On the Distribution of Nutrient Salts in the Equatorial North Pacific*

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Introduction

Among the factors which govern the distribution of chemical constituents such as nutrient salts and dissolved oxygen in sea water, in addition to the hydrographical movements of sea water, it is clear that the biological factor, namely consumption or regeneration of the constituents by living organisms or from their corpses, play an important rôle in natural processes. Since 1937, various investigators[1] have discussed this problem in connection with the existence of the oxygen minimum layer in the oceans, and it has generally been accepted that the biological factor cannot be ignored in natural processes. As the author had an opportunity of analysing the water samples collected from the equatorial region of the North Pacific Ocean, where the movements of sea water represent a characteristic feature of the tropical region, the distribution of nutrient salts has been investigated taking the biological factor into consideration.

Samples and Analytical Methods

Water samples were collected by members of the Nankai Regional Fisheries Research Laboratory (Kôchi, Kôchi Prefecture, Japan) when the marine observations on the fishing ground of tunny were carried out aboard "F.R.S. Tenyô Maru" in the summer of 1951. The analysis of the samples except those of dissolved oxygen was carried out by the author at the Tôkai Regional Fisheries Research Laboratory (Tokyo, Japan), after about four weeks standing. The chemical constituents analysed were chlorine, phosphate-phosphorus and nitrate-nitrogen. Dissolved oxygen was determined by a member of the Nankai Regional Laboratory aboard the ship. As the area in which the observations were carried out was within a district of high temperature, the water samples to be analysed for phosphate and nitrate were carefully preserved by adding chloroform-toluol mixture and mercuric chloride solution respectively immediately after the sampling, in order to prevent bacterial growth. Although some changes in phosphate contents in the samples collected from the upper layers containing living organisms must be expected even if the above mentioned procedure has been adopted, serious errors will not be introduced since the phosphate contents of the upper layers are much lower than those of the deeper layers.

The analytical methods adopted were as follows: chlorine: titration method proposed by Fajans using uranine as the indicator[2]; phosphate: colorimetric determination by Denigès-Atkins using Beckman's Model DU Quartz spectrophotometer[3]; nitrate: colorimetric method with Harvey's reduced strychnine reagent[4].

Data for nutrient salts obtained from the equatorial region of the Pacific were accumulated through the observations made on board the "Carnegie" and the "Dana". But the data obtained from this region are much fewer than those from the equatorial Atlantic and there is a lack of systematic data in the Eastern Hemisphere. The data dealt with in this paper were obtained along the longitude 150°E and 160°E between the equator and latitude 20°N. Twelve samples were collected at each station from different layers above a depth of 1000 meters. Collection was carried out at about 50 stations, then about 600 samples were collected and analysed.

The distribution of the constituents was considered on the basis of the data obtained from longitudinal section along 150°E, since the conditions along 160°E did not differ significantly from those along 150°E.

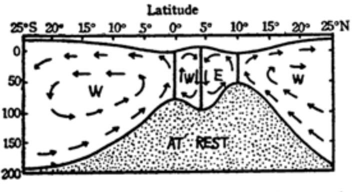

Fig. 1. Schematic representation of the vertical circulation within the equatorial region of the Atlantic. W: westward current. E: eastward current. (After Defant, 1936).

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[1] H. R. Seiwell, *Papers in Phys. Oceanogr. and Meteor.*, **5**, No. 3 (1937); H. U. Sverdrup, *J. Conseil permanent intern. pour l'exploration de la mer*, **13**, 163 (1938).

[2] Y. Miyake, This Bulletin, **14**, 29 (1939).

[3] R. Fukai, *J. Oceanogr. Soc. Japan*, in press.

[4] H. Wattenberg, *Rapp. et Proc.-Verb. des Reunions, Conseil permanent intern. pour l'exploration de la mer*, **103**, 1 (1937).

Results and Discussion

1. General Feature of Water Movements in the Region in Question—A. Defant[5] derived theoretically a schematic representation of vertical circulation of water within the equatorial region of the Atlantic as shown in Fig. 1. According to the schema, convergence (sinking of water) or divergence (upwelling of water) is developed at the boundary between the currents, and it is expected that the distribution of chemical constituents may fit with the schema. Based upon the data obtained on board the "Carnegie" (1929), Sverdrup et al[6]. recognised the close agreement between the water movements and the distribution of the constituents in the upper layers.

2. Chlorinity Distribution in the Longitudinal Section—The data for chlorine determination were given in term of chlorinity. In Fig. 2, distribution of chlorinity in the longitudinal section along 150°E is given. In this figure, it is obvious that the intermediate water of the North Pacific appears within the depths between 400 m. and 800 m. at lat. 12°N and northwards. As going to the south, the water below the intermediate layer becomes homogeneous and the characteristic water of the equatorial region having high chlorinity (Cl>19.30%) appears in the upper layer. But whether the water movement has influence on the distribution of chlorinity is not clear.

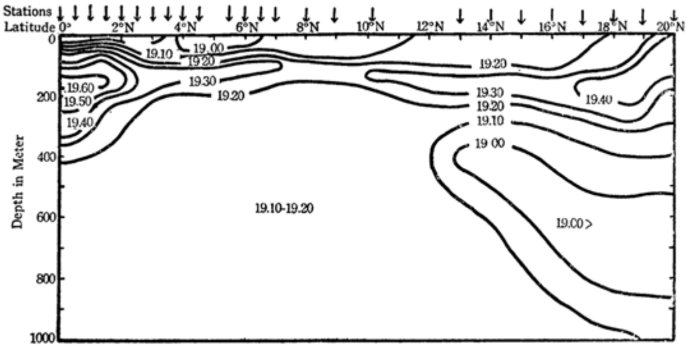

Fig. 2. Chlorinity distribution in the longitudinal section along 150°E. Units: %.

3. Distribution of Dissolved Oxygen and Phosphate-phosphorus in the Section—The distributions of dissolved oxygen and phosphate are illustrated in Figs. 3 and 4, respectively. In these figures, the corresponding distribution of these constituents with the schema presented by Defant is clearly shown. The convergence occuring near lat. 3°N and divergence near 6°N are recognised. The water movements suggested by the distribution of the constituents are shown by the arrows. From these figures, it is concluded that the vertical movements of water affect

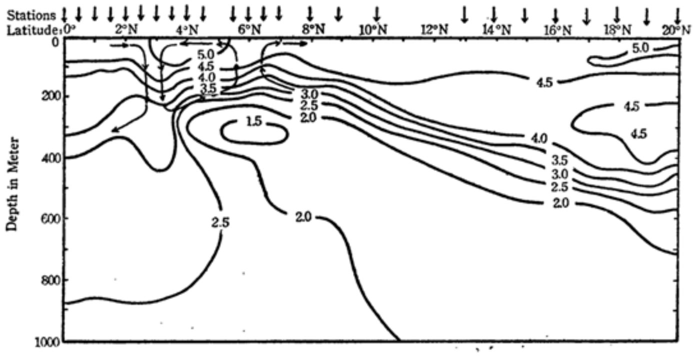

Fig. 3. Distribution of dissolved oxygen in the longitudinal section along 150°E. Units: O_2 ml. per liter.

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[5] A. Defant, Deutshe Atlantische Expd. *Meteor*, Bd. VI, Teil I (1936).

[6] H. U. Sverdrup et al., "The Oceans", Prentice-Hall, New York, 1946, p. 711.

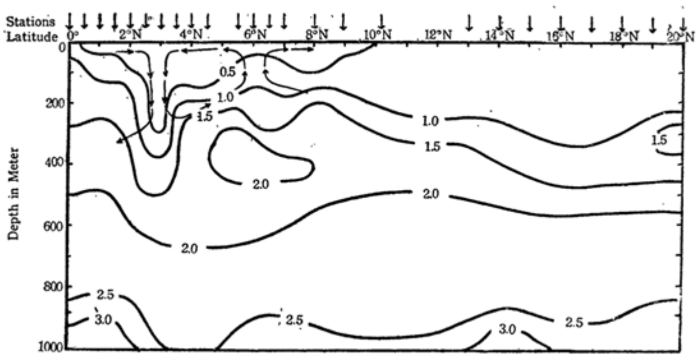

Fig. 4. Phosphate distribution in the longitudinal section along 150°E. Units: μg. -atoms PO_4-P per liter.

the distribution of the constituents at a depth as low as 500 m.

Although the water movements affect decidedly the distribution of the constituents in the region in question, it cannot be explained simply by the structure of water movements that a pool of minimum content of dissolved oxygen or maximum content of phosphate appears at a depth of about 300 m. The extreme value of the constituents in an enclosed domain should appear only when the decomposition of dead organisms, namely the consumption of dissolved oxygen or the regeneration of phosphate takes place within the domain⁷⁾. It is a remarkable fact that the domain lies just below the divergence, for areas in which upwelling of water is taking place have high fertility due to the nutrient salts transported from the layers below, and are able to support larger populations of organisms than other areas. If a greater quantity of dead organisms in this area decomposes while sinking, decomposition processes occuring in this water column will be more vigorous than those in other areas. In consequence, it is probable that the maximum decomposition may occur in the above mentioned domain.

4. Relationship between Oxygen Minima and Maxima of Nutrient Salts—Before considering the decomposition processes quantitatively, the vertical distribution of the constituents is given in Fig. 5. From the figure, it can be seen that the extreme values of these constituents appear in close correlation with each other and are centered at a depth of 300 m. Although vertical distributions of phosphate and nitrate seem to be in parallel correlation, it is noteworthy that the gradient of phosphate increment is larger than that of nitrate increment at depths within 200～300 m. This may be attributed to the difference in the rates of liberation between phosphate and nitrate *in situ*, as the author has recently pointed out⁸⁾. Due to the lack of available data for nitrate, further detailed discussion concerning the vertical distribution of nutrient salts is impossible.

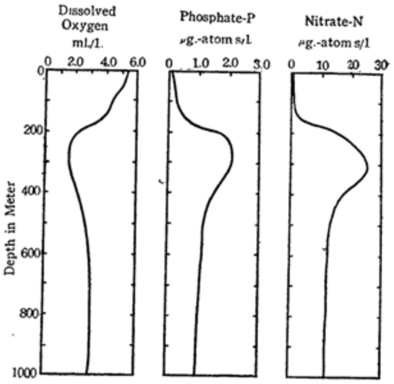

Fig. 5. Typical vertical distributions of dissolved oxygen, phosphate-phosphorus and nitrate-nitrogen in the Equatorial North Pacific based on the data obtained at Station 29 (lat. 4°30′N, long. 150°02′E).

5. Quantitative Consideration on the Rate of Decomposition—In order to obtain quantitative knowledge upon the rate of decomposition in connection with the appearence of oxygen minima and nutrient salts maxima, computations were carried out introducing some simplifying assumptions.

If we consider a cube of sea water of a unit volume *in situ*, the change of concentration of the constituents affected by the biological factor in this cube can essentially be expressed⁹⁾.

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7) G. A. Riley, *Bull. Bingham Oceanogr. Collection*, **8**, Article 1 (1951).

8) R. Fukai, This Bulletin, **25**, 323 (1952).

9) H. U. Sverdrup, *J. Conseil permanent intern. pour l'exploration de la mer*, **13**, 163 (1938).

$$\frac{\partial c_o}{\partial t} = R + \frac{\partial}{\partial x}\left(\frac{Ax}{\delta}\cdot\frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{Ay}{\delta}\cdot\frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{Az}{\delta}\cdot\frac{\partial c}{\partial z}\right) - \left(V_x\frac{\partial c}{\partial x} + V_y\frac{\partial c}{\partial y} + V_z\frac{\partial c}{\partial z}\right) \text{......(1)},$$

where, C_o: Concentration of the constituent in the cube,

δ: Specific gravity of sea water,

R: Biological rate of change,

A_x, A_y, A_z: Coefficents of eddy diffusivity along x-, y- and z-axis, respectively,

V_x, V_y, V_z: Current velocity components along x-, y- and z-axis, respectively.

We take x-axis from the east to the west, y-axis from the south to the north and z-axis from the surface to the bottom and make the following assumptions.

1. Steady state has been established. In other words, the distribution of the concentration is not altered in the course of time.

2. The distribution of the concentration is homogeneous along the east-west axis.

3. Current velocities except along the east-west axis, are negligibly small in the computation.

Under these assumptions, equation (1) is reduced as follows:

$$R = -\left[\frac{\partial}{\partial y}\left(\frac{Ay}{\delta}\cdot\frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{Az}{\delta}\cdot\frac{\partial c}{\partial z}\right)\right] \text{......(2)}.$$

Assumptions 1 and 2 are supposed to be reasonable, because the difference between the distribution pattern along 150°E and that along 160°E is small. Assumption 3 is also likely correct since the vertical current velocity is nearly equal to zero at depths such as an oxygen minimum layer and horizontal current velocity along y-axis, V_y, may also be ignored because it does not exceed the order of 0.5 cm./sec.

Now let us assume that δ equals unity and A_y and A_z are constant and rewrite the equation (2) into a finite form. Then we may obtain.

$$R = -\left[A_y\frac{\delta^2 c}{\delta y^2} + A_z\frac{\delta^2 c}{\delta z_2}\right] \text{......(3)}.$$

We cannot calculate the values of R unless the values of A_y and A_z are known. However, the derivation of physical coefficents, A_y and A_z, from the present data is difficult. Accordingly, the values which have been obtained so far for these coefficents in various regions[10] are introduced. Thus, the values of R are calculated by introducing the gradients of the concentration near 300 m. depth. The results are shown in the tables. Tables I and II indicate the rate of phosphate liberation and oxygen consumption, respectively. As it is considered that $A_y = 10^7$ C.G.S.[11] and $A_z \leqq 10$ C.G.S.[12] in the layer in question, the rate of $3 \sim 8 \times 10^{-8}$ μg.-atoms PO_4-P/1. sec. for phosphate liberation and of $3 \sim 12.5 \times 10^{-8}$ ml. O_2/1. sec. for oxygen consumption may be estimated. Knowledge concerning the biological rate of change *in situ* has scarcely been accumulated. The values here proposed are about ten times higher than those proposed by Riley in 1951.[7] But, these values are prolobly reliable, for they are estimated for a particular layer within the tropical region of high temperature, while Riley's values are those for the whole Atlantic Ocean.

TABLE I

VALUES CALCULATED FOR PHOSPHATE LIBERATION

Units: 10^{-8} μg.-atoms PO_4-P/1. sec.

A_z/ A_y	10^6	10^7	10^8
0	0.3	3.4	34
10	5.1	8.2	39
50	24	27	58

TABLE II

VALUES CALCLATED FOR OXYGEN CONSUMPTION

Units: 19^{-8} ml. O_2/1. sec.

A_z/ A_y	10^6	10^7	10^8
0	−0.4	−3.6	−36
10	−9.3	−12.5	−45
50	−45	−49	−81

Summary

The present author carried out the determination of nutrient salts of the water samples collected from the equatorial region of the North Pacific in 1951, and their distributions have been investigated taking the biological factor into consideration.

The author found that the distributions of nutrient salts were closely connected with the structure of the movements of sea water in this region and that the effect of water movements was extended to a depth of 500 m. On the other hand, it is suggested that the oxygen minima and nutrient salts maxima developed just below the divergence are caused by the biological factor.

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[10] H. U. Sverdrup et al., "The Oceans", Prentice-Hall, New York, 1946, p. 484.

[11] R. B. Montogomery and E. Palmen, *J. Marine Res.*, 3, 112 (1940).

[12] H. R. Seiwell, *Papers in Phys. Oceanogr. and Meteorol.*, 3, No. 1 (1935).

The estimations of biological rate of change of the constituents in the layer in which the decomposition processes might occur were made, introducing some simplifying assumptions. As the results, the values of $3\sim 8\times 10^{-8}$ μg.-atoms PO_4-P/1; sec. for phosphate liberation and $3\sim 12.5\times 10^{-8}$ ml. O_2/1. sec. for oxygen consumption were obtained. These values are probably reliable as the measure indicating the rate of decomposition processes which take place in the subsurface layer within the region in question.

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