Shallow Currents Along the Northeastern Coast of South America[1]

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ABSTRACT

It has generally been considered that the Guiana Current carries South Atlantic Central water in an uninterrupted flow along the northeastern coast of South America and then into the Caribbean Sea. Certain phenomena observed in the western tropical Atlantic and in the Caribbean indicate that the picture is not that simple. The formation of the Equatorial Undercurrent, the pattern of the subsurface-salinity maximum along the Brazilian Coast, the distribution of lenses of the Amazon River outflow, and the relative lack of South Atlantic Central water in the Caribbean Sea all suggest that the Guiana Current undergoes major changes somewhere along the Brazilian Coast. Recent data indicate that a major interruption in this Current occurs in the area off the mouth of the Amazon River.

According to the conventional picture of the western tropical Atlantic circulation, the Guiana Current, which represents an extension of the South Equatorial Current, carries South Atlantic Central water along the Brazilian and Guinea Coasts and then into the Caribbean Sea. Sverdrup et al. (1942) assumed that a large quantity of South Atlantic water enters the Caribbean from the southeast, and, in order to account for the fact that the water leaving the Caribbean through the Yucatan Channel is dissimilar to South Atlantic water, they suggested that a large amount of western Sargasso Sea water mixes with South Atlantic water within the Caribbean Sea. Table I, reproduced from Sverdrup et al., shows the proportions of South Atlantic and western Sargasso Sea water at different σ_t surfaces; these waters, if mixed together, could produce Yucatan Channel water.

Western Sargasso Sea water would have to enter the Caribbean through the Windward, Mona, and Anegada Passages while the South Atlantic water

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Table I. Corresponding temperatures and salinities at stated values of σ_t in waters of the South Atlantic and of the western Sargasso Sea and Yucatan Channel. From Sverdrup et al. (1942).

	A		B				
Value of	South Atlantic		West Sargasso Sea		Yucatan Channel		Ratio A/B
σ_t	Temp. (°C)	S (°/oo)	Temp. (°C)	S (°/oo)	Temp. (°C)	S (°/oo)	in Yucatan Channel
26.4	15.8	35.64	18.3	36.55	17.8	36.38	1/4
26.6	13.6	35.39	16.8	36.32	16.1	36.11	1/3.5
26.8	11.3	35.08	14.8	35.98	13.9	35.74	1/3
27.0	9.0	34.82	12.4	35.61	11.6	35.40	1/3
27.2	6.0	34.52	10.0	35.29	8.7	35.03	1/2

carried by the Guiana Current would be expected to enter primarily through the passage between Trinidad and Grenada. However, observations in the northern passages provide no evidence of any substantial inflow of Sargasso Sea water. Profiles of temperature, salinity, and oxygen in five north-south sections (Metcalf 1959) all across the Caribbean have shown that remarkable uniformity exists in this water, both north to south and east to west (also, see Fuglister 1960, and Wüst 1964).

Furthermore, as a result of studies of the Atlantic Equatorial Undercurrent, Metcalf and Stalcup (1967) have shown that the flow of South Atlantic water from the eastern tip of Brazil to the Antilles is not continuous throughout the water column. Instead, in the vicinity of the Amazon River mouth, near 50°W, much of the upper 150 m–200 m of the column—that part between 13°C and 24°C—curves to the right and nearly back on itself to form the eastward-flowing Equatorial Undercurrent. This conclusion was based partly on the temperature-oxygen relationship in the 13°C–24°C layer, which shows relatively high oxygen concentrations to the southeast of the Amazon mouth as compared with the same layer to the northwest. In the region northwest of where this recurving takes place, the 13°C–24°C portion of the water column is apparently supplied from the North Equatorial Current. There is some indication (see below) that the flow of South Atlantic water along the South American Coast may be interrupted, even to the depth of the 6°–7°C isotherm (ca. 500 m).

The water of the North Equatorial Current shown in the IGY trans-Atlantic profiles of temperature, salinity, and oxygen at 16°N (Metcalf 1958) is found generally throughout the Caribbean above the sill depth of the passages among the Lesser Antilles. The salinity-minimum layer in the North Equatorial Current and in the Caribbean at about 600 m–800 m shows definite Antarctic Intermediate water influence in the temperature-salinity relationship.

Because of the changes that take place in the make-up of the water column near the Amazon River mouth, Metcalf and Stalcup (1967) have suggested

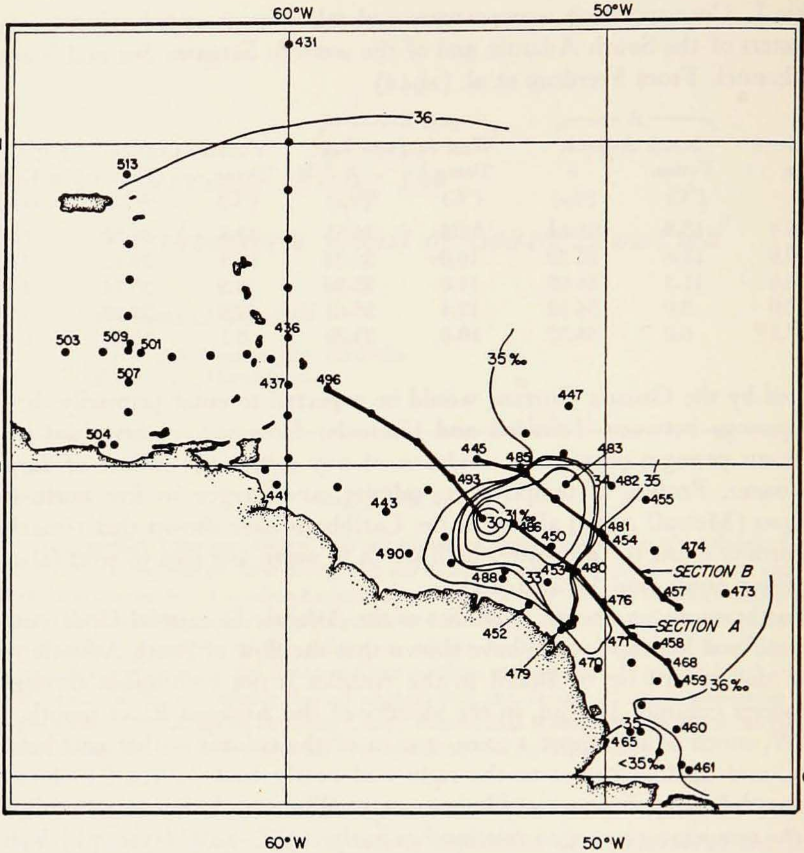

Figure 1. Station positions and surface salinity contours for ATLANTIS II Cruise 14, October–December 1964. After Ryther et al. 1967.

that the current southeast of that region be called the North Brazilian Coastal Current and that the term Guiana Current be used to denote the current along the Guiana Coast.

In a complex surface-salinity pattern that extends as much as 400 miles northeast of the Amazon mouth, isolated lenses of water of less than 32‰ were described by Cochrane (1965). In addition, Cochrane has presented a chart of maximum observed salinity in a network of stations within a wide area off the northeastern coast of South America; this chart shows that the high-salinity core in the North Brazilian Coastal Current, consisting of salinities greater than 36.4‰, is entirely disconnected from the high-salinity core in the Guiana Current. Within the intervening area, off the mouth of the Amazon, the salinity maxima are markedly lower (Cochrane 1965: fig. 5). This lower salinity is not a local phenomenon that results from mixing with

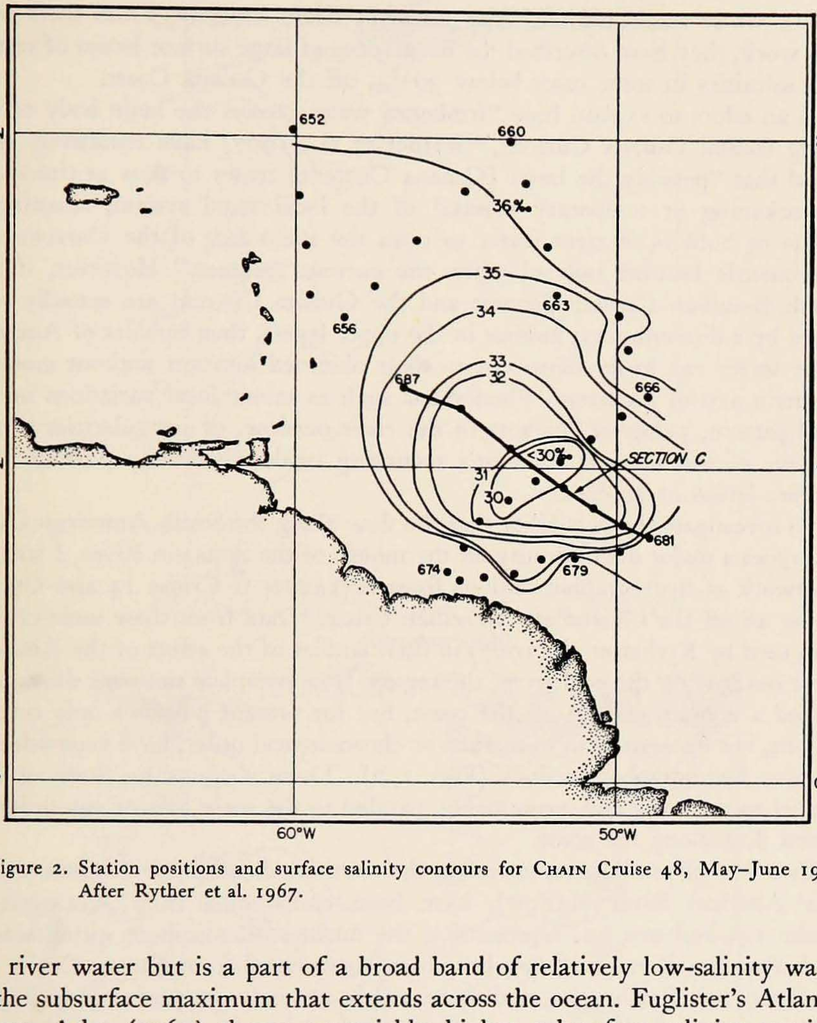

Figure 2. Station positions and surface salinity contours for Chain Cruise 48, May–June 1965. After Ryther et al. 1967.

the river water but is a part of a broad band of relatively low-salinity water in the subsurface maximum that extends across the ocean. Fuglister's Atlantic Ocean Atlas (1960) shows appreciably higher subsurface salinity maxima east of the 50th meridian in the 16°N section and Equator section than in the 8°N section. The lower salinity in the subsurface maximum off the mouth of the Amazon is directly connected to this latter section. However, the bottle spacings at the hydrographic stations along those sections were too great to reveal adequately the subsurface salinity maximum. In 1966, Cochrane modified his earlier views of the current along the northeastern coast of South America when he stated that it "appears not to be a continuous current but a succession of westward limbs of eddies."

Ryther et al. (1967), in replotting the Meteor Atlas data (Böhnecke 1936), have shown for each month the presence of broad areas of relatively fresh surface water associated with the Amazon River outflow. From their own field work, they have described the occurrence of large surface lenses of water, with salinities in some cases below 30‰, off the Guiana Coast.

In an effort to explain how "freshened water crosses the main body of the strong coastal Guiana Current," Ryther et al. (1967) have tentatively suggested that "possibly the latter [Guiana Current] ceases to flow at times due to slackening or temporary reversal of the local wind system, allowing a bubble or bubbles of river water to cross the main axis of the Current and subsequently become isolated when the current resumes." However, if the North Brazilian Coastal Current and the Guiana Current are actually separated by a discontinuity, at least in the upper layers, then bubbles of Amazon River water can easily move out to their observed location without crossing the main axis of a current. Phenomena such as minor local variations in the wind pattern, pulses of any sort in the river outflow, or irregularities in the location of the Coastal Current's recurving could divide the outflow into separate lenses or bubbles.

To investigate the possibility that the flow along the South American Coast undergoes a major discontinuity off the mouth of the Amazon River, I studied a network of hydrographic stations from ATLANTIS II Cruise 14 and CHAIN Cruise 48 off the Guiana and Brazilian Coasts. Data from these same cruises were used by Ryther et al. (1967) in their studies of the effect of the Amazon River outflow on the ecology of the region. The complete network of stations formed a zig-zag pattern off the coast, but for present purposes only certain stations, not necessarily in numerical or chronological order, have been selected to form hydrographic sections (Figs. 1, 2). These sections lie more or less parallel to the coast and, presumably, parallel to the main axis of any uninterrupted flow along the coast.

Two sets of profiles, representing the northern-hemisphere autumn season (low Amazon River outflow), have been constructed from ATLANTIS II Cruise 14; and one set, representing the northern-hemisphere spring season (high Amazon River outflow), have been constructed from CHAIN Cruise 48. Profiles of salinity, oxygen, and thermosteric anomaly are presented in Fig. 3. Keeping in mind the extreme vertical exaggeration (1:5000), which grossly overemphasizes the slopes of the isopleths, it can be seen in all of the profiles that there is at least one major discontinuity that would not ordinarily be expected in a profile along the axis of a current.

Toward the southeastern (right-hand) end of each profile there is a pronounced slope up to the left of the isopleths between 50 m and 200 m; this slope is accompanied by a pool of low-salinity water directly above or slightly to the northwest. This probably means that the Amazon River outflow, though discernable only as a thin surface lens, is associated in its position and movements with the subsurface current structure rather than with the local wind pattern only. It is believed that this is the area where the North Brazilian Coastal

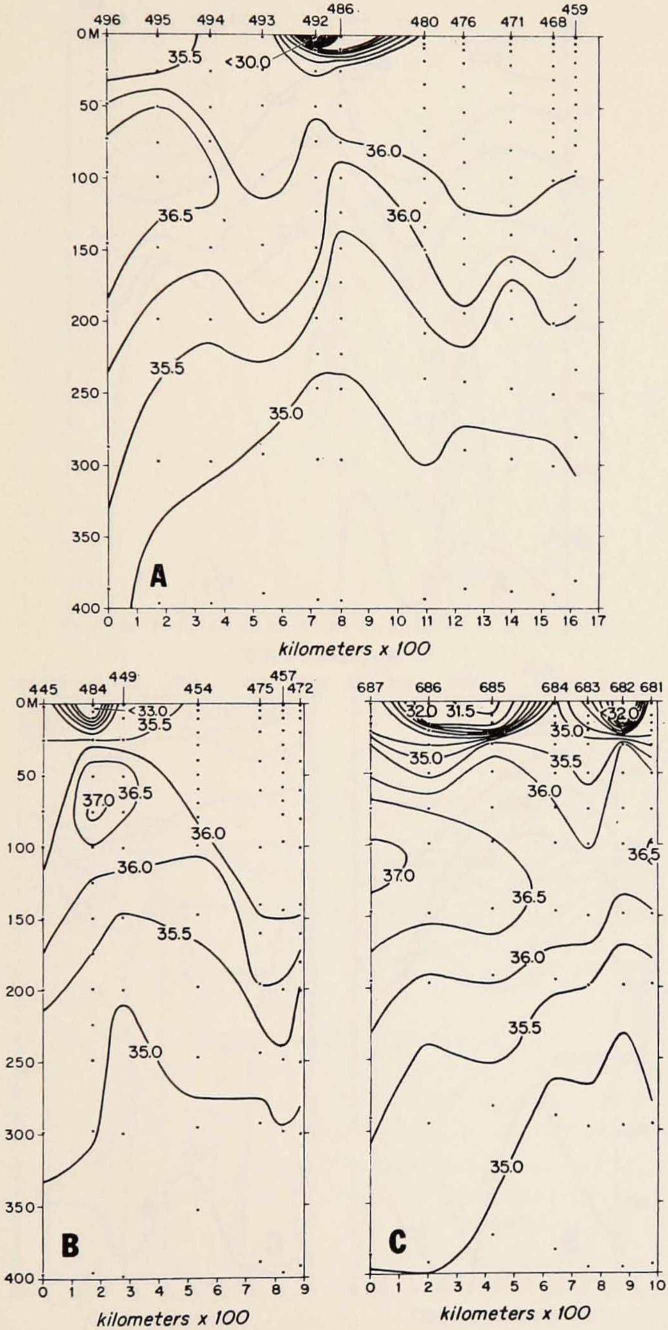

Figure 3 A. Salinity profiles of three along-shore sections shown in Figs. 1 and 2. Vertical exaggeration, 1:5000.

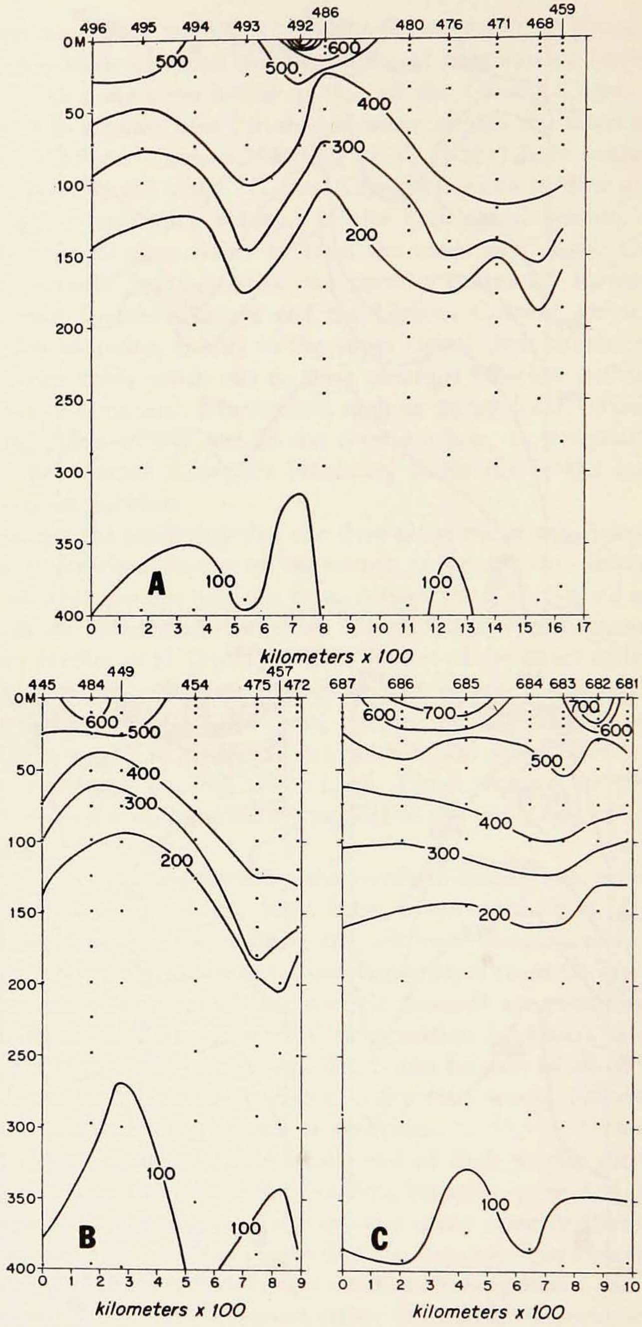

Figure 3 B. Thermosteric anomaly profiles of the same three sections used in Fig. 3 A. Vertical exaggeration, 1 : 5000.

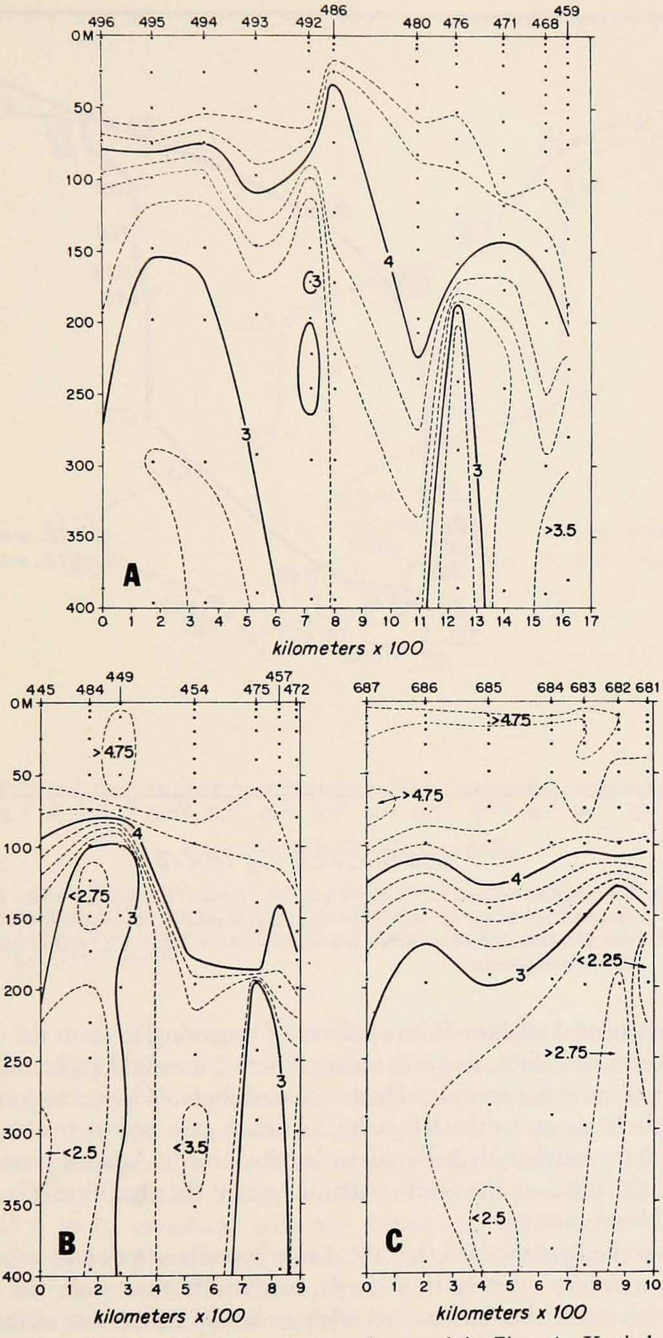

Figure 3 C. Oxygen profiles of the same three sections used in Fig. 3 A. Vertical exaggeration, 1:5000.

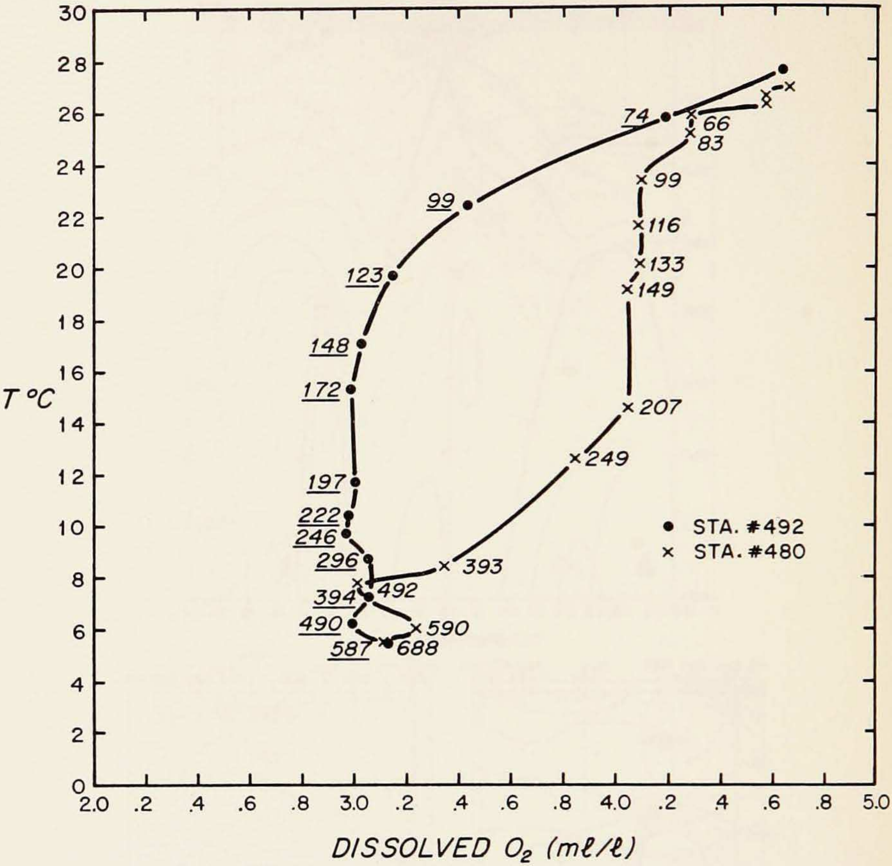

Figure 4 A. Temperature-oxygen curves for a pair of stations on opposite sides of the major discontinuity in section A. Numbers indicate depths of observations. See Fig. 1 for station positions relative to surface low-salinity lens. See Fig. 3 for station positions within the vertical profile.

Current has turned offshore in the process of recurving to form the Equatorial Undercurrent; therefore, this is the place where one would expect the Amazon outflow to be carried a considerable distance offshore. The corresponding slope of the isopleths down to the left, which in each case occurs to the northwest of the offshore current, is believed to be the North Atlantic water moving in to take the place of the South Atlantic water that has turned eastward to form the Undercurrent.

It can also be hypothesized that these two opposite slopes represent two sides of a great meander or eddy in a single current. If that were the case, then pools of fresh water that had moved offshore would be left out at that location when the meander or eddy is cut off and the current resumes its former course.

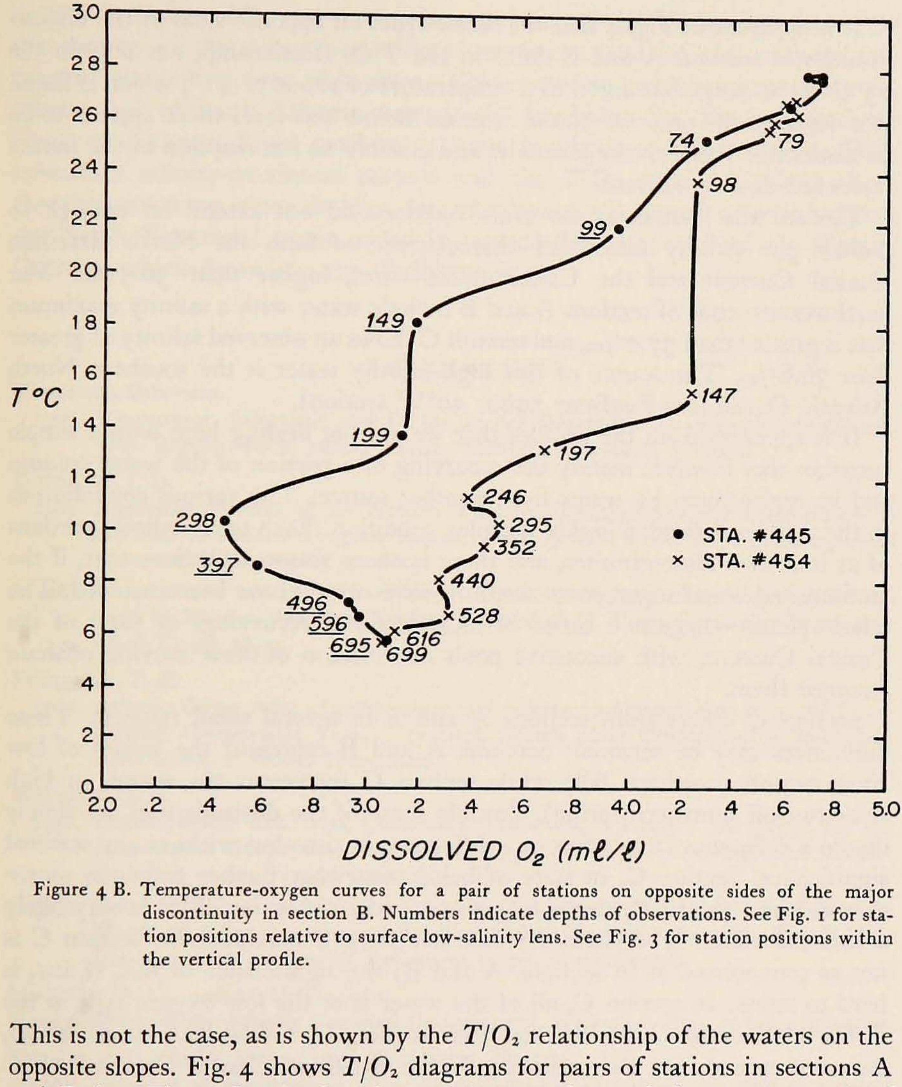

Figure 4 B. Temperature-oxygen curves for a pair of stations on opposite sides of the major discontinuity in section B. Numbers indicate depths of observations. See Fig. 1 for station positions relative to surface low-salinity lens. See Fig. 3 for station positions within the vertical profile.

This is not the case, as is shown by the T/O_2 relationship of the waters on the opposite slopes. Fig. 4 shows T/O_2 diagrams for pairs of stations in sections A and B (see Fig. 1 for the location of these stations relative to the pools of fresh surface water, and Fig. 3 for their location relative to the subsurface features). In each case, the southeastern station exhibits relatively high oxygen content in the 13°C–24°C range, which has been shown by Metcalf and Stalcup (1967) to be associated with the Equatorial Undercurrent and with its source, the North Brazilian Coastal Current. The northwestern stations exhibit the low oxygen content that is associated with the water to the north and west of the Undercurrent and its source. In other words, the origin of the water types on the opposite sides of this feature is quite different.

It is apparent in Fig. 4 that the water types on opposite sides of the discontinuities in sections A and B differ in the T/O_2 relationship, not only in the 13°C–24°C range but down to a temperature of about $7° \pm 1°$, which is found at a depth of the order of 500 m–700 m. Below this level there appears to be no distinction between the two sides and possibly no interruption in the northwestward-flowing current.

Toward the southeast, the cruise sections do not extend far enough to include the salinity maximum characteristic of both the North Brazilian Coastal Current and the Undercurrent—i.e., higher than 36.5‰. The northwestern ends of sections A and B include water with a salinity maximum that is greater than 37.0‰, and section C shows an observed salinity of greater than 36.8‰. The source of this high-salinity water is the southern North Atlantic Ocean (see Fuglister 1960: 50°W section).

It is apparent from the profiles that we are not dealing here with a simple situation that involves merely the recurving of a portion of the water column and its replacement by water from another source. The various convolutions in the profiles indicate a highly complex condition. Each profile shows portions of at least two discontinuites, and there is every reason to believe that, if the sections had been longer, more discontinuities would have been included. The whole picture suggests a series of meanders and recurvings of parts of the Coastal Current, with successive pools of Amazon outflow moving offshore amongst them.

Section C differs from sections A and B in several small respects. These differences may be seasonal: Sections A and B represent the season of low river run-off (northern fall) while section C represents the season of high river run-off (northern spring). Possibly some of the dissimilarities are simply due to a difference in location or a difference in time but without any seasonal significance. Section C, in spite of being somewhat further from the source than sections A and B, shows larger lenses of river water. This is very likely a seasonal effect. The shallow subsurface oxygen maximum in section C is not as pronounced as in sections A and B; the significance of this, if any, is hard to assess. In section C, all of the water is of the low oxygen type in the T/O_2 relationship. This indicates that section C, unlike sections A and B, does not extend into the recurving North Brazilian Coastal Current.

In a wide area off the mouth of the Amazon, it is probable that the mixing of various water types and the changes in direction and speed of both large-scale and small-scale water movements take place so constantly and so rapidly that it is virtually impossible to obtain a truly synoptic picture from the present data. The unusual type of survey, which requires a period of weeks, cannot be expected to disclose the true picture that obtains at any one time.

However, despite the limitations imposed by the available data, some interrelated patterns are apparent. In summary, the recurving of the high salinity core in the North Brazilian Coastal Current to form the Equatorial Undercurrent is indicated by the water characteristics of the Undercurrent and by the pattern of the subsurface salinity maximum and of the temperature-oxygen relationship over wide areas. This recurving, which accounts for the relative lack of South Atlantic water in the Caribbean Sea, also permits large lenses of Amazon River outflow to move hundreds of miles offshore. The subsurface salinity-maximum pattern and the T/O_2 relationship both show that this recurving is not simply a meander in a single coastal current but that the North Equatorial water moves in toward the coast to form the Guiana Current, which flows into the Caribbean Sea.

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