OCEANOGRAPHIC RESEARCH IN DELAGOA BAY AREA

- A PROGRESS REPORT -

by

António Jorge da Silva

Instituto de Investigação Pesqueira

Maputo - Mozambique

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RESUMO

Uma investigação oceanográfica realizada na área de Boa Paz-Inhaca (Delagoa Bay area) em Janeiro de 1982 confirmou a presença de um vórtice ciclónico entre a Corrente de Moçambique e a isóbata de 200 m, influenciando uma área total de aproximadamente 150 km x 80 km. A topografia do fundo parece ter um papel importante na geração do vórtice que, de acordo com os resultados de investigações realizadas entre 1957 e 1980, se comporta como quase-estacionário.

SUMMARY

Oceanographic research carried out in Delagoa Bay area in January 1982 has confirmed the presence of a cyclonic eddy influencing a total area of approximately 150 km x 80 km between the Mozambique Current and the 200 m isobath. The bottom topography seems to play a major role upon the generation of the eddy. Comparison with results of investigations carried out in the area from 1957 to 1980 suggests that the eddy is quasi-stationary.

1. INTRODUCTION

The Delagoa Bay area can be considered as the shelf, slope, and deep-sea area roughly between latitudes 25° and 27°S west of longitude 35° E (Figure 1). It is situated within one of the source regions of the Agulhas Current (GRÜNDLINGH, 1974, 1980; HARRIS, LEGECKIS and VAN FOREEST, 1978). It is an important area under the fisheries point of view. Spiny lobster is presently being caught by pots in depths of 300-400 m. Trawl fishing for deep-water prawns is being carried out between 400 and 800 m.

Despite its importance for fisheries, very little oceanographic research has been specifically done in this area. Until 1980 the area was mainly covered by single zonal sections at latitudes 26°00'S and 26° 43'S (ORREN, 1963; LUTJEHARMS, 1972; SAETRE and PAULA E SILVA, 1979; ISAENKO _et al_., 1980; JORGE DA SILVA, MUBANGO and SAETRE, 1981). At best, very small parts within the whole area have been covered during a few cruises (EROFEEVA, 1970; BUDNICHENKO _et al_., 1977). In 1980 two better, although partial, coverages of the area were made in August (BRINCA _et al_., 1982) and October (BRINCA _et al_., 1981).

The results obtained thus far indicated the presence of a cyclonic eddy between the coast and the 1,000 m isobath, centered near latitude 26°S. The bottom topography seems to exert a major influence on the origin of the eddy. Evidence of this can be found in the profiles of "Atlantis II" in 1963 and 1965, presented in JORGE DA SILVA, MUBANGO and SAETRE (1981).

A clear subsurface front is associated with the eastern boundary of the eddy. The front can be seen in the temperature profiles but is particularly evident in the salinity, oxygen and nutrient profiles (see, for instance, the profiles at latitude 26°S shown in JORGE DA SILVA _et al_., 1981). The highest salinities, associated with the core of the Subtropical water, are always seen to the east of the eddy. Oxygen values are lower, and nutrients higher over the eddy than eastwards at deep-sea. The front may occasionally extend to the surface. This was the case in May 1979 (ANON., 1981).

In order to determine the characteristic horizontal dimension of the eddy, and to study its influence above the 500 m isobath, the Delagoa Bay area was surveyed from 4 to 7 January 1982 by the GDR research vessel "Ernst Haeckel". Additional evidence about the role played by the bottom topography upon the origin of the eddy was also expected to be obtained with this investigation.

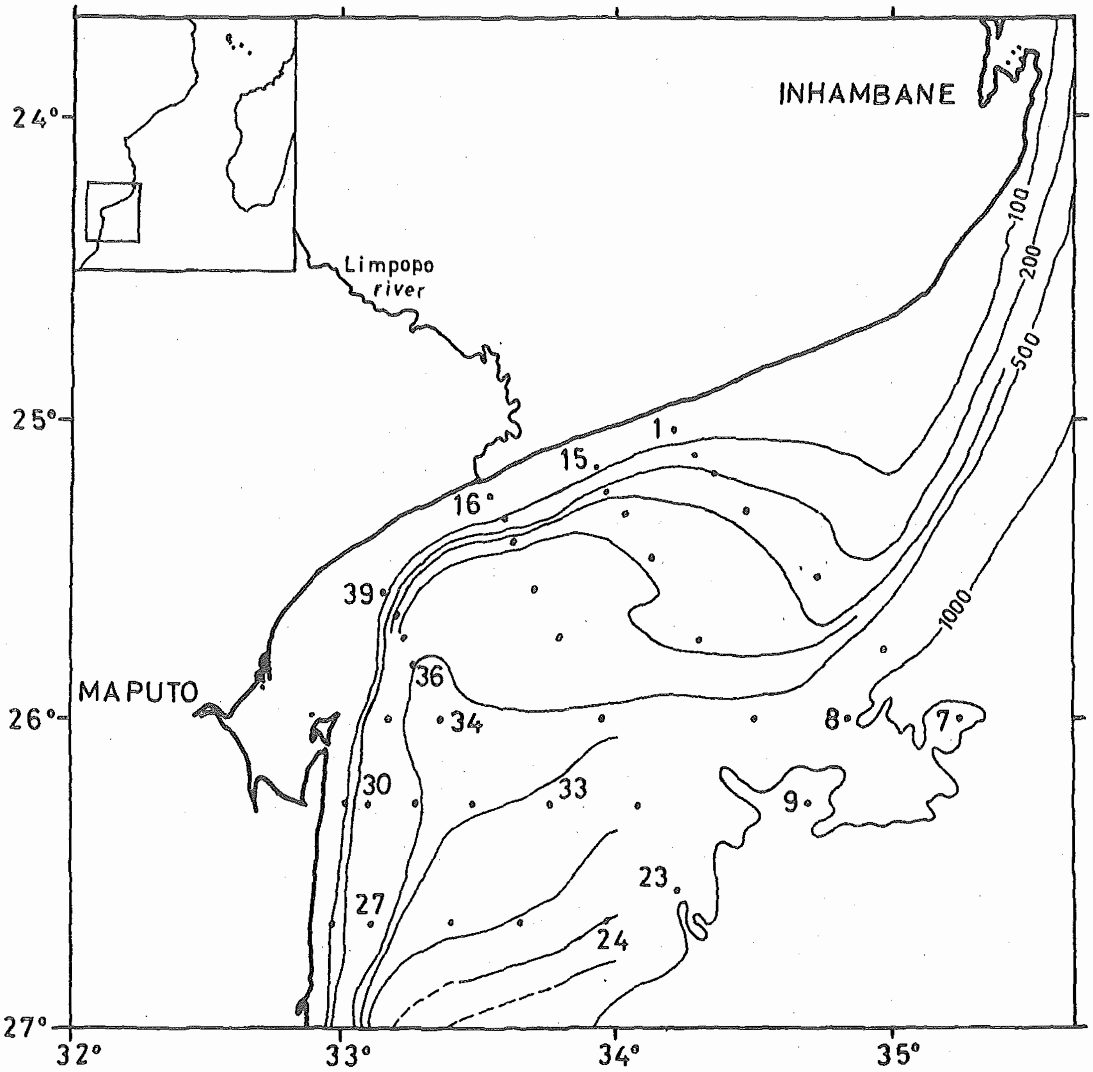

Figure 1. Grid of stations and isobaths in metres

2. BATHYMETRY

Figure 1 shows the isobaths in 100 m intervals down to 1,000 m. The chart was constructed on the basis of the information contained in the hydrographic charts nos. 401, 437, 438 and 440 of the Portuguese Hydrographic Institute. Omissions in the continuity of some of the isobaths are due to identical omissions in the original charts. Unecessary compression of lines was also avoided in some areas.

The shelf is very narrow north of latitude 24°S and south of latitude 26°S, being widest between latitudes 24° and 25°S, in the so-called Boa Paz Bank area. A mountain with several peaks and a bank (79 m) is present near 26°S, 35°E. This is not shown for sake of figure simplicity.

According to the terminology proposed by INTERNATIONAL HYDROGRAPHIC ORGANIZATION/ INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (1981), one can say that a hook-shaped terrace exists between the 300 m and the 700 m isobaths, in the latitude range 25° 15' - 26° 40'S. The minimum slope of the terrace occurs between the 500 m and the 400 m isobaths where depth decreases approximately 1.2 m/km, roughly in WSW-ENE direction. At the shoreward side of this flatest part there is a steep escarpment up to the 100 m isobath, reaching a maximum slope of 31 m/km (the greatest inclination in the whole area). At the seaward side the slope is much more gentle, tending to increase with increasing depth.

This marked change in bathymetry between latitudes 24° and 27°S is likely to introduce changes in the current pattern. SAETRE and JORGE DA SILVA (1982) have already suggested that the cyclonic eddy quite often found off Maputo is probably topographically induced. However, no research programme was ever carried out in order to fully study this whole area. The station network depicted in Figure 1 is, to our knowledge, the first attempt to do such a study.

3. METHODS

At each station (Figure 1) water samples were collected at 0-10-20-30-50-75-100-125-150-200-250-300-400-500-600 metres (nominal depth) for temperature and salinity determination. Unprotected thermometers were used in the water bottle submerged to 125 m (nominal depth) and in the deepest bottle. Salinity was determined on board by means of a BECKMAN RS-7 B inductive salinometer. Station positions were determined by satellite navigator.

Horizontal distributions of temperature at selected depth levels were used to portray the circulation pattern. SAETRE and JORGE DA SILVA (1982) have employed the temperature distribution at 150 m for the samme purpose and justified the use of the method in terms of a close t - sigma-t relationship in Mozambique waters. Horizontal distributions of salinity at the same depth levels were also used to illustrate the influence of the circulation pattern in the distribution of water masses.

4. WATER MASSES

The surface distributions of temperature and salinity depicted in Figures 2-A and 3-A reveal a clear association of the highest temperatures with the lowest salinities. Temperatures above 27°C and salinities below 35.3, characteristic of (modified) Equatorial Surface water[a], were distributed in a tongue roughly parallel to the 1,000 m isobath occupying the upper 30 m. Cooler and more saline Subtropical water entered the area from the east, cutting the warmer tongue in two parts.

Water mixing was apparently taking place in the surface layer, as revealed by the alternating pockets of lower and higher salinity that can be seen in Figures 4 and 5 in the upper 100 m. As a result of this process a very weak salinity minimum is revealed by the t-S scatter diagram around 23°C (Figure 6).

Surface salinities lower than 35.3 were also observed in stations 38 and 39 (Figures 3-A and 5-A). They are believed to be associated with river runoff into Maputo Bay and subsequent offshore water transport. No traces were found of the Limpopo river runoff.

Figures 4, 5 and 6 clearly show that the subsurface water at stations 6, 7, 9 and 23 was more saline than in all other stations. In station 7 the difference extended to the surface, which is also evident in Figure 3-A.

(a) The nomenclature of water masses adopted in this paper is that proposed by SAETRE and JORGE DA SILVA (1982)

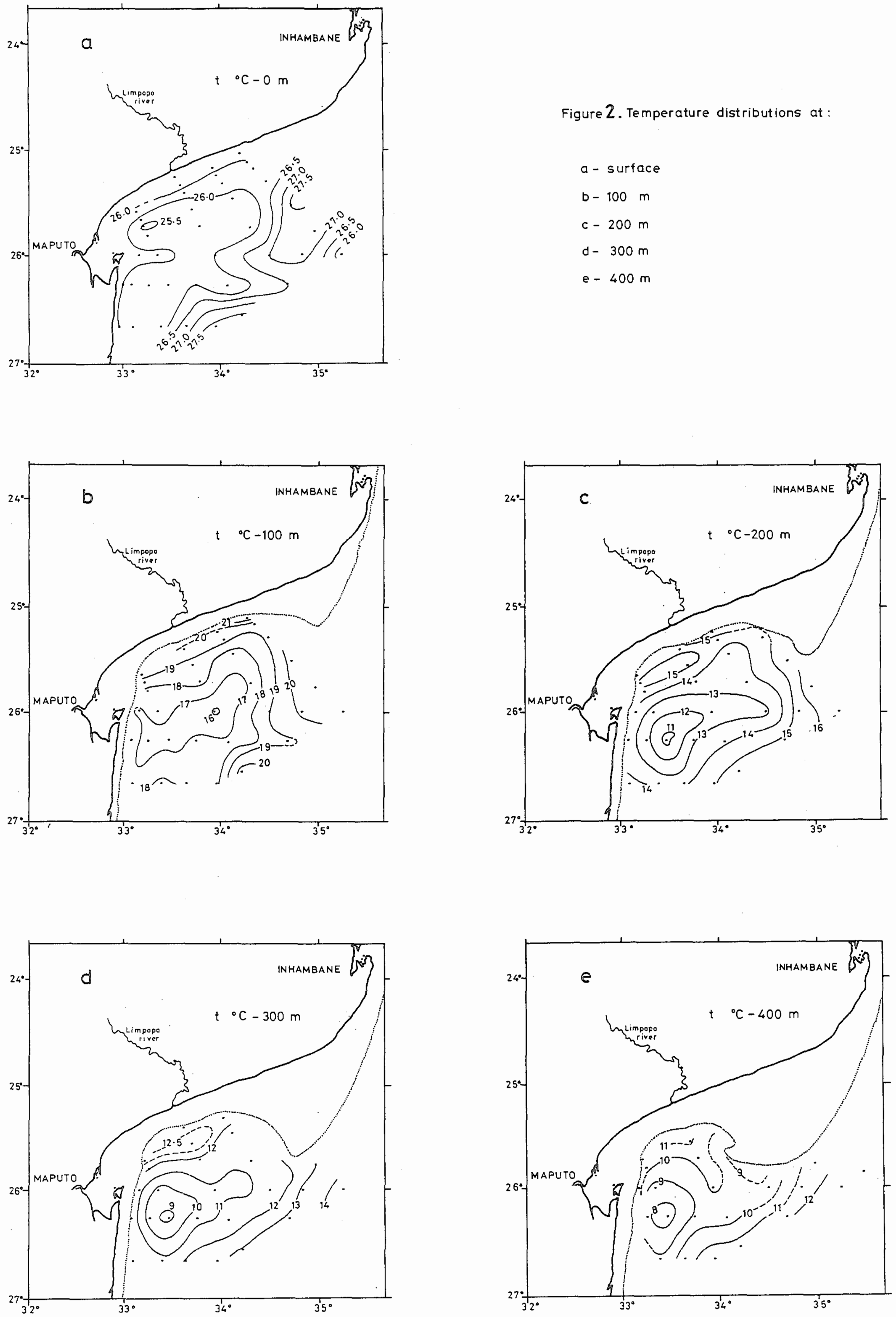

Figure 2. Temperature distributions at :

a - surface
b - 100 m
c - 200 m
d - 300 m
e - 400 m

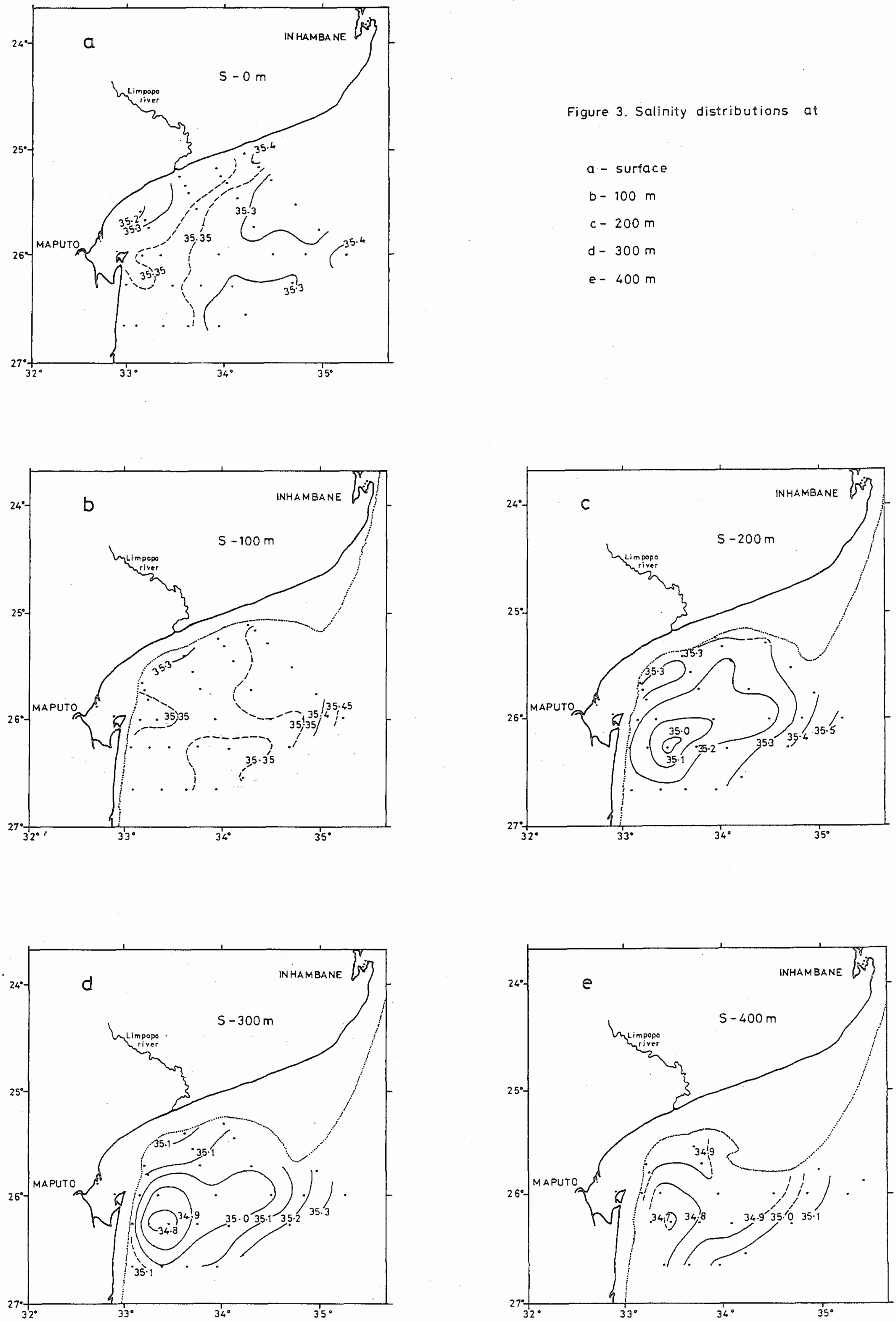

Figure 3. Salinity distributions at

a - surface
b - 100 m
c - 200 m
d - 300 m
e - 400 m

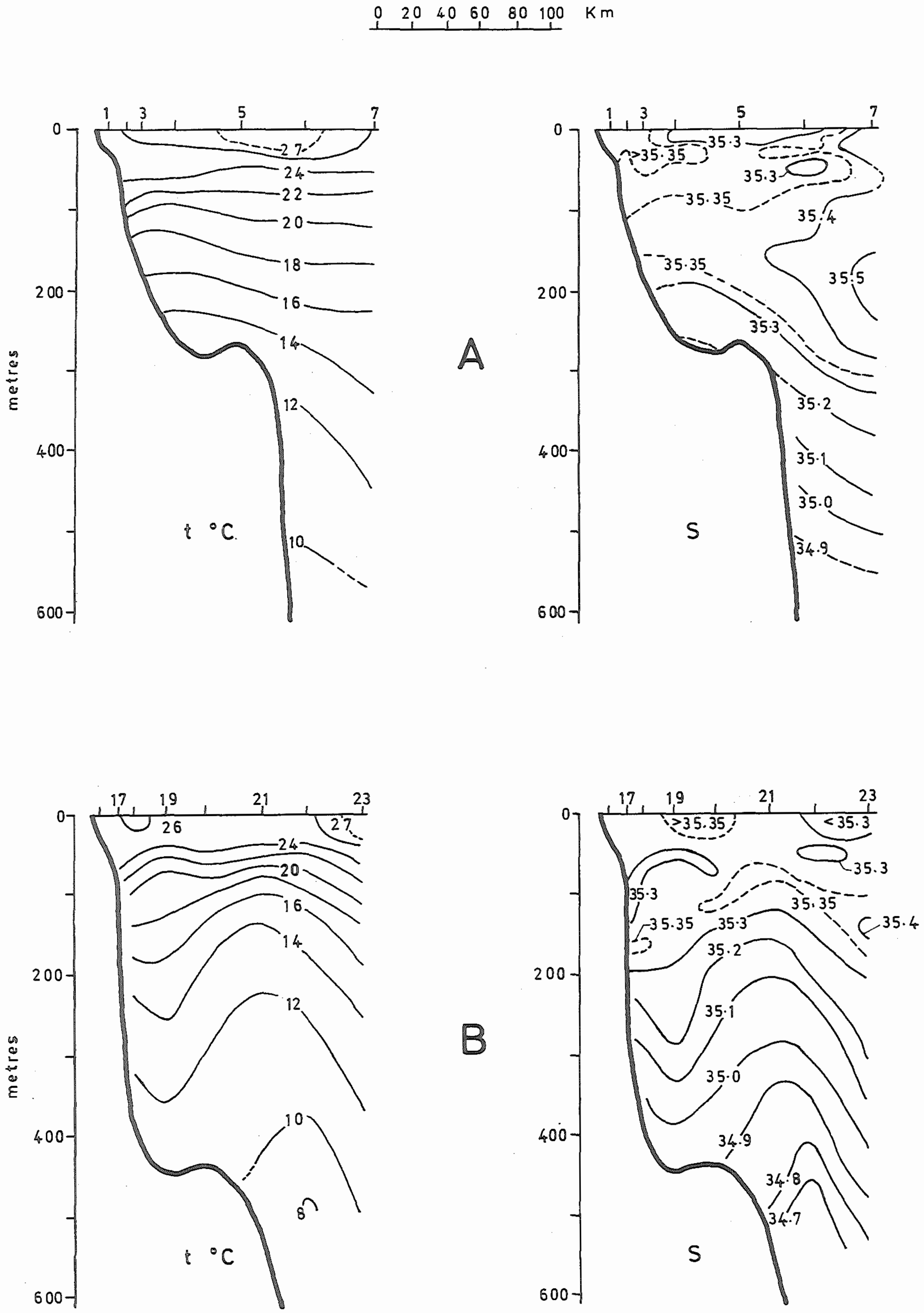

Figure 4. Temperature and salinity profiles at:

A - Section I, 4 January 1982

B - Section II, 5-6 January 1982

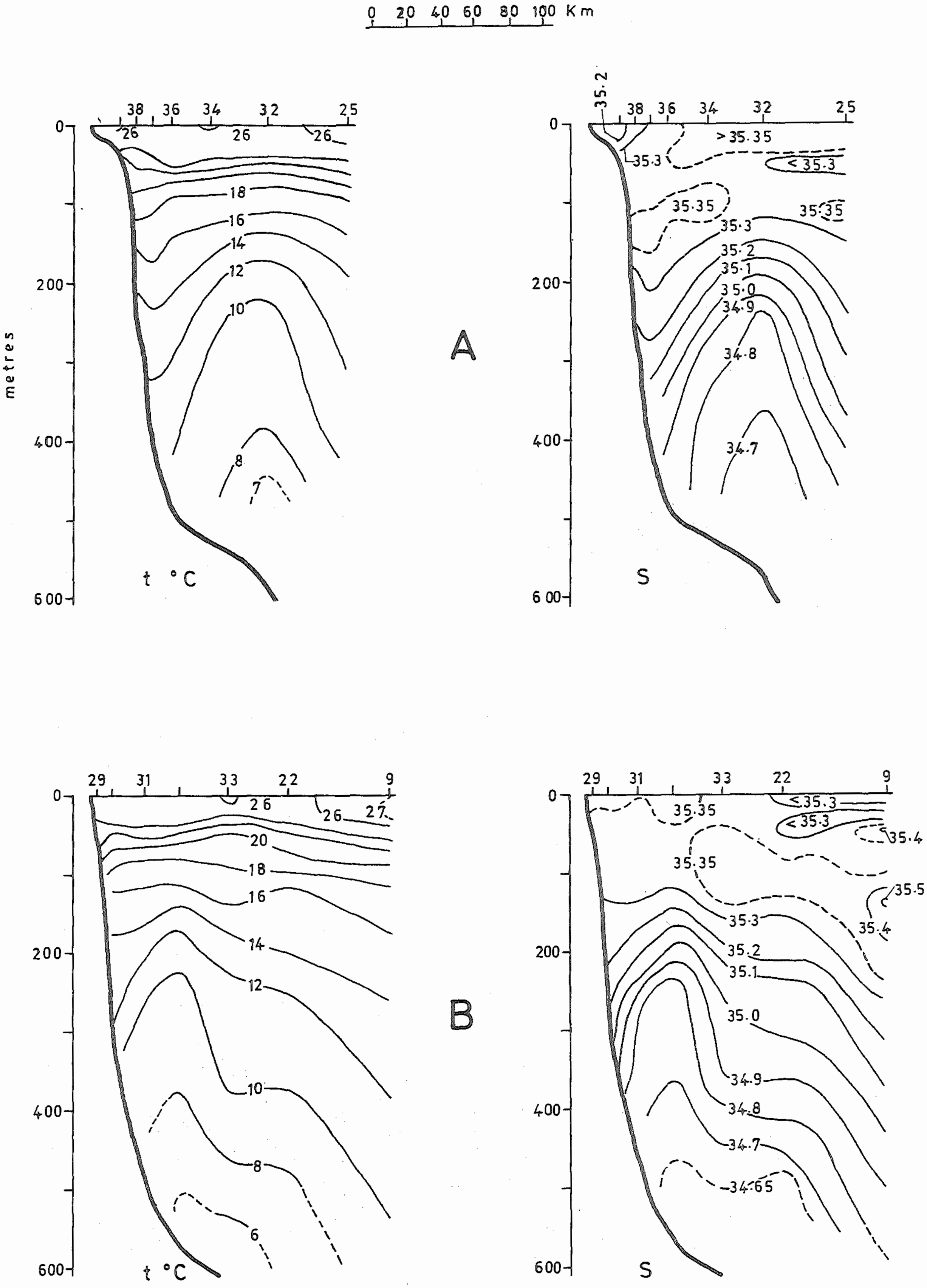

Figure 5· Temperature and salinity profiles at:

A – Section III, 5–7 January 1982

B – Section IV, 6–7 January 1982

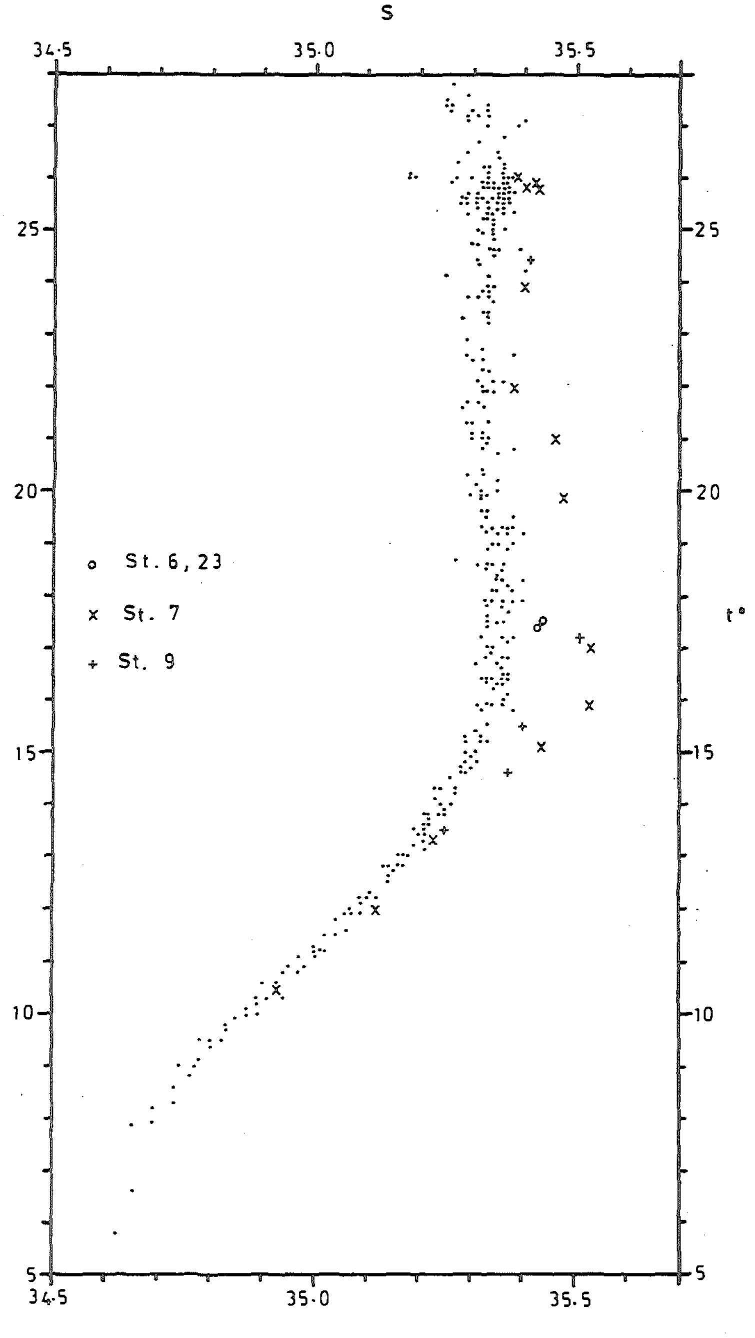

Figure 6· t – S scatter diagram

The t-S diagram of station 7 also shows a different slope of the straight portion corresponding to the Central water. According to the terminology of SAETRE and JORGE DA SILVA (1982), station 7 had a structure of type A in the upper layer while the major part of the stations had a structure of type B. The water structure of station 9 was probably a transition between types A and B. In the lower layer all deep stations reveal a structure of type A, with t-S values characteristic of Antarctic Intermediate water being found in sections III and IV (Figure 5) below 500 m. The presence of similar t-S values can also be inferred at the same depth level in section II (Figure 4-B).

5. CIRCULATION

Figures 2 and 3 clearly show a cyclonic eddy influencing the area between the 200 m and the 700 m isobaths. It can be identified in the temperature and salinity distributions at 200, 300 and 400 m. At surface and 100 m depth only the temperature distributions provide some evidence of its presence. This agrees well SAETRE and JORGE DA SILVA (1982) who claim that the eddy is particularly well developped below 200 m.

The eddy was consistently centered around 26° 15'S, 33° 30'E from 200 m downwards, but at 100 m the center was displaced some 60 km towards ENE. At 400 m the minor diameter was directed roughly ENE-WNW. This diameter apparently increased with decreasing depth, becoming the major one at 200 m. At 100 m the eddy extended towards NNE of its center, influencing the area shallower than 500 m. A total area of about 150 km x 80 km was influenced by the eddy, at least from 300 m upwards, in good agreement with SAETRE and JORGE DA SILVA (1982).

The profiles of Figures 4-B and 5 show that the eddy was located above the hook-shaped terrace. To the north of the terrace only an upward sloping of the isolines towards the coast could be observed. Apparently, the water was strongly lifted along the slope off the edge of the terrace. The upward slope of the isolines decreased towards shallower water, the lines becoming horizontal roughly over the 600 m isobath. Actually, the central area of the eddy is seen in Figures 2 and 3 to lay above that depth line. Towards the coast the isolines tended to slope downwards. However, at sections II and III (Figures 4-B and 5-A), as the bottom slope increases again inshore of the 450 m isobath, the water also tended to slope upwards roughly until 150 m depth. This feature, that may indicate a southgoing subsurface current, is apparently limited to the inshore area covered by these two sections. Indications of its presence can be found in the distributions of temperature and salinity at 200 and 300 m (Figures 2-C,D and 3-C,D).

6. EDDY EFFECTS ON THE DISTRIBUTION OF WATER MASSES

The strong vertical movement associated with the eddy has promoted the Antarctic Intermediate water to levels of 500-600 m, while its core is usually found offshore at about 900 m. The core of the Central water, characterized by the 11°C isotherm and the 35.0 isohaline (SAETRE and JORGE DA SILVA, 1982) was also lifted from about 500 m to 200 m. The lifting of intermediate water masses to subsurface levels is likely to prevent the core of the Subtropical water from reaching the eddy area. Figures 4-B and 5 do support this statement, salinities greater than 35.4 never being found over the eddy. A similar effect, is pointed out by PEARCE (1977) for the area off Durban where a dome of cool, low-salinity water was observed. On the other hand, it is interesting to note the good correspondance between the warmer surface layer (temperature above 27°C) and the shoreward limit of the 35.4 isohaline at subsurface levels, suggesting that the (modified) Equatorial Surface water was transported along the eastern margin of the eddy.

Due to the presence of the eddy a front was devellopped below the surface layer. This can be seen in Figures 4-B and 5, with mixing ocurring in the upper 100 m. The front is seen to sepparate two different water structures in the upper layer (above the core of the Central water). SAETRE and JORGE DA SILVA (1982) claimed that the transition between structures A and B is rather sharp and not gradual. The present results do support these authors' statement.

7. DISCUSSION

The temperature distribution at 150 m from the cruise of "Dr. Fridtjof Nansen" in January-March 1978 (SAETRE and JORGE DA SILVA, 1982) shows the eddy center at 26° 10'S, 33° 50'E, in very good agreement with the results of January 1982. The results concerning the longitude of the eddy center from other research cruises covering the area in the vicinity of latitude 26°S are summarized in Table 1. The agreement with the results of January 1982 is also rather good.

Table 1 - Approximate longitude of eddy center, as deduced from research done in the vicinity of latitude 26°S

VESSEL	PERIOD	LONGITUDE OF EDDY CENTER		REFERENCES	
Com. R. Girand	Oct. 1957	east of	33° 30'E	MÉNACHÉ	(1963)
Africana II	Jun. 1961		33° 40'E	ORREN	(1963)
Atlantis II	Nov. 1963	west of	34° 30'E	JORGE DA SILVA et al.	(1981)
Atlantis II	Jun. 1965		34° 10'E	ibid	
Ariel	Aug. 1968	east of	33° 30'E	ibid	
Dr. Fr. Nansen	Sep. 1977	east of	33° 30'E	Unpublished	
N. Reshetnyak	Dec. 1978	west of	34° 30'E	ANON.	(1979)
E. Haeckel	Mar. 1979		33° 45'E	JORGE DA SILVA et al.	(1981)
N. Reshetnyak	May 1979		33° 50'E	ANON.	(1981)
A. V. Humboldt	Mar. 1980		33° 40'E	NEHRING	(1983)
E. Haeckel	Aug. 1980	ca.	33° 30'E	BRINCA et al.	(1982)
Dr. Fr. Nansen	Oct. 1980	west of	33° 55'E	Unpublished	

Altoghether, these results suggest that the eddy is quasi-stationary. On the other hand, the comparison of the horizontal distributions of temperature and salinity (Figures 2 and 3) with the bottom topography (Figure 1) strongly suggests that the eddy is topographically induced.

The presence of a semi-permanent cyclonic eddy off the Natal coast has been mentioned by several authors (ANDERSON, SHARP and OLIFF, 1970; PEARCE, 1975; PEARCE, 1977; PEARCE, SCHUMANN and LUNDIE, 1978; MALAN and SCHUMANN, 1979; SCHUMANN, 1982). PEARCE (1977) suggested that it might be induced by the alongshore terrace-like bottom topography of the area. GILL and SCHUMANN (1979) have shown that the return flow off Durban is probably due to the inherent vorticity structure of the Agulhas Current over the shallower shelf regions, forcing the water to move inshore and then northwards.

The changes in the direction of the coastline, as well as in the bottom topography, between latitudes 24° and 27°S are much more pronounced than in the Natal bight. Interestingly, the horizontal dimensions of the eddy in Delagoa Bay, as well as its vertical extent, appear to be much larger than those of the eddy off Durban. Once we are dealing with the same current system it is not unlikely that the arguments of GILL and SCHUMANN (1979) will be also valid for the Delagoa Bay area.

PEARCE et al. (1978) found it unlikely that a single cyclonic eddy of the scale of the Natal bight will be a permanent feature. They beleive it is more probable that, at any one time, a succession of eddies of different scales may be present in the area as a result of shear processes and meteorological forcing. In the Delagoa Bay area, however, no evidence was ever found of more than one cyclonic eddy. Most on the contrary, the best available data point to the presence of a single cyclonic eddy between the 200 m isobath and the Mozambique/Agulhas Current (see, for instance, SAETRE and JORGE DA SILVA, 1982).

The eddy was not always observable as clearly as in January 1982. Actually, in December 1978 (ANON., 1979) the eddy could only be detected below 200 m and was clearer in the salinity and phosphate profiles than in the temperature profile. In August-September 1978 (ANON., 1978) only an upward sloping of the isolines towards the coast could be observed in the upper 500 m. This could have been caused by the presence of a streched anticyclonic eddy between latitudes 21° and 26°S (SAETRE and JORGE DA SILVA, 1982) that had probably forced the eddy towards the coast, where the grid of stations was rather poor. On the other hand, SAETRE and JORGE DA SILVA (1982) suggested that the apparent intensification of the eddies during the southern summer in levels shallower than 200 m is probably related to a lifting of the baroclinic structure during that period.

The subsurface current over the escarpment shoreward of the terrace, suggested by Figures 2-C,D, 3-C,D, 4-B and 5-A, may also have been topographically induced. Part of the water transported along the northern margin of the eddy over the terrace area with the minimum slope (between the 500 m and 400 m isobaths) may have turned backwards on reaching greater bottom slopes, while another part followed the general cyclonic movement.

PEARCE et al. (1978) found it likely that the frequently observed southerly flow close inshore north of Durban would be associated with an anticyclonic eddy that might form in the lee of the Durban Bluff. Evidence of such anticyclonic eddy was obtained by MALAN and SCHUMANN (1979) from a LANDSAT image of the area (the cyclonic eddy off Durban was also clear in the image). The subsurface current found in Delagoa Bay might also have been the inshore margin of a small anticyclonic eddy. However, no conclusive evidence was obtained about its effect at surface.

8. CONCLUSIONS

The results obtained thus far suggest that the topography of the Delagoa Bay area is likely to induce important modifications in the circulation pattern and the distribution of water masses in the upper and intermediate layers. Apparently the core of the southgoing Mozambique/Agulhas Current tends to follow the direction of the 1,000 m isobath, giving rise to the development of a cyclonic eddy between the current core and the 200 m isobath. In January 1982, a total area of about 150 km x 80 km appeared to be influenced by this eddy.

Comparison with results from previous cruises reveals that the eddy can be considered quasi-stationary. Oscillations of the current core are, however, likely to induce oscilations in the position of the eddy center. Vertical changes of the baroclinic structure might also be reflected in the intensity of the eddy in the upper layer.

AKNOWLEDGEMENTS

I am grateful to Dr. R. Saetre for his critical review of the manuscript and very helpful suggestions. Thanks are also due to Dr. P. Contreras for his comments on the first draft. I am indebted to the officers and crew of the R/V "Ernst Haeckel" for their cooperation during the research cruise.

REFERENCES

ANDERSON, F.P., SHARP, S.O. and OLIFF, W.D. (1970) The reaction of coastal waters off Durban to changes in atmospheric pressure. *Symposium on Oceanography in South Africa,* Durban, *paper H2:* 22 pp.

ANON. (1978) Relatório preliminar da 1^{a} parte da Expedição Conjunta Moçambicano-Soviética de Investigação Científica no Domínio das Pescas realizada a bordo do SRTM "Myslitel" de Agosto a Novembro de 1978. *Informação N^{o} 1, Serviço de Investigações Pesqueiras*, Maputo: 27 pp.

ANON. (1979) Relatório preliminar da 2^{a} parte da Expedição Conjunta Moçambicano-Soviética de Investigação Científica no Domínio das Pescas realizada a bordo do SRTM "Nikolay Reshetnyak" de Novembro de 1978 a Março de 1979. *Informação N^{o} 2, Serviço de Investigações Pesqueiras*, Maputo: 12 pp.

ANON. (1981) Relatório preliminar da 3^{a} parte da Expedição Conjunta Moçambicano-Soviética de Investigação Científica no Domínio das Pescas realizada a bordo do SRTM "Nikolay Reshetnyak" de Maio a Agosto de 1979. *Informação N^{o} 3, Instituto de Desenvolvimento Pesqueiro*, Maputo: 12 pp.

BRINCA L., REY F., SILVA C. and SAETRE R. (1981) A survey on the marine fish resources of Moçambique, Oct.-Nov. 1980. *Reports on surveys with the R/V "Dr. Fridtjof Nansen"*. *Instituto de Desenvolvimento Pesqueiro*, Maputo. *Institute of Marine Research*, Bergen. 58 pp.

BRINCA L., BUDNICHENKO V., JORGE DA SILVA A. and SILVA C. (1982) A report on a survey with the R/V "Ernst Haeckel" in July-August 1980: shallow-water shrimp and by-catch; oceanography. *Informação N^{o} 11, Instituto de Desenvolvimento Pesqueiro* Maputo: 106 pp.

JORGE DA SILVA A., MUBANGO A. and SAETRE R. (1981) Information on oceanographic cruises in the Mozambique Channel. Revista de Investigação Pesqueira, N^{o}. 2, Instituto de Desenvolvimento Pesqueiro, Maputo: 89 pp.

LUTJEHARMS J.R.E. (1972) The south west Indian Ocean - a guide to oceanological research. Department of Oceanography, University of Cape Town.

MALAN, O.G. and SCHUMANN, E.H. (1979) Natal shelf circulation revealed by Landsat imagery. South African Journal of Science, 75: 136-137.

MENACHE M. (1963) Première campagne océanographique du "Commandant Robert Giraud" dans le canal de Mozambique, 11 Octobre-28 Novembre 1957. Cahiers océanographiques, 15 (4): 224-35.

NEHRING, D. (Ed.) (1983) The oceanological conditions in the western part of the Mozambique Channel in February-March 1980. Geodätische und Geophysikalische Veröffentlichungen, Reihe IV (in press)

ORREN M.J. (1963) Hydrological observations in the south west Indian Ocean. Investigational Report, Division of Sea Fisheries of South Africa, 45: 61 pp.

PEARCE, A.F. (1975) Ode to an eddy. Nature, 258: 486

PEARCE, A.F. (1977) Some features of the upper 500 m of the Agulhas Current. Journal of Marine Research, 35 (4): 731-753

PEARCE, A.F., SCHUMANN, E.H. and LUNDIE, G.S.H. (1978) Features of the shelf circulation off the Natal coast. South African Journal of Science, 74: 328-331

SCHUMANN, E.H. (1982) Inshore circulation of the Agulhas Current off Natal. Journal of Marine Research, 40 (1): 43-55

BUDNICHENKO V. A., LEDNICHENKO V. A., MIROSHNIKOV V. S., PORTSEV P.I. and SAVICH M. S. (1977) Results obtained from the "Aelita" exploratory surveys undertaken in the shelf and open waters continuous to the coast of the People's Republic of Mozambique (May 1976 through August 1977). AzcherNIRO, Kerch.

EROFEEVA E.E. (1970) On the seasonal variation of oceanographic conditions in the Boa Paz Bank area (East Africa). Trudi AzcherNIRO, 29: 34-44.

GILL, A.E. and SCHUMANN, E.H. (1979) Topographically induced changes in the structure of an inertial coastal jet: application to the Agulhas Current. Journal of Physical Oceanography, 9: 975-991

GRÜNDLINGH, M.L. (1974) A description of inshore current reversals off Richards Bay based on airborne radiation thermometry. Deep-Sea Research, 21 (1): 47-55.

GRÜNDLINGH, M.L. (1980) On the volume transport of the Agulhas Current. Deep-Sea Research, 27 A (6): 557-563

HARRIS, T.F.W. (1972) Sources of the Agulhas Current in the spring of 1964. Deep-Sea Research, 19 (9): 633-650

HARRIS, T.F.W., LEGECKIS, R. and VAN FOREEST, D. (1978) Satellite infra-red images in the Agulhas Current System. Deep-Sea Research, 25 (6): 543-548

INTERNATIONAL HYDROGRAPHIC ORGANIZATION, INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (1981) Standardization of undersea feature names. Guidelines proposal form terminology. International Hydrographic Bureau, Monaco: 27 pp.

ISAENKO L.A., LANIN V.I., TYULEVA L.S. and KORZUN Y.V. (1980) Report on the work of the Second Soviet-Mozambican Expedition on Fisheries Research (August 1978 to September 1979) AzcherNIRO. Kerch.

SAETRE R. and JORGE DA SILVA A. (1982) Water masses and circulation of the Mozambique Channel. Revista de Investigação Pesqueira, Nº. 3, Instituto de Desenvolvimento Pesqueiro, Maputo, 83 pp.

SAETRE R. and PAULA E SILVA R. (1979) The marine fish resources of Mozambique. Reports on surveys with the R/V "Dr. Fridtjof Nansen". Serviço de Investigações Pesqueiras, Maputo. Institute of Marine Research, Bergen, 179 pp.