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CHEMICAL OCEANOGRAPHY IN THE SOUTH ATLANTIC OCEAN, ADJACENT TO NORTH – EASTERN BRAZIL

By Taizo OKUDA

INTRODUCTION

We have as yet very little available data as to oceanographic observation in the South Atlantic Ocean especially in the area adjacent to Brazil. The data available have been obtained by "Meteor" (1926), "Discovery" (1931) "Toko- Maru" (1957), "Crawford" (1957-1958), 'Almirante Saldanha" (1957-1960), and "Atlantis" (1959).

Since 1957, the oceanographic observations in the South Atlantic Ocean adjacent to Brazil have been conducted as a part of the program of the International Geophysical Year. As a part of the series of this program, the oceanographic observations in the sea adjacent to north eastern Brazil were made by the "Almirante Saldanha", Oceanographic Ship of the Brazilian Navy, from August to October 1959. These observations extend from latitude 13º to 3.5º S. and from longitude 30ºW. to the coast of Brazil. The oceanographical data were published by the "Diretoria de Hidrografia e Navegação" of the Brazilian Navy.

The author, by invitation of the Brazilian Navy, participated in the oceanographic observation in the northern area from 9ºS., and was in charge of the analysis of inorganic phosphorus, total phosphorus and inorganic nitrogen such as ammonia-N, nitrite-N, and nitrate-N.

This report deals with the general features of oceanographic conditions, with especial reference to the major features of chemical oceanography in this area. Although the data presented in this paper were obtained from a relative narrow area, they furnish information on the chemical and physical oceanographic conditions.

ACKNOWLEDGMENT

The author wishes to express his gratitude to Cte. Paulo Moreira da Silva, Commander of "Almirante Saldanha" Oceanographic Ship of the Brazilian Navy, for his invitation to make the observations and for his invaluable advice. Thanks are also due to all members of the "Almirante Saldanha" for their kind collaboration on the cruise.Equal

thanks are made to Prof. Francois Ottmann for his valuable criticism, and also to Mr. José Bernardo de Oliveira for his assistence with the preparation and analysis of total phosphorus. Furthermore, the author wishes to acknowledge his indebtedness to Prof. Dr. João Alfredo Gonçalves da Costa Lima, President of University of Recife, for his kindness to carry out this study. Finally, thanks are expressed to Dr. Henry B. Morrison, U.S.O.M. to Brazil, advisor to E.T.A. Project 20, for his valuable suggestions made in the preparation of the manuscript.

GENERAL DESCRIPTION OF THE AREAS INVESTIGATED AND PROCEDURE OF INVESTIGATION

The ocean area surveyed comprises deep water for the greater part, and the continental shelf for the smaller part. In the north-eastern part near the Cape of São Roque, there lies the Island of Fernando de Noronha and ridge, resulting from a submarine volcano. Therefore, the oceanographic conditions in this area are influenced by complicated topography. In the other area investigated, the topography is rather regular; that is, the slope next to the narrow shelf (10-20 miles in width) drops steeply to the deep sea floor of the South Atlantic Ocean to a depth of 4,000 or more meters.

The observation cruise was conducted at intervals of 60 miles from east to west, and of 120 miles from south to north, extending from 13°S, to 3.5°S; 30°W, to the coast of Brazil. Sea water characteristics were observed at 42 stations. In the ocean, the sea water was collected vertically from the surface layer to a depth of approximately 3,000 m. As to plant nutrients such as nitrogen and phosphorus, however, only the results from 25 stations which were analysed by the author, will be discussed in this paper. (Fig. 1)

ANALYTICAL METHOD

The estimation of inorganic nitrogen, and inorganic and total phosphorus was made as follows: the inorganic nitrogen was analyzed on shipboard at the time of collection by the following methods, namely, the estimation of ammonia-N was done by the Witting method, nitrite-N with Griess-Romin reagent, and nitrate-N with the reduced strychnin (Harvey's method).

The determination of phosphorus was made at the laboratory after the voyage. In order to stop bacterial action, a solution of toluene and chloroform (1:1) was added to these samples at the time of collection. The phosphate-P was estimated by the molybdenum blue method, and total phosphorus was also determined by the same method after the decomposition of the organic phosphorus with perchloric acid (70%). The procedure for total phosphorus is as follows;

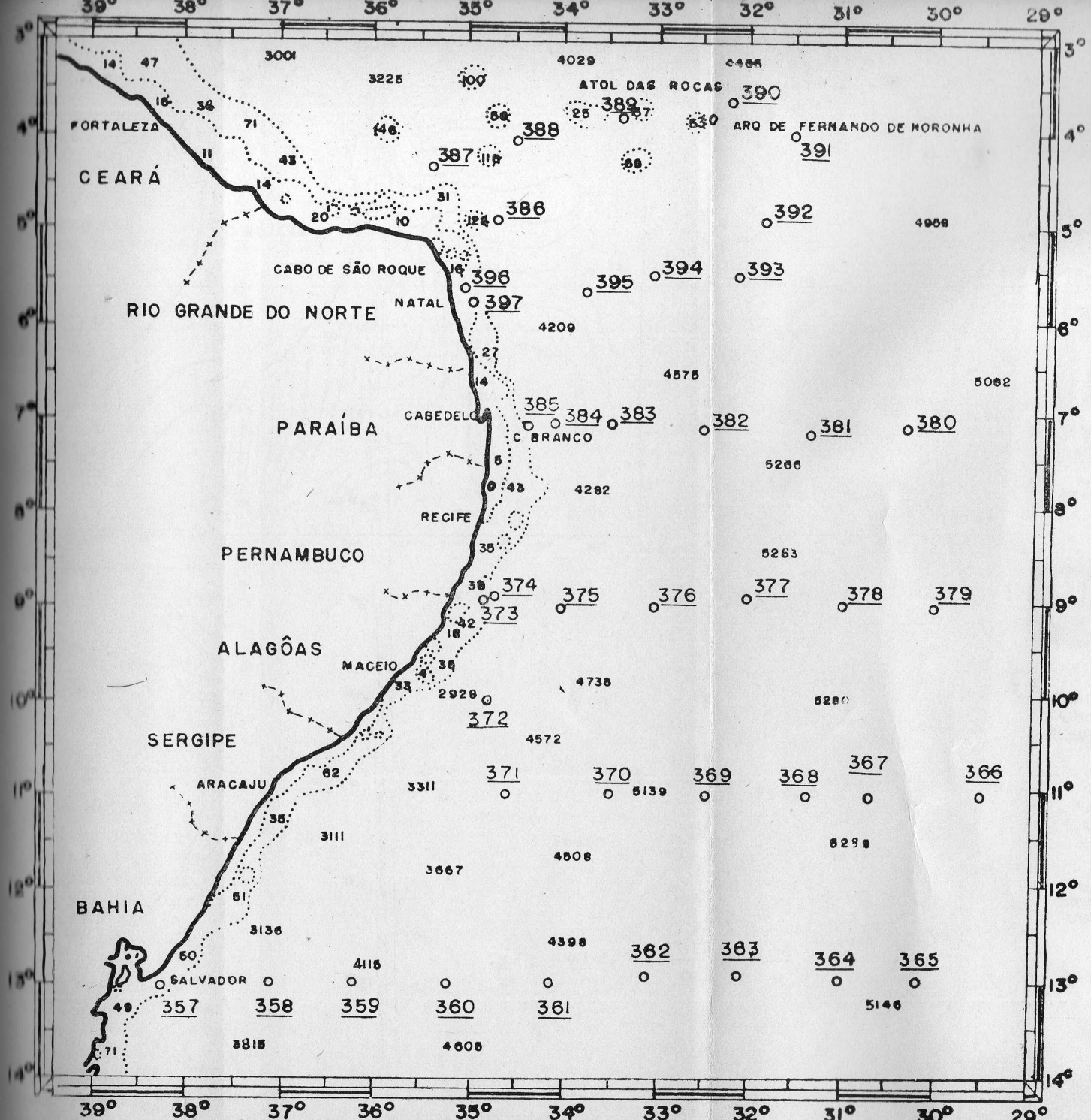


Fig. 1: Stations observed in north-eastern area of Brazil
Estações observadas no nordeste do Brasil
Stations observées dans le nordest du Brésil

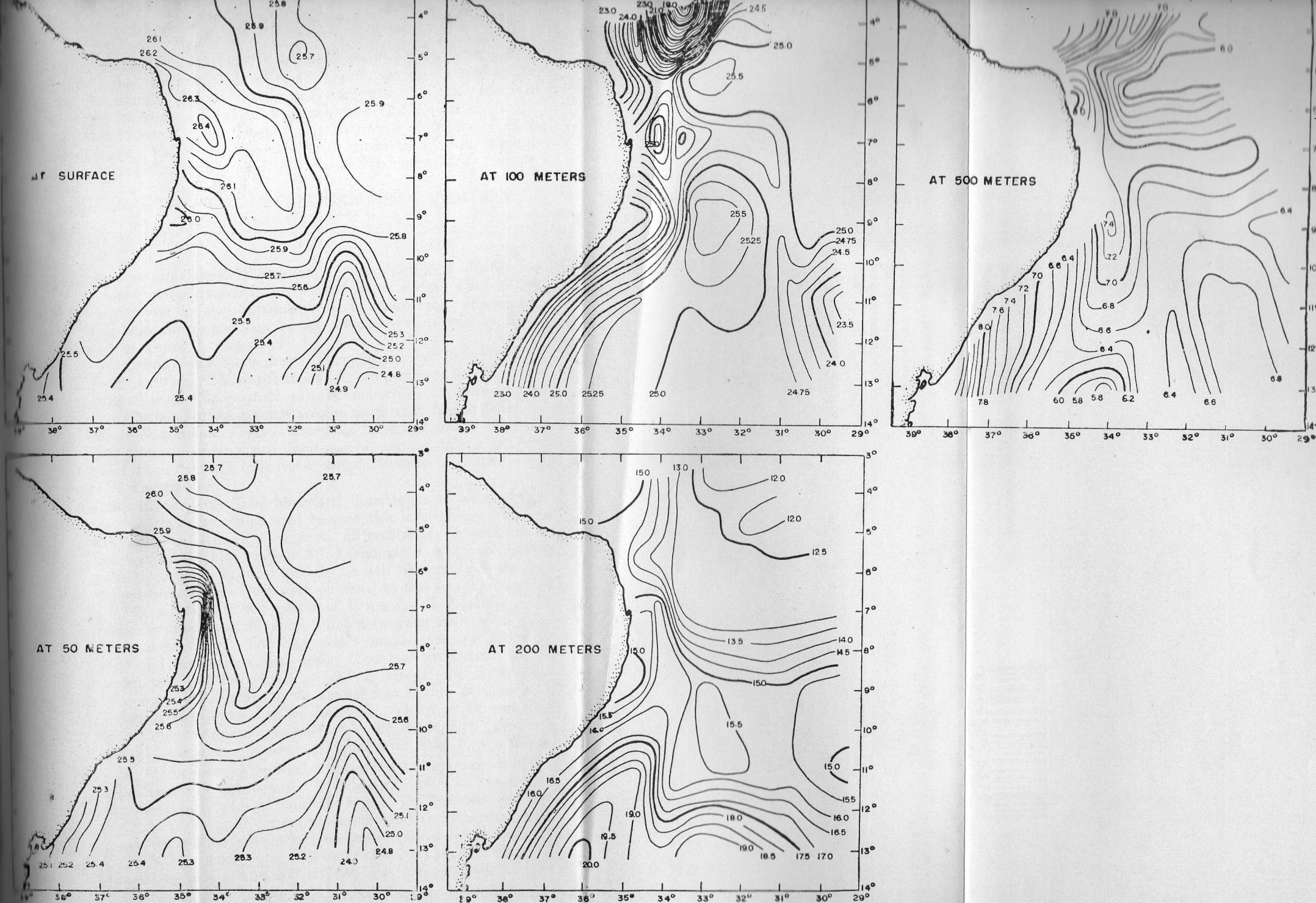


Fig. 2: Horizontal distribution of water temperature at various levels
Distribuição horizontal da temperatura da água em diversos níveis
Répartition horizontale de la temperature de l'eau à des niveaux differents

2 ml of perchloric acid (70%) were added to 25 ml of sea water in a beaker, the sample was then heated gently on an electric heater until the fuming stopped shortly after becoming dry. In order to get rid of arsenate, 1,5 ml of hydrochloric acid were added to the above dried sample, then heating was continued until the fuming stopped again. The sample was then made up to 50 ml with distilled water, and estimation was made by the molybdenum blue method.

GENERAL PHYSICAL OCEANOGRAPHIC CONDITION

TEMPERATURE

There are only small differences in the horizontal distribution of the water temperatures in the stratosphere deeper than 800m, nevertheless those in the troposphere have considerable differences. The horizontal distributions of water temperature at various levels are shown as figure 2, respectively.

At the surface and 50 m level: There appears to be an obvious resemblance between the distributions of temperature at these two levels. Some noticeable features can be derived from these figures as follows; The band of warm-water sweeps southward from offshore of the Cape of São Roque. This warm-water band encounters with the cool-water tongue occuping the south-eastern part in this area. The warm-water band and the cool-water tongue involve a relative large gradient of temperature.

At the 100 m level: The horizontal distribution of water temperature at this level was complicated because this level corresponded to the thermocline surface. The regional difference of temperature at this level was rather high (about 8°C), though it was only within 2°C in the layer above 50 m. Especially, it will be noted that the low water temperatures at this level were obtained in the area of the ridge near St. 389, adjacent to the Island of Fernando de Noronha. The temperature distribution at this level differed fundamentally from those at the layer above 50 m. The high water temperature was found in the central and the north-eastern areas. The low temperature at the south-eastern part was recognized as well as that at the layer above 50 m. The water temperature in the coastal area at this level, in general, was considerably lower than in the ocean. This may be associated with the fact that the thermocline surface in the coastal area (shown in Fig. 4 and 11) exists in a somewhat higher layer than in the ocean.

At the 200 m level: A noticeable feature is the appearance of the zone of cool-water in north-eastern part and the zone of warm-water in the southern part, with a transition zone lying between the two. From both sides, the north-eastern cool-water and the southern warm-water push toward the transition zone with relative larger gradient.

At the 500 m level: The cool-water zone, which was found in the north-eastern part at the 200 m level was still recognized at this

level. An outstanding feature of the temperature distribution is that the higher temperature was obtained in the area near the coast.

In the vertical profile of temperature, as will be readily seen from Fig. 4, the profile curve consists of the different parts; the upper mixed layer, the thermocline layer, and the weak gradient layer.

SALINITY

The horizontal distribution of salinity at various levels are shown in Fig. 3.

At the surface and the 50 *m level*: In general, the salinity at these levels in this area increase gradually with increasing latitude, and the horizontal gradient is somewhat sharp. Furthermore, a great resemblance appears between the distributions of the temperature and the salinity at these levels. It is notable that the low-salinity zone having the slight horizontal gradient was found in the north-eastern part of the area investigated.

At the 100 *m level and* 200 *m level*: The salinity distribution at the 100 m level differed remarkably from the temperature distribution at the same level. The horizontal distribution of salinity at these levels resembled each other in the feature as well as those of temperature at the 200 m level. Namely, there were the low-salinity zone in the north-eastern part, the high salinity zone in the southern part and the transition zone at the central part.

At the 500 *m level*: In general, there was found only a small horizontal difference in the salinity distribution at this level.

In the vertical profile of salinity, Fig. 4, it is seen that the curve is divided into five parts; namely, the upper layer, the salinity maximum layer, the large salinity gradient layer, the salinity minimum layer and the layer of weak salinity gradient. In general, the salinity maximum layer (36.41°/oo on average) is found at approximate 100m, corresponding to the discontinuity surface as will be seen from the average values of every station in Fig. 4. The vertical salinity gradient from the surface to maximum salinity is exceedingly high generally. The discontinuity layer of salinity existed from 100 to 300 m and the values of salinity in this layer varied from 36.41°/oo at 100m to 34.87°/oo at 300m with a large gradient.

The minimum salinity (34.44°/oo) was obtained at about 800m, at which depth the water corresponded approximately to the Antarctic Intermediate Water. There was only small differences in the vertical distribution of salinity deeper than about 1,500m.

TEMPERATURE-SALINITY (T-S) RELATIONSHIP

In order to further understand the distribution of temperature and salinity, the temperature-salinity diagram characterizing water masses was shown in Fig. 5. In the T-S diagram, the mean curve of

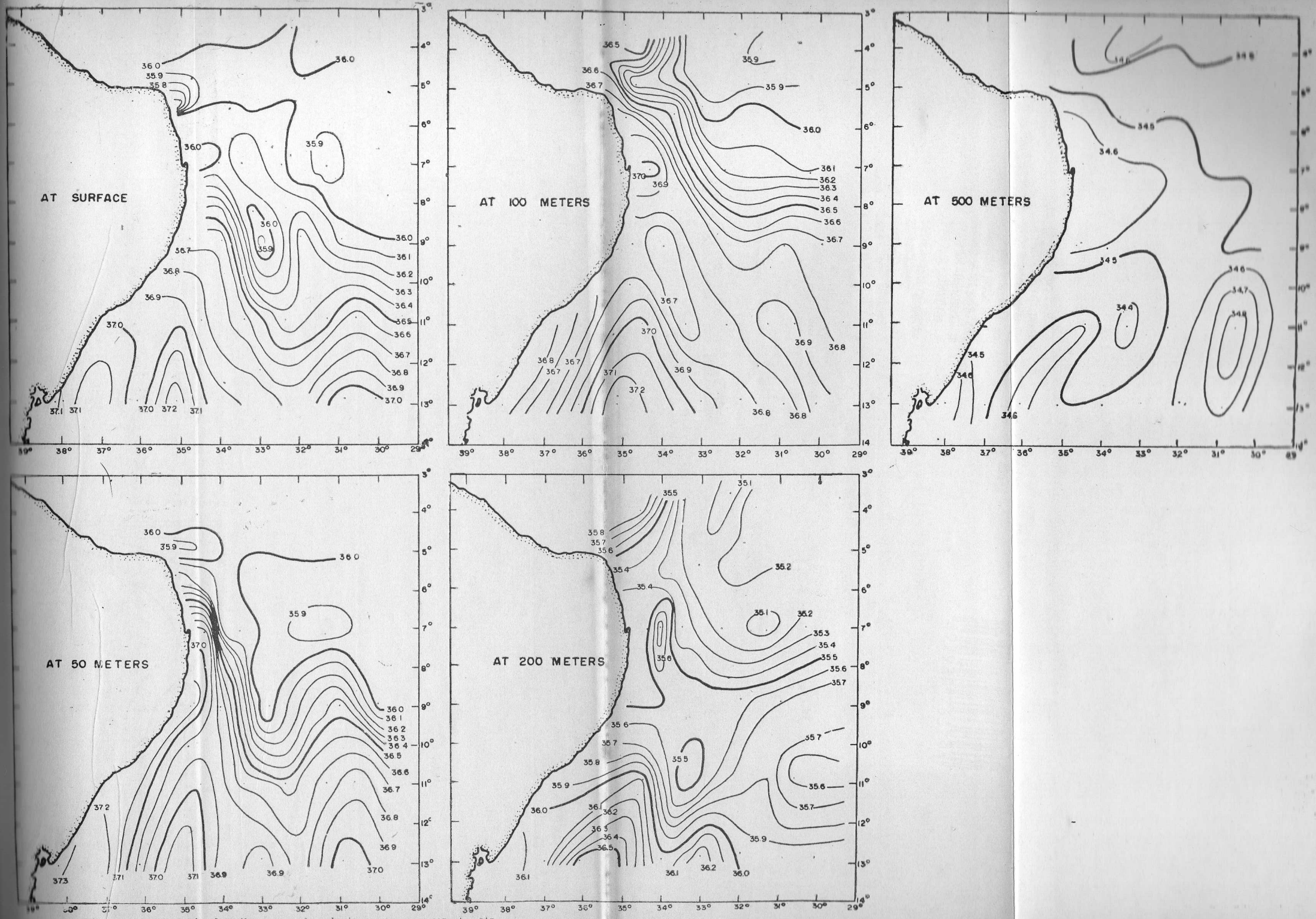


Fig. 3: Horizontal distribution of salinity at various levels
Distribuição horizontal da salinidade em diversos níveis
Répartition horizontale de la salinité à des niveaux différents

South Atlantic Water is shown as reference curve after Sverdrup (1946).

In the T-S diagram in Fig. 5, it is clearly seen that below about the 100-200 m level in this area, generally well-defined water masses are present in a good agreement with the mean curve of South Atlantic Water of Sverdrup, and tow maxima and one minimum are found in the vertical distribution of salinity. It can be said that the water in this area has the typical properties of water masses in the South Atlantic Ocean. Furthermore, it will be noted from Fig. 5 that the temperature and the salinity between the 200 and 400m level increase with increasing latitude.

The following well-defined water masses are known to exist in the South Atlantic Ocean, namely; (1) the South Atlantic Central Water originating from sinking surface water in the region of the subtropical convergence between about 30° and 40°S, and flowing north between depth of 100-200 m and 600-700 m., (2) the Antarctic Intermediate Water flowing north below the Central Water in a layer which is about 750 m thick, (3) below the Antarctic Intermediate Water, the North Atlantic Deep Water flowing south, and (4) below this North Atlantic Deep Water, the Antarctic Bottom Water moving north.

At the sea surface as well as in the upper mixed layer, water temperature is primarily affected by such meteorological conditions as heating, cooling, evaporation, and local wind. Accordingly, the characteristic properties of the surface temperature distribution are not so clear as that in deeper layers where water temperature is essentially associated with water-mass properties and water circulation. In the layer above 100 m, however, some noticeable features can be observed, as will be easily seen from Fig. 6, namely, (1) the upper water temperatures in this area show a tendency to increase with decreasing latitude, though the horizontal gradient is very slight, (2) contrary to the water temperature, the upper salinity decreases gradually with decreasing latitude and (3) the characteristic properties of the coastal area where the thermocline surface lies at a rather high level, often show high vertical variation in comparison with those in the deep water area.

VERTICAL AND HORIZONTAL DISTRIBUTION OF OXYGEN

The horizontal distribution of oxygen at several levels are shown in Fig. 7.

In general, the oxygen content in the layer less than 50 m and in the layer deeper than about 1.000m showed only small regional difference. However, there were great differences in the regional distribution of oxygen in the other layers, especially a large difference was found at about 400 m, corresponding to the oxygen minimum layer. In these layers, there was generally found a tendency for oxygen to increase from the coast to the deeper part of the ocean. In the

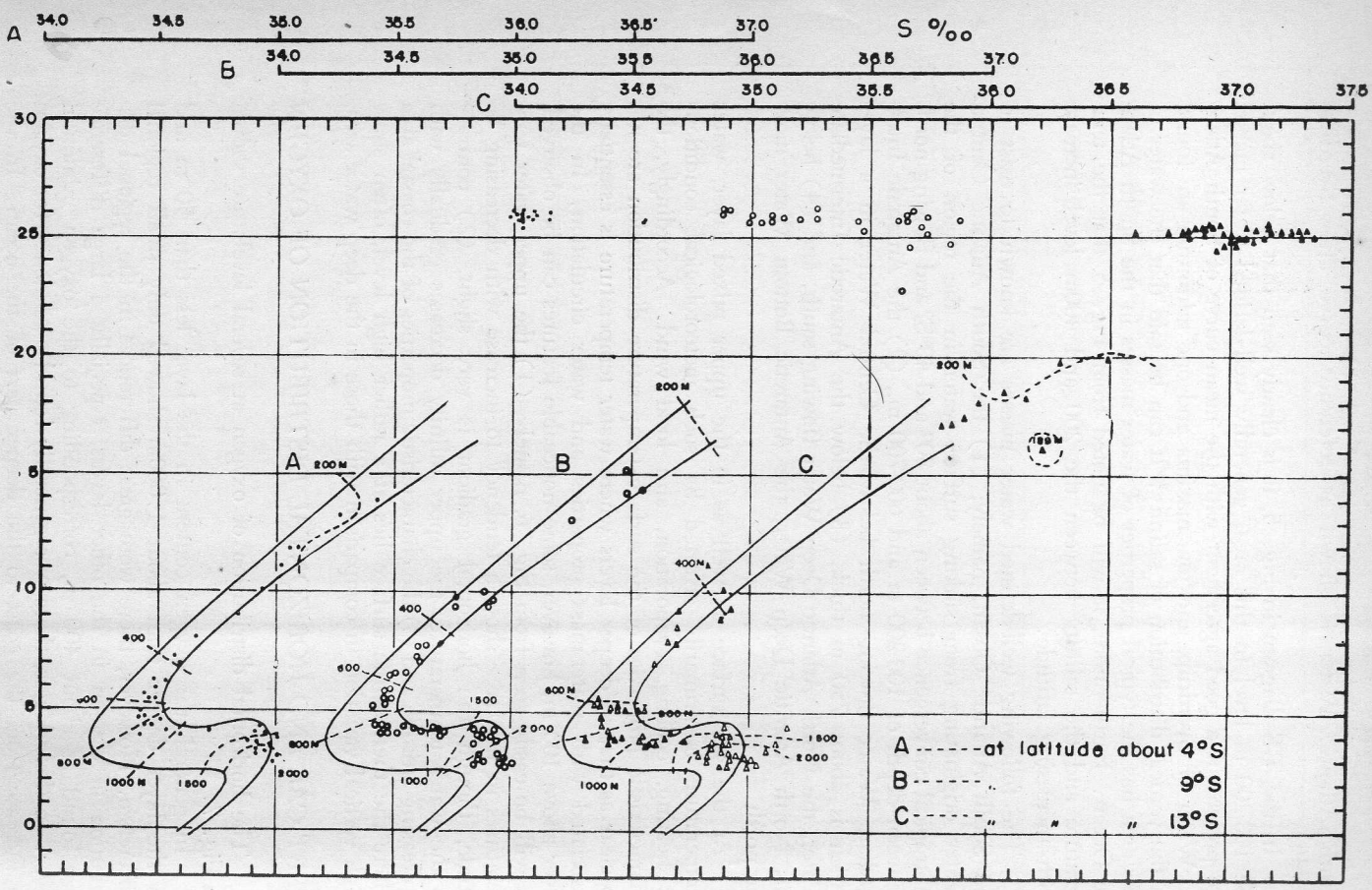


Fig. 5: Temperature — salinity (T—S) diagram in whole water column
Diagrama da temperatura — salinidade (T—S) na coluna total de água

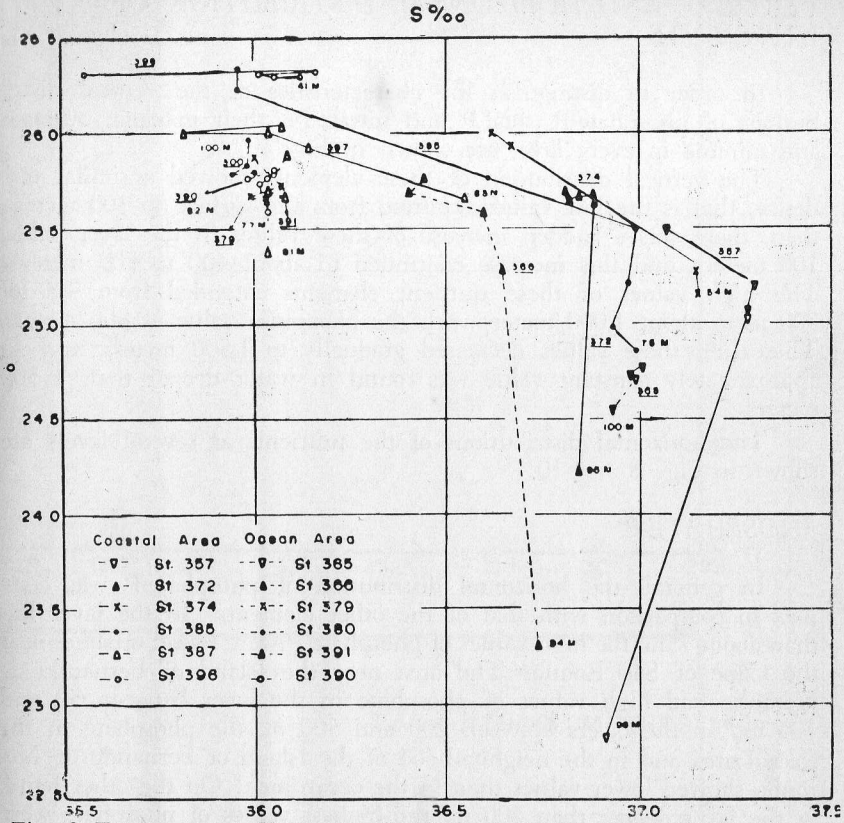


Fig. 6: Temperature-salinity (T—S) diagram in the upper layer
Diagrama de temperatura-salinidade (T—S) na camada superficial
Diagramme température-salinité (T—S) en surface

layer between about 200m and 600 or more meters, the lowest values for oxygen were obtained in the southern part.

In the coastal zone, it is interesting to note the high value of oxygen distributed vertically to a depth of several hundred meters. The reason for this will discussed later on. It was also notable that the oxygen content in the 75m to 100 m layer at St. 389 showed rather low values in comparison with the other stations. As St. 389 is located in the vicinity of the ridge, this indicates that there is upwelling in this zone, judging from water temperature, nutrients etc.

In the vertical distribution of oxygen values, the curve in Fig. 4 clearly shows five different parts, namely, the oxygen rich layer at the sea surface, the oxygen decreasing layer with high gradient (100-400m), the oxygen minimum layer (about 400-500m), the oxygen increasing layer with high gradient (500-2,000 m), and the oxygen rich layer (below 2,000 m).

VERTICAL AND HORIZONTAL DISTRIBUTION OF NUTRIENTS

In order to distinguish the characteristics of the vertical distributions of phosphate-P, total-P and nitrate-N, their maxima, averages and minima in every layer are shown in Fig. 4.

The vertical distribution of these elements showed a similar tendency, that is the low values occurred from the surface to 100 meters, then, there was a sudden increase of these values in the layer below 100 meters, and this increase continued to about 400 to 500 meters. The high values of these nutrient elements extended from 400 or 500 m to about 1,000 meters with the maximum value at 800 meters. Thereafter, these values decreased gradually to 1,500 meters, and an approximately constant value was found in water deeper than 1.500 meters.

The horizontal distributions of the nutrients at several levels are shown in Fig. 8 — 10.

PHOSPHATE-P

In general, the horizontal distribution of phosphate-P was complex in comparison with that of the other elements. In the layer less than about 75m, the high values of phosphate-P were found offshore near the Cape of São Roque. The area near the Island of Fernando de Noronha had high values of phosphate in the layer between 50 and 100 m. In the layers between 200 and 500 m, the phosphate in the coastal area and in the neighborhood of the Island of Fernando de Noronha showed lower values than in the ocean area. On the other hand, in the layer deeper than 500 m, the highest values of phosphate were obtained in the area between 6°S. and 9°S., except for the area close to the Island of Fernando de Noronha and offshore from the Cape of São Roque.

Although the phosphate from the surface to 100 m showed low values, the phosphate in the layer deeper than 100 m showed remarkably high values, with the maximum value (2.29 μg-at/L) at 800 m. Then, the phosphate decreased slightly below 1,500 m.

TOTAL PHOSPHORUS

The horizontal distribution of the total phosphorus showed a somewhat different pattern than that of phosphate. The total phosphorus offshore of the Cape of São Roque showed low values through the whole water column, while the phosphate-P in this area was high. Furthermore low values of total phosphorus were obtained in the south-eastern part of this area. As a whole, it is remarkable that the wide and long area from north-east to south-west in the area investigated showed high values of total phosphorus through the whole water column,

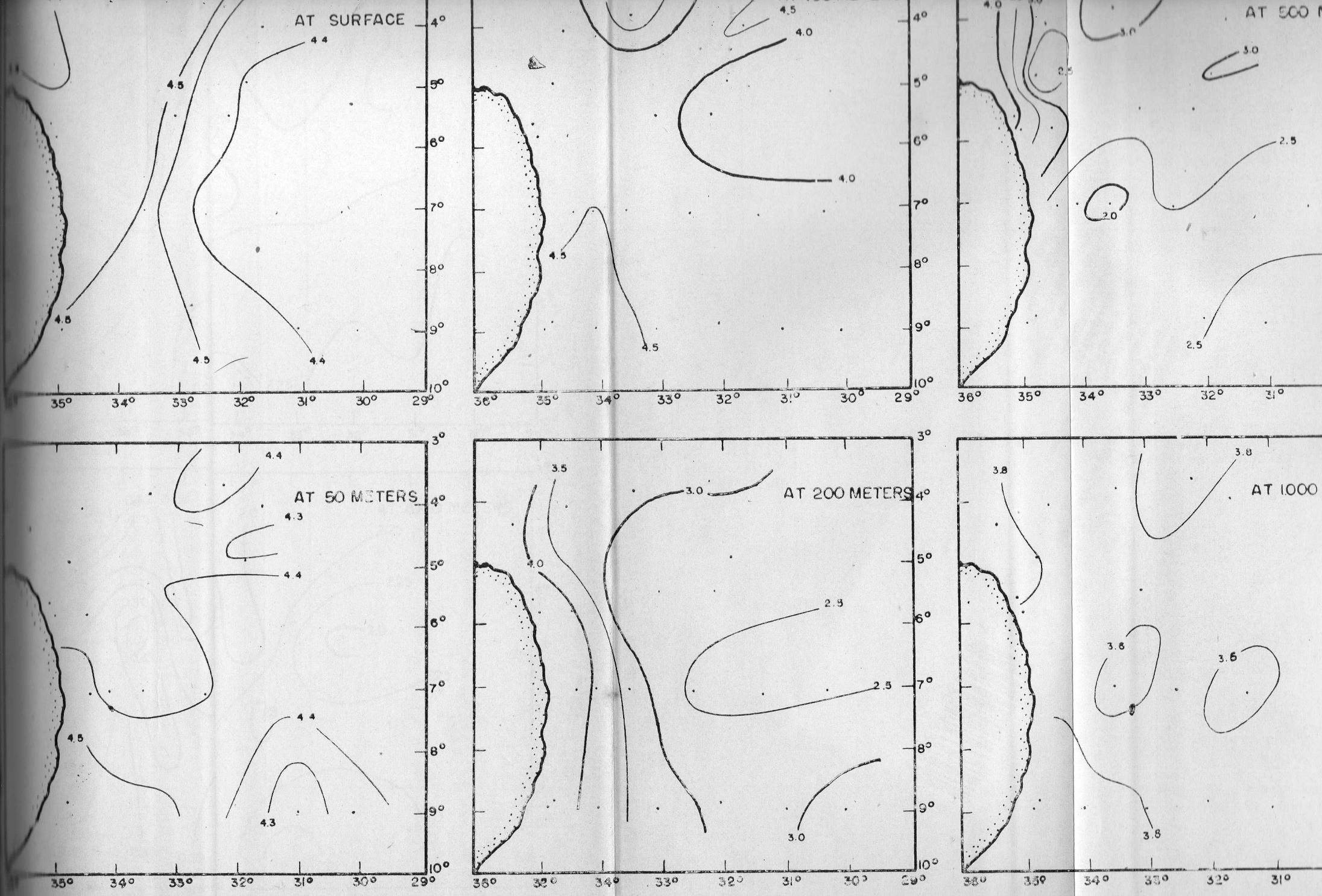
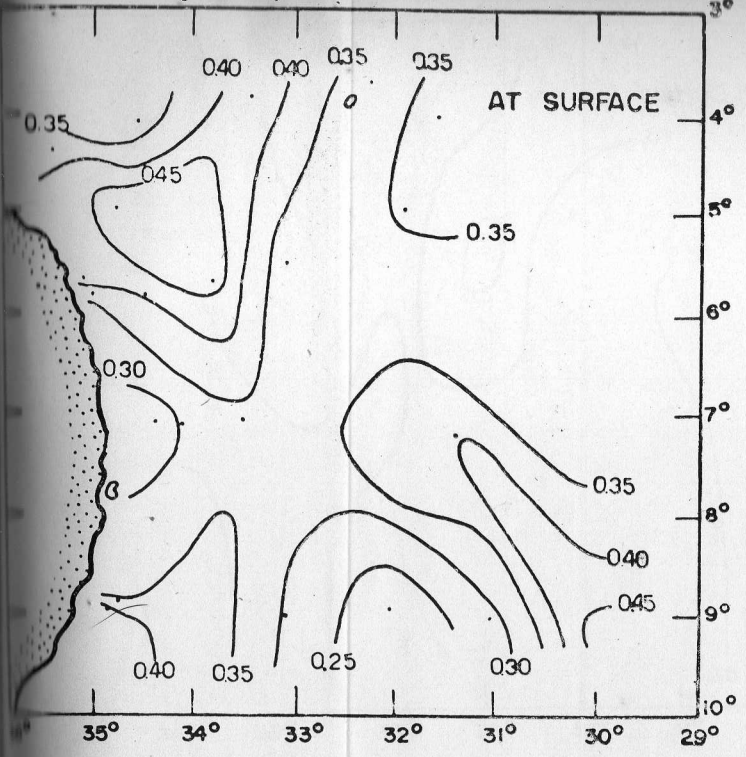


Fig. 7: Horizontal distribution of oxygen at various levels
Distribuição horizontal de oxigênio em vários níveis
Répartition horizontale de l'oxygene à différents niveaux


AT SURFACE
0.40
0.40
0.35
0.35
0.35
0.45
0.35
0.30
0.35
0.40
0.45
0.40
0.35
0.25
0.30
3°
4°
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7°
8°
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35°
34°
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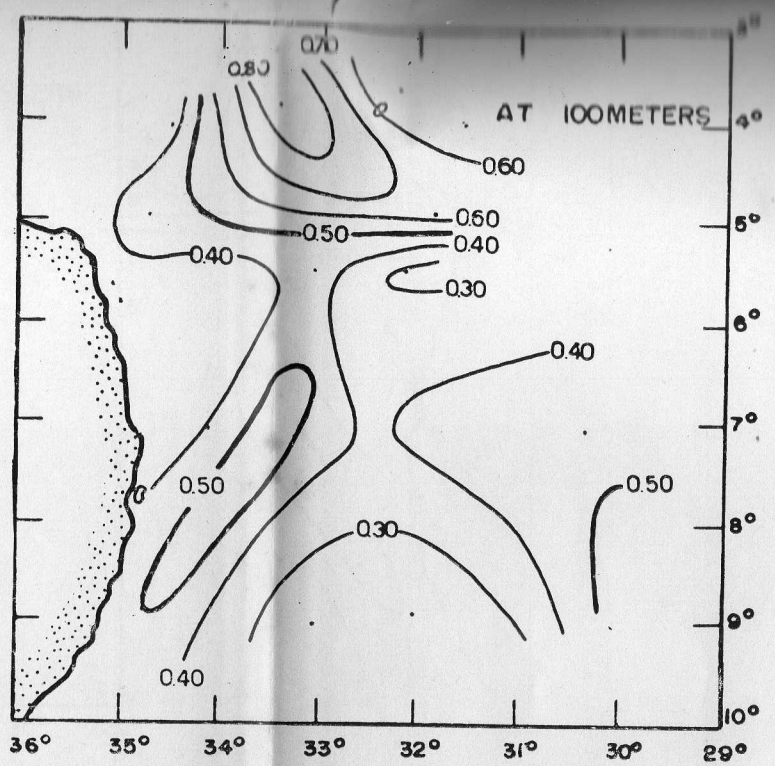
32°
31°
30°
29°


AT 100METERS
0.80
0.70
0.60
0.60
0.50
0.40
0.30
0.40
0.50
0.50
0.30
0.40
3°
4°
5°
6°
7°
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9°
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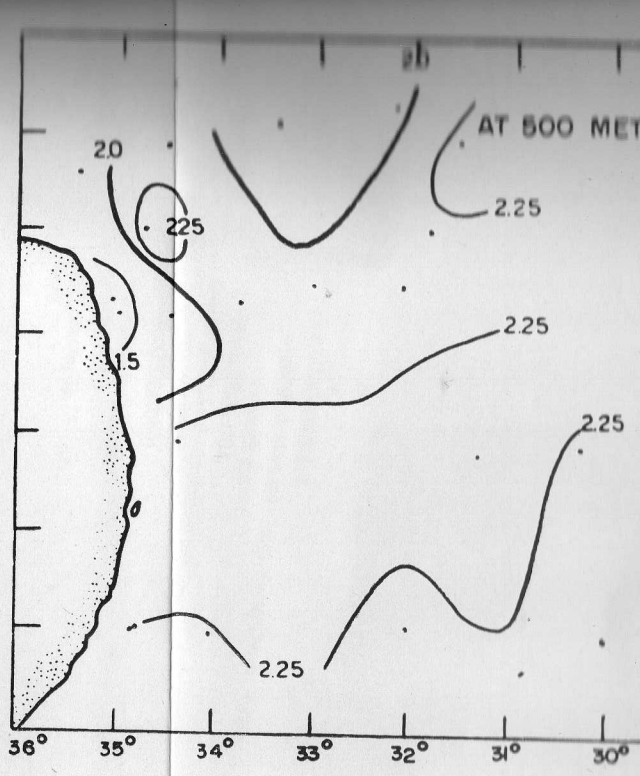
36°
35°
34°
33°
32°
31°
30°
29°


AT 500 MET
2.0
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2.25
1.5
2.25
2.25
2.25
36°
35°
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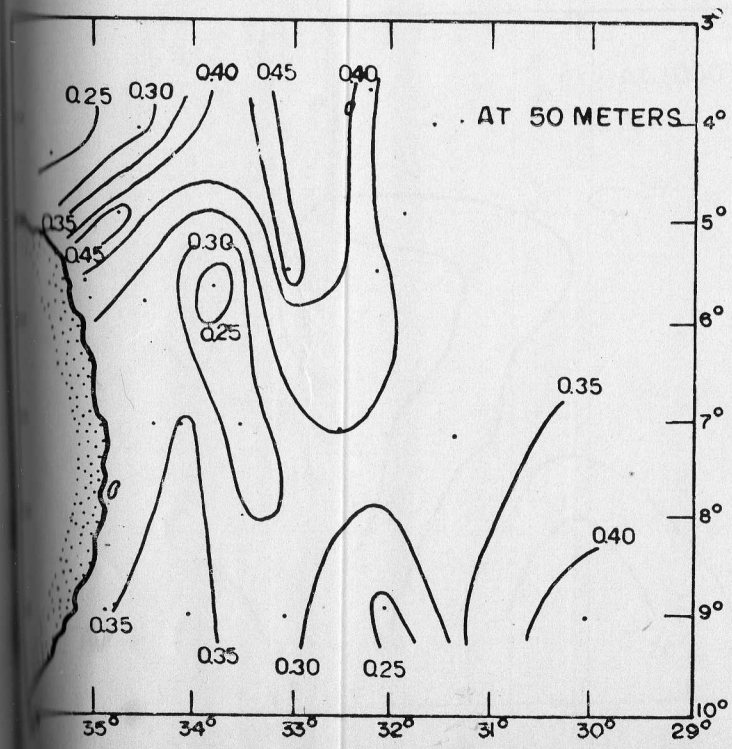
32°
31°
30°


AT 50 METERS
0.25
0.30
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0.35
0.45
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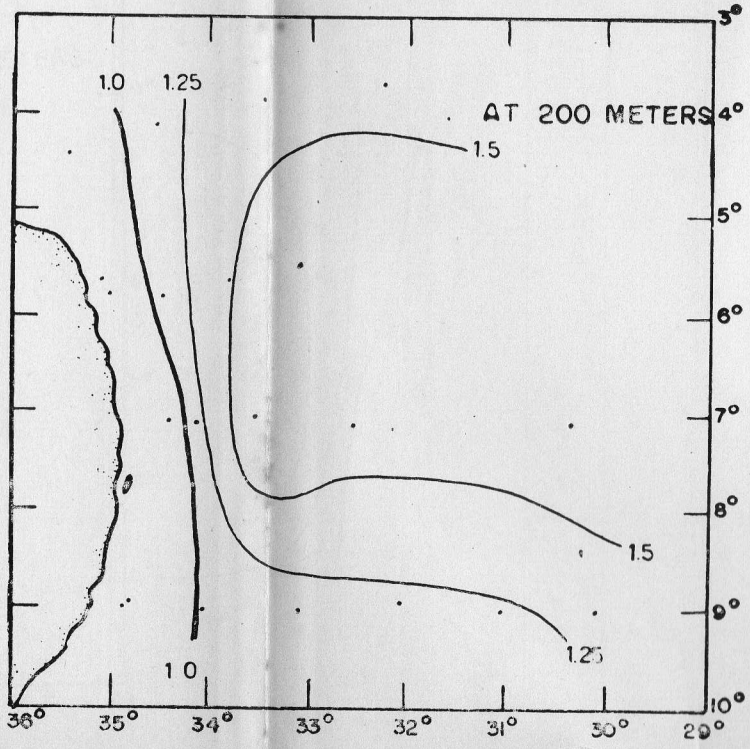
AT 200 METERS
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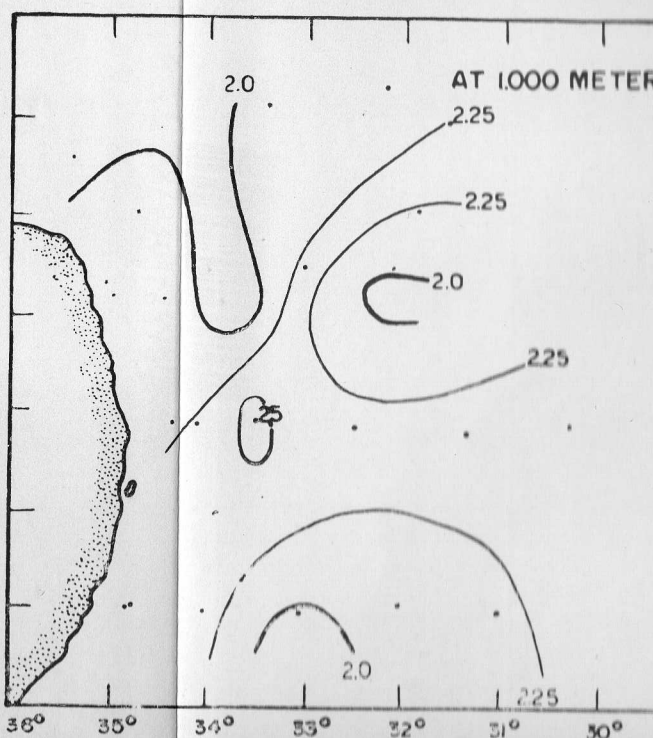
AT 1.000 METER
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36°
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32°
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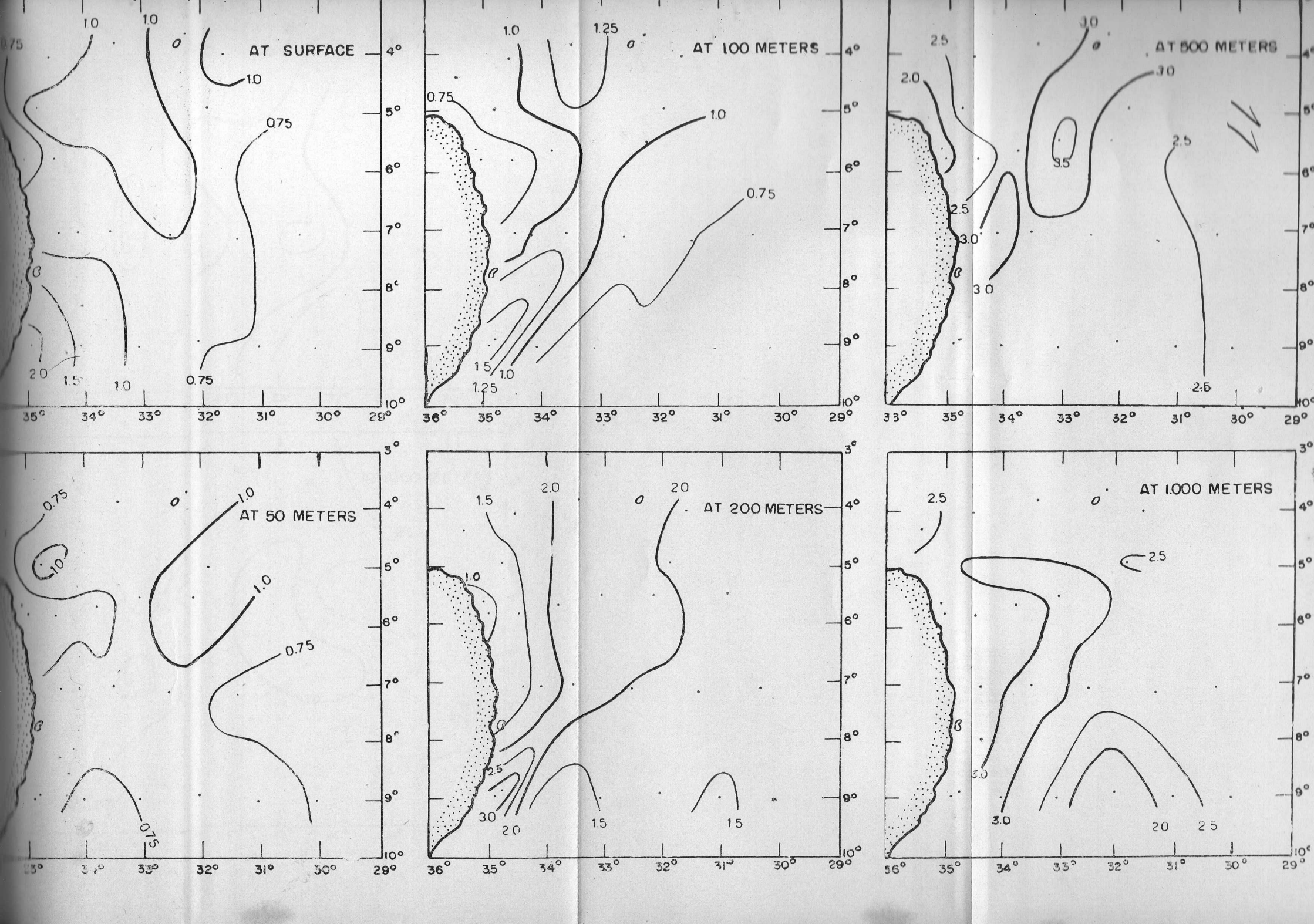

AT SURFACE
AT 100 METERS
AT 500 METERS
AT 50 METERS
AT 200 METERS
AT 1,000 METERS

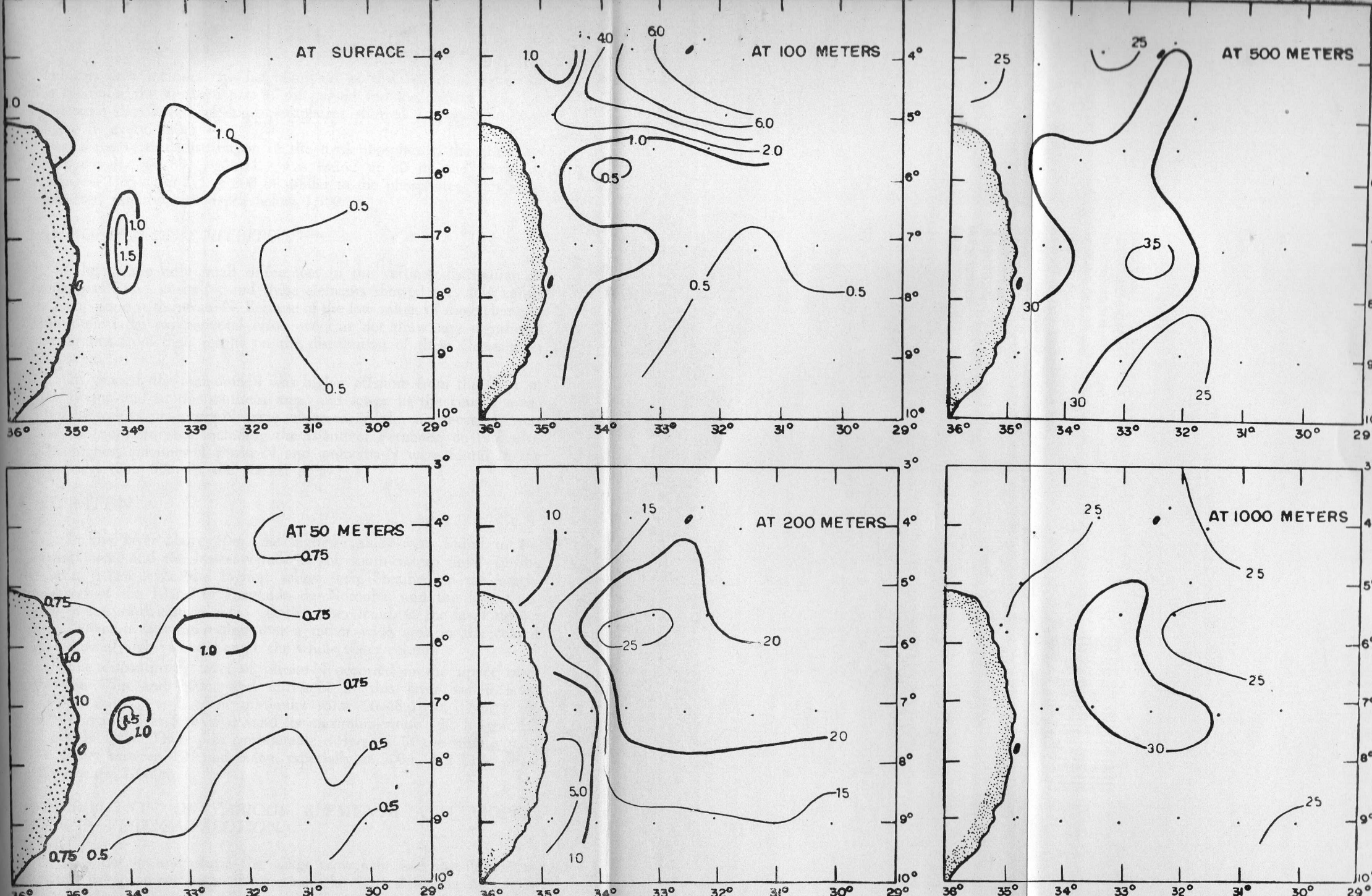


Fig. 10: Horizontal distribution of nitrate-N at various levels
Distribuição horizontal de nitrato-N em vários níveis
Répartition horizontale du nitrate-N à des niveaux différents

and this area includes the neighborhood of the Island of Fernando de Noronha, the southern part of the coastal and the central area. The horizontal distribution of total phosphorus showed an analogous tendency in every layer.

In the vertical distribution of the total phosphorus, the minimum average value (0.83 μg at/L) was found at 50 m, the maximum average (2.85 μg-at/L) at 800 m similar to the phosphate. This value decreased slightly with depth below 1,500 m.

AMMONIA-N AND NITRITE-N

There were only small differences in the vertical distribution of ammonia-N and nitrite-N, and these elements showed very low values in comparison with nitrate-N. Because of the low values of these elements and their large experimental error, we can not draw any significant conclusions from their results on the distribution of these elements in this area.

In general, the ammonia-N was higher offshore from the Cape of São Roque and in the southern area, and lower in the central area. Highest values of nitrite-N were observed in the north-eastern area and the northern area including the Island of Fernando de Noronha. The highest amounts of nitrite-N and ammonia-N were found in the layer less than 50m in the coastal area.

NITRATE-N

In the layer above 50m, the highest values were found in the central area, and the lowest values in the south-eastern area. In the 75m to 100m layer, the highest values were obtained in the neighborhood of the Island of Fernando de Noronha, and the lowest valeus in the south-eastern area. On the other hand, in the layer deeper than 200m, it was interesting that a rather wide area in the coastal part showed high values through the whole water column.

The discontinuity layer of nitrate-N occurred in the upper layer between 75m and 300m, and nitrate-N in this layer varied from 0.87 to 23.3 μg-at/L. The minimum value (0.68 μg-at/L) of nitrate-N was found at 50m layer, and its maximum value (30.1 μg-at/L) at 800 m layer. There was considerable difference in the nitrate-N in the layers between 100 and 800m, especially at 300m, but little difference below 1.000m.

DISTRIBUTION OF VARIOUS ELEMENTS AND PROPERTIES IN VERTICAL SECTION

In order to understand the water movement and distribution of various water properties in the section, the vertical section of temperature, salinity, density (σt) oxygen and nutritive elements are shown

in Fig. 11-17. These vertical sections include four sections, namely: A, B, and C sections running from the coast eastward at latitude about 4°S (A), 9°S (B), and 13°S (C), respectively, and D-section crossing from the north to south. In the distributions of temperature, salinity and σt in vertical sections only the layer above 500m were shown in figures 11-13, because of the small horizontal differences of the water properties in the layers below 500m.

A discontinuity surface of water properties existed at 75-100m. The thermocline surface was found at about 100m in the deep water area. In general, the discontinuity surface of water properties in the coastal area lies at a higher level than those in the deep water area. The discontinuity layer of water properties in the northern area have a remarkably sharp gradient and are limited to a relative narrow layer. On the other hand, in the southern area, these discontinuity layers have a weak gradient and extend to relatively deeper points. In the area nearest the coast, as will be seen from A-C sections, it is noteworthy that the high concentrations of oxygen were observed vertically to the deepest layer without much difference, and a layer of minimum oxygen was not found in this region. Furthermore, although the nutrients on these sections are not so distinct as the oxygen, their isolines showed somewhat the same tendency toward dropping in the same coastal area. On the other hand, the vertical profiles of temperature, salinity (σt) did not agree with that of oxygen. Although the features of oxygen and nutrients in these sections will lead us to expect the existence of convergency in this area judging from the direction toward the coast of current and wind, we can not always draw such a conclusion from the profiles of temperature, salinity and density (σt), as will be seen in Figs. 11-13.

Consequently the reason of the above vertical feature of oxygen and nutrients may be attributable to biological factors.

In section A, the remarkable feature on distribution of temperature, salinity, oxygen and nutritive elements was found on the St. 389, namely, there is a definite increase of the isolines of every elements. Such an increase of the isolines may indicate the existence of upwelling of the deeper water characterized by low temperature, low salinity, low oxygen and high nutrients.

Existence of the ridge band extending toward east, may influence the water characteristics belw 100m in the areas both north and south of the ridge band. Unfortunately as we have not the data in the area north of the ridge, this problem can not be resolved at this moment.

NITROGEN PHOSPHORUS RATIO, N/P.

The nitrogen-phosphorus ratio, N/P in sea water has been estimated by many workers, with the ratio in plankton, from the biochemical viewpoint. Cooper (1938) proposed a modified nitrogen-phos-

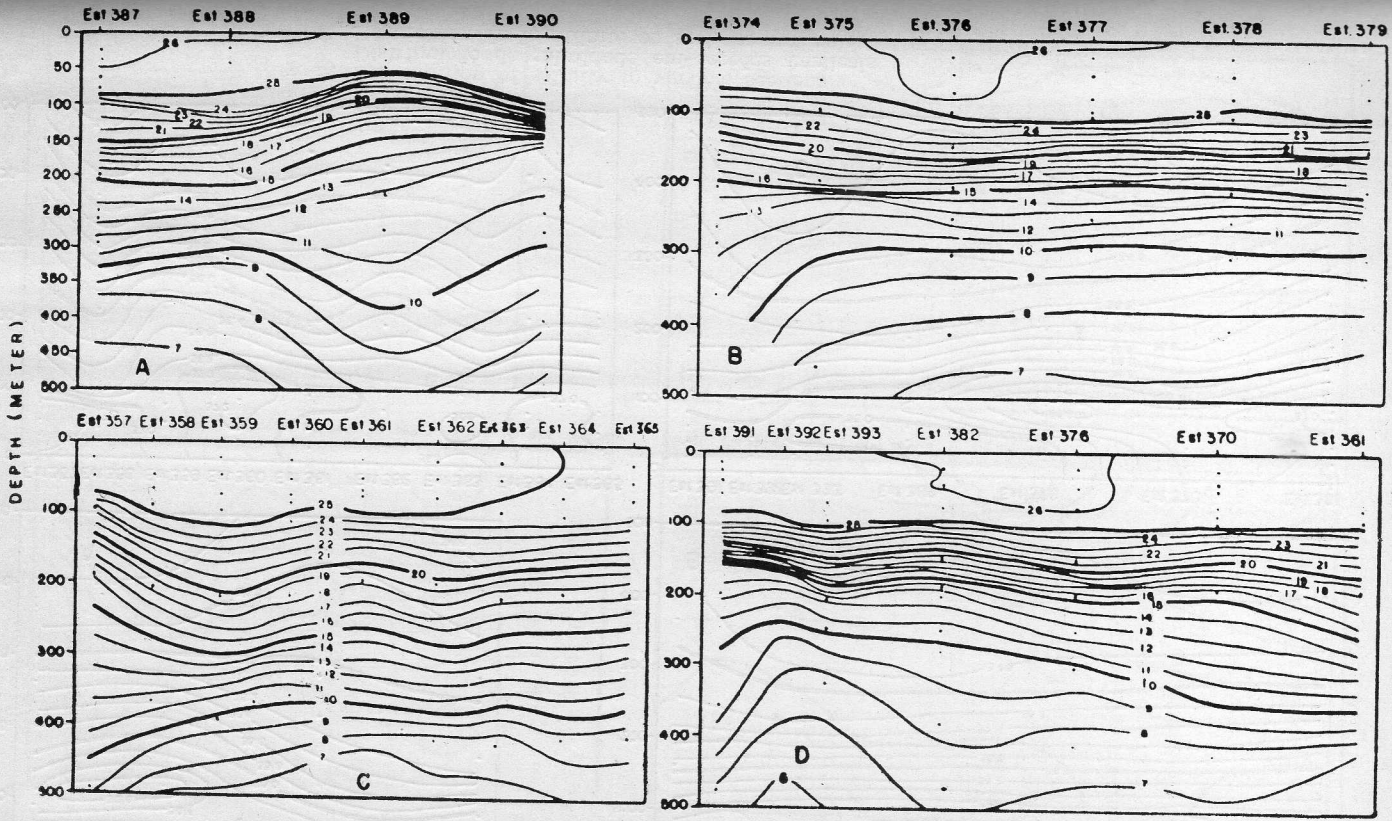


Fig. 11: Distribution of water temperature in vertical sections
Distribuição da temperatura da água em secções verticais
Répartition de la température de l'eau en sections verticales

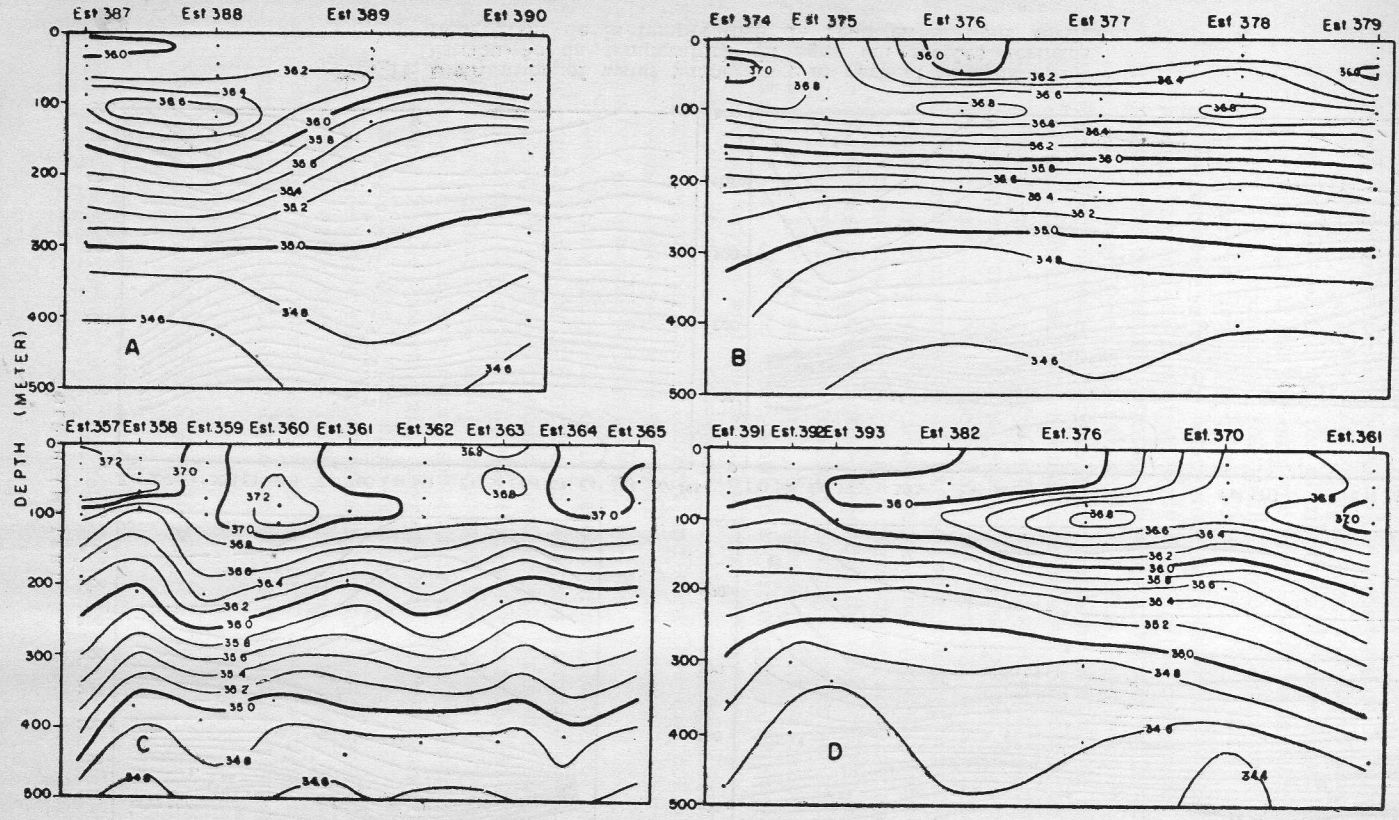


Fig. 12: Distribuition of salinity in vertical sections
Distribuição do salinidade em secções varticais
Répartition de la salinité en sections verticales

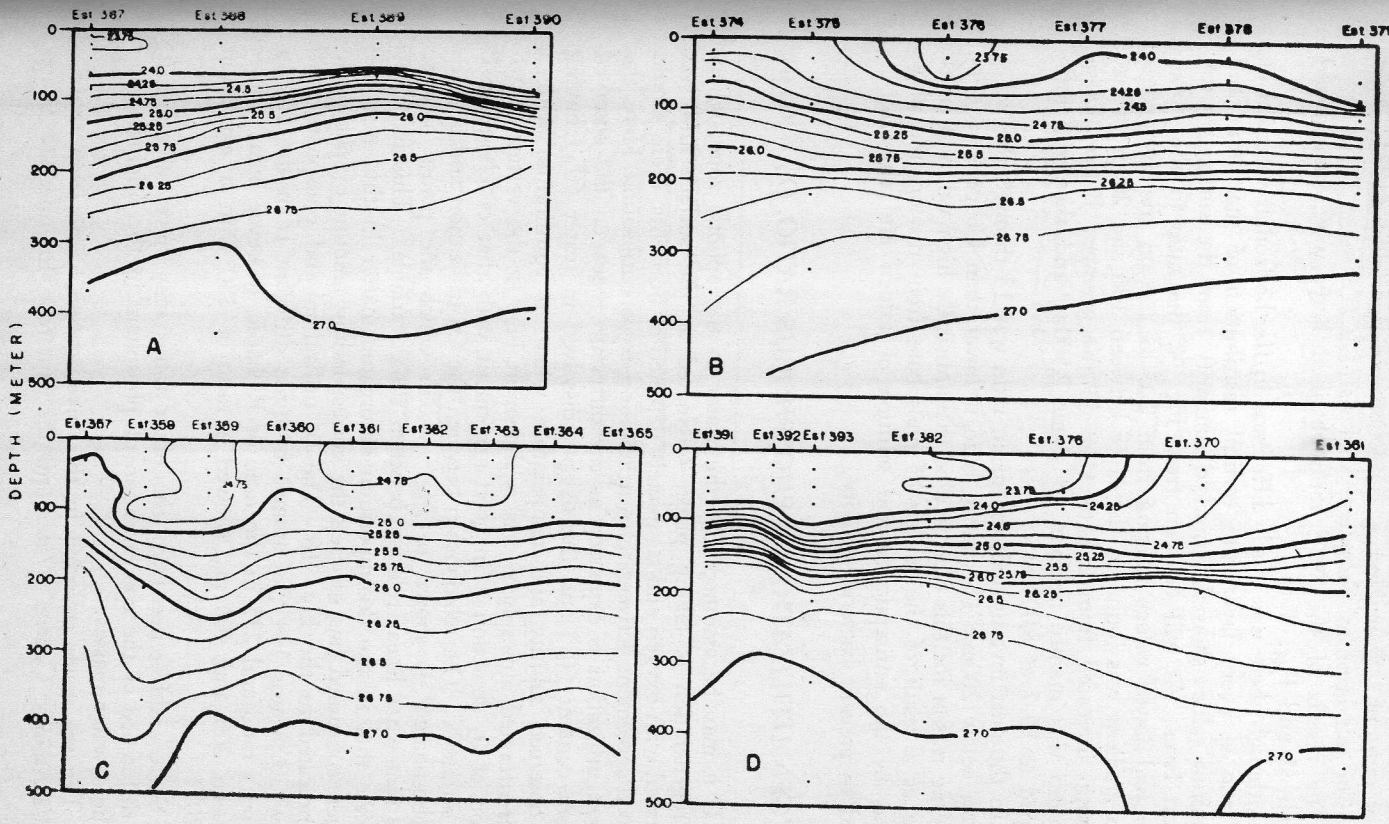


Fig. 13: Distribution of density (σ t) in vertical sections
Distribuição da densidade (σ t) em secções verticais
Répartition de la densité (σ t) en sections verticales

phorus ratio of 15, making a correction on Redfield's (1934) ratio of 20 for salt error in phosphate analysis.

The results of the N/P ratio obtained here, were summarized in Tab. 1 and Fig. 4

Although there was much difference in the horizontal variation of this ratio at every layer, the vertical distribution of maximum and minumum values showed a marked similarity from the surface to the deepest layer. As will be seen from Fig. 4, the ratio in the upper 100m had lower values ranging from 2.0 to 2.6 on the average, a sharp gradient was found in the layer between 100 and 200m. Here, the ratio increased from 2.6 to 11.2 on the average. Below 300m, the ratio was mainly uniform to about 2,500m, and then the ratio dropped to 10.7 at 3,000m.

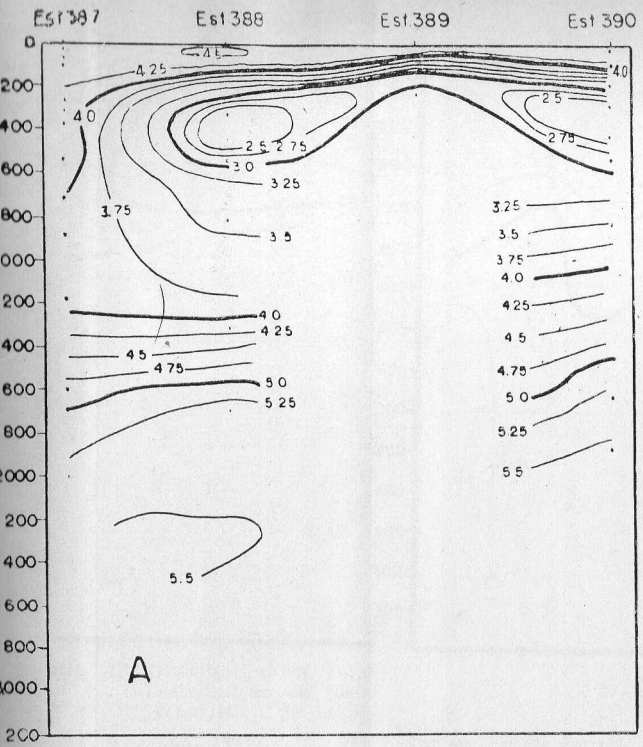
In the area investigated, the mean ratio was 13 through the water column below 200m. This mean ratio is lower than Cooper's ratio of 15. One reason for this fact may be the unusually high value of phosphate as a result of the release of phosphate from the organic phosphorus by the antiseptic (mixed solution of toluen and chloroform) added to prevent bacterial activity.

OXYGEN UTILIZATION – PHOSPHORUS RATIO, $O'_2 - O_2/P$.

If it may be assumed that the water in the aphotic zone, where the regeneration is taking place, originated at the surface and was saturated with oxygen and completely depleted of nutrients, there should be good agreement between the nutrients and oxygen utilization. Here, the oxygen utilization is expressed as the difference between the observed oxygen content (0_2) and the oxygen dissolved in water ($0'_2$) having the observed salinity and temperature when in equilibrium with a water-saturated atmosphere. As is shown in Fig. 4, the vertical distribution of 0_2 depletion is in good agreement with that of phosphate-P and nitrate-N. The relationship between the O_2 utilization and amount of phosphate-P is shown in Fig. 18, in which the points increase with somewhat linear relation between those variables. This fact may indicate that in the decomposition of organic matter in this area, the oxygen consumed has set free the corresponding amount of phosphate as indicated in the Fig. 18. The 0_2 utilization and phosphate ratio below 200m was 144 (by atoms) in quite different from the 180 in Cooper's ratio and 235 in the ratio of Richards, however many values between 200 and 400 m. showed a ratio of 180 with a maximum of 205.

Such a difference from the other ratios may have reference to the difference of the concentration of phosphate in the original water of these water masses.

The sea water collected in this investigation, came from the the South Atlantic Central Water and the Antarctic Intermediate Water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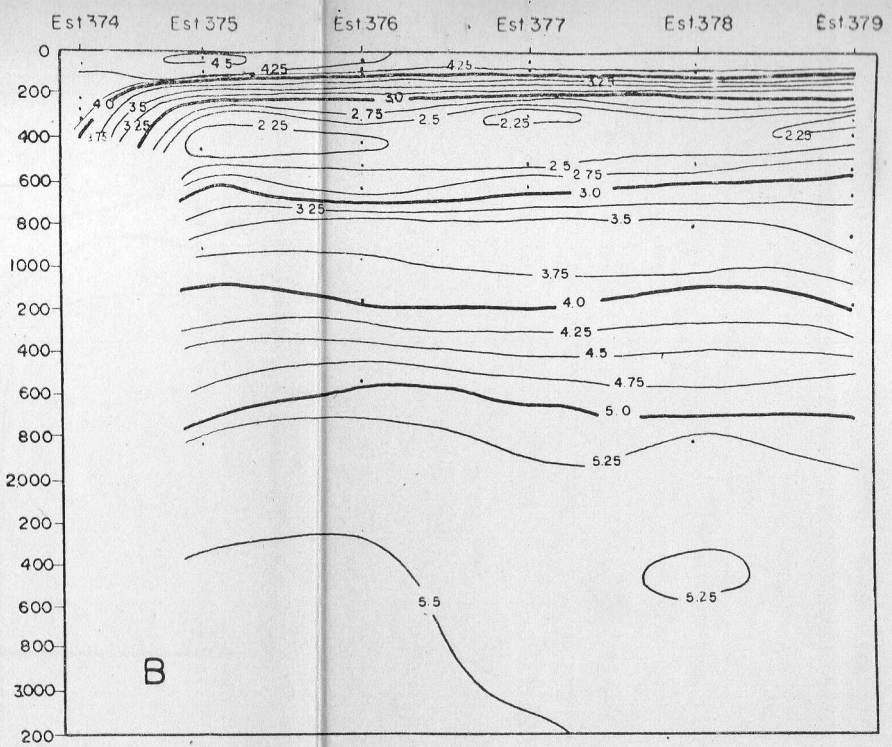
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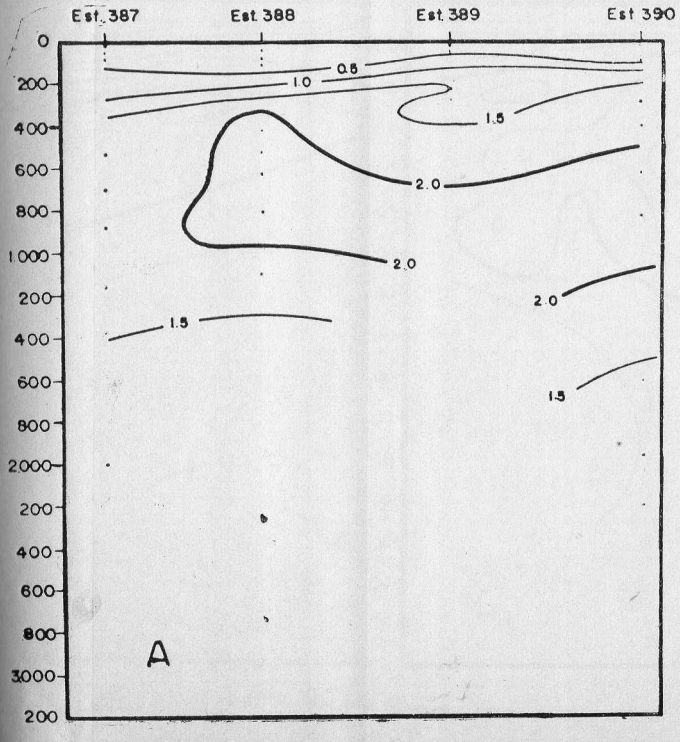
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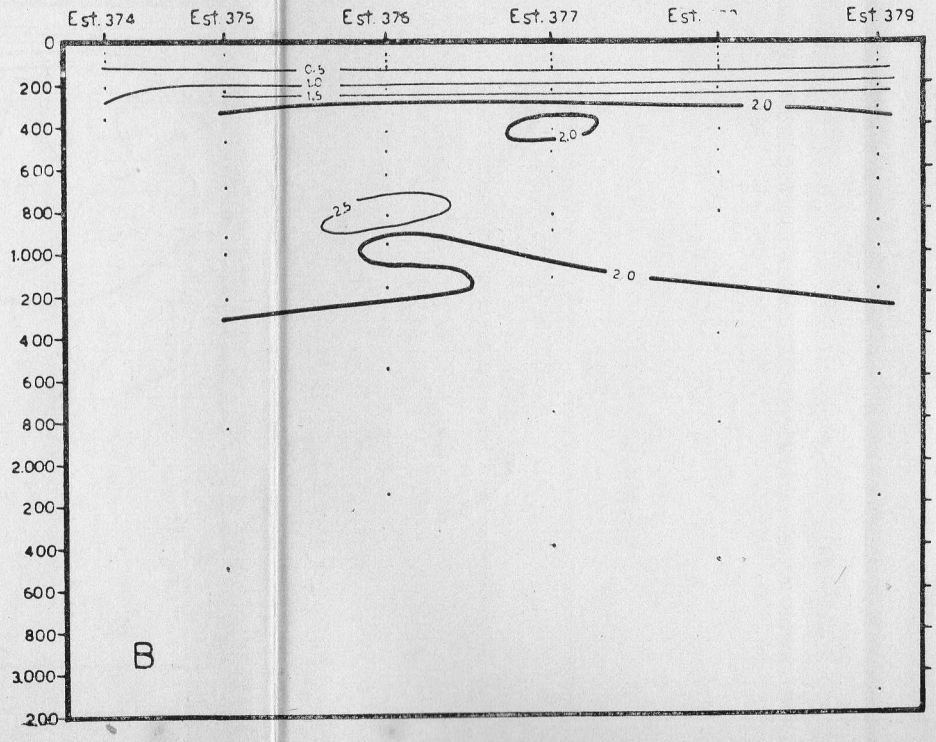
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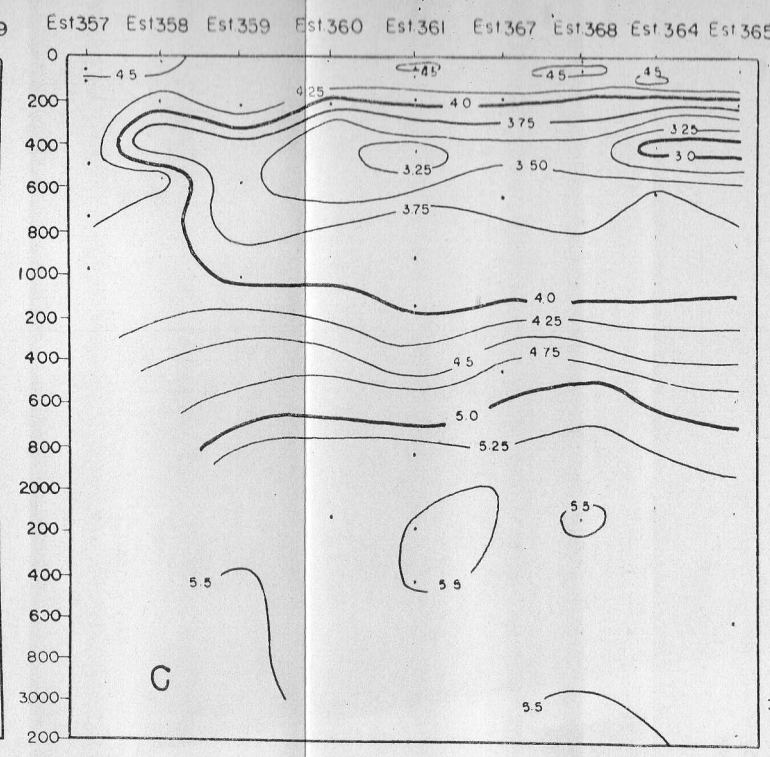

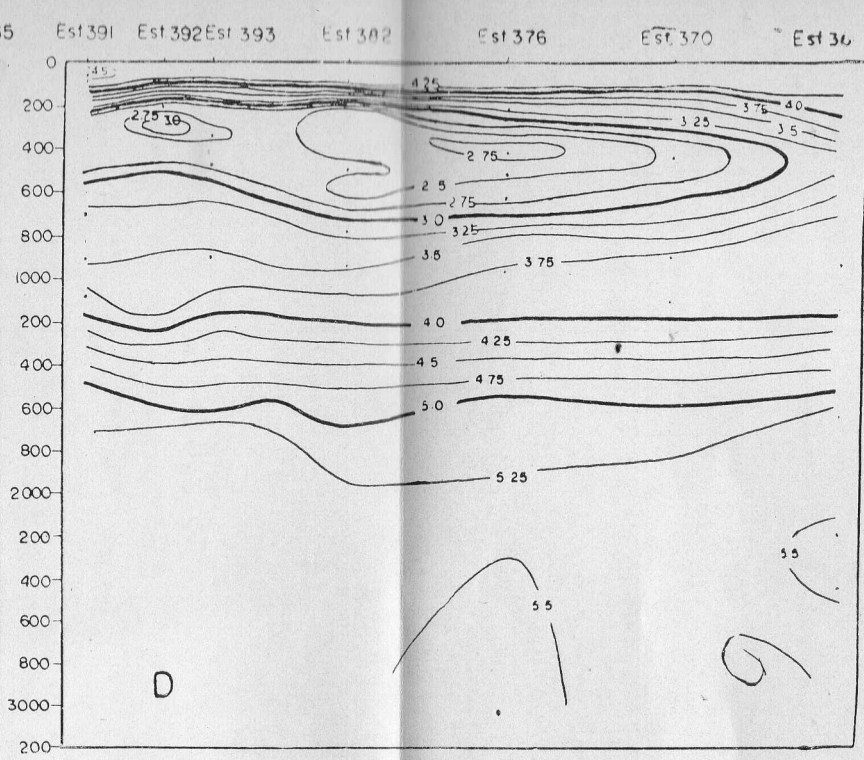

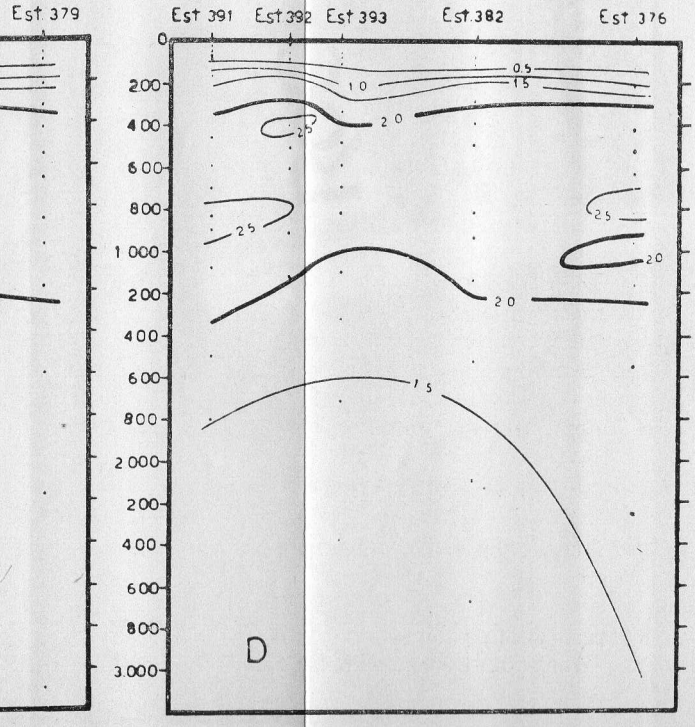

Fig. 14: Distribution of oxygen in vertical sections
Distribuição do oxigênio em secções verticais
Répartition de l'oxygene de l'eau en sections verticales

Fig. 15: Distribution of phosphate-P in vertical sections
Distribuição do fosfato-P em secções verticais
Répartition de phosphate-P en sections verticales

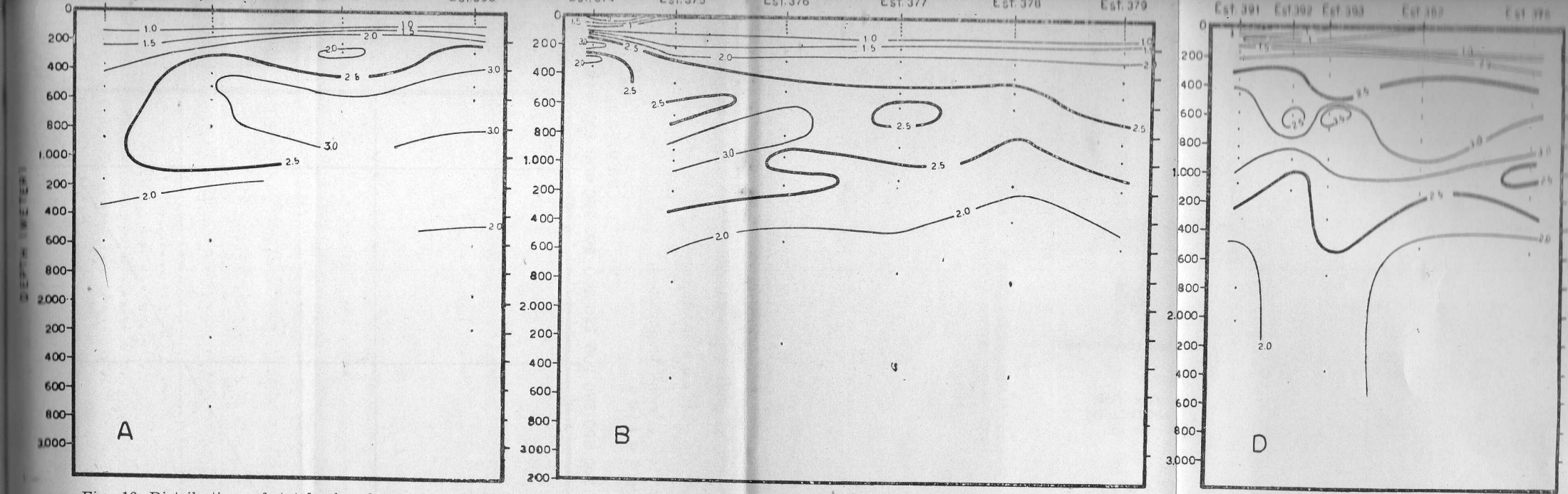

Fig. 16: Distribution of total phosphorus in vertical sections
Distribuição do fósforo total em secções verticais
Répartition de la phosphore total en sections verticales

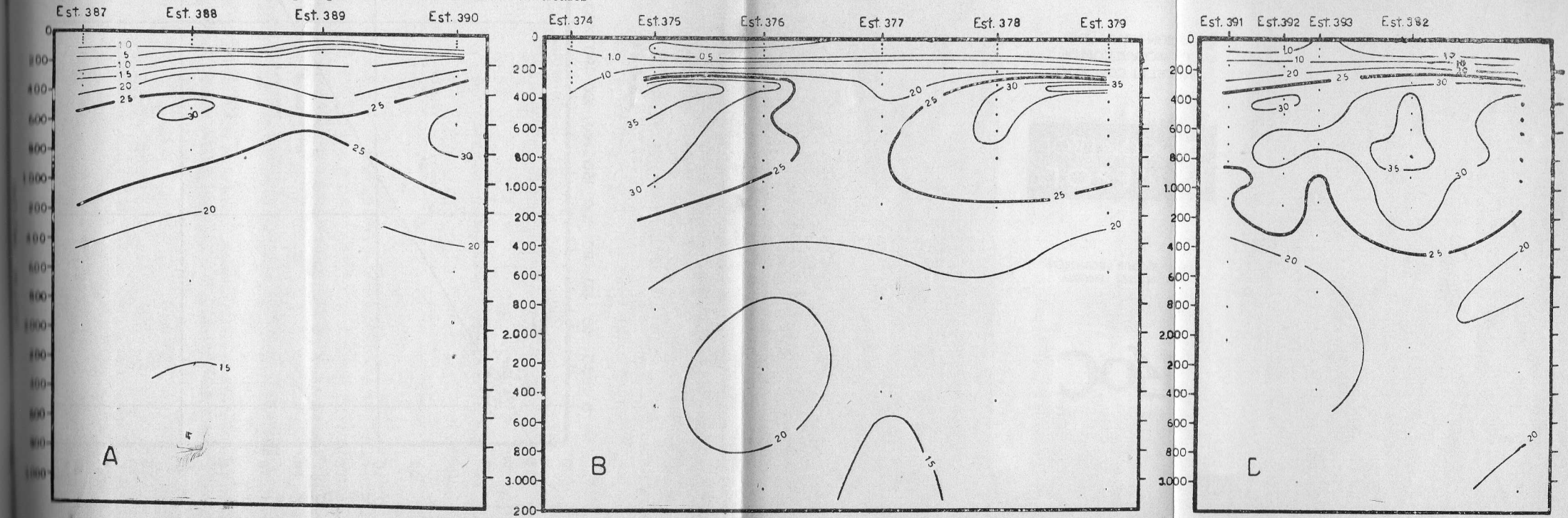

Fig. 17: Distribution of nitrate—N in vertical sections
Distribuição do nitrato—N em secções verticais
Répartition du nitrate—N en sections verticales

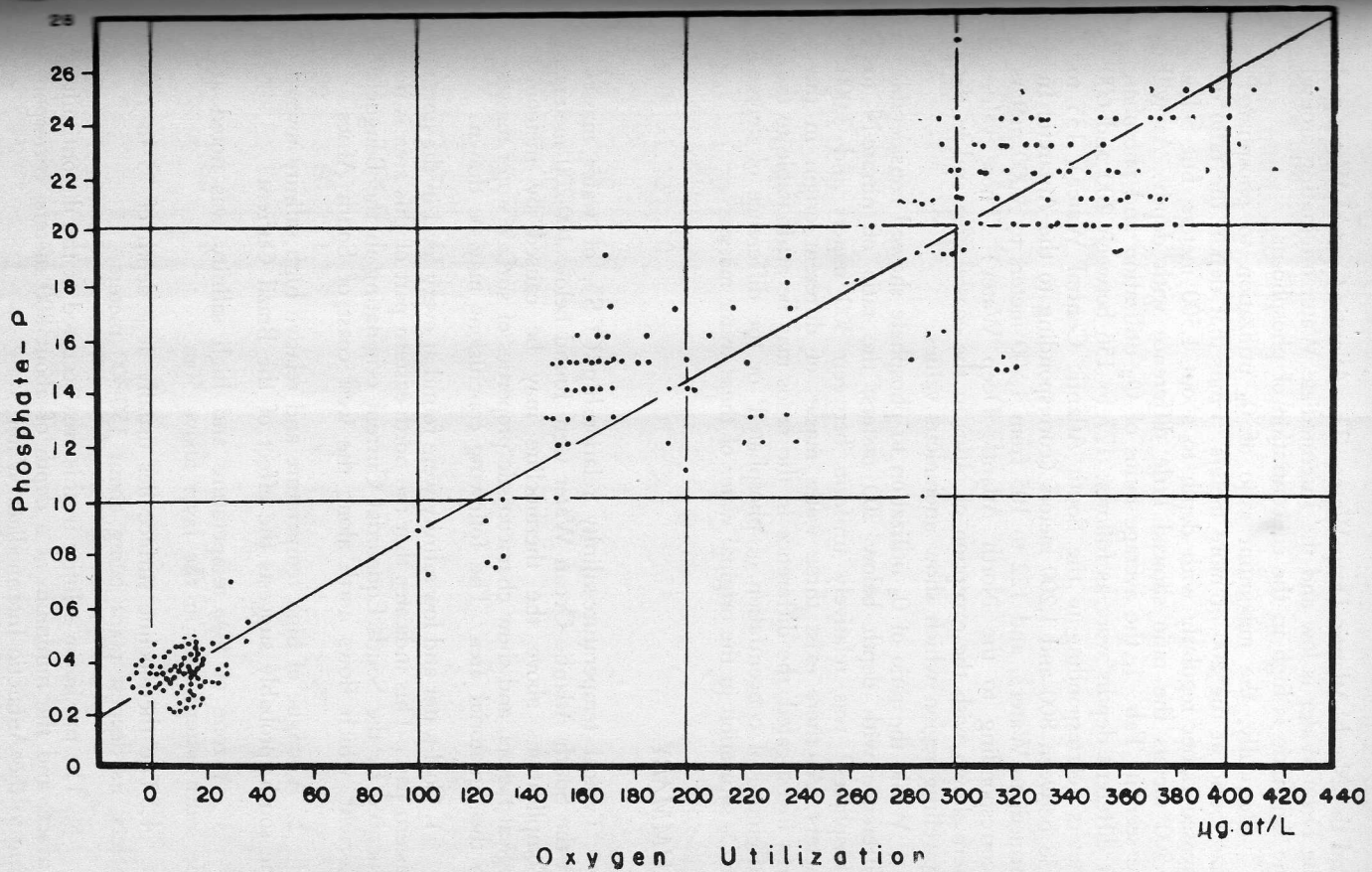

Fig. 18: Relations of oxygen utilization ($ó_2$ — O_2) to phosphate—P concentration.
Relação entre a utilização de oxigênio ($ó_2$ — O_2) e a concentração de fosfato—P.
Relation entre l'oxygene utilisé ($ó_2$ — O_2) et la concentration en phosphate—P

and the North Atlantic Deep Water. The Atlantic Central Water and the Deep Water is low and the Intermediate Water originating around the Antarctic is high in the concentration of phosphorus.

Vertically, the maximum ratio of 0_2 utilization to phosphate-P, was found at the 200 or more meters. From that depth, the ratio decreased rather regularly with depth to about 1,500 meters, but below 1,500 meters the ratio showed little difference with depth. As will be seen in Tab. 1, the average ratios of O_2 utilization and phosphate at different depths were as follows: 177 to 156 between 200 and 600 meters (corresponding to the South Atlantic Central Water), 135 to 138 between 800 and 1,200 meters (corresponding to the Antarctic Intermediate Water), and 122 to 105 from 1,500 meters to 3,000 meters (corresponding to the North Atlantic Deep Water). These values were shown with the exception of ratios in the coastal area and in the upwelling region which show anomalous values.

While the ratio of 0_2 utilization to phosphate showed considerable difference with depth below 200 meters, the ratio of nitrate-N to phosphate-P was relatively uniform between 300 meters and 3,000 meters. As there exist three water masses of different origin in the area investigated, the difference in the ratios may be attributable to the difference of concentration of phosphate-P or the difference of degree of O_2 saturation in the original water of these water masses.

SUMMARY

Typical temperature-salinity relationship (T-S), of water masses in the South Atlantic Ocean Water were found below 100-200 meters. Complications above the thermocline may be caused by meteorological factors, and show characteristic properties of surface water masses in the equatorial area. The following conclusions may be drawn.

1. Cool-water and low-salinity were found at every level in the north eastern part. This indicates that the north-eastern part of this area is influenced by the South Equatorial Current originating in the Benguela Current, which flows north along the west coast of South Africa.

2. A tongue of high temperature and relative high salinity toward the south, probably suggests the effect of the Brazil Current.

3 .A zone of low temperature and high salinity was noted at the south-eastern part in the layer above 50m.

4. The thermocline surface lies usually at a depth of 75 to 100 meters, its deepest point being about 150-300 meters.

5. The maximum salinity in this area occurred at the discontinuity surface, and the minimum at a depth of about 800 meters, corresponding to the Antarctic Intermediate Water.

TABLE 1

Nutrient elements, nitrogen – phosphorus ratio N/P, and oxygen utilization – phosphorus ratio O'_2-O_2/P at every depth.
Elementos nutritivos, relação nitrogênio – fósforo N/P, e utilização de oxigenio – relação de fósforos O'_2-O_2/P em cada profundidade
Eléments nutrifs, azote-phosphore rapport N/P et oxygen utilisé phosphore rapport O'_2-O_2/P à differents profondeurs.

Water Depth	Phosphate-P			Total Phosphorus			Nitrate-N			N/P			$O_2'-O_2/P$		
	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average
0	0.49	0.21	0.35	2.20	0.56	0.99	1.6	0.3	0.73	5.2	0.7	2.2	55	(9.6)	20
25	0.47	0.22	0.35	2.94	0.58	0.94	1.7	0.2	0.69	4.5	0.6	2.1	73	(16)	23
50	0.46	0.21	0.34	1.20	0.52	0.83	1.5	0.2	0.68	4.3	0.5	2.0	74	(17)	35
75	0.46	0.22	0.36	1.26	0.52	0.85	4.0	0.2	0.87	6.0	0.6	2.3	170	(10)	38
100	0.90	0.21	0.43	1.72	0.52	0.93	6.6	0.3	1.7	7.6	0.6	2.6	330	(8)	73
200	1.70	0.72	1.26	3.06	0.94	1.80	26.	2.7	15.	19.	3.0	11.2	205	48	164
300	2.12	0.88	1.70	2.90	1.36	2.21	38.	9.0	23.	20.	8.1	13.1	197	116	166
400	2.50	1.24	1.99	3.52	1.38	2.49	37.	17.	27.	18.	11.	13.4	190	125	165
500	2.50	1.42	2.16	3.60	1.72	2.75	36.	21.	28.	20.	10.	13.4	181	138	161
600	2.40	1.72	2.15	3.56	1.92	2.72	36.	20.	29.	18.	9.6	13.6	171	127	154
800	2.60	1.86	2.29	3.40	2.20	2.85	37.	24.	30.	17.	10.	13.2	155	117	139
1.000	2.58	1.90	2.20	3.36	2.32	2.75	33.	24.	27.	17.	9.7	12.5	158	120	138
1.200	2.60	1.70	2.01	3.48	2.00	2.49	32.	20.	25.	16.	9.9	12.3	163	110	136
1.500	1.84	1.46	1.65	2.50	1.64	2.02	27.	16.	20.	18.	9.0	12.3	137	105	122
2.000	1.62	1.28	1.47	2.36	1.50	1.82	25.	14.	19.	17.	8.7	12.7	119	100	111
2.500	1.56	1.26	1.48	1.92	1.52	1.73	24.	14.	18.	17.	9.3	12.5	129	97	112
3.000	1.90	1.50	1.57	2.20	1.50	1.75	22.	14.	17.	12.	9.0	10.7	115	89	105

6. The minimum oxygen was found at about 400 or 500 meters, and the layer of maximum phosphate-P, total phosphorus and nitrate-N was found somewhat below the oxygen minimum, at approximately 800 meters. This disagreement between the oxygen minimum layer and the maximum layer of nutrients may be due to the difference in origin of water masses of these two layers, the South Atlantic Central Water having a low concentration of nutrient in the upper layer, and the Antarctic Intermediate Water having a high concentration of nutrients in the lower layer.

7. Discontinuity layers were observed in the vertical distribution of phosphate-P, total phosphorus and nitrate-N from about 100 to 300 or more meters. This was true as well for water temperature, salinity and oxygen.

8. Great differences in the horizontal distribution of the above elements were found in the layer between 100 and 1.000 meters. There were only small differences below 1.500 meters.

9. In the above 200 meters, a relation was found between the horizontal distributions of these elements at every layer. The water in the coastal and in the southern area had relatively high salinity and showed low phosphate-P, low nitrate-N and high oxygen. On the contrary, the northeastern water had relatively low salinity and showed high nutrients and low oxygen.

10. The high oxygen concentration in the coastal area extended considerably deeper (300-700 m approximately) than in the ocean area. This may be caused by biological conditions.

11 In the vicinity of the ridge offshore from the Cape of São Roque, upwelling exists judging from the horizontal and vertical distribution of the above elements.

12. The concentration of nitrite-N and ammonia-N was very low throughout the whole water column, and the most abundant form of inorganic nitrogen was nitrate-N.

13. The ratio of nitrogen to phosphorus deeper than about 300 meters showed approximately uniform values (12.3 to 13.6 on the average), except for a slightly low value (10.7 on the average) at 3.000 meters. The mean ratio of N/P in the area investigated was 13 through the water column below 200 meters. This mean value (13) is slightly lower than Cooper's ratio of 15.

14. The maximum ratio of oxygen utilization to phosphorus was found at 200 or more meters deep, and from this depth, the ratio decreased rather regularly to about 1,500 meters. Below 1,500 meters the ratio showed only small differences with depth. The ratio of the oxygen depletion to phosphorus, below 200 meters, averaged 144, with a considerable difference from the 180 of Cooper and 235 of Richards.

15. The ratio of O:N:P: in the sea water of the area investigated was found to be 144:13:1 by atoms in the water column below 200 meters.

RESUMO

QUÍMICA OCEANOGRÁFICA NO OCEANO ATLÂNTICO SUL ADJACENTE AO NORDESTE DO BRASIL

Como parte da série do programa do Ano Geofísico Internacional, as observações oceanográficas no mar adjacente ao Nordeste do Brasil, foram feitas pelo Navio Oceanográfico "ALMIRANTE SALDANHA", da Marinha Brasileira no período de agôsto a outubro de 1959. Estas observações estendem-se desde a latitude 13° a 3,5° e de longitude 30°W à costa do Brasil.

Êste relatório dar as características das condições oceanográficas, com referência as principais características da oceanografia — química nestas aréas.

Como foi visto na relação entre temperatura e salinidade (T-S), as propriedades típicas das massas d'água do Oceano Atlântico Sul, estão compreendidas entre 100 e 200 metros, e a camada acima da temperatura apresenta perfil consideràvelmente complicado. Estas irregularidades podem ser causadas por fatôres metereológicos, e, podem apresentar propriedades características das massas d'água superficiais da zona equatorial.

A termoclina encontra-se usualmente numa profundidade que varia de 75 a 100 metros, localizando-se algumas vêzes cêrca de 300 metros.

O máximo de salinidade da área, ocorreu frequentemente na superfície descontinua, e o mínimo na profundidade cêrca de 800 metros, correspondendo à Água Intermediária Antartica.

O mínimo de oxigênio foi obtido a cêrca de 400 ou 500 metros, e a camada máximo de fosfato-P, fósforo total e nitrato-N, está situada um pouco abaixo da referida camada de oxigênio, a saber aproximadamente 800 metros.

Na distribuição vertical do fosfato-P, fosfato total e nitrato, as camadas descontínuas foram observadas a cêrca de 100 à 300 e algumas vêzes até mais profundas.

Isto em boas condições para temperatura, salinidade e oxigênio. A grande diferença na distribuição horizontal dos elementos acima, foi obtido na camada entre cêrca de 100 e 1.000 metros.

Houve sòmente pequenas diferenças abaixo de 1.500 metros. Nas camadas acima de 200 metros da area considerada, a água correspondente a região costeira e sul apresentou oxigênio e salinidade relativamente alta, e valores baixos de fosfato e nitrato-N ao passo que a água relativa a região nordeste, apresentou salinidade relativamente baixa, com nutrientes e oxigênio altos.

Nas vizinhanças das elevações ao largo de São Roque, provàvelmente existe a ressurgência em vista da distribuição horizontal e vertical dos elementos acima.

Notou-se que as concentrações de nitrito-N e amonia-N, foram muito baixas através de tôda a coluna d'água, e a forma mais abundante de nitrogênio foi nitrato-N.

A menor relação de nitrogênio e fósforo (N/P) na área estudada foi 13, em média, através da coluna de água abaixo de 200 metros. A relação de oxigênio utilizado e fósforo (O'_2—O_2/P) abaixo de 200 metros foi em média 144. Consequentemente, a relação de O:N:P na água do mar na área é dada pelo pêso atômico 144:13:1 baseada na média dos valores através da coluna d'água abaixo de 200 metros.

RÉSUMÉ

CHIMIE DES EAUX DANS L'ATLANTIQUE SUD, SUR LES CÔTES NE DU BRÉSIL

A titre de contribution à l'année géophysique internationale, la Marine Bresilienne e fait avec le bateau océanographique "Almirante Saldanha", une campagne océanographique dans le NE du Brésil en aout octobre 1959. La région étudiee est limitée de 3°5 ae 13°S et entre la côte et le 30°W.

Cet article traite des caractères océanographiques généraux et particulièrement des problèmes liés à la chimie de l'eau de mer dans cette région.

Dans le diagramme température-salinité (T-S), on rencontre à une profondeur inférieure à 100 ou 200 m, les caractéristiques typiques des eaux de l'Atlantique Sud, quant à la couche au-dessus du thermocline, elle présente un profil très compliqué. Celles-ci sont peut-être dues à des facteurs météorologiques, ou peuvent être des propriétés caractéristiques des eaux de surface dans cette régios equatoriale.

Le thermocline se trouve généralement à une profondeur de 75 à 100 m, le point le plus bas ayant été trouvé à 300 m.

Le maximum de salinité se rencontre souvent dans la zone de discontinuité, et le minimum à la profondeur de 800 m environ correspond aux eaux antartiques intermédiaires.

Les valeurs minimum de l'oxygène ont été obtenues vers 400 ou 500 m, et les teneurs maximum en phosphate-P, phosphore total et en nitrate-N ont été rencontrées à une profondeur inférieure à celle du minimum dé l'oxygène, c'est à dire vers 800 m.

Dans la distribution verticale des phosphates-P, P total et du nitrate-N, une discontinuité des couches a été observée entre 100 et 300 m ou plus. Ceci était également observé pour la température, la salinité et l'oxygène. Les plus grandes différences dans la distribution horizontale des éléments ont été trouvées dans la tranche d'eau entre 100

et 1.000 m, alors qu'il n'y a plus des diférences très faibles au dessous de 1.500 m.

Dans la couche au-dessus de 200 m, les eaux ayant une grande salinité montrent des valeurs basses pour le phosphate-P, le nitrate-N et hautes pour l'oxygène. Au contraire, les eaux de faible salinité présentent de valeurs hautes pour les éléments nutritifs et des valeurs faibles pour l'oxygène.

Au voisinage de la dorsale du Cap São Roque, il existe probablemente un phénomène d'up-welling, souligné par la répartition horizontale et verticale de ces éléments.

II faut noter que les concentrations en nitrite-N et ammoniac-N sont les plus faibles sur tout la colonne d'eau, et que l'azote inorganique se rencontre surtout sous forme de nitrates.

Dans la zone étudiée, la moyenne du rapport N/P est voisine de 13 dans un couche d'eau au-dessus de 200m. Le rapport entre l'oxygene utilisé et le phosphore ('0_2–0_2/P), au-dessus de 200 m est voisin de 144. En conséquence le rapport de O:N:P: dans la zone au-dessus de 200 m est le suivant: 144:13:1.

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