25

TEMPERATURE AND DENSITY OF OCEAN WATER

25.1 INTRODUCTION

The temperature of the oceanic water is important for marine organisms including plants (phytoplanktons) and animals (zooplanktons). The temperature of sea water also affects the climate of coastal lands and plants and animals therein. The study of both, surface and subsurface temperature of sea water is significant. Standard type of thermameter is used to measure the surface temperature while reversing thermameters and thermographs are used to measure the subsurface temperature. These thermameters record the temperature upto the accuracy of $\pm 0.02^0$ centrigrade. With respect to temperature, there are three layers in the oceans from surface to the bottom in the tropics viz.

(i) The **first layer** represents the top-layer of warm oceanic water and is 500m thick with temperature ranging between 20^0 and 25^0C. This layer is present within the tropics throughout the year but it develops in mid-latitudes only during summer. (ii) The **thermocline layer** represents vertical zone of oceanic water below the first layer and is characterized by rapid rate of decrease of temperature with increasing depth. (iii) The **third layer** is very cold and extends upto the deep ocean floor. The polar areas have only one layer of cold water from the surface (sea level) to the deep ocean floor.

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

25.2 DAILY RANGE OF TEMPERATURE

The difference of maximum and minimum temperature of a day (24 hours) is known as daily range of temperature. The daily range of temperature of surface water of the oceans is almost insignificant as it is around 1^0C only. On an average, the maximum and minimum temperatures of sea surface water are recorded at 2P.M. and 5 A.M. respectively. The daily range of temperature is usually 0.3^0C in the low latitudes and 0.2^0 to 0.3^0C in high latitudes.

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

25.3 ANNUAL RANGE OF TEMPERATURE

The maximum and minimum annual temperatures of ocean water are recorded in August and February respectively (in the northern hemisphere). Usually, the average annual range of temperature of ocean water is -12^{0}C (10^{0}F) but there is a lot of regional variation which is due to regional variation in insolation, nature of seas, prevailing winds, location of seas etc. Annual range of temperature is higher in the enclosed seas than in the open sea (Baltic Sea records annual range of temperature of 4.4^{0}C or 40^{0}F). The size of the oceans and the seas also affects annual range of temperature *e.g.* bigger the size, lower the annual range and vice versa. The Atlantic Ocean records relatively higher annual range of temperature than the Pacific Ocean.

25.4 DISTRIBUTION OF TEMPERATURE

The distributional pattern of temperature of ocean water is studied in two ways viz. (i) horizontal distribution (temperature of surface water) and (ii) vertical distribution (from surface water to the bottom). Since the ocean has three dimensional shape, the depth of oceans, besides latitudes, is also taken into account in the study of temperature distribution. The following factors affect the distribution of temperature of ocean water.

(1) **Latitudes**-The temperature of surface water decreases from equator towards the poles because the sun's rays become more and more slanting and thus the amount of insolation decreases poleward accordingly. The temperature of surface water between 40^{0}N and 40^{0}S is lower than air temperature but it becomes higher than air temperature between 40th latitude and the poles in both the hemispheres.

(2) **Unequal distribution of land and water**-The temperature of ocean water varies in the northern and the southern hemispheres because of dominance of land in the former and water in the latter. The oceans in the northern hemisphere receive more heat due to their contact with larger extent of land than their counter-parts in the southern hemisphere and thus the temperature of surface water is comparatively higher in the former than the latter. The isotherms are not regular and do not follow latitudes in the northern hemisphere because of the existence of both warm and cold landmasses whereas they (isotherms) are regular and follow latitudes in the southern hemisphere because of the dominance of water. The temperature in the enclosed seas in low latitudes becomes higher because of the influence of surrounding land areas than the open seas *e.g.* the average annual temperature of surface water at the equator is 26.7^{0}C (80^{0}F) whereas it is 37.8^{0}C (100^{0}F) in the Red Sea and 34.4^{0}C (94^{0}F) in the Persian Gulf.

(3) **Prevailing wind**-Wind direction largely affects the distribution of temperature of ocean water. The winds blowing from the land towards the oceans and seas (*e.g.* offshore winds) drive warm surface water away from the coast resulting into upwelling of cold bottom water from below. Thus, the replacement of warm water by cold water introduces longitudinal variation in temperature. Contrary to this, the onshore winds pile up warm water near the coast and thus raise the temperature. For example, trade winds cause low temperature (in the tropics along the eastern margins of the oceans or the western coastal regions of the continents) because they blow from the land towards the oceans whereas these trade winds raise the temperature in the western margins of the oceans or the eastern coastal areas of the continents because of their onshore position. Similarly, the eastern margins of the oceans in the middle latitudes (western coasts of Europe and North America) have relatively higher temperature than the western margins of the oceans because of the onshore position of the westerlies.

(4) **Ocean currents**-Surface temperatures of the oceans are controlled by warm and cold currents. Warm currents raise the temperature of the affected areas whereas cool currents lower down the temperature. For example, the Gulf Stream raises the temperature near the eastern coasts of N. America and the western coasts of Europe. Kuro Shivo drives warm water away from the eastern coast of Asia and raises the temperature near Alaska. Labrador cool current lowers down the temperature near north-east coast of N. America. Similarly, the temperature of the eastern coast of Siberia becomes low due to Kurile cool current. It may be mentioned that warm currents raise the temperature more in the northern

hemisphere than in the southern hemisphere which is apparent from the fact that the 5⁰C isotherm reaches 70⁰ latitude in the northern Atlantic Ocean whereas it is extended upto only 50⁰ latitude in the southern Atlantic Ocean. This is because of more dominant effects of the warm Brazil current in the southern Atlantic Ocean.

(5) **Minor factors** include (i) submarine ridges, (ii) local weather conditions like storms, cyclones, hurricanes, fog, cloudiness, evaporation and condensation, and (iii) location and shape of the sea. Longitudinally more extensive seas in the low latitudes have higher temperature than the latitudinally more extensive seas as the Mediterranean Sea records higher temperature than the Gulf of California. The enclosed seas in the low latitudes record relatively higher temperature than the open seas whereas the enclosed seas have lower temperature than the open seas in the high latitudes (Baltic Sea records 0⁰C (32⁰F) and open seas have 4.4⁰C or 40⁰F).

25.5 HORIZONTAL DISTRIBUTION OF TEMPERATURE

On an average, the temperature of surface water of the oceans is 26.7⁰C (80⁰F) and the temperature gradually decreases from equator towards the poles. The rate of decrease of temperature with increasing latitudes is generally 0.5⁰F per latitude. The average temperatures become 22⁰C (73⁰F) at 20⁰ latitude, 14⁰C (57⁰F) at 40⁰ latitude, and 0⁰C (32⁰F) near the poles. The oceans in the northern hemisphere record relatively higher average temperature than in the southern hemisphere. The highest temperature is not recorded at the equator rather it is a bit north of it. The average annual temperature of all the oceans is 17.2⁰C (63⁰F). The average annual temperatures for the northern and southern hemispheres are 19.4⁰C (67⁰F) and 16.1⁰C (61⁰F) respectively. The variation of temperatures in the northern and southern hemispheres is because of unequal distribution of land and ocean water.

The decrease of temperature with increasing latitudes in the northern Atlantic Ocean (figs. 25.5 and 25.6) is very low because of warm ocean currents. The average temperature between 50⁰-70⁰N latitudes is recorded as 5⁰C (41⁰F). The decrease of temper ture with increasing latitudes is more pronounced in the southern Atlantic Ocean. According to Krumel the highest temperature of surface water of the oceans is at 5⁰N latitude whereas

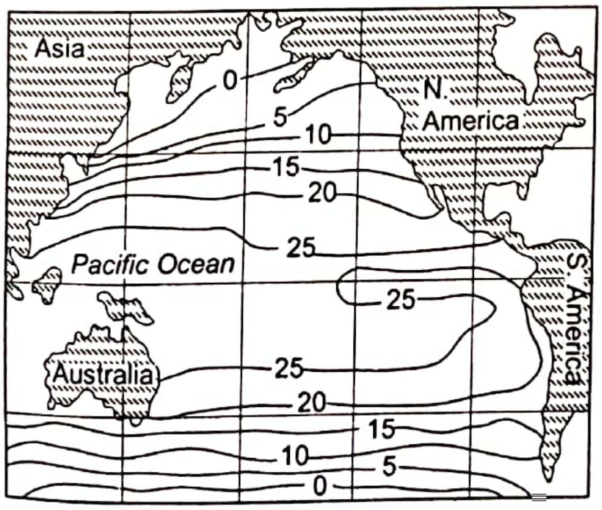

*Fig. 25.1: Horizontal distribution of temperature in the Pacific Ocean (**February**).*

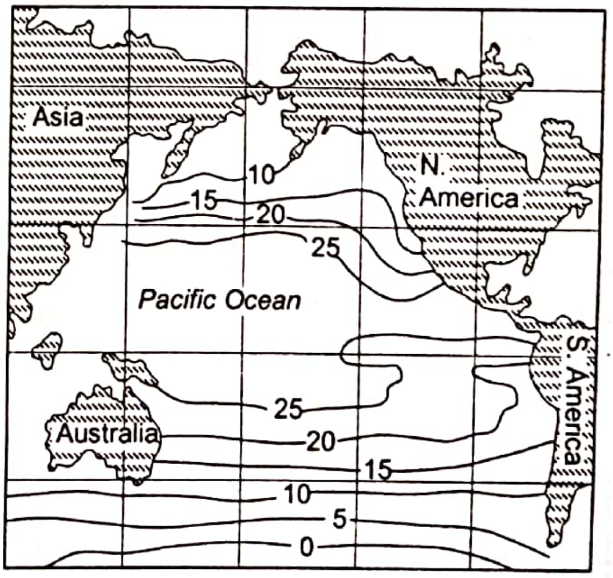

Fig. 25..2 : Horizontal distribution of temperature in the Pacific Ocean (August).

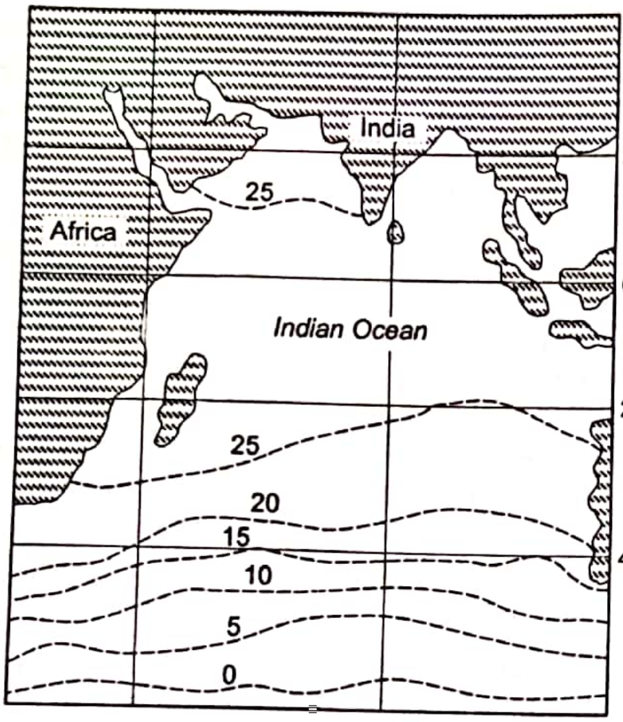

Fig. 25.3 : Horizontal distribution of temperature in the Indian Ocean (February).

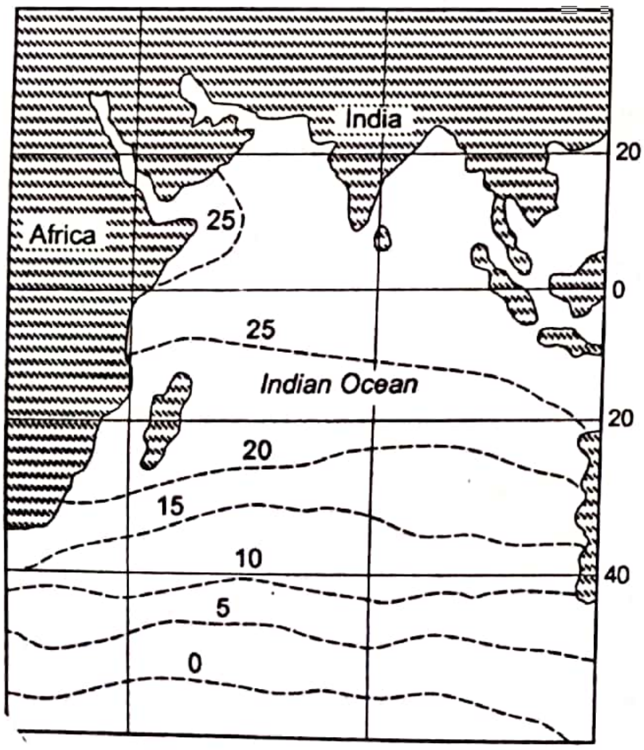

Fig. 25.4: Horizontal distribution of temperature in the Indian Ocean (August).

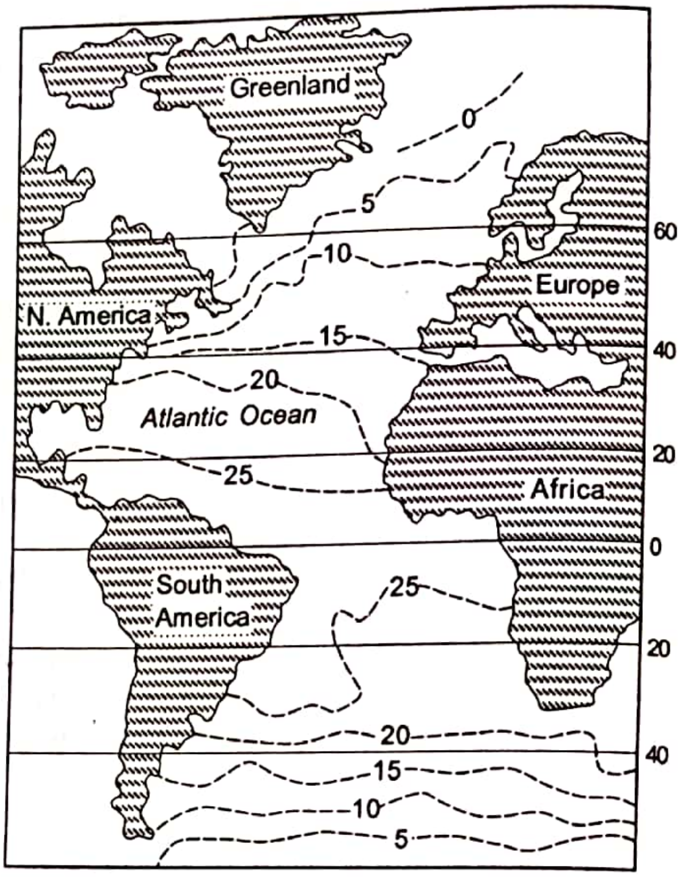

Fig. 25.5 : Horizontal distribution of temperature in the Atlantic Ocean (February).

the lowest temperature is recorded between 80^{0}N and the north pole and between 75^{0}S and the south pole. The average annual temperature of the Pacific Ocean is slightly higher than the Atlantic Ocean (16.91^{0}C or 60^{0}F) and the Indian Ocean (17^{0}C or 60.6^{0}F). The lowest (3.3^{0}C or 35.94^{0}F) and the highest (32.2^{0}C or 89.96^{0}F) temperatures of the oceans are recorded near New Scottland and in the western Pacific Ocean respectively. The highest temperature of the Indian ocean (25^{0}C or 82.4^{0}F) is recorded in the Arabian Sea and Bay of Bengal but the enclosed seas of the Indian Ocean record still higher temperatures (Red Sea = 32.2^{0}C or 90^{0}F and Persian Gulf = 34.4^{0}C or 94^{0}F). The average seasonal temperatures (February and August) of surface water of the oceans have been represented through isotherms (figs. 25.1, 2, 3, 4, 5 and 6).

The temperature of the surface water of the oceans is higher than the air temperature above the ocean surface which means ocean surface gives off heat to the atmosphere. This phenomenon

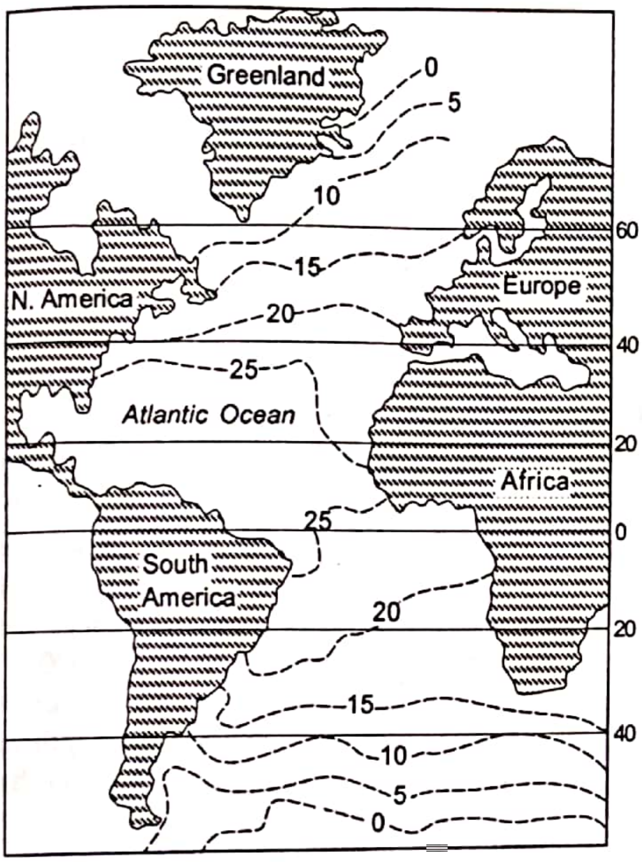

Fig. 25.6 : Horizontal distribution of temperature in the Atlantic Ocean (August).

influences the generation of oceanic circulation mainly sea waves and ocean currents. It has been observed that the air tempera ture at the height of 8m from the sea surface between 20^0N and 55^0S latitudes in the Atlantic Ocean is cooler by 0.80^0C than the sea surface. There is a lot of variation in the heat emitted from the oceans to the atmosphere during winter and summer and this phenomenon causes differences of air temperature over the oceans and the continents mainly during winter season. 'The temperature for January is 22.2^0C higher over the oceans between 20^0 and 80^0N, while in July it is 4.8^0C lower. The mean annual temperature is 7^0C higher over the water meridian' (C.A.M. King, 1975). The difference between air and sea surface temperatures causes fogs over the seas and the oceans. This happens when warm air passes over a cold sea surface having the temperature below dew point of the air. Consequently the air over the sea surface is cooled from below and sea fog occurs. Generally, sea fogs are frequently formed during spring and early summer because air coming from over the land is warmer while the sea surface is still cold. Sea fogs are very common in the high latitudes but are generally absent in the tropics.

Table 25.1 : Surface Water Temperature of the Oceans (in 0^0C)

Latitudes	N. Hemisphere	N. Hemisphere	N. Hemisphere
70-60		5.60	-
60-50	5.74	8.66	-
50-40	9.99	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

Latitudes	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
	S. Hemisphere	S. Hemisphere	S. Hemisphere

25.2 VERTICAL DISTRIBUTION OF TEMPERATURE

It may be pointed out that maximum temperature of the oceans is always at their surface because it directly receives the insolation and the heat is transmitted to the lower sections of the oceans through the mechanism of conduction. In fact, the solar rays very effectively penetrate upto 20m depth and they seldom go beyond 200m depth. Consequently, the temperature decreases from the ocean surface with increasing depth but the rate of decrease of temperature with increasing depth is not uniform every where. The temperature falls very rapidly upto the depth of 200m and thereafter the rate of decrease of temperature is slowed down. From this stand point the oceans are vertically divided into two zones. (1) **Photic** or **euphotic zone** represents the upper surface upto the depth of 200m and receives solar radiation. (2) **Aphotic zone** extends from 200m depth to the bottom and does not receive solar rays. The following are the salient features of vertical distribution of temperature of ocean water.

- Though the sea temperature decreases with increasing depth but the rate of decrease of temperature is not uniform. The change in sea temperature below the depth of 2000m is negligible. The following trend of decrease in temperature with increase in depth has been reported by Murray during his Challenger Expedition.

Depth in fathoms	Temperature (0^{0}F)	Depth (fathoms)	Temperature (0^{0}F)
100	60.7	1,000	36.5
200	50.1	1,500	35.5
500	45.1	2,200	35.2

- Diurnal and annual ranges of temperature cease after the depth of 5 fathoms (30 feet) and 100 fathoms (600 feet) respectively.
- The rate of decrease of temperature with increasing depth from equator towards the poles is not uniform. Though the surface temperature of the seas decreases from equator towards the poles but the temperature at the ocean bottoms is uniform from the equator towards the pole, which means that the rate of decrease of temperature with increasing depth is more rapid near the equator than towards the poles. The result of German Antarctic Expedition in 1911 revealed that the temperature at the depth of 100m at 7.30^{0}N latitude equalled the surface temperature at 40^{0}N latitude. Similarly, the temperature at 200m depth at 7.30^{0}N latitude equalled the temperature of sea surface at 50^{0}N latitude and the temperature at the depth of 700-800m was the same as it was at the surface at 60^{0}N latitude. Table 25.3 reveals these trends.

Table 25.3 : Comparison of Temperature at Sea Surface and Different Depths

Latitudes (N)	0-10	10-20	20-30	30-40	40-50	50-60	60-70
Surface Temperature (O^{0}C)	26.88	25.60	23.90	20.30	12.94	8.94	4.26
Depth at 7.30^{0}N (metres)	0	100	200	400	800	1000	—
Temperature (O^{0}C)	26.86	18.57	10.71	7.70	5.13	4.81	—

- The areas from where sea surface water is driven away by offshore winds resulting into upwelling of water from below record low temperature at sea surface and thus the rate of decrease of temperature with increasing depth becomes low. Contrary to this the areas where there is pilling of sea water because of on-shore winds, record relatively high temperature at sea surface and thus the rate of decrease of temperature with increasing depth becomes rapid.
- In some areas high temperature is recorded at greater depths *e.g.* in Sargasso Sea, Red Sea, Mediterranean Sea, Sulu Sea etc. The Mediterranean Sea records 24.4°C at the depth of 1,829m whereas the Indian Ocean has only 1.1°C temperature at the same depth. Such anomalous conditions are noticed in the enclosed seas of low latitudes. The enclosed seas of high latitudes register inversion of temperature *i.e.* the temperature of sea surface is lower than the temperature below.
- There is clear-cut leyered thermal structure of ocean water. Vertically the oceans are divided into 3 layers from the stand point of thermal conditions of seawater, in the lower and middle latitudes as follows :
  (1) The **upper layer** represents the top-layer of warm water mass with a thickness of 500 meters with average temperature ranging between 20°C to 25°C. This lighter ocean water mass floats over the thickest heavy water mass of the oceans extending upto the ocean bottoms. This layer is present within the tropics throughout the year but it develops in middle latitudes only during summer season.
  (2) The **lower layer** extends beyond 1000m depth upto the ocean bottoms. This layer is very cold and represents denser ocean water mass.
  (3) The upper and lower ocean water masses are separated by a transitional zone of rapid change of temperature with increasing depth. This zone of ocean water mass is called **thermocline** which extends between 300m-1000m depth.

Besides, there are **seasonal thermoclines** between the depth of 40m and 100m.

These seasonal thermoclines are formed due to heating of water surface through solar radiation during summer season. There are also **diurnal thermoclines** which form in shallow water depth usually less than 10-15m. The polar seas have only one layer of cold water mass from the ocean surface (sea level) to the deep ocean floor.

25.3 DENSITY OF OCEANS

Meaning and Significance

Density refers to the amount of mass per unit volume of substance. It is usually measured in gram (amount of mass) per cubic centimeter of volume and is expressed g/cm³. The density of pure (distilled) water is 1.00 g/cm³ at the temperature of 4°C. The density of pure water is taken as standard for the measurement of density of other substances. Since the seawater carries a few dissolved substances such as salt in it, its density is slightly higher than that of pure water. In fact, the average density of seawater is 1.0278g/cm³ (1.02677 g/cm³) which is 2 to 3 percent higher than the density of pure water (1.00g/cm³) at 4°C temperature. The density of seawater gradually increases with decreasing temperature and highest density is recorded at the temperature of-1.3°C.

It may be mentioned that it becomes cumbersome and unpracticable to use density value upto 5 decimal points and hence sigma t (σt) value is derived to simplify the density value as follows :

$$\frac{1.02677 g/cm^3}{1.00000 g/cm^3} = 1.02677$$

Thus, the units (g/cm³) have been removed. In order to derive σt (sigma value) first 1 is substracted from 1.02677 and then the derived value is multiplied by 1000 as follows :

$$\sigma t = (1.02677 - 1) \times 1000$$
$$= 26.77$$

The density is very important physical property of seawater because it determines the dynamics of ocean water *i.e.* whether the seawater will sink (subsidence and hence downward vertical movement of seawater), or will float (expansion and hence horizontal movement) depends upon its density. As per rule, relatively lighter seawater (less dense seawater) floats and moves horizontally, whereas heavier seawater (more dense water) sinks (downward movement). This is the reason that a person floats over seawater having high salinity because salinity increases density of seawater.

Controlling Factors of Density of Seawater

The density of seawater is related to the following 3 factors in one way or the other :

- temperature → thermal expansion
- pressure → compressive effects
- salinity → addition of dissolved substances

(1) **Temperature** is the most significant controlling factor of density of seawater. Temperature and density of seawater are, on an average, inversely related *i.e.* higher the temperature, lower the density, and lower the temperature, higher the density. In fact, seawater is heated through insolation when more insolation is received on the sea surface and hence seawater expands. This phenomenon is called **thermal expansion** due to insolational heating resulting into low density. On the other hand, low temperature causes cooling of seawater and hence **thermal contraction** resulting into decrease in volume and increase in density of seawater.

Thus, warm water having large volume but low density easily floats on cold seawater of less volume and relatively more density. It is significant to point out that the role of temperature in controlling seawater density is more pronounced in low latitudes areas (tropical and subtropical oceans), whereas the importance of temperature in controlling seawater density decreases poleward. 'Thus, a change in temperature of warm, low-latitude water has about three times the effect on density of an equal change in temperature occurring in colder, high latitude waters' (Thurman and Trujillo, 1999).

It is also important to note that temperature of seawater below freezing point cannot increase seawater density because at 0°C temperature water starts freezing with the formation of ice erystalls which do not allow the water molecules to come closer and coalesce rather they are kept apart and hence few water molecules are present in per unit volume (one cubic centimeter) of seawater. Thus, the seawater becomes less dense. This is why ice floats in water. It is thus apparent that cooling effect on increase in the seawater density continues upto 4°C temperature only. Since there is less variation in temperature of seawater in polar areas, and hence the role of temperature as controlling factor of seawater density is minimised.

(2) **Salinity** is directly positively related to seawater density *i.e.* on an average, seawater density increases with increasing salinity and decreases with decrease in salinity. This is because of the fact that dissolved salt in the seawater becomes more dense than pure water. It is also important to note that salinity factor is sometimes offset by temperature factor. Similarly, sometimes temperature factor is suppressed by salinity variable. As already described that the density of pure water is 1.00g/cm^3 whereas density of seawater of 4°C temperature and carrying 35‰ salinity is 1.028 g/cm^3. This is why fresh water floats over saline water. It may also happen that water with high salinity may lie over less saline water, if the temperature of high saline water is much higher than the temperature of underlying cold less salty water. This is the reason that in some areas of tropical oceans and seas high salinity warm water mas overlies low salinity cold water mass. This is because of the fact that greater evaporation of surface water of the oceans and seas in tropical areas increases seawater salinity. Thus such unique situation of high salinity seawater above and low salinity water below is caused due to evaporation factor.

Table 25.4 : Relationship between temperature and density of ocean water

Temperature (°C)	0	10	20	25	30
Density (g/cm^3)	1.0281	1.0270	1.0248	1.0234	1.0217

(3) **Pressure** is directly positively related to ocean water density through its **compressive effects,** seawater density increases with increasing pressure, and decreases with decrease in pressure of seawater. It may be mentioned that unlike air seawater (even water) is not much compressible, rather 'it is nearly incompressible', and hence it exerts negligible control over seawater density. Thus, pressure is considered as minor factor of seawater density. The effect of pressure of thick water mass on density may be observed only in deep sea mainly in deep sea trenches, but here too the density of seawater at the bottom of trenches is only 5 percent higher than that of the sea surface area.

Relationships Between Density, Temperature and Salinity

As stated above, density of seawater and temperature are inversely proportional *i.e.* if temperature of seawater increases, its density decreases and vice versa. It is apparent from fig. 25.7 that temperature of seawater sharply declines from 200m depth to 1000m depth in low latitudes areas (tropical and subtropical regions), and thereafter there is no variation in seawater temperature with increasing depth (curve A in fig. 25.7). On the other hand, there is no change in seawater temperature with increasing depth in high latitudes areas (polar regions, curve B in fig. 25.7). The zone of sharp change of seawater temperature (decrease in temperature with increasing depth upto 1000m) between 200m and 1000m is called **thermocline.**

Contrary to seawater temperature, the density of seawater increases sharply with increasing depth between 200m and 1000m in low latitudes areas (curve A in fig. 25.8) but in high latitudes areas (polar regions) there is no change in seawater density (fig. 25.8) as is revealed by curve B. This zone of 200m to 1000m depth characterized by sharp change in density of seawater (increase in seawater density with increasing depth) in tropical and subtropical regions is called **pycnocline** (pycno means density, cline means slope or gradient). It is evident

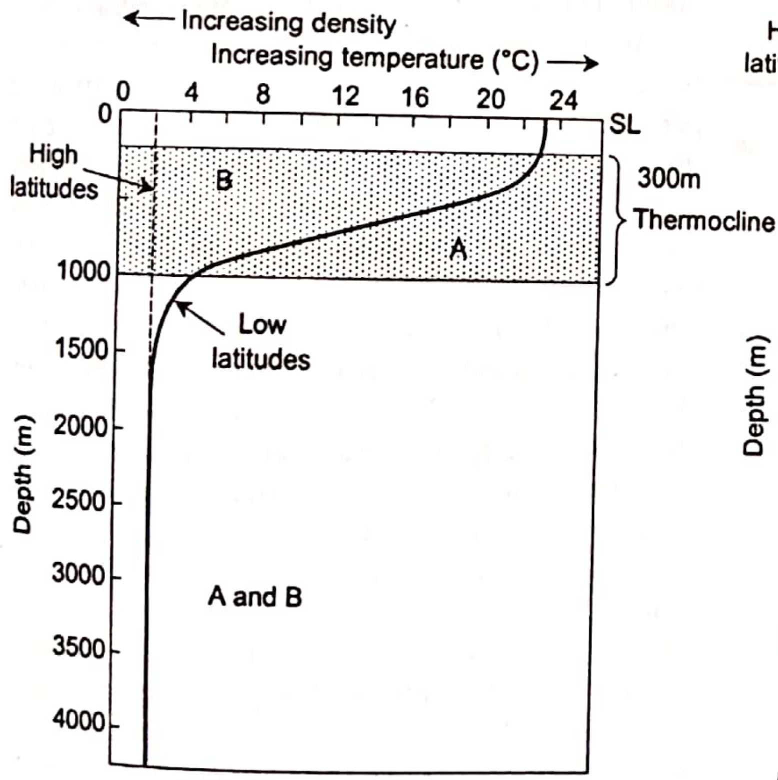

Fig. 25.7 : Variations of seawater temperature with increasing depth in low and high latitudes areas. Based on Thurman and Trujillo, 1999.

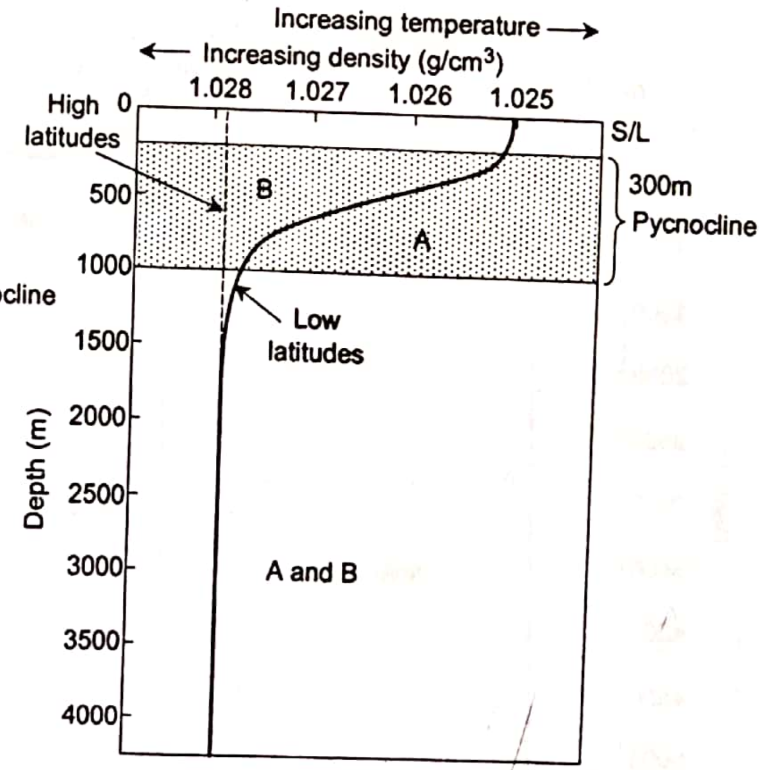

Fig. 25.8 : Variation of seawater density with increasing depths in low (tropical and subtropical regions) and in high latitudes (polar) regions. Based on Thurman and Trujillo, 1999.

from figs. 25.7 and 12 that the density of seawater and temperature are inversely proportional in tropical and subtropical oceans. It means zones of pycnocline and thermocline are confined to the depth zone of 200m-1000m in tropical and subtropical oceans (figs. 25.7 and 25.8).

The coincidence of thermocline and pycnocline in the same depth zones denoting very close relationship between seawater density and temperature is clearly seen in fig. 25.9 wherein the same curve (A) denotes decrease in seawater temperature and increase in ocean water density with increasing depth from 200m to 1000m depth.

Salinity decreases with increasing depth between the depth zone of 200m-1000m in the low latitudes regions whereas it increases with increasing depth in high latitudes areas. Thus the depth zone of 200 m-1000 m of the oceans denotes sharp change in ocean salinity → decrease in salinity with increase in depth in the tropical and subtropical regions. This zone of sharp decline of seawater salinity is called **halocline** (sharp salinity gradient). If we compare figs. 25.7, 8, 9 and 25.10 it becomes evident that salinity factor has little control over seawater density atleast in the tropical and subtropical oceans whereas seawater temperature emerges as the most potent factor of seawater density.

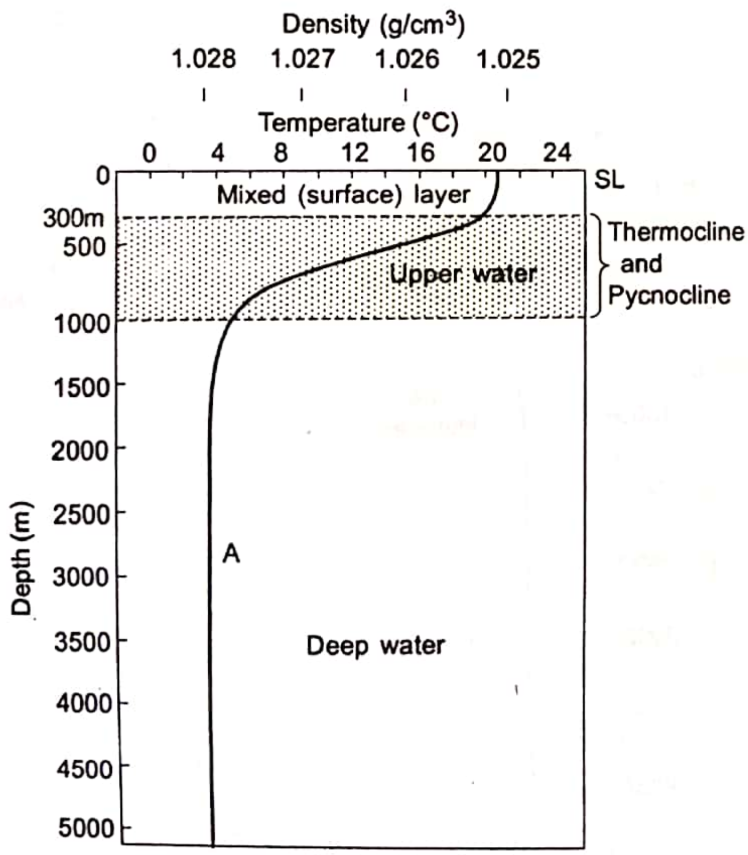

Fig. 25.9 : Illustration of the close relationship between seawater temperature and density. Based on Thurman and Trujillo, 1999.

Density Stratification of Oceans

It is evident from the above discussion that there are 3 layered structures *i.e.* 3 strata of seawater columns from sea surface to the ocean bottoms as follows:

- surface layer of lowest density,
- pycnocline layer of sharp density gradient, and
- deep or bottom layer of highest but uniform density.

(1) **Surface layer** represents the thin topmost layer of the oceans ranging in thickness of 100 to 200m. This layer is also called as **photic zone** which is directly penetrated by solar radiation and hence it is illuminated layer. This surface layer carries 2 percent of total volume of ocean water. Because of thermal expansion of seawater due to direct insolational heating density becomes minimum in this layer in the tropical oceans but due to more evaporation in the subtropical oceans, density becomes a bit higher than the low latitude areas because of increased salinity consequent upon more evaporation. Since this layer is subjected to temporal variations (diurnal, seasonal and annual) in the temperature and salinity of seawater due to its (of surface layer) direct contact with the atmosphere and hence density in this zone is also liable to temporal variations. This zone is very significant for marine plants (phytoplanktons) because this is the only zone where there is photosynthesis, through which phytoplanktons prepare their food and become source of food energy to zooplanktons. Extremely low temperature due to least insolational heating of sea surface water in the polar regions cause higher density than in the tropical and

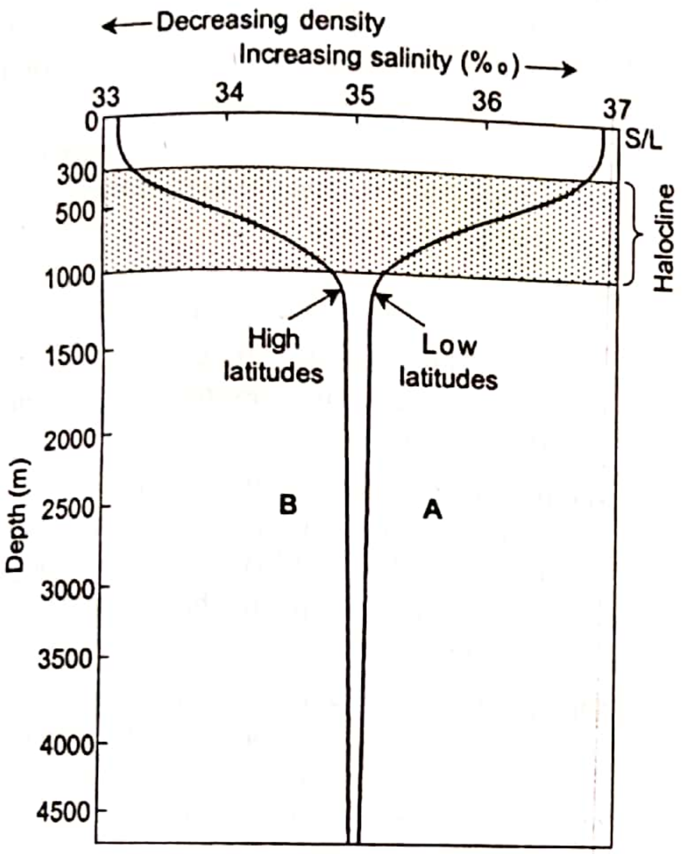

Fig. 25.10 : Relationships between ocean depth, seawater salinity and seawater density, and halocline. Modified from Thurman and Trujillo, 1999.

subtropical regions, with the result dense water sinks in the polar oceans. This is why there is no sharp density gradient in polar oceans and hence there is absence of **pycnocline.**

(2) **Pycnocline layer** represents a transition zone of rapidly changing seawater density between low density upper surface (sea surface) water layer (water mass) and high density deep seawater below. In fact, pycnocline consists of two words, namely **pycno,** which means density, and **cline,** which means slope or gradient. The pycnocline layer is found between 300m-1000m depth of ocean water. As already stated pycnoline, **thermocline** (thermo, means **heat,** temperature, and cline, means slope or gradient, steep gradient of change of temperature of seawater), and halocline (sharp increase in salinity, salinity gradient) occupy almost the same depth zones of 300m-1000m. Pycnoline layer is characterized by sharp increase in seawater density, thermocline layer denotes sharp decrease in seawater temperature, and halocline indicates sharp increase in salinity with increasing depth between 300m-1000m in the tropical and subtropical oceans (figs. 25.7, 8, 9 and 10).

The Pycnocline layer carries 18 percent of total volume of ocean water. It is interesting to note that the pycnocline layer coincides with the thermocline layer of the ocean water mass in the tropical and subtropical oceans whereas it coincides with the halocline in the middle latitudes. The pycnocline layer having high degree of gravitational stability stops vertical mixing of ocean water masses lying above and below it. It is significant to note there is absence of pycnocline and thermocline in the polar areas of the oceans because of least insolational heating of sea surface due to receipt of minimum amount of insolation. In fact, temperature of the surface layer remains very low throughout the year, and hence thermocline and pycnocline are not developed.

(3) **Deep layer** represents high density water mass which extends from 1000m depth to the ocean floor, and carries 80 percent of total volume of the ocean water. Extremely low temperature in the polar areas is responsible of contraction of water and hence increase in seawater density. This leads to sinking of high density water mass of polar regions and causes still high density of deep water mass. The sinking of high density seawater in high latitudes causes undersea flow of water towards low latitudes (tropical areas). Thus, the high density surface water reaches deep water masses in the tropical regions.

25.4 IMPORTANT DEFINITIONS

Absorption, refers to the retaining of a portion of incident energy (radiation) by a substance and its conversion into heat energy (sensible heat).

Aphotic zone, represents non-illuminated portion of the oceans extending between 200m depth to the ocean floor.

Density, refers to the amount of mass per unit volume of substance, usually measured in gram per cubic centimeter (g/cm^3).