B.A/B.sc - IIIrd Semester Geography
FLP-II (Assi.)
(Physical Geography-IInd.)

Unit-Ist.

Q.1. Explain the structure of the different Layers of the atmosphere with diagram.

Unit-IInd.

Q.2. What is cyclone? Explain the 'Polar Front Theory' of Origin of temperate cyclone.

Unit-III

Q.3. Provide a detail account of Ocean Bottom.?

Unit-IVth

Q.4. What are Coral reefs? Critically analyse Drawin's views on their Origin.

Topic - (I)

COMPOSITION AND STRUCTURE OF THE ATMOSPHERE

Q·1 Explain the structure of the different layers of the atmosphere with digram.

32.1 COMPOSITION OF THE ATMOSPHERE

The atmosphere is a thick gaseous envelope which surrounds the earth from all sides and is attached to the earth's surface by gravitational force. The atmosphere is a significant component of the biospheric ecosystem because the life on the earth's surface is because of this atmosphere otherwise the earth would have become barren like moon. Besides providing all necessary gases for the sustenance of all life forms in the biosphere, it also filters the incoming solar radiation and thus prevents the ultraviolet solar radiation waves to reach the earth's surface and thus protects the earth from becoming too hot. The height of the atmosphere is estimated between 16 to 29 thousand kilometres from the sea level. It is estimated that 97 per cent of the effective atmosphere is upto the height of 29 km. In fact, the air is mechanical mixture of several gases. The atmosphere is composed of (i) gases, (ii) vapour and (iii) particulates.

Gases—Nitrogen (78%) and oxygen (21%) are major gases which constitute 99% of the total gaseous composition of the atmosphere. The remaining one per cent is represented by argan (0.93%), carbon dioxide (0.03%), neon (0.0018%), helium (0.0005%), ozone (0.00006%), hydrogen (0.00005%), krypton (trace), xenon (trace), methane (trace) etc. Oxygen is the most important gas from the stand point of living organisms because they inhale it for their survival. Oxygen is also essential for combustion of burning matter. Nitrogen acts as dilutent and is generally chemically inactive. Carbon dioxide is used by green plants for photosynthesis. It absorbs most of radiant energy from the earth and reradiates it back to the earth. Thus, carbon dioxide, a **greenhouse gas,** increases the temperature of the lower atmosphere and the earth's surface. The concentration of carbon dioxide in the atmosphere is gradually increasing due to burning of fossil fuels (coal, petroleum and natural gas) and deforestation. Ozone gas absorbs most of the ultra-violet rays radiated from the sun and thus prevents the earth from becoming too hot.

Water Vapour—The vapour content in the atmosphere ranges between zero and 5 per cent by volume. Climatically, water vapour is very important constituent of the atmosphere. The atmospheric vapour is received through the evaporation of moisture and water from the water bodies (like seas and oceans, lakes, tanks and ponds, rivers etc.), vegetation and soil covers. Vapour depends on temperature and therefore it decreases from the equator poleward in response to decreasing temperature towards the poles. The content of vapour in the surface air in the moist tropical areas, at 50^0 and 70^0 latitudes is 2.6%, 0.9% and 0.2% (by volume) respectively. The content of vapour decreases upward. More than 90 per cent of the total atmospheric vapour is found upto the height of 5 km.

If there is condensation of all the atmospheric vapour at a time, there would result a one-inch thick layer of water around the earth. Even this meagre amount of water vapour in the atmosphere is responsible for various types of weather phenomena.

The moisture content in the atmosphere creates several forms of condensation and precipitation e.g. clouds, fogs, dew, rainfall, frost, hailstorm, ice, snowfall etc. Vapour is almost transparent for incoming shortwave solar radiation so that the electromagnetic radiation waves reach the earth's surface without much obstacles but vapour is less transparent for outgoing shortwave terrestrial radiation and therefore it helps in heating the earth's surface and lower portion of the atmosphere because it absorbs terrestrial radiation.

Particulate Matter—The solid particles present in the atmosphere include dust particles, salt particles, pollen, smoke and soot, volcanic ashes etc. Most of the solid particles are kept in suspension in the atmosphere. These particulates help in the scattering of solar radiation which adds varied charming colour of red and orange at sunrise and sunset. The sky appears blue in colour due to selective scattering of solar radiation by dust particles. Salt particles become hygroscopic nuclei and thus help in the formation of water drops, clouds and various forms of condensation and precipitation.

32.2 STRUCTURE OF THE ATMOSPHERE

The modern knowledge about the atmosphere is based on the information received through rockets, radar and satellites. The effective height of the atmosphere is estimated between 16 and 29 thousand kilometres from the sea level but the height of the atmosphere upto 800 km is most important. About 50 per cent of the atmosphere lies below the altitude of 5.6 km and 97 per cent of the atmosphere is confined to the height of only 29 km. The upper limit of the atmosphere, though unknown, is considered to be 10,000 km from sea level. The earth's atmosphere consists of a few zones or layers like spherical shells. On the basis of the characteristics of temperature and air pressure there are four layers from the earth's surface upward e.g. (1) troposphere, (2) stratosphere, (3) mesosphere, and (4) thermosphere (fig. 32.1).

(1) Troposphere

The lowermost layer of the atmosphere is known as troposphere and is the most important layer because almost all of the weather phenomena (e.g. fog, cloud, dew, frost , rainfall, hailstorm, storms, cloud-thunder, lightning etc.) occur in this layer. Thus, the troposphere is of utmost significance for all the life forms including man in the biospheric ecosystem because these are concentrated in the lowest part of the atmosphere. Temperature decreases with increasing height at the rate of 6.5°C per 1000m. This rate of decrease of temperature is called **normal lapse rate.** There is seasonal variation in the height of troposphere.

In other words, the height of troposphere changes from equator towards the poles (decreases) and from one season of a year to other season (increases during summer while it decreases during winter). The average height of the troposphere is about 16 km over the equator and 6 km over the poles. The upper limit of the troposphere is called **tropopause** which is about 1.5 km thick. The height of tropopause is 17 km over the equator and 9 to 10 km over the poles.

There is also seasonal variation in the height of tropopause. Its height is 17 km during January and July over the equator and the temperature at this height is –70°C. The height of tropopause during July and January over 45°N latitude is 15 km (temperature –60°C) and 12.5 km (temperature –58°C) respectively. The height decreases further poleward as it is 10 km during July (temperature –45°C) and 9 km during January (temperature –58°) over the north pole. It is apparent that temperature at the top of tropopause is lowest over the equator (–70°C) and is relatively high over the poles. Since temperature decreases upward at the rate of 6.5°C per 1000m and hence it is natural that temperature at the height of 17 km over the equator becomes much lower than at the height of 9–10 km over the poles. The word troposphere literally means 'zone or region of mixing' whereas the word tropopause means 'where the mixing stops'.

(2) Stratosphere

The layer just above the troposphere is called stratosphere but there is contrasting opinion about the height and thickness of this layer. The average height over the middle latitudes has been determined to be 25–30 km, whereas it is estimated to be 80 km by others. On an average the upper limit of the stratosphere is taken to be 50 km. There is also contrasting opinion about the change or no change of temperature with increasing height in this sphere. A few scientists believe that the stratosphere is isothermal i.e. there is no change in temperature with increasing height while others hold that temperature gradually rises upward as it becomes 0°C or 32°F at the height of 50 km, the upper limit of the stratosphere which is known as **stratopause.** Though the stratosphere is more or less devoid of major weather phenomena but there is circulation of feable winds and cirrus cloud in the lower stratosphere. The lower part of this layer is very important for life-forms in the biospheric ecosystem because there is concentration of ozone between the height of 15-30 km though ozone has been discovered upto the height of 80 km.

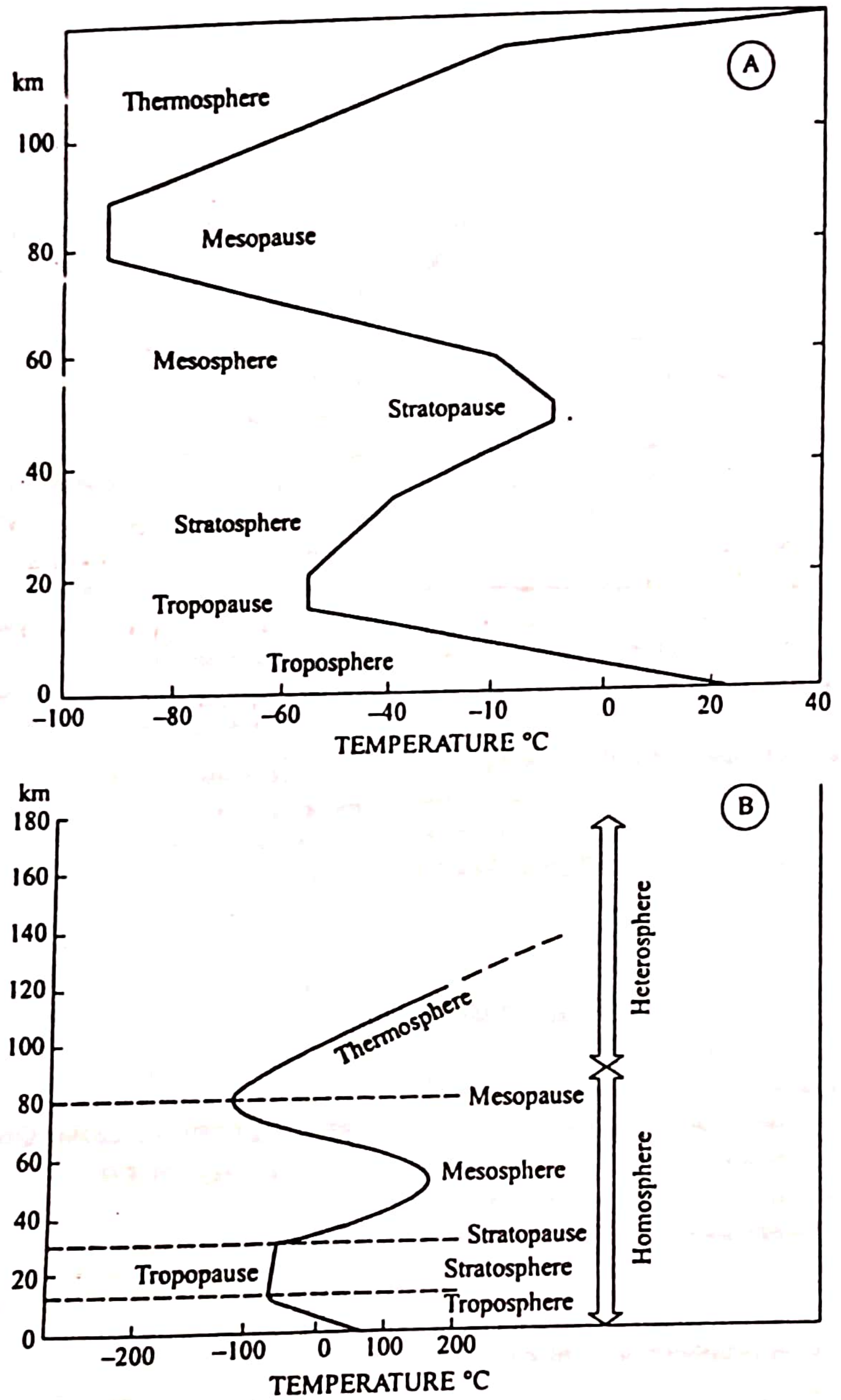

Fig. 32.1 : Stratification of the atmosphere. A– According to Bary and Chorley. B– According to A.N. Strahler.

The lower portion of the stratosphere having maximum concentration of ozone is called **ozonosphere,** which is confined between the height of 15 km to 35 km from sea level though the upper limit has been fixed at 55 km. Ozone (O_3) defined as 'a three-atom isotope of oxygen or merely a triatomic form of oxygen (O_3)' is a faintly blue irritating gas with a characteristic pungent odour. The ozone gas is unstable because the creation and destruction of this gas is a gradual and continuous natural process. It acts as a protective cover for the biological communities in the biosphere because it absorbs almost all of the ultra-violet rays of solar radiation and thus protects the earth's surface from becoming too hot. Recently, the researches have shown that there is gradual depletion of ozone gas in the atmosphere due to human activities.

It may be pointed out that combining of atmospheric oxygen (O_2) with individual oxygen molecules results in the creation of ozone ($O_2 + O \rightarrow O_3$) whereas the breaking of ozone (O_3) into O_2 and O results in the depletion or destruction of ozone. The main culprits of ozone destruction are halogenated gases called chlorofluorocarbons, halons and nitrogen oxides. The chlorofluorocarbons, popularly known as CFCs, belong to the category of synthetic chemicals and are relatively simple compounds of the elements chlorine, fluorine and carbon and are initially stable compounds which do not have any toxic effect on life processes in the biosphere at ground level.

These synthetic chemicals are widely used as propellants in spray can dispensers, as fluids in air conditioners and refrigerators etc. Chlorofluorocarbons, when used as propellants, are released into the air and are transported in the stratosphere by vertical atmospheric circulation. Chlorine when separated from chlorofluorocarbons reacts with water and thus depletes ozone rather breaks ozone into O_2 and O. Besides, nitrogen oxides released by supersonic jets which fly at the height of 18–22 km also depletes ozone. Depletion of ozone would result in the rise of temperature of the ground surface and lower atmosphere. This would cause global warming, acid rain, melting of continental glaciers and rise in sea level, skin cancer to white-skinned people, poisonous smogs, decrease in photosynthesis, ecological disaster and ecosystem instability.

(3) Mesosphere

Mesosphere extends between 50 km and 80 km. Temperature again decreases with increasing height. In fact, the rise of temperature with increasing height in the stratosphere stops at stratopause. At the uppermost limit of mesosphere (80 km) temperature becomes –80°C. This limit is called **mesopause** above which temperature increases with increasing height.

(4) Thermosphere

The part of the atmosphere beyond mesopause is known as thermosphere wherein temperature increases rapidly with increasing height. It is estimated that the temperature at its upper limit (height undecided) becomes 1700°C. It may be pointed out that this temperature cannot be measured by ordinary thermometer because the gases become very light due to extremely low density. That is why one does not feel warm when one stretches one's arm in the air. Thermosphere is divided into two layers viz. (i) ionosphere, and (ii) exosphere.

(1) Ionosphere extends from 80 km to 640 km. There are a number of ionic layers (with increasing heights) in this sphere e.g. D layer, E layer, F layer, and G layer. **D layer** (between the height of 60 km – 99 km) reflects the signals of low frequency radio waves but absorbs the signals of medium and high frequency waves. This layer disappears with the sunset because it is associated with solar radiation. **E layer,** also known as **Kennelly – Heaviside layer,** is confined in the height between 99 km – 130 km. This layer reflects the medium and high frequency radio waves back to the earth. This layer is produced due to interaction of solar ultra–violet photons with nitrogen and nitrogen molecules and thus it also disappears with the sunset.

Sporadic E layer is associated with high velocity winds and is created under special circumstances. This layer reflects very high frequency radio waves. **E_2 layer** is generally found at the height of 150 km and is produced due to reaction of ultra–violet solar photons with oxygen molecules and thus this layer also disappears during nights. **F layer** consists of two sub-–layers e.g. F_1 and F_2 layers (150 km – 380 km) and are collectively called **'appleton layer'.** These layers reflect medium and high frequency radio waves back to the earth. **G layer** (400 km and above) most probably persists day and night but is not detectable.

(2) Exosphere represents the uppermost layer of the atmosphere. In fact, we know very little about the atmosphere extending beyond 640 km height from the sea level. The density becomes extremely low and the atmosphere resembles a nebula because it is highly rarefied. The temperature becomes 5568°C at its outer limit but this temperature is entirely different from the air temperature of the earth's surface as it is never felt.

32.3 CHEMICAL COMPOSITION OF THE ATMOSPHERE

On the basis of chemical composition, the atmosphere is divided into two broad zones viz. (1) homosphere, (2) heterosphere.

(1) Homosphere represents the lower portion of the atmosphere and extends upto the height of 90 km from sea level. The main constituent gases are oxygen (20.946%) and nitrogen (78.084%). Other gases are argan, carbon dioxide, neon, helium, krypton, xenon,. hydrogen etc. This zone is called homosphere because of the homogeneity of the proportion of various gases. In other words, the proportions of different gases are uniform at different levels in this zone. It may be pointed out that man is increasingly disturbing the natural proportions of gases through his everincreasing economic activities and modern technologies. For example, the proportion of carbon dioxide is rapidly increasing due to burning of fossil fuels (coal, petroleum and natural gas) and deforestation.

The concentration of atmospheric carbon dioxide at the beginning of the industrial revolution (1860 A.D.) was fixed at 280 to 290 ppm (parts per million) by volume but now it has increased to 350–360 ppm (1988 A.D.) thus registering an overall increase by 25 per cent from the pre–industrial level. On the other hand, the proportion of ozone gas is rapidly decreasing due to everincreasing production and consumption of CFCs (chloro-fluorocarbons) and halogenated gases. On the basis of thermal conditions the homosphere has been divided into three layers viz. (i) **troposphere**, (ii) **stratosphere**, and (iii) **mesosphere.**

(2) Heterosphere extends from 90 km to 10,000 km. Different layers of this sphere vary in their chemical and physical properties. There are four distinct layers of gases in this sphere. (i) **Molecular nitrogen layer** is dominated by molecular nitrogen and extends upward upto the height of 200 km (90 to 200 km). (ii) **Atomic oxygen layer** extends from 200 to 1100 km. (iii) Further upward there is **helium layer** which extends upto the height of 3500km. (iv) **Atomic hydrogen layer** is the topmost layer of the atmosphere and extends upto the outermost limit of the atmosphere.

32.4 ELEMENTS OF WEATHER AND CLIMATE

Weather refers to the sum total of the atmospheric conditions in terms of temperature, pressure, wind, moisture, cloudiness, precipitation and visibility of a particular place at any given time. In fact, weather denotes short–term variations of atmospheric conditions and it is highly variable. On the other hand, climate is defined as aggregate weather conditions of any region in long–term perspective.

According to Trewartha 'climate represents a composite of day to day weather conditions, and of the atmospheric elements, within a specified area over a long period of time.' According to Critchfield 'climate is more than a statistical average; it is the aggregate of atmospheric conditions involving heat, moisture, and air movement. Extremes must always be considered in any climatic description in addition to means, trends, and probabilities.' According to Koeppen and De Long 'climate is a summary, a composite of weather conditions over a long period of time; truly portrayed, it includes details of variations–extremes, frequencies, sequences–of the weather elements which occur from year to year, particularly in temperature and precipitation.

Climate is the aggregate of the weather.' G.F. Taylor has maintained that 'climate is the integration of weather, and weather is the differentiation of climate. The distinction between weather and climate is, therefore, mainly one of time.' Temperature, pressure, wind, humidity, precipitation, cloudiness etc. are elements of weather and climate.

32.5 CONTROLS OF WEATHER AND CLIMATE

There are frequent changes in weather conditions. These changes from one day to the other or from one place to the other are due to variations in the quantity, intensity and distribution of the elements of weather and climate. Similarly, there is variation in climatic conditions from one area to the other area. The factors controlling the variations of the elements of weather and climate from one place to the other place and from one season to the other season are called controls of weather and climate. These factors include latitudes, altitudes, unequal distribution of land and water, ocean currents, air pressure and wind, mountain barrier, nature of ground surface, different types of atmospheric storms etc.

32.6 IMPORTANT DEFINITIONS

Auroras : are cosmic glowing lights produced by a stream of electrons discharged from the sun's surface due to magnetic storms. Auroras (borealis-northern, australis-southern) are seen as unique multicoloured fireworks hanging in the polar sky during mid-night in the exosphere and magnetosphere.

Boyle's gas law : pertains to relationships among air pressure, volume of gas and its density.

Charle's gas law : shows relationship between air pressure and temperature with constant gas volume.

Cold point : the height at which (tropopause) decrease of temperature with increasing altitude stops is called cold point.

Combined gas law : is related to derive any one variable with two known variables.

Lussac's gas law : shows relationship among pressure, volume of gas and temperature.

Mesopause : is the upper limit (80 km) of mesosphere.

Noctilucent clouds : formed through the process of condensation in association with meteoric dusts and some moisture transported upward by convective mechanisms, are noticed during summer season over polar areas.

Stratopause : is the upper limit (50 km) of stratosphere.

Tropopause : is the upper limit (16 km over equator) of troposphere.

cold winds set in.

38.7 CYCLONES

Cyclones are centres of low pressure surrounded by closed isobars having increasing pressure outward and closed air circulation from outside towards the central low pressure in such a way that air blows inward in anticlockwise in the northern hemisphere and clockwise in the southern hemisphere (fig. 38.5). Cyclones are also termed as atmospheric disturbances. They range in shape from circular, elliptical to 'V' shape.

When the velocity of winds increases to such an extent that they attain gale force, the atmospheric disturbance or cyclone is called a **cyclonic storm.** From the locational point of view cyclones are classified into two principal types *e.g.* (i) extratropical cyclones (also called as temperate cyclones or wave cyclones) and (ii) tropical cyclones.

38.8 TEMPERATE CYCLONES

Temperate cyclones, also called as **extratropical cyclones** or **wave cyclones** or simply **depressions** are atmospheric disturbances having low pressure in the centre and increasing pressure outward. They are in fact low pressure centres produced in the middle latitudes characterized by converging and rising air, cloudiness and precipitation. Because of their varying shapes such as near circular, elliptical or wedge (V) they are variously called as **'low'**, **'depressions'** or **'troughs'**. They are formed in the regions extending between 35^0-65^0 latitudes in both the hemispheres due to convergence of two contrasting air masses *e.g.* warm, moist and light tropical air masses (westerly winds) and cold, and dense polar air masses.

The polar fronts created due to these two opposing air masses are responsible for the origin and development of temperate cyclones. After their formation temperate cyclones move in easterly direction under the influence of westerly winds and control the weather conditions in the middle latitudes.

Types of Temperate Cyclones

Though temperate cyclones are mainly originated due to convergence of two contrasting air masses in terms of temperature, pressure, and humidity but some local cyclones also form due to other reasons related to temperature variations and consequent pressure differences. Based on above considerations temperate cyclones are divided into 3 categories viz. (i) dynamic cyclones, (ii) thermal cyclones, and (iii) secondary cyclones.

(1) Dynamic cyclones are, in fact, real temperate cyclones because they are formed due to convergence of cold polar air masses and warm and moist maritime tropical air masses. These cyclones affect the weather conditions of very large areas in middle latitudes. Different fronts (*e.g.* warm front and cold front) and sectors (*e.g.* warm and cold sectors) are fully developed in dynamic cyclones. They are called dynamic because they are dynamically produced *e.g.* due to convergence and invasion of two contrasting air masses into the territories of one another.

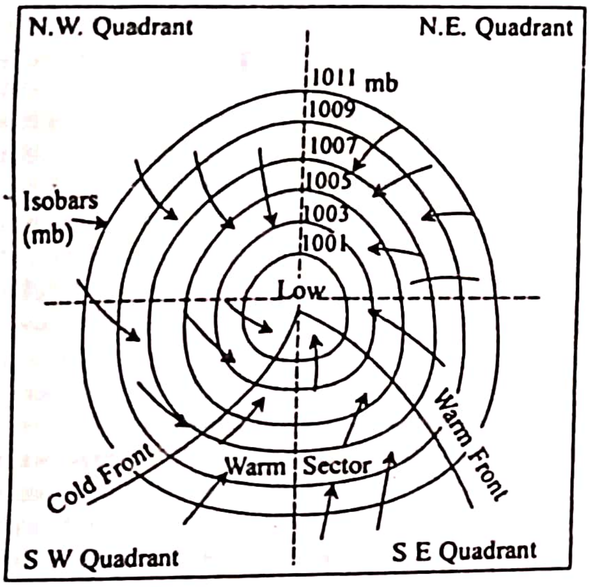

Fig. 38.5 : An average temperate cyclone in northern hemisphere.

(2) **Thermal cyclones**-According to Brunt thermal cyclones are formed due to development of low pressure centres on the continents in summers in temperate regions and as such winds blow from all directions towards the low pressure centres. Such thermally induced temperate cyclones are stationary at their places of origin and different fronts are not developed. Such thermally induced cyclones in the middle latitudes have been named by Humphreys **insolation cyclones.**

According to Humphreys thermal cyclones are produced due to development of low pressure centres over warm water surfaces of seas surrounded by cold land surfaces during winter season. It may be pointed out that both types of cyclones as referred to above are, in fact, thermal cyclones because they are directly related to insolation. The only difference is that they develop over land surfaces in summers (*e.g.* over Iberian Peninsula, Alaska, S. W. USA, and N. W. Australia) and over sea surfaces in winters (e.g. over Okhotsk Sea, Norwegian Sea, to the south of Iceland and Greenland etc.).

(3) **Secondary cyclones** are those which develop due to passage of cold winds over warm sea after the occlusion of main cyclone. They are short-lived and very weak.

Shape, Size and Velocity

Temperate cyclones are of different shapes *e.g.* circular, semi-circular, elliptical, elongated or 'V' shaped, but all of them are characterized by low pressure in their centres and closed isobars. The pressure difference between the centre and periphery is about 10 to 20mb but some times it increases to 35mb. It means that pressure increases from the centre towards outer margin. Temperate cyclones also greatly vary in size and extent. Average large diameter of an ideal cyclone is about 1900km (1200 miles) while short diameter measures 1000km (640 miles).

It may be pointed out that no two cyclones are identical in terms of their size as their diameters range from 150km to more than 3000km. Some times, temperate cyclones are so large and extensive that they cover an area of 1,000,000 square kilometres. The vertical extent of an average cyclone is about 10-12 km. The temperate cyclones move eastward under the influence of westerly winds with average velocity of 32km per hour in summers and 48km per hour in winters.

Wind System

Since there is low pressure in the centre of temperate cyclone and air pressure increases outward and hence winds blow from the periphery towards the centre but these winds do not reach the centre straight rather they cut the isobars at the angle of 20^0 to 40^0 due to friction and coriolis force and thus wind direction becomes anticlockwise in the northern hemispere and clockwise in the southern hemisphere.

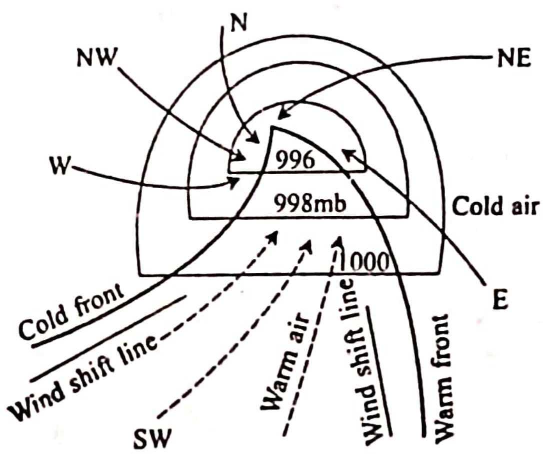

Fig. 38.6 : Wind pattern in temperate cyclone (northern hemisphere).

The centre-bound inward air circulation becomes of convergent pattern but the winds do not aggregate at the centre but they ascend upward and expand outward so that low pressure centre is always maintained so long as the cyclone is alive. Since temperate cyclones are formed due to convergence of two contrasting air masses (*i.e.* cold, dry and dense air mass and warm, moist and light air mass) and hence it is natural that there are variations in the nature and direction of winds in different parts of the cyclones.

The tropical and subtropical warm and moist air is of generally westerly direction while polar cold air is generally easterly. The convergence of these air masses forms warm front, warm sector, cold front, and cold sector. Before the arrival of warm front the wind direction is easterly but it changes to southerly and southwesterly at the time of the arrival of warm front.

The warm front and warm sector are, thus, characterized by warm southerly and southwesterly winds while the direction of winds changes to westerly, northwesterly and northerly at the arrival of cold front and cold sector. The cold front and cold sector are characterized by cold winds. It is apparent that there is sudden change in wind direction along the warm and cold fronts. The line along which wind changes its direction is called wind shift line (fig. 38.6).

Temperature

Different temperatures are noted in different parts of temperate cyclones because of their origin due to convergence of two thermally contrasting air masses. The southern part of cyclone records higher temperature because of the dominance of warm air while the north-eastern, northern and north-western parts record low temperature because of the dominance of cold polar air mass.

The western part records lowest temperature. The temperature within the cyclones depends on the properties of air masses, general weather conditions and moisture content in the air. Isotherms generally tend in north-northeast to southwest direction (fig. 38.7) in the northern hemisphere.

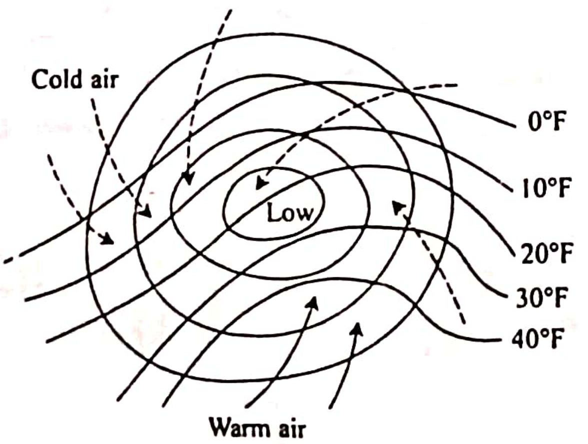

Fig. 38.7 : Temperature and isotherms in temperate cyclones (northern hemisphere).

Source Regions and Tracks of Movement

The areas frequented by temperate cyclones mostly lie in the middle and high latitudes extending between 35°-65° latitudes in both the hemispheres. These cyclones move, on an average, in easterly direction but since their tracks are highly variable and hence cyclonic tracks are always considered in zonal pattern rather than in linear pattern.

The paths followed by these cyclones are called **'storm tracks'**. The following are the most favourable breeding areas of temperate cyclones. (1) Cyclones after originating in the north Pacific off the north-east and eastern coasts of Asia move in easterly and northeasterly direction towards the Gulf of Alaska and ultimately merge with Aleutian Lows from where they follow southerly direction and reach as far south as southern California. The cyclones moving inland dissipate and are occluded at the windward western slopes of the Rocky mountains. (2) There are four principal areas of frontogenesis in North America *e.g.* (a) area east of Sierra Nevada Range, (b) eastern Colorado, where temperate cyclones are called **Colorado Lows,** (c) area east of Canadian Rocky mountains, where cyclones are known as **Alberta Lows,** and (d) Great Lakes region, (3) The cyclones originating in the Gulf of Mexico follow northerly trajectory to the east of the Appalachians and following the course of the Gulf Stream merge with the Icelandic Zone of frontogenesis. (4) North-west North Atlantic off the north-east coast of North America- the cyclones originating in this area move in easterly direction and enter the northwestern parts of Europe. (5) Cyclones originating in the area between Iceland and Barents Sea follow easterly trajectory and affect the weather conditions of north Europe. (6) There are two main zones of frontogenesis in continental Europe *e.g.* (a) Baltic Sea and (b) Mediterranean Sea.

Some of the cyclones originating over the Mediterranean Sea after following easterly direction reach Pakistan and north India in winter season where most of the winter precipitation is received through these storms. Majority of the cyclones of Mediterranean origin move north-eastward and reach Commonwealth of Independent States (CIS, some Republics of former USSR).

Weather Conditions Associated With Temperate Cyclones

Different parts of temperate cyclones are associated with varying weather conditions because of different types of air masses and varying temperature conditions. The observation point of a moving temperate cyclone experiences different weather conditions at the time of arrival and passage of warm front, warm sector, cold front and cold sector.

(i) **Arrival of Cyclone-**When the cyclone coming from the western direction draws nearer to the observation point, wind velocity slows down considerably, air pressure decreases and the sun and the moon are encircled by halo which is infact the reflection of thin veneers of cirrus and cirrostratus clouds in the west. Temperature suddenly increases when the cyclone comes very close to the observation point, wind direction changes from easterly to south-easterly, the cloud cover thickens and the sky becomes overcast with dark, thick and low clouds.

(ii) **Warm Frontal Precipitation**-Clouds become very thick and dark with the arrival of warm front of the cyclone and heavy showers begin with nimbostratus clouds. Since the warm air rises slowly along the front, and hence the precipitation is slow, gradual but of long duration.

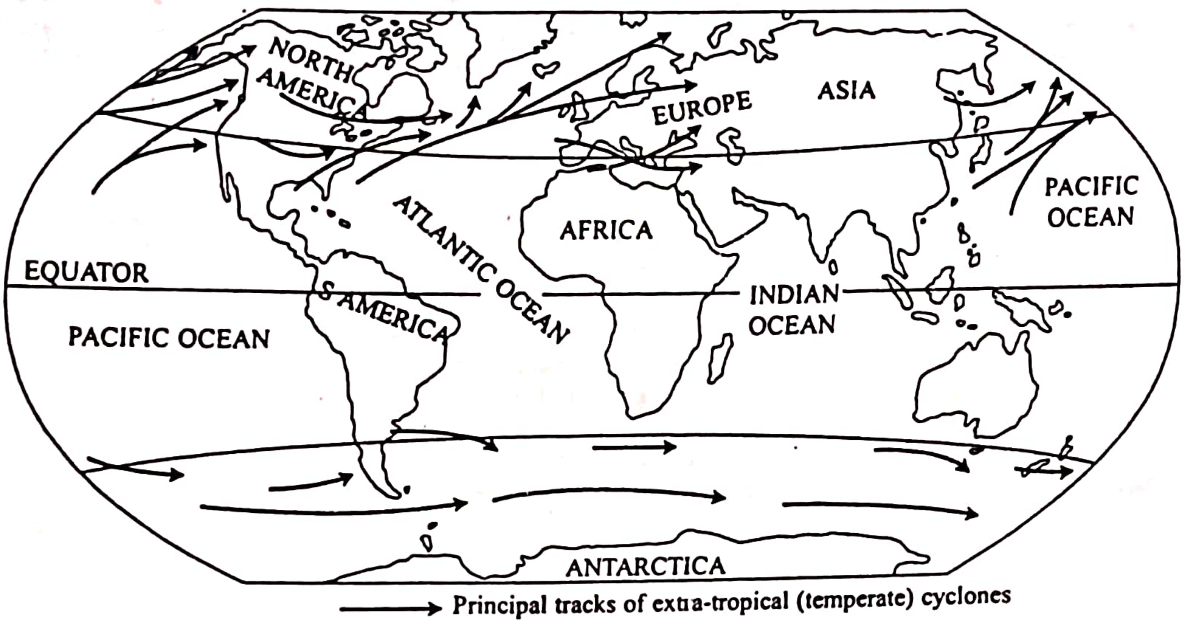

Fig. 38.8 : Principal tracks of temperate cyclones.

The warm frontal precipitation largely depends on the amount of moisture and instability of the rising warm air. If the air is full of moisture and is unstable, there is sufficient precipitation, the sky is overcast and the sun is not visible for several hours.

(iii) **Warm Sector**-The warm sector comes over the observation point after the passage of warm front and there is sudden change in the pre-existing weather conditions. The wind direction becomes southerly. The sky becomes cloudless and clear. There is sudden rise in air temperature and increase in the specific humidity of the air but air pressure decreases remarkably. Though weather becomes clear but there may be some occasional drizzles. In all, the weather is clear and pleasant.

(iv) **Cold Front**-Temperature registers marked decrease with the arrival of cold front. Cold increases considerably. The cold air pushes the warm air upward and there is change in wind direction from southerly to south-westerly and westerly. Sky is again covered with clouds which soon start precipitation.

(v) **Cold Frontal Precipitation**-Sky becomes overcast with cumulonimbus clouds which yield heavy showers. Since the warm air is forcibly lifted upward hurriedly, the cold frontal precipitation is in the form of heavy downpour with cloud thunderand lightning but the precipitation is of short duration and less widespread because the cold sector is very close.

(vi) **Cold Sector**-Weather again changes remarkably with the passage of cold front and arrival of cold sector. Sky becomes cloudless and hence clear. There is sharp fall in air temperature and considerable rise in air pressure but decrease in specific humidity. Wind direction changes from 45^0 to 180^0 and thus it becomes true westerly. After the occlusion of cyclone the weather conditions of pre-cyclone period again set in.

Origin of Temperate Cyclones

No commonly acceptable theory of the origin of temperate cyclones could be propounded as yet. The first pioneer serious attempt was made by Fitzroy in the year 1863 in this precarious field. He postulated that extratropical or temperate cyclones originated because of the convergence of two opposing air masses of contrasting physical properties (*i.e.* temperature, pressure, density and humidity). In 1911 Shaw and Lempfert pointed out that temperate cyclones originated due to inflow of winds from all directions towards the centre. The theory of cyclongenesis as propounded by Shaw and Lempfert is known as **dynamic theory**. At a later date **convection current theory** was postulated to explain the origin of temperate cyclones but this theory was severely criticised and discarded.

Thereafter came **eddy theory** according to which temperate cyclones originate due to the formation of eddies caused by obstructions in the advancing air masses. Two Norwegian meteorologists, V. Bjerknes and J. Bjerknes put forth 'polar front theory', also knows as **wave theory** or **Bergen theory** in the year 1918 to explain the origin of extratropical cyclones. Lately, **baroclinic wave theory** was formulated for cyclone development on the basis of recent data from middle and upper troposphere derived through satellites and radars.

Polar front theory also called as **'frontal theory'** or **'wave theory'** or **Bergen theory** as propounded by V. Bjerknes and J. Bjerknes in 1918, is primarily based on the processes of the formation of fronts. It may be pointed out that fronts are formed due to convergence of two air masses of different physical properties coming from opposite directions.

One air mass is polar in character and is cold, denser and north-easterly in direction while the other air mass is tropical or subtropical in origin and is warm, moist, lighter and south-westerly in direction (in the northern hemisphere). When these two contrasting air masses converge along a line in the middle latitudes (temperate regions), they move parallel to each other and thus a **stationary front** is formed (fig. 38.8A). No cyclone can develop from such stationary front because there is no vertical movement in the air, rather winds are more or less stable.

On the other hand, when two opposing air masses collide against each other and try to attack the territory of one another, **unstable waves** are formed which help in the origin and development of temperate cyclones (fig. 38.8B). In the beginning the surface separating two air masses (more technically called as **surface of discontinuity**) is almost straight but it becomes unstable and wave-like when the warm and cold air masses attempt to penetrate in the regions of one another. Such unstable wavy front is called **polar front.**

When south-westerly warm and moist air mass enters the territory of cold polar air mass along the polar front, it being lighter rises upward, with the result a centre of low pressure is formed. Now winds from all directions rush up towards this centre of low pressure and thus a cyclone is formed.

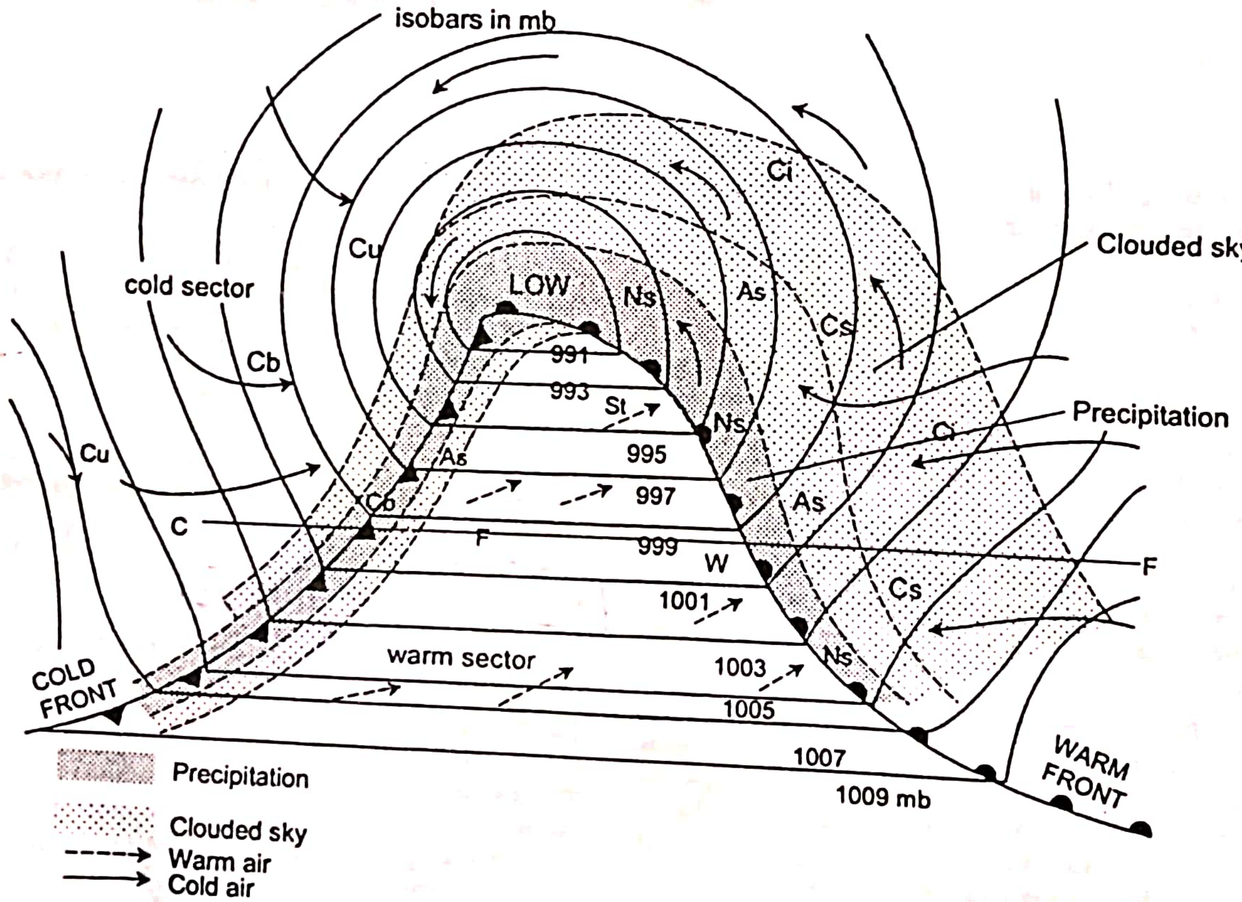

Fig. 38.9 : A section through a fully developed temperate cyclone and wealther phenomena assoicated with different fronts and sectors. WF = vertical cross-section along warm front (fig. 11.10). CF = vertical cross-section along cold front (fig. 11.11), Ns = nimbostratus cloud, Cs = cirro-stratus cloud, As = alto-stratus clouds Cb = cumulonimbus cloud.

It may be pointed out that the cyclone forming wave developed due to convergence of cold and warm air masses is divided into two parts *e.g.* the eastern part of the wave, where eastward advancing warm tropical or subtropical air mass ascends over a wedge of cold air mass is called **warm front** (fig. 38.8C) while the western part, where cold polar air mass pushes warm air mass upward forcibly, is called **cold front** (fig. 38.8C).

It is to be remembered that warm air mass is aggressive along the warm front where it overrides cold air mass whereas the cold air mass becomes aggressive along the cold front because it replaces warm air by pushing it upward. The south-western and north-western sectors of the cyclone are called **warm sector** and **cold sector** respectively.

The low pressure in the eastern part of the cyclone is intensified with the arrival of warm air. This draws the winds towards the centre from nearby areas, with the result cold front advances more rapidly than warm front. Consequently, cold and warm fronts come close to each other resulting into the destruction of warm front.

The cyclone dies due to disappearance of warm front. This process of cyclone destruction is called **occlusion** (fig. 38.8E and F). Some times, weak and feable minor cyclone is formed after the occlusion of main cyclone. Such **secondary cyclone** is called **subcyclone.** Secondary cyclone is generally formed when some warm air still remains in the cold front after the occlusion of main front with the result a centre of low pressure is re-established and winds blow towards this centre from all sides forming a new weak cyclone.

It may be pointed out that though the formation and development of temperate cyclones is a quick process but it passes through a series of successive stages. The period of a cyclone from its inception (cyclogenesis) to its termination (frontolysis or occlusion) is called the **'life cycle of cyclone'** which is completed through six successive stages (fig. 38.8).

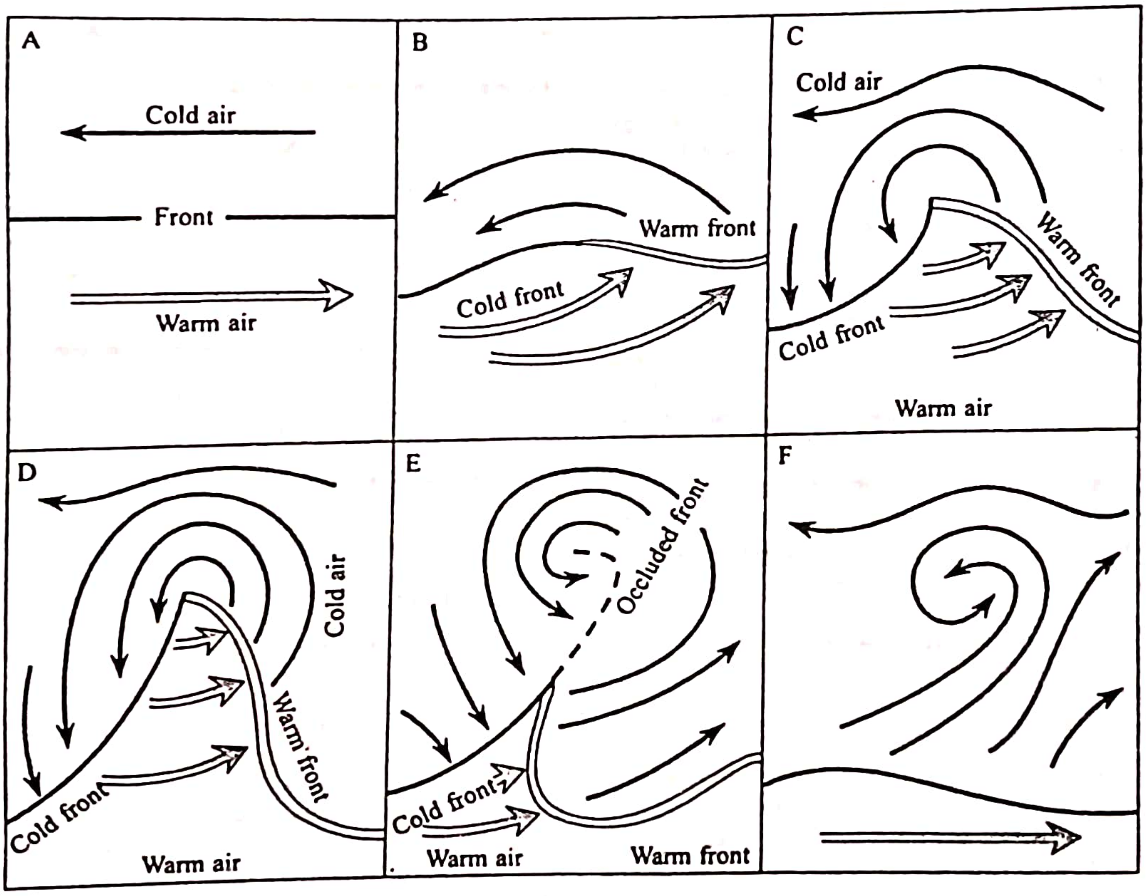

Fig. 38.10 : Stages of life-cycle of a cyclone.

(1) **First stage** involves the convergence of two air masses of contrasting physical properties and directions. Initially, the air masses (warm and cold) move parallel to each other and a stationary front is formed. This is called initial stage.

(2) **Second stage** is also called as 'incipient stage', during which the warm and cold air masses penetrate

into the territories of each other and thus a **wave-like front** is formed.

(3) **Third stage** is the mature stage when the cyclone is fully developed and isobars become almost circular.

(4) **Fourth stage**-warm sector is narrowed in extent due to the advancement of cold front than warm front, as cold front comes nearer to warm front.

(5) **Fifth stage** starts with the occlusion of cyclone when the advancing cold front finally overtakes the warm front and an occluded front is formed.

(6) **Sixth stage**—warm sector completely disappears, occluded front is eliminated and ultimately cyclone dies out.

24

RELIFES OF THE OCEAN BASINS

Q.3. Ocean Bottom :-

24.1 INTRODUCTION

About three-fourth of the globe is covered by hydrosphere. Out of the total surface area of the globe (509, 950, 000 km^2) hydrosphere and lithosphere cover 361,060,000 km^2 (about 71 per cent) and 148,890,000 km^2 (about 29 per cent) respectively. The hydrosphere is divided on the basis of size and location into oceans, inland seas, small enclosed seas, bays etc. The Pacific Ocean (165,000,000 km^2), the Atlantic Ocean (82,000,000 km^2) and the Indian Ocean (73,000,000 km^2) are important among the oceans whereas significant seas are Arctic Sea, Malay Sea, Middle American Sea, Mediterranean Sea, Bering Sea, Barnets Sea, Kara Sea, East Siberian Sea, Japan Sea, East China Sea, Okhotsk Sea, Yellow Sea, Andman Sea, South China Sea, Yellow Sea, Caribbean Sea, North Sea, Celebes Sea, Labrador Sea, Beaufort Sea, Arabian Sea, Red Sea etc. Like lithosphere, the hydrosphere is also characterized by various types of relief features like mid-oceanic ridges, trenches, deep sea plains, basins, submarine canyons etc.

The average depth of the oceans is 3,800 m against the 840m average height of the lithosphere. The different height and depth zones of the lithosphere and the hydrosphere are represented by hypsographic or hypsometric curve. The ocean basins are characterized by four relief zones *e.g.* continental shelves, continental slopes, deep sea plains and oceanic trenches (fig. 24.1).

World's Largest Underground Ocean

The world's largest underground **'ocean'** i.e. **'subterranean water body'** was discovered in the year 2007. This massive underground ocean extends from Indonesia to the northern tip of Russia for a length of 700 to 1400 km below the ground surface. This subterranean water body has been formed due to subduction of plate carrying the bottom of the Pacific Ocean under continental plate and infiltration of immense volume of water therein.

24.2 CONTINENTAL SHELF

The continental marginal areas submerged under oceanic water with average water depth of 100 fathoms (one fathom = 6 feet) and gently sloping (1^0-3^0) towards the sea or the oceans are called continental shelves. The width of continental shelves largely depends on the nature of reliefs of the coastal land *i.e.* (1) the shelves are narrow where high mountains are very close and parallel to the coast (*e.g.* the Pacific continental shelf along the western coast of S. America is narrow (16 km) because of the presence of the Andes mountain), and (2) the shelves are wider where the coast lands are wide plains.

Though the continental shelves are generally wider in front of river mouths but the shelf off the Mississippi mouth is exceptionally narrow. On an average, the width of continental shelves is about 48 km though Sheppard has taken 67km (42 miles) as average width. The Pacific continental shelf of South

America represents the example of narrow shelf (16 km), the Atlantic continental shelf off the east coast of North America represents the example of medium size shelves (96-120 km) and extensive shelves having width of a few hundred kilometres are found off the coast of East Indes, in the Arctic Sea, China Sea, Adriatic Sea, Arafura Sea etc. Continental shelves represent 8.6 per cent of the total area of the ocean basins. Regionally these cover 13.3 per cent, 5.7 per cent and 4.2 per cent of areal coverage of the Atlantic Ocean, the Pacific Ocean and the Indian Ocean respectively.

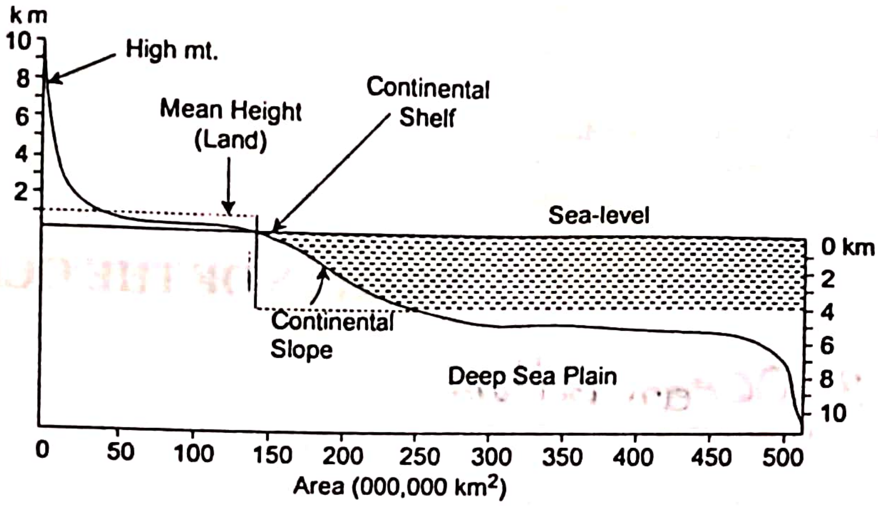

Fig. 24.1 : Hypsometric/hypsographic curve.

The maximum seaward limit of the continental shelves off the Indian coast is demarcated by 100 fathom contour. The continental shelves along the eastern and the western coasts of India are 50 km and 150 km wide respectively. The shelves are narrow (30-35 km) off the mouths of the Ganga, the Mahanadi, the Godawari, the Krishna and the Cauvery rivers but these are wider off the estuaries of the Narmada, the Tapi and the Mahi rivers. The average slope of the continental shelves off the eastern Indian coast is about 21^0 whereas it is 10^0 near Cape Comorin and only 1^0 near the Gulf of Combay.

Origin of Continental Shelves

The Nature, composition, extension and depth of continental shelves are so varied that it becomes difficult to explain their exact mode of origin through a single mechanism and process. The following different views have been expressed by several authorities to explain the complex origin of continental shelves—

(1) Continental shelves are basically the extended form of continental platforms. Marine waves and currents erode the continental margins and thus form extensive platforms which receive deposits of sediments brought down by the rivers and sea waves. These sediments are continuously consolidated under sea water and ultimately extensive continental shelves are formed. Thus, the continental shelves are the result of marine erosion and fluvial deposits.

(2) Continental shelves are formed through prolonged deposition of detritus (under sea water) brought by the rivers alone. Such type of continental shelves is formed only in those areas where sea conditions are calm so that prolonged sedimentation goes on uninterruptedly resulting into subsidence and thus allowing more and more sedimentation. Such continental shelves are constructional and are most extensive.

(3) Rising thermal convective currents from beneath the continents and the ocean basins converge along the continent-ocean boundary and descend. The resultant compressive force causes subsidence of the continental margins and thus continental shelves are formed.

(4) Some times, parallel faults are created in the continental margins. This event causes subsidence of the marginal land areas and consequent submergence under sea water. Such submerged land areas become continental shelves, which are generally called as **tectonically formed continental shelves.**

(5) Continental shelves are formed through marine erosion of the continental margins when there is negative change in sea-level (fall in sealevel) either during ice ages or due to subsidence of oceanic floors. According to R.A. Daly the sea level fell by 38

fathoms during Pleistocene Ice Age, with the result the continental margins which were previously submerged became free from sea water. These exposed land areas were glacially eroded and extensive platforms were formed. Due to deglaciation the sea level rose again and these platforms were submerged under seawater and thus extensive continental shelves were formed. This concept of the origin of the continental shelves belongs to **glacial control theory.**

(6) The coastal lands are effectively eroded through abrasive work of strong sea waves and several sea cliffs are formed. These cliffs gradually but continuously recede towards the land due to basal erosion and consequent fall of their hanging crests and thus extensive wave-cut platforms are formed. These platforms are submerged under sea water to form continental shelves.

(7) The submergence of continental margins due to tilting of land towards the sea results into the formation of continental shelves. This process also leads to the extension of existing continental shelves.

The continental shelves of India have been formed differently. The continental shelves off the Ganga, the Godawari, the Krishna and the Cauvery mouths have been formed through delta formation. The continental shelves from Midinapur to Madura are the result of sedimentation and consequent subsidence while the shelves of Andman Nicobar, Lakshadweep, Gulf of Manar (between India and Sri Lanka) are originated due to coral reefs. The continental shelves of western coast are due to faulting and consequent submergence.

24.3 CONTINENTAL SLOPE

The zone of steep slope extending from the continental shelf to the deep sea plains is called continental slope which varies from 5^0 to more than 60^0 at different places e.g. 40^0 near St. Helena, 30^0 off Spanish coast, 62^0 near St. Paul, 5^0 to 15^0 near Calicut coast (India) etc. The depth of water over continental slope varies from 200m to 2,000m. Continental slopes occupy only 8.5 per cent of the total area of the ocean basins but it varies from one ocean to the other *e.g.* 12.4 per cent in the Atlantic Ocean, 7 per cent in the Pacific Ocean and 6.5 per cent in the Indian Ocean.

The most extensive continental slopes are found between 20^0N and 50^0N latitudes and on 80^0N and 70^0S latitudes. Generally, the steep gradient of the continental slopes does not allow any marine deposits because the materials coming down from the continental shelves are immediately removed downward but in some cases a thin veneer of deposits does exist. The most significant reliefs on the continental slopes are **submarine canyons** and trenches which are generally transverse to the continental shelves and the coasts.

The origin of continental slopes has been related by various authorities to erosional, tectonic and aggradational processes. The erosion theory of the origin of continental slopes is based on the presence of submarine canyons. According to this theory slopes are formed due to erosion by marine processes mainly sea waves. According to tectonic theory faulting is

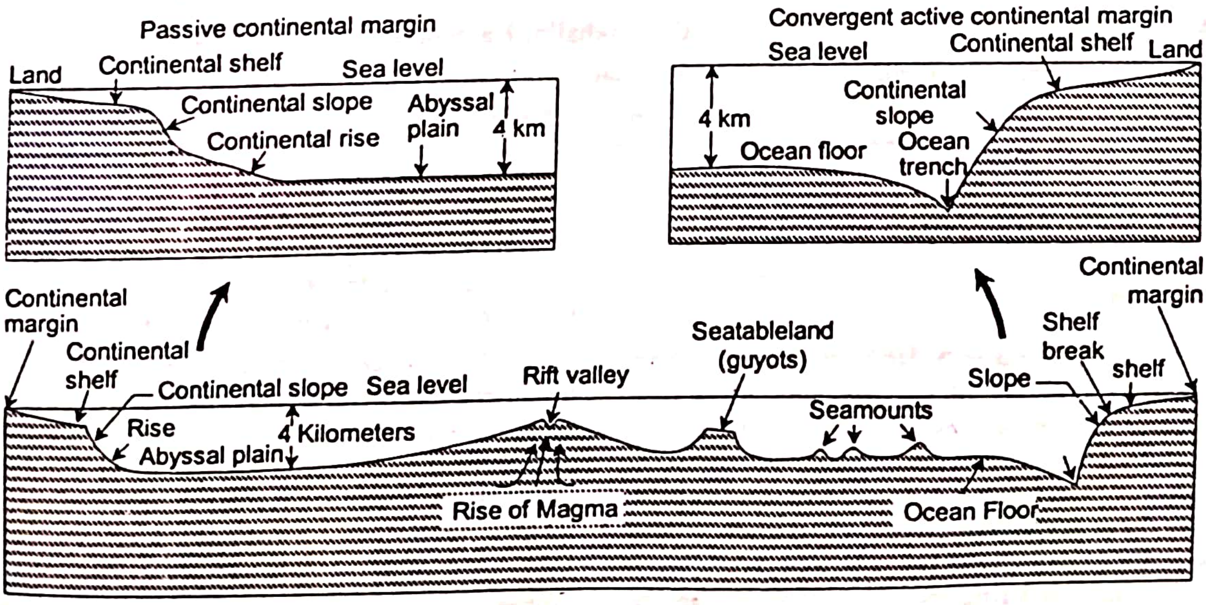

Fig. 24.2 : Configuration of ocean floors; modified from Thurman and Treijillo, 1999.

held responsible for the origin of continental slopes. Some exponents believe that the continental slopes are formed due to bending and warping of continental shelves followed by sedimentation.

24.4 DEEP SEA PLAINS

Deep sea plain characterized by flat and rolling submarine plain is the most extensive relief zone of the ocean basins. These deep-seated plains having the depth from 3000m to 6000m cover 75.9 per cent of the total area of the ocean basins but this areal coverage varies from one ocean to the other (80.3 per cent in the Pacific Ocean, 80.1 per cent in the Indian Ocean and 54.9 per cent in the Atlantic Ocean). Remarkably low areal coverage of deep sea plains in the Atlantic Ocean in comparison to the Pacific and Indian Oceans is attributed to larger extent of continental shelves in the former. Though vast and extensive deep sea plains are generally featureless but a few long, narrow and elongated ridges, guyots etc. are significant reliefs. The submarine ridges with steep side-slopes some times reach the sealevel and even project above the water surface and appear as islands. Mid-Atlantic ridge, East Pacific Rise and mid-Indian Ocean ridge are typical examples. Deep sea plains are characterized by pelagic deposits of plant, marine animal and siliceous remains but there is absence of erosional debris of terrigenous origin. Volcanic deposits have been reported at few places in different oceans.

24.5 OCEAN DEEPS

Ocean deeps representing depressions and trenches on the ocean floors are the deepest zones of the ocean basins. These are generally located parallel to the coasts facing mountains and along the islands. Ocean deeps are grouped into two categories according to size viz. (1) very deep but less extensive depressions are called **deeps** while (2) long and narrow linear depressions are called **trenches**. These deeps and trenches are characterized by very steep slopes. Some times, these rise almost to verticality. These deeps and trenches have been usually named after the explorers and their geographical locations *e.g.* Murray Deep (after J. Murrary), Japan and Sunda Trenches (after geographical location). Out of the explored and surveyed 57 deeps, the Pacific Ocean, the Atlantic Ocean and the Indian Ocean account for 32, 19, and 6 deeps respectively. Mariana Trench located to the west of Philippines in the North Pacific Ocean is the deepest (11.02 km deep) of all the ocean deeps.

Table 24.1 : Major Ocean Deeps

Name	Location	Depth in metres
1. Challenger or Mariana Trench	N. Pacific	11,022m
2. Aldrich or Tonga Trench	Central S. Pacific	10,882m
3. Swire or Philippine Trench	N.W. Pacific	10,475m
4. Nares or Puerto Rico Trench	Off West Indian Islands	8,385m
5. Kurile Trench	Off Sakhalin, Kamchatka	10,498m
6. Tizard or Romanche Trench	S. Atlantic	7,631m
7. Java Trench	E. Indian Ocean	7,450m

24.6 SUBMARINE CANYONS

1. Introduction

Long, narrow and very deep valleys or trenches located on the continental shelves and slopes with vertical walls resembling the continental canyons are called submarine canyons because of their location under oceanic water. On the basis of morphogenetic processes these are classified into (i) **glacially eroded canyons** and (ii) **non-glacial canyons.** The non-glacial submarine canyons being more in number than the glacial canyons and widely spread in all the oceans have been studied in much detail.

The non-glacial canyons, thus, will be described as submarine canyons in the following discussion. These, besides a few exceptions, are found transverse to the coasts and in front of the mouths of major rivers.

On an average, there is little difference in the transverse and longitudinal profiles of submarine and subaerial (continental) canyons. According to Sheppard the submarine canyons are similar to the youthful river valleys on the land but are decidedly deeper and a few of them have dendridtic pattern of tributaries of secondary canyons. The longitudinal course of submarine canyons is usually sinuous while that of the subaerial canyons is generally straight. The gradient of submarine canyons is steeper than the

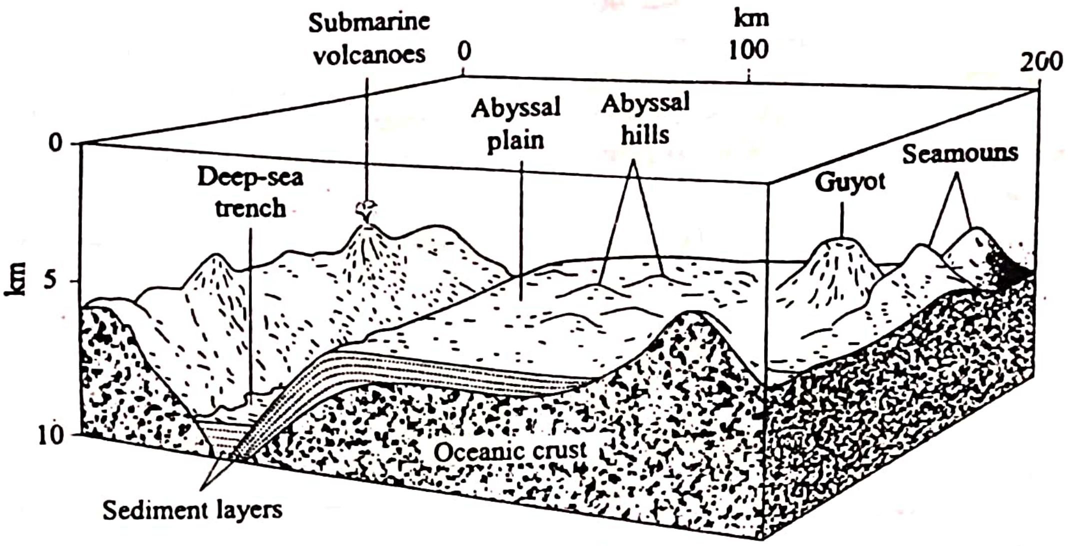

Fig. 24.3 : Morphology of ocean basins, source : based on P. R. Pinet, 2000.

continental canyons. The submarine canyons are generally several kilometres wide at their heads and their average length is 16 km.

Though the gradient of longitudinal profiles of the canyons varies significantly but on an average it is 1.7 per cent. The canyons facing the river mouths are usually long (*e.g.* Congo Canyon) but have gentle gradient. The canyons located near the island are deep with steepest gradient (13.8 per cent). According to the studies of 102 submarine canyons by Sheppard and Beard average gradients of the upper, middle and lower segments of the canyons are 11.62 per cent, 6.63 per cent and 4.76 per cent respectively. The depths of submarine canyons vary from 610m to 915m. At few places the depth has been noted upto 3,048m. The submarine canyons carry various types of ocean deposits but the steep valley sides are devoid of unconsolidated materials. The floors of the canyons have coarser materials than the adjacent continental shelves. The deposits include sands, clays, silt, gravels and pebbles.

Table 24.2 : Submarine Canyons on the East Coast of India

Name of the canyons	Location	Depth	Shape of the valley
1. Cuddalore Canyon	11^{0}35'N-79^{0}56'E	329m	V
2. Pondichery Canyon	11^{0}50'N-80^{0}00^0'E	466m	U
3. Palar Canyon	37km SSE from Palar river mouth 12^{0}06'N-79^{0}52'E	1,141m	V
4. Pulicat Canyon	13^{0}45'N-80^{0}25'E	—	V
5. Armagon Canyon	13^{0}45'N-80^{0}25'E	—	V
6. Swarnamukhi Canyon	14^{0}14'N-80^{0}19'E	80-108m	—
7. Gudur Valley	14^{0}24'N-80^{0}19'E	30-40m	U
8. Penner Canyon	East of Penner river mouth 14^{0}41'N-80^{0}16'E	225m	U
9. Krishna Canyon	Opposite to the Krishna river mouth 15^{0}35'N-80^{0}50'E	30m	V

10. Vasishta Godavari Canyon	16°10'N-81°50'E	30-60m	—
11. Godavari canyon	16°45'N-82°32'E off the mouth of Nilarevu river	60-250m	—
12. Kakinada Canyon	16°55'N-82°30'E	10-20m	—
13. Mahadeva Canyon	18°00'N-84°00'E	350m	V
14. Paradip Depression	20°5'N-86°42'E	—	—
15. Ganga Canyon (Swatch of No Ground)	Off the Ganga Delta 21°15'N-21°23'N 89°28'E-89°33'E	variable 278 to 421m in the northern portion; 543 m to 892 m in the middle portion; a few depressions are 1,050 m to 1,088 deep	V

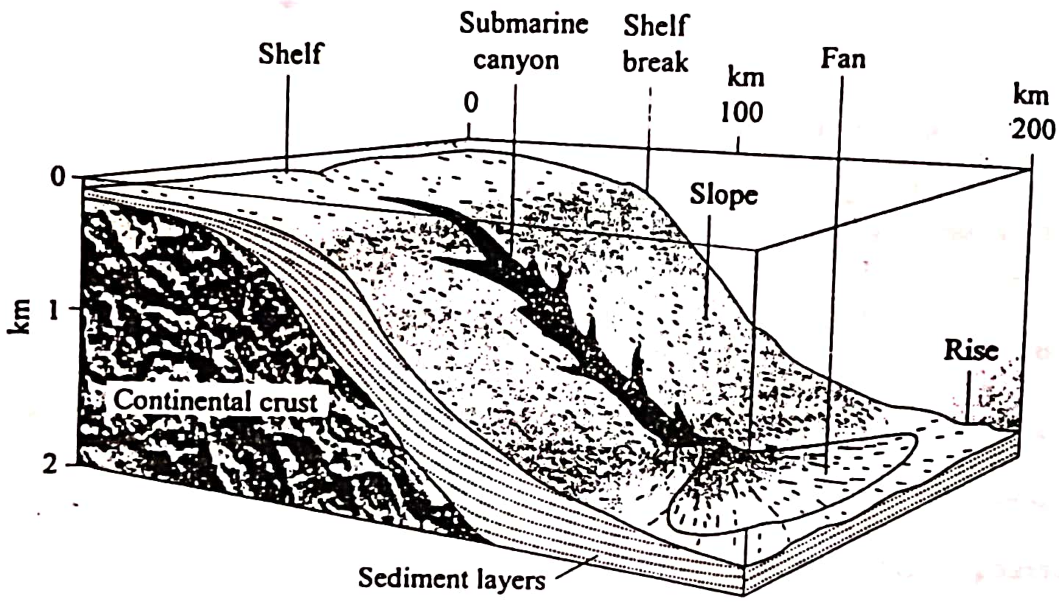

Fig. 24.4 : Continental slope and submarine canyons, Source : based on P. R. Pinet, 2000.

2. Distribution of Submarine Cayons

The world distributional pattern of submarine canyons does not reveal any control of latitudes on their distributions and location. Francis Sheppard and Charles Beard have located 102 submarine canyons in the world on the basis of soundings of the continental shelves and slopes.

Generally, submarine canyons are more abundantly found along the straight coasts than highly indented and crenulated coastlines. They are found along the stable and unstable coasts alike. They are more commonly found off the east coast of the USA from Canada to Cape Hatteras; off the Californian and Mexican coasts; along the north Mediterranean, Philippines, Jappan and Aleutian islands; off the coast of west Africa; off the east coast of India etc.

Atlantic Ocean—Significant submarine canyons of the Atlantic Ocean are Hudson Cayon (facing the mouth of the Hudson river, 827m deep), Chesapeak Canyon, Mississippi Trough, Fosse de Cape Brenton Canyon (in the Bay of Biscay off the south-western coast of France), Nazare Canyon (off the western coast of Portugal, 4000m deep), Congo Canyon (near the mouth of the Congo river) etc.

Pacific Ocean—Columbia Canyon; Monterey Canyon (which has several tributary canyons like Ascension canyon, Soquel canyon, Carnel canyon etc.); Mugu canyon, Scripps canyon and Dume canyon (all are off the Californian coast); Panama canyon (off Burica Peninsula) etc. are the important canyons on the western coast of North America while Piseu

Chang canyon (off the coast of Korea), Philippine canyon (on the main coast of Luzon), Saganin canyon, Fizi canyon etc. are a few prominent canyons of the western Pacific Ocean.

Indian Ocean—Canyons are found along the eastern coast of India (table 24.2), in front of the Indus river, along the north-eastern coast of Sri Lanka, along the eastern coast of Africa etc.

3. Origin of submarine canyons

Though there are divergent opinions about the mode of origin of submarine canyons but majority of the exponents consider them as recent geologic phenomena of Canozoic era, mainly of Quaternary period. A few canyons are still in the process of formation. The following theories have been put forth to explain the origin of submarine canyons :—

(1) Diastrophic theory—A few exponents (Andrade, Lawson, De la Roche Ponie, J.W. Gregory, Yanasaki, Jensen, Bourcart etc.) have related the origin of submarine canyons to various types of earth movements and tectonic implications (faulting, folding, warping, sinking of sea floor etc.). The tensional forces caused by earth movement due to endogenetic forces result in the formation of faults and graben on the continental shelves and slopes. These fault-troughs and graben become submarine canyons. Similarly, warping and steep folding give birth to synclinal basins and synclinal troughs respectively which become submarine canyons.

According to De Andrade submarine canyons are formed due to creation of a series of graben - like valleys during local coastal displacements. Such tectonically originated submarine canyons have been reported by Lawson off the Californian coast, by De la Roche Ponie near the coast of Cyprus and Morocco, by J.W. Gregory (Hudson Canyon and St. Lawrence Trough), by Yanasaki (near Japan coast) etc. According to Jensen and Bourcart submarine canyons were formed during Quaternary period due to subsidence and drowning of river valleys along the continental marginal flexure.

This diastrophic theory of the origin of submarine canyons is criticised mainly on three counts. (i) Majority of submarine canyons are found transverse to the coast whereas faulting generally occurs parallel to the coasts. (ii) Many of the submarine canyons have dendritic pattern of their tributaries which cannot be explained through faulting. (iii) Not all the continental shelves and slopes show evidences of faulting. This theory may explain the formation of canyons along the Pacific coasts (western coasts of North and South Americas and eastern coasts of Asia) and Mediterranean Sea where Tertiary and Quaternary earth movements were most active but the canyons along the western (eastern coasts of North and South Americas) and eastern (off the western coasts of Europe and Africa) of the Atlantic Ocean may not be explained in the absence of such movements. The canyons on the eastern coast of North America cut across the lithology of Tertiary and Quatenary periods.

(2) Subaerial erosion theory—Several exponents (*e.g.* J.D. Dana, F.P. Sheppard, Hull etc.) on the basis of resemblance of submarine canyons to the continental canyons in shape and deposition have related the formation of the former to the entrenching of river valleys by running water and subsequent drowning of these valleys due to subsidence and submergence of continental margins. According to them the rivers eroded their valleys very deep forming deep gorges during the period of emergence when land rose higher well above the sealevel and the channel gradient was steepened. Later on the continental margins were either subsided due to earth movements or the sealevel rose (due to deglaciation) and thus these deep and long valleys were drowned and submarine canyons were formed. The drowned valleys in Java Sea, Philippine Canyon, Monterey Canyons etc. have been cited as typical examples of submarine canyons formed due to subaerial erosion because their longitudinal profiles show upward concavity like continental canyons and there is significant terrigenous deposits in them.

W.M. Davis while contradicting the above theory argued that the formation of submarine canyons through subaerial erosion required vertical oscillation of land say upheaval of the continental margins upto thousands of feet above sealevel and subsequent equivalent regional subsidence to submerge the entrenched river valleys. This would require long geological period as the aforesaid tectonic mechanism is not possible within short geological time. Secondly, if the submarine canyons are the result of subaerial erosion during emergence and subsequent drowning during submergence, these canyons must have continued over the land also but these are found far away from the river mouths. Emery and Sheppard while reacting to the first objection of W.M. Davis maintained that the lowering of sealevel upto 1000 m during Pleistocene glaciation provided ideal continental platforms for the entrenching of valleys by the rivers and subsequent rise of the sealevel due to deglaciation submerged the deeply entrenched valleys to form submarine canyons. If this explanation is accepted, the submarine canyons beyond the depth of 2000m remain unexplained.

(3) Submarine density current theory—Holimann (1883), Adolf Von Salis (1884) and Florel have related the formation of submarine canyons to the submarine density currents. These density currents are originated due to difference in density caused by temperature and salinity variations. Such density currents erode the continental shelves and form trenches while stagnant water on either side of the trenches allows sedimentation and dyke formation (levees). The density currents are originated mainly in front of the river mouths because of differences (in terms of temperature and salinity) in the water brought by the rivers and sea water. It may be pointed out that density currents are confined to enclosed seas, reservoirs and lakes only and these are seldom originated over shallow continental shelves and thus density currents may not be taken as causative factors of the formation of submarine canyons.

(4) Turbidity current theory—Turbidity currents having fine materials in suspension have been held responsible by several exponents (W.M. Davis, W.E. Rither, Tangier Smith, P.D. Trask, Lawson, Daly, Buchanan etc.) for the origin of submarine canyons in one way or the other. Strong onshore winds pile up water near the sea-shore with the result undercurrents are generated which flow towards the sea. These undercurrents bring fine materials in suspension and so they are called turbidity currents. The higher density of these currents due to suspended sediments with them forces them to flow seaward under the surface water. The turbidity currents erode the continental shelves and form submarine valleys and canyons. According to Daly there is increased rate of erosion of coastal land through marine waves due to fall in sea-level during glacial period, with the result turbidity of sea water is increased due to which density of sea water is also increased, consequently seaward turbidity currents are originated. These currents while moving over the continental shelves and slopes erode them in linear manner and form submarine cayons and valleys.

Many critics (Zeppelin, Heim, Bucher etc.) have doubted the efficiency of turbidity currents to form submarine canyons. According to them the velocity of these currents is not such that they can powerfully erode the hard rocks of continental shelves to form canyons. Bucher is of the opinion that currents generated through earthquakes and volcanic eruptions are more rapid and powerful and hence are more capable of eroding the continental shelves to form canyons.

Following Kunen it may be forwarded that submarine canyons in defferent localities having varying lithologies and structures should be explained separately. The canyons developed in stable areas of compact and tenaceous lithologies are formed due to drowning of subaerial valleys, while those carved in unconsolidated lithogloies might have been formed through landslides, turbidity currents etc.

24.7 BOTTOM RELIEFS OF THE ATLANTIC OCEAN

1. Introduction

The Atlantic Ocean located between North and South Americas in the west and Europe and Africa in the east covers an area of 82,000,000 km^2 which is 1/6th of the geographical area of the globe and half of the area of the Pacific Ocean. The 'S' shape of the ocean indicates the fact that landmasses (continents) on its either side were once a contiguous part. The Atlantic Ocean was formed due to drifting of North and South Americas to the west due to plate tectonics. The ocean widens to the south of equator and attains the maximum width of 5,920 km at 35^{0}S latitude. It narrows down towards the equator. It is only 2560 km wide between Liberian coast and Cape Sao Roque. The width further increases northward and it becomes 4800 km at 40^{0}N latitude. It narrows down in the extreme north where it maintains its contact with the Arctic Ocean through Norwegian Sea, Denmark Strait and Davis Bay. The average depth of the ocean is less than the Pacific Ocean because of extensive continental shelves and marginal and enclosed seas. About 24 per cent of the Atlantic Ocean is less than 915m deep.

The Atlantic Ocean was first formed about 700 million years ago due to seafloor spreading (see fig. 5.13, chapter 5) and westward movement of the Eurasian and African plates from the mid-Atlantic ridge. About 300 million years BP (before present) the Atlantic Ocean was closed due to convergence of the American and Eurasian-African plates. The ocean again started to open about 150 million years BP due to the movement of aforesaid plates in opposite directions. The widening of the ocean still continues which is evidenced through seafloor spreading at an average rate of 4 cm per year.

(2) Continental Shelf

Continental shelves have developed along both the coasts of the Atlantic Ocean and the width ranges from 2-4 km to more than 80 km. In fact, the width of continental shelves has been largely controlled by the reliefs of the coastal lands. These become significantly narrow where mountains and hills border the coasts *e.g.* the African shelves between Bay of Biscay and Cape of Good Hope and Brazilian shelves between 5^{0}S and 10^{0}S latitudes. The shelves become 200 to 400 km wide along the north-eastern coast of North America and the north-western coast of Europe. Extensive shelves are found around Newfoundland (Grand Bank) and British Islands (Doggar Bank).

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CORAL REEFS AND ATOLL

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30.1 INTRODUCTION

Coral reefs and atolls are significant submarine features. These are formed due to accumulation and compaction of skeletons of lime secreting organisms known as coral polyps. Coral polyps thrive in the tropical oceans confined between 25^0N-25^0S latitudes and live on lime. Numerous coral polyps live, at a place, in groups in the form of colony and form calcareous shells around them. Coral reefs are formed due to formation of one shell upon another shell along submarine platforms at suitable depth. Since coral polyps cannot survive above water level and hence coral reefs are always found either upto sealevel or below it. They are generally attached to submarine platforms or islands submerged under seawater. It may be mentioned that coral reefs are more diverse than the tropical rainforests because the coral reefs have about 1,000,000 species of which only 10 per cent have been studied. This is why these are called as **rainforests of the oceans.**

30.2 CONDITIONS FOR THE GROWTH OF CORAL POLYPS

(1) Corals are found mainly in the tropical oceans and seas because they require high mean annual temperature ranging between 68^0F and 70^0F (20^0C-21^0C) for their survival. It may be pointed out that they cannot survive in the waters having either very low temperature or very high temperature.

(2) Corals do not live in deeper waters *i.e.* not more than 200-250 feet (60-77m) below sea level because they die in waters deeper than 77m due to lack of sufficient amount of sunlight and oxygen which are very much required for the growth of coral polyps. According to M.S. Land and J.E. Hoffmeister (1936) the maximum depth for ideal growth of corals is 200 to 300 feet (60m to 91m) below sea-level while Gardiner located some corals thriving at the depth of 150 to 170 fathoms (273m to 310m) below sealevel.

(3) There should be clean sediment-free water because muddy water or turbid water clogs the mouths of coral polyps resulting into their death.

(4) It may be pointed out that though coral polyps require sediment-free water but fresh water is also injurious for the growth of corals. This is why corals avoid coastal lands and live away from the areas of river mouths.

(5) Very high proportion of oceanic salinity is injurious for the growth of coral polyps because such waters contain little amount of calcium carbonates whereas lime is important food of coral polyps. The oceanic salinity ranging between $27^0/_{00}$ and $30^0/_{00}$ is most ideal for the growth and development of coral polyps.

(6) Ocean currents and waves are favourable for corals because they bring necessary food supply for the polyps. It is obvious that corals grow in open seas and oceans but they die in langoons and small enclosed seas because of lack of supply of food. Currents and waves also determine the shapes of coral reefs.

(7) There should be extensive submarine platforms for the formation of colonies by the coral

polyps. Such platforms should not be more than 50 fathoms (300 feet or 91m) below sealevel. The polyps start their colonies from a firm base of hard rocks and grow upward until they reach the sealevel. Besides, polyps also grow outward from the submarine platforms.

(8) **Human economic activities** viz. deforestation, industrialization etc. causing global warming adversely affect corals in their habitats. Corals are more susceptible to long-term climatic change. Corals are generally termed as **rainforests of the oceans.** These cannot survive in extreme warm environment. The scientists claim that about 10 per cent of the corals have died and become skeletons due to global warming caused by anthropogenic factors mainly industrialization.

According to report published in Down to Earth (August 15, 1999) 30 per cent of corals are in critical condition and a further 30 per cent are under severe environmental stress. According to the report of the United Nations' Inter-Government Panel on Climate Change (IPCC) 'If the projected levels of climate change are not stopped, the doom may be just 30 year away' (Down to Earth, August 15, 1999). The increase in temperature causes bleaching in the corals wherein the corals lose their algae and become white in colour. This process is called **coral bleaching,** which causes death to corals.

According to Clive Wilkinson of the Global Coral Reef Monitoring Network (GCRMN) coral bleaching has occurred at large scale off the coasts of West Asia, East Africa, South, Southeast and East Asia, in the Indian Ocean, East Pacific, the Caribbean Sea and the Atlantic Ocean (1998). According to him the Indian Ocean is the most adversely affected region wherein 'more than 70 per cent mortality has been observed off the coasts of Kenya, the Maldives, the Andamans and the Lakshwadweep islands.

The studies have shown that coral bleaching begins when the temperature rises 1^0C above normal temperature. The year 1998 has been reported to be the warmest year in the last 1200 years. The temperature in the Indian Ocean was recorded 2^0C higher than the normal temperature in 1998. **El Nino** phenomenon has also been associated with coral bleaching (coral death). El Nino was the strongest on record in 1997-98 and hence caused large-scale bleaching of corals.

(9) Besides global warming, human activities at local to regional levels such as pollution of oceanic water through excess flux of sediments and nutrients, industrial effluents, urban wastes, sewage; over fishing; clearance of maritime forest and filling of wetlands; mining of coral rocks; collection of rare species etc. cause fatal diseases to corals. Recent studies have shown that 58 per cent of the world's coral reefs are threatened by human activities (Down to Earth, 1999).

30.3 TYPES OF CORAL REEFS

The submarine coral reefs are classified in two ways *e.g.* (1) on the basis of nature, shape and mode of occurrence (*e.g.* (i) fringing reef, (ii) barrier reefs and (iii) atoll, and (2) on the basis of location (*e.g* (i) tropical coral reefs and (ii) marginal belt coral reefs).

1. Fringing Reef

Coral reefs developed along the continental margins or along the islands are called fringing reefs (fig. 30.1). The seaward slope is steep and vertical while the landward slope is gentle. The upper surface is uneven and corrugated. Though fringing reefs are usually attached to the coastal land but some times there is gap between them and land and thus lagoon is formed between the fringing reef and the land. Such lagoon is called **boat channel.** Coral reefs are generally long but narrow in width. The continuity of coral reefs is broken wherever rivers drain into the seas and oceans. Coral reefs are basmically of two types *e.g.* (i) coral reefs facing open ocean and (ii) coral reefs protected by a barrier. Such fringing reefs are found along Sakau island, southern Florida, Mehetia island (of Society Group of Islands) etc.

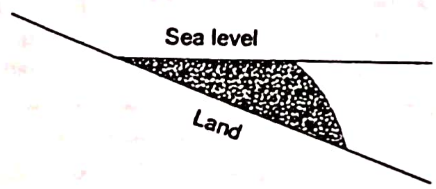

Fig. 30.1 : Example of fringing reef.

2. Barrier Reef

The largest coral reefs off the coastal platforms but parallel to them are called barrier reefs (fig. 30.2). Barrier reefs are the largest, most extensive, highest and widest reefs of all types of coral reefs. The average slope is about 45^0 but some barrier reefs are characterized by 15^0-25^0 slope. There is extensive but shallow lagoon between the coastal land and barrier reef. Barrier reefs are seldom found as continuous chains rather they are broken at many places and thus the lagoons have contact with the open seas and oceans through tidal inlets. Some times, tidal inlets are so wide that ships enter the lagoons through them. Some times, the base of barrier reefs exceeds the required depth for the development of coral polyps *i.e.* 300 feet (91m). Thus, the existence of barrier reefs at such greater depth (beyond the permissible depth of 60-77m) poses the problem of their formation. It may be argued that barrier reefs might have been formed at suitable depth but at much later date there might have been subsidence.

Great Barrier Reef, located parallel to the east coast of Australia, is the largest of all the barrier reefs of the world. This reef is located between 9^0S to 22^0S latitudes and stretches for a length of 1200 miles (1920 km) and thus covers about two-third of the coastal length of Queensland province of Australia. The northern and the southern parts of this reef are

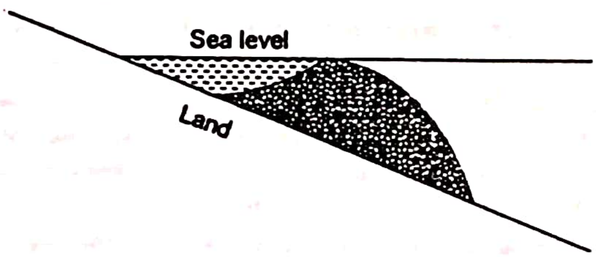

Fig. 30.2 : Example of barrier reef.

80 miles (128 km) and 7 miles (11km) away from the coast the reef from the coast ranges between 20 to 30 miles (32 to 48 km). The depth of lagoon between the coast and the reefs is 40 fathoms (240 feet) whereas the width ranges between 7 to 80 miles (11 km to 128 km). The reef is broken at places and hence there are frequent openings in the form of tidal inlets which enable the lagoon to maintain contacts with the open ocean.

3 Atoll

A ring of narrow growing corals of horseshoe shape and crowned with palm trees is called atoll (fig. 30.3). It is generally found around an island or in elliptical form on a submarine platform. There is a lagoon in the middle of coral ring. The depth of lagoon ranges between 40 to 70 fathoms (240 to 420 feet). Atolls are divided into 3 types.e.g. (i) **true atoll** characterized by circular reef enclosing a shallow lagoon but without island, (ii) **island atoll** having an island in the central part of the lagoon enclosed by circular reef, and (iii) **coral island or atoll island** does not have island in the beginning but later on island is formed due to erosion and deposition by marine waves. Atolls are found in Antilles Sea, Red Sea, China Sea, Australian Sea, Indonesian Sea. Funfutti Atoll of Ellice Island is a famous atoll. The enclosed lagoon is 12.8 km wide and 19.2 km long.

Shallow lagoon reefs are minor reef features which are annular in shape and are found in epi-continental seas like Indonesian Sea, South China Sea etc. The lagoon is a small pool. **Faros** are chains of small atolls having shallow small lagoons. **Coral banks** are isolated shapeless reefs. **Coral pinnacles** are small ridges which rise within the lagoons.

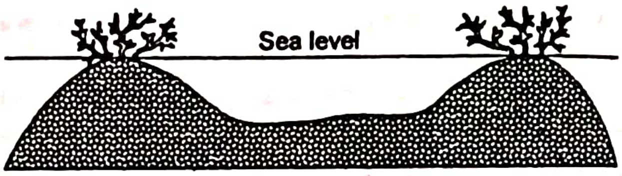

Fig. 30.3 : Example of an atoll.

30.4 ORIGIN OF CORAL REEFS AND ATOLLS

The problem of the origin of coral reefs in general and atoll in particular is highly complex. Several contrasting theories have been advanced to explain the mode of origin of different types of coral reefs. If the salient features of all the theories are considered carefully then it becomes obvious that these theories have been based on two considerations *e.g.* (i) Pleistocene sealevel changes and (ii) the stability or instability of the land involved in the formation of coral reefs. The stability of lands involves three conditions *e.g.* (i) **stable or stationary land** or island. (ii) **subsiding land** or island and (iii) **emerging land** or island. The origin of fringing reefs is quite simple and easy to explain but the origin of barrier reefs and atolls is highly complex. The theories of the origin of coral reefs and atolls are grouped into two broad categories viz. (1) Subsidence Theory and (2) Non-Subsidence Theory.

1. Subsidence Theory of Darwin

Charles Darwin postulated his subsidence theory first in 1837 and modified it in the year 1842 during his Voyage on the 'Beagle'. After close observation of different types of reefs in the oceans Darwin was convinced that coral polyps could grow only in shallow oceanic waters though coral reefs were found at greater depths where coral polyps could not survive at any cost. Darwin postulated his theory in order to solve the riddle of this contradiction *i.e.* confinement of coral polyps to shallow depth but their occurrence, in practice, at greater depth. According to him the land or island involved in the origin and growth of coral reefs is seldom stationary rather it undergoes gradual subsidence. According to him fringing reefs, barrier reefs and atolls are successive stages of the development of coral reefs.

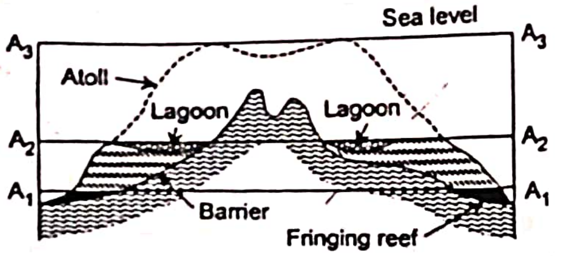

Fig. 30.4 : Origin of coral reefs according to Charles Darwin. A_1-A_1 = Sea-level and the formation of fringing reefs, A_2-A_2=sea-level after subsidence and the formation of barrier reef and A_3-A_3 = sealevel after complete submergence of the island and the formation of atoll reef.

First of all coral polyps flock together along a suitable submarine platform (fig. 30.4, A_1-A_1 and 30. 5B) and grow upward and ultimately reach sea-level and fringing reef is formed. Thus, fringing reef is formed in stable condition of the land. After this, the land is subjected to subsidence because of tectonic forces and thus coral polyps also reach greater depth where they may not survive. Consequently, they grow upward and outward at much faster rate so that they can get food for their survival. The growth of polyps is retarded near the shore of the land but it is very phenomenal and vigorous at the outer edge of the land. Consequently, a lagoon is formed between the coast and fringing reef and barrier reef is formed (fig. 30.4, A_2 - A_2 and 30.5 C). There is further subsidence of the land and the island is completely submerged under water and a ring of coral reef in the form of atoll is formed (fig. 30.5D). It may be pointed out that Darwin did not invoke sudden and rapid subsidence of land rather he conceived gradual and slower rate of land subsidence than the rate of upward growth of corals so that they could never find themselves in deeper waters.

It may be noted that the depth of lagoon does not increase inspite of gradual subsidence of the land because there is continuous sedimentation in the lagoon.

The following evidences and points strongly support the validity of Darwin's subsidence theory:—

(i) The shallowness of lagoons indicates gradual subsidence of land. If the land is taken to be stable, the lagoon would be filled due to deposition of sediments. (ii) The absence of cliffs along the coral islands validates the idea of subsidence of land because cliffs are found along only those coral islands which are stationary. (iii) The coasts and the islands of the Pacific ocean having raised beaches (indicative of emergence of land) are devoid of barrier and atoll reefs. (iv) The islands having atolls are characterized by very steep slopes. It may be mentioned that very steep slopes are found only along the upper parts of the islands. This fact also denotes subsidence of the land. (v) The thickness of coral reefs increases downward. This feature reveals the fact that coral reefs are formed along the subsiding base of submarine platforms.

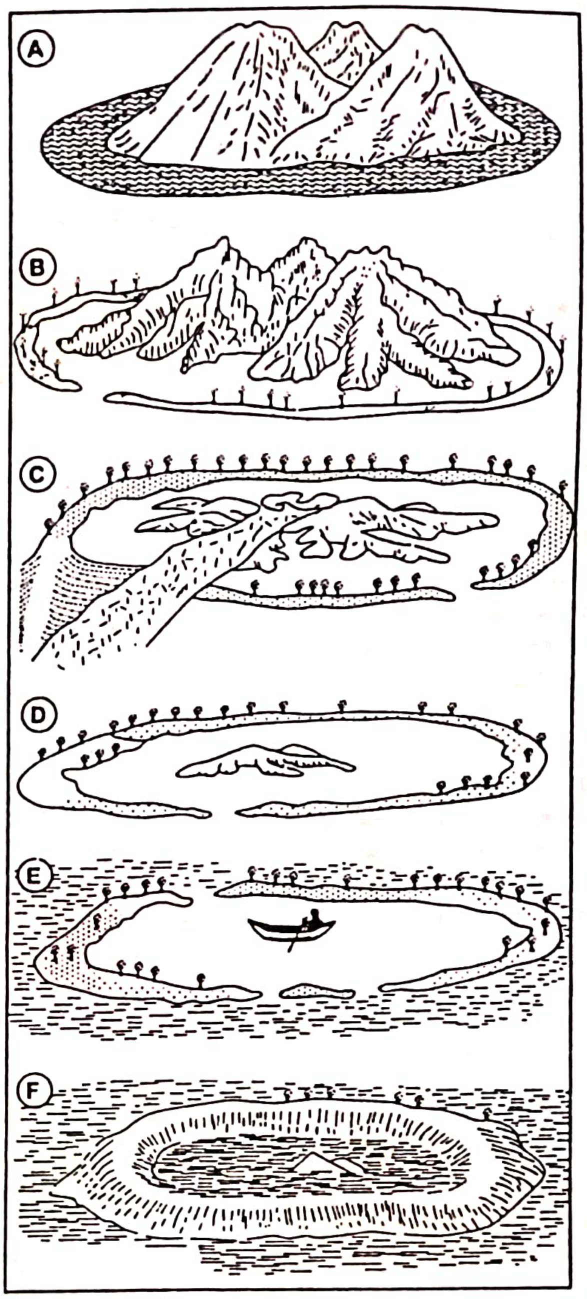

Fig. 30.5 : Stages of the development of coral reefs and atolls on the basis of subsidence theory.

Evaluation of the Theory—If fringing reefs, barrier reefs and atoll reefs, as maintained by Darwin,