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SOME SEASONAL CHEMICAL CHANGES IN THE OPEN OCEAN

BY

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Several studies have been made of the seasonal changes in the chemical composition of sea water, especially of the so-called "nutrient substances." But most of these have been in localities relatively near shore and in the temperate zones where climatic fluctuations are relatively great. During the years 1937 and 1938 an opportunity arose to study such changes in the open ocean in connection with an investigation of the variations of the Gulf Stream (Iselin, 1940).

Three stations were chosen on a line between Montauk Point, N. Y., and Bermuda as follows: Station A, on the Continental Shelf about 30 mi. SE. of Montauk Point (Lat. 40° 40' N; Long. 71° 45' W); Station B, in the slope water northwest of the current of the Gulf Stream (Lat. 39° 00' N; Long. 70° 40' W); Station C, in the Sargasso Sea southeast of the Gulf Stream (Lat. 35° 30' N; Long. 67° 30' W). These stations were visited seven times during the year from October 1937 to September 1938, and determinations were made of the following chemical properties and substances: pH, alkalinity, phosphate, nitrate, nitrite, ammonia. These, along with temperature and salinity, would have afforded a comprehensive chemical picture of conditions, but, unfortunately, it was seldom possible to complete such an extensive chemical program at any one station. There are many gaps, therefore, in the chemical data, but enough information was obtained to suggest some conclusions.

The methods used were those which have been described before: pH by the indicator method using cresol red and the Hastings bicolorimeter without buffers (Mitchell and Taylor, 1935; Mitchell, et al., 1936); alkalinity by the method of Mitchell and Rakestraw (1933); phosphate, nitrate, and nitrite by the standard methods of Atkins (1923), Harvey (1926), and Griess (1879) and Ilosvay (1889), respectively; ammonia by a modification of the method of Krogh (1934).

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The concentration of free carbon dioxide was calculated from the pH, alkalinity, temperature, and salinity, by the procedure of Buch, et al. (1932).

The times at which the stations were visited were as follows:

Cruise I, October 2–9, 1937
II, December 6–16, 1937
III, January 3–5, 1938
IV, April 6–12, 1938
V, May 29–June 5, 1938
VI, July 10–17, 1938
VII, August 24–September 1, 1938

The significant results are shown in Figs. 1–6.

From Figs. 1 and 2 it may be seen that the conditions at Station A were substantially the same as at other similar locations which have been studied heretofore, as, for example, the English Channel and the Gulf of Maine. During the summer months, when a strong thermocline develops, the upper levels become depleted of nutrient substances. In the winter a temperature inversion takes place, the whole water column becomes homogeneous or even unstable, and vertical circulation brings about replenishment from the richer deep water. The curves for pH and carbon dioxide concentration show vigorous biological activity going on in summer, with less in winter.

This is one of the few occasions on which ammonia and nitrite determinations have been made simultaneously, and it is important to notice that the two follow the same general pattern. Both are found at the surface during the winter and both are generally lacking there in the summer. This lends some support to the view, developed from
experimental studies (von Brand, et al., 1937), that ammonia, which is the first product of organic decomposition, is the precursor of nitrite in the sea.

Fig. 3 shows the relation between temperature, oxygen, pH, and carbon dioxide at Station B. It will be noted that the position of the oxygen minimum follows the thermocline up and down with the seasons and, as usual, is slightly above the pH minimum. The carbon dioxide concentration, more clearly than the pH, also follows the fluctuations of the thermocline.
The curves for pH at different times of the year do not coincide as closely as might be expected. There is little reason to believe that there should be as great differences at, say 1,000 meters, as are indicated. In the method for this determination, which makes use of the dissociation constant of the indicator rather than a set of standard buffers, significant errors may be introduced by using different batches of indicator, or even the same indicator over a considerable period of time. The glass electrode had not at that time been developed to its present state of reliability and convenience, otherwise the indicator could have been repeatedly standardized by this means. Consequently, although the relative values on each cruise are probably reliable, it is not safe to compare too closely the results obtained on different cruises. It would have been possible to assume that pH changes are insignificant below the thermocline and to have shifted all the curves to the right or left to make them pass through a common point at some standard depth (1,000 or 1,500 meters). The validity

Figure 4. Seasonal distribution with depth at Station B of: ammonia-nitrogen, nitrate-nitrogen, phosphate-phosphorus, nitrite-nitrogen, in µg at./l. The upper scale of units is for nitrate, the lower for ammonia, phosphate, and nitrite.
of this assumption is not certain, however, and the results of such an adjustment do not bring out any clearer relations.

The pH value is involved in the calculation of the carbon dioxide concentration, and since the variations in the latter (for five cruises) agree well with the variations in oxygen, it would seem that the pH values on at least these five cruises are fairly reliable.

Fig. 4, showing the distribution of nitrate, nitrite, ammonia, and phosphate at Station B, reveals two interesting facts. First, the positions of the phosphate and nitrate maxima fluctuate with the thermocline, which might have been expected from their close relation to the oxygen minimum. Secondly, in the upper levels, the same changes take place—although somewhat less clearly—as at Station A.

The temperature is lower at the surface in winter, and the upper layer becomes homogeneous. Vertical circulation brings nitrate and phosphate up from the transition layer to the surface. In summer, stable stratification again sets in and nutrients disappear by consumption. Nitrite also appears at the surface in winter and disappears in summer. In this case ammonia did not show as clear a relation to nitrite as at the shallower station; only in December was it found in small amounts, principally in the upper levels.
Nitrite appeared in the surface in December and remained through January and April; in June, July, and September, however, it had disappeared from the surface. Somewhat lower down, in a narrow
zone extending to 100 or 200 meters, significant amounts were still to be found. This is in accord with a previous study (Rakestraw, 1936).

The conditions at Station C were in general the same as those at Station B, although in some respects less clear. Fig. 5 shows the same relation between oxygen distribution and the temperature structure. The remarks already made about the pH results are equally true at this station. Although the surface values for nutrients are not conclusive, partly because of incomplete data from the December cruise, there is nevertheless a strong indication that there is not as much replenishment from the transition zone as at Station B. Thermal stratification is not completely destroyed in the winter.

For some reason, significant amounts of ammonia seem to have been present commonly in the surface, although only in December did these extend further down. Notwithstanding this, no nitrite was present at this time. This is different from the condition at Station B but it may be highly significant. It suggests that nitrite, which is never abundant in this semitropical oceanic water, had not yet been formed by oxidation of its precursor, ammonia. The ammonia, on the other hand, may have been a recent result of organic decomposition. By January, however, the oxidation had taken place, and the nitrite persisted through April until June and July, when only a small trace was found.

SUMMARY

At least to the extent to which seasonal changes in temperature, etc., take place in the upper layers in the open ocean, the seasonal variations in nutrients and other chemical factors are the same as those which occur in shallow inshore regions of the temperate zones. In addition, however, the distribution of chemical constituents and properties varies with the movements of the water mass and the changes in its physical properties, such as the rise and fall of the thermocline.

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