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FISHERIES OCEANOGRAPHY
(Revised Edition)

by

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FOREWORD FOR THE REVISED EDITION

The present textbook was revised to include additions and further diagrams. It constitutes one of the volumes in the Oceanography and Meteorology Series, the others being Marine Meteorology, published in March 1979, and Oceanographic Observation Methods, which will be published in the near future. The author hopes that this series of textbooks will prove useful, not only to the trainees but also to all those interested in these subject.

Finally, the author wishes to express his thanks to Miss B. Mountfield for her helpful suggestions and comments during revision of the text, as well as to Mrs. Kanchana Rodchareon for her devoted assistance in the preparation of the draft.

Bangkok
April 1979

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PREFACE

This textbook is the third volume in the Text and Reference Book Series, published by the Training Department of the Southeast Asian Fisheries Development Center. The first volume was the Handbook for Fisheries Scientists and Technologists, edited by Dr. Otohiko Suzuki and published in March 1978, and the second, a textbook on Fisheries Resources and Optimum Utilization by Dr. Shigeaki Shindo, published in April 1978.

The Editor hopes that further volumes in the same series will be issued in the near future.

Other series of the Training Department technical Publications are: Cruise and Practice Report Series, Current Technical Paper Series and Miscellaneous Paper Series. For detailed information, please contact the Training Department.

Bangkok
September 1978

Otohiko Suzuki

Editor, Training Department
Technical Publications.

FOREWORD

The present textbook was prepared for the Fishing Technology and Navigation Course Trainees of the Training Department. The author hopes that it will prove useful, not only to the trainees but also to all those interested in the subject. Since, however, the textbook was drafted in a relatively short time, between mid-June and mid-August of this year, it may not fully cover the field of fisheries oceanography. Therefore, the author would welcome comments and suggestions, which would enable him to publish a revised edition in the near future.

Finally, the author wishes to thank Mrs. Francesca Sreesangkom and Miss B. Mountfield for their assistance in the compilation of this textbook.

Bangkok
September 1978

Otohiko Suzuki

Training Department
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1. OCEAN

1.1 Oceans

When comparing the areas of sea and land on the earth, it will be seen that water occupies a much larger area than land. Actually water covers 361 million km^2, which is nearly 70.8% of the 510 million km^2 total surface area of the earth, and is 2.42 times more than the 149 million km^2 area of land.

Of the area of water, 46% is occupied by the Pacific Ocean, 23% by the Atlantic Ocean and 20% by the Indian Ocean; these are known as the three oceans. The boundary between the Pacific Ocean and the Atlantic Ocean follows the line of longitude 60° 16' W which passes through the southernmost tip of South America. The Atlantic Ocean and the Indian Ocean are separated by the line of 20° 01' E, passing through the southernmost part of Africa, and the Indian Ocean and the Pacific Ocean by the line of 146° 53' E which passes through Tasmania to the south of Australia. Of the three oceans, the Pacific Ocean is the largest with an area of 165.72 million km^2, which is nearly half of the total area of oceans and is 6 times greater than the African continent. The areas of the Atlantic and Indian Oceans are 81.66 and 73.44 million km^2 respectively. The Pacific Ocean is separated by the equator into two parts, which are called the South and North Pacific Oceans, and the Atlantic Ocean is separated similarly into the South and North Atlantic Oceans. The waters near the north and south poles are called the Arctic Ocean and the Antarctic Ocean respectively.

Seas which are dependent on the three oceans are called dependent seas. The oceanographic properties in a dependent sea are believed to be considerably changed if the water is separated from the ocean and there is no strong independent current in the sea. Dependent seas include mediterranean and marginal seas. The Arctic Mediterranean, American Mediterranean, Mediterranean Sea and Black Sea, Asiatic Mediterranean, Baltic Sea, Hudson Bay, Red Sea and Persian Gulf are grouped as mediterranean seas. To marginal seas belong the North Sea, Gulf of St. Lawrence, Andaman Sea, Bering Sea, Okhotsk Sea, Japan Sea, East China Sea, Gulf of California, etc.

1.2 Depth of Ocean and Bottom Configuration

The depth of water increases with the advance offshore from a coastline. Studying the bottom configuration in more detail, we observe that it usually extends as deep as about 200 m with a gentle slope of 1^{o} to 2^{o} on an average, forming a

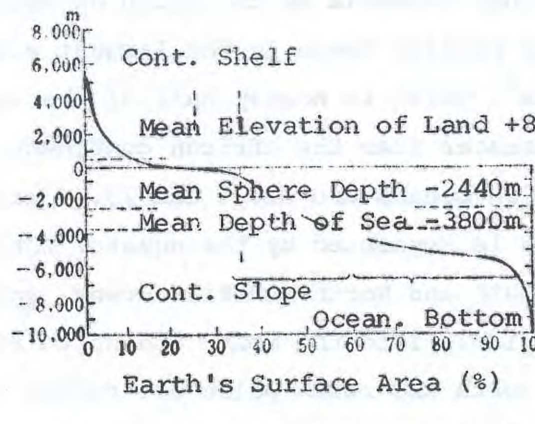


Fig. 1.1. Hydrographic Curve.

kind of shelf around the land; this part of the bottom is called the continental shelf (Fig. 1.1). Most of the continental shelves were originally land and sank in a relatively recent geological age.

The area of continental shelf differs greatly from locality to locality. In an area where there is a high mountain range near a coastline, the continental shelf is narrow and inclines steeply. In an area facing a plain the shelf is wider and slopes gently. The shelf around an island is called an insular shelf. The total area of shelves in the world is nearly 8% of that of all the sea bottom. The bottom configuration of the shelf shows some complex patterns; there are many ups and downs just as on land, and mud sediments transported from rivers accumulate there. In the region, vertical mixing is active and nutrient salts are rich. Therefore, so many planktons propagate themselves that many species of fish live there. Thus the continental shelves are important places for the fisheries industry.

When approaching an area deeper than 200 m through a continental shelf, the bottom can clearly be distinguished from that of the continental shelf because of a steeper slope. The slope of the bottom is usually 3° to 5°, but may reache 20° to 30°, and continues down to nearly 2,500 m in depth. This part is called the continental slope and the total area of the slope is about 15% of that of all the sea bottom.

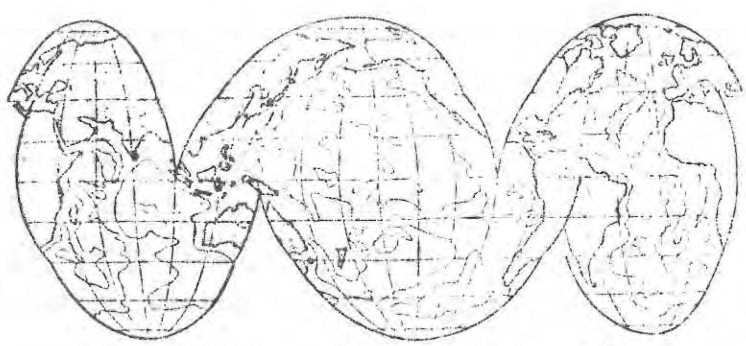
On proceeding to deeper places through the continental slope, the slope becomes gentle again and leads to the ocean bottom whose depth ranges between 2,600 and 6,000 m. The total area of the ocean bottom accounts for 77% of the whole sea bottom. The ocean bottom is not flat throughout and, in some areas, there are seamounts with flat tops, also known as guyots, whose origin is not clearly known. These seamounts reach up to a half to one nautical mile beneath the surface. They help considerably in determining a ship's position.

As already mentioned, there are many mountains and valleys on the sea bottom and the bottom configuration shows very complex patterns. Among these elevations a bank is the most important one for fisheries. This rises from depths shallower than 400 m and the top is more or less flat; the depth of water over the top is relatively shallow but sufficient for surface navigation. In an area around a bank there are special patterns of surface current and distribution of temperature; consequently there is plankton distribution. In most cases, there are upwelling currents which make the waters fertile and rich in nutrient salts. Planktons propagated in the waters, lure small-size fish and these in turn attract larger sized fish. Thus a good fishing ground is formed in the area around a bank.

Among other submarine elevations, there are ridges and rises or swells. A ridge is a long, narrow elevation with sides steeper than those of a rise. A rise is specified as a long, broad elevation which rises gently from the ocean bottom. Isolated mountain-like structures rising from the ocean bottom are know as seamounts, as referred to previously. When the ridges are curved, and particularly if parts of them rise above sea level, they are sometimes termed arcs. The broad top of a rise is called a plateau. The expression sill is applied to a submerged elevation separating two basins. The sill depth is the greatest depth at which there is free, horizontal communication between the basins. The elevations mentioned above result from crustal deformation.

The other category of elevation which results from erosion, deposition or biological activity, comprises banks, shoals and reefs. A detailed description of a bank has been given previously. A shoal is a detached elevation, not composed of rock or coral, with such shallow depths that it is a danger to surface navigation. A reef is a rocky or coral elevation (generally elongated), which is also dangerous to surface navigation, since it may extend above the surface.

For depressions resulting from crustal deformation, the terms trough, trench, and basin are those most commonly applied to the large-scale depressions on the ocean bottom. A trough and trench are elongated depressions, but the former is wide with gently sloping sides and the latter narrow with relatively steep sides. A basin is a large depression of more or less circular or oval form. For those parts of a depression which exceed 6,000 m in depth, the term deep is used (Fig. 1.2). For depressions resulting from erosion



Deeper than 6,000m
Shallower than 4,000m

Fig. 1.2. Depth Contours of the World.

or deposition, a variety of names has been applied to the steep-walled fissures that penetrate the slope and cut across the shelf. The most commonly used terms are canyon or valley, but gully, gorge, or mock-valley are also applied to these features.

The average depth of water is approximately 3,800 m, while the average height of land is about 840 m. If the surface of the earth were levelled, it would be changed into water about 2,440 m deep.

1.3 Shorelines

Shorelines are always changing their features by such actions as crustal deformation, erosion by wave, and transportation of mud and sand by river flow and tidal current. There are many types of shore but the most typical are rocky coast and sandy coast.

Cliffs where there is erosion by the action of wave and currents are typical retrograding coasts, while areas where deltas are formed with transported sand and mud from rivers are called prograding coasts. A shoreline is the boundary between land and sea; this boundary changes considerably with tidal movement especially at a gently sloping beach. However, the term shoreline usually means the low water line.

The beach is defined as the zone extending from the upper and landward limit of effective wave action to low-tide level. Consequently, the beach represents the real transition zone between land and sea, since it is covered and exposed intermittently by the waves and tides. The characteristics of beaches depend much upon the nature of the source material composing their sediments and the effects of the erosion, transportation, and deposition by waves and currents. The upper part of the beach is covered only during periods of high waves, particularly when storms coincide with high spring tides. The slope of the beach is largely determined by the texture of the sediments, but the extent of the beach will depend upon the range of the tide. The terminology applied to the various parts of the beach and the adjacent regions is shown in Fig. 1.3.

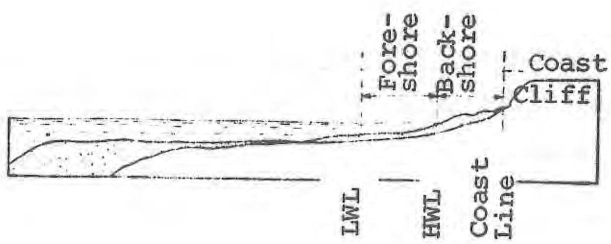


Fig. 1.3 Beach Profile.

1.4 Bottom Character

Sand or mud are settled on most of the sea bottom, while rocky beds are exposed in areas of strong currents as in channels or near points. Gravels, rocky fragments and coarse sands are seen near wavy coasts. The materials thus forming the sea bottom are called the bottom materials or the bottom character.

On continental shelves shallower than 200 m, terrigeneous deposits of relatively coarse particles such as rocky fragments, gravels, sands, muddy sands, sandy muds and shells are settled, while on continental slopes deeper than 200 m the sands and muds transported from the land are seldom seen. The bottom is covered with hemipelagic sediments of fine particles, composed of pelagic and terrigeneous muds; the pelagic muds are mostly skeltal remains of organisms and organic matter. The 200 m depth contour line is called the mud line because it is the depth limit whithin which terrigeneous muds settle.

On the ocean bottom, pelagic deposits of very fine muds are settled. Generally speaking, the fastest in the rate of sedimentation are terrigeneous deposits, followed by hemipelagic deposits, and the slowest are pelagic deposits. The rate of sedimentation for pelagic deposits is estimated to be less than 1 cm per 1,000 year in oceans and 10 cm per 1,000 year in near shore areas.

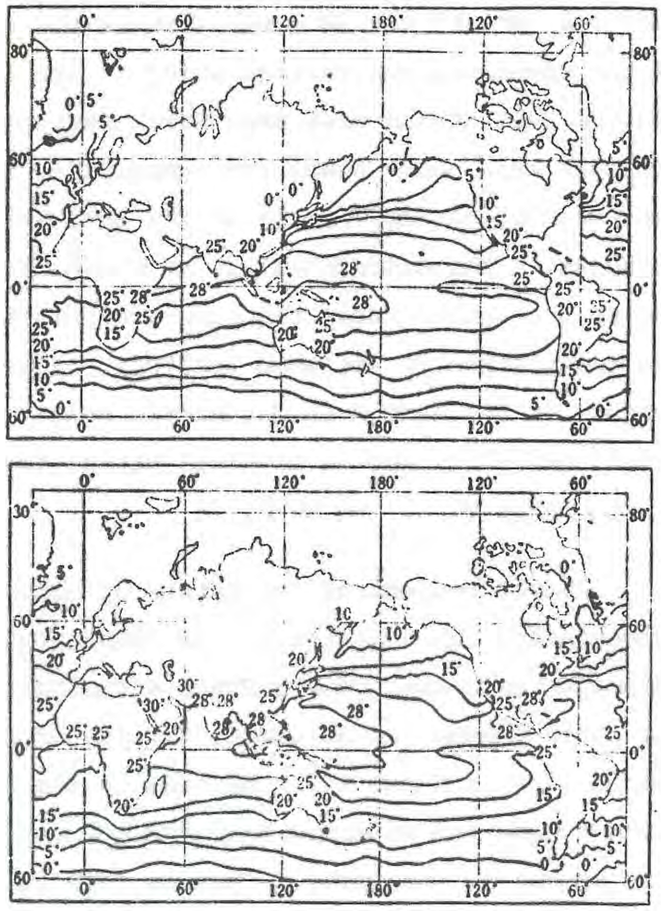
2. SEA Water

2.1 Distribution of Temperature

The direct rays of the sun falling on the earth's surface are strongest near the equator and decrease with increase of latitude. In consequence, the sea-surface temperature is high in low latitudes and low in high latitudes. However, the distribution pattern of temperature is considerably affected by existing ocean currents. Near the equator the Equatorial Counter-currents flowing towards the east are imbedded between the equatorial currents of the northern and southern hemispheres. Temperature in the countercurrent region is lower than in the equatorial currents, because of the upwelling sub-surface water in the countercurrent region. In the Gulf Stream area near North America and in the Kuroshio Current area near Japan, the temperature is considerably higher than the average temperature in the same latitude areas. The temperatures in the eastern waters of the Saghalien and the Kuriles and in the waters near Greenland are remarkably lower than the average temperature in the same latitude, because of the existing cold currents. In the Arctic and Antarctic seas the temperatures are between 0° and $-2^{\circ}C$, and in tropical waters the temperatures are usually in the range of 25° to $30^{\circ}C$.

Curves connecting the points of equi-temperature are called isotherms and the distribution of temperature is clearly shown by drawing isotherms. The surface distribution of temperature of the three oceans in the summer and winter seasons are illustrated in Figs. 2.1 and 2.2. As seen in the figures, temperature over the oceans and adjacent seas between approximately $40^{\circ}S$ and $40^{\circ}N$ are higher in the westside waters than in the eastside waters. On the other hand, in the areas extending from about 40° or 50° of both hemispheres to the polar seas, temperatures in the westside waters are lower than in the eastside waters.

The highest temperature zone is called the thermal equator. This thermal equator is located near the equator, though in the summer of the northern hemisphere this temperature zone deviates considerably towards the north, affected by the cold water masses in the Antarctic sea.



Figs. 2.1-2. Distribution Pattern of Surface Temperature in Winter (upper) and in Summer (lower).

2.2 Diurnal and Annual Variations of Temperature

Sea water temperature varies with the time of day; this is called the diurnal variation of temperature. Water temperature reaches the maximum around 2.00 to 5.00 pm and the minimum around 4.00 to 8.00 am; the occurrence of the maximum and the minimum water temperature is delayed about two hours compared with that of the air temperature. The difference between the maximum and the minimum temperature in a day is called the diurnal range (amplitude) of temperature; on an average the diurnal range is less than 1°C. The diurnal range is usually about 0.5°C between latitudes 30° to 40° over the oceans and nearly 0.9°C in tropical waters. However, the diurnal variation of temperature is affected by the weather: it is slight on a cloudy and windy day, but is relatively large on a fine and calm day.

Water temperature varies considerably with the season even in the same locality. This variation is called the annual variation. It is usually slight in the oceans in the low and high latitudes, as little as 1° to 2°C. In the mid-latitudes, however, the annual variation is large, especially in the areas around 40°N where the variation reaches more than 10°C. Compared with the slight variation in oceans, the annual variation of temperature in coastal waters, especially in shallow areas, is much greater. In the waters east of the Asiatic continent the annual variation reaches 25° to 26°C.

In areas adjacent to Japan, the temperature of near-surface layers reaches a maximum in August to early September and a minimum in February to March. Compared with the air temperature, there is one month's delay in the occurrence of the maximum and minimum water temperatures.

The specific heat of sea water (heat capacity required to heat 1 gram of water by 1°C in temperature) is 0.931 at 35°/oo in salinity, a value much larger than 0.24 for air and 0.2 for rocks. This is the reason why sea water does not heat nor cool easily. Time variations of water temperature, therefore, are slow and slight compared with those of air temperature and the occurrence of the maximum and minimum temperature is delayed. The annual mean water temperature is usually 0.5°C higher than that of air. Oceanic climate depends upon the above facts.

2.3 Vertical Structure of Temperature and Circulation of Sea Water

Water temperature is usually higher at the surface layers where it is warmed by solar heat, decreasing towards the deeper layers. In the layers from the surface down to about 100 m deep, water is well stirred by such actions as wind, wave and convection; this layer is called the mixing layer. In the mixing layer temperature difference is not so great. Beneath the mixing layer, however, temperature decreases very sharply with depth; this layer is called thermocline. In layers deeper than 1,000 m, vertical difference of temperature is not so large and temperature becomes almost constant between 2,000 and 3,000 m in depth. In the Pacific Ocean, the temperature is about 2°C at 2,000 m, 1.5°C at 4,000 m and 1°C at 5,000 m. In the layers deeper than 5,000 or 6,000 m, temperature increases slightly with depth because of pressure.

Considering how the mid-layer water temperature varies with latitude, it is found that, unlike the distribution of the surface temperature, temperature in the 400 to 500 m layer is slightly warmer near the tropics of Cancer and Capricorn (latitudes 23° 27' North and South) than near the equator. Fig. 2.3 shows the thermocline depth of ocean on a longitudinal cross-section extending from the North Pole through the equator to the South Pole. When taking only the solar heat received by sea water

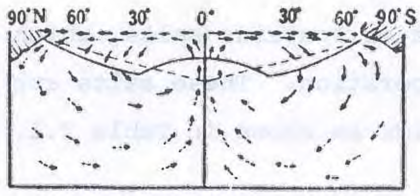


Fig. 2.3. Thermocline Depth.

into consideration, the thermocline depth is supposed to be deepest at the equator, as shown by the broken line in the figure. The actual thermocline depth, however, is much shallower at the equator than the assumed one. This discrepancy is attributed on the following fact: the shallow layer water near the equator is constantly carried away by ocean currents; consequently cold water masses upwell from the deeper layers as compensation and this cools the mid-layer water near the equator. Near the tropics of Cancer and Capricorn, evaporation exceeds precipitation and this results in an increase in salinity. Therefore specific gravity of the water mass becomes large (the water mass becomes heavy) and this tends to cause the shallow layer water to sink. In consequence, water of high temperature is found even in relatively deep layers.

A part of the warm currents moves towards the polar seas, mixing with neighbouring waters, and submerges into deeper layers of the polar seas where salinity is low. In the deep layers a compensating bottom current of extremely low speed prevails from the polar region towards the equator. Thus, near the oceanic bottom, water is almost homogeneous at a temperature of 1° to $2^{\circ}C$.

2.4 Salinity

Sea water contains salts, which can be obtained by the process of evaporation. These salts are composed of various compounds of chloride as shown in Table 2.1.

Table 2.1. Mass of salts per one kg of sea water.

Salts	gram	Salts	gram
$NaCl$	23.476	KBr	0.096
$MgCl_2$	4.981	H_3BO_3	0.026
Na_2SO_4	3.017	$SrCl_2$	0.024
$CaCl_2$	1.102	NaF	0.003
KCl	0.664		
$NaHCO_3$	0.192	Total	34.481

The total amount of salts dissolved in sea water is approximately 35 grams in 1,000 grams of sea water when averaged over the seas of the world, although this amount is different in different localities. Salinity (S) of sea water was defined by an International Commission (1902) as the total amount of salts in grams contained in one kilogram of sea water; viz. the salinity is expressed in parts per thousands, or per mille, for which the symbol $^{o}/oo$ is used. According to Knudsen et al., the above defined salts mean the total amount of solid material when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized. By this definition, therefore, if 35 grams of the above-mentioned salts are contained in 1,000 grams of sea water, the salinity is expressed as $S = 35^{\circ}/oo$.

Chlorinity (Cl) of sea water was also defined by the Commission as the total amount of chlorine expressed in $^{\circ}/oo$; viz. the total amount of chlorine in grams contained in 1,000 grams of sea water. In the above definition, the chlorine means the total amount of chlorine, bromine and iodine, assuming that the bromine and iodine have been replaced by chlorine. For example, $Cl = 19^{\circ}/oo$ means that 19 grams of the above defined chlorine are contained in 1,000 grams of sea water.

Referring to Table 2.2, it will be seen that sea water contains more chlorides than carbonates. This can be understood from the following facts: marine organisms actively absorb calcium carbonate to form their skeltons, whereas chlorides are seldom consumed but, when so, these chlorides are discharged in a relatively short time. In consequence, chlorides gradually accumulate in sea water.

Table 2.2. Composition of sea-water (per cent).

Na	30.52	Cl	55.17
Mg	3.73	SO_4	7.70
Ca	1.19	CO_3	0.30
Sr	0.04	Br	0.19
K	1.10	BO_3	0.08

As shown in Table 2.2, the ratios between the more abundant substances in sea water are virtually constant, regardless of the absolute concentration of total solids. Even comparing the Red Sea, of extremely high salinity (S = 40 ^{o}/oo), and the Baltic Sea, of extremely low salinity (S = 7 ^{o}/oo), there is uniformity of the relative composition of the sea water and constancy of the ratios in weight of the constituents. Therefore, salinity can be known by determining chlorinity, which makes up approximately 55 % of the dissolved solids. The empirical relationship between salinity and chlorinity is given by

$$S = 0.030 + 1.805 \text{ Cl}.$$

2.5 Distribution of Salinity

Sea water is a solution and, in consequence, diffusion and mixing by ocean currents continuously tend to equalize the salinity and the constituents of sea water all over the world. On the other hand, however, there are other actions which produce spatial differences in the salinity of the surface layer; these differences can be attributed mainly to meteorological and geographical conditions. Under the effect of intensive insolation, a higher water temperature than that of air, and strong winds, evaporation increases and thus in turn the salinity of sea water increases. Conversely, with more precipitation and more inflow of fresh water, salinity decreases.

Considering the distribution pattern of salinity, it will be seen that salinity increases with movement offshore from a coastline, and decreases towards the icy waters of the

North and South Poles. Surface salinity is generally lower than salinity in deeper layers, because of precipitation and other causes. This phenomenon is conspicuous in the summer rainy season and in the polar seas where ice melts in summer.

In tropical areas, sunshine is strong but the seas are calm and above all there is much precipitation; in consequence, the surface salinity is low. Salinity is much higher near the tropics of Cancer and Capricorn where trade winds blow. Studying the surface salinity distribution of the world, it will be seen that the concentration of salts is nearly proportional to the difference between evaporation and precipitation. Evaporation is greater in the trade wind zone where the sunshine is strong and a relatively dry wind is always blowing. The waters with the highest salinity are in the trade wind regions of both hemispheres between latitudes 10° and 30° (Fig. 2.4).

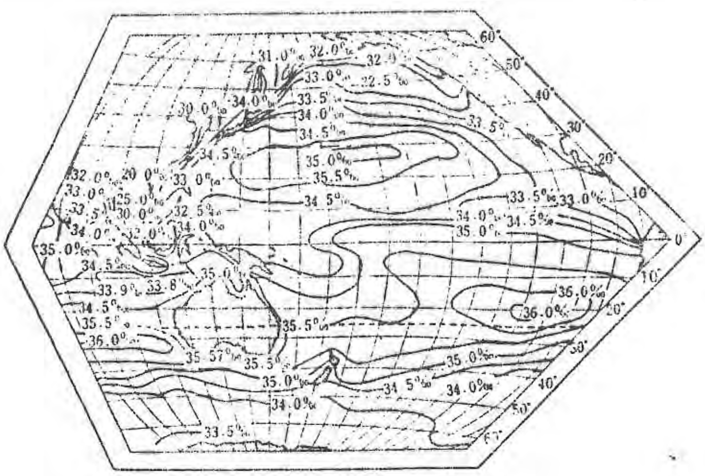


Fig. 2.4. Distribution Pattern of Surface Salinity in the Pacific Ocean.

In the Pacific Ocean, the salinity shows an average of 35.5 to 36^{o}/oo at about 20^{o} to 25^{o}N and more than 36^{o}/oo on an average near 20^{o} South. In the above-mentioned waters, salinity increases with movement away from the continents. In dependent seas which are close to continents, the spatial difference in salinity is great; salinity reaches as much as 40 to 43^{o}/oo in the Bay of Suez, at the head of the Red Sea, which penetrates deep into land with an extremely dry climate. On the other hand, in the Arctic Ocean where ice melts in summer, the salinity is as low as 25.5^{o}/oo on an average. In the Baltic Sea having much fresh water inflow from rivers, the salinity is 7.8^{o}/oo on an average.

There are many types of vertical salinity structures; low salinity in the upper layers and high in the deeper layers; relatively high in the upper layers with low salinity in the mid-layers, etc. In the deep layers (deeper than 600 m) of the oceans, the salinity is relatively uniform, the value being around 34.6^{o}/oo in the Indian Ocean, 34.8^{o}/oo in the Atlantic Ocean, and 34 to 34.6^{o}/oo in the Pacific Ocean. The maximum salinity layers are usually between a depth of 50 and 200 m in the Kuroshio Current region, and at about 150 m in the Equatorial Currents regions. The minimum salinity layers are found between a depth of 600 and 1,000 m in the waters south of Japan; this is considered to be caused by the cold undercurrent from the polar sea. In layers deeper than 1,000 m, salinity increases slightly with depth. Even in the Arctic Sea, where surface salinity is relatively low, the salinity at 1,000 m depth shows 35^{o}/oo. In high latitudes, when snow and ice melt in spring and early summer, surface layers consist of cold water of low salinity. Between the surface layer and deeper layers, a layer of very steep variation in salinity called salinocline or halocline, is found.

2.6 Seasonal Variation of Salinity

Diurnal variation of salinity is not noticeable, but seasonal variation throughout a year is clearly observed. In seas adjacent to Japan, the seasonal range of salinity (difference between the maximum and minimum salinity) is generally 1 to $2^{\circ}/oo$, but reaches $5^{\circ}/oo$ in the Tsushima Straits. The depth limit to which seasonal variation can reach is as much as 100 m from the surface, but the variation may reach a depth of 200 m in channels or in areas where different water masses come into contact.

2.7 Composition of Sea Water

The major constituents of sea water include the following: chlorine, sodium, potassium, sulfate, magnesium, calcium, carbonate and bromine. Constituents other than the above are strontium, aluminium, fluorine, silicon, boron, lithium, nitrate, iron, manganese, phosphorus, copper, barium, iodine, silver, nitrite, arsenic, zinc, gold, radium, etc. Lime and silicate are useful for constructing organisms' skeltons and some marine animals contain relatively large amounts of nickel, lead and copper.

Silver is as little as a few parts per hundred million in sea water, but the total amount in all the seas of the world is estimated to be 13.3 billion tons. Gold is approximately 0.001 to 0.009 parts per million so that the total amount in sea water is estimated to be some billion tons.

2.8 Nutrient Salts

Nutrient salts such as phosphates, nitrates and silicates are dissolved in sea water in small amounts, viz. as little as a few milligrams per one kilogram of sea water. These salts are indispensable to marine organisms such as phytoplanktons, so that the propagation of these micro-organisms is directly controlled by the above-mentioned salts. In other words, of the many constituents in sea water, these extremely small amounts of substances directly govern the existence of these organisms.

According to Liebig, plants require, for their life and growth, certain essential nutrient salts, which they absorb in definite proportions, according to their species. Even though there are available larger quantities of other nutrient salts, the plants will not absorb these in proportion to the existing quantities. The limiting factor is, therefore, the availability of the minimum quantities of the substances that are essential to the plant's growth and not of the substances that occur in minimal absolute amounts. In his theory, Brandt assumed that Liebig's law of minimum substances could be applied to the production of the micro-organisms in the sea. In sea water, the minimum substances are phosphates and nitrates. Important substances, other than the above, are silicates and nitrogen compounds such as carbonates and ammonium nitrate. The nutrient salts fertilize the sea, result in the propagation of phytoplanktons, and thus in turn result in the propagation of zooplanktons. In consequence, plankton-feeding species of fish propagate. The remains of these become bait for benthos and demersal fish or are finally decomposed by bacteria back into nutrient salts. The newly produced salts are utilized again to propagate phytoplankton in the euphotic zone (a zone which is abundantly supplied with light sufficient for the photo-synthetic processes of plants). Thus, the life cycle and the food chain are repeated. Accordingly, the deeper the layer, the more nutrient salts are present. In other words, deeper layers are regarded as a huge warehouse of nutrient salts. In an area where the bottom is elevated, such as a fishing bank, nutrient rich water is pushed up into the euphotic layers by upwelling currents or vertical mixing, and the planktons propagated lure fish schools. Waters rich in nutrient salts are waters of high productivity.

In general, there are more nutrient salts in coastal waters and less in off-shore waters. The upper layers of shallow waters are rich in nutrient salts, because large quantities of the salts are transported from rivers into the sea, and convective mixing takes place in these areas.

There are less nutrient salts in warm seas and more in cold seas. In certain localities, these salts are more abundant in winter than in summer. The quantities of salts are mainly determined by the existing convective mixing. In warm waters, the temperature is higher at the surface and lower in the deeper layers; the surface water is always lighter than the water in the deeper layers. In consequence, vertical convection is not active in these areas and thus the nutrient salts are stored in deeper layers not moving up to the upper layers. Conversely, in cold water vertical temperature difference is not so great. In the winter season, the surface water is sometimes much cooler than that of the deeper layers, and this causes the exchange of the upper and the lower layer water by convection. Moreover, strong wind and wave actions mix the upper and the lower layer waters, and this vertical mixing results in an increase of nutrient salts in the surface layers.

2.9 Gases in Sea Water

Oxygen, nitrogen, carbon dioxide, etc. are dissolved in sea water. Oxygen and carbon dioxide are essential for the respiration of animals and the photosynthesis of plants. Fishes breathe dissolved oxygen with their gills, like human beings breathe oxygen from the air into their lungs. When a surface is covered either with a water layer of low specific gravity and high in temperature as after a long drought in summer, or with an oil film, fresh oxygen is prevented from dissolving into the sea water. Under such conditions, fishes breathe with difficulty and gasp for breath at the surface. This can sometimes be observed in a fish culture pond or in a bayhead area.

Gases can be more easily dissolved into sea water with a wavy surface. Therefore, sea water can be refreshed after a storm. Part of the carbon dioxide is present as free carbonic acid gas, but in sea water by far the greater part is present as carbonates. Dissolved carbon dioxide accounts for 1.6% of the gases in sea water. This value shows a higher ratio compared with 0.03% in the air. If carbon dioxide increases in the atmosphere, this dissolves into the sea under the equilibrium of the pressure of gases, and thus the sea plays an important role in the purification of the atmosphere.

In the atmosphere nitrogen and oxygen account for 78% and 21% of the total respectively (the ratio of these gases is about 4 to 1), while in sea water the above percentages change to 64 and 34% respectively (the ratio is about 2 to 1), though the values vary depending on temperature and pressure. However, the absolute quantities of the dissolved gases are much smaller than in the air. One litre of air contains 780 cc of nitrogen, 210 cc of oxygen and 3 cc of carbon dioxide, and these constitute 78, 21 and 0.03% of the total respectively, while one litre of surface sea water at $S = 35\ ^{o}/oo$ and $T = 10^{o}C$ contains 12 cc of nitrogen, 6.4 cc of oxygen and 0.3 cc of carbon dioxide, and these correspond to 64, 34 and 1.6% of the total gases dissolved. The quantity of dissolved oxygen is small in waters of high temperature and high salinity, and large in waters of low temperature and low salinity. Since oxygen is dissolved through the sea surface, the surface layers contain more oxygen than the deeper layers. In deeper layers much oxygen is consumed through respiration of living creatures and decomposing process of the organisms' remains, and the replenishment in oxygen becomes insufficient.

Generally animals cannot live in places with extremely low oxygen. For example, water of high salinity (of high specific gravity) from the Mediterranean Sea flows in the Black Sea through the Bosporus Straits, and sinks to the bottom layer. This water is stagnant near the bottom. Owing to the considerable difference in specific gravity of the upper and the lower layer water, the Black Sea is strongly stratified and vertical circulation seldom occurs. In consequence, hydrogen sulfide occurs through the decomposing process of organic matter and this reaches as much as 6.5 cc per litre; the water has a bad smell and contains so little oxygen that fishes cannot live there. As mentioned previously, when surface water is of very low specific gravity and water of high specific gravity is lying on the bottom, water exchange between the upper and lower layers virtually ceases so that the dissolution of air into the water is interrupted. In tropical regions near the equator, the surface water is of high temperature and low salinity (i.e. considerably low in specific gravity) and, therefore, the waters of the upper and the lower layers do not easily mix together. Accordingly, oxygen cannot be adequately transported into the deeper layers. The minimum oxygen layer is found at a depth of about 400 to 500 m. This layer surrounds the earth like a belt along the equator and is termed the azoic zone.

2.10 Specific Gravity (Density)

As mentioned previously, sea water contains many substances so that it is heavier than the same volume of pure water. Mass in grams per one millilitre of sea water is referred to as the density of sea water, while the ratio of the mass of sea water to that of the same volume of pure water at 1 atmosphere and $4^{o}C$ is termed the specific gravity of sea water at that temperature. In the CGS system, the specific gravities of sea water are numerically identical with the densities. In oceanography, the term density is generally used, although, strictly speaking, specific gravity is always considered.

Specific gravity (or density) varies with temperature, even when dealing with the same sea water sample. Therefore, when a measurement is made the temperature should be specified. Density ($\int$) of sea water is usually in the range of 1.02000 to 1.03100 and, for simplification, the symbol σ is introduced, where σ is defined as $\sigma = (\int - 1) \times 1000$. With this notation, the density can be expressed as σ = 20.00 to 31.00. Density of sea water at 1 atmosphere and $t^{\circ}C$ is expressed as σ_t. Assuming that the temperature in a certain situation is $t^{\circ}C$, σ_t means the density of sea water sampled up to the surface, the sample having been insulated thermally. Density in the situation (density <u>in situ</u>) $\sigma_{s,t,D}$ is a function of pressure (or depth D), temperature (T) and salinity (S), but there is no great difference in density even at the surface (1 atmosphere) or in deeper layers. Therefore, the density <u>in situ</u> $\sigma_{s,t,D}$ can approximately be expressed as σ_t.

As already mentioned, density of sea water varies with temperature. When comparing water samples from different parts of the world, the temperature should be specified.. In Japan, σ_{15} is adopted as the standard (density of sea water measured at 15°C), but σ_0 is in international use. Density of sea water is determined by temperature and salinity and, therefore, the density (or specific gravity) at a definite temperature could be used instead of salinity.

2.11 Pressure in Sea Water

Pressure in sea water increases nearly 1 atmosphere (about 1 kg per 1 cm^2) every 10 m in depth so that at a depth of 10,000 m, which is the deepest in the world, the pressure is approximately 1,000 atmospheres (corresponding to about 1 ton per 1 cm^2). Therefore, considerable restrictions are imposed on a man working underwater.

By skin diving a man can reach a depth of 40 m, and with diving apparatus a maximum of 185 m. A specially constructed bathyscaphe has reached a depth of 4,000 m. Sea water in deeper layers is compressed due to pressure. When a sample of water is taken up adiabatically to the surface from a certain depth, the temperature decreases due to expansion of the volume; the phenomenon is referred to as adiabatic expansion. For example, if a sea-water sample of 35 °/oo and 0°C is taken up to the surface from 1,000 m, the temperature decreases by 0.044°C. Compressibility of sea water decreases with increase of temperature, salinity and pressure (depth). A water column whose length was originally 10 m at 1 atmosphere and 30 to 35 °/oo in salinity is compressed by some 9 to 5 cm, if the column is lowered 10 m in depth.

2.12 Underwater Acoustic Waves

The velocity of sound waves in water is a function of temperature, salinity and pressure (depth); the velocity increases approximately 2% with an increase of 1°C in temperature, 0.07% with an increase of 1 °/oo in salinity, and 0.11% with an increase of 100 m in depth (10 atmospheres). With the variation of 1 to 1,000 atmospheres (equivalent to the variation from the surface to 10,000 m depth), the sound wave velocity in sea water at 0°C and 35 °/oo varies from 1,446 to 1,617 m/sec.

Sound wave velocity is generally higher in warm and high salinity waters and lower in cold and low salinity waters. Acoustic waves can reach as far as 10 to 15 km in water so they are applied in many fields such as in the echo sounder, fish finder, etc.

In 1945, during a survey using a fish finder off California, a cloud-like layer was detected in a mid-layer around 3,300 m depth. This layer was observed to rise up rapidly towards the surface in the evening and to sink again into the deeper layers in the following early morning. During the observation, sampling was made and plenty of crustaceans such as copepod and euphausia were collected. The layer is referred to as the deep scattering layer (DSL) or sonic scattering layer. Later, a similar phenomenon was observed in the Pacific Ocean, Indian Ocean, Atlantic Ocean, Mediterranean Sea and Antarctic Ocean. The DSL is of great importance in fisheries, because it is closely related to the formation of fishing grounds and good fishing conditions.

2.13 Underwater Illumination

Natural sunlight consists of seven different coloured rays. Of these, the red rays are absorbed immediately in the near-surface layers and become completely extinct around 50 m depth. The blue rays can penetrate deeply into sea water and at 50 m depth one fifth of the original intensity still remains. By refraction and dispersion of the blue rays, even in shallow waters, the surroundings look blue and in deeper layers a red fish looks black. As already mentioned, since sunbeams are mostly absorbed in the upper layers, in the 50 to 100 m layers at the deepest the light decreases so that the surroundings appear fainter. The euphotic zone, within which marine animals perceive light and plants' anabolism is possible, extends to 200 m at the deepest.

Extremely faint blue rays can still be observed even at 1,000 m in depth, but in the layers deeper than 1,000 m there is a dark world where no effect from the sun can be seen. The depth of the dark layers varies greatly between tropical and polar waters.

3. WAVE

3.1 Wave

Waves occurring on the surface of the sea can be roughly classified into wind-waves and swells, although both are caused by wind action. Wind-waves are caused directly by the winds blowing in the area, while swells are long waves propagated from a far distant area where a wind is blowing; the swell can be observed even at a place where there is no wind. From their appearance, these can clearly be differentiated: wind-waves have steep crests and the wave length and period are relatively short, while swells have round crests and look smooth (Fig. 3.1). The wave length

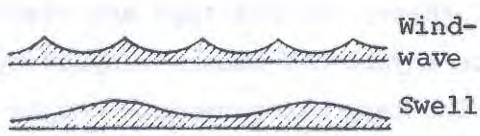


Fig. 3.1. Wind-wave and Swell.

of a swell is usually several ten meters but may reach several hundred meters. The period of swell is 5 to 6 sec at the shortest, while that of a wind wave is some 2 sec. A very high swell (more than 2 m in wave height) may be observed, even on a calm day.

Waves are not a forward motion of sea water, but a transmission of a wavy contour formed at the surface. The undulation is caused by circular motions, with different phases, of water particles. The elements of a wave are wave length, wave height, wave period, wave velocity and wave direction. Wave length (L) is defined as the horizontal distance from crest to crest or from trough to trough. Wave height (H) is the vertical distance from trough to crest. Wave period (T) is the time that elapses in a fixed locality between the occurrence of one wave crest and the occurrence of the next. Wave velocity (V) is the distance travelled by the wave in unit time,and is equal to the division of the wave length by the period ($V = L/T$). Wave velocity is generally in the range of 11 to 15 m/sec. Wave direction is applied to the direction from which the wave advances.

3.2 Wind Wave

When there is no wind, the surface is of oily smoothness. With blowing winds, the surface is covered with crepe-like creases, which change to scale-like creases and finally to ripples. Ripples appear when wind velocity is more than 23.2 cm/sec; these wavelets are called capillary waves. At the beginning stage, the wave length of ripples is usually about 2 cm. When wind velocity exceeds 1 m/sec, a regular form of ripples,whose wave length is 5 to 8 cm,occurs. Waves develop with increasing wind velocity. With more than 2 m/sec of wind velocity, the ripples change to gravitational waves, which are usually called wind waves. The troughs become deeper and the crests steeper with increasing wind velocity. The cross sectional view of a wave in the open sea shows that the wave form is trochoidal ($H/L = 0.07$). When wind velocity exceeds 3 or 5 m/sec, the crests begin to break and white caps appear. When H/L exceeds 0.14, the trochoidal wave form begins to change and the crests are covered with white caps.

When wind velocity becomes more than 10 m/sec, the wave form becomes longer and the crests are broken to produce foam. With more than 20 m/sec of wind velocity, the surroundings are covered with spray from the small mountain-like crests. As may be seen from the above, the stronger the wind and the longer the wind blows, the higher the wave height becomes. When wind is blowing from land, the longer the distance from land (fetch), the more the wind wave develops. For a high wave, in the ocean, the wave height is generally as high as 2 to 5 m, wave length as long as 30 to 40 m, period 4 to 5 sec and velocity 10 to 15 m/sec. In a storm, however, wave length may reach more than 100 m, height 10 to 15 m and period around 10 sec. Generally, the ratio of H/L is nearly 1/30.

In wind waves, the diameter of circular motion of water particles decreases to nearly a half of that at the surface with an increase of depth by 1/9 of the wave length. Therefore, at the depth which is nearly the same as the wave length, the amplitude (corresponding to the radius of a circle) of the wave decreases to 1/500 of that at the surface so that the effect of the wave action is negligible. Generally speaking, no turbulence caused by surface waves reaches down to a depth of 200 or 300 m. In shallow waters, the wave is an ellepsoidal trochoid and the two axes of the ellipse and the ratio of the minor axis to the major axis decreases with the depth. This elliptic motion of water particles finally becomes a horizontal reciprocating motion at the bottom.

When two waves from different directions intersect, crossed waves occur. These waves are seen near the central area of a typhoon. From observed data, it is estimated that the period is 14 sec, height 12 m, length 306 m and velocity 21.9 m/sec.

3.3 Swell

During late summer in Japan, long waves having round crests reach the coasts even on a calm day and the waves dash against the shore intermittently. On a sandy beach the wave becomes a plunging breaker (or roller). As already mentioned, this is caused by swells approaching a coast; the swell is propagated from the central region of a typhoon (or cyclone) very far away. At the origin, the wave is steeply crested as seen in the eye of a typhoon, but during propagation the crest becomes rounded. The velocity of a swell is more than twice as fast as compared with that of the typhoon. Therefore, the swell can arrive two or three days earlier as a forerunner at a coast more than 1,000 km away from the typhoon.

The wave period is 5 to 30 sec, the length is at the most 200 to 800 m, and the velocity 40 to 45 km/hr. When swells approach a coast and break, the noise sounds like thunder even in an inland area some distance from the coast.

The direction of a swell almost coincides with that of the storm area. However, the swell does not always arise from the centre of a typhoon or a low pressure. Sometimes it comes from a winter monsoon. The Atlantic coast of Morocco is famous for its violent swell. Transportation from a ship to the land sometimes becomes impossible because of a huge swell. The swell arises from low pressures passing through an area between Iceland and Ireland, approximately 1,600 nautical miles distant from Morocco. It arrives at the coast of Morocco two to four days after the low pressure has passed between those islands. The velocity of the swell is 30 to 50 Km/hr., the period 7 to 20 sec, and the height 0.5 to 5.0 m.

4. TIDE

4.1 Tide

Observing the sea from a coast, it will be seen that the sea surface usually rises and falls periodically twice a day; this phenomenon is referred to as the tide. Tide is caused by the gravitational attraction of the moon and sun, and this elevation and depression of the sea surface is called the astronovical tide. The astronomical tide is distinguished from the meteorological tide, which is the rising and falling of the sea surface by meteorological variations such as variation in wind direction, wind velocity, atmospheric pressure, precipitation, etc.

According to Newton's law of universal gravitation, the moon's or the sun's attraction acting on a body on the earth is in inverse proportion to the square of the distance between the two bodies. Therefore, the gravitational attraction of the moon and sun acting on sea water is different in different localities. If the gravitational attraction of the moon or the sun were the same everywhere on the earth, the attraction would put the earth in a uniform motion as a whole, not producing a relative motion such as the tidal phenomenon on earth. The gravitational attraction to the earth is acting on the centre of gravity of the earth.

Referring to Fig. 4.1, assume that the whole surface of the earth is covered with sea water. The sea water at one

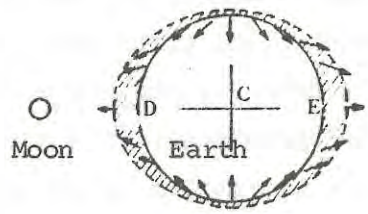


Fig. 4.1. Tide-generating Force due to the Moon's Gravitational Attraction.

side (D) of the earth is facing a celestial body such as the moon or the sun and is nearer than the centre (C) of the earth. The sea water at the opposite side (E) is farther than the center (C) from the celestial body. Therefore, the attraction acting on the sea water at D is stronger compared with that at the centre C and the attraction on the sea water at E is weaker than at the centre C. Accordingly, the difference of the celestial body's attraction acting on sea water on the earth from that acting on the whole earth (the attraction acting on the centre C of the earth) becomes the force generating the motion of sea water relative to the solid earth. The horizontal component of the force is referred to as the tide generating force.

Let us consider the problem in more detail, and assume a simple case that there exists only the earth and the moon and these bodies are rotating with the same angular velocity around a common centre of gravity. Under these conditions, the gravitational attraction between the moon and the earth is in equilibrium with the centrifugal force caused by rotation. Each point on the earth is rotating on a circumference of the same radius with the same angular velocity, so that the centrifugal force is the same everywhere on the earth and is directed outside from the centre of a circle drawn by the respective points. On the other hand, as mentioned previously, the attraction is different in different localities; the attraction is greater at the side of the earth facing the moon than at the centre of the earth, and smaller at the opposite side of the earth than at the centre. In consequence, the attraction is greater than the centrifugal force at one side of the earth and smaller at the opposite side. By obtaining the distribution of the tide producing force caused by the difference between the attraction and the centrifugal force, it is seen that the sea surface rises on the side of the earth facing the moon and on the opposite side. These two elevations of the sea surface rotate around the earth corresponding to the moon's motion relative to the earth. Therefore, we can observe that at a fixed point on the earth two high waters and two low waters occur every day; this movement is called tidal wave. The sun's effect on the tide is only 46% of that of the moon, and the effect of other celestial bodies is negligible. Actual tidal phenomena are more complex, because the effects of the moon and sun sometimes overlap. The dominant tide generating force is semidiurnal and other tide generating forces comprising longer periods have only a slight effect.

4.2 Tidal Phenomena

As mentioned previously, two rises and two falls of the sea surface occur in a day, and the period from one high water to the next is 12 hr. 25 min. on an average. Rising and falling of the surface two times require 24 hr. 50 min. As discussed in the preceding section, tide is caused mainly by the moon and 24 hr. 50 min. corresponds to the time interval for the moon to go around the earth (a lunar day). Accordingly, the occurrences of high and low waters are delayed by about 50 min. compared with the previous day. The period from one high water to the following low water is called the ebb tide and that from one low water to the next high water is called the flood tide. Just before and after the high and low waters, the rise and fall of the surface become slow; these are called the stand of tide. The difference between high and low waters is called the range of tide. The range of tide is not constant but varies with the phase of the moon. Around the new moon and full moon, the moon, earth and sun are nearly in alignment and, in consequence, the effects of the moon and sun are joined to produce the spring tide. Around the half moon of the first or the last quarter, the lines connecting the moon and the sun with the earth make a right angle and, consequently, the tide generating forces of both celestial bodies are cancelled out to produce the neap tide (Fig. 4.2). The range of neap tide is about 60% of that of the spring tide. The largest range of tide occurs around the vernal and autumnal equinoxes, because then the moon, sun, and earth are exactly in alignment and, in consequence, the sum of the tide generating forces reaches the maximum. The time of high water or low water is closely related to the moon's motion. Therefore, the time interval between the southing of the moon and the high water or low water is almost constant at a fixed point; these time intervals are called the high water interval and the low water interval respectively. Both

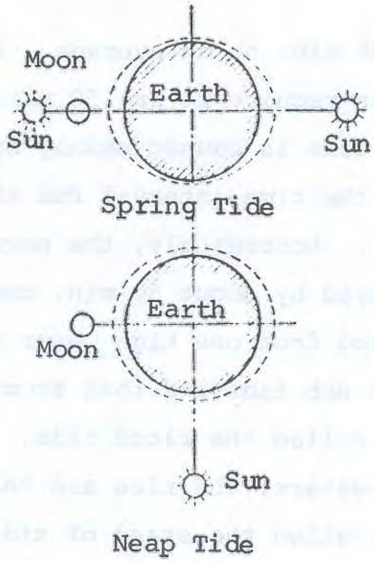


Fig. 4.2. Spring and Neap Tides.

are collectively called the lunitidal interval. These intervals vary slightly with the moon's phase though the variation is only several minutes. The means of the above intervals are called the mean high water interval and the mean low water interval respectively. The mean of the high water intervals during the spring tide is called the establishment. The establishment in the world ranges from 0 to 12 hours.

The reason why the high water occurs several hours after the southing of the moon is mainly due to frictional resistance, caused by the irregular distribution of land, water and bottom configuration. Comparing the high and low waters which occur usually twice a day, the heights and the intervals do not, generally speaking, show the same values respectively; this phenomenon is called the diurnal inequality. Of the two high waters occurring in a day, the higher one is called the higher high water and the lower the lower high water. Likewise, of the two low waters, one is called the higher low water and the other the lower low water (Fig. 4.3). This diurnal inequality occurs depending on the seasons and the

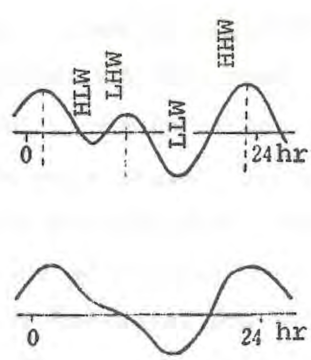


Fig. 4.3. Diurnal Inequality.

localities. In an extreme case, only one high water and one low water occur in a day. This particular phenomenon is called the vanishing tide.

Diurnal inequality results from co-existence of the diurnal and semidiurnal tides. In the case where the moon and sun are located near the plane through the equator of the earth, two high waters and two low waters occur regularly in a day everywhere on the earth and the tides in the morning are almost equal to those in the afternoon. This occurs around the new and full moons in spring and autumn, and around the waxing and waning moons in summer and winter. The further from the equator the moon deviates, the larger the diurnal inequality becomes. Diurnal inequality reaches peaks around the waxing and waning moons in spring and autumn,and around the new and full moons in summer and winter. The largest diurnal inequality occurs when the moon is farthest from the equator; the tide is called the tropical tide.

4.3 Cotidal Lines

The time interval between a standard meridian (135°E in Japan) passage of the moon and the occurrence of high water is called the cotidal hours and is given in lunar hours (1 lunar day is equal to 24 lunar hours). Points that have high water at the same hour can be joined by lines which are called the cotidal lines. The progress of the tide can be shown in terms of the cotidal lines on a chart which is called the cotidal chart (Fig. 4.4). The cotidal lines all meet at a point where the tide

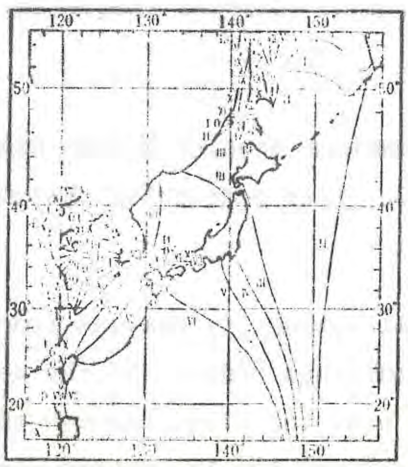


Fig. 4.4 Cotidal Chart of Semidiurnal Component in the Seas adjacent to Japan.

vanishes (no rise and fall of the surface occurs), which is called the amphidromic point.

4.4 Distribution of Range of Tide

The range of tide greatly varies from one locality to another. The largest range of tide in the world is seen at the head of the Bay of Fundy, Canada, where the range reaches more than 15 m. The Bay of Bristol, Alaska, ranks second and there the range is more than 12 m.

In the seas adjacent to Japan, the mean range of spring tides is 1 to 1.5 m in the northern part along the Pacific coast, 2.5 to 3.5 m on the west coast of Kyushu (it reaches 5.5 m in the Ariake Sea, Kyushu), and 0.2 to 0.6 m along the Japan sea coast. The range of tide is large along the west coast of Korea, and is 3 to 4.5 m in the southern part, more than 6 m to the north of Mokpo and 10 m at Inchon.

The mean sea level gradually rises and falls, usually with one cycle in a year. This variation depends mainly on meteorological causes such as atmospheric pressure, wind, rainfall, variation in temperature, etc. In waters neighbouring Japan, this reaches the minimum from January to April and the maximum from July to October, but the difference between the minimum and the maximum is as slight as 0.3 m. Datum for soundings given in navigation charts is not the same in all countries. In most countries, however, the lowest low water level is taken as the standard sea level.

4.5 Tide Prediction

The two high and low waters occurring within a day vary greatly, as already mentioned, because of the diurnal inequality and variations in the range of the tide, and the lunitidal intervals, which are closely related to the moon's motion. These differences result from the fact that the orbital courses of the moon and sun, the main tide producing celestial bodies, are different; the planes of their orbits do not coincide with that of the earth's equator, and the distances and positions of these celestial bodies relative to the earth are always changing, owing to the differences in their revolutional velocity.

By leaving aside actual conditions and assuming that the tides consist of regular tide components caused by imaginary celestial bodies which are revolving around the earth's equator keeping constant distances and with respective velocities, then the tide components assumed to be caused by the imaginary bodies can be obtained through calculations, using data from tidal stations. Half the range of the tide constituents thus obtained is called the semi-range, and the time interval between a celestial body's passing through the meridian and the next high water of the corresponding tide constituents is called the phase lag and is expressed in terms of an angle. The semi-range and phase lag are collectively called the harmonic constants; these constants can be obtained through harmonic analysis, using the data from tidal stations. Observed data on tide are usually resolved into twenty to thirty constituents, and the future tidal levels of the respective tide constituents are calculated. Astronomical tides are obtained by superimposing the tidal levels thus obtained, and tide prediction is possible by adding meteorological tide data, if available. The tide table, published annually, is compiled using the astronomical tides obtained in the above manner.

4.6 Tide Current

Tidal current is a horizontal motion reciprocating periodically, accompanied by the tidal motion of sea water. Its velocity is changing all the time. Tidal current gradually increases its velocity, after movement towards a certain direction has begun, and reaches its maximum velocity. Thereafter, it decreases in velocity and finally ceases to move. The state when the current stops is called the slack water. Then, it starts to move again changing its direction almost opposite to its previous direction (called the turning of current) and a similar process is repeated. In most cases, four turnings of current occur in a day about every six hours, but, in one specific case, only two turnings occur in a day. The strongest current occurs during the spring tides of the new and full moons, and the weakest during the neap tides of the waxing and waning moons. Generally speaking, the time interval between one turning of current and the next and the maximum current velocity does not show the same values in the morning and in the afternoon; this phenomenon is called the diurnal inequality in tidal current and is very similar to that of the tide.

Tidal current in off-shore areas changes its speed and direction in the course of time and has no slack water. In most cases, the current direction rotates twice a day (one rotation per 12 hours 25 minutes), but in some areas only one rotation occurs in a day (one rotation per 24 hours 50 minutes); both are called the rotatory current. The relation between the tide and tidal current is different in different localities. In most places, the flood and ebb currents, which flow towards a certain direction between the low and high waters, and in the opposite direction between the high and low waters respectively, turn their directions at the high and low waters respectively. In other places, however, the turning of current occurs after a certain time has elapsed after the high or low waters. In an extreme case, the maximum current velocity is seen at the high and low waters, and the current turns its direction about three hours after the high and low waters; this phenomenon is called the tide and half tide. In oceans, the tidal current velocity is extremely weak, sometimes even negligible. However, in an area where the depth is shallow and the range of tide is extensive, the current velocity is strong. Remarkably strong tidal currents are observed at places such as narrow straits, inland seas, shoals on a continental shelf, etc. In the Seto Straits, Japan, the tidal current reaches almost ten knots during spring tides from April to May.

5. OCEAN CURRENT

5.1 Ocean Current

The motion of sea water can roughly be divided into two groups: the steady and the periodical motions. Ocean current belongs to the former. The term ocean current means that a considerable quantity of sea water moves steadily and continuously from one place to another. Of course, ocean current is not steady in a strict sense. Its velocity varies with a clear cycle of one year, and its direction changes to some extent. However, the current can be regarded as steady when compared with the tides, the most evident cyclic motion of sea water, or the waves, the periodic motion with shorter cycles.

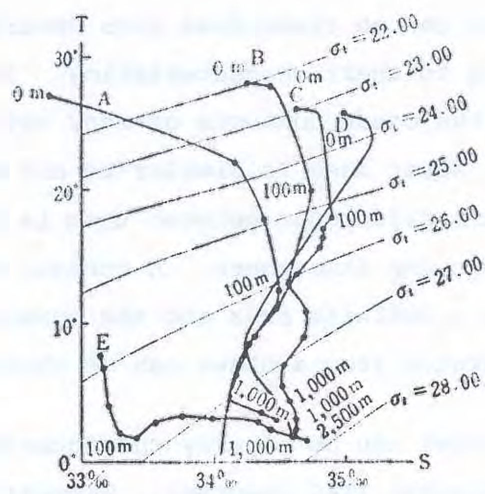
Needless to say, ocean current is of great importance in navigation. In the mid-nineteenth century, Maury, an American naval officer, clarified the pattern of oceanic currents by dealing statistically with the data from many ships' log books. It is a well known fact that ships' cruising time was greatly shortened by applying his currents chart. As mentioned previously, ocean currents are liable to variations within long term cycles, and these variations in turn result in variations in fishing grounds, fishing seasons and catch amounts. Along a boundary where two different currents meet and around an upwelling area, fishes are found to concentrate and thus good fishing grounds are formed. In many ways, variations in ocean current are closely related to fisheries.

5.2 Water Mass

Sea water can be classified into several different water masses, according to their characteristics. In other words, it is considered that the ocean consists of many water masses of different properties. Water mass is similar to air mass in meteorology. However, the main difference between them is that the ocean is much more steady than the atmosphere. A certain water mass is nearly always found in a definite area and the boundary by which one water mass is separated from another can be clearly observed.

Water masses can be clearly characterized using the temperature-salinity diagram (T-S diagram). Temperature and salinity are taken on the vertical and horizontal axes of the diagram respectively; the observed temperatures and salinities at a station are then plotted layer by layer on the diagram and the plots are connected with lines from the uppermost to the lower layers. The relation between temperature and salinity appears clearly by using the T-S diagram, and the variation of temperature and salinity with depth can be made even clearer by inserting the observed depths near to the corresponding plots. When equi- σ_t curves, produced by plotting the points of equivalence in density of sea water at 1 atmosphere and $t^{o}C$, are inserted on the T-S diagram, the stability of the stratified sea water can easily be judged from the slope of the σ_t curve.

In Fig. 5.1 are shown the T-S curves of the representative regions in the North Pacific Ocean. The plots on



A 41°N 145°E Tsushima Cur. Region
B 8°N 141°W Eq. Count. Cur. Region
C 31°N 140°E Kuroshio Cur. Region
D 16°N 172°E Nor. Pac. Tr. Wind Zone
E 53°N 177°W Bering Sea

Fig. 5.1. Temperature-Salinity Diagram.

the curves represent the depths in meters and are from top to bottom 0, 25, 50, 100, 150, 200, 400, 600, 800, 1,000, 1,500, 2,000, 3,000, ... The figure shows that the T-S characteristics of sea water deeper than a depth of 1,000 m do not vary much in different localities. As seen in the figure, the angles between the T-S curves and the σ_t curves are small in the near-surface layers in most regions and in the 100 to 150 m layers of the Bering Sea. These facts show that the sea waters are unstable and vertical mixing is active. A homogeneous water mass, formed by thick layers as seen in a sea basin, is expressed as a point on a T-S diagram (expressed as a set of temperature and salinity); such a water mass is sometimes called a water type. Fig. 5.2 shows the distribution pattern of water masses in the upper layers of the oceans.

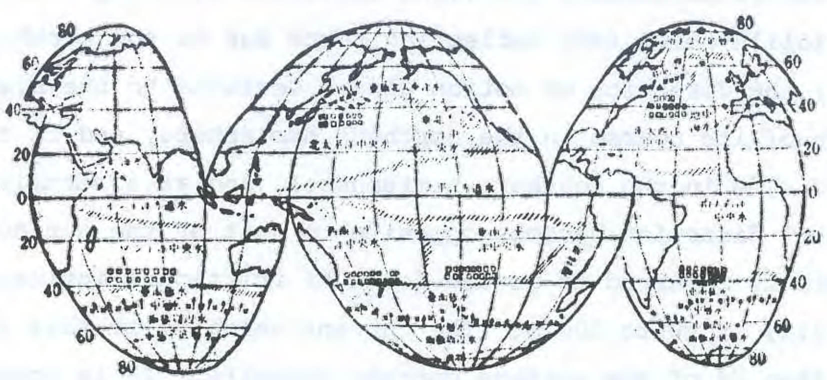


Fig. 5.2. Distribution Pattern of Water Masses in the Upper Layers of the Oceans.

5.3 Causes and Kinds of Ocean Current

The causes of ocean current can be divided into external and internal causes. Among the external causes, winds, in particular, should be mentioned; as regards internal causes the variation in density of sea water is the main factor to be considered.

When winds blow on a sea surface, the sea water is driven in a definite direction by the frictional force between the wind and the sea surface; the current thus occurring is called the drift current (the wind or wind-driven current). According to Ekman's theory, the direction of drift current at the surface deviates 45° to the right hand side from the wind direction in the northern hemisphere, and 45° to the left hand side in the southern hemisphere. With the movement of water in the upper layers owing to wind action, water in the subsequent layers is set in motion. In the northern hemisphere, the deviation of the current direction towards the right increases with depth in accordance with Corioli's force (the deflecting force due to the earth's rotation; the direction of motion always deviates to the right hand side of its course in the northern hemisphere, and to the left hand side in the southern hemisphere), and at a certain depth the current direction becomes opposite to that of the surface current. This depth is referred to as the depth of frictional influence and is generally at 60 to 200 m. The current velocity at this depth is less than 5% of the surface current velocity. It is considered that friction due to winds produces effects down to this depth.

Denoting the drift current velocity and the wind velocity by V and W respectively, the ratio V/W is referred to as the wind factor which, from the observed data, has been confirmed to be in the range of 0.014 to 0.05. According to this data, the velocity of a drift current at the surface is 1/100 to 5/100 of that of the wind blowing just above the surface. However, the current velocity thus obtained is too low and actual ocean currents cannot be fully interpreted using only Ekman's model. In other words, ocean currents are considered to result not only from the winds, but also from the spatial difference of density in sea water due to radiation, evaporation, precipitation or melting of ice, and the spatial difference of atmospheric pressure. In their theory, Bjerknes and Sandstrom assumed that Corioli's force accompanied by ocean current is in equilibrium with the pressure gradient in sea water due to density distribution. After trials of the dynamic calculation of ocean currents, it has been shown that their model can well be fitted to most of the large-scale currents. In the Kuroshio Current and Gulf Stream regions where winds are not very strong, the results from dynamic calculation agree well with the observed data. It is not correct to consider, however, that the density current (convection current) is caused by the spatial difference of density in water. In fact, the above-mentioned density distribution (pressure distribution) results from the wind distribution (in more precise terms, the energy distribution due to the prevailing winds such as the westerlies and trades). Therefore, the ocean current which can be explained by mass distribution (density distribution) has more recently been referred to as the geostrophic current. As mentioned previously, the Kuroshio Current and Gulf Stream are typical examples of a geostrophic current.

The main causes of currents are the stress caused by winds. In the actual oceans, however, the space is definite and bounded by land. Therefore, with the movement of sea water in a certain direction owing to the winds, the sea water is accumulated near the coast and the surface slopes. This in turn results in a pressure gradient in the water and thus the sea water is set in motion, under the equilibrium of the gradient. The current caused by the sloping surface is called the slope current (gradient current).

Of the sea waters at the surface, those heavier than the surrounding masses sink downwards and stop where water of the same density is encountered; thus vertical convection occurs. The waters that stopped sinking at a certain depth tend to spread horizontally. This motion is very slow but can be found widely at great depths. Since the density of sea water is usually greater in the deeper layers, the sea waters which have sunk down from the cold surface at high latitudes near the north and south poles reach the deeper layers at several thousand meters near the bottom, then move very slowly towards the equator. This horizontal motion, which is a type of advection, is called spreading.

If water moves from one place to another owing to some external cause, other waters move in as compensation. This motion is called the compensation current. The Equatorial Counter-current belongs to this type of current.

The motion of sea water flowing out radially from a point, or outwards from both sides of a line, is called divergence. The opposite motion of sea water flowing into a point or towards a line from both sides is called convergence. Besides these two motions, there is a neutral condition. Divergence and convergence both occur in relation to meteorological conditions such as winds, and topographical conditions such as land contour and bottom configuration. Convergence and divergence can be observed as sinking and upwelling at the surface, respectively. Those vertical motions are called the sinking and upwelling currents respectively. When the surface water in a coastal area is driven off-shore owing to winds, the water from layers shallower than a depth of 200 to 300 m upwells to the surface as compensation and lowers the surface temperature. Such upwellings can be observed along the coasts of California and Peru.

5.4 Distribution of Surface Temperature

As mentioned previously, the surface currents consist of the drift current, density current, slope current and compensation current. Fig. 5.3 gives the distribution pattern of the surface currents,

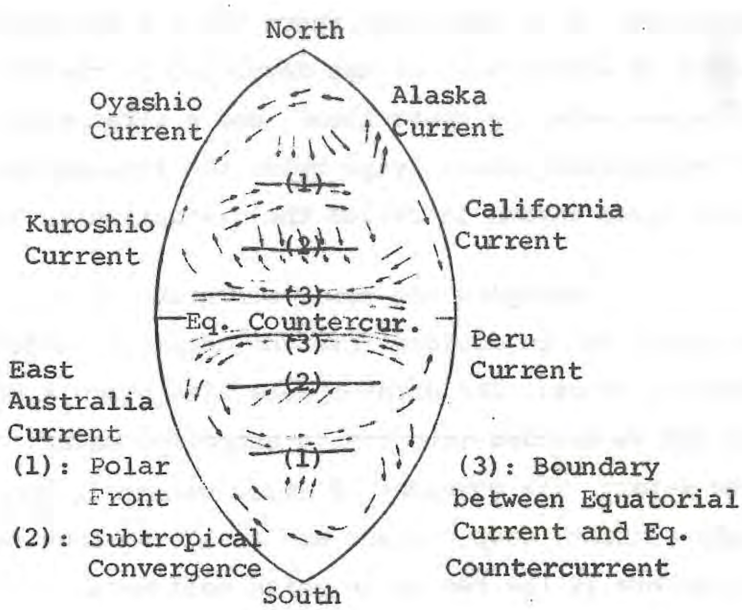


Fig. 5.3. Surface Currents in the Pacific Ocean.

which is similar to that of atmospheric circulation. The polar front, subtropical convergence and boundary of the Equatorial Countercurrent form the boundaries of the different water masses and these boundaries constitute the convergence lines of the currents. Thus, there exist the Equatorial Countercurrent towards the east along the equator, the Equatorial Currents towards the west situated north and south of the equator and the West Wind-drifts towards the east in high latitudes beyond the subtropical convergence. Roughly speaking, there exists a clockwise circulation in the northern hemisphere and, symmetrical to this, an anticlockwse circulation in the southern hemisphere. Through these circulation processes, sea water is warmed in the tropical area and cooled in the temperate area.

5.5 Vertical Circulation of Sea Water

By examining the vertical section of an ocean along a longitude, it is seen that there exist a troposphere which consists of warm water and has developed in the shallow layers (well-mixed water by convection), and a stratosphere of cold water (well stratified water) lying below the troposphere. The boundary between these layers is called the discontinuity layer.

Studying the ocean structure in more detail, the troposphere can be divided into the tropical surface water and the subsurface water. The stratosphere lies below a depth of 500 to 800 m and is divided into the intermediate water, deep water and bottom water. The movement of these waters is called the intermediate current, deep current and bottom current respectively. The stratosphere is the region in which cold water is circulating. The water masses can be clearly distinguished one from the other by the salinity distribution. The boundary between the troposphere and stratosphere almost coincides with the upper limit of the intermediate water. The troposphere is located between the north and south polar fronts, and is deep in the mid-latitudes and shallow near the equator. The boundary almost coincides with the oxygen minimum layer (Fig. 5.4).

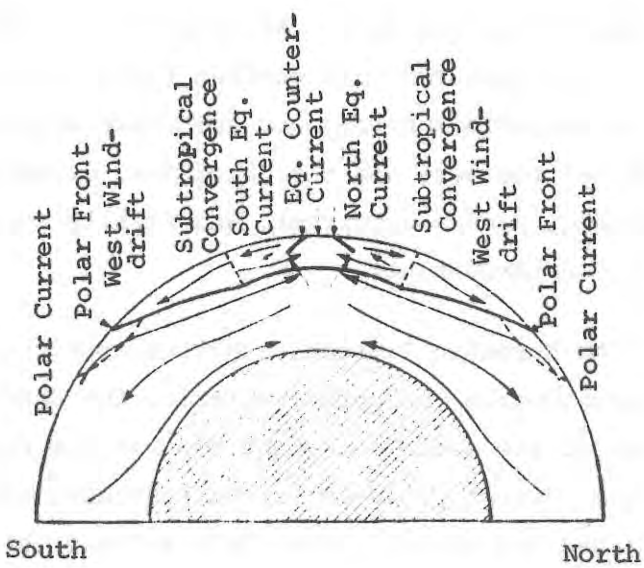


Fig. 5.4. Boundary Layer between Troposphere and Stratosphere.

5.6 Currents in the North Pacific Ocean

The current pattern in the North Pacific Ocean is somewhat different in winter and in summer. In the region, the largest current is the North Equatorial Current existing between the tropics of Cancer and the vicinity of the equator. This strong warm current flows with a speed of 0.5 to 1.0 knot towards the west, starting from off Mexico (the northernmost end of the current) and reaching the north of the Philippines at its westernmost point; the southern limit is at about 5° to 7° N in winter (February to March). The water in the current consists of tropical clear water, which is driven by the trade winds. The thickness is about 200 m and the variations are not considerable throughout the seasons, although the speed of the current becomes faster as it approaches the west. At about 7° N, north of Mindanao, the current divides into two: one current flows towards the north and becomes the Kuroshio Current, and the other southerly flowing current passes off the east coast of Mindanao, becoming the strong, though small-scale, Mindanao Current, and finally connecting with the Equatorial Countercurrent.

The Kuroshio Current, starting from the southeast of Taiwan, flows towards the north, entering the East China Sea, and then passes to the south of Kyushu towards the Pacific Ocean. Thereafter, this current proceeds to the northeast along the coasts of Kyushu, Shikoku and Honshu. Its width is less than 100 nautical miles and its depth extends down to some 400 m on an average. Its velocity is 1 to 2 knots between areas off Taiwan and the south of Kyushu, and usually 2 to 3 knots along the Pacific coast of Japan where it may reach a maximum of 4 to 5 knots. The flow amount, heat quantity and quantity of salts transported per second reach 222×10^5 m^3 , 38×10^{10} kg.cal and 788×10^3 tons respectively. The Kuroshio Current is not a uniform belt-like current, but as it flows the water quality changes by mixing with the adjacent waters. The water masses in the Kuroshio Current are of high temperature and high salinity. On an average, the salinity is more than 34.5 ^{o}/oo and the maximum salinity layer (34.8 to 35 ^{o}/oo) is between a depth of 100 to 200 m. The temperature is more than 15°C down to a 100 m depth. The transparency is about 25 m, the water colour 1 to 2, and the dissolved oxygen 5.5 ^{cc}/litre.

The Kuroshio Current finally neets with the Oyashio Current off Sanriku district, Japan. These two currents form the polar front, The Oyashio Current sinks below the Kuroshio Current and flows towards the south as the subarctic intermediate water. The extension of the Kuroshio Current becomes the North Pacific Current and flows towards the east in the prevailing westerlies wind zone of 40° to 50°N.

Part of the North Pacific Current extends as far as the coast of Alaska , then divides into two branches, of which one the northwest and the other towards the west-southwest. The current towards the northwest forms the anticlockwise Alaska Current together with a compensation current; a part of it enters into the Bering Sea passing through the Aleutian Islands.

The greater part of the easterly flowing warm current - an extension of the Kuroshio Current - spreads branches towards the south and comes in contact with the marginal part of the North Equatorial Current between the Bonin Islands and the north of Hawaii along a line near 25°N, which forms the subtropical convergence. The Kuroshio Current is originally dark blue but it becomes more transparent after entering into the North Equatorial Current region through subtropical convergence. The convergence line corresponds to the boundary between the northeast trades in low latitudes and the prevailing westerlies wind zone in mid-latitudes.

Along the coastline of North America centering off the coast of California, a weak cold current towards the south-southwest (California Current) exists; it flows in winter from about $40^{\circ}N$ almost parallel to the coast of Central America. Along the coast, upwelling currents develop owing to the monsoon during winter to spring and consequently the temperature is low. The California Current almost reaches the equator, then flows to the west and connects with the North Equatorial Current. Roughly speaking, in the North Pacific Ocean, a large-scale clockwise circulation is seen in the region from $40^{\circ}N$ towards the south. The Equatorial Countercurrent flows towards the east, forming a narrow belt whose width is about 100 nautical miles, centered at about 4° to $6^{\circ}N$ in winter.

In summer (July to August), the North Equatorial Current shifts to the north of $10^{\circ}N$ and the subtropical convergence moves slightly towards the north. The Kuroshio Current becomes stronger and this results in a decline of the Oyashio Cold Current. Consequently, the polar front is pushed towards the north and becomes almost parallel to the line connecting the Kurile Islands and the Kamchatka Peninsula. During this season, a northerly flowing current of about 0.5 knot appears near the Bering Strait. The Equatorial Countercurrent deviates northwards and flows between 5° and $8^{\circ}N$. The current becomes stronger, its width measuring some 270 nautical miles. The southern limit is generally at about 2° to $3^{\circ}N$. The California Current moves towards the off-shore usually from July onwards, and the Davidson Current towards the north occurs between the California Current and the coast. This current lasts until November.

5.7 Currents in the South Pacific Ocean

The South Equatorial Current flows to the west in the southwest trades wind zone, and the northern limit reaches the south of the Equatorial Countercurrent. During the summer in the southern hemisphere (about February-March)- the current declines slightly, in particular, the current pattern at the centre becoming irregular. At about 40°S there is a subtropical convergence line. Along this line the South Equatorial Current and the West Wind-drift Current converge. The South Equatorial Current occupies wide waters from 4°N to 40°S and is much broader than the North Equatorial Current. As an extension of the South Equatorial current, a southwesterly or southerly flowing current (East Australia Current) is seen off the east coast of Australia. This current transports tropical and subtropical waters of high temperature; the current velocity is about 0.5 to 3 knots. The East Australia Current corresponds to the Kuroshio Current in the northern hemisphere, but it is not so strong because its waters are not so completely surrounded by land as those of the Kuroshio Current in the northern hemisphere.

In the waters south of 40°S, a strong westerly wind prevails. Consequently, a stronger West Wind-drift Current develops in this region than in the northern hemisphere. This West Wind-drift Current changes direction towards the northeast near South America, and divides into two branches near the Drake Strait; one branch becomes the Cape Horn Current towards the east and the other the Peru Current (Humboldt Current) flowing northwards along the southwest coast of America. The Peru Current consists of cold water and many upwellings are observed in the region. The temperature in the area of the Peru Current is remarkably low, even when the water mass is transported into tropical areas. The water is turbid, but of high productivity.

The West Wind-drift Current produces a countercurrent near Tasmania or South Australia, a part of which flows towards the northeast off the coast of New Zealand. The subtropical convergence in the southern hemisphere runs from east to west broadly along the line of 40°S, but in the area east of 100°W the convergence line takes a northeast direction and approaches the tropics of Capricorn near the west coast of South America. The water masses, which have their original sources in the south of the tropical seas, are sometimes observed in far distant northern areas. In the waters south of 60°S, drifting icebergs are encountered and a strong westerly current is observed surrounding the Antarctic Continent; the current is called the Antarctic Circumpolar Current and corresponds to the Oyashio Current in the northern hemisphere. A polar front is formed between the West Wind-drift and the Antarctic Circumpolar Current. The front runs east to west at about 55° to 60°S, approaching 60°S near Cape Horn.

In summer, the northern limit of the South Equatorial Current is at about 5°N and the southern limit at about 35°S, its width becoming narrower compared with that in winter. Its velocity is highest near the equator between the coast of Peru and the north of New Guinea. The subtropical convergence is at about 40°S in the neighbouring waters of Australia, but deviates as far northwards as 35°S when proceeding towards the east and reaches 30°S in the eastern South Pacific Ocean. The location of the polar front is almost stationary throughout the seasons (Fig. 5.5).

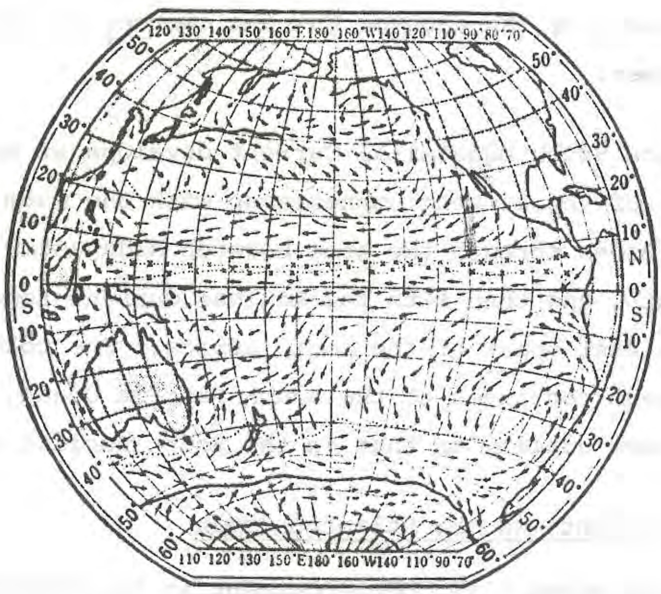


Fig. 5.5. Surface Currents in the Pacific Ocean (summer in the Northern Hemisphere).

5.8 Currents in the Indian Ocean

In the Indian Ocean, the area north of the equator is narrow and the trade winds do not fully develop. However, the monsoons are well-developed; in winter the northeast monsoon from the Continent of Asia blows over the Bay of Bengal and the Arabian Sea, and in summer the southwest monsoon blows towards and over the continent. Corresponding to the monsoons, the clockwise Monsoon Current develops in winter in the water between the two bays and the equator, and in summer it changes into an anti clockwise current. In winter, the Equatorial Countercurrent is located slightly southwards of the equator but the current is not clearly observed in summer.

The South Equatorial Current develops at about $15^{\circ}S$. The western end of the current connects up with the warm Mozambique Current which passes through the area between Madagascar and Africa towards the south, and then with the Agulhas Current towards the south along the east coast of the South Africa. The cold West Wind-drift Current continues to the South Pacific Ocean, and the water has the same quality as that in the South Pacific Ocean.

5.9 Currents in the Atlantic Ocean

The Equatorial Countercurrent in the Atlantic Ocean is small-scale and is observed along $5^{\circ}N$ in the Bay of Guinea and the adjacent waters; the current is called the Guinea Current. The North Equatorial Current has its center between 15° and $20^{\circ}N$. The western end of the current takes a northwest direction along the east side of the West Indies and connects up with the Antilles Current. The Antilles Current joins the Florida Current and these compose the Gulf Stream; this warm current is stronger than the Kuroshio Current. The Florida Current is part of the North Equatorial Current; it enters the Caribbean Sea, passes through the Gulf of Mexico and flows out to the Atlantic Ocean through the Florida Strait. Strictly speaking, the Gulf Stream should be referred to as the Gulf Stream System. The current system, starting from the Gulf of Mexico, proceeds towards the northeast along the east coast of America, flows to the south of Newfoundland, the north of the Azores, the west of Ireland and finally enters the Arctic Sea, passing through the Greenland between Norway and

Iceland. Thus, the Gulf Stream System forms a large-scale motion of sea water.

Between the Florida Strait and Cape Hatteras, the east coast of America receives the Florida Current, whose velocity reaches more than 3 knots. From Cape Hatteras to the Azores, located almost at the center of the eastern North Atlantic, the Gulf Stream flows with a velocity of about 1 knot. The current from the Azores to the waters adjacent to Ireland is called the Irish Current, and is a west wind-drift towards the east. Its velocity decreases but its width increases. The huge mass of water and, in consequence, the huge quantity of heat transported make the climate of north Europe mild.

The current from the seas adjacent to England, passing through the Norwegian Sea to the Arctic Sea, is called the North Atlantic Current or the Norwegian Current. The Norwegian Current divides into two brances near the northeast corner of the Norwegian Sea; one branch passes through the Barents Sea and sinks down into the mid-layers of the Arctic Sea; the other proceeds towards the north along the west side of Spitsbergen, a part of it flows round the north of the island, and finally sinks down into the intermediate layers of the Arctic Sea.

The East Greenland Current, originating in the Arctic Sea, flows towards the south along the east coast of Greenland. This current is, of course, a cold current and transports many ice drifts and icebergs in the spring season. The Labrador Current is another cold current, starting from the Baffin Bay; it passes through the Davis Strait and comes in contact with the Gulf Stream off Newfoundland. Both currents form the polar front. The Labrador Current finally sinks below the warm current. The Labrador Current transports a large number of icebergs from about March to July and causes danger to navigation in the North Atlantic Ocean.

An extension of the Gulf Stream towards the east changes its direction to the south off Portugal and becomes the cold Canary Current. In the South Atlantic Ocean, the South Equatorial Current flows close to the equator and divides into two branches near the Cape of Sao Roque, the easternmost tip of Brazil; one branch enters the Caribbean Sea, passing through the equator, proceeds into the Gulf of Mexico and becomes the origin of the Florida Current. The other flows towards the south along the east coast of South America and becomes the warm Brazil Current, which corresponds to the Gulf Stream in the North Atlantic. The Brazil Current passes between the South American Continent and the Falkland Islands off Argentina, and comes in contact with the Falkland Current, which is an extension of the Cape Horn Current, and with the West Wind-drift Current.

The West Wind-drift Current has the same water quality as that in the Indian and Pacific Oceans. A part of it takes a northerly direction off the west coast of Africa and becomes the Benguela Current. This current is a compensation current to the Atlantic South Equatorial Current.

6. OCEAN AND MARINE ORGANISMS

6.1 Sea, the Environment for Living Creatures

Living creatures are affected to some extent by environmental conditions and most of them posses a certain ability to regulate their internal conditions to meet variations in their surroundings. According to their environment, living organisms on the earth can be divided into those that live on land (or in the atmosphere) and those that live in water. Water, especially sea water, as the environment has more complex properties than the atmosphere on land. It is considered that the difference in these environmental conditions has resulted in the difference between animate creation on land and in water.

By comparing the aquatic and terrestrial environmental conditions, it will be seen that the main difference between them is based chiefly on the physical and chemical differences of air and water. From the viewpoint of biology, air is useful only for the respiration of terrestrial animals, while water has more complex constituents and, in consequence, is essential not only for respiration but also for nutrients absorption by the marine organisms. In particular, sea water contains organic and inorganic nutrients so that the marine organisms are living in conditions similar to those of a culture fluid. Therefore, respiration and nutrients absorption can be done naturally by the marine animals and plants in their environment. As mentioned above, the physical and chemical properties of sea water provide favourable conditions for marine organisms.

6.2 Sea, the Living Space

Water occupies horizontally about 2/3 of the earth's surface, and vertically an average depth of 3,800 m; the space in which the marine organisms can spread is, therefore, very wide. On land, the animals and plants are distributed only horizontally not vertically; therefore, the whole extent of the living space on land is much narrower than the space available in water. This reflects on the ecological and morphological differences of the animals and plants in these two living spaces. Water has high productivity and contains several ten million tons of annual production in food resources. Thus, marine resources are highly valuable to human beings.

6.3 Density of Sea Water

The density of sea water is nearly 100 times higher than that of the air. In sea water, therefore, living organisms can withstand the earth's gravity much more easily. Marine organisms need little energy to keep themselves in a desired position and can easily float in water. This has resulted in the difference in body structure between the organisms living on land and those living in water. For example, in order to stand upright and spread out its branches, a tree on land has a strong trunk and its roots fasten deep into the soil. On the other hand, seaweeds have soft bodies and simply cling to rocks or stones, but they can remain upright and stretch out their branches like the trees on land. However, once taken out of the water, the seaweeds cannot keep upright as in water. Most of the jellyfish, whose body is as frail as jelly and is composed mainly of water, cannot be taken out of the water without their breaking up.

The heavy specific gravity of sea water provide favourable living conditions for large-sized animals. The fact that almost all gigantic animals on land, which flourished during prehistoric times, have become extinct is to be attributed not only to a change in climate but also to other reasons described below. It is supposed that, for those animals which frew to a huge size, much energy consumption was necessary for motion and this resulted in their defeat in the competition for existence. In water, however, huge animals such as whales still exist, and the fact that their gigantic body can move swiftly depends on the buoyancy due to the heavy specific gravity of sea water.

Some groups of marine organisms have a special manner of life, which has never been seen on land, and this is considered to have resulted from the fact that the specific gravity of sea water is almost the same as that of these marine organisms. They either have no power for motion at all, or very little power. Therefore, they live by drifting in the water. Such organisms are called planktons; they are divided into the phyto- and zooplanktons. Planktons play an important role as bait for other marine organisms.

In sea water, micro-organisms such as plankton drift at various depths and move according to the motion of the water. For some plankton-feeders, therefore, it is not always necessary to search for bait. Among the marine animals, some have no power to move, and cling to rocks or stones, or stay in the mud of the sea bottom; they can take the planktons or their remains drifting in water merely by sucking in water. Crinoidea, Melithaea, and corals look like plants, they would never be taken for animals at first glance. Barnacles and goose barnacles, which belong to Crustacea (the same group as lobsters, prawns and crabs), have the appearance of shellfish. There are many sedentary species of animals other than the above.

6.4 Viscosity of Sea Water

Resistance in water is much greater than in the air. The viscosity of water is about 100 times greater than that of air. The difference in viscosity between water and air as well as the difference in specific gravity result in the fundamental difference between the manner of motion of the animals on land and those in water. For the animals on land, the resistance of air is not an important problem, the basic problem of motion being to withstand gravity and to make the body advance in spite of it. Therefore, the most suitable manner of motion is walking. For the marine animals, however, the body floats in water so that the problem of motion is the resistance of water, and the most usual manner of motion is swimming. To reduce this resistance, the animals called nektons (the typical ones are fishes) are streamlined in shape.

6.5 Temperature in Sea Water

As compared with temperature variations on land, the temperature in water is almost constant. The terrestrial animals' body functions are so made as easily to retain and discharge heat, as a protection against a sudden change of air temperature. For marine animals, the control of body temperature is not always necessary. Therefore, homoiothermic animals are numerous on land, while pikilothermic animals are usually found in water.

6.6 Dissolved Gases in Sea Water

About 210 cc of oxygen are contained in 1 litre of air, while sea water at $0^{\circ}C$ contains 1/20 less oxygen than the air (less than 10 cc). In the case of the terrestrial animals, the respiratory organs are deep inside their bodies like the lungs of mammalia and the tracheas of insects, whereas the aquatic animals' respiratory organs, like the gills of fishes and crustaceans, are exposed outside their bodies. Such a difference in body structure depends not only on the dry or wet conditions of the environment, but also on the quantity of oxygen in the environment.

Sea water contains few free carbonates. However, free carbon dioxides, ionic bicarbonates and ionic carbon dioxides are in equilibrium so that if the free carbon dioxides decrease, the other two ions dissociate and compensate the carbon dioxides. Therefore, the carbons which are essential for the anabolism of plants are very plentiful in sea water.

6.7 Light in Sea Water

The lower limit of the layers in which anabolism is possible is usually about 200 m. The marine plants assimilate by utilizing the phto-energy and produce carbohydrates ($C_6H_{12}O_6$) and oxygen from water (H_2O) and carbon dioxide (CO_2). The process is as follows:

$$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

The phytoplanktons which are widely distributed in sea water play the most important role in producing organic matter in water. Seaweeds in the shallow waters play only a minor part in this regard. The propagation of phytoplankton is affected by the light intensity in sea water; the lower limit of the euphotic zone is at a depth of 100 to 200 m. Even in shallow places where the water is transparent and there is sufficient light, the visible distance is short so that the eyes of marine animals generally do not develop well. Fishes are short-sighted.

6.8 Effects of Pressure on Marine Organisms

Terrestrial animals live under the pressure of 1 atmosphere. In sea water, the pressure increases about 1 atmosphere every 10 m in depth so that the marine organisms living in the 100 m depth layer are under 10 atmospheres and those at 1,000 m are under 100 atmospheres. However, the marine organisms have functions to regulate their bodies supprisingly well to variations in pressure.

When a man dives into the sea a little deeper than usual, it can happen that his eardrums break. Even with a diving suit, compressed air from aboard, and gradual increase in pressure inside and outside his body, man is hardly able to tolerate 10 atmospheres. Even at a low pressure, if the pressure changes abruptly, troubles occur and submarine sickness might ensue.

It has been found, however, that some pelagic molluscs can tolerate 600 atmospheres, some copepods are well adopted to 200 atmospheres but can hardly tolerate 600 atmosphere. Deepsea fishes such as lantern fish and cod can swim up to the shallower layers from a deep place of high pressure at night. The reason why some marine animals can tolerate such high pressures and variations in pressure is not yet clearly known, but it is supposed that they have a body structure that equilibrates the internal and external pressures by absorbing water into the tissues of their bodies.

6.9 Constituents of Sea Water and Bodies of Living Organisms

Sea water contains the supply of nutrients for marine life and enables respiration, because the water contains various constituents. The chemical composition of sea water has great significance for the physiology of marine life. The situation is very different for terrestrial life; air is necessary only for the respiration of animals whereas for plants carbon dioxide is utilized only as a part of their nutrient supply. The roots of seaweeds, unlike those of terrestrial plants, are designed to cling to rocks or stones; nutrient absorption and anabolisms can be done with the whole body except the roots. Among marine animals, some absorb organic matter dissolved in sea water directly through their body's surface while others take the necessary inorganic substances not from the foods but from the sea water. An example is seen in shellfish which take calcium from sea water to form their shells.

Sea water contains almost all necessary substances for living organisms. These substances are contained not in a disorderly but in a meaningful fashion. Considering the concentrations, the osmotic pressures, and the harmony of ions, sea water has very effective properties for the existence of living creatures. The coeliac liquid and blood of the marine animals of the lower order are almost the same as sea water in their concentration and constituents. It is specially interesting that the inorganic composition of the terrestrial higher animals' blood is very similar to that of sea water. From the above facts, the assumption has been made that the blood of animals originated from sea water. As seen in Table 6.1, sea water contains much more magnesium than is found in the blood of animals. It is considered that in geological times when sea water was absorbed into animals' blood it contained less magnesium, and that the quantity of magnesium as found in the sea water at the present time increased at a later date.

It has long been considered that the first life on the earth was born in the sea. Many animals living at the present time are shown, from divers evidence, to have originated in the sea. It is a natural consequence, therefore, that marine creatures have a close relationship with the water of the sea, the mother of life.

Table 6.1 Comparison between inorganic composition of sea water and blood of animals.

	Na	K	Ca	Mg	Cl
Sea water	100	3.6	3.8	12.1	180
Jellyfish	100	5.2	4.1	11.4	186
Cod	100	9.5	3.9	1.4	150
Frog	100	11.8	3.2	0.8	136
Dog	100	6.6	2.8	0.8	140

6.10 The Sea and the Evolution of Organisms

The evolution of organisms, starting from the lowest order to a certain stage of evolution, are supposed to have taken place in the sea. Thereafter, some of the organisms are believed to have moved onto the land, and to have differentiated and developed into the present complex faunae; the above theory has been deduced from divers evidence.

Fossil animals, found in the strata of the oldest geological age, are mostly marine organisms, although those which remained as fossils are limited to some specific animals having skiltons, and, therefore, these records in the rocks do not always show precisely the evolution of organisms. In the strata of the Cambrian period, the oldest period in the Paleozoic era dating back five hundred million years, fossil marine invertebrates such as trilobites and brachiopods have been found. In those days, there was no animal on land.

By comparing the animals on land and those in water according to their phylum and class in taxonomy, it will be found that the marine animals are definitely more numerous than those on land, the reason being that there are many primitive animals of the lower order in the sea. These animals are connected systematically to one another, as shown in Fig. 6.1. As seen in the figure, the marine animals occupy the root of the genealogical tree. This shows that the sea was the environment during the early stage in the evolution of living organisms and that the sea has a tendency to conserve the animal groups for a long time, once they appear. In the sea, the helmet crabs, which are close to brachiopods and trilobites (both prospered in the old geological age), are still living.

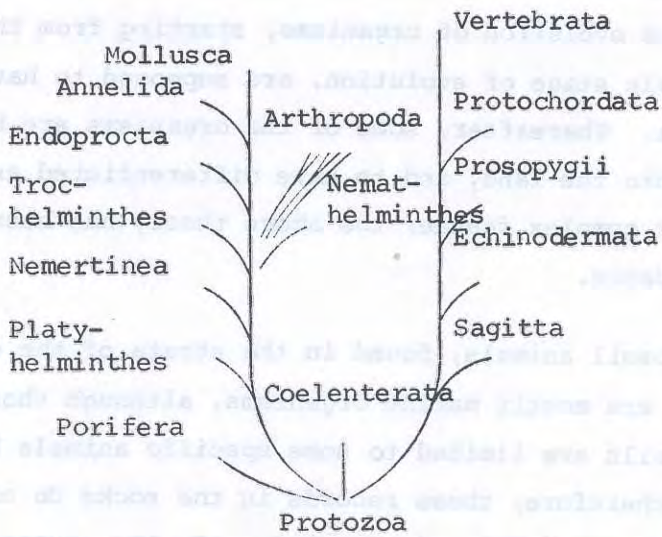


Fig. 6.1. Genealogical Tree of Animals.

On the other hand the sea, which remained stable and underwent fewer environmental changes, did not play an important role in developing animals to the higher order. The land whose environment is unstable and much more variable caused the animals to develop into the higher orders, althouth this was limited to some groups only. Certain animals of the higher orders, now living in the sea, such as some mammals, stayed on land during the greater part of the evolution period, returned into the sea in a relatively recent era and changed their forms to suit life in the sea. It is considered that the teleosts, the higher order of fishes, were developed from the lancelet which moved to fresh waters from the sea.

Of the animals which used to live in the sea, some groups moved onto the land in the geological age and adapted to life on land; this fact is considered to be a very important process in the history of evolution. It is interesting in many respects that some groups of animals are now in the process of moving into fresh waters or onto land from the sea; examples are seen in some crustaceans such as Eriocheir.

In this connection, the environment of the intertidal zone is of particular interest;in this zone, the two different environments of land and water overlap. There occur two cycles of high and low waters in a day; between the high and low water lines two different environments of air and water occur alternately, and the variation in environmental conditions is fast and intensive. In spite of these harsh conditions, however, there are many living organisms which are adapted to this environment and can generally tolerate the dry state. It is known from experiments that some crustaceans such as acorn shells, and molluscs such as periwinkles can continue to live for several ten days without water. It is assumed that the migration of marine animals to the land was done gradually and steadily, probably through the intertidal zone.

6.11 Marine Organisms and their Living Space

There are many varieties of marine organisms and these can be divided, according to their pattern of living, into three groups; benthos, nekton and plankton. In the sea, the physical conditions vary in different localities and the organisms adapt to these conditions. As a consequence, different organisms live in different localities. The living space of marine organisms can be divided into the tidal zone (intertidal zone), littoral zone (neritic province), deep sea zone and oceanic province (Fig. 6.2).

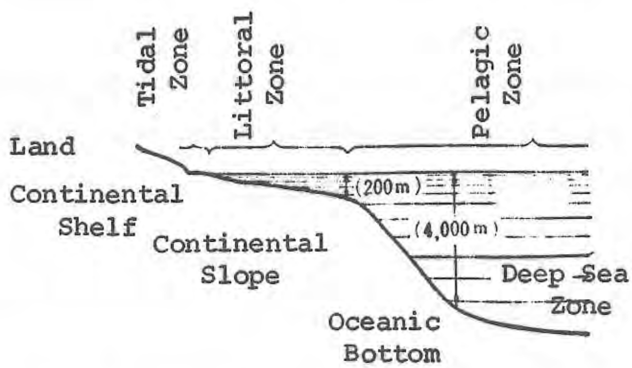


Fig. 6.2. Ecological Zones in the Ocean.

Tidal zone: The tidal zone lies between the high and low water lines and is, therefore, the connecting point between water and land, from the viewpoint of ecology. The organisms in this zone have intermediate properties between the terrestrial and marine organisms. The area has shallow waters so that the organisms are generally in close relationship with the bottom. Extreme variations occur in the temperature, salinity, light and motion of the water. Most of the animals and plants can tolerate these variations in environmental conditions. Among the plants, algae are widely distributed in the area and among the animals benthos are abundant. A study of the area shows that it is considerably affected physically by the inflow of fresh water and strong wave action, and biologically by the terrestrial animals such as human beings and birds.

The extent of the area depends on the slope of the land and the range of the tide so that it varies in different localities. From the standpoint of fisheries this region is most important for culturing shellfish, seaweeds, etc.

Littoral zone: The littoral zone is situated on the continental shelf extending from the low water line to the shoulder of the shelf, and the depth ranges from the surface to about 200 m. Variations in the physical conditions are not as great as those in the tidal zone, though the zone is still affected in some measure by these variations. The extent of the zone also depends on the bottom configuration. Below a 200 m depth, the bottom slopes down steeply and the zone changes to that of deep sea. Among the plants, algae live there attached to the bottom, and among the animals, nekton and benthos are found in abundance; of all the zones, this littoral zone is most rich in organisms. It, therefore, contains good fishing grounds and is the most important area for coastal fisheries.

Deep sea zone: The deep sea zone is the deeper area towards off-shore, including the continental slope. In this area, variations in physical conditions are seldom observed and there is no wave action. The penetrating sunlight is minimal so that seaweeds are seldom found, and the animals have special adaptability to light. Temperature variations due to current and direct sunshine seldom occur; consequently the temperature is always low. Since there are no direct contacts with the atmosphere and no action by light, the sea water contains different constituents from those in the upper layers. The main difference, compared with the upper layers, is the pressure; pressure increases 1 atmosphere for every 10 m of depth so that, say, 500 atmospheres act at a 5,000 m depth. The organisms are mainly plankton and nekton and the quantities are relatively small. Sediments found there are peculiar to the locality.

Oceanic province: The zone is horizontally the area towards the off-shore from the shoulder of the continental shelf and vertically from the surface to a depth of 200 m. This area has particular ecological features compared with the littoral and deep sea zones. The sunshine and thermal supplies are sufficient and the surface is in contact with the atmosphere so that the air dissolves sufficiently. It is a region of phytoplankton propagation and, in consequence, zooplanktons are abundant. Many varieties of nektons are also seen in the region. An ecological feature is that most of the organisms float or swim and have no relationship with the bottom. In places of large-scale rises on the bottom, good fishing grounds such as banks are formed and productivity is high.

6.12 Food Chain

If we turn our attention to one group of marine animals, we see that they feed on certain animals and plants and, likewise, another group of animals takes the initial group of animals as their bait: i.e., bait ⟶ certain groups of animals, taking the bait ⟶ other groups of animals, taking the first groups of animals ⟶ ... For foods available in water, a mutual relaticnship, which is called food chain, is apparent among these animals. The food chain in the sea is not so simple; different groups of animals prey on the same bait and, among these groups of animals, there are struggles for existence as the prey and predator. Some groups of animals are polyphagous. Thus, even among the groups of animals which search for the same bait (the same bait feeding group of animals), there exists a relationship connecting them one to another like a network. This relationship can be dealt with from the viewpoint of the quality, size and quantity of the bait on which they prey.

1) Quality of bait: Plants synthesize organic matter using solar energy from the inorganic matter in water. These plants are the basic nutrient source for the marine animals. In other words, marine plants are generally the starting point of the food chain. By marine plants we do not mean the seaweeds, but mainly the phytoplanktons, floating everywhere in the water. Comparing the sea to pasture grounds, the phytoplankton can be regarded as the pasture. Analysis of the phytoplanktons has shown an interesting result: the quantities of protein, fat, carbohydrate and vitamine they contain are very similar to those in a pasture.

The phytoplanktons become bait for the zooplanktons which are herbivorous, and the zooplanktons in turn become bait for carnivorous animals. The carnivorous animals are eaten by other larger animals and thus the food chain continues. Apart from the zooplankton, the bivalves and some fishes are herbivorous and take phytoplanktons directly as their nutrient. On the other hand, some groups of animals feed on the remains of animals and organic deposits. It is known that some groups of animals have a special manner of taking nutrients: they absorb organic matter dissolved in the sea water through the surface of their body.

2) Size of bait: The size of the food, taken by the same bait feeding group, is generally within a definite range depending on the feeding group, and there is an optimum sized bait for each of the feeding groups. Compared with the feeding group, the bait is usually smaller, but, if too small, it is not effective as a

nutrient source. If the bait is too large, however, apart from the consideration whether or not the bait is optimum in size, there is a possible danger for the predator to hunt so large a bait.

Thus, the food chain proceeds towards the larger sized animals, starting from the basic phytoplankton. However, there are some exceptions in the relation between the size of the bait and that of the feeder. An extreme example can be seen in the case of the gigantic blue whale which feeds on planktons; the difference in size between prey and predator is enormous. An opposite example is seen in the case of an orc attacking a large whale. Deep sea fishes have specially big mouthes and stomachs, and swallow any animal which they happen to encounter, regardless of its size. From the standpoint of ecology, however, there may be some natural reasons for the above exceptions. Phytoplankton, which is the basic food for marine animals, is very tiny so that some members of the plankton feeding group have various well developed organs with which to filter these minute water-borne foods.

3) <u>Quantity of bait</u>: Prey is generally more abundant in number than its predator. In water, the number of individuals in an animal group is roughly in reverse proportion to the body size of the animal; the larger the body size of the animal, the smaller the number of individuals. Therefore, take the phytoplankton - the fundamental food - as a base, place the herbivorous group above it, the primary carnivorous group on the second rung and continue the process, placing the highest carnivorous group uppermost. The various rungs will taper off to form a pyramid because each rung

will be narrower than the last owing to the difference in the rate of propagation of each group. The pyramid thus formed is called the food pyramid.

Plants, especially unicellular phytoplankton, increase by one or more cell divisions in a day, under the most favourable conditions. The rate of propagation is surprisingly fast. The unicellular zooplankton also propagates fast, but not as fast as the phytoplankton. As regards rate of propagation, other zooplanktons rank third, fishes and mammals rank forth and fifth respectively. The larger the size of the animal, the slower the rate of propagation and the increase in the number of individuals.

However, the quantitative relationship between each animal group in the food pyramid is not always in equilibrium owing to the rate of propagation in each group being different. Actually, many other factors overlap one another, and the relationship is more complex and dynamic. It is not rare that, unlike the terrestrial plants, increases and decreases in phytoplankton occur alternately in cycles of one month or less. The phytoplankton feeders are sometimes pressed by hunger, and it is not rare that the propagation of the feeders is reduced because of lack of food. This, in turn, affects indirectly the higher carnivorous animal groups. From the standpoint of the food chain, the quantitative relationship between marine organisms still remains an unknown factor.

6.13 <u>Productivity in the Sea</u>

Considering the food chain of inorganic matter ⟶ plants ⟶ animals, the inorganic matter in water is finally stored by the highest order of the carnivorous animal group and the substances cease moving. However, the remains and discharged matter of the animals and plants are decomposed into inorganic matter by the action of bacteria and the substances are retained in the water. Thus, the substances' circulation is completed; this circulation is called the food cycle. The plants as the producers, the animals as the consumers and the bacteria as the decomposers of the remains are linked to form the food cycle. The productivity in the sea is determined by the rate of circulation of the substances and the quantities circulating.

6.14 Marine Organisms and Temperature

Temperature is an important factor which governs the marine organisms' environment, and the distribution of each group of these organisms is determined mainly by their respective ranges of temperature. For example, fishes have their own temperature ranges, and an optimum for their specific life patterns; and fish schools are found in the places of their own optimum temperature. In most cases, the optimum temperature coincides with the most catchable temperature.

Fishes are very sensitive to temperature variations, and it is known from some experiments that they show reactions to a 0.03° to $0.06^{\circ}C$ temperature variation. The most catchable temperature is 20° to $24^{\circ}C$ for bonito, 16° to $18^{\circ}C$ for saury, 18° to $19^{\circ}C$ for albacore, about $15^{\circ}C$ for yellow-tail, 11° to $19^{\circ}C$ (centered around 13° to $14^{\circ}C$) for sardine, 13° to $18^{\circ}C$ (centered around 14° to $15^{\circ}C$) for mackerel and about $15^{\circ}C$ for sea bream. Pelagic fishes, staying in the nearsurface layers, such as bonito and saury swim near the surface in the water mass of optimum temperature, and the fishes in the mid-layers such as mackerel and tuna stay in the depth layers of the optimum temperature. The temperature in the places where fish schools of a specific species are frequently seen, in other words, the most catchable temperature has a relatively narrow range as shown in Fig. 6.3 (usually the range of the variation is within 4° to 5°C).

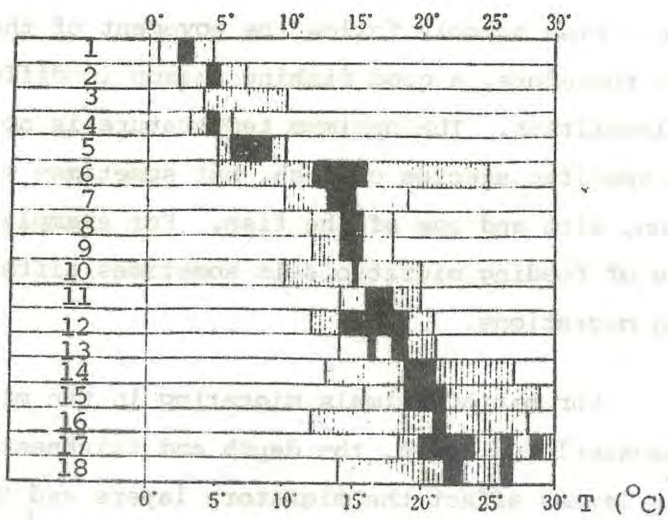


Fig. 6.3. Catchable Temperatures of Commercially Important Species of Fish.

Note: 1. Cod. 2. King crab. 3. Herring. 4. Halibut. 5. Salmon. 6. Squid. 7. Sardine. 8. Mackerel. 9. Yellow-tail. 10. Sea bream. 11. Saury. 12. Tuna. 13. Albacore. 14. Swordfish. 15. Marline. 16. Big-eyed tuna. 17. Skipjack. 18. Yellow-fin tuna.

Each species of fish has its own optimum temperature zone. When the other optimum conditions in water quality, such as salinity, are specified, the water is called the optimum water zone. For locating a good fishing ground, the structure of the optimum water zone and its location should be investigated concurrently with searching for the fish schools directly. The optimum water mass moves in the course of time. The annual variation in the beginning and the end of a certain fishing season is similar to the case of the flowering season on land, which is not always fixed but depends on variations in the air temperature. Fish schools follow the movement of the optimum water mass; therefore, a good fishing season is different in different localities. The optimum temperature is not always the same for a specific species of fish, but sometimes varies with the location, size and age of the fish. For example, the optimum temperature of feeding migrations is sometimes different from that of spawning migrations.

For marine animals migrating in the mid-layers, such as tuna, mackerel and squid, the depth and thickness of the optimum temperature layers affect the migratory layers and the concentration of the migrating schools. Therefore, for successful tuna long lining, the hooks should be lowered to layers of about 18°C in temperature, and for good mackerel fishing, the hooks or the drift nets should be set at depths of 14° to 16°C. Fishes, swimming in the near-surface layers, are found in places where the optimum water masses appear on the surface; they concentrate especially in places where eddies are formed, and where the water mass is pressed by surrounding water masses of unfavourable conditions. Bonito and tuna like to gather along a convergence line between the optimum water mass and the other different water masses, especially when the temperature gradient at the boundary between those water masses is steep and the boundary meanders. They also have a tendency to gather around an upwelling area.

A specific water mass is sometimes delimitated by temperatures or other properties. This boundary, formed by natural circumstances, acts on fish schools as if they were surrounded by a net. For example, several fish schools gather in an optimum water mass to form a more dense fish school, if the water mass is pressed by different water masses of higher or lower temperatures.

6.15 Marine Organisms and Depth

Depth is an important factor by which the distribution of organisms can be determined, especially in a coastal or a shallow area. Shallow depths where seaweeds grow are the spawning and breeding places of some species of fish. The continental shelves shallower than 200 m are the spawning grounds for many demersal fishes and are utilized as trawl fishing grounds. In this sense, the area of continental shelves can be regarded as that of demersal fishing grounds. The total area of shelves in the world is 27,500 thousand km^2, but the area of the fishing grounds is estimated to be less than half of this area. On the continental shelves, good fishing grounds are formed around the places of complex bottom configuration such as the margine of a submarine canyon or the shoulder of a shelf.

In areas deeper than 200 m, deep sea fisheries such as vertical long lining and bottom long lining are carried on usually down to 800 m, and down to 1,000 m at the deepest. Commercially important fishes are not always distributed uniformly, but the area of the bottom between 200 and 1,000 m in depth is 15,500 thousand km^2 in the world and has the possibility of being exploited as deep sea fishing grounds. In the seas adjacent to

Japan, with the exception of the East China Sea, the area of the fishing grounds shallower than 200 m is 2,910 thousand km^2 and that of the fishing grounds between 200 and 800 m in depth is 2,740 thousand km^2; both are almost the same in area. Deep sea fish resources on the continental slope still remain to be fully exploited.

There are many migrating fishes in the oceans; the fishing grounds of bonito and tuna are widely distributed. In a place where there is a bank, standing like a mountain in the ocean, the distribution patterns of the surface temperature, surface current and plankton are different from the ordinary patterns, and an upwelling current occurs transporting the nutrient salts up to the upper layers. Thus, plankton propagate there, small fish are lured and these, in turn, attract large-sized fish to form a good fishing ground.

6.16 Marine Organisms and Bottom Materials

It is well known by fishermen that the distribution of demersal fish is considerably affected by depth as well as by bottom materials. In the East China Sea, sea bream and porgy are abundant on the east side ground of the sea, and jewfish and gurnard are distributed on the west side of the sea.

Fishing methods are governed by the bottom materials; trawl fishing is suitable for a sandy or muddy bottom, and hook and line fishing, such as vertical long lining, is appropriate when the bottom is rocky.

6.17 Marine Organisms and Water Quality

The distribution and migration of marine organisms are greatly affected by salinity as well as temperature. For the eggs and fries, the salinity affects the osmotic pressure which acts on their cell wall. With increasing salinity in dry weather, the number of hatch from sardine eggs decreases. The relation between the fishes' behaviour such as distribution and spawning, and salinity depends on the species.

Fishes breathe oxygen dissolved in water with their gills. With more violent wave action, gases in the air dissolve more readily into the water, dissolved oxygen increases in quantity and fishes become more active. As seen sometimes in a bay head area, if oil covers the surface and prevents oxygen being dissolved from the atmosphere, the fishes gradually have difficulty in breathing, gasp for breath at the surface and finally die.

Nutrient salts are transported to the surface by upwelling or convective mixing, and phytoplankton propagates by the aid of solar energy. The phytoplankton's propagation results in the zooplankton's propagation and finally in the formation of a good fishing ground. Therefore, the quantity of nutrient salts can be regarded as an index of marine productivity; especially phosphates are observed to be abundant in good fishing grounds.

River water polluted by discharged water from factories is harmful to shellfish and seaweeds. Pollution problems arise in the field of fisheries with the development of industries and the expansion of cities.

6.18 Marine Organisms and Flow of Water

Concentrations of fishes are determined by flow patterns; fishes are attracted to areas of stagnant waters or eddies, and not to places where strong currents prevail. They frequently concentrate around shoals, in stagnant waters around an island or a point, in downstream areas of a channel, near both sides of a river mouth, etc. Good fishing can also be expected about the turning time of a tidal current. Fishes concentrate in places which provide optimum conditions and these places (or the water mass) move with the current; thus, a so-called migration route is formed.

Good fishing grounds are often found in places where two different water masses come into contact; generally, good fishing grounds are formed near the boundary of water masses. The unusual movement of an optimum water mass towards the coast guides fish schools into the coastal area and results in a good catch in set net fishery. Upwelling currents are seen near a bank and a coastal area; world famous fishing grounds such as the coastal areas of California, Peru and Southwest Africa, the east coast of Korea, the Kurile Islands, the south coast of Hokkaido and off the Sanriku district of Japan provide the above-mentioned conditions.

Ocean currents vary annually and this variation result in a variation in fishing grounds, fishing seasons, and, in turn, catch amount. In the seas adjacent to Japan, the long-term variations in the Oyashio, Kuroshio and Tsushima Currents result in the spatial and temporal variations in catch of sardine, herring, bonito, tuna, mackerel, squid and saury.

6.19 Marine Organisms and Turbidity

Most fishes are sensitive to light. Because of the tendency of fish to be attracted by light, luring lamps are used in fisheries; these lamps are effective in attracting sardine, horse mackerel, squid, saury, etc. Light penetration in water is greatly affected by turbidity. Yellow-tail tends to come to coastal areas with yellowish turbid water after a storm, and a good catch is also expected for sardine and black porgy in turbid water. On the other hand, mackerel and bonito like transparent water and keep away from turbid water. Therefore, fishermen use the water colour as a means of locating fishing grounds; as another means, they look for sea birds flying over a fish school, or for ripples, eddies, foam, etc. appearing on the surface.

6.20 Marine Organisms and Meteorological Conditions

Variations in meteorological conditions affect marine organisms through the consequent variations in oceanographic conditions. Of the meteorological conditions, low pressure has the greatest influence on fishing conditions; in waters neighbouring Japan, low pressure frequently occurs in winter. With a low pressure or a line of discontinuity passing through a fishing ground, the wind direction changes suddenly, strong winds blow and wind-wave and swell occur. A current in a coastal area changes its direction and speed; sometimes strong currents flow towards the coast and the water temperature increases suddenly with the intrusion of off-shore water. Deposits on the bottom are stirred up by the wind-wave, swell and strong current, and inflow from the land changes into muddy water owing to rainfalls or snowfalls. These change the water colour and the transparency of the coastal water. Thus, the sudden change in meteorological conditions changes the oceanographic conditions from a calm even state to an unusual disturbed state; this, in turn, results in a sudden change in current and consequently in variations in the temperature, salinity and other properties of the water, and finally in a sudden change in fishing conditions.

6.21 Oceanographic Survey

Fisheries resources in the wide seas cannot be regarded as inexhaustible. Coastal and demersal fishes are more liable to be overfished. Based on the data from scientific researches in the oceans, rational planning should be made so as not to exhaust the resources; the management of resources is similar to the relation between the capital deposited in a bank and the interest. If fisheries are exploited in such a manner as to catch only the fishes corresponding to the interest, the resources corresponding to the capital will never be exhausted. Moreover, the interest can be increased under scientific management.

In order to set up a rational management of fisheries, the following problems need urgent study: 1) the great variations in catch amount, 2) the decrease of catch in coastal areas, 3) the spatial variation in catch, 4) the temporal variation in catch, etc. In order to solve the above problems, fundamental research should be carried out on the seas as the environment of marine organisms, and fisheries should be managed rationally, taking the economic effects into consideration. Fishing conditions are governed by the environmental conditions of fishery resources; the physiological and ecological conditions such as distribution, migration, spawning, growth, etc. are governed by environmental conditions, and variations in these condition result in variations in the stock. Therefore, oceanographic surveys contribute to the management of resources as well as to the long- or short-term forecasting of fishing conditions, and, in consequence, become a basis of fisheries management.

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