# 26

# SALINITY

## 26.1 INTRODUCTION

Salinity is defined as the ratio between the weight of the dissolved materials and the weight of the sample sea water. Generally, salinity is defined as 'the total amount of solid material in grams contained in one kilogram of sea water and is expressed as part per thousand (‰) *e.g.* 30‰ (means 30 grams of salt in 1000 grams of sea water). The oceanic salinity not only affects the marine organisms and plant community but it also affects the physical properties of the oceans such as temperature, density, pressure, waves and currents etc. The freezing point of ocean water also depends on salinity *e.g.* more saline water freezes slowly in comparison to less saline water. The boiling point of saline water is higher than the fresh water. Evaporation is also controlled by salinity as it is lower over more saline water than over less saline water. Salinity also increases the density of sea water. This is why man is seldom drowned in the sea water with very high salinity. Variation in salinity causes ocean currents.

## 26.2 COMPOSITION OF SEAWATER

Sea water contains a complex solution of several mineral substances in dilute form because it is active solvent. The total amount of salt in seawater is gradually increasing because it is brought from the land every year. Several efforts have been made to estimate the total amount of salt in the oceans and the seas. The estimates of Joly, Murray, and Clarke put the total salt in the oceans and seas at 50 billion tons, 5 billion tons and 2.7 billion tons respectively. According to Joly if all the salts of all the oceans and seas are dried up and are spread over the globe these will form a 45.72 m thick layer and if these salts are spread only over the land, these will form 152.4 m thick layer. If all the salts are removed from the oceans and seas, there will be fall in sea level by 30.48m (100 feet). Dittmar during his Challenger Expedition in 1884 reported the existence of 47 types of salts in seawater out of which 7 are most important. Sodium chloride or common salt is by far the most important constituent of sea salt. Table 26.1 represents the weight of salt in grams per 1000 grams ($^0$/oo) and percentages of 7 important salts with a total salinity of 35$^0$/oo as given by Dittmar.

Besides salts, silver, gold and radium also occur but in minute proportion in seawater. These elements are 0.3, 0.006 and 0.000,000,2 mg per metric ton or part per thousand million. It may be mentioned that the proportion of various elements remains constant in seawater every where though the total salinity may vary from place to place. The average salinty varies from 33$^0$/oo to 37$^0$/oo in different oceans and seas. There are numerous nutrients in the seawater which are used by living marine organisms. These elements are silicon, nitrogen, and phosphorous. Besides, arsenic, iron, manganese and copper are also found in the seawater though in smaller quantities. Salinity is measured by Electric Salinity Meter to an accuracy of $\pm0.003^0/oo$.

**Table 26.1 : Significant Salts in the Oceans**

| Salts | Amount ($^0/_{00}$) | Percentage | Salts | Amount ($^0/_{00}$) | Percentage |
|---|---|---|---|---|---|
| 1. Sodium Chloride (Nacl) | 27.213 | 77.8 | 5. Potassium Sulphate ($K_2SO_4$) | 0.863 | 2.5 |
| 2. Magnesium Chloride ($Mgcl_2$) | 3.807 | 10.9 | 6. Calcium Carbonate (Ca $CO_3$) | 0.123 | 0.3 |
| 3. Magnesium Sulphate ($MgSO_4$) | 1.658 | 4.7 | 7. Megnesium Bromide ($MgBr_2$) | 0.076 | 0.2 |
| 4. Calcium Sulphate ($CaSO_4$) | 1.260 | 3.6 | | | |
| Total : | | | | 35.00 | 100.00 |

## 26.3 SOURCES OF OCEANIC SALINITY

Basically the source of oceanic salinity is land. Rivers bring salts in solution form from the continental areas. Surprisingly, there is a lot of variation in the composition of sea salt and riverine salt as calcium sulphate constitutes 60 per cent of river salinity while sodium chloride dominates in the salinity of the oceans (77.8 per cent of total salinity). River water contains only 2 per cent of sodium chloride. This is why some scientists do not accept the rivers as major source of salinity of the oceans and the seas but it may be pointed out that major portion of calcium brought by the rivers into the oceans is consumed by marine organisms. Secondly, the salt brought by the rivers is bit modified in the oceans. Volcanic ashes also provide some salt to the oceans.

## 26.4 CONTROLLING FACTORS OF SALINITY

There is a wide range of variation in the spatial distribution of salinity within the oceans and the seas. The factors affecting the amount of salt in different oceans and seas are called as controlling factors of oceanic salinity. Evaporation, precipitation, influx of river water, prevailing winds, ocean currents and sea waves are significant controlling factors.

**(1) Evaporation**-There is direct positive relationship between the rate of evaporation and salinity *e.g.* greater the evaporation, higher the salinity and vice versa. In fact, salt concentration increases with rapid rate of evaporation. Evaporation due to high temperature with low humidity (dry condition) causes more concentration of salt and overall salinity becomes higher. For example, salinity is higher near the tropics than at the equator because both the areas record high rate of evaporation but with dry air over the tropics of Cancer and Capricorn. According to Wust (1935) the average annual rate of evaporation in the Atlantic Ocean is 94 cm to the north of $40^0$N, 149 cm at $20^0$N and 105 cm near the equator (say **thermal equator** which is at $5^0$N). Salinity is $34.68^0/_{00}$ at $5^0$N and more than $37^0/_{00}$ at $20^0$N. Evaporation in the southern Atlantic Ocean is 143 cm (per year) at $10^0$S and only 43cm at $5^0$S. In general subtropical high pressure belts and trade wind belts record rapid rate of evaporation which increases salinity but cloudy sky with high humidity lowers down salinity in the equatorial belt. It may be pointed out that salinity also controls evaporation.

**(2) Precipitation** is inversely related to salinity *e.g.* higher the precipitation, lower the salinity and vice versa. This is why the regions of high rainfall (equatorial zone) record comparatively lower salinity than the regions of low rainfall (sub-tropical high pressure belts). The extra water in the temperate regions supplied by melt-water of ice coming from the polar areas increases the volume of water and therefore reduces salinity. It may be simply stated that the volume of water in the oceans is increased due to heavy rainfall and thus the ratio of salt to the total volume of water is reduced.

**(3) Influx of river water**-Though the rivers bring salt from the land to the oceans but big and voluminous rivers pour down immense volume of water into the oceans and thus salinity is reduced at their mouths. For example, comparatively low salinity is found near the mouths of the Ganga, the Congo, the Nizer, the Amazon, the St. Lawrence etc. The effect of influx of river water is more pronounced in the enclosed seas *e.g.* the Danube, the Dneister, the Dneiper etc. reduce the salinity in the Black Sea ($18^0/_{00}$). Salinity is reduced to $5^0/_{00}$ in the Gulf of Bothnia due to influx of immense volume of water brought by the rivers. On the other hand, where evaporation exceeds the influx of fresh river waters, there is increase in salinity (Mediterranean Sea records $40^0/_{00}$). There is seasonal variation of surface salinity with maximum and minimum runoff from the land *i.e.* salinity decreases with maximum runoff during rainy season and increases in the season of minimum runoff.

**(4) Atmospheric pressure and wind direction**-Anticyclonic conditions with stable air and high temperature increase salinity of the surface water of the oceans. Sub-tropical high pressure belts represent such conditions to cause high salinity. Winds also help in the redistribution of salt in the oceans and the seas as winds drive away saline water to less saline areas resulting into decrease of salinity in the former and increase in the latter. In other words, in the areas of upwelling of water less saline water moves up from below (and hence low salinity) whereas the areas where water is piled up, salinity is increased. For example, trade winds drive away saline waters from the western coasts of the continents (or eastern margins of the oceans) and pile them up near the eastern coats (or western margins of the oceans) causing low salinity in the former area and high salinity in the latter. This is why the Gulf of Mexico records $36^0/_{00}$ to $37^0/_{00}$ salinity whereas it is only $34^0/_{00}$ in the Gulf of California. Westerlies increase the salinity along the western coasts of the continents whereas they lower the salinity along the eastern coast. Some times, winds minimize the spatial variation in salinity.

**(5) Circulation of oceanic water**-Ocean currents affect the spatial distribution of salinity by mixing seawaters. Equatorial warm currents drive away salts from the western coastal areas of the continents and accumulate them along the eastern coastal areas. The high salinity of the Mexican Gulf is partly due to this factor. The North Atlantic Drift, the extension of the Gulf Stream increases salinity along the north-western coasts of Europe. Similarly, salinity is reduced along the north-eastern coasts of N. America due to cool Labrador current. Ocean currents have least influence on salinity in the enclosed seas but those marginal seas which have communication with open seas through wide openings are certainly affected by currents in terms of salinity. For example, the North Atlantic Drift raises the salinity of the Norwegian and the North Seas.

According to Wust oceanic salinity is affected mainly by three factors viz. (i) salinity is reduced by precipitation, (ii) salinity increases due to evaporation, and (iii) salinity varies due to mixing of water of different character. There is also temporal variation in oceanic salinity. The oceans in the northern hemisphere record maximum and minimum salinity during June (increased evaporation) and December (low evaporation) respectively.

## 26.5 DISTRIBUTION OF SALINITY

The average salinity in the oceans and the seas is $35^0/_{00}$ but it spatially and temporally varies in different oceans, seas, and lakes. The variation in salinity is both horizontal and vertical (with depth). Salinity also varies from enclosed seas through partially closed seas to open seas. Thus, the spatial distribution of salinity is studied in two ways *e.g.* (1) horizontal distribution and (2) vertical distribution.

### 1. Horizontal Distribution

Horizontal distribution of oceanic salinity is studied in relation to latitudes but regional distribution is also considered wherein each ocean is separately described. Similarly, the pattern of spatial distribution of salinity in enclosed seas, partially enclosed seas and open seas is also considered.

**(i) Latitudinal distribution**- On an average, salinity decreases from equator towards the poles. It may be mentioned that the highest salinity is seldom recorded near the equator though this zone records high temperature and evaporation but high rainfall reduces the relative proportion of salt. Thus, the equator accounts for only 35‰ salinity. The highest salinity is observed between $20^0$-$40^0$N (36‰) because this zone is characterized by high temperature, high evaporation but significantly low rainfall. The average salinity of 35‰ is recorded between $10^0$-$30^0$ latitudes in the southern hemisphere. The zone between $40^0$-$60^0$ latitudes in both the hemispheres records low salinity where it is 31‰ and 33‰ in the northern and the southern hemispheres respectively. Salinity further decreases in the polar zones because of influx of melt-water. On an average, the northern and the southern hemispheres record average salinity of 34‰ and 35‰ respectively. On the basis of latitudinal distribution of salinity four zones of oceanic salinity may be identified *e.g.* (i) equatorial zones of relatively low salinity (due to excessive rainfall), (ii) tropical zone ($20^0$-$30^0$) of maximum salinity (due to low rainfall and high evaporation), (iii) temperate zone of low salinity, and (iv) sub-polar and polar zone of minimum salinity.

It may be pointed out that the marginal areas of the oceans bordering the continents have lower salinity than their central parts because freshwater is added to the marginal areas through the rivers. The salinity varies in the open seas according to the latitudes though it depends on the ocean currents but there is no control of latitudes on the distribution of salinity in the inland seas. Salinity of partially enclosed seas in the higher latitudes is seldom controlled by latitudes rather it depends on influx of melt-water. This is why the Baltic Sea records comparatively lower salinity than the North Sea though the latitudinal extent of both the seas is the same. Table 26.2 presents latitude- wise distribution of oceanic salinity in both the hemispheres.

**Table 26.2: Latitudinal Distribution of Salinity**

| Latitudinal zones | Salinity (‰) | Latitudinal zones | Salinity (‰) |
|---|---|---|---|
| $70^0$-$50^0$N | 30-31 | $10^0$-$30^0$ S | 35-36 |
| $50^0$-$40^0$N | 33-34 | $30^0$-$50^0$ S | 34-35 |
| $40^0$-$15^0$N | 35-36 | $50^0$-$70^0$ S | 33-34 |
| $15^0$-$10^0$N | 34.5-35 | | |

**(2) Regional distribution** of surface salinity of the oceans and the seas is described in two ways viz. (a) distribution of salinity in individual oceans and (b) salinity zones of all the oceans together. Jenkins has divided the oceans on the basis of salinity variations into three categories as follows-

**(A) Seas having salinity above normal-**(a) Red Sea (34-41‰), (b) Persian Gulf (37-38‰), and (c) Mediterranean Sea (37-39‰).

**(B) Seas having normal salinity-** (a) Caribbean Sea and Gulf of Mexico 35-36‰, (b) Bass Strait (35.‰), and (c) Gulf of California (25-35.5‰).

**(c) Seas having salinity below normal-**(a) Slightly less: (i) Arctic Ocean (20-35‰), (ii) North Australian Sea (33-34‰), (iii) Bering Sea (28-33‰), (iv) Okhotsk Sea (30-32‰), (v) Japan Sea (30-34‰), (vi) China Sea (25-35‰), (vii) Andman Sea (30-32‰), (viii) North Sea (31-35‰), (ix) English Channel (32-35‰), and (x) Gulf of St. Lawrence (30-32‰); (b) Much below: (i) Baltic Sea (3-15‰), Hudson Bay (3-15‰).

### Pacific Ocean

There is wide range of salinity difference in the Pacific Ocean because of its shape and larger areal extent (fig. 26.1). Salinity remains 34.85‰ near the equator. It increases to 35‰ between $15^0$-$20^0$ latitudes in the northern hemisphere but it becomes still higher (36‰) in the southern Pacific Ocean between the same latitudes. Salinity again decreases further northward in the western parts of the Pacific where it becomes 31‰ in the Okhotsk Sea and 34‰ near Manchuria because of influx of melt water brought by the Oyashio current coming from the Bering Strait and due to weakening of Kuroshio warm current. Salinity also decreases along the

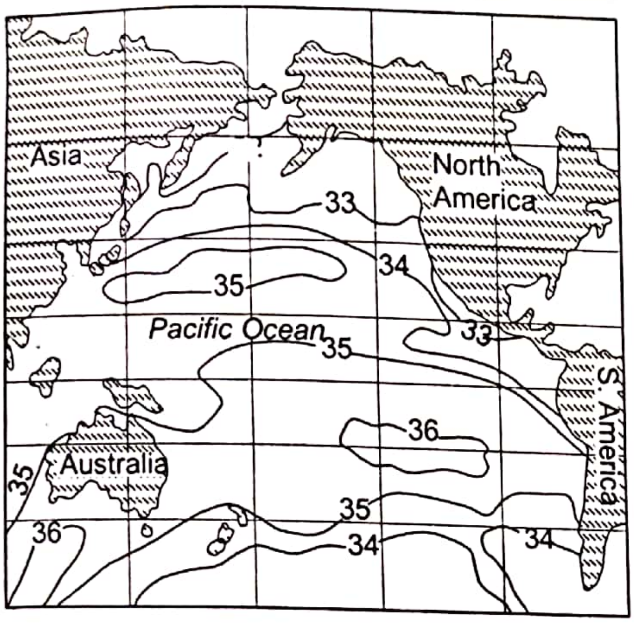


*Fig. 26.1: Horizontal distribution of salinity in the Pacific Ocean.*

Californian, Middle American and Peruvian Coasts due to transfer of water and upwelling of cold water from below. Just to the south of high salinity zone (between $15^0$-$20^0$S) in the southern Pacific as referred to above ($36^0/_{00}$) it becomes low along the Peruvian and Chilean coasts ($33^0/_{00}$). Low salinity is noted infront of river mouths (Yellow River = $30^0/_{00}$, and Yangtzekiang = $33^0/_{00}$).

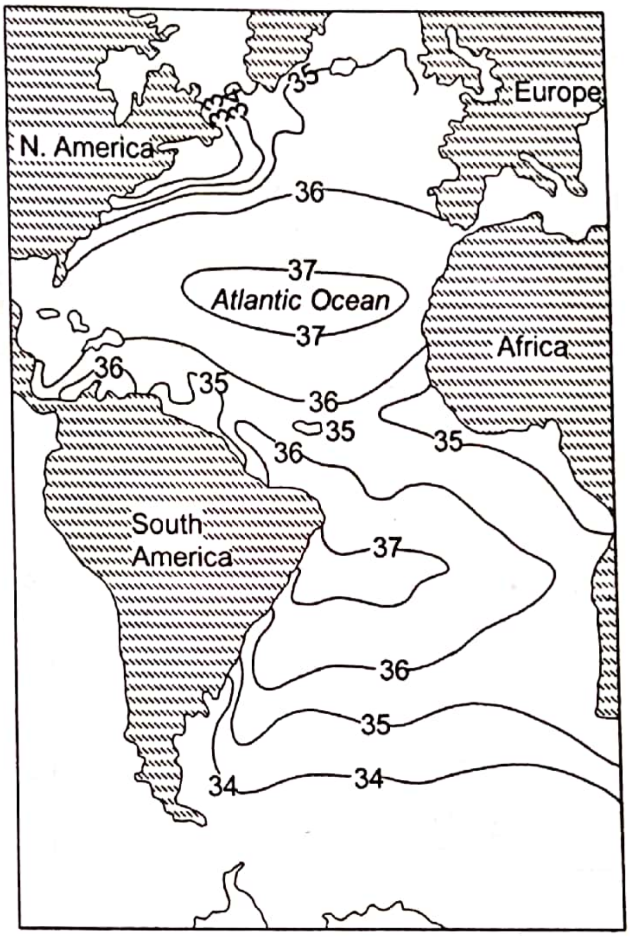


*Fig. 26.2 : Horizontal distribution of salinity in the Atlantic Ocean.*

### Atlantic Ocean

The average salinity of the Atlantic Ocean is $35.67^0/_{00}$. The highest salinity is not observed at the equator rather it is recorded between $15^0$-$20^0$ latitudes. Salinity recorded at $5^0$N, $15^0$N and $15^0$S as $34.98^0/_{00}$, $36^0/_{00}$ and $37.77^0/_{00}$ respectively indicates increasing trend of salinity from equator towards the tropics of Cancer and Capricorn. The central zone of the North Atlantic Ocean located between $20^0$N and $30^0$N and $20^0$W-$60^0$W records maximum salinity ($37^0/_{00}$) and it gradually decreases further northward but with varying trends. The eastern marginal areas of the North Atlantic beyond $40^0$ latitude record comparatively higher salinity than the western margin (east American coast ) because the Gulf Stream carries saline water from the American coast to the north-western European coast. Maximum salinity of $37^0/_{00}$ in the southern Atlantic is found in a region demarcated by $12^0$S-$20^0$S latitudes and $40^0$W-$15^0$W longitudes. Salinity, thereafter, gradually decreases southward. It is apparent from fig. 26.2 that salinity is higher along the western margin than the eastern margin between $10^0$-$30^0$ in the South Atlantic because of upwelling of water along the African coast. Comparatively low salinity is found in front of river mouths (St. Lawrence $31^0/_{00}$, Amazon $15^0/_{00}$, Congo $34^0/_{00}$, Niger $20^0/_{00}$, Senegal $34^0/_{00}$, Rhine $32^0/_{00}$ etc.

The pattern of spatial distribution of salinity is quite different in the partially enclosed seas of the Atlantic Oceans. The North Sea in spite of its location in higher latitudes records $34^0/_{00}$ salinity due to more saline water brought by the North Atlantic Drift. Baltic Sea, on the other hand, records low salinity due to influx of river water. Further northward salinity continues to decrease as it becomes 7 to $8^0/_{00}$ around Rugen Island. It becomes as low as $2^0/_{00}$ in the Gulf of Bothnia due to influx of

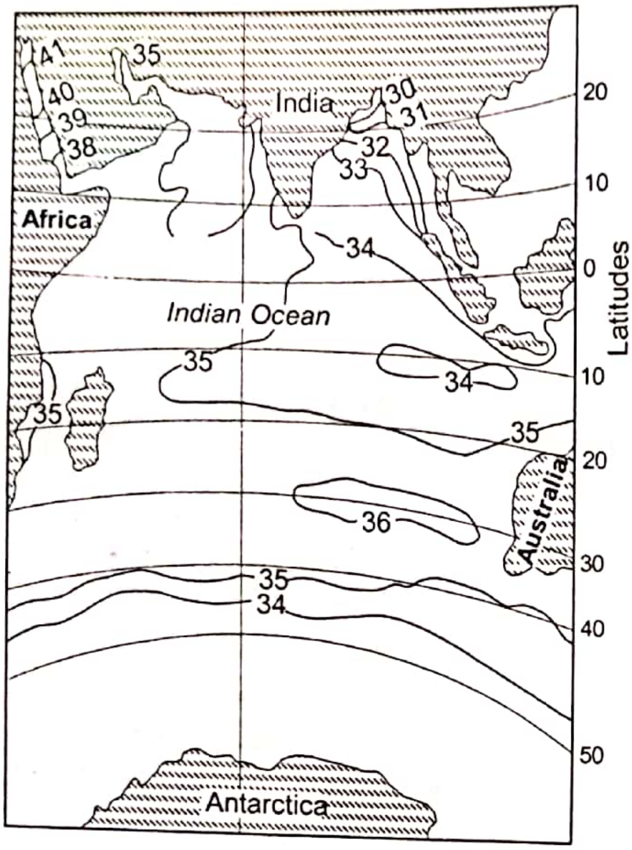


*Fig. 26.3 : Horizontal distribution of salinity in the Indian Ocean.*

freshwater. Salinity of 8 to $11^0/_{00}$ is recorded to the south of Sweden (around Bornholm in Baltic Sea). The Mediterranean Sea records high salinity due to evaporation and little mixture of Atlantic water. Salinity increases from the western part of the Mediterranean Sea ($36.5^0/_{00}$) to the eastern part ($39^0/_{00}$) but it is remarkably reduced to 17-$18^0/_{00}$ in the Black Sea due to enormous volume of freshwater brought by the Dneiper, the Danube etc. There is high salinity in the Gulf of Mexico ($36^0/_{00}$) and the Caribbean Sea due to more saline water brought by the north equatorial current.

### Indian Ocean

The spatial distribution of salinity in the Indian Ocean is more variable and complex than the Pacific and Atlantic oceans. An average salinity of $35^0/_{00}$ is found between $0^0$-$10^0$N but it gradually decreases northward in the Bay of Bengal ($33.5^0/_{00}$ at $10^0$N lat to $30^0/_{00}$ at the mouth of the Ganga) because of influx of immense volume of freshwater brought by the Ganga river. On the other hand, the Arabian Sea records higher salinity ($36^0/_{00}$) than the Bay of Bengal because there is higher rate of evaporation due to relatively less humid conditions and low influx of freshwater as compared to the Bay of Bengal. The western coast of Australia records higher salinity due to dry weather. The partially enclosed seas have higher salinity *e.g.* it is $37^0/_{00}$ at the head and $40^0/_{00}$ in the interior of the Persian Gulf. The Red Sea records the highest salinity (varying between $36^0/_{00}$ and $41^0/_{00}$ in its different parts) because of low precipitation and very high evaporation.

It may be mentioned that spatial distribution of surface salinity of the oceans and the seas is represented by **isohalines** which are the lines that join the places of equal salinity at the sea surface (on the map).

### Inland Seas and Lakes

The amount of salt in the inland seas and lakes is controlled by the rate of evaporation, temperature, influx of river water and the presence or absence of outlets. Wherever a river comes out of a lake or inland sea, salinity is reduced because salt is taken out of the water bodies by the river. The influx of fresh water brought by the river into the lakes and inland seas also lowers down the salinity. For example, low salinity of the northern part of Caspian Sea ($14^0/_{00}$) is because of addition of enormous volume of water brought by the rivers like Volga, Ural etc. but it becomes as high as $170^0/_{00}$ in the southern part *i.e.* the Gulf of Karabugas. Very high salinity is found in Great Salt lake ($220^0/_{00}$, Utah, USA), Red Sea ($240^0/_{00}$), Lake Van ($330^0/_{00}$, Turkey), Dead Sea ($238^0/_{00}$) etc.

### 2. Vertical Distribution

No definite trend of distribution of salinity with depth can be spelt out because both the trends of increase and decrease of salinity with increasing depths have been observed. For example, salinity at the southern boundary of the Atlantic is $33^0/_{00}$ at the surface but it increases to $34.5^0/_{00}$ at the depth of 200 fathoms (1200 feet). It further increases to 34.75% at the depth of 600 fathoms. On the other hand, surface salinity is $37^0/_{00}$ at $20^0$S latitude but it decreases to $35^0/_{00}$ at greater depth. The following characteristics of vertical distribution of salinity may be stated-

- Salinity increases with increasing depth in high latitudes *i.e.* there is positive relationship between the amount of salinity and depth because of denser water below.
- The trend of increase of salinity with increasing depths is confined to 200 fathoms from the surface in middle latitudes beyond which it decreases with increasing depths.
- Salinity is low at the surface at the equator due to high rainfall and transfer of water through equatorial currents but higher salinity is noted below the water surface. It again becomes low at the bottom. More studies and data of salinity distribution at regular depths in different oceans and seas are required so that definite characteristic features of vertical distribution of salinity may be determined.
- Maximum salinity is found in the upper layer of the oceanic water. Salinity decreases with increasing depth. Thus, the upper zone of maximum salinity and the lower zone of minimum salinity is separated by a transition zone which is called as **thermocline zone**, on an average above which high salinity is found while low salinity is found below this zone. It may be remembered that this should not be taken as a general rule because the vertical distribution of salinity is very complicated.
- It may be mentioned that the depth zone of oceans between 300m and 1000m is charactrized by varying trends of vertical distribution of temperature (fig. 25.7, chapter 25), density of seawater (fig. 25.8, chapter 25), and salinity of ocean water (fig. 25.10, chapter 25). This zone is characterized by rapid change of seawater density (increase in density with increasing depth in low latitudes, but constant high density in high latitudes) and is known as **pycnocline**, while this zone represents rapid decrease of temperature with increasing depth upto 1000m in low latitudes (fig. 25.7, chapter 25), and is called as **thermocline.** On the other hand, this zone, representing rapid change of salinity (decrease in seawater salinity with increasing depth in low latitudes, and increase in seawater salinity with increasing depth in high latitudes) is known as **halocline** (fig. 25.10). It is apparent from fig. 25.9 (chapter 25) that **thermocline** and **pycnocline** reveal opposite trends of vertical distribution of temperature and density of seawater, while fig. 4.14 shows positive relationship between salinity and density of seawater.

## 26.6 SIGNIFICANCE OF SALINITY

The ocean salinity has significant effects on physical property of seawater and other aspects of the oceans as follows :

- The freezing and boiling points are greatly affected and controlled by addition or substraction of salts in seawater. The saline water freezes slowly in comparison to fresh water. It is known to all that pure water freezes at the temperature of 0°C freezing point. If the salinity of seawater becomes 35‰ then it would freeze at the temperature of - 1.91°C. On the other hand, the boiling point of saline water (seawater) is higher than fresh water.
- Salinity and density of seawater are positively correlated *i.e.* the salinity of seawater increases its density because solutes (here salts) in water have greater atomic weight than the molecules of fresh water. This is why man is seldom drowned in the seawater with very high salinity.
- Evaporation is controlled by salinity of the oceans. In fact, solutes (salts) in water lowers the rate of evaporation in the oceans. Thus more saline water is less evaporated than less saline water. It may be mentioned that evaporation also controls salinity of seawater. More evaporation reduces the volume of seawater and hence the concentration of salts increases (*i.e* seawater salinity increases).
- Spatial variation in seawater salinity becomes potent factor in the origin of ocean currents.
- The ocean salinity affects the marine organisms and plant community.

## 26.7 IMPORTANT DEFINITIONS

**Adsorption :** The process of adsorption involves sticking of cations of potassium and magnesium to clay minerals which form ferromanga-