

OCEANOGRAPHY

FIS310

LECTURE GUIDE

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WHAT IS OCEANOGRAPHY?

Oceanography is the application of all science to the phenomena of the ocean. To truly understand the ocean and how it works, one must know something about almost all fields of science and their relationship to the marine environment. Thus, oceanography is not a single science but rather a combination of various sciences.

The objective of oceanography, at least to the scientist, is to increase human understanding of all aspects of the world's ocean and of the processes and mechanism that have made, and now make, the ocean what it is. This, of course, encompasses the subsidiary aim of describing as many marine features as possible. Of the many scientific disciplines that make up oceanography, one would be justified in calling the study of the oceans a very broad science, and however in another sense oceanography is restrictive. It is not a universal science like physics or chemistry; where-in the physical laws governing matter appear to have application throughout our universe.

Scope:

- (1) Chemical
 - (2) Physical
 - (3) Biological
 - (4) Geological which includes marine geology and geophysics
 - (5) Ocean engineering
 - (6) Marine policy.
1. Chemical oceanography: chemical reactions that occur both in the ocean and on the sea floor.
 2. Biological Oceanography: deals with the distribution and environmental aspect of life in the ocean.
 3. Physical oceanography: physical reactions such as changes and motion of the ocean.
 4. Geological oceanography: studies the sediments and topography of the ocean floor.
 5. Ocean engineering: concerns with the development of technology for oceanographic research and exploitation.
 6. Marine policy: considers the application of social and political sciences such as economics, law, and policy towards the use and management of the ocean.

Why study oceanography?

Water covers 72% of the world

- Source of food for man for many centuries and still holds the promise of solving today's food problems.
- Source of commercially valuable chemical resource including iodine, bromine, potassium, manganese, e.t.c.
- Desalinization of ocean water is yielding increasingly important amounts of freshwater in the arid areas of the world.
- Sea-floor mineral accumulations, like phosphorite, Mn nodules, heavy-metal rich muds, sand, gravel, are valuable commodities that are already being exploited.
- Accumulations of oil and gas below the sea floor are very important natural resources, supplying already almost 20% of the world's needs. This energy, when released, helps power the earth's atmospheric circulation.
- The ocean is necessary to commerce, communication, and natural defense.
- For recreation, sports of during, boating, water skinning, and scuba diving, as well as swimming attract ever greater numbers of pensions each year.

Origin of the ocean

- a. Where did the water come from?
- b. Second, how did it get its unique concentration of salt and other elements?
 - i. From the primordial atmosphere of the earth.
 - ii. From the decomposition of volcanic rocks
 - iii. From incremental addition of water throughout geological time.

Condensation in the atmosphere at one time formed the ocean. The present atmosphere of the earth in fact can hold no more than about $13,000\text{km}^3$ of water; whereas the volume of water in the ocean is over 1 billion km^3 .

Original water was chemically bound into volcanic rock and subsequently has been removed by decomposition of the rocks to form ocean.

- 5% water in volcanic rocks
- All volcanic rocks have less than 50% of water in the ocean.

This shows that the whole water in ocean did not come from the weathering of rocks – Na⁺, Mg, Ca⁺, etc come from these rocks.

The source of the water is from volcanic activity, hot springs, and the heating of igneous rocks – and also anions are released from volcanoes.

However, volcanic activity is the source of the water and the anions and that the cations come mainly from decomposition and weathering of igneous rocks.

THE WORLD OCEANS

The ocean basins of the world are large depressions on the earth's surface which are filled by a great mass of salt water. These oceans cover about 71% of the earth's surface which means that about 29% of the earth's surface is occupied by the land and rivers. The world oceans have an average depth of 3,700m. There are four major oceans of the world.

These are as follows:

- i. The Pacific ocean
- ii. The Atlantic ocean
- iii. The Indian ocean
- iv. The arctic ocean

The Atlantic, Pacific and Indian Ocean are the three oceanic extensions of the Antarctic Ocean which surrounds the Antarctic continent, but they are separated by the continental barrier into these three oceans. The other small oceans and seas are referred to as the Arctic Ocean. It is from here the Mediterranean Sea projects from. There are connections between the major ocean basin which allows for exchange sea waters and marine organisms.

PACIFIC OCEAN

This is the largest of the entire ocean basins in the world. The Pacific Ocean basin occupies 1/3 of the total earth's surface. In size, it measures about 180 million square kilometres. Infarct, the Pacific Ocean is far bigger in size than every other continent in the world. In depth, it has a maximum depth of 10,542 m.

THE ATLANTIC OCEAN

This ocean is one of the largest oceans in the world. It is located between Africa and Europe to the east and the Americas to the west. It is the busiest sea route in the world with a total area of about 82million km² and a depth of about 9,218 m. It is narrow in equatorial latitude and this has made it possible for the two basins, the North Atlantic and the South Atlantic basins.

In the northern hemisphere, a larger part of the continental shelf occurs, for instance in the North-western Europe and round New Foundland as well as the maritime, parts of Canada. There is a broad shelf off Patagonia in the Southern hemisphere. However, apart from the places mentioned above, continental shelf is narrow elsewhere. e.g. in the blocks of Africa and Brazil.

INDIAN OCEAN

The Indian Ocean has an area of about 74million km². Comparatively, it is smaller in size than the Atlantic and totally different from other two main oceans because it is wholly enclosed to the north and lies mainly in the southern hemisphere.

The ocean is bounded in the West by Africa, in the East by Australia, Asia in the north and to the south by Antarctica. It has a total depth of about 7,450 metres.

THE ARCTIC OCEAN

The Arctic Ocean occupies the areas around the North Pole. It is a shallow basin with a mean depth of 5,449metres and it occupies an area of about 14million square kilometres.

PROPERTIES OF SEA WATER

A. SALINITY

Salinity is defined as the total amount of solid material, in grams, contained in one kilogramme of sea water when all carbonate has been converted to oxide, the bromide and iodine replaced by chlorine, and all organic matter completely oxidized. In the sea, salinity ranges from 32-38‰. In the ocean and seas of the world, it ranges from nearly 0‰ where large rivers empty into sea to over 40‰ where the river influx from the land is negligible and

where surface evaporation is great. At the depth of the ocean, salinity ranges from 35-36‰. And higher salinity values occur near the arid equatorial areas whereas lower values occur near the polar regions.

Surface water salinity is usually influenced by two major factors:

- i. Evaporation
- ii. Precipitation

An excess of evaporations over precipitation removes water from the sea surface thus, concentrating the salts and increases the salinity. This is usually facilitated when the water is warmer than air. It is greater when cold air flows over warm water. But when the sea is colder than air, turbulence as well as evaporation is reduced. Excess precipitation decreases salinity by diluting the sea salts. Run-offs from rivers, thawing of ice both have the same effect in diluting the sea salts.

The difference between evaporation and precipitation shows a linear correlation with surface salinity. Precipitation is inverse to evaporation. e.g. the effect of evaporation on the salinity of sea water is found in the Mediterranean sea. The relatively fresh Atlantic water flowing into the Mediterranean Sea is completely altered by processes including evaporation and flow-out of the sea as saline water. This change is due to great increase in evaporation and the relatively low rainfall and run-offs into the Mediterranean Sea area. In the Black sea, the reverse situation occurs, precipitation and run-offs exceed evaporation thus water becomes less saline.

When sea water freezes, only the molecules are incorporated into the ice-crystal, the dissolved salts are left-out thus increasing the salinity of the remaining sea waters. The process is reversed when ice thaws or melts. Freezing and thawing of sea water are usually seasonal phenomena resulting in little long term salinity differences.

A vertical distribution of salinity is very similar to temperature and this distribution can be expressed into three or four major zones:

- i. A well mixed surface zone of generally uniform salinity. This zone is usually between 50-100m.
- ii. A zone with a relatively large salinity change below surface water – the Halocline zone.
- iii. A thick zone of relatively uniform salinity extending to the ocean bottom

iv. Occasionally, there is a zone of about 600-1000m in some areas where there is a minimum salinity.

The normal chemical content of sea water with a total salinity of 35‰ is as follows:

MAJOR CONSTITUENTS OF SEA WATER

ION	CHM SYMBOL	G/KG OF WATER OF SALINITY 35‰
Chloride	Cl ⁻	19.353
Sodium	Na ⁺	10.762
Sulfate	SO ₄ ²⁻	2.709
Magnesium	Mg ²⁺	1.293
Calcium	Ca ²⁺	0.411
Potassium	K ⁺	0.399
Bicarbonate	HCO ₃ ⁻	0.142
Bromide	Br ⁻	0.0673
Strontium	Sr ²⁺	0.0079
Boron	B ³⁺	0.00445
Fluoride	F ⁻	0.00128

The proportion of these various elements remains very constant in sea water from place to place even when the total salinity differs. A good measure of any of these constituents gives a good index of salinity.

In addition to the major constituents, there is in the sea virtually every natural element, but most are in very small concentration. The elements and compounds associated with living organisms such as carbon, oxygen, nitrate and phosphate are found in small but highly variable amounts. The trace elements that are important for biology, e.g. Copper, Cobalt, etc. have even smaller concentrations. As an example of the relative concentrations of major constituents, nutrient elements, and trace elements, the typical concentration ratio of Na: N (in NO₂, NO₃, NH₄): C: O are roughly 10⁷: 10³: 1.

MEASUREMENT SALT CONTENT

The most abundant solutes in seawater are Cl^- , Na^+ , Mg^{2+} , SO_4^{2-} , Ca^{2+} , and K^+ . They are referred to as the major or conservative ions. They constitute over 99.8% of the mass of the solutes dissolved in seawater. The Na and Cl alone account for 86%.

$$= \frac{\text{g of inorganic dissolved ions}}{1\text{Kg seawater}} \times 1000$$

The most accurate and precise salinity measurements are made with an inductive salinometer, which measures the conductivity of a seawater sample.

The conductivity reading is converted to salinity using an empirical equation. The precision of a good inductive Salinometer is $\pm 0.001\%$. Accuracy is insured by calibrating the salinometer on a routine basis against IAPSO (International Association for Physical Sciences of the Ocean) standard sea water, which is the international accepted salinity standard.

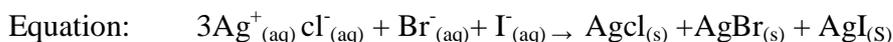
Chlorinity

Because the major ions are present in constant proportions, their concentrations can be used to infer the salinity of seawater. Before the invention of the salinometer, salinity was calculated from the chloride concentration of seawater because of the ease and accuracy with which this measurement can be made.

$$\text{Salinity} = 1.80655 \times \text{Chlorinity}$$

Where chlorinity is defined as the mass in grammes of halides (Expressed as Cl^-) that can be precipitated from 1000g of seawater by Ag^+ .

Chlorinity is determined by titrating a sample of seawater with a standard solution of silver nitrate.



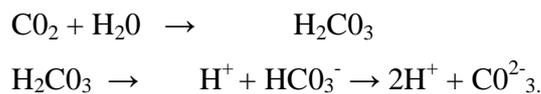
Thus:

$$\text{Chlorinity} = \text{Atomic weight of Cl}^- \times \text{Moles of Ag}^+ \text{ required to precipitate halides per } 1\text{Kg seawater} \times 1000$$

B. DISSOLVED GASES

Nitrogen, carbondioxide and oxygen are the most abundant gases dissolved in sea waters. The solubility of gases is a function of a temperature. And as temperature increases, solubility decreases/reduces. Nitrogen is comparatively inert, and it is therefore not involved in the basic life processes of most organisms.

Carbondioxide and oxygen are metabolically very active and they are therefore the most important dissolved gases in the ocean. Carbon dioxide is abundant in seawater in higher concentration than in the atmosphere. In the sea, the CO₂ concentration is never too low to support plant growth because sea water has unusually large capacity to absorb CO₂ due to the fact that most of the dissolved CO₂ does not remain as a gas, much combines with water to form carbonic acid (H₂CO₃) which is a weak acid. H₂CO₃ normally breaks-down to form H⁺ and a HCO₃⁻ or 2H⁺ and a CO₃²⁻.



The abundance of hydrogen ion in water controls its acidity or alkalinity i.e. the pH or the hydrogen ion concentration. The above reaction is reversible. The carbonic acid-bicarbonate-carbonate system in water functions to buffer or limit changes in water pH. If there is excess H⁺ in water, the above reaction proceeds to the left removing the ion from the solution thus preventing the increase in acidity. But if it is too low, the reaction will proceed to the right making more ion available (by conversion of carbonic acid to HCO₃⁻, and HCO₃⁻ to CO₃²⁻) and preventing alkalinity.

Oxygen – is one of the most essential elements for marine life. It is necessary for the survival of most organisms except the anaerobic organisms. The abundance or lack of oxygen in sea waters therefore strongly influences the distribution and abundance of most marine organisms. Like in most waters, oxygen is available in sea waters from the (transfer) air/atmosphere and also during photosynthesis by marine organisms/plants. These two processes are limited to the surface area of the ocean hence this area is very rich in oxygen. Oxygen replenishment in the deep water near the bottom occurs by very slow diffusion process from the oxygen rich surface layer downward and also by vertical water movements i.e. Upwelling (convection) which mixes surface and bottom waters, as well as, thermocline through water circulation.

The amount oxygen decreases with depth. At intermediate depth, plant and animal respiration as well as bacterial decomposition and organic debris use oxygen as fast as it is replaced thereby creating an oxygen minimum zone. The presence or absence of oxygen minimum zone depends on whether the depth of oxygen respiration exceeds the renewal of oxygen by mixing of surface and deeper waters. The increase in oxygen in depth below the oxygen minimum zone is believed to be due to the influx of oxygen rich water from the polar region into the deeper parts of the ocean.

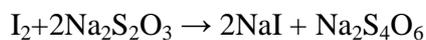
DETERMINATION OF DISSOLVED OXYGEN

It can be determined by

- (i) Oxygen meter (electrical or battery)
- (ii) Titration method (Winkler's method)

In the Winkler's method, concentrated magnesium chloride and alkaline KI are added to the water sample. Both are thoroughly mixed with the water sample under vacuum. A white precipitate of magnesium hydroxide is first formed and some of this is first oxidized into magnesium hydroxide by the DO in the water sample. This magnesium hydroxide which is a brown precipitate settles on the bottom of the specimen bottle (rate of setting depends on the salinity). Concentrated H_2SO_4 is then added, this dissolves the magnesium hydroxide. The magnesium hydroxide liberates iodine from the KI by an oxidation process and is reduced to magnesium oxide. The liberated I_2 takes up excess I^- and forms a complex compound I_3^- .

A rough estimate of the DO content in the sample can be made by noting the depth of colour of the I_2 at this stage. The liberated I_2 is titrated with $Na_2S_2O_3$ using a starch solution indicator. The end point is blue colour. The amount of DO is equivalent to the quantity of $Na_2S_2O_3$ titrated to reach the end point.



Also at any given temperature, pressure and salinity DO can be deduced:

$$CS = \frac{475}{33.5} + t$$

CS = Solubility of oxygen (mg/l)

t = temperature ($^{\circ}C$).

⁰ c	CS (mg/l)	⁰ c	CS (mg/l)
0	14.18	25	8.12
1	13.7	26	7.98
20	8.88	27	7.85
21	8.72	28	7.72
22	8.56	29	7.69
23	8.41	30	7.48
24	8.26	31	7.37

$$\text{General DO} = \frac{C_s + P}{100}$$

P = % saturation of oxygen in the water

Cs = Solubility of O₂ of any given temperature.

C. DISSOLVED ORGANIC NUTRIENTS

Most important dissolved organic nutrient in sea water are nitrogen and phosphorus. They are chemically combined in organic compounds and eventually oxidized to nitrate and phosphate. There are known as the fertilizers of the sea. Their sources are from excreta of animals, dead remain of plants and animals which drop to the bottom and decomposed by bacteria. These and other amounts of nutrients are usually utilized during photosynthesis by plant at or near the surface of the water. This, therefore, depletes the surface water nutrient and increases their concentration in deeper water. This mixing of surface and bottom waters are very vital for their distribution.

Other dissolved organic compounds in seawater include organic carbon, CHOs, proteins, amino acids, organic acids and vitamins. Generally dissolved organic matter/nutrient is present in seawater in moderately small and usually variable amount of between 0-6mg/l.

D. TEMPERATURE

This is the relative measure of the condition caused by heart energy. In the world's ocean, temperature ranges from -2⁰c (bottom, near the Antarctic) to 30⁰c (equatorial regions). However, at the lower limits, ice usually forms. The surface of the ocean is heated by:

- i. Radiation from the sky and sun

- ii. Conduction of heat from atmosphere
- iii. Condensation of water (vapour).

The surface is cooled by:

- i. Back radiation from the sea surface to the atmosphere
- ii. Back conduction of heat to the atmosphere
- iii. Evaporation.

The surface temperature of the ocean is closely related to the latitude and season of the year. Usually more heat for unit area is received at the equator just as more heat is received in dry season and summer. In the sea, temperatures do not vary throughout the year like on land. There is, however, an important seasonal fluctuation of surface water temperature in the ocean. This is known to vary with ocean currents, prevailing winds, and these variations occur most in the middle latitudes.

The change of temperature with depth depends on four (4) factors:

- i. Variation in the amount of heat absorbed
- ii. Effect of heat conduction
- iii. Lateral displacement of water by current.
- iv. Vertical motion of water.

In most seas, there is thermal stratification. In the mid and low latitude, the temperature profile with depth consists of 3 layers:

1. A warm, well mixed (uniform) layer probably up to 500m, depth where temperature is virtually similar to the surface.
2. A transition layer below the surface called the thermo chine. This is a region where there a rapid decrease in temperature from that in the surface layer above. It can be from about 500m - 1000m depth.
- iv. Deep layer of cold water with relatively homogeneous water temperature. It is usually below 100m and temperature slowly decreases towards the bottom.

The water in the region has its origin in the high latitudes.

Thermocline is usually about in polar regions since in these regions, most of the ocean surface is covered by ice in winter and solar radiation is usually low in summer. In the tropics, the thermocline may be very close to the surface (at times 20-50m depth). So all areas with strong seasonal warming have a temporary seasonal thermocline in the surface area. Off

Nigerian coast there is a minor thermocline during the period of high temperature. This usually disappears during the harmattan and rain when the water is cool.

The relationship between air temperature and sea temperature is responsible for Seafog formation. Seafog are formed when warm damp air passes over a cold sea surface. The air is then cooled below its dew point and fog is formed. Seafog can also occur with strong winds which are not dependent on daily heating and cooling. This occurs when there is a diurnal variation in seawater temperatures. Seafog occur monthly in spring and early summer when air passing off the land may be warmer while the sea is still very cold. Fogs are most common in high latitude, very rare in the tropics and do not often occur in the Mediterranean region.

Dew point is the temperature at which a given parcel of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur. When this temperature is below 0°C it is sometimes called frost point i.e. the highest temperatures at which atmospheric moisture will sublime in form of a frost of a cooled polished surface.

Fog: this is a visible aggregate of minute droplets suspended in the atmosphere in the earth surface \rightarrow result of condensation.

Seawater is slightly compressible and this leads to an increase in temperature of water when it is compressed adiabatically (i.e., without exchange of heat). Thus at great depths, the measured temperature may be found to increase with depth. The adiabatic effect of increasing pressure leads to temperature increase of the order of 0.1°C for 1000m.

Potential temperature is defined as the temperature a water sample would have if it were brought adiabatically to the sea surface.

DETERMINATION OF TEMPERATURE

Temperature of sea water at different depths is generally determined "in-situ". It is usually done with contact thermometer of various types. There are (1) the fluid thermometer – includes Hg type (for surface water) thermometer. It can be done in a scoop bucket or also in water.

To obtain the temperature of selected depths of the ocean, (2) the tipping thermometer is used. It is usually attached to a suitable water bottle (3). Also the bathythermograph is used

to record continuous temperature as a function of depths. It is accurate up to about 270m depth after which it is relatively inaccurate. (4). Metal resistance thermometer; metals are said to have the ability to increase their electrical resistance when they are heated. The most popular metal with this characteristic is platinum. (5). Thermistors: this also operates on the principles that certain semi-conductors can react with heat by showing a strong fall for a resistance. These thermistors are also described as heat conductors and they are very sensitive. Thermistors can be used alongside with recording thermometer for the measurement of surface water temperature both in anchor as well as moving ship. It can continuously measure and record total water temperature or temperature stratification of surface water.

E. DENSITY

This is referred to as mass per volume. In the seas, it ranges from $1.02 - 1.07\text{g/cm}^3$, it is usually controlled by salinity, $T^{\circ}\text{C}$, pressure or depth. Generally it increase with increase in salinity, increase in pressure or depth, and decreases with increase $T^{\circ}\text{C}$. so colder, deeper, more saline water is usually the densest water.

However, increase in density with decreasing temperature continues only to 4°C below which density decreases with increase in temperature thus, continuous cooling below 4°C causes the density of water to decrease until the freezing point (0°C) is reached. At this point water is turned into ice, there is a sharp decrease in density, and the ice formed floats. This proficient of ice floating is of great advantage of living organisms that are heavier than water. Without this unique temperature/density relationship, the ice formed would sink and water bodies would freeze from bottom making life difficult and almost impossible.

F. LIGHT

Although very small amounts of water appear to be transparent, the ocean absorbs most of the solar radiation incident at the surface within several tens and metres from the surface. It is this absorption of solar energy that supplies most of the energy input to the ocean and that limits most of the primary production to the upper layers of the sea. The average energy input to the sea by solar radiation is about 10^4 times that input by the wind or tides.

The spectrum (distribution of energy as a function of wavelength or frequency) of solar radiation that reaches the sea surface covers the spectral range from 290 to 3000nm

($1\text{nm} = 10^{-9}\text{m}$) in wavelength, of which the range 350 to 750nm is visible. The energy has a peak near 480nm (blue-green) by nearly half the energy is in the infra-red. Some of the light is reflected at the sea surface (only a few % for angles of incidence less than 45° from normal) and the rest enters the sea to be refracted, and alternated by scattering and absorption; the latter is the ultimate fate of most of the light.

Clear sea water is most transparent to blue green portion of the light spectrum and is least transparent to the red portion. Hence blue light penetrates sea water more deeply than red light. Hence, blue light penetrates sea water more deeply than red light. Even in the clearest tropical waters, almost all the red light is absorbed in the first 10m whereas the blue light penetrates up to 100m. The blue colour common to most clear Open Ocean is due to the greater penetration, and eventual back scattering of blue light.

G. SOUND IN THE SEA

Sound is mechanical radiation, a propagating pressure disturbance, and the ocean is an excellent medium for propagating acoustic waves. The speed, C , at which sound waves propagate is given as $C^2 = (k\rho)^{-1}$ where k is the adiabatic compressibility of the water, which like ρ is a function of salinity, temperature and pressure. The speed increases with increasing salinity, temperature or pressure (depth). Since the speed of sound varies significantly in the ocean, sound undergoes refraction. The concept of an acoustic ray, analogous to a light ray, is used and Snell's law, which relates the angle of incidence and the angle of refraction to the ratio of wave propagation speeds, can be applied. In the thermocline the effect of temperature dominates and the speed of sound decreases with depth, and sound rays tend to 'bend' (refract) downward. In relatively uniform water below 2000m, the pressure effect dominates and sound speed increases with depth and the rays tend to "bend" back upward. Thus the sound energy tends to be trapped in a 'sound channel' and is propagated extremely well over great distances.

Acoustic radiation, like electromagnetic radiation (e.g. light) is attenuated by absorption and scattering. In absorption, the radiation interacts with the water molecules and the dissolved ions in sea water and is irreversibly altered and the energy transformed into heat, or chemical potential energy. Scattering is any random process by which the direction of radiation is changed without any other alteration. Absorption and scattering decrease the

intensity of sound exponentially with distance. This is very useful for the detection of the limits of the sea water (the bottom) and objects within it e.g fish.

SEA MOTIONS

The ocean said to be constantly in motion and their motions have been an immense advantage to marine environment. Such motions are known to enhance the mixing and diffusion processes. Secondly, they are known to minimize salinity and temperature variation. Thirdly they serve to enhance the dispersal, swimming and floating of organisms and their reproductive products. Fourthly, the oceanic circulation carries away toxic wastes. They recycle and replenish food nutrients, dissolved gases and essential elements.

The primary driving forces behind these oceanic circulations include:

- i. Heat from the sun
- ii. Additional contributions from gravitational attractions or the moon and sun.

Motions of the ocean include waves, current, vertical water movements, and tides.

Waves:

Wave is a disturbance propagated in a medium in such a manner that at any point in time in the medium the displacement is a function of time while at any instant, the displacement of a point is a function of position of the point. Different solar heating of the various regions of the earth's surface and the atmosphere generate wind. In turn, the wind blows across the seas surface to produce waves. The size of these waves produced depends on:

- i. Velocity of wind
- ii. Direction of the wind
- iii. The distance of the area over which the wind blows which is known as fetch
- iv. Duration of wind.

Waves are characterized by (i). the period, T . – this is the time it takes the wave formed to move through one wavelength. (ii) wave length, l , is the distance between two successive wave crests measured perpendicular to the wave crest. (iii) wave height, H , - the distance between opposite wave crests and wave troughs measured perpendicular to both crests and troughs.

The depth to which waves produce a noticeable motion is about half its wavelength. Wavelength seldom exceeds 100m in any ocean. The depth of effective mixing by “wind drive waves” is generally not greater than 50m. the period, J, and velocity of the wave formed are closely related to the wavelength. The relationship between the three can be represented as

$$L = CT$$

L= wavelength

C= velocity

T = period.

This formula differs in deep water because of velocity in deep water is represented by

$$C = \sqrt{(gL/2\pi)} \quad g = \text{force of gravity}$$

While in shallow water it is:

$$C = \sqrt{\frac{gL}{2\pi} \tan \frac{2\pi d}{L}} \quad d = \text{depth of water}$$

Types of wave:

- a. **Ripples** or capillary waves – there are waves with wavelength less than 6.28cm, generally caused by winds.
- b. **Swells:** this happens when a wave attenuates there the wave out of generating area into calmer waters. It is then modified to become swell. Swells are more uniform and larger crested due to reduced height. They are also caused by wind/
- c. **Solitary waves:** there are waves that move independently of each other. These are found in shallow waters where the velocity of the waves depends only on the depth. There are also caused by wind. Each solitary wave consists of crest separated from its neighbours by flat water in which the water particles are at rest.
- d. **Long waves** there are waves in the ocean whose lengths are considerably longer. There are different types of longer. There are different types of long wave.
 - a. **Surf beats:** these are long waves with period which have been recorded to range from 1-10minutes. These are caused by gravity and are sometimes menace in the harbour. They are forced waves that can be modified into a free-wave close to the shore.

b. Microseism: there are long waves associated with ocean storm. The main cause of this type of wave is the interference between two wave trains of equal period travelling in opposite directions. Sometimes the reflection from a steep coast can result in interference between waves of the same period. Microseism travels much more and rapidly in the earth's crust than the waves on the ocean surface so that they frequently arrive at the coast sometimes before the storm wave will reach the coast. This, thus, gives a warning of approaching damaging waves or storms or storm dwells.

c. Tsunami: this is seismic wave. It is a long wave caused by seismic activity (earthquake). It is usually generated by a submarine earthquake know as "Tsunami" (by Japanese). Any sudden movement in the earth crust under the sea will affect the water above resulting in "Tsunami". Waves produced by earth quakes have enormous lengths of about 160km though their height in the open sea may only be between 30-60mm. They are so long that their velocity depends only on water depth. They are normally not felt by ship in the open seas but as they approach close to the shore where water depth decreases, the speed of the wave will slow down and the height increases. Long wave of this type can travel an immense distance with out substantial loss of energy. There have been reports of devastating effects of "Tsunami" in Japan, Hawaii, and Alaska.

d. Meteorological surges: they are long waves generated by meteorological condition. Very sudden change in wind direction is important in the formation of surges. Exceptional strong wind drives a considerable amount of water causing surge.

Surges result in a rise in sea water level. These may coincide with high or low water tides and may increase water level beyond predictable values. They are particularly dangerous when they coincide with high tide. Surges are very prominent in the Northern seas. They are two major types:

- i. External surges: these are generated outside the sea and move as free waves anticlockwise round the sea.
- ii. Internal surges: which originate inside the sea.

Tides:

These are periodic rise and fall of the sea surface usually unnoticed in the open sea but only against coast lines. They are known to have long period waves and are usually caused by gravitational attraction of the earth, moon and sun from one another. Tides are characterized by

- i. **High tide:** this is the max elevation of the tide due to rise in sea water level.
- ii. **Low tide:** the minimum level due to fall in sea water level following high tide. Too low or too low tides occur every day on most coast lines.
- iii. **Tidal range:** is the vertical difference between high and low tides. It can vary less than 1m to over 15m depending on the coast lines.
- iv. **Intertidal zone:** this is the zone of the range of high and low tides on the coast lines. It is usually covered at high tide and exposed at low tide. It is a zone of unique marine life because here, the sea, land and air all play important roles in establishing the complex physical conditions in which all the intertidal plants and animals must adapt to. Tide seas are important in influencing the
 - i. The movement of materials
 - ii. Morphology of the sea floor.
 - iii. Waves and shipping activities at the coast.

Tides producing forces:

Ocean tides are the consequences of gravitational attraction of the moon and sun and the ocean of the earth. From the Newton's law of gravitational, the gravitational force of attraction between two bodies is directly proportional to the product of their masses and inversely proportion to the square of distance between the bodies.

The mass of the sun is about 27million times greater than that of the moon. Yet, the moon exerts twice as much influence on the earth's tide. This is because of the earth-moon distance which is only 1/400 of the earth-sun distance i.e it is nearer to the earth and thus compensates for the moon small size.

The moon completes an orbit around the earth each lunar month (28days) and in reality it is 27 days. To maintain this orbit, the gravitational force between the earth and the moon must exactly balance the centrifugal force holding the bodies apart. On earth, the centrifugal force everywhere is equal in direction and magnitude and is directly opposite the gravitational force.

Lunar tides are produced by the attraction of moon while solar tides (1/2 as high as lunar) are produced by gravitational attraction of sun.

Assuming hypothetically that the earth is completely covered by water, two bulges of waters (temporary increase in volume) will normally pile up; one on the side facing the moon and other on the opposite side of the globe.

Each day, as the earth rotates under its tidal bulges, a point on the surface experiences high tide when under the tidal bulges and low tides when at right angle to the bulges. As the earth makes a complete rotation every 24hours on the earth surface, it first experiences (a) high tide (b) low tide (c) high tide (d) low and finally (e) high tide.

Similarly the sun-earth system also generates tide producing forces that yield solar tides about 1/2 as that of the lunar tides. The solar tide is expressed only as a variation on the basic lunar tide pattern rather than as individual sets of tides.

Types of oceanic tides

- i. Semi diurnal tide: in this tide, there are two high tides similar to each other and two low tides similar to each other. The main characteristic of east coast of USA.
- ii. Daily (Diurnal) tide: here there is only one low and one high tide each day.
- iii. Mixed semi-diurnal: there are two high tides and two low tides each day but they are different from each other.

Tidal conditions of any day of a selected coast lines can be predicted. This is because the movements of the bodies which bring about tides are regular and well known enabling the tide to be predicted with accuracy, therefore the periodic nature of tides are easily observed and recorded. The meteorological condition can, however, bring about some differences in the predicted and actual tides.

Currents:

These are non-periodic water movement generated by external forces. These forces include:

- i. Friction exerted by wind.
- ii. Horizontal density variation
- iii. Changes in atmospheric pressure.

Usually 1 & 3 cause major currents. Currents in the surface layers of ocean are usually caused by wind stress, while the main cause of deep water movements is caused by density variation.

Surfaces currents: these are large scale horizontal transports of surface water occurring in different regions of the world where wind velocity and direction are slowed down over the ocean. This slow down velocity that flows from the equatorial region to the polar region are called the WARM CURRENTS because they have a high surface temperature. Those that flow from polar to equator are known as the COLD CURRENTS because they have lower surface temperature.

The direction of flow of surface current is influenced mainly by planetary winds. There are three major planetary winds:

- i. Trade wind: between the equator and the tropics e.g NE trade wind which causes the north equatorial current. SE trade wind which causes the subequatorial current.
- ii. WESTERLIES: there usually blow in the temperate region and is responsible for the N. Westerly of the N. hemisphere.
- iii. Polar easterlies: they occur at the very high latitude and usually blow from east to west. They include the antarctic sub-polar current and the arctic current in the N. hemisphere.

Generally, currents move clockwise in the N. hemisphere, and anticlockwise in the S. hemisphere.

Types of current:

- i. **Geostrophic currents:** they are frictionless currents which flow horizontally without change in velocity. Gravity is the only external force that causes geostrophic current.

ii. Inertial currents: there are due to sudden changes in the forces that cause currents.

They result from a lack of balance between the pressure gradients, friction, and the resultant geostrophic acceleration.

iii. Wind drift currents: there are the current that do not flow in the direction of wind due to the friction between the wind and the sea surface as well as friction within the water which results to what is known as “Ekman’s” spiral. This shows that as the wind blow over the surface of the water the current gradually changes further right of the wind direction, and hence become slower as the depth increases. This change with depths is referred to as **CORIOLIS** effect. This reduces momentum with depth. The deflection of current to the right in the NH and to the left in the SH, is the most important feature of wind drifting current.

Vertical water movements:

These are produced by sink and upwelling processes. The processes breakdown the vertical stratifications by the thermocline. Seawater sinks when its density increases, and the processes which result in increase density occur, strictly at the water surface.

“UPWELLING”- This is the massive rising of water from the deep bottom to the surface. Whatever the cause, upwelling processes bring deeper nutrient, rich waters to the surface layers and therefore redistribute the nutrient and increase primary productivity.

Wind and tides wave create turbulence in the near surface-water and these will mix deeper nutrient water upward. Mixing is mostly effective over the continental shelf where the shallow bottom prevents the escape of nutrients into deeper waters.

In sub-tropical latitudes of most oceans, the strong permanent thermocline near the base of the photic zone inhibits upwelling, hence, the regions have very low rate of primary productivity. Thermocline in the temperate waters is seasonal. In winter, the surface water cools (becomes denser), sinks and the thermocline disappears and upwelling occurs enriching the surface layers with nutrients. As temperature increases in the spring, the thermocline is established which becomes well developed in summer like the permanent thermocline in tropical waters. This prevents upwelling until autumn and winter when the temperature is now lowered, the thermocline weakens and disappears giving way to upwelling again.

Types of upwelling:

- i. Coastal upwelling:** this is produced by winds blowing surface water away from coastline. The surface water is now replaced by deeper water rising to the surface. There are four major coastal upwelling areas, there include: California, Peru, Canary, Benguela.
- ii. Central pacific upwelling:** it occurs in the central Pacific Ocean and limited to this area. Here, the equatorial current flows westward and the carioles forces cause a slight displacement of the current the right in the NH. The resultant divergence of the water away from the equator, creates any upwelling of deep waters to replace the surface water that moved away. This area of upwelling is the basis for an important Japanese Tuna fishery.
- iii. Antarctic upwelling:** major upwelling areas occur around the Antarctic continent. In this region, the water that sank surfaces with accumulated nutrients and provides extra ordinary fertility of the Antarctic seas. All Antarctic live forms depend on the marine food chain supported by this massive upwelling.