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The series ceased independent publication after Volume 19, Article 2, and was merged into the *Bulletin of the Peabody Museum of Natural History* monograph series after 1967.

See also the Bingham Oceanographic Collection Archives, Invertebrate Zoology, Yale Peabody Museum, in the Archives at Yale:
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A CONTRIBUTION TO THE CHEMISTRY OF THE CARIBBEAN AND CAYMAN SEAS

Norris W. Rakestraw and Homer P. Smith

Metcalf Chemical Laboratory of Brown University and the Woods Hole Oceanographic Institution

Issued August, 1937
New Haven, Conn., U. S. A.
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NORRIS W. RAKESTRAW AND HOMER P. SMITH

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INTRODUCTION

During the 1933 Caribbean cruise of the "Atlantis," jointly sponsored by the Woods Hole Oceanographic Institution and the Bingham Oceanographic Laboratory of Yale University, a number of chemical analyses were made on board in addition to those used for the purely

1 Joint contribution from the Woods Hole Oceanographic Institution (No. 140), Metcalf Chemical Laboratory of Brown University, and Bingham Oceanographic Foundation of Yale University.

Figure 1. Location of Stations.
### TABLE 1.
CALCULATED VALUES FOR CARBON DIOXIDE FUNCTIONS: FREE CARBON DIOXIDE ($C_{CO_2}$), TOTAL CARBON DIOXIDE ($C_{\Sigma CO_2}$), CARBONATE ($CO_3^{2-}$), BICARBONATE ($HCO_3^{-}$) IN MOLAR UNITS, CARBON DIOXIDE TENSION ($P_{CO_2}$) IN ATMOSPHERES

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hydrographic work in the manner which has now become more or less routine in oceanographic investigations. A general description of the cruise and a discussion of the hydrographic results has already been published by Parr (1). In the present report an account will be made of the special chemistry of the Caribbean and Cayman Seas with reference to phosphate, nitrate, nitrite, pH and buffer capacity. Serial samples were taken at various depths, from two to twenty or more at a station. In such samples, phosphate was determined at 59 different stations; nitrate at 29; pH at 28; nitrite at 22; buffer capacity, or "alkalinity," at 12. These data have been drawn on for studies on nitrite and buffer capacity which have already been published (2, 3). All the raw data have been made available in the Bulletin Hydrographique (4).

In adapting the originally published data for use in this paper two minor changes have been made: All values for phosphate and nitrate have been converted into terms of milligram atoms per liter (of P and N, respectively), in accordance with the recommendations of the International Council for the Exploration of the Sea, and all pH values have been corrected for depth (5), to represent conditions in situ.

To convert phosphate values into milligrams of P\textsubscript{2}O\textsubscript{5} per liter multiply by 71; mg. of PO\textsubscript{4} by 95; mg. of P, by 31. To convert nitrate values into milligrams of nitrate-nitrogen per liter multiply by 14.

The methods of analysis used were those which have become standard, for the most part: Atkins' method for phosphate; the Harvey reduced-strychnine method for nitrate; colorimetric method for pH, using cresol red and the bicolorimeter. More detailed information on this last procedure has recently been given by Mitchell and Taylor (6), and by Mitchell, Buch and Rakestraw (7). The corrections and methods of calculation used are explained in the source of the original data (4).

Figure 1 shows the location of stations at which chemical analyses were made. Although it contains fewer stations than Parr's complete list for the Caribbean, it includes a number of additional stations in the western Sargasso Sea, during the earlier part of the cruise.
Table 1 gives the calculated results for the tension and concentration of carbon dioxide, and the concentrations of carbonate, bicarbonate and total carbon dioxide. These have been calculated from the equations and tables of Buch and others (5, 8, 9).

**VERTICAL DISTRIBUTION**

Figures 2 to 9 present vertical station curves for the chemical data at a few selected stations. These are not only chosen to be representative of different areas, but also include those at which the most extensive observations of the carbon dioxide equilibrium were made. Oxygen curves are also drawn in some cases, for comparison. Stations 1469 and 1482 are generally representative of the Sargasso, Nos. 1503, 1512 and 1527 represent the Caribbean proper, and 1581, 1598 and 1606 the western basin which Parr (1) has named the Cayman Sea. Nos. 1558 and 1572 are included because of their adjacency to the Windward Passage, at which special conditions sometimes obtain.

The most striking condition at Station 1503 is the unusually low phosphate above 1500 meters, although nitrate is of normal magnitude. This exception is discussed later.
The general character of these curves is the same as found invariably in the deep water of the Atlantic, and elsewhere. The zone of maximum phosphate and nitrate, and of minimum pH, falls between 600 and 1000 meters, usually at about 800. It is clearly associated with the most extreme part of the thermocline. In fact, close inspection shows it to coincide very closely, in the Carib-
Below the maximum zone, from 800 to 1500 meters, phosphate and nitrate diminish, and pH increases, and below this the water is almost, if not completely, homogeneous.

Figure 4. Vertical distribution at Station 1469. Depths vertically in meters. Temperature (T); pH; phosphate (P) and nitrate (N), in milligram atoms per liter; oxygen, in ml. per liter; free carbon dioxide (C\text{CO}_2), total carbon dioxide (C\text{CO}_3), carbonate (C\text{CO}_3^2), bicarbonate (C\text{HCO}_3), in molar units; carbon dioxide tension (P\text{CO}_2), in atmospheres.

Considering only the higher concentrations, between the maximum zone and the bottom, the atomic ratio between nitrogen and phosphorus is about 16 to 1, a little less than that calculated by Redfield (10).

The picture of the carbon dioxide functions is practically the same at all stations, with the exception of the northern Sargasso station, No. 1469, at which total CO\textsubscript{2} was somewhat lower than elsewhere. In every case the carbonate ion concentration increased between its minimum (800 meters) and the bottom.
Samples for these analyses were taken at intervals of every 500 meters. As a result of this the maximum-minimum level was missed by 100 meters or more. This is indicated at Stations 1581 and 1598, where it is particularly apparent, by broken lines in the curves.

The changes in the carbon dioxide equilibrium must be closely related to the distribution of nitrate and phosphate, for they all result from different parts of the general cycle of decomposition and oxidation of organic matter. We are not yet in a position to discuss this in detail. It may be pointed out, however, that these values are on the whole consistent with those published by Wattenberg (11) for the Atlantic. His data seem to indicate a somewhat lower CO₂ tension (P₂O₅) in the western part of the Atlantic than in the eastern, and in this sense the Caribbean is a still further extension, for our values are even somewhat lower, on the average. But since different methods were used in the two studies for the determination of both pH and alkalinity it is hardly safe to compare absolute values. Although we have studied a smaller number of stations the relative picture at each is fully as consistent as those of the "Meteor" stations.

Figure 5. Vertical distribution at Station 1482. Depths vertically in meters. Temperature (T); pH; phosphate (P) and nitrate (N), in milligram atoms per liter; oxygen, in ml. per liter; free carbon dioxide (C₉O₂), total carbon dioxide (C₅CO₂), carbonate (C₉O₂), bicarbonate (C₉CO₂), in molar units; carbon dioxide tension (P₂O₅), in atmospheres.
Figure 6. Vertical distribution at Station 1527. Depths vertically in meters. Temperature (T); pH; phosphate (P) and nitrate (N), in milligram atoms per liter; oxygen, in ml. per liter; free carbon dioxide (\(\text{CO}_2\)), total carbon dioxide (\(\text{CO}_2\)), carbonate (\(\text{CO}_3\)), bicarbonate (\(\text{HCO}_3\)), in molar units; carbon dioxide tension (\(\text{P}_{\text{CO}_2}\)), in atmospheres.

Figure 7. Vertical distribution at Station 1606. Depths vertically in meters. Temperature (T); pH; phosphate (P) and nitrate (N), in milligram atoms per liter; oxygen, in ml. per liter; free carbon dioxide (\(\text{CO}_2\)), total carbon dioxide (\(\text{CO}_2\)), carbonate (\(\text{CO}_3\)), bicarbonate (\(\text{HCO}_3\)), in molar units; carbon dioxide tension (\(\text{P}_{\text{CO}_2}\)), in atmospheres.
Figure 8. Vertical distribution at Station 1581. Depths vertically in meters. Temperature (T); pH; phosphate (P) and nitrate (N), in milligram atoms per liter; oxygen, in ml. per liter; free carbon dioxide (C\textsubscript{CO\textsubscript{2}}), total carbon dioxide (C\textsubscript{\Sigma CO\textsubscript{2}}), carbonate (C\textsubscript{CO\textsubscript{3}}), bicarbonate (C\textsubscript{HCO\textsubscript{3}}), in molar units; carbon dioxide tension (P\textsubscript{CO\textsubscript{2}}), in atmospheres. Broken lines indicate probable maxima and minima of the CO\textsubscript{2} curves.
Figure 9. Vertical distribution at Station 1598. Depths vertically in meters. Temperature (T); pH; phosphate (P) and nitrate (N), in milligram atoms per liter; oxygen, in ml per liter; free carbon dioxide \((\text{C}_3\text{O}_2)\), total carbon dioxide \((\text{C}_2\text{O}_4)\), carbonate \((\text{C}_2\text{O}_3)\), bicarbonate \((\text{H}_2\text{C}_2\text{O}_4)\), in molar units; carbon dioxide tension \((\text{P}_\text{C}_2\text{O}_2)\), in atmospheres. Broken lines indicate probable maxima and minima of the \(\text{CO}_2\) curves.

HORIZONTAL DISTRIBUTION

Figures 10 to 21 show the horizontal distribution of phosphate, nitrate and pH at certain different depths. These depths were chosen to show most clearly the relations through the maximum-minimum layer. Accordingly, it seemed best to plot the data at the surface and at 400, 500, 600, 800, 1000, 2000 and 3000 meters. Since phosphate was determined at about twice as many stations as were nitrate and pH the picture for phosphate distribution is the most comprehensive. Nitrate and pH were generally determined at the same stations. The following general features seem to be apparent in these data:
Phosphate. At the surface, the central area of very low phosphate (less than .10 milligram atoms per liter) suggests an inflow of Sargasso water from the northeast. This is in accordance with Parr's hydrographic findings. Higher surface concentrations are found to the south and west.

At 400 meters the Sargasso water to the north has very little phosphate, but the concentration increases continuously to the South American coast, where the area of highest concentration has no connection with water outside the Caribbean basin.

The intrusion of intermediate water from the north, at 500 meters, which Parr (1) found to take place through the Anegada and Windward Passages, seems to be evident here also. High concentrations to the south reach their maximum in the vicinity of the eddy in the Panamanian bight.

At 600 and 800 meters the phosphate concentration throughout the Caribbean area is higher than in the waters to the east and north. The maximum phosphate zone is at about 800 meters, except in the center of the Cayman Sea, where it is somewhat lower. There seems to be some mixing with water from the north through the Windward Passage at this level.

In the Sargasso we find the maximum phosphate at 1000 meters, but in the Caribbean area, except for the center of the Cayman Sea, values are somewhat less than maximal at this depth.

At 2000 meters the Cayman basin is entirely homogeneous, but the Caribbean is not completely so. The higher concentrations are still in the south, for the most part, but reach a maximum in the east. The peculiar conditions in the eastern end of the Caribbean will be discussed later.

At 3000 meters the Caribbean and Cayman basins are practically homogeneous, but somewhat lower concentrations of phosphate occur in parts of the Sargasso.

In general, the Caribbean area is rather richer in phosphate than are the outside waters. This applies to all levels. Unfortunately, the data from this cruise give us no insight into the composition of the north equatorial water, which contributes so largely to the Caribbean, but the figures given by Seiwell (12) are regularly lower than those here shown. With due allowance for differences in analytical results by different observers, it seems nevertheless evident that phosphate is actively regenerated by organic decomposition throughout a large part, at least, of the Caribbean, and even more in the Cayman Sea. The effects of circulation and the mixing of water masses are superimposed upon this process.

Nitrate. Values are so low at the surface, throughout, that the only significant feature seems to be the somewhat higher concentration in the Cayman Sea. The slightly lower figures along the coast to the south may indicate a higher rate of biological activity here. This factor is perhaps mainly responsible for the slight differences in concentration, although circulation may also play a part.
At 400 and 500 meters the picture is quite similar to that of phosphate at the same levels. Concentrations are distinctly higher to the south, and there is some indication of the inflow of intermediate water from the northeast and through the Windward Passage.

At 600 meters there is apparently still some inflow from the northeast, and concentrations have considerably increased to the southwest. At 800 meters the maximum zone is reached, which extends over all the southern and western part of the area. Meantime, concentrations in the Sargasso are consistently lower than in the Caribbean, but increase continually down to 1000 meters. At this level in the Caribbean nitrate has diminished considerably, although a zone of high concentration still persists in the northern part of the Cayman Sea.

At 2000 and 3000 meters both basins are quite homogeneous, but nitrate concentration is distinctly higher than in the outside waters. This conclusion is partly presumptive, as there are no data for nitrate in the north equatorial water. But since in the case of the Sargasso the nitrate relation is the same as that for phosphate, it seems safe to assume the same condition for the water to the southeast.

Evidently, therefore, the Caribbean is an area of nitrate regeneration as well as phosphate.

pH. Throughout the Caribbean area pH values at the surface are somewhat lower than in the Sargasso, except for a zone in the northeast, which, again, is probably modified by the inflow of Sargasso water.

At 400 meters distinctly lower values are found to the south. A close relation is of course to be expected between pH and nitrate and phosphate, since the generation of the latter substances results from the oxidation of organic matter. This is accompanied by the formation of carbon dioxide from the simultaneous oxidation of carbon, and increase in acidity (lowering of pH) is the result.

At 500 and 600 meters the minimum zone of pH has moved to the west, where its correspondence with the maximum nitrate is easily seen.

The full extent of the minimum zone occurs at 800 meters except in the Sargasso where it is again somewhat lower. But neither at this level nor at any other are the values in the Sargasso as extreme as those in the Caribbean or Cayman Seas.

At 1000 meters the lowest values are found in the Cayman and western Caribbean, consistent with the behavior of phosphate and nitrate.

At 2000 and 3000 meters both basins are again nearly homogeneous, but the characteristics of the water are distinctly different from that outside.
Figure 10. Horizontal distribution of phosphate, at surface and 400 meters. Units, milligram atoms per liter.
Figure 11. Horizontal distribution of phosphate, at 500 and 900 meters. Units, milligram atoms per liter.
Figure 12. Horizontal distribution of phosphate, at 800 and 1000 meters. Units, milligram atoms per liter.
Figure 13. Horizontal distribution of phosphate, at 2000 and 3000 meters. Units, milligram atoms per liter.
Figure 14. Horizontal distribution of nitrate, at surface and 400 meters. Units, milligram atoms per liter.
Figure 15. Horizontal distribution of nitrate, at 500 and 600 meters. Units, milligram atoms per liter.
Figure 16. Horizontal distribution of nitrate, at 800 and 1000 meters. Units, milligram atoms per liter.
Figure 17. Horizontal distribution of nitrate, at 2000 and 3000 meters. Units, milligram atoms per liter.
Figure 18. Horizontal distribution of pH, at surface and 400 meters.
Figure 19. Horizontal distribution of pH, at 500 and 600 meters.
Figure 20. Horizontal distribution of pH, at 800 and 1000 meters.
Figure 21. Horizontal distribution of pH, at 2000 and 3000 meters.
RELATION TO TEMPERATURE AND SALINITY

From a consideration of Figures 10 to 21 it is apparent that there is a "sloping" of the whole water mass from north to south. This has been shown by Parr (1) to be true also with respect to both temperature and salinity. At any level consistently lower temperatures are found in the south, with corresponding displacements of salinity. In view of this it seemed advisable to attempt a correlation between the chemical data and either temperature or salinity.

Figure 22 shows nitrate plotted against temperature at a number of stations chosen from the three principal areas, Caribbean, Cayman and Sargasso Seas. In the first two cases all points are included within fairly narrow envelopes, while in the Sargasso there is somewhat more scattering at the lower temperatures. In the upper levels, however, a more consistent relation exists in the Sargasso than in the other areas.

The relation between nitrate and salinity at the same stations is shown in Figure 23. The same sort of qualitative difference is seen between the three areas, but no information is obtained from these curves which was not to be found in the nitrate-temperature relation. Accordingly, since the salinity curve is somewhat more complicated, all subsequent correlations were made to temperature only.

Figure 27 shows the mean curves taken from the envelopes in Figures 22 and 23. Although these relations are obviously not as valuable for diagnostic purposes as are temperature-salinity curves, it is nevertheless evident that a fair characterization of a water mass may often be made in terms of such correlations. Three distinctly different situations can be seen in the three different areas.

An example of the possible use of such relations is to be observed in the case of Station 1565. This station, which lies in the Windward Passage, is on the boundary between the Sargasso area and the Caribbean. An analysis of its nitrate-temperature relation, however, shows that it properly belongs with the Sargasso. The points plotted for this station in Figure 22 would fall far outside the envelope for the Cayman Sea. The situation is reversed, however, at Station 1572, which is somewhat further inside the boundary. This station must obviously be included with the others of the Cayman area.

A similar relation between pH and temperature is shown in Figure 24, and the mean curves from these envelopes, represented in Figure 28, are thoroughly consistent with those for the nitrate-temperature relation.
Since the phosphate figures were more extensive a more detailed analysis of their temperature relation was attempted. The Sargasso stations were divided into two groups: those to the north (Nos. 1467 to 1481) in one group, and those to the east (Nos. 1482 to 1490) in another. The few stations in the Cayman Sea were included in one group as before, but the larger number in the Caribbean were divided into the three N-S profiles (called respectively the East Line, Mid-Line and West Line) and another group of stations constituting a profile roughly E-W across the southern part of the basin. The phosphate-temperature relations for these seven groups are shown in Figures 25 and 26.

The points for the stations in the Cayman Sea, and those in the middle and western N-S profiles in the Caribbean, fall quite satisfactorily within narrow envelopes; those for the stations on the E-W profile are perfectly regular, with the exception of the easternmost station, 1503. The stations in the northern Sargasso group show regular phosphate-temperature relations, excepting certain depths at Station 1481, which lies immediately adjacent to the eastern group of stations. This latter group, on the other hand is highly irregular.

Mean curves for all these groups have been drawn in Figure 28, disregarding those points which fall far outside the envelopes. The result shows close similarity throughout all the Caribbean area, and the same qualitative difference between this and the Sargasso area that was observed in the case of nitrate. Since the mean curve for the eastern group of Sargasso stations is rather arbitrarily drawn it is not safe to compare it too closely with that for the northern group. The principal difference between these two groups of stations is the greater irregularity of the eastern one.

The eastern profile in the Caribbean is for some reason a very special case. The phosphate-temperature relations differ so much from station to station that an average curve would be entirely meaningless. Even the envelope drawn to include the points in Figure 26 is so diffuse as to be little more than roughly indicative.

The reason for the irregular results from this group of stations is not easy to see, although there is other evidence of unusual conditions at the eastern end of the Caribbean basin. The fact that the irregularity extends for a short way up into the Sargasso to the north is perhaps significant.

*Turn to page 35*
Figure 22. Relation of nitrate to temperature. Stations grouped according to areas. (See Fig. 1.) Broken lines comprise envelopes including points plotted.
Figure 23. Relation of nitrate to salinity. Stations grouped according to areas. (See Fig. 1.) Broken lines comprise envelopes including points plotted.
Figure 24. Relation of pH to temperature. Stations grouped according to areas. (See Fig. 1.) Broken lines comprise envelopes including points plotted.
Figure 25. Relation of phosphate to temperature. Stations grouped according to areas. (See text and Fig. 1.) Broken lines comprise envelopes including points plotted, with certain exceptions.
Figure 26. Relation of phosphate to temperature. Stations grouped according to areas. (See text and Fig. 1.) Broken lines comprise envelopes including points plotted, with certain exceptions.
Figure 27. Mean relation of nitrate to temperature and salinity. Mean curves taken from envelopes in Figs. 22 and 23.
Figure 28. Mean relation of pH and phosphate to temperature. Mean curves taken from envelopes in Figs. 24, 25 and 26.
The vertical distribution of phosphate in the three N-S profiles is shown in the upper portions of Figures 29, 30 and 31. The irregularity of the eastern profile and the regularity of the middle and western ones is again apparent. There are three peculiarities in the eastern profile: the low phosphate concentrations in the south, at all depths; the broadening of the maximum zone in the middle of the profile and its downward displacement, to 2000 meters; a very pronounced maximum at the northern end, rather broad and displaced somewhat towards the surface. In addition to these features there is the irregularity of many individual results at several stations. Contrasted with this, the middle and western profiles are smooth and regular. The only tangible connection with the eastern profile is the broad zone of high concentrations at Stations 1509 and 1527, which seems to be connected with Nos. 1497 and 1499. This is also to be seen in Figure 13.

The eastern profile may be extended north into the Sargasso in an irregular line through Stations 1488 to 1482, as shown in Figure 32. Although this does not help in explaining the unusual phosphate-temperature relations at these stations, it is interesting to observe how this figure fits onto the northern end of Figure 29, even though there is a rather considerable lateral jump between the two lines of stations.

The oxygen profiles for these same groups of stations have been constructed and are given in the lower portions of Figures 29, 30, 31 and 32. The oxygen relations in the eastern profile also show some slight irregularities in the lower depths, as compared with the middle and western ones. The area of highest oxygen concentration, in the lower depths to the southeast, corresponds with low phosphate values.

Comparison of Figures 29 to 32 shows that the oxygen minimum is generally slightly above the phosphate maximum and that the 4.90 contour for oxygen roughly corresponds with the 1.75 for phosphate. In the eastern profile, no relation is found between the oxygen minimum and phosphate maximum, except at the northern end, but 4.90 oxygen corresponds with 1.75 phosphate at Stations 1497 and 1498, although not at 1499.

Unpublished results from two “Carnegie” stations in this same region confirm these findings to a certain extent. One of these stations (No. 31, Cruise 7) nearly corresponds with Station 1499, and the other (No. 32) is mid-way between 1509 and 1512. The methods for determination and calculation of phosphate concentrations were evidently different from those in this work, so that strict comparison cannot be made, but, nevertheless, at 800 meters the phosphate was 25% higher at the western station than at the eastern, which is approximately the same difference as that between these two profiles.

It is unfortunate that the data for nitrate are too limited to confirm those for phosphate. Only at Stations 1497 and 1503 were nitrate analyses made, and in neither case was any particular irregularity noted.
It does not appear possible to explain the three main features of the eastern line by means of any simple picture of circulation or mixing of water masses. A certain degree of abnormality in this profile was found by Parr (1). The relatively shallow passages between the Lesser Antilles constitute a threshold between the Atlantic and Caribbean, and it is suggested that some of the bottom water of the latter has its source in the process of “cascading” over this threshold, as a result of the rise and fall of the lower levels outside. The low phosphate and high oxygen in the deeper water at the southern end of the profile do indeed have their counterparts in the equatorial waters to the southeast. The oxygen values reported from two of the “Dana” stations, near Barbados and further to the east, correspond closely to those at Stations 1499, 1500 and 1501. The phosphate at Stations 1501, 1502 and 1503 is similar in amount to the values cited by Seiwell (12) for waters to the southeast.

While such a picture might help us to understand the southern end of this profile it offers no explanation for the high phosphate in the central and northern parts. The source of phosphate, as well as the explanation of the other irregularities, must be sought within the water itself.

This should cause us no great concern, for the same is true—although perhaps to a less extent—throughout the water of the Caribbean area. Neither phosphate nor the nitrate can be accounted for in terms of the inflowing water.

Their concentration in the water is the result of the nature and state of the biological activity within it. Constancy of the P/T ratio, for example, is dependent upon a uniform biological environment; variation may result from local differences in this environment, as well as from mixture with water of a different source. The explanation of the distribution of nitrate and phosphate and their apparent rise and fall across an area like this involves the mechanism of the cycle of decomposition and regeneration of organic and nutrient matter. Although some of the general features of this cycle are known, the explanation of the picture observed at any one point necessitates more information that these data yield. The distribution of plankton in a given area, the effect of adjacent rivers (such as the Orinoco near the location under discussion above), unknown factors which may determine the rate of hydrolysis and oxidation of organic phosphorus and nitrogen compounds—all these are considerations which may well be important but which have necessarily been left out of account.

Our present results indicate a peculiar biological environment in this region. Whether this is true in general, or only a temporary phenomenon at the time it was visited, there is no indication. It would seem well worth further study.
Figure 30. Above: Phosphate in the Mid-Line of the Caribbean. Below: Oxygen.
Depths vertically in meters. Phosphate units, milligram atoms per liter. Oxygen units, ml. per liter.
Figure 31. *Above:* Phosphate in the West Line of the Caribbean. *Below:* Oxygen. Depths vertically in meters. Phosphate units, milligram atoms per liter. Oxygen units, ml. per liter.
Figure 32. Above: Phosphate in the Sargasso (East Group). Below: Oxygen. Depths vertically in meters. Phosphate units, milligram atoms per liter. Oxygen units, ml per liter.
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