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Bottom water throughflows at the Rio de Janeiro and Rio Grande Fracture Zones

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Abstract:

Bottom water throughflows at the Rio de Janeiro Fracture Zone (22°S) and Rio Grande Fracture Zone (26°S) of the Mid-Atlantic Ridge are identified from hydrographic anomalies observed along 9°W in the Angola Basin. The throughflow water is supplied by a meridional band of cold and fresh water lying against the western flank of the Ridge.

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Introduction

The maps of bottom temperature and bottom salinity established by *Mantyla and Reid* [1983] show that ocean ridges are major obstacles to the spreading of bottom water (BW). Flows of BW across the ridges are detected in these maps by the temperature and salinity anomalies in the downstream basins. Considering the eastern South Atlantic, such anomalies were evidenced in the Guinea and Sierra Leone Basins but were absent in the south of the Angola Basin (the names of the major bathymetric structures are shown in Fig. 1). This led *Mantyla and Reid* [1983] to conclude that the main arrival of BW in the eastern South Atlantic, north of the Walvis Ridge, is through the Romanche Fracture Zone at the equator. This result matches *Connary and Ewing's* [1974] analysis who, although tracing Antactic Bottom Water (AABW) from the Cape Basin into the Angola Basin through the Walvis Passage, considered that the associated flow is limited.

Fig. 1

At depths greater than the crest of the Mid-Atlantic Ridge, the contrast between the temperature and salinity fields in the Brazil Basin and those in the Guinea and Angola Basins creates a zonal pressure gradient for any water denser than $\sigma_4 = 45.85$ (Fig. 2). Given a sufficiently deep passage (≥ 4000 m, say), this pressure gradient is expected to sustain an eastward flow which can be detected from observations of the BW properties in the eastern basin, provided that it generates anomalies in the deep hydrographic characteristics. As part of the French contribution to WOCE (World Ocean Circulation Experiment) a hydrographic section named A14 by WOCE was realized at a nominal longitude of 9°W between the coast of Africa and 46°S (Fig. 1). After

Fig. 2

running through the Guinea Basin, the section follows the eastern flank of the Mid-Atlantic Ridge (MAR) at an approximate ocean depth of 4000 m. It intersects the Guinea Rise at 15°S, crosses the Angola Basin, then reaches the Walvis Ridge around 37°S. In this paper, we show that signatures of throughflows at the Rio de Janeiro Fracture Zone (22°S) and the Rio Grande Fracture Zone (26°S) exist in the tracer fields at 9°W.

Data

We use hydrographic data collected between 1983-95 (Table 1). These data have an accuracy of ± 2 dbar for pressure, ± 0.003°C for temperature, ± 0.003 for salinity and ± 1.2 μmol kg^{-1} for dissolved oxygen.

Table 1

If greater than 4000 m, the sill depth of a fracture zone of the MAR is an indicator of potential BW throughflow. The sill depths of the fractures zones of the MAR were estimated from the General Bathymetric Chart of the Ocean (GEBCO). Besides the Romanche and Chain Fracture Zones [*Mercier et al.* 1994], the Rio de Janeiro and Rio Grande Fracture Zones at 22°S and 26°S, respectively, are the only passages with sill depths around or greater than 4000 m.

Property anomalies

Detailed examination of the θ-S diagrams along 9°W in the Angola Basin, reveals anomalous profiles which, at a given temperature, are fresher than the surrounding profiles (Fig. 3). The most pronounced anomaly is observed at Sta. 59 at 21° 40'S which presents a quasi-constant salinity for $\theta < 2.15$°C. The bottom salinity at Sta. 59 is 0.01 fresher than that at Sta. 58. Significant fresh anomalies are also detected at Stas. 60, 61 and Sta. 66 at 25°S (Fig. 3). At Stas. 59-61, the negative salt anomaly is associated with a positive dissolved oxygen anomaly visible on Fig. 4. No oxygen anomalies are detected at Sta. 66. Stas 59-61 are located to the east of the Rio de Janeiro Fracture Zone and Sta. 66 to the east of the Rio Grande Fracture Zone (Fig. 1). We will argue that these tracer anomalies are the signatures of BW flows through these two passages which were identified above as potential locations of BW flows from the Brazil Basin to the Angola Basin.

Fig. 3

Fig. 4

Speer et al. [1995] give evidence of the basin-wide extent of the Namib Col Current at about 22°S in the depth range 1300-3000 m. This zonal current which transports North Atlantic Deep Water (NADW) is characterized by a 1000 km-wide oxygen maximum (Fig. 4). The positive oxygen anomaly detected at Stas. 59-61 appears as a narrow downward extension of the Namib Col Current oxygen maximum.

Origin of the property anomalies

For each hydrographic profile acquired during the cruises listed in Table 1, we have determined the salinity and dissolved oxygen values at $\sigma_4 = 45.855$ and contour maps of both quantities on this isopycnal were hand drawn (Fig. 5). The depth of this isopycnal is in the range 3500-3700 m in the Brazil Basin where it lies within the lower part of the NADW. It is found at a depth of about 4000 m in the Angola Basin.

Fig. 5

In the Brazil Basin, the tracer patterns on $\sigma_4 = 45.855$ reveal the competition between the salty and oxygen-rich NADW to the North-west and the fresher and oxygen-poor Circumpolar Deep Water (CDW) to the South-east. Along the western flank of the MAR in the Brazil Basin, Fig 5. reveals a vein of fresh and oxygen-poor CDW of limited longitudinal extent except between 12°-19°S where the westward extent is larger. The presence of this water mass over the western flank of the MAR is ubiquitous in the East of the Brazil Basin as was previously observed at 11°S and 24°S by *Warren and Speer* [1991] and at 4.5°S by *Arhan et al.* [1998].

In the Guinea Basin, relative salt and oxygen maxima along the equator allow us to trace the BW exiting the Romanche and Chain Fracture Zones [*Mercier and Morin* 1997](Fig. 5). This BW flows southward through the sills of the Guinea Rise and enters the Angola Basin [*Warren and Speer,* 1991]. South of this rise, the Guinea Basin BW salinity maximum is found to the North-east of the Angola Basin extending south-westward. The associated oxygen minimum is created by a chemical reaction taking place at about 4000 m depth at the breaking of the African continental slope [*Warren and Speer,* 1991]. In the south of the Angola Basin, the Cape Basin CDW that flows through the Walvis Ridge is relatively fresh and oxygen-poor.

Immediately east of the MAR, Fig. 5 reveals two negative salt anomalies centered at 22°S and 25°S and a positive oxygen anomaly centered at 22°S. These property anomalies, which show the same characteristics as those identified in the θ-S diagrams, cannot be fed from the north by the salty Guinea Basin BW nor from the south by the fresh and oxygen-poor Cape Basin CDW. As fresh and oxygen-rich water is found on the western flank of the MAR, the origin of these anomalies must be the western basin. They point to flows through the Rio de Janeiro and Rio Grande Fracture Zones.

The comparison of the salinity profiles taken at the entrance of the Rio de Janeiro Fracture Zone at 15°W with those at the exit at 9°W shows the modification of the properties of the BW resulting from the passage through the Fracture Zone (Fig. 6). In the Brazil Basin, the salinity profile reflects the characteristics of the AABW. East of the Rio de Janeiro Fracture Zone, salinity shows only a slight decrease with density. For $\sigma_4 > 45.83$, the BW in the eastern basin is saltier and warmer at a given density than that in the Brazil Basin while the opposite holds for $\sigma_4 < 45.83$. This evolution of the salt profile is typical of strong diapycnal mixing which might be caused by the combined action of two different mechanisms. First, mixing intensification is known to occur at the MAR in relation with the enhanced energy lost from barotropic tides over rough to-

Fig. 6

pography [*Polzin et al.,* 1997]. Second, as this signal is related to a flow through a fracture zone, it is likely that downstream of the fracture zone sills, the throughflow accelerates downslope under the effect of gravity and becomes unstable, generating intense mixing as was observed in the Romanche Fracture Zone [*Ferron et al.* 1998].

Geostrophic transports were computed for the depth range 3200 m-bottom at the entrance of the Rio de Janeiro Fracture Zone between 21°-23.6°S at 15°W and at the exit between 20.5°-22°S at 9°W using a 3200 m reference level which is appropriate if, as expected, the flow is bottom intensified. Eastward flows of 0.59 10^6 m^3 s^{-1} at the entrance and 0.44 10^6 m^3 s^{-1} at the exit of the Rio de Janeiro Fracture Zone are diagnosed. In the Angola Basin, 3200 m is the approximate depth of the 2.1° isotherm. This transport represents about one third of the 1.6 10^6 m^3 s^{-1} found for $\theta < 2.1$°C for the Romanche and Chain Fracture Zone throughflows by *Mercier and Speer* [1998] and might be important for the Angola Basin deep mass budget.

Discussion

We have given evidence of BW throughflows at the Rio de Janeiro and Rio Grande Fracture Zones. The source of the throughflows is a vein of CDW lying above the western flank of the MAR. This water mass might be advected northward in the anticyclonic circulation suggested by *Reid* [1989] in the deep Brazil Basin. Recent modelling work conducted by *Lou St Laurent, John Toole, Ray Schmidt and Kurt Polzin* [personal communication 1999] shows that the enhanced mixing found over the western flank of the MAR causes an upwelling of BW. This upwelling could be another candidate to the maintenance of this narrow stretch of fresher and less oxygenated water along the ridge.

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Figure 1. Bathymetric setting. The 200 m and 3000 m contours are shown. The locations of the hydrographic stations of lines 9°W and selected station numbers are indicated. The following abbreviations are used : B. (Basin), C. (Col), F. Z. (Fracture Zone), P. (Passage), R. (Ridge).

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Figure 2. Averaged vertical profiles of σ_4 in the Brazil Basin along 19°W and Angola Basin along 9°W.

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Figure 3. θ-S diagrams at 9°W in the Angola Basin for Stas 54 to 79. See Fig. 1 for station locations. Stas. 59, 60, 61 are plotted in red, Sta. 58 in green, and Sta. 66 in blue.

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Figure 4. Vertical section of dissolved oxygen at 9°W in μmol kg^{-1}.

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Figure 5. Distribution of salinity and dissolved oxygen (μmol kg^{-1}) on the isopycnal surface $\sigma_4 = 45.855$. The 200 m and 3000 m bathymetric contours are plotted. Dots indicate the locations of the hydrographic stations.

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Figure 6. Salinity profiles at the entry and exit of the Rio de Janeiro Fracture Zone. See Fig. 1 for station locations. The vertical coordinate is σ_4.

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Table 1. Hydrographic sections

Name	Date	Reference
Cither 1 : 7.5°N (A6)	1993	*Arhan et al.* [1998]
Cither 1 : 4.5°S (A7)	1993	*Arhan et al.* [1998]
Oceanus 113 : 11°S	1983	*Warren and Speer* [1991]
Oceanus 113 : 24°S	1983	*Warren and Speer* [1991]
45°S (A11)	1993	*Saunders and King* [1995]
Cither 2 (A17)	1994	
Hydros 4 : 25°W (A16)	1989	*Tsuchiya et al.* [1994]
19°W (A15)	1995	
15°W	1991	*Speer et al.* [1995]
Cither 3 : 9°W (A14)	1995	*Groupe Cither 3* [1996]
AJAX : 0°W	1983	*AJAX Expedition* [1985]
SAVE 1, 2, 3	1987	*SAVE* [1992]
Romanche 1	1991	*Mercier and Morin* [1987]

MERCIER ET AL.: THROUGHFLOWS AT THE RIO DE JANEIRO AND RIO GRANDE FRACTURE ZONES
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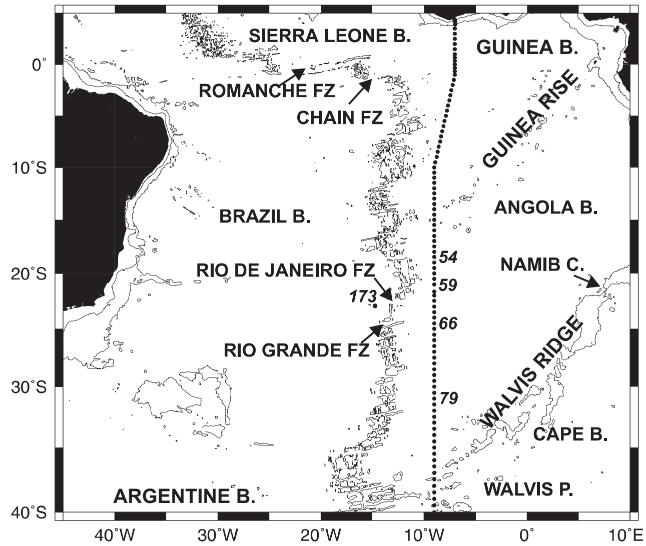
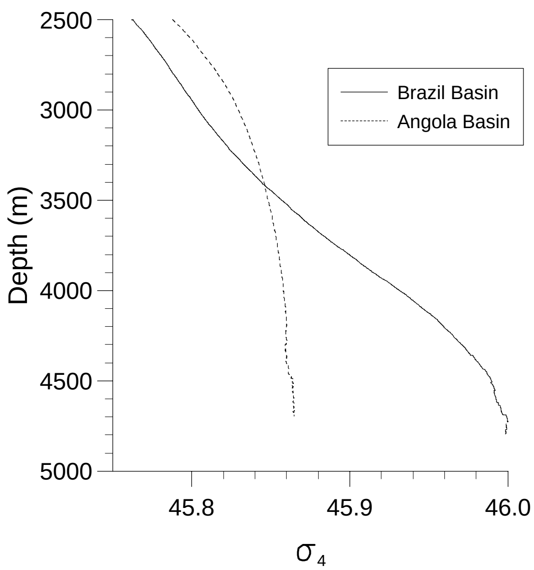
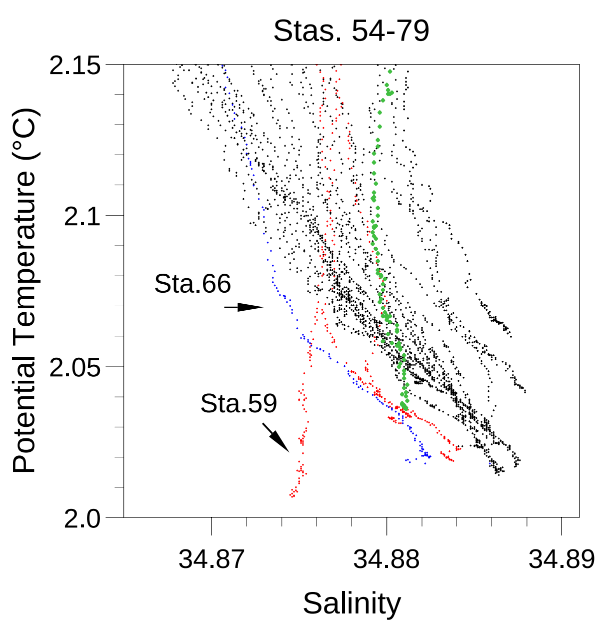


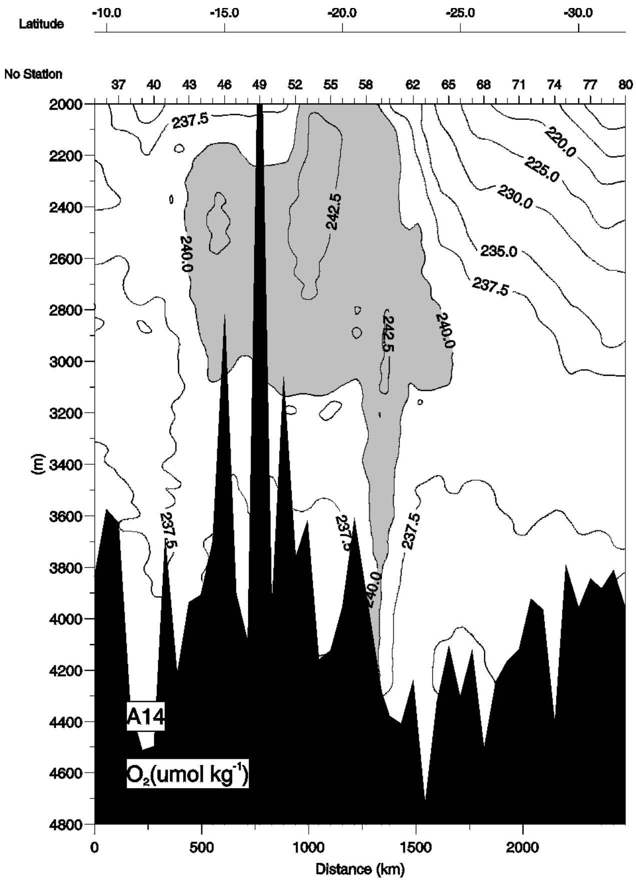
SIERRA LEONE B.
GUINEA B.
ROMANCHE FZ
CHAIN FZ
GUINEA RISE
BRAZIL B.
ANGOLA B.
54
NAMIB C.
RIO DE JANEIRO FZ
59
173
66
RIO GRANDE FZ
79
WALVIS RIDGE
CAPE B.
ARGENTINE B.
WALVIS P.
0°
10°S
20°S
30°S
40°S
40°W
30°W
20°W
10°W
0°
10°E



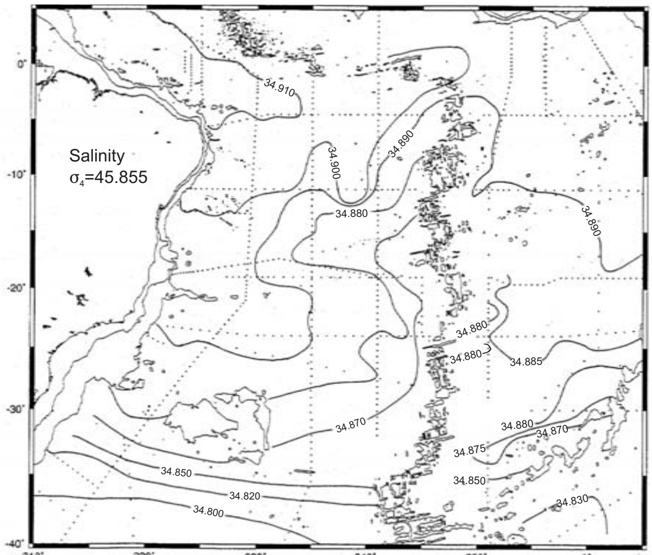
Brazil Basin
Angola Basin
Depth (m)
2500
3000
3500
4000
4500
5000
45.8
45.9
46.0
σ_4

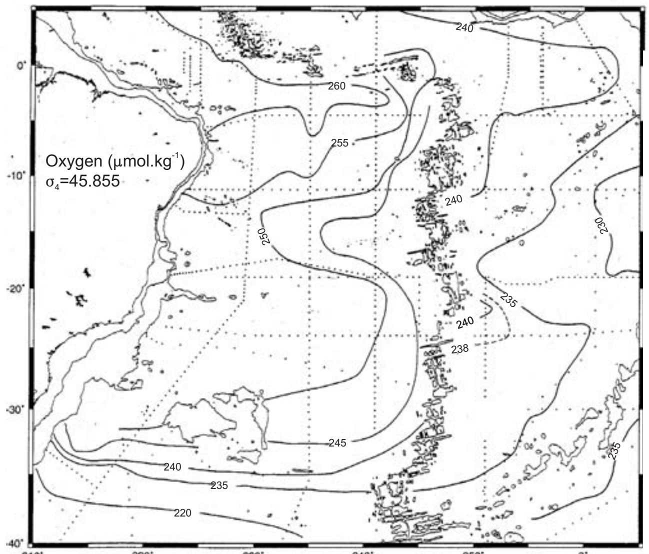


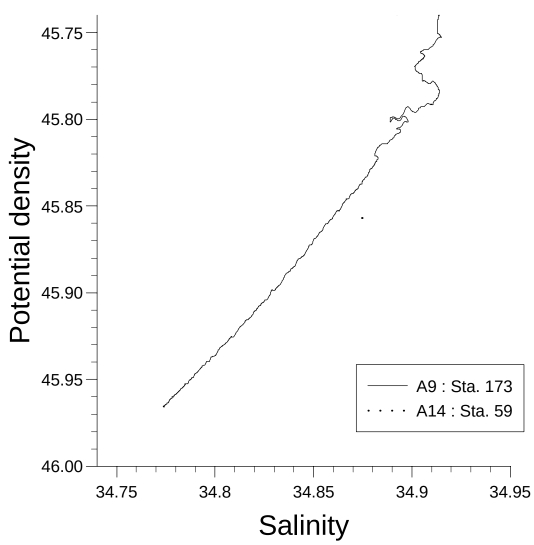
Stas. 54-79
Potential Temperature (°C)
2.15
2.1
2.05
2.0
34.87
34.88
34.89
Salinity
Sta.66
Sta.59



Latitude
-10.0
-15.0
-20.0
-25.0
-30.0
No Station
37
40
43
46
49
52
55
58
62
65
68
71
74
77
80
237.5
242.5
240.0
220.0
225.0
230.0
235.0
237.5
240.0
242.5
237.5
237.5
237.5
240.0
(m)
A14
O2(umol kg-1)
Distance (km)


Salinity
σ4=45.855
34.910
34.900
34.890
34.880
34.890
34.880
34.880
34.885
34.870
34.880
34.870
34.875
34.850
34.850
34.820
34.830
34.800
0°
-10°
-20°
-30°
-40°
310°
320°
330°
340°
350°
0°


Oxygen (μmol.kg-1)
σ4=45.855
240
260
255
250
240
230
235
240
238
245
240
235
235
220
0°
-10°
-20°
-30°
-40°
310°
320°
330°
340°
350°
0°



45.75
45.80
45.85
45.90
45.95
46.00
Potential density
34.75
34.8
34.85
34.9
34.95
Salinity
A9 : Sta. 173
A14 : Sta. 59