart from inorganic continental materials, littoral deposits are also dominated by calcareous shells which are organic in nature. Colour muds also form a part of terrigenous deposits. This however occurs at about 100 fathom depth.

B. Neritic Deposits

Oceans are a habitat of a wide variety of aquatic creatures like shelled fish, molluscs etc, which are distributed over the entire ocean area. However the waves carry their eggs to the shallow water region. Neritic deposits actually consist of deposits formed from the decomposition of shells and skeletons of these organisms. They are predominantly found up to a depth of 50 fathoms. However, some deep water neritic deposits also occur specially around the oceanic islands. So, in a way they are not restricted to any particular area in the oceans.

C. Pelagic Deposits

Pelagic deposits cover about 75.5 per cent area of the oceans. These deposits are formed of three different categories of organisms as described by the famous oceanographer ***Johnson***. One belongs to the organisms which have roots and are attached to the bottom surface of the oceans and are immobile. The deposits from these organisms are categorised as ***Benthos***. The second category belongs to those organisms which have well-developed locomotory organs and are mobile. They are called as ***Nekton***. The last category belongs

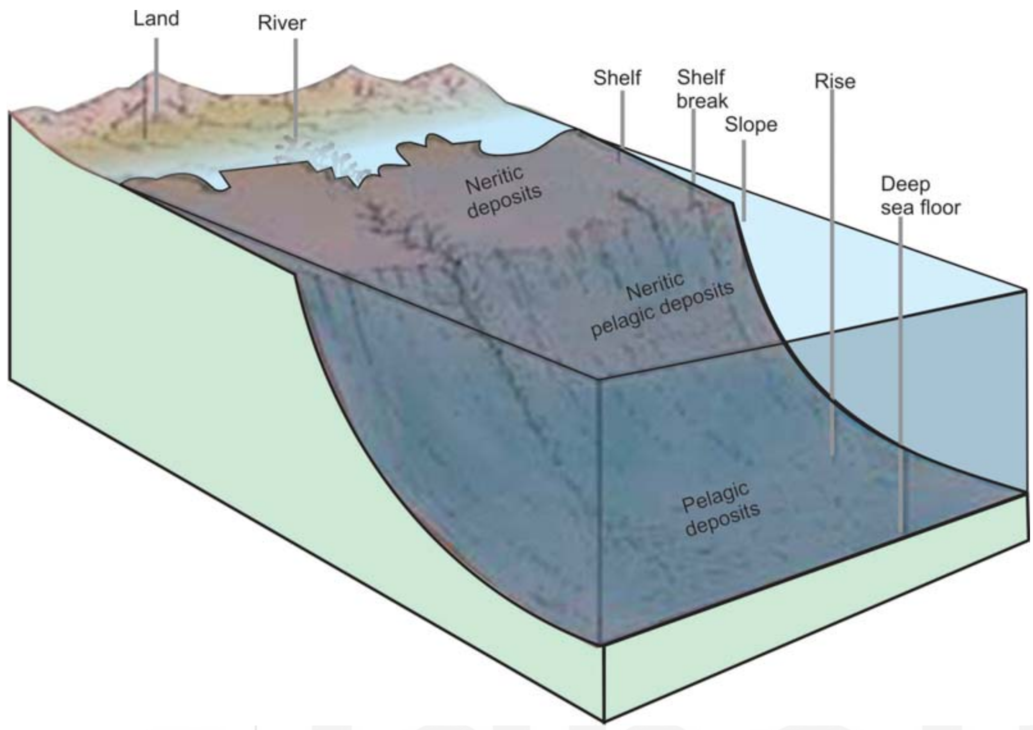

Fig. 19.1: Classification of Ocean Deposits on Basis of Area of Occurrence

to unicellular organisms like protozoa, diatoms etc and comes under the ***Planktons***. Red Clay also forms a part of pelagic deposits. We would be discussing about these in detail in the next section where ocean deposits are categorised in terms of their composition and sources.

Spend
5 *mins*

SAQ 1

State True (**T**) or False (**F**) for the following statements:

a) Shallow water deposits extend between high tide and low tide.

b) Neritic deposits consist of decomposed shells and skeletons of shelled fish and molluscs.

c) Sea organisms which have well developed locomotory organs are grouped as Nekton, while those have which have roots and are immobile are called as Benthos.

19.3 CLASSIFICATION OF OCEAN DEPOSITS ON THE BASIS OF SOURCE AND ITS COMPOSITION

In the previous section of this unit, we have discussed about the types of ocean deposits on the basis of location. In this section you will study in detail about the real composition of ocean deposits and also its source. Sources play a major role in determining the composition of ocean deposits. Source can be varied. It can be continental, volcanic or even extraterrestrial.

On the basis of source and composition, ocean deposits can be broadly divided into following six types:

- Terrigenous Deposits
- Volcanic Deposits
- Deposits Related to Organic Remains
- Inorganic Deposits
- Red Clay
- Extra Terrestrial Matter

Let us study them in detail.

A. Terrigenous Deposits

Terrigenous deposits are composed of gravels, sand, clay, mud etc which results from weathering and decomposition of continental rocks. Transportation of these disintegrated and decomposed blocks takes place by various agents of erosion like rivers, winds, glaciers etc. As mentioned already, terrigenous deposits are composed of both coarser and finer sediments which gets deposited nearer and farther to the coast respectively. This is because of greater carrying capacity of the waves regarding finer sediments which are carried to a greater distance into the oceans. On the basis of texture, chemical composition and nature of the constituent rocks, these deposits are broadly divided into gravels, sands, silt, clay and mud of which gravel is the coarsest deposit and mud is the finest one. Refer to Table 19.1 to know the details.

Table 19 .1: Terrigenous Deposits and Their Size

Deposits	Size in mm (Diameter)
Gravel	2- 256
Sand	1 - 1/6
Silt	1/32 - 1/256
Clay	1/256 - 1/8192
Mud	Finer than 1/8192

Let us now get a brief acquaintance to these deposits.

a) Gravels

Gravels refers to the coarser terrigenous deposits whose diameter ranges between 2-256 mm. As there is a wide variation in the size of gravels, so bigger ones of the order of 256 mm are called boulders and smaller ones of the order of 2-4 mm are called granules and pebbles respectively. Due to relatively bigger size of gravels compared to sands and muds, they get deposited along the coastal area specially along the continental shelves and formed pebble banks.

b) Sands

Sand particles are also formed due to weathering of continental rocks which may be either igneous, sedimentary or metamorphic rocks with the diameter ranging from 0.166 mm to 1 mm. Quartz is the most dominant mineral found in sands obviously due to its abundance on the earth's crust. Sands are also carried by rivers as prime agents of erosion apart from other agents of erosion and brought to the oceans. There is a variation in the diameter of the sand deposits. Coarse ones are 0.5-1 mm in diameter while finer ones are 0.125-0.166 mm in diameter. The coarser ones are deposited near to the coast and finer ones are deposited to a little more distance into the sea.

c) Silt, Clay and Muds

These are much finer sediments and are deposited in relatively deeper parts of the oceans. Their diameter size range from 1/32 mm to lesser than 1/8192 mm (refer to Table 19.1) of which mud is the finest one. Clay acts as a cementing material. These deposits basically have a heterogeneous composition and also have aluminium content in them. Unlike sand, they are devoid of quartz. Mud is further divided into 3 types on the basis of color by Murray. They are blue mud, red mud and green mud.

Blue mud is called so, simply due to its bluish-black colour. It is formed due to disintegration of rocks containing iron sulphide. Sulphur reduces the iron to ferrous state. However the upper layers of this mud continues to be in ferric state. It contains 35% of calcium carbonate. They are mostly found in Atlantic, Mediterranean and Banda Sea.

Ochre is an earthy, powdery, red, yellow or brown iron oxide that is used as a pigment for example yellow and brown ochre (limonite) and red ochre (haematite). Ochres are also clays strongly coloured by iron oxides. **(*Hoffman*, *M.*, *1988*)** Ochres are brown or yellow earthy forms of limonite. **(*Gribble*, *1991*)**

Red mud, as the name suggests is reddish in colour. This colour is imparted by iron oxide especially ferric oxide and ochreous matter. They have an average of 32 % calcium carbonate. They are mostly confined to Yellow Sea or Atlantic Ocean along the Brazilian coast. Red mud is limited to localities where a large amount of ochreous matter is carried into the oceans by big rivers.

Green mud is basically green in colour as the name suggests and this is because of the presence of glauconite or silicates of potassium and iron. They are found at places where coasts are devoid of big rivers and so continental rocks along the coast are exposed to the denuding action of the sea. In course of time green silicates of potassium and iron are deposited on the rocks thus imparting its green colour. They have about 7-8% glauconite and only 0.56 % calcium carbonate.

B. Volcanic Deposits

Volcanic deposits are of 2 types viz, sub-aerial and sub-marine. Sub-aerial deposits are the product of volcanic eruptions from land area and include materials brought by rivers or other agents of erosion from these volcanoes or volcanic islands after being exposed for long time. The process of weathering changes these lava fragments and boulders into smaller particles of sand or mud. Sub-marine deposits, on the other hand are those which are directly deposited on ocean floor. They are not brought by any erosional agents but are formed due to upwelling of molten lava on the floor of ocean. These are therefore found along tectonically active zones having greater frequency of volcanism. Sub-aerial volcanic deposits are mixed with several clay and alluvial deposits and therefore it is hard to recognize them.

C. Deposits Related to Organic Remains

Apart from terrigenous deposits which are mainly continental in origin, marine organisms also contribute to a huge amount of sediments or oceanic deposits. They are termed as organic deposits. They are however two categories of organic deposits. One is neritic and the other one is pelagic. You are already familiar with these terms as you have studied them in the previous section but with respect to location. Now let us study these, in terms of their composition.

a) **Neritic Deposits** are composed of calcareous and siliceous deposits of various marine organisms, both plants and animals. These are in abundance in shallow waters with low salinity.

b) **Pelagic Deposits** generally consist of remains of different types of algae and shells and skeletal remains of various sea organisms. These occur in the form of liquid mud which is also known as ooze. When dried, it turns into an amorphous, powdery mass. There are two broad categories of pelagic oozes based on their calcareous and siliceous nature. Calcareous oozes are further divided into two types that is, ***Pteropod Ooze*** and ***Globigerina Ooze***. Siliceous oozes are also two types, that is, ***Radiolarian Ooze*** and ***Diatom Ooze***. Let us discuss them separately.

Pteropod Ooze has 80% calcium carbonate and are formed of pteropod molluscs having thin conical shells with a diameter of 0.5 inches. They generally occur at about 800-1000 fathoms depth and almost disappear beyond 2000 fathoms. They have a greater predominance in eastern and western Pacific Ocean and are found in patches in Azores, Antilles, Canary Island, central ridge of Mediterranean Sea and Indian Ocean.

Globigerina Ooze is having 64.47% Calcium, 1.64% silica and 3.33% other minerals. They are formed of shells of various foraminifera especially Globigerina. The deposits are found extensively in Atlantic Ocean, eastern and western continental shelves of Indian Ocean and eastern Pacific Ocean. It is widespread in both tropical and temperate waters as Globigerina can survive well in both tropical and temperate waters. These oozes are found at greater depths ranging between 2000-4000 fathoms. In deep oceans, its colour appears milky white but along the coasts it appears bluish grey. Sometimes it also appears yellowish in colour.

Radiolarian Ooze is siliceous in nature due to the abundance of siliceous matter. It is formed of shells of foraminifera and appears dirty grey when dried. These deposits have very insignificant amount of calcareous content averaging only to about 4%. It is found in deep waters reaching up to 2000-5000 fathoms depth. It occurs in small patches in Indian Ocean and Atlantic Ocean and is widespread in tropical regions of Pacific Ocean.

Diatom Oozes are formed due to decomposition of shells of very microscopic plants containing silica in abundance. These are found at depths ranging between 600-2000 fathoms and sometimes even extend up to 4000 fathoms. They appear yellowish in general but turns white on drying and appears bluish when found near the coastal regions. It is found abundantly around Antarctic Ocean and a narrow belt extending from Alaska to Japan in the North Pacific.

D. Inorganic Deposits

Inorganic precipitates generally occur in the form of dolomite, amorphous silica, magnesium oxide, and even phosphorus, clay, feldspar etc. These precipitates occur at different places and are carried to the oceans by different transporting agents like rivers, winds etc and gets deposited there. In this process they get so mingled with each other that it becomes very difficult to distinguish them.

SAQ 2

Spend 5 mins

What is the difference between neritic and pelagic deposits?

E. Red Clay

Red clay is also a member of pelagic deposits and is basically composed of hydrated silicates of aluminium and Iron oxide. Aluminium silicates account to about 85.35% of red clay while it also contains calcium and silicon content accounting to about 6.7% and 2.39% respectively. However, its red colour differentiates it from other pelagic deposits, which is imparted by the iron oxide content in it. It contains more radioactive substance than any other marine deposit. It is soft, plastic and greasy in character. It covers 36.1% area of ocean floor and is perhaps the most widely spread pelagic deposit. It is dominantly found in Atlantic Ocean between 40° North and 40° South latitudes, eastern part of Indian Ocean and North Pacific Ocean.

F. Extra Terrestrial Matter

They are in the form of meteoric dust or cosmic spherules coming from heavenly bodies and so they are also called as cosmogenous deposits. They are widely scattered due to which it is difficult to recognise them easily. They normally consist of iron oxide particles especially that of magnetite iron. They are intact only in ocean deeps e.g. in Pacific Ocean deep. They fall in the form of burnt ashes. Although there amount is insignificant compared to other deposits in the oceans, they hold a lot of significance for oceanographers or scientists who might be interested in the study of these extraterrestrial particles.

It is thus evident from the above discussion that pelagic deposits dominate the ocean floor while other deposits occupy the peripheral parts of oceans. Let us get an idea about the overall percentage of different types of ocean deposits of the total oceanic floor area from Table 19.2.

SAQ 3

Spend 5 mins

a) Red clay is red in colour due to the presence of …………..

b) Red Clay covers ……. area of ocean floor

c) Pteropod Ooze and Globigerina Ooze are …………, while Radiolarian Ooze and Diatom Ooze are ………… However they come under ……… deposits.

Table 19.2: Percent of Different Types of Ocean Deposits of the Total Oceanic Floor Area

Types of Ocean Deposits		Per cent Area
Littoral and shallow water		9.1
Terrigenous		15.4
	Globigerina Ooze (29.2%)	
	Pteropod Ooze (0.4%)	
Pelagic	Diatom Ooze (6.4%)	75.5
	Red Clay (36.1%)	
	Radiolarian Ooze (3.4%)	
Total		100

19.4 DISTRIBUTION OF OCEAN DEPOSITS

So far, you have studied the oceanic sediments or deposits based on their area of occurrence or their source and composition. Now let us should study their horizontal and vertical distribution in different oceans of the world.

A. Horizontal Distribution of Ocean Deposits

Horizontal distribution generally pertains to the distribution of oceanic sediments in different oceans of the world. You can refer to Fig. 19.2, that terrigenous deposits are mostly confined along the coastal regions with greater concentration along East Indies, North Pacific, and Labrador Coast. Pacific Ocean has a huge area of red clay deposits. However, red clay is also found along the eastern and southern parts of Indian Ocean. Globigerina is found along the western parts of Indian Ocean. It also has predominance over a major portion of Atlantic Ocean. Diatom is found along the southern portion of all major oceans. Please refer to Fig. 19.2 for getting a general overview of the horizontal distribution of ocean deposits. Also refer to Table 19.3 which gives the distribution of pelagic deposits in all major oceans of the world.

B. Vertical Distribution of Ocean Deposits

Vertical distribution of marine sentiments is studied in the form of various layers or strata and this was first noticed by the oceanographer Philippi in his famous Gauss expedition of the oceans. It was observed that even in the same strata there was a change of colour from reddish-brown in the upper portion to blue in the lower portion and this was probably attributed to reduction of iron from ferric in upper layers to ferrous in lower layers. A proper hierarchy was also seen in the nature of sediments from pteropod ooze in shallow waters to Globigerina and then radiolarian and diatoms extending up to deep waters and finally red clay occupying the deepest portion of the oceans. This is because pteropods dissolve even in shallow water and cannot extend up to the depths to which Globezerina is found. Globezerina can tolerate cold waters due to which it is found both in tropical and temperate regions. On the other hand, radiolarians and diatoms are silicious and so they do not get dissolved easily. So they extend even up to deeper parts of the oceans. Let us have a look at the

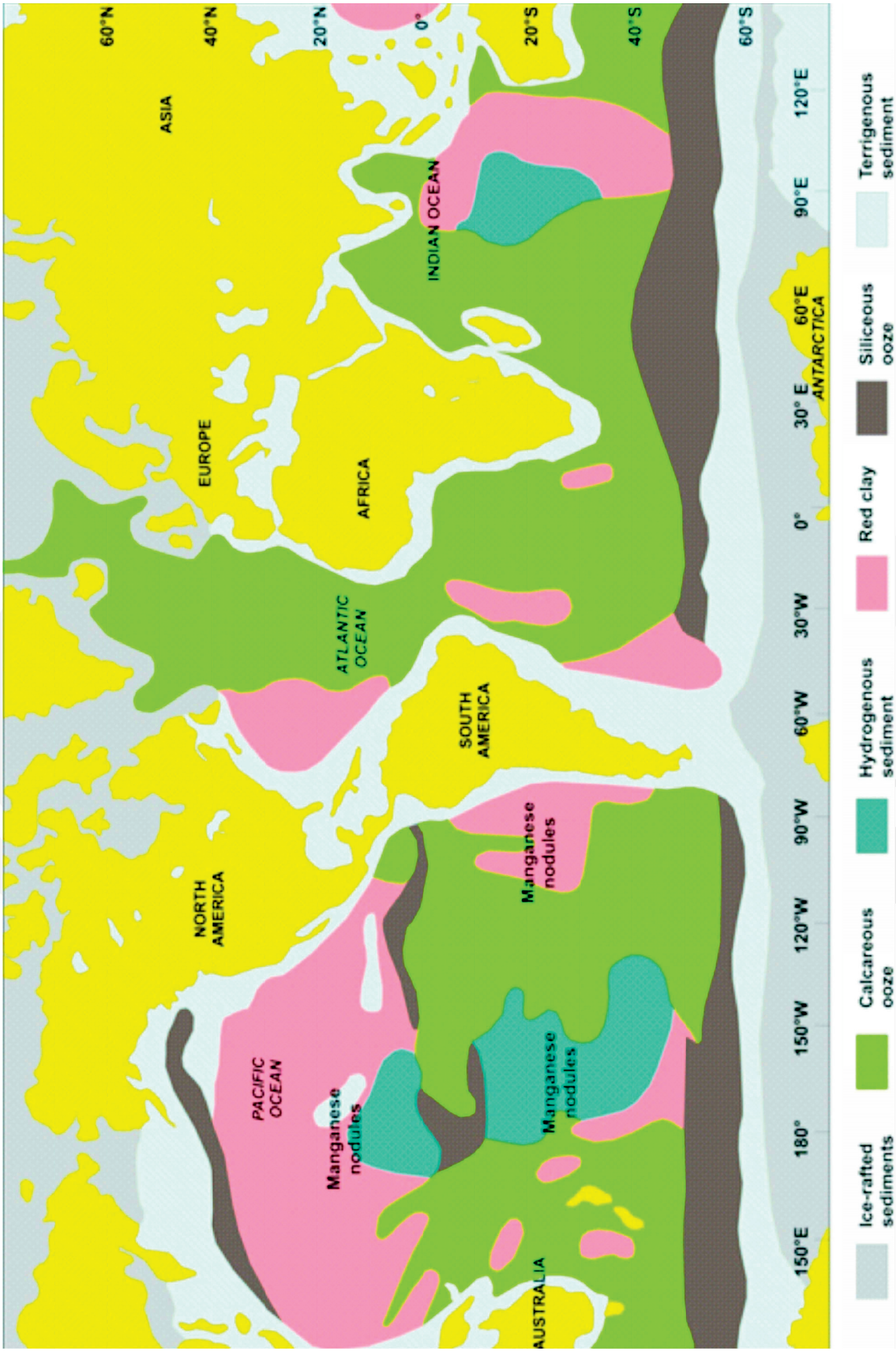

Fig 19.2: Global Distribution of Ocean Deposits.

(Source: Redrawn from http://apps.usd.edu/esci/creation/age/content/creationist_clocks/ocean_floor_sediment.html)

sediments in the major oceans of the world.

Table 19.3: Areas Covered by Pelagic Sediments (Million km^2)

	Atlantic Ocean	Pacific Ocean	Indian Ocean	Total
Calcareous Oozes	41.6	51.9	34.4	127.9
Globigerina	40.1	51.9	34.4	……
Pteropod	1.5	..	…	…
Siliceous Oozes	4.1	21.0	12.9	38.0
Diatom	4.1	14.4	12.6	….
Radiolarian	…	6.6	0.3	…
Red Clay	15.9	70.3	16.0	102.2
Total	61.6	143.2	63.3	268.1

19.5 TRANSPORTATION AND DEPOSITION OF OCEANIC SEDIMENTS

We have already been talking at various sections in this unit regarding the transportation of sediments from continents and other places by various agents. So now you can quickly recall a few agents that may be useful in the transportation of sediments from various sources and their deposition in the oceans. Lets assume that you are familiar with those agents as you have studied about them in the previous block of this course. They can be rivers, waves, glaciers, wind etc. Let us discuss their work in brief.

Rivers: Perhaps rivers are regarded as the prime agents of erosion. They not only help in disintegration of continental rocks but also transport these rock chunks of different sizes and deposit them in the oceans. However you all know that, coarser ones are deposited near the coast and finer ones are carried up to a greater depth into the oceans.

Waves/Currents/Tides: Waves too play a great role in the disintegration of coastal rocks as well as carrying the rock fragments and boulders into the oceans. You have already studied about the erosional and depositional action of waves in brief in ***Unit 9*** of this course on ***Exogenetic Processes II***. Apart from various coastal landforms these waves also carry sediments from the coasts to deeper parts of the oceans. Besides waves, other agents like tides and currents also transfer sediments which are brought to the oceans. This is the reason why these sediments do not get deposited to the ocean floor as soon as they are brought to the oceans. They do travel inside the oceans itself due to the action of waves, tides and currents and get deposited elsewhere. However, this transportation of sediments depends on their size and carrying capacity of these agents.

Glaciers: Glaciers and icebergs also carry materials and debris and deposit them to different places in the oceans. Their action is however restricted to high altitude and high latitudinal regions, where they occur.

Winds: The transportation work of winds is prominent in arid regions or regions which are devoid of vegetation or cultivation. So, the soil or bare rock surfaces are exposed to these agents and the eroded particles get transported to huge distances and at places they get deposited into the oceans if they happen to come on their way. The volcanic ash and inorganic deposits in oceans occur due to the transportation work of wind as they are carried to far-off places from their place of origin.

Miscellaneous: Sometimes natural hazards or disasters like earthquake, tsunami, floods, cyclones etc bring enormous amount of debris from the land areas to the oceans which in course of time get transformed into ocean deposits. Human beings also play a great role in transporting sediments to the oceans through their activities.

Let us now recapitulate what we have learnt so far in this unit.

19.6 SUMMARY

Oceanic deposits may be defined as unconsolidated layer of sediments lying on the ocean floor. Ocean deposits are classified on the basis of their location or area of occurrence and also on the basis of their source and composition. On the basis of area of occurrence, we broadly divide ocean deposits into three types, that is, Continental or terrigenous deposits, Neritic deposits and Pelagic deposits. Terrigenous deposits include continental rocks which after getting disintegrated are carried by agents of erosion to the sea. These deposits include both ***littoral*** and ***shallow water deposits***. ***Quartz*** is the most dominant element for terrigenous deposits. Neritic deposits actually consist of deposits formed from the decomposition of shells and skeletons of organisms and are basically found up to a depth of 50 fathoms. Pelagic deposits are found beyond 100 fathom depth. On the basis of source and composition, ocean deposits can broadly be divided into terrigenous deposits, volcanic deposits, deposits related to organic remains, inorganic deposits, red clay and extra terrestrial matter. Terrigenous deposits are again divided into gravels, sands, silt, clay and mud of which gravel is the coarsest deposit and mud is the finest one. Muds are also further divided into 3 types on the basis of color, that is, blue mud, red mud and green mud. Volcanic deposits are of 2 types viz, sub-aerial (from volcanic eruptions from land area) and sub-marine (upwelling of molten lava on the ocean floor). Neritic and Pelagic are Organic deposits. Pelagic deposits occur in the form of liquid mud which is also known as ooze. Pelagic oozes are further divided on the basis of their calcareous and siliceous nature. Calcareous oozes are ***Pteropod Ooze*** and ***Globigerina Ooze*** and silicious oozes are ***Radiolarian Ooze*** and ***Diatom Ooze***. Some extraterrestrial matter also form a part of ocean deposits. A proper hierarchy is seen in the nature of sediments from pteropod ooze in shallow waters to Globigerina and then radiolarian and diatoms extending up to deep waters and finally red clay occupying the deepest portions of the ocean.

19.7 TERMINAL QUESTIONS

1. Give an account of ocean deposits on the basis of source and composition.

2. Discuss in brief horizontal and vertical distribution of ocean deposits.

19.8 ANSWERS

Self-Assessment Questions

1. a) F

   b) T

   c) T

2. Some of the important differences between neritic and pelagic deposits are discussed below:

   a) Neritic deposits are mostly found on the continental shelves in shallow water area while pelagic deposits are found in deep ocean basins.

   b) Neritic deposits includes calcareous and siliceous deposits of marine organisms, that is both plants and animals while pelagic deposits consists of skeletal remains of various types of algae and shells of other sea organisms.

   c) Neritic deposits are coarser compared to pelagic deposits which occur in the form of liquid mud called ooze.

3. a) Iron Oxide

   b) 36.1%

   c) Calcareous Siliceous Pelagic

Terminal Questions

1. Discuss in brief all the six types of ocean deposits as given in Sec.19.3 of this unit.

2. Elaborate your answer by giving a rough sketch of world map regarding horizontal distribution and then also discuss the vertical distribution of ocean deposits. Refer to Sec. 19.4 of this unit.

19.9 REFERENCES/FURTHER READING

Sharma, R. C. and Vatal, M. (1993). *Oceanography for Geographers*, Chaitanya Publishing House, Allahabad.

Singh, S. (2003). *Physical Geography*, Prayag Pustak Bhawan, Allahabad.

Hoffman, M. (1988). *Dictionary of Geology*, Goyalsaab, New Delhi.

Gribble, .D. (1991) *Rutley's Elements in Mineralogy*, Unwin Hyman Ltd, London.

http://apps.usd.edu/esci/creation/age/content/creationist_clocks/ocean_floor_sediment.html

Murray, J. and Hjort, J. (1912). Depths of the Oceans, Macmillan and Co Ltd., London.

GLOSSARY

Amphidrome : Central point in a ocean basin where water remains calm and stationary while the water level changes around them and results in the formation of waves which move in anti-clockwise direction around them.

Antinode : The point of maximum wave height produced on sides of ocean basin by superimposition of crest of one wave over trough of another wave.

Aquifer : A unit of rock or an unconsolidated deposit which can yield a usable quantity of water.

Aquicludes : These are impermeable rock material or clay which is so dense that the pores do not allow water to traverse through them.

Fathom : It is a unit very often used for measuring depth of water especially oceanic depth and equal to 6 feet or 1.8288 m.

Isohalines : Imaginary lines on the map of oceans connecting all points of equal salinity.

Node : A mid-point of intersection of two waves where movement of water is nil in a basin.

Ocean Deposits : They are unconsolidated layer of sediments lying on the ocean floor.

Oceanography : It is a branch of geography or earth science and covers a wide range of topics including marine life and ecosystem, oceanic circulation, plate tectonics and geomorphology of ocean floor and physical and chemical properties of oceans.

Ooze : Deposits occurring in the form of liquid mud is known as ooze.

Pelagic Deposits : They contain very minute amount of land detritus and largely consist of deposits made up of pelagic organisms (which secrete hard shells of Calcium carbonate or of silicon) with the exception of Red clay.

Progressive Wave : Crests and trough of each wave moving one after another with time.

Quadrature : A position when earth, sun and moon are at right angles during first and third quarter of lunar phase.

Salinity : The total amount of solid materials in grams (g) contained in 1 kg of sea water and is expressed as parts per thousand (%o).

Standing Wave : Crests and trough of each wave superimposing one over another with time.

Terrigenous Deposits : As the word suggests it means originated from earth and includes continental rocks which after getting disintegrated are carried by agents of erosion to the sea.

Zone of Aeration : It is the topmost zone immediately underlying the surface of earth composed of a mixture of solids, water and air where pores are partially filled with water and partially filled with air.

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