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THE PRESENT EVIDENCE FOR SUMMER UPWELLING OFF THE NORTH EAST COAST OF VICTORIA

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SUMMARY

An examination of the present information indicates that upwelling occurs during summer along the north east coast of Victoria (Lakes Entrance - Gabo Is.). Although this upwelling has an appreciable effect on surface temperature (14-15° onshore relative to 23°C offshore) its effect on nitrate concentrations is much less than for other upwelling regions off northern NSW. This is attributed to a high degree of annual winter overturn of eastern Bass Strait waters to depths below that of the source water of the upwelling. The causes of the upwelling are not known; wind does not appear a sufficient explanation; an association with an anticyclonic eddy may be significant and the local bottom topography may provide a final trigger.

CONTENTS

1. INTRODUCTION

Two areas of known upwelling around Australia have already been described. These are off Evans Hd (Rochford (1972) and off Laurieton (Rochford 1975) (Fig. 1). Other areas of suspected upwelling or enrichment by other processes are thought to exist elsewhere around Australia.

This paper is the first of a series which will assemble and review the evidence to date for upwelling or other forms of enrichment at these other locations. The location reviewed in this paper is the coastal zone between Lakes Entrance and Gabo Is. (Victoria) (Fig. 1).

2. DATA SOURCES

The data available are summarized in Tables 1 and 2. Three kinds are available:

(a) The research cruises of HMAS *Diamantina* and *Kimbla* from which the vertical structure, nutrient status and general dynamics of the region can be ascertained (Table 1).

(b) The surface temperatures from an airborne infrared radiometer (Hynd 1969) on flights since 1975 when the flight plan has been over the north eastern coast of Victoria. These data have provided nearly synoptic and detailed information of several upwelling events (Table 1).

(c) The surface temperature-salinity records from merchant ships plying between Gabo Is. and Wilsons Promontory since 1971, on direct passage, which provide information about the seasonality of the upwelling, albeit along the offshore margin only (Table 2).

Copies of these data are available:

(a) and (c) from World Oceanographic Data Centres A and B;

(b) from CSIRO Division of Fisheries and Oceanography, Cronulla.

3. EVIDENCE OF UPWELLING

During the cruise of HMAS *Kimbla* (28/2-1/3/76) in the northern half of the eastern approach to Bass Strait, upwelling was occurring on, or had occurred earlier than the 28th February. Coastal temperatures were low (<14°C) in relation to quite high offshore temperatures of between 22 and 24°C, (Fig.2) and coastal nitrate values were relatively high (>2.0 μg-at/l) compared with offshore values of less than 0.5 μg-at/l (Fig. 3). There were very marked horizontal gradients in surface temperatures (Fig. 2) and in temperatures at 30m (Fig. 4) indicative of a strong long-slope current to the west.

On the 15-16/3/76 surface radiometer temperatures along the north east coast of Victoria were colder than elsewhere (Fig. 5), indicating that upwelling on a reduced scale (minimum surface temperatures between 17 and 18°C) was again occurring, or had occurred. Again the presence of a marked surface temperature gradient indicated a current flow to the west.

On an earlier cruise of HMAS *Kimbla* (1-5/2/76) in the same area, there was by contrast (Fig. 6) no evidence of a strong gradient in the surface temperatures.

On the 16-17/2/76 surface temperatures less than 16°C indicative of an upwelling event on or about these dates, were found from Rame Head to S.E. of Lakes Entrance (Fig. 7).

It is possible therefore that upwelling in the area Rame Head to Conran Pt and offshore occurred more or less continuously from mid February to mid March. However experience elsewhere (north coast of New South Wales, Rochford 1972, 1975) suggests that this upwelling could have been intermittent during this period.

On the cruise of HMAS *Kimbla* (28/2-1/3/76), the temperatures at 30m indicate an enclosed area of warm water accumulation (A Fig. 4) south of the coastal upwelling region. This accumulation of warm water extended to depths of at least 250m on this cruise (Fig. 8). No such enclosed warm water accumulation occurred on the earlier *Kimbla* cruise (1-5/2/76) (Fig. 9). It is presumed that the warm water accumulation at A (Fig. 4) during late February - early March was caused by an anticyclonic eddy, which could have been a major contributor to the upwelling during that time.

4. CHARACTERISTICS OF THE UPWELLING

(a) Annual timetable

From the summary of relevant data of the region (Tables 1 and 2), the predominant months for an upwelling event seem to be mid to late February until the end of March each year. There is no evidence from the merchant ship data for other months of the year that lowered coastal surface temperatures indicative of upwelling occur at other times.

(b) Area of upwelling

The limited information suggests that, as off the north coast of New South Wales (Rochford 1972 and 1975), the area of upwelling is confined to a narrow coastal zone of some 5 miles width and some 30 miles in coastwise extent (Fig. 2). However during the less intense periods of upwelling (15-16/3/76 Fig. 5) the area involved may be reduced by attenuation to the west.

(c) Location of upwelling

The area involved in upwelling events during February 1971 - March 1976 (Tables 1 and 2) extended from Gabo Is. in the east to Lakes Entrance in the west. There was some evidence, from radiometer measurements of a cold water occurrence further west, that upwelling might also occur on and over the eastern entrance to Bass Strait itself (Fig. 10). However these cold waters could equally well be the result of westward drift of cold upwelled water during summer (Vaux and Olsen 1961) or of strong vertical mixing in the region itself. No nutrient values were available to evaluate the fertility potential of either of these processes.

(d) Depth of origin of upwelled water

The depth of 14°C water (upwelled water Fig. 2) was constant at around 100m along the continental slope during both an upwelling and non upwelling situation (Figs. 8 and 9). However further offshore the depth of the 14°C isotherm was controlled during the upwelling by the anticyclonic eddy previously discussed (Section 3). Near the coast dynamic tilting probably contributed greatly to the elevation of the 14°C isotherm. The depth of origin of the upwelled water is therefore thought to be around 100m, not very dissimilar to the depth of origin of upwelled water off northern NSW (Rochford 1972 and 1975). Rates of ascent of the 14°C water cannot be established.

(e) Enrichment status

The maximum surface nitrate during the upwelling of greatest intensity in eastern Bass Strait was 2.8 μg-at/l (28/2-1/3/76 Table 1). Relative to peak nitrate values of 6.7 μg-at/l at Laurieton (Rochford 1975) and of 4.1 μg-at/l at Evans Hd (Rochford 1972), the Bass Strait nutrient enrichment would presumably have less effect on productivity than in the areas of Evans Hd and Laurieton. The relatively low nitrate values of the eastern Bass Strait upwelled water, despite its very low temperature, can possibly be attributed to the annual renewal by convective winter overturn of the upper 300m waters in eastern Bass Strait (Boland 1971). This results in the upper 300m of water, for the most part, being formed annually from the nutrient impoverished sub-tropical surface layers, resulting from biological production in the previous summer and autumn.

5. METEOROLOGICAL CONDITIONS

Table 3 shows the monthly average direction of wind flow at Gabo Is. at the eastern limit of Bass Strait (Fig. 1). At both 0900 and 1500 the expectancy of winds from the NE, which would provide an offshore component of water flow due to wind stress in the upwelling area, is only marginally greater in February than in other months. Moreover winds from the SW or W can occur just as frequently during the February-March upwelling period.

Daily pressure charts (Bureau of Meteorology 1976) for the days just prior to, or during the February-March upwelling period in 1976, show the occurrence of a cyclonic low (≈1000 m bars) just south of Tasmania on 29/2/76, but disappearing by 2/3/76.

Winds during this period would have been from the North or North West, and could have caused an offshore movement of surface waters away from the coast off the NE coast of Victoria. However the depression is thought to have been too short-lived to be a prime factor in the upwelling.

6. POSSIBLE CAUSES

The occurrence of the upwelling event in early March 1976 was associated with a well developed anticyclonic eddy offshore. This eddy caused a strong dynamic uplift of the 14°C source water of the upwelling event, and could have either directly induced upwelling or facilitated the final uplift to the surface by other factors. Wind stress however does not appear to be important and other contributing factors are difficult to suggest.

The bathymetry of the seabed along the continental slope indicates a marked indentation in the vicinity of the upwelling (Fig. 10). An association between the location of such a bathymetric feature and the upwelling region off Laurieton NSW has been shown (Rochford 1975). It is likely that the strong long slope current of the anticyclonic eddy would have a component of flow directed up such an indentation.

The initial location of upwelling may therefore be determined by this bathymetric feature in conjunction with a strong westward flowing current across it. Moreover in the region of cold water accumulation in the centre of the eastern approaches to Bass Strait (Fig. 10) there is another declivity (Fig. 10) which could be a factor causing the vertical mixing thought to be responsible for the cold water at the surface.

7. CONCLUSIONS

(1) Upwelling has been shown to occur off NE Victoria in limited areas and for short intervals during February-March of several years.

(2) No definite causes of this upwelling can be shown although local bathymetry, strong currents around an anticyclonic eddy, and some wind stress effects could be involved.

(3) Despite pronounced lowering of surface temperatures, the nutrient enrichment in terms of surface nitrates is lower than that of the upwelling situation off Evans Hd and off Laurieton.

REFERENCES

AUSTRALIA. Bureau of Meteorology. (1976)
Monthly weather review, NSW. January, February, March, 1976.

BOLAND, F.M. (1971)
Temperature salinity anomalies at depths between 200m and 800m in the Tasman Sea.
Aust. J. Mar. Freshwater Res. 22, 55-62.

HYND, J.S. (1969)
Isotherm maps for tuna fishermen.
Aust. Fish. Leafl. No. 14.

ROCHFORD, D.J. (1972)
Nutrient enrichment of East Australian coastal waters. I. Evans Head upwelling.
CSIRO Aust. Div. Fish. Oceanog. Tech. Pap. No. 33.

ROCHFORD, D.J. (1975)
Nutrient enrichment of East Australian coastal waters. II. Laurieton upwelling.
Aust. J. Mar. Freshwater Res. 26, 233-43.

ROYAL AUSTRALIAN NAVY HYDROGRAPHIC DEPARTMENT (1969)
Australia pilot Vol. 2. 5th edn. 1969.

VAUS, D. and OLSEN, A.M. (1961)
Use of drift bottles in fisheries research.
Aust. Fish. Leafl. No. 3.

TABLE 1. Cruises and radiometer flights in the Bass Strait upwelling area

Dates	Cruise	Upwelling at surface				
		Present	Location	Min.Temp (°C)	Max. NO_3 μg-at/l	
22-26/2/61	*Gascoyne*	-	-	-	-	-
14-16/1/75	Radiometer	-	-	-	-	-
22-24/1/75	Radiometer	-	-	-	-	-
28/29/1/75	Radiometer	-	-	-	-	-
3/2/75	Radiometer	-	-	-	-	-
10-11/2/75	Radiometer	-	-	-	-	-
17/2/75	Radiometer	-	-	-	-	-
25-27/2/75	Radiometer	*	Eastern Bass Strait	<17	-	-
10-12/3/75	Radiometer	-	-	-	-	-
17/3/75	Radiometer	*	Gabo Is. to L.Entrance	<17	-	-
24-25/3/75	Radiometer	-	-	-	-	-
20-22/1/76	Radiometer	-	-	-	-	-
1-5/2/76	*Kimbla*	-	-	-	-	-
16-17/2/76	Radiometer	*	C.Everard to Conran Pt	<16	-	-
28/2-1/3/76	*Kimbla*	*	C.Everard to Conran Pt	<14	-	2.8
15-16/3/76	Radiometer	*	Gabo Is. to Conran Pt	<18	-	-
29-31/3/76	Radiometer	-	-	-	-	-

Table 2. Merchant ship cruises in the vicinity of the Bass Strait upwelling area during February - March (1971-75)

Date	Upwelling				Remarks
	Present	Absent	Sur.Temp.	Location	
Feb. 1971	*	-	<16	S.W. of Gabo Is.	Accompanied by very low S‰
Mar. 1971	*	-	<17	S. of Gippsland L.	
Feb. 1972	*	-	<17	S.W. of Gabo Is.	
Mar. 1972	?	?	-	-	Insufficient coastal data
Feb. 1973	-	*	-	-	
Mar. 1973	-	*	-	-	
Feb. 1974	?	?	-	-	Insufficient coastal data
Feb. 1975	-	*	-	-	
Mar. 1975	-	*	-	-	

TABLE 3. Average Wind directions at Gabo Is. (R.A.N. 1969)
N.B. only dominant directions indicated

Month	0900 hrs Percentage of observations from			1500 hrs		
	NE	SW	W	NE	SW	W
January	29	33	12	29	43	6
February	35	18	21	36	30	6
March	22	16	33	31	27	10
April	19	21	32	28	35	17
May	16	17	29	27	34	29
June	7	19	36	12	33	27
July	10	13	37	19	34	24
August	17	19	28	27	39	9
September	18	21	28	26	44	7
October	30	33	14	30	39	3
November	29	33	16	34	36	5
December	28	30	18	30	32	10

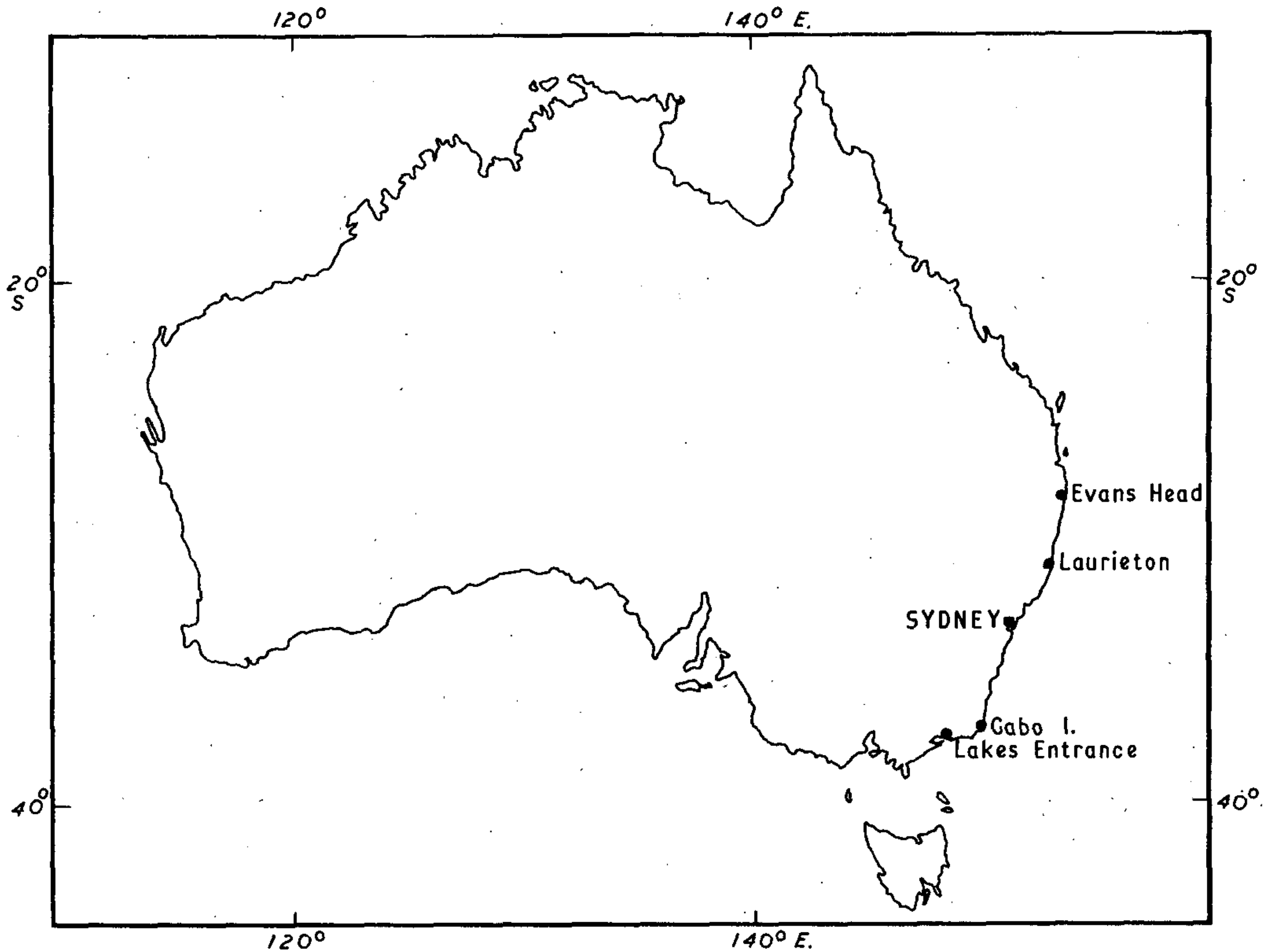

Fig. 1 Chart showing location of Lakes Entrance-Gabo Is. area in relation to other known upwelling areas off Evans Hd and Laurieton NSW.

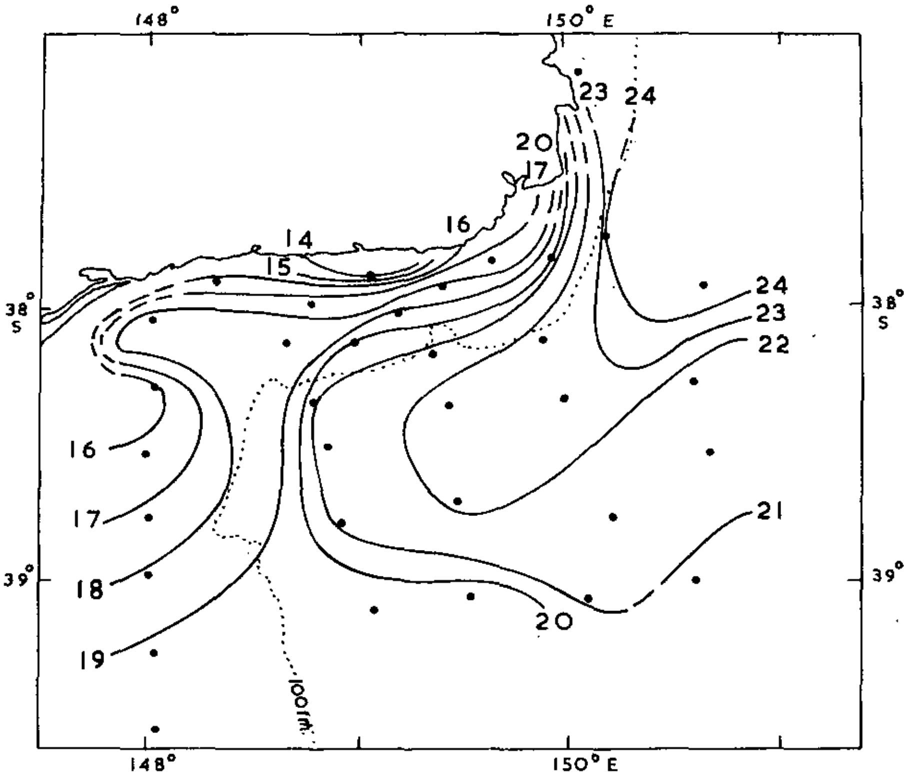

Fig. 2 The distribution of surface temperatures (°C) on *Kimbla* cruise 8103, 28/2-1/3/76.

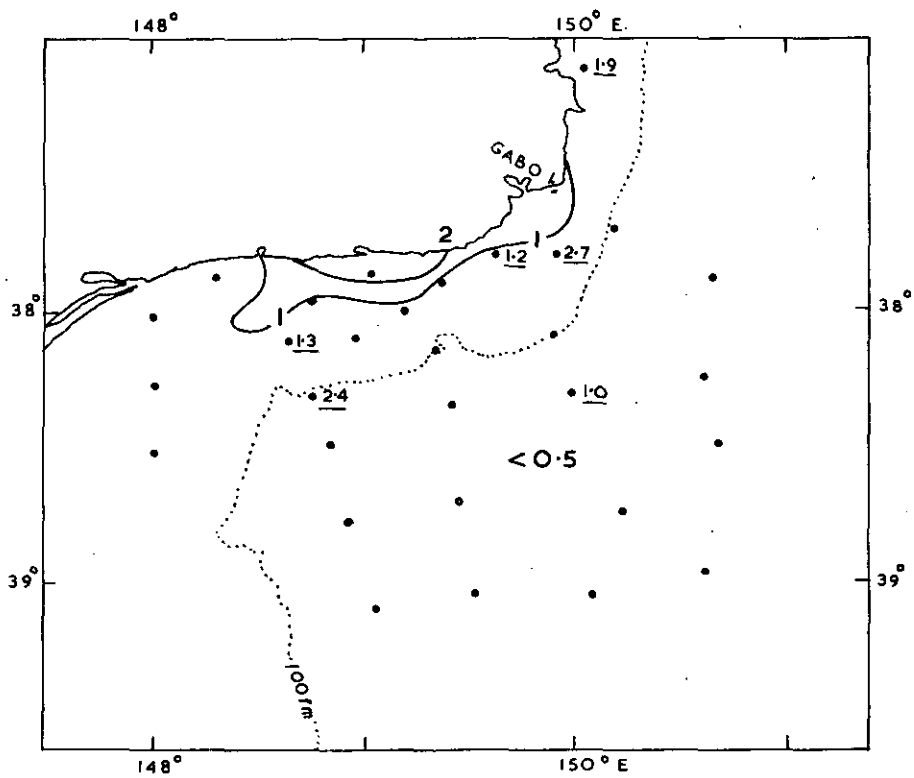

Fig. 3 The distribution of surface nitrate nitrogen (μg-at/l) on *Kimbla* cruise 8103. Underlined values: high nitrate not directly attributable to upwelling.

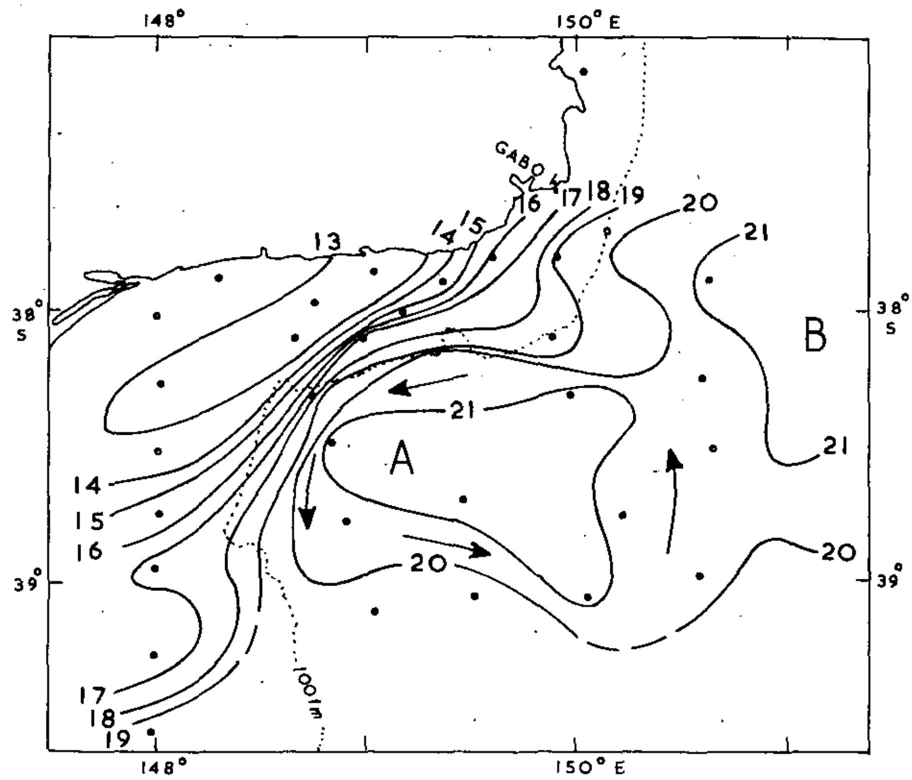

Fig. 4 The distribution of temperatures (°C) at 30 m on *Kimbla* cruise 8103, 28/2-1/3/76.

A Anticyclonic eddy

B Suspected second anticyclonic eddy

→ Direction of flow around A

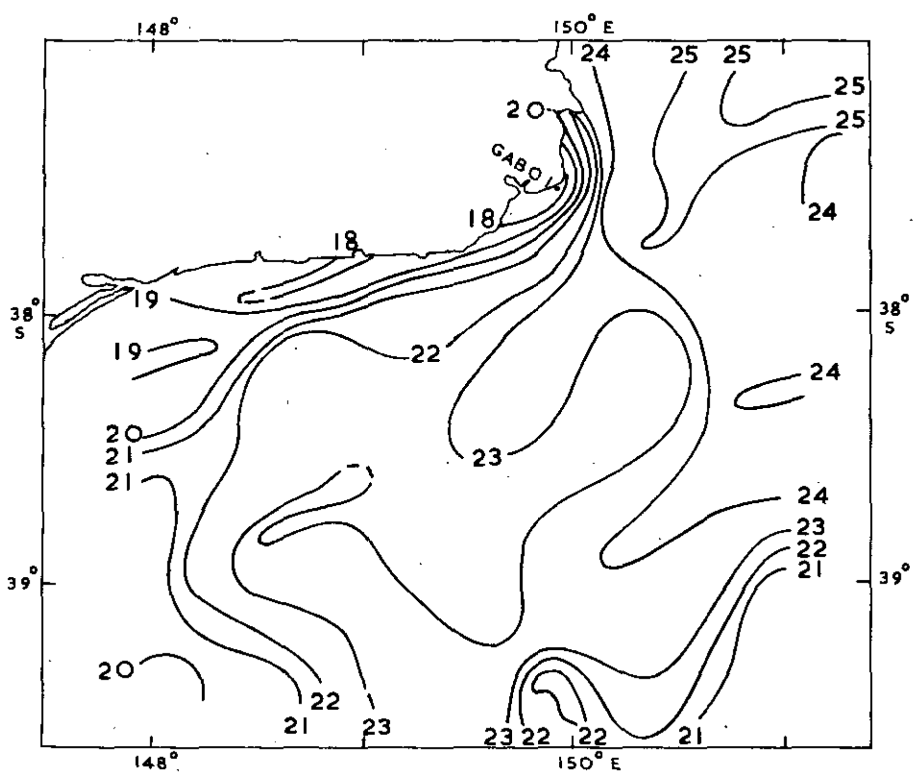

Fig. 5 Distribution of surface temperatures (°C) from aircraft radiometer flights 15-16/3/76.

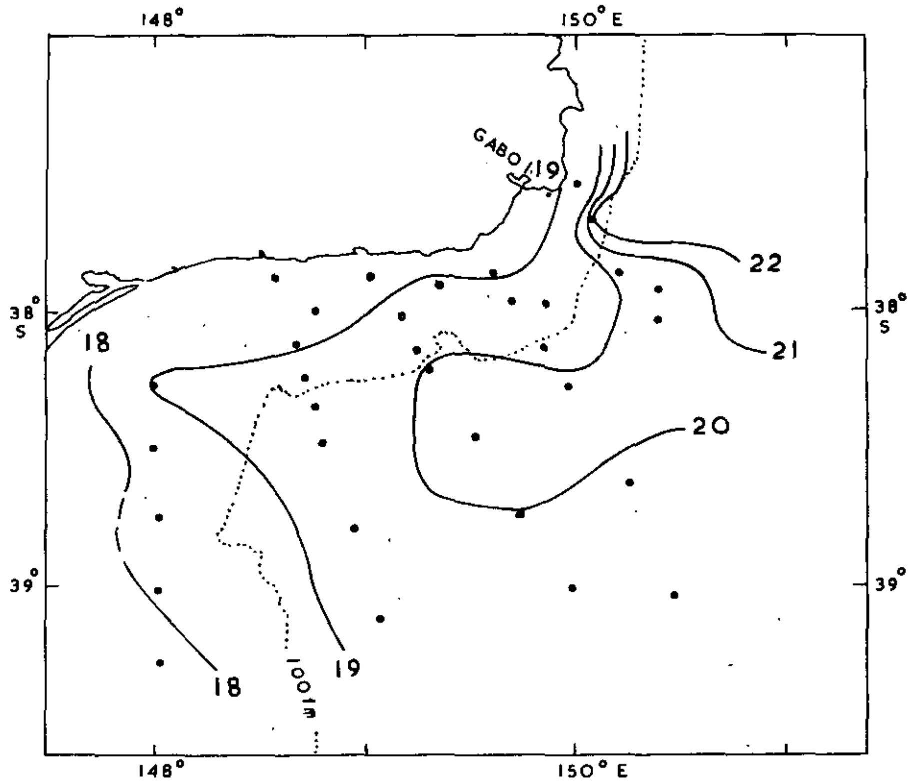

Fig. 6 Distribution of surface temperatures (°C) on *Kimbla* cruise 8101, 1-5/2/76.

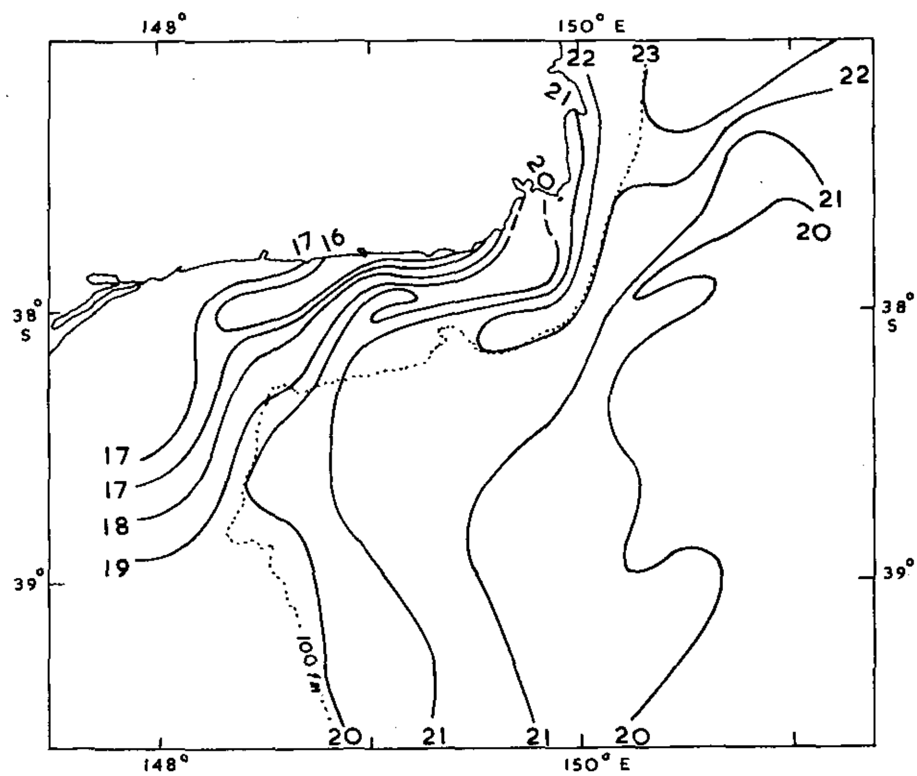

Fig. 7. Distribution of surface temperatures (°C) from aircraft radiometer flights 16-17/2/76.

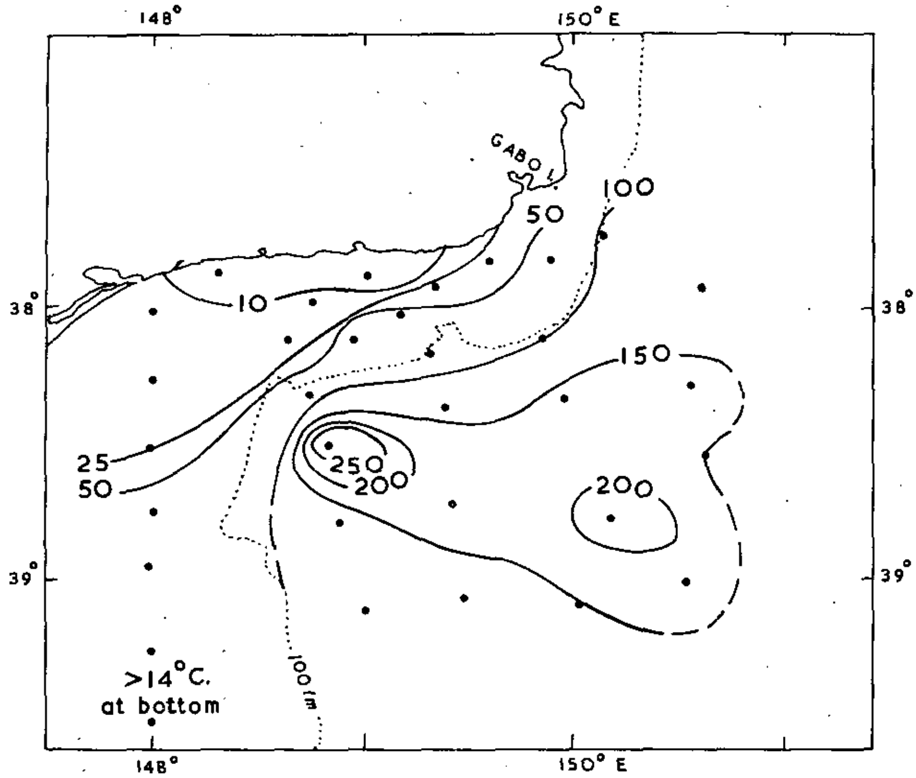

Fig. 8 Depth (m) of the 14°C isotherm on *Kimbla* cruise 8103, 28/2-1/3/76.

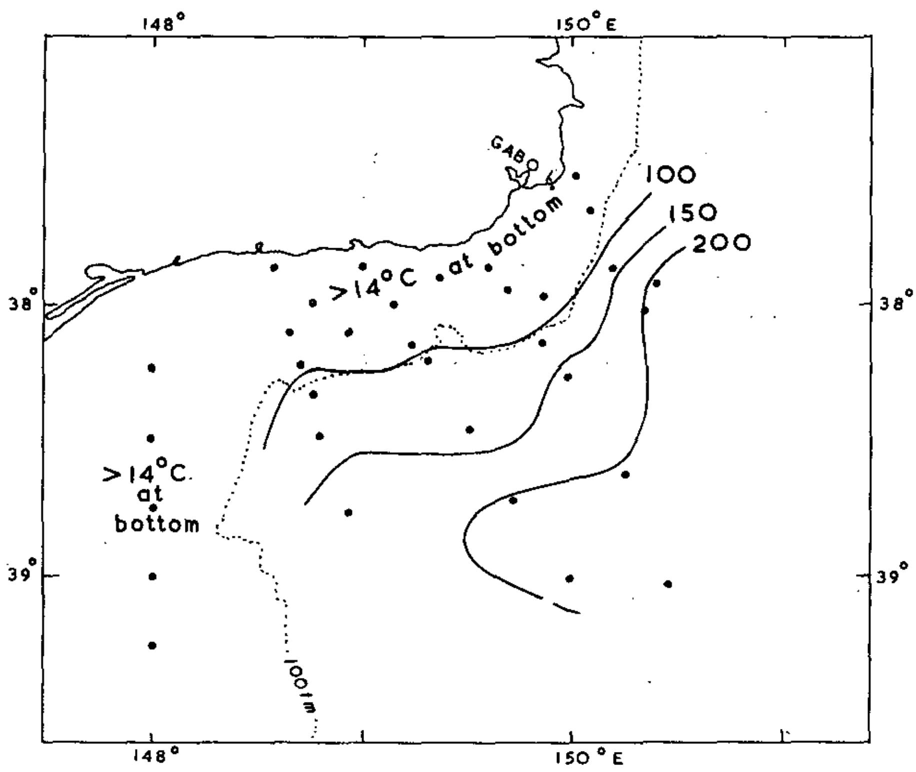

Fig. 9 Depth (m) of the 14°C isotherm on *Kimbla* cruise 8101, 1-5/2/76.

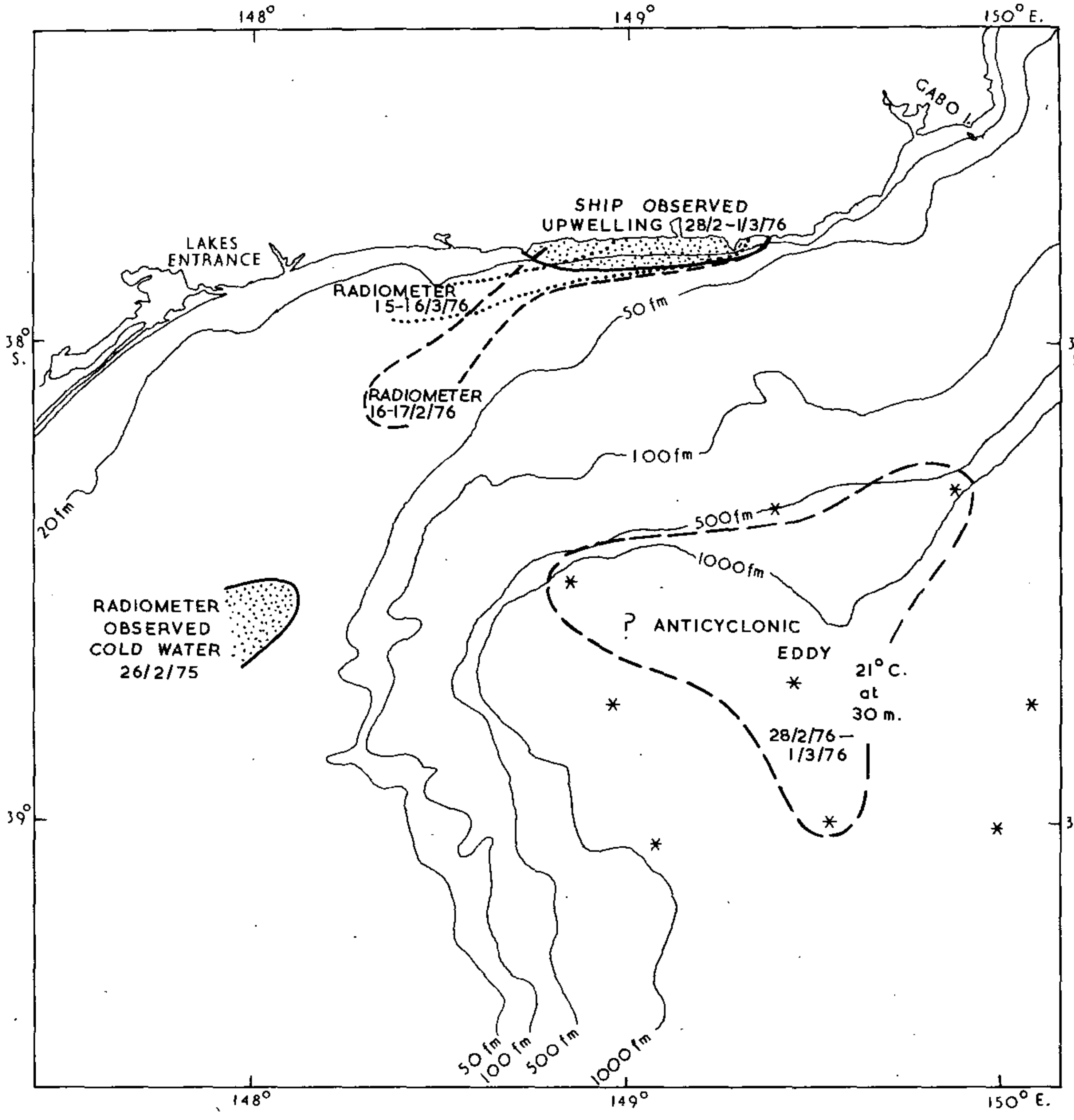

Fig. 10 Bathymetric features in relation to principal upwelling situation and to the anticyclonic eddy (A Fig. 4).