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IN VIVO CHLOROPHYLL *a* FLUORESCENCE IN THE VICINITY OF WARM-CORE EDDIES OFF THE COAST OF NEW SOUTH WALES. 2. OCTOBER 1978

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Abstract

In October 1978, warm-core eddy "F" had a higher surface standing crop and lower surface nitrate concentration than it had the previous month when it was located some 130 km to the south in close association with warm-core eddy "E". The bulk of the October bloom extended from 25 m to 100 m and its fate is being followed during the course of November and December. There was some evidence of surface heating but the summer thermocline had not yet become well developed.

Another area of high standing crop and phytoplankton growth rate was found nearshore to Eden. Further north along the coast, waters with relatively high standing crop were overlain by relatively barren waters, perhaps of tropical origin.

INTRODUCTION

The anti-clockwise warm-core eddies which persist for a year or so off the east Australian coast are thought to have their origin in the "pinching off" of the southward flowing East Australian Current (Nilsson *et al.* 1977). Likened to a capsule of warm water floating in a cooler sea, these eddies are characterized by a submerged isothermal layer across the boundaries of which the interchange of water is small, relative to their total volume. Our working hypothesis is that a given eddy will progressively become impoverished by detrital fallout and this will be reflected by progressive diminution of its standing crop. We have chosen to test this hypothesis by sequentially characterizing the water, both within and without one or more eddies, using *in vivo* chlorophyll *a* fluorescence.

Our rationale for using *in vivo* fluorescence is given in an earlier report (Tranter *et al.* In Press). The objective is to measure the standing crop of phytoplankton, its vertical and horizontal distributions and its rate of primary production. Traditionally, this has been done by estimating the chlorophyll *a* concentration of a sample by quantitative analysis of the extractable photopigments and by either oxygen evolution or ^{14}C uptake. The chlorophyll:carbon ratio, however, varies by a factor of 10 and chlorophyll:particulate organic nitrogen by a factor of 3. Thus, chlorophyll *per se* is not so useful a parameter for the analysis of food chains or ecological cycles that it is worth converting *in vivo* fluorescence measurements into chlorophyll units as a matter of routine. We have chosen, instead, to report our results in standard

fluorescence units called "Turner Units" or TU. For comparison with the work of others we provide the regression equation between TU and chl *a*. We measure variable fluorescence (F_A) continuously in surface transects and occasionally by vertical profiles (Lorenzen 1966). Samples of water are treated with DCMU (Diuron) to yield maximum *in vivo* fluorescence (F_M) as an estimate of biomass (Slovacek and Hannan 1977), and photosynthetic efficiency (ϕ_p) as a relative estimate of gross primary production rate (Samuelsson and Oquist 1977). In the present work, fluorescence from free photopigments and their breakdown products (F_0) is ignored and ϕ_p is estimated as

$$\phi_p = (F_M - F_A)/F_M.$$

This report is the second of a projected series. It should be noted that the primary objectives of these cruises were related to the physics and chemistry of the western Tasman Sea. For our biological work, these were merely "cruises of opportunity". As a result, much of the data have little or no bearing on our main objective which was the seasonal study of a warm-core eddy. However they do provide a useful contrast with other areas, using identical methodology.

MATERIALS AND METHODS

The present data were obtained during the period 13-19 October 1978 on R.V. "Sprightly" (SP14/78). This cruise called for seaward transects as well as coastwise steaming and provided an opportunity to examine an interesting section of east Australian water using *in vivo* fluorescence. A summary of the cruise was given by Golding (1978).

A full discussion of methods and instrumentation is given by Tranter *et al.* (In Press). On this cruise, underway samples were dosed with DCMU by manually introducing two 10 mℓ aliquots of the 180 µM concentrate in rapid succession through a non-return valve on the upstream side of the fluorometer. The Variosens *in situ* fluorometer was unavailable and profiles of fluorescence were obtained from water bottle samples. These measurements cannot be compared with those obtained underway by pump. However they are considered to be comparable among themselves.

Two types of bottles were used for batch samples. At "beach stations" (< 50 m) samples were taken with 6 ℓ Niskin bottles, and at deep stations (> 100 m) with 2 ℓ Nansen bottles. Water from Niskin bottles was used for intercalibration with other phytoplankton parameters - 200 mℓ was fixed with Lugol's iodine for phytoplankton identification and micromeasurements, 250 mℓ was used for F_A and F_M measurements, and about 5000 mℓ was used for filtration and estimation of particulate chlorophyll *a* by spectrophotometric analysis of acetone extracts. Chlorophyll samples were held under cover in dark glass containers, generally for 30-40 minutes, before filtration. Water samples for fluorescence were held in plastic containers in the dark for 15 or more minutes before measurement with the Turner Design fluorometer.

Blanks were prepared by filtering sea water (FSW), either from the fluorometer discharge or from bottle casts. There was so much variability in FSW blanks that they were not used in the analyses. Instead, an instrument blank of 13 TU for both F_A and F_M has been used throughout, this value having been obtained as an average of several measurements on particle free distilled water. The purpose of blanks is twofold, (a) to eliminate F_0 (fluorescence from non-vital pigments) and (b) to eliminate instrument dark current and refracted light due to the optics, cuvette, water, etc. Filtering seawater does not eliminate all of F_0, in fact the treatment may increase the amount of "soluble fluorescence" and lead to illogical results. The distilled

water blank, however, establishes the non fluorescence base for measurements of total fluorescence.

Figures 2-5 show the location of eddy "F", determined by colleagues at this laboratory from records of drift by satellite tracked buoys, surface temperatures and XBT profiles (Cresswell, unpublished data).

RESULTS

The cruise track on SP14/78 is shown in Fig. 1. The ship departed Launceston, Tasmania, on the morning of 13 October and worked northward along the coast of N.S.W., returning to Sydney on 20 October from a position N.E. of Newcastle.

Figure 2 shows the position of two warm-core eddies tracked by satellite buoys and thought (Cresswell, unpublished data; Boland and Church, unpublished data) to be the same as eddies "E" and "F" whose *in vivo* chlorophyll characteristics in September were described in an earlier report (Tranter *et al.* In Press). It appears that these two eddies were separating in September after which eddy "F" had moved to a position approximately 130 km to the N.W. The temperature at 250 m (Fig. 3, 4) indicates that eddy "F" was located at about $35^{\circ}30'S$, $152^{\circ}E$ during the present cruise. South of it, at about $37^{\circ}S$, $151^{\circ}15'E$, was a structure which may have been a cold core eddy. Surface isotherms (Fig. 5) suggest that eddy "F" was separated from this structure by a ribbon of warm ($19^{\circ}C+$) water. The cruise track of SP14/78 did not intercept eddy "E" nor cross the centre of eddy "F". The entire trace of surface F_A and temperature is shown in Fig. 6. Two features are remarkable: 1) the fluctuating nature of the fluorescence trace which has been considerably smoothed in transcription (10 min intervals were used), and 2) the contrasting zones of high and low fluorescence which appear to be related to low and high surface temperatures.

Isopleths of F_M are plotted in Fig. 7. These suggest an area of relatively high standing crop coincident with eddy "F" (compare with Fig. 2). A second area of high F_M was present east of Newcastle. A coastal strip of lower standing crop ($F_M < 200$ TU) south of Jervis Bay appears to swing offshore north-east of the Eden feature which had a slightly greater standing crop ($\simeq 200$ TU). An area of relatively high F_M was located nearshore, north and south of Eden.

The relationship between F_M and chlorophyll *a* (Fig. 8) was calculated as a linear regression with its origin at 0,0, ($\beta_1 = 2.03 \times 10^{-3}$). There is considerable variation among the data points. The coefficient of determination (R_1^2) = 0.81 (Black and Griffiths 1975).

Three offshore-inshore transects were made which replicated data obtained at specified geographic locations (but not necessarily in identical water masses). Estimates of ϕ_p showed extreme variability where locations were replicated; some of this may be due to a diel rhythm (Fig. 9). The diel effect in these data was removed as follows - All available on-stream surface data were plotted as functions of time, regardless of date and geographic position and the data were averaged within 3 hour cells. These averages were then connected by a freehand curve from which coefficients were estimated to remove the average diel effect within each 30 minute time cell, standardized against the midnight value. This treatment reduced the relative standard deviation of the data by 23%. The modified values are designated $\hat{\phi}_p$. All results were generalized to provide the estimated distribution of $\hat{\phi}_p$ shown in Fig. 10. Two areas had a relatively high quantum photochemical efficiency: 1) an area near $34^{\circ}30'S$, $152^{\circ}30'E$, north-east of eddy "F", and 2) a coastal area off Eden.

Table 1. Fluorescence (F_M) of water samples obtained at stations 1-14, SP14/78.

Station	Depth in metres (bottle casts)					
	0[1]	25	50	75	100	$\int_{0\ 100\ m}/100$ [2]
1	227	247	247	237	49	217
2	457	477	457	407	24	395
3	927	967	847	148	(0)	606
4	507	557	151	22	28	249
5	557	517	267	57	41	285
6	607	697	637	557	173	570
7	567	407	197	104	61	255
8	307		627			
9	367	637	417	120	59	347
10	357	317	297	407	297	337
11	840		98			
12	537	577	126	136	75	286
13	158	151	158	82	36	122
14	467	487	537	287	467	444

[1] There was a consistent difference between "on-stream" observations taken on arriving at a station and observations based on samples taken from surface Niskin bottles. The reason for this difference has not yet been determined but it emphasizes the need to treat the two as different types of measurement, not strictly comparable though, of course, related.

[2] Values in this column are averages derived by first integrating the total F_M/depth to 100 m, then dividing by 100 to estimate the average F_M for the 100 m column of water. This is an estimate of the average biomass per m^3 in the 100 m water column.

Evidence on the vertical distribution of *in vivo* fluorescence is restricted to the 14 stations shown in Fig. 1, of which stations 8, 11 and 14 are in shallow water. Results are given in Table 1. The integrated 100 m column values in Table 1 suggest that the standing crop within the bottle series was relatively high at stations 3 and 6, and relatively low at station 13, the remainder being of intermediate value. The bottle series is in general agreement with the underway on-stream series shown in Fig. 6. The high integrated value for station 6 reflects the penetration of the population to depths beyond 75 m, in contrast, for example, with the profile for station 3.

While these data are sparse and variable, it is still useful to draw depth isopleths of F_M for transects out to sea. Figure 11a shows the 37°S transect (stns 2-5) and Fig. 11b the 35°23'S-35°50'S transect (stns 6-9). There is a relatively high F_M close to shore at Eden extending from the surface to ≃ 60 m, and, at Jervis Bay, submerged below 50 m. Sub-surface F_M values in excess of 600 TU extending to 60 m occurred at station 6, our closest sampling location to eddy "F". It appears that eddy "F" had become the locus of high phytoplankton biomass, a reversal of the September situation.

Although the present cruise did not pass completely across eddy "F", station 6 may have been sufficiently close to the centre (T_{250} = 16°C) for a comparison to be made with an equivalent station in September. For this purpose, station 8 of Sp12/78

was chosen (T_{250} = 17°C). Figure 12 shows the profiles of nitrate and F_M at these two selected stations. The bulk of the phytoplankton at the October station lay between 25 m and 75 m and was far greater than in September. In the interim the nitrate concentration had become considerably reduced above 150 m.

DISCUSSION

The area of high surface phytoplankton concentration between latitudes 34°30' to 36°S and longitudes 152°-153°E coincides with the location of eddy "F" whose previous *in vivo* chlorophyll *a* characteristics were described by Tranter *et al.* (In Press). During this October cruise the photosynthetic efficiency ($\hat{\phi}_p$) at the surface was of the same order as that recorded in September (ϕ_p = 0.3-0.4). However F_M (index to standing crop) in the 0-75 m stratum (Niskin samples) had increased from an average of about 150 TU to about 640 TU. Meanwhile nitrate concentration had decreased from about 2 µg-at N ℓ^{-1} to about 0.5 µg-at N ℓ^{-1}.

In contouring our data, we have tended to assume that the development of the spring bloom was more or less in phase throughout the eddy. This might not be so. An observer searching from the air for surface shoals of fish, a few days after the October cruise, saw alternate expanses of warm blue water (> 19.5°C) and cool green water (< 18°C) in the general area of eddy "F". The latter was conspicuously marked by surface windrows. The significance of this phenomenon needs to be investigated.

Another interesting surface feature was the ribbon of low fluorescence water that separated eddy "F" to the north from the "cold core eddy" to the south (Fig. 6). This coincided with a ribbon of warm water (Fig. 5).

Although it seems clear that the phytoplankton bloom which developed in eddy "F" between September and October was fed by nutrients introduced into the euphotic zone during winter mixing, the timing of the bloom is still not understood. There appeared to have been some warming of surface waters by October (Fig. 4), but the summer cap had not yet become established. It is not clear what was the source of nutrients in the eddy in the first place, given that the East Australian Current is thought to draw its water from water masses that are relatively poor in nutrients.

Tranter *et al.* (In Press) thought that the September standing crop in eddy "F" was probably limited by light not nutrients. The depth of the mixed layer extended to about 250 m, well beyond the accepted euphotic zone (Jitts 1959). The October data are too scanty to assess the nature of contemporary constraints on phytoplankton production or likely future trends. The nitrate was low but not exhausted. Further clarification of the processes at work depends upon studies during and after the period of formation of the summer thermocline.

The most significant feature of the data, other than the location and character of eddy "F", was the area of coastal water near Eden, where the standing crop (F_M) was high, both at the surface (Fig. 7) and at depth (Fig. 11a, Table 1), and where the photosynthetic efficiency ($\hat{\phi}_p$) was also high (> 0.5, Fig. 11). These are characteristics of upwelling areas. The apparent vigor of phytoplankton near Eden may have been due either to upwelling or to nutrient enrichment of coastal waters by Subantarctic components brought in from Bass Strait (Newell 1961).

Further northward at coastal station 8 there was a high standing crop at depth (Fig. 11b) associated with low

surface values both of standing crop (F_M < 200 TU) and growth rate (ϕ_p < 0.30) (Fig. 10). These data suggest productive water overlain by relatively barren water, perhaps a northward flow at depth and a southward flow at the surface.

The use of F_M as a crude index of phytoplankton standing crop seems justified from the chl/F_M calibrations presented in a previous report (Tranter *et al.* In Press). In this study, chl *a*/F_M index (Fig. 8) suggests that 81% of the variation in chl *a* was accounted for by covariation in F_M. The remaining uncertainty may be due to error in estimating either parameter, as well as to variation in the underlying functional relationship. It is by no means certain that the data available to us for this cruise are best described by a linear regression. However, since this question is peripheral to the present study, it is dealt with in a later paper in the context of more extensive data. It is still a moot question as to whether *in vivo* fluorescence or extractable chlorophyll is the better index of phytoplankton biomass.

It is not easy to decide what sort of blank is most appropriate in this work. Even with careful handling, total fluorescence appears to rise in a sample that is bottled, pumped, stored or otherwise removed from the sea. In the present case, capture and storage of samples in Nansen and Niskin bottles significantly increased F_M. This could happen in two ways: (1) by increasing the light absorption capacity of living cells, and (2) by killing and lysing the more tender cells, viz., the photosynthetic microflagellates. Filtering and using the so-called dissolved chlorophyll fluorescence as a blank seems inappropriate if lysing is enhanced by filtering, or if filtering is incomplete. This problem needs thorough investigation in the laboratory.

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We are especially indebted to physical and chemical oceanographers in this Laboratory for helpful discussions, especially with Dr J.S. Godfrey, Dr G.R. Cresswell who tracked the eddies by means of drifting buoys, and Mr T. Golding, Cruise Leader of SP14/78. Details of the aerial sighting of surface phytoplankton blooms in late September were provided by Mr K. Williams. Dr G.R. Cresswell read and discussed the manuscript with us.

REFERENCES

Black, J.L. and Griffiths, D.A. (1975). Effects of dry weight and energy intake on nitrogen balance and total N requirement of lambs. *Br. J. Nutr.* 33, 399-413.

Golding, T.J. (1978). Cruise Summary, R.V. "Sprightly" Cruise SP14/78. Mimeo, CSIRO Aust. Div. Fish. Oceanogr., Cronulla.

Jitts, H.R. (1959). Measurements of light penetration in the Tasman Sea, 1955-57. CSIRO Aust. Div. Fish. Oceanogr. Tech. Pap. 6, 26 pp.

Lorenzen, C.J. (1966). A method for the continuous measurement of *in vivo* chlorophyll concentration. *Deep-Sea Res.* 13, 223-227.

Newell, B.S. (1961). Hydrology of southeast Australian waters: Bass Strait and New South Wales tuna fishing area. CSIRO Aust. Div. Fish. Oceanogr. Tech. Pap. 10, 22 pp.

Nilsson, C.S., Andrews, J.C. and Scully Power, P. (1977). Observations of eddy formation off east Australia. *J. Phys. Oceanogr.* 7, 659-69.

Samuelsson, G. and Öquist, G. (1977). A method for studying photosynthetic capacities of unicellular algae based on *in vivo* chlorophyll fluorescence. *Physiol. Plant.* 40, 315-9.

Slovacek, R.E. and Hannan, P.J. (1977). *In vivo* fluorescence determinations of phytoplankton chlorophyll *a*. *Limnol. Oceanogr.* 22, 919-25.

Tranter, D.J., Parker, R.R. and Vaudrey, D.J. (In Press). *In vivo* chlorophyll *a* fluorescence in the vicinity of warm-core eddies off the coast of New South Wales. 1. September 1978. CSIRO Aust. Div. Fish. Oceanogr. Rep. 105.

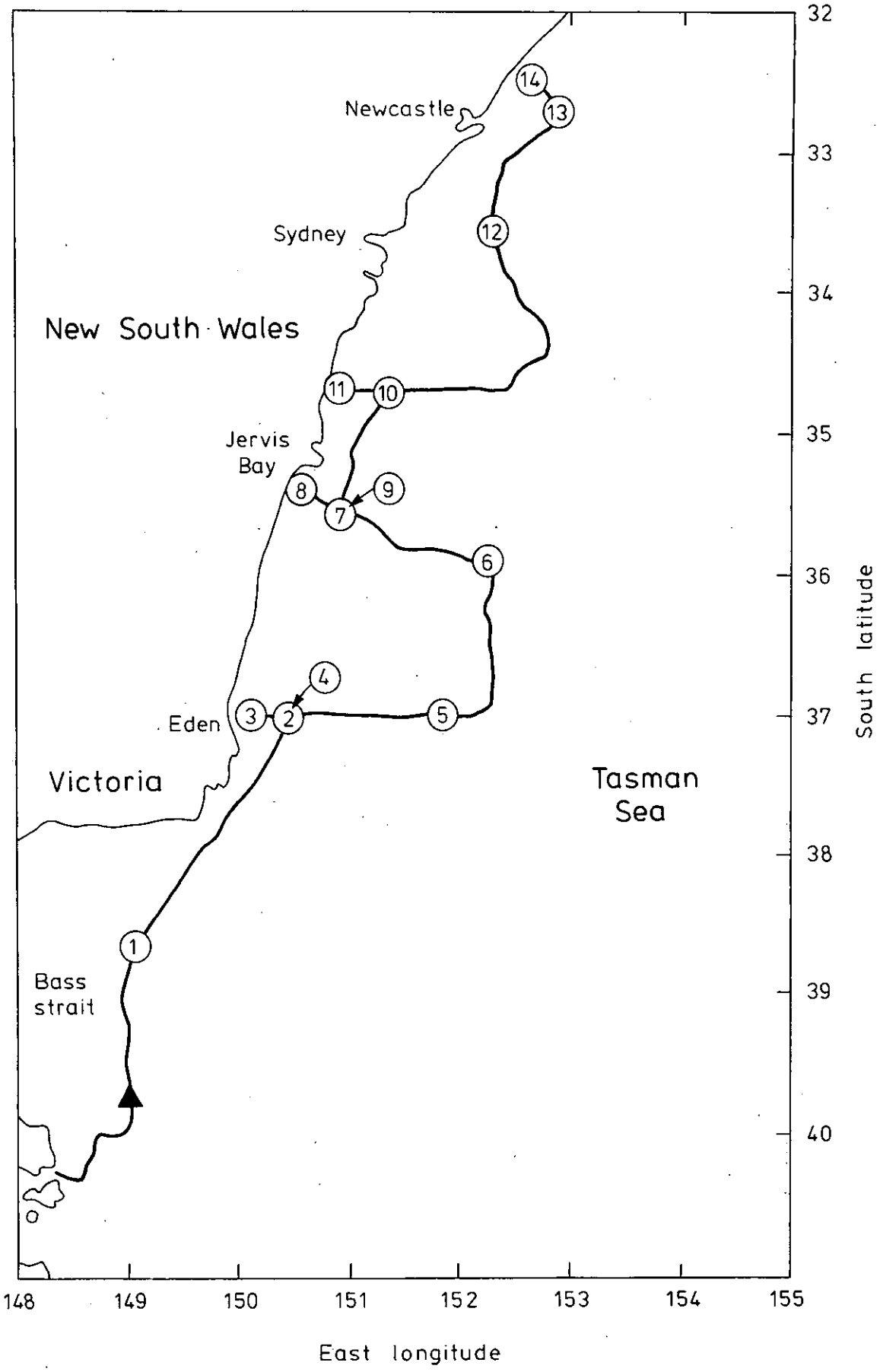

Fig. 1. Cruise track of the "Sprightly" 13-19 October 1978 (SP14/78). The positions of stations held for vertical profiling are shown as numbers enclosed in a circle.

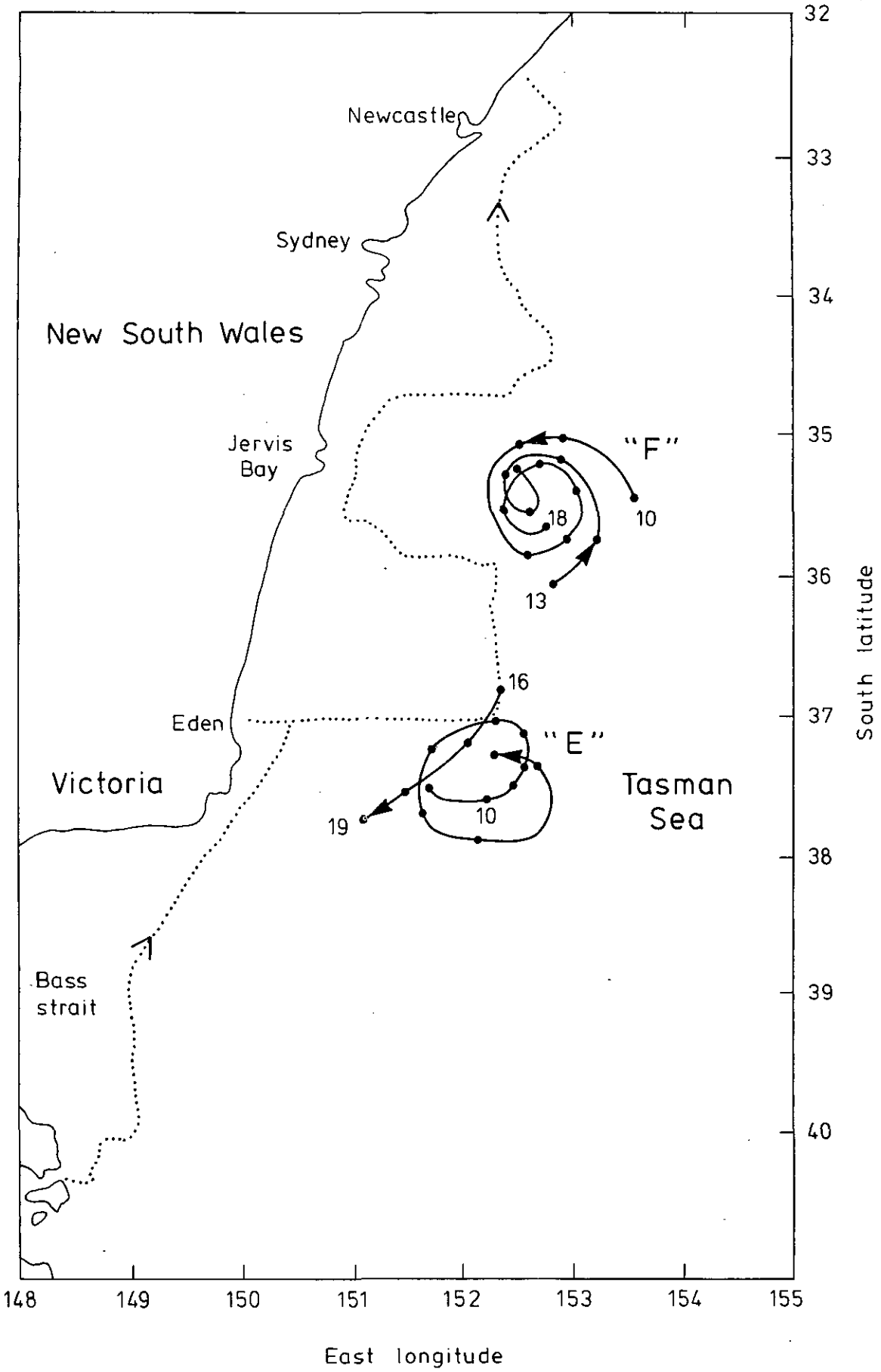

Fig. 2. Buoy tracks as observed by satellite. The numbers refer to the date of the observation (not all are shown). The position of the buoy on each succeeding date is shown by a dot. These tracks identify the centre of eddy "F" during the cruise period but do not define its boundary. Courtesy of Dr G. Cresswell.

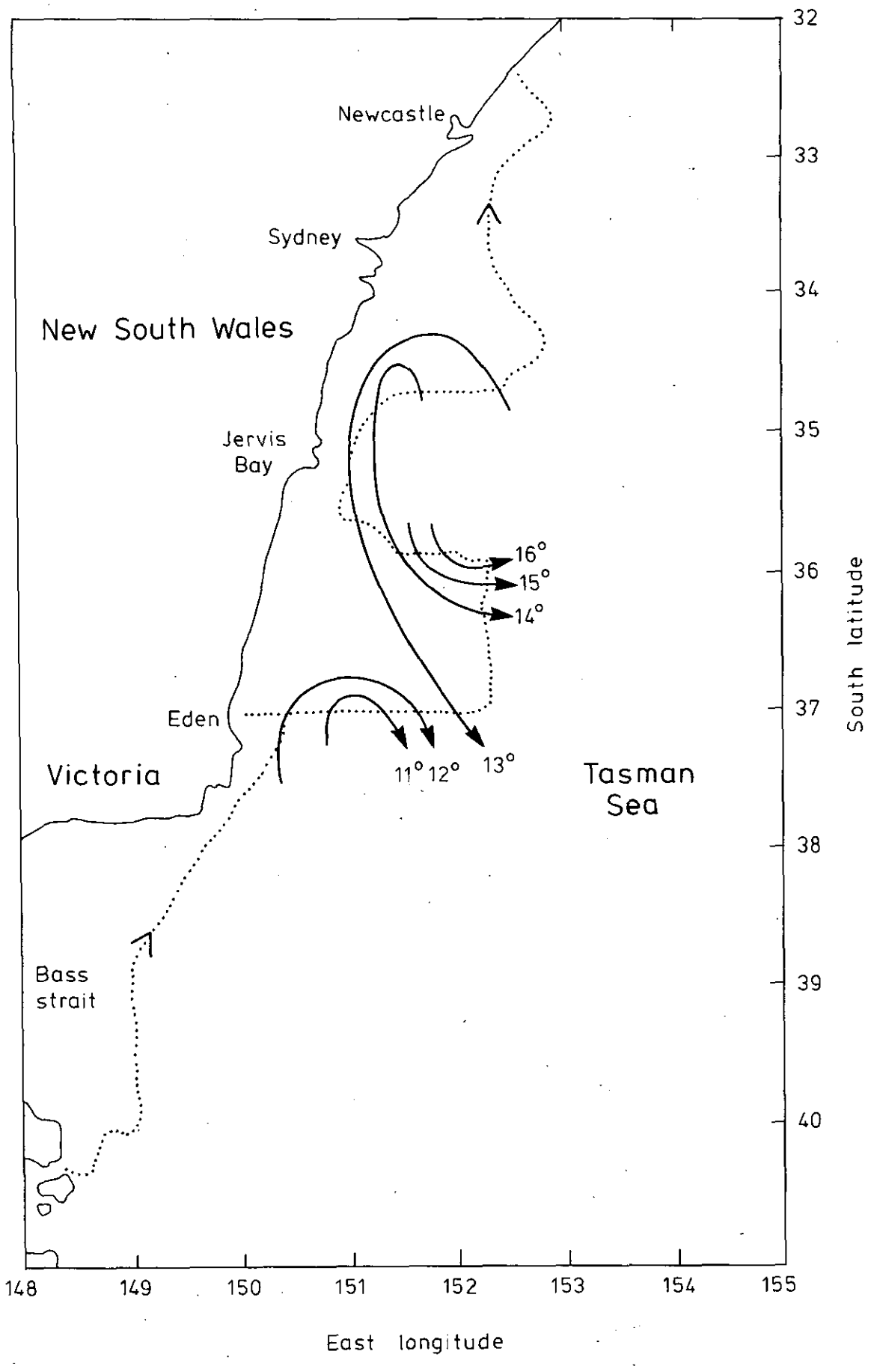

Fig. 3. Temperature isopleths at 250 m based on XBT data taken along the cruise track. Courtesy of Mr T. Golding.

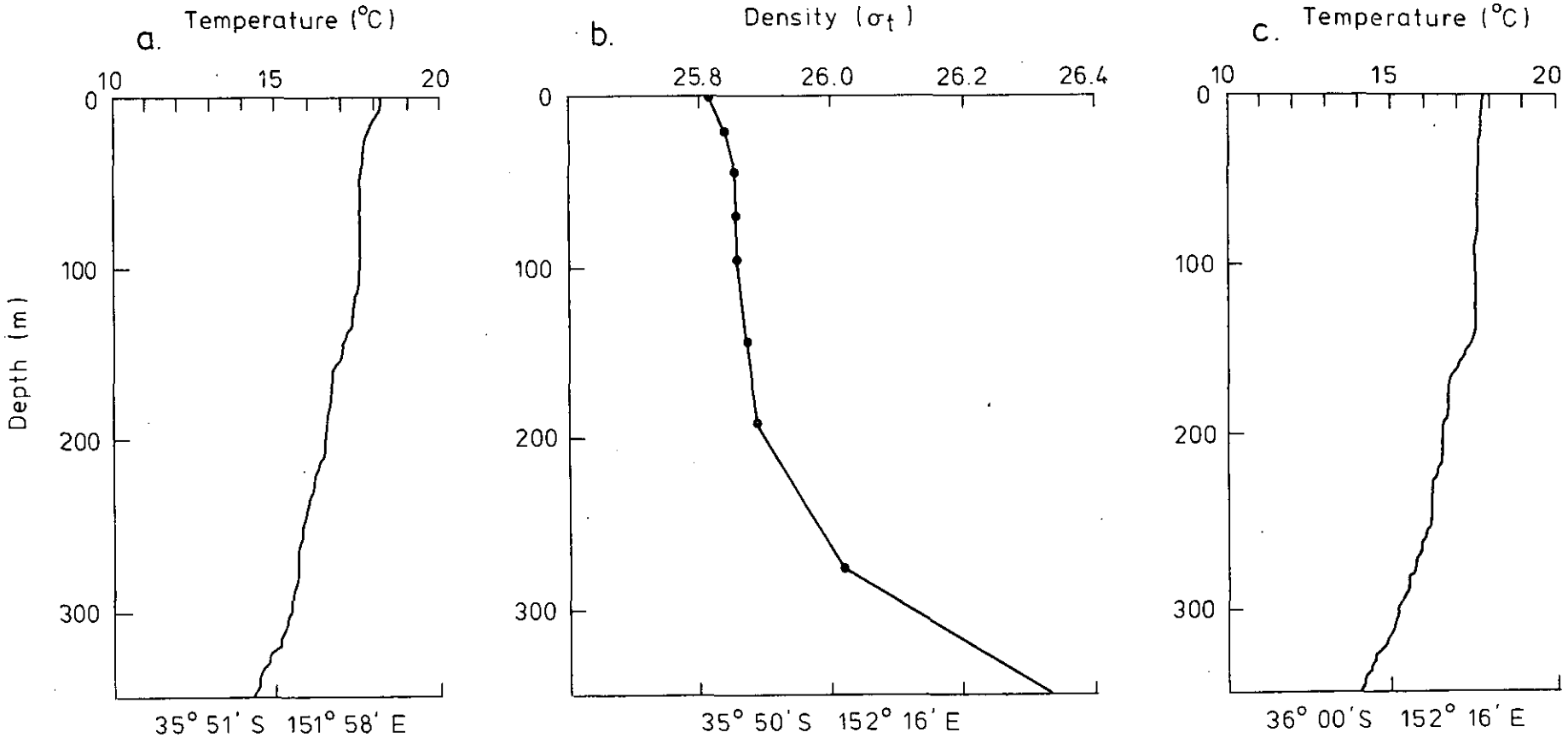

Fig. 4. Depth of the mixed layer at the nearest points reached on this cruise to the centre of eddy "F". (a) XBT trace 2 hours before Station 6; (b) Station 6 (σt); (c) XBT trace 2 hours after Station 6. Some surface warming is evident but the summer thermocline has not yet become well established.

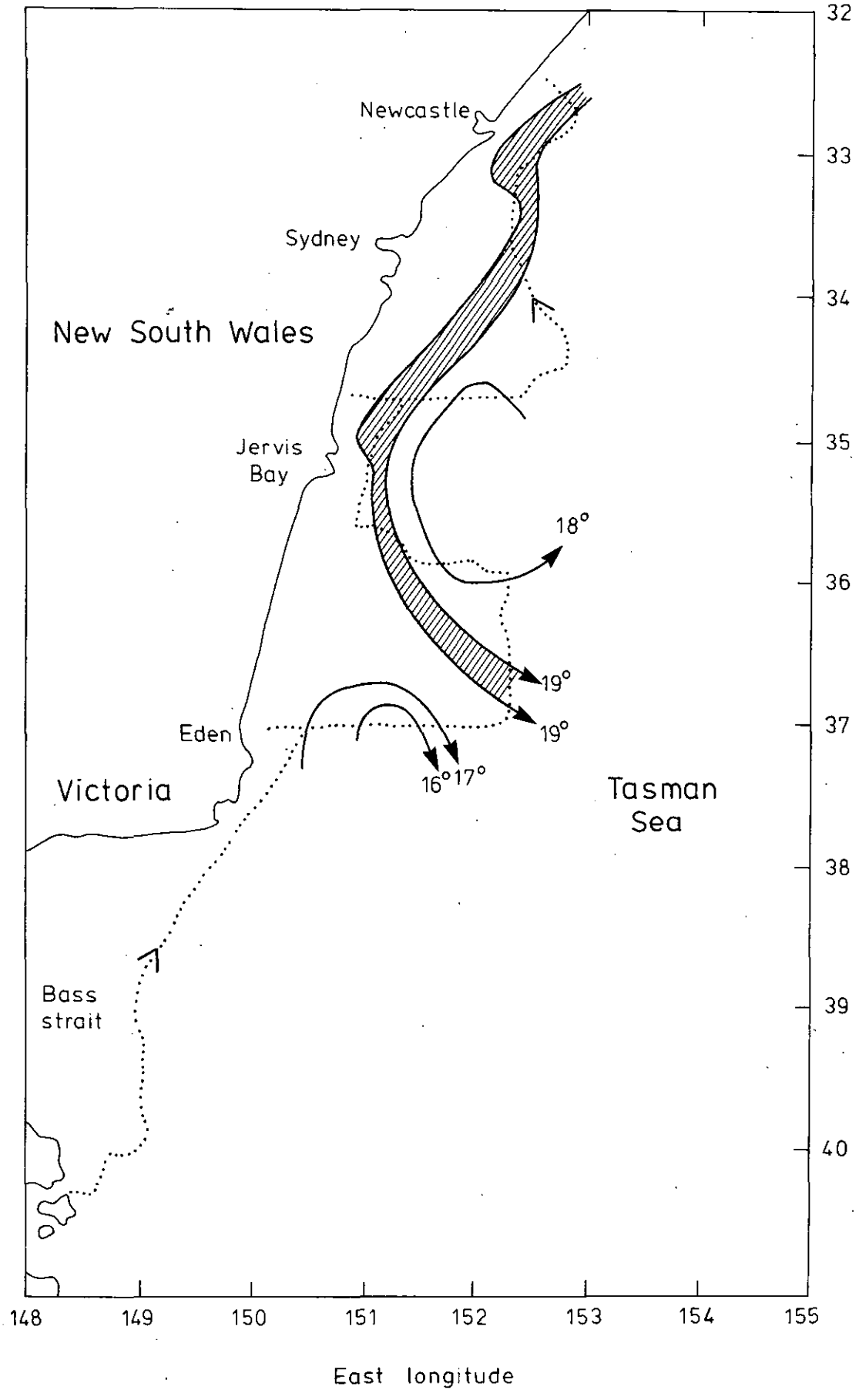

Fig. 5. Temperature isopleths at the surface (2 m) based on recordings of pumped water supply along the cruise track. Courtesy of Mr T. Golding.

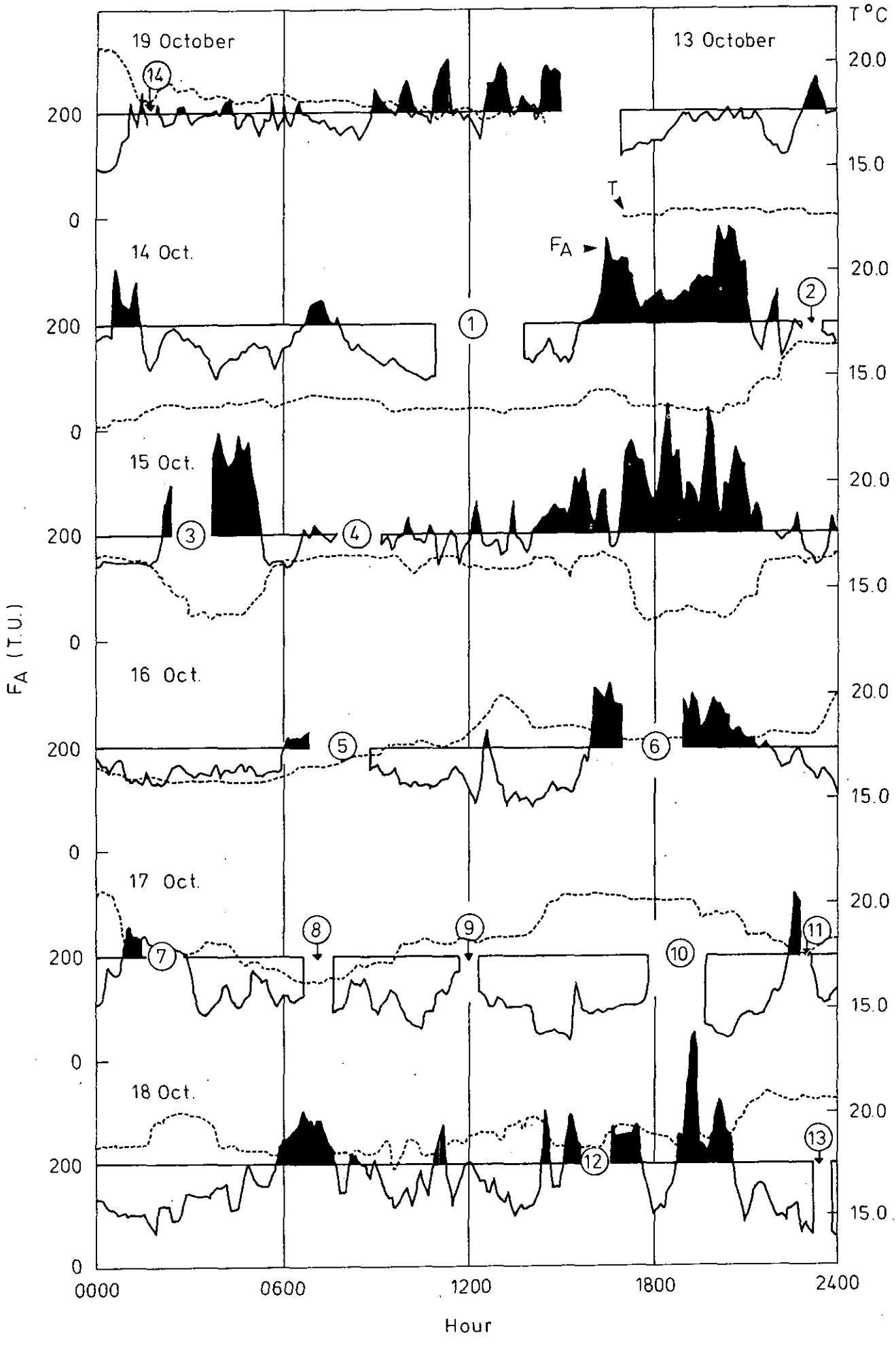
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Fig. 6. Fluorescence (F_A) recordings from flow-through (Turner Design fluorometer) pumped water supply along the cruise track. Values of more than 200 TU are blacked in to call attention to areas of relatively high fluorescence. Gaps in the record are due to stations occupied, identified by numbers in circles, when the fluorometer was operated in batch mode. The continuous data were averaged in 10 minute intervals to produce this figure so that considerable smoothing to the original record has occurred. The temperature record shown is from a continuous record of the same pumped water supply. An inverse correlation between F_A and T is apparent.

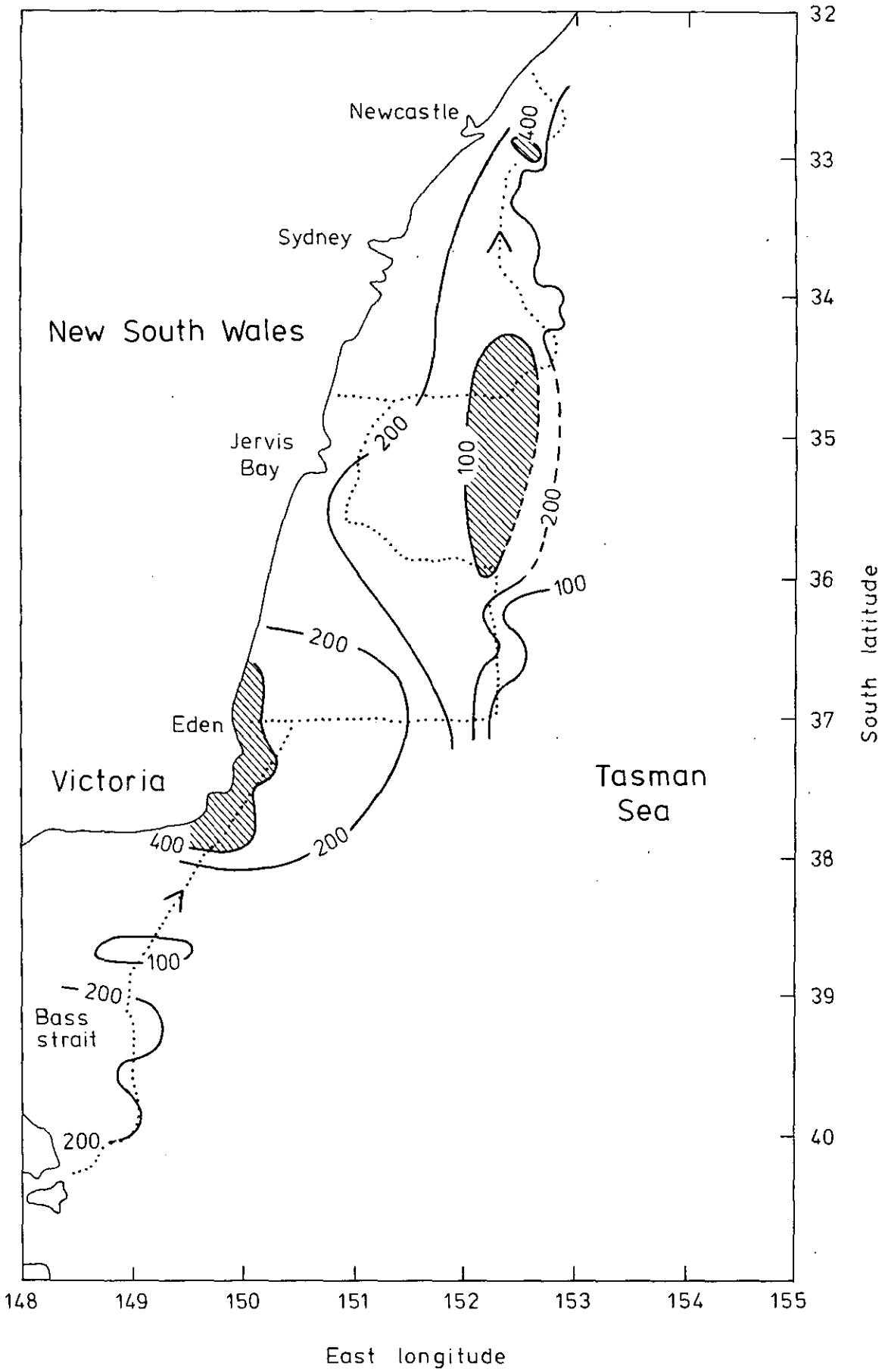

Fig. 7. Fluorescence (F_M) isopleths based on DCMU treated samples along the cruise track. Two major areas of high F_M (> 400 TU) are shown by hatching, one between 34°30' and 36°S by 152° to 153°E coinciding with eddy "F" and the other at the coast near Eden. A smaller area was found at 33°S x 152°30'E.

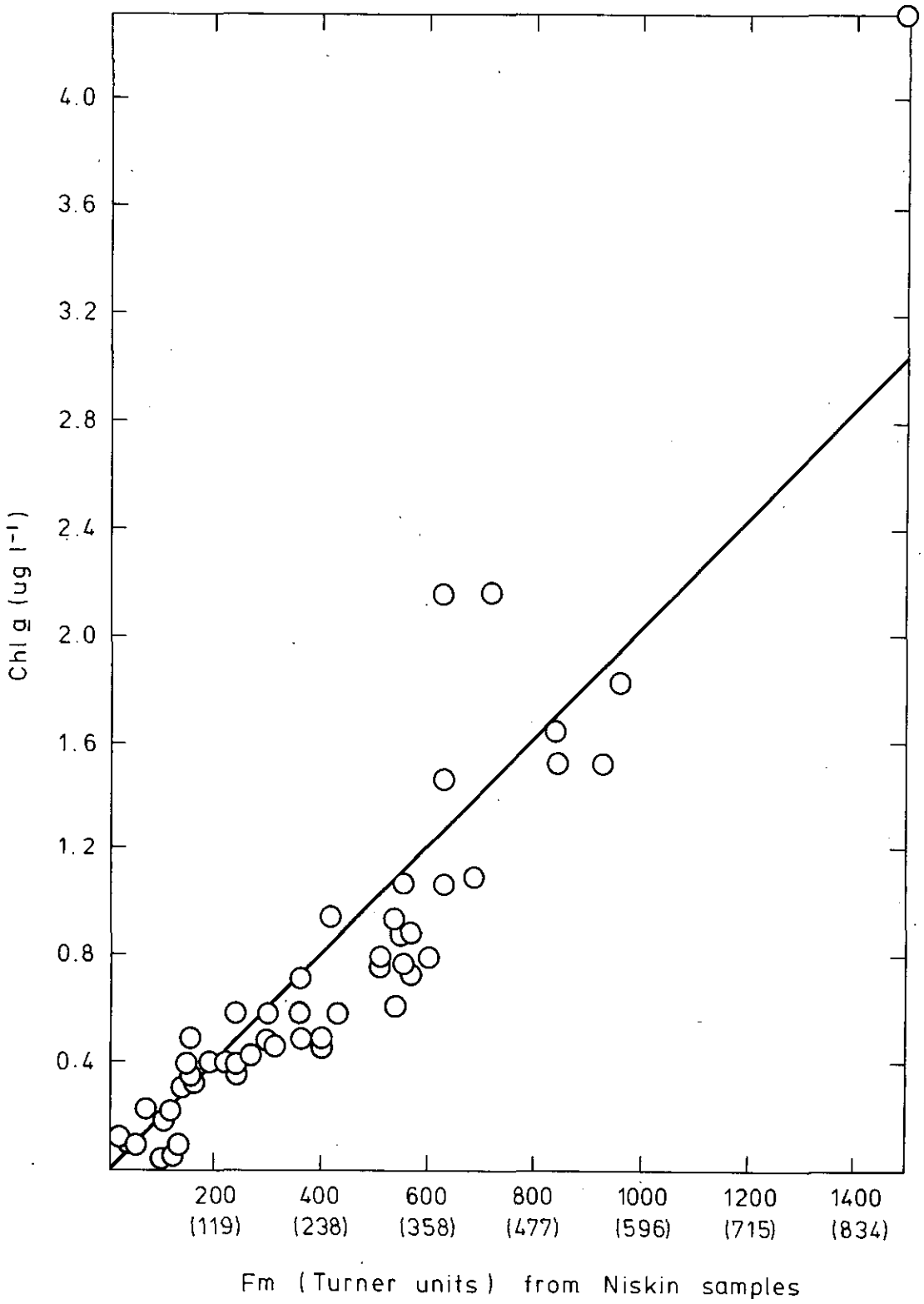

Fig. 8. A correlation diagram between chl a and F_M of water samples obtained from surface to 100 m depths by Niskin bottles. (Regression through 0,0), chl $a = \beta F_M$. $\beta = 2.03 \times 10^{-3}$. The coefficient of determination, $R_1^2 = 0.81$, n = 48.

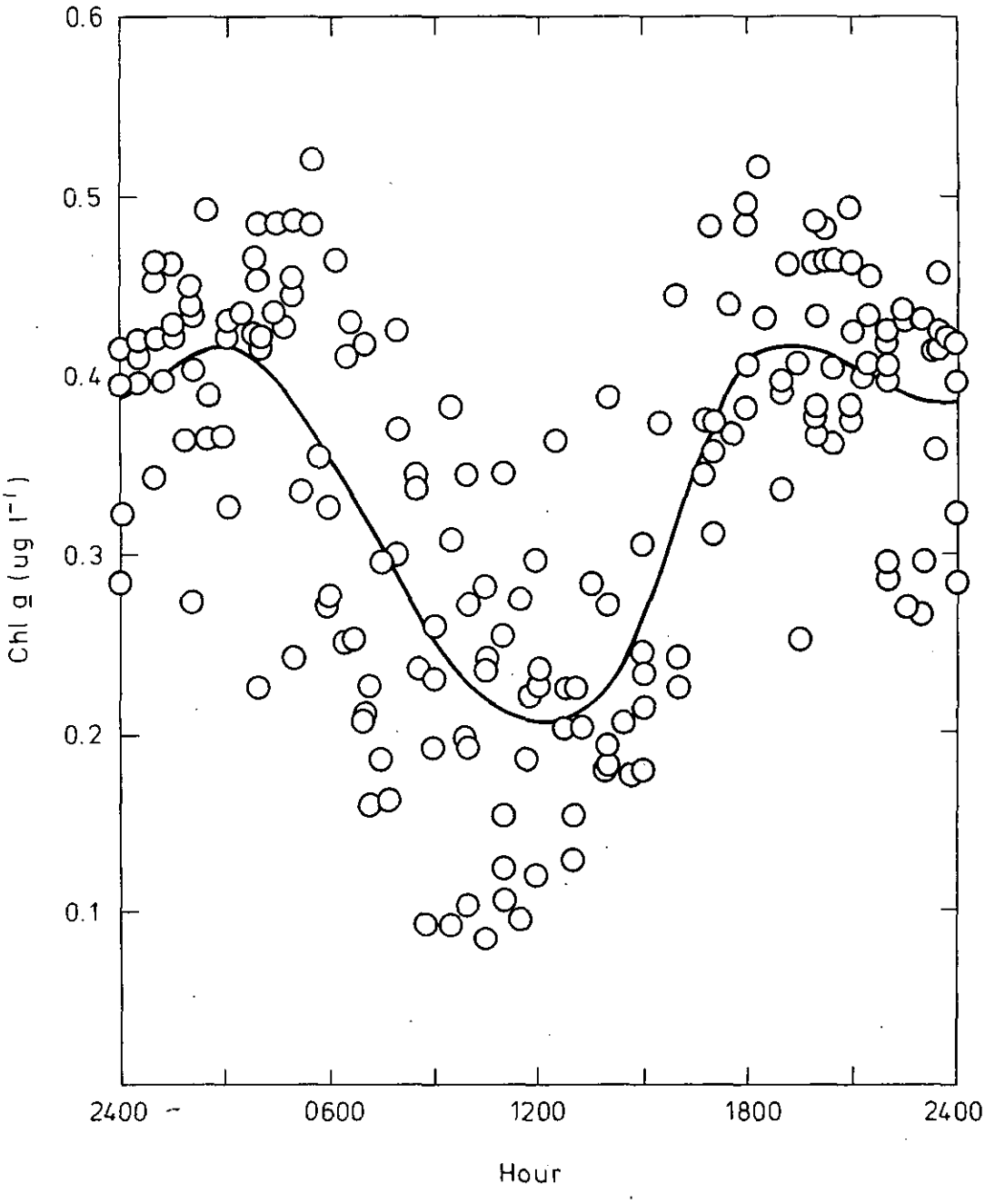

Fig. 9. The diel effect on ϕ_p. All available values from the flow-through system are plotted. Data were averaged within three-hour time periods and a faired line drawn to connect the average ϕ_p and T values. Values were read off this line and divided by the 2400 value to produce a table of correction coefficients. These were then used to correct observed data to an estimate $\hat{\phi}_p$ from which the diel effect is removed.

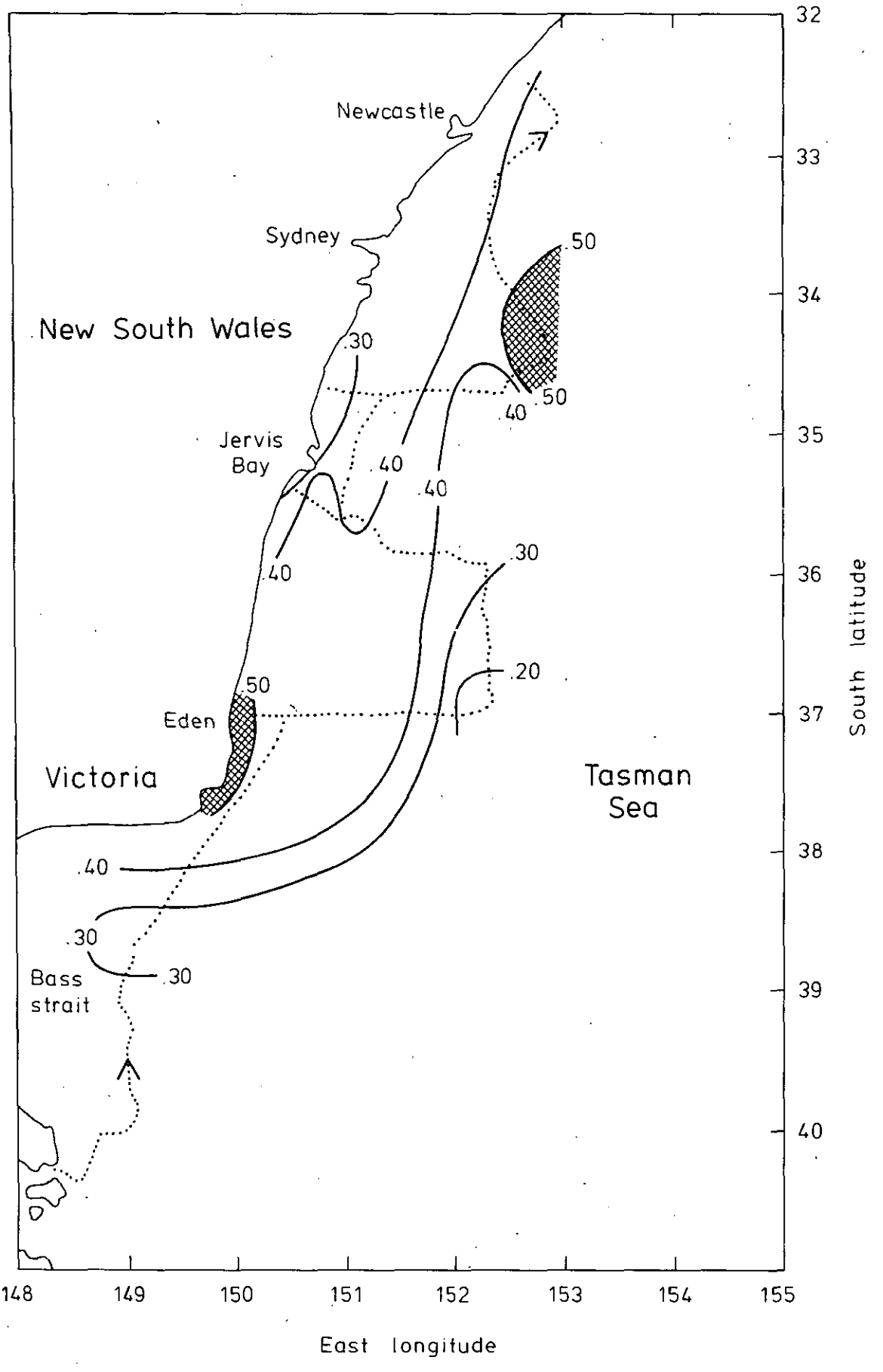

Fig. 10. Isopleths of surface $\hat{\phi}_p$. Two areas of relative high $\hat{\phi}_p$ are hatched, one on the coast at Eden coinciding with the area of high F_M and the other, between 34° and 34°39' along the cruise track, an area of relatively low F_M. The area of eddy "F" was characterized by medium values of $\hat{\phi}_p$.

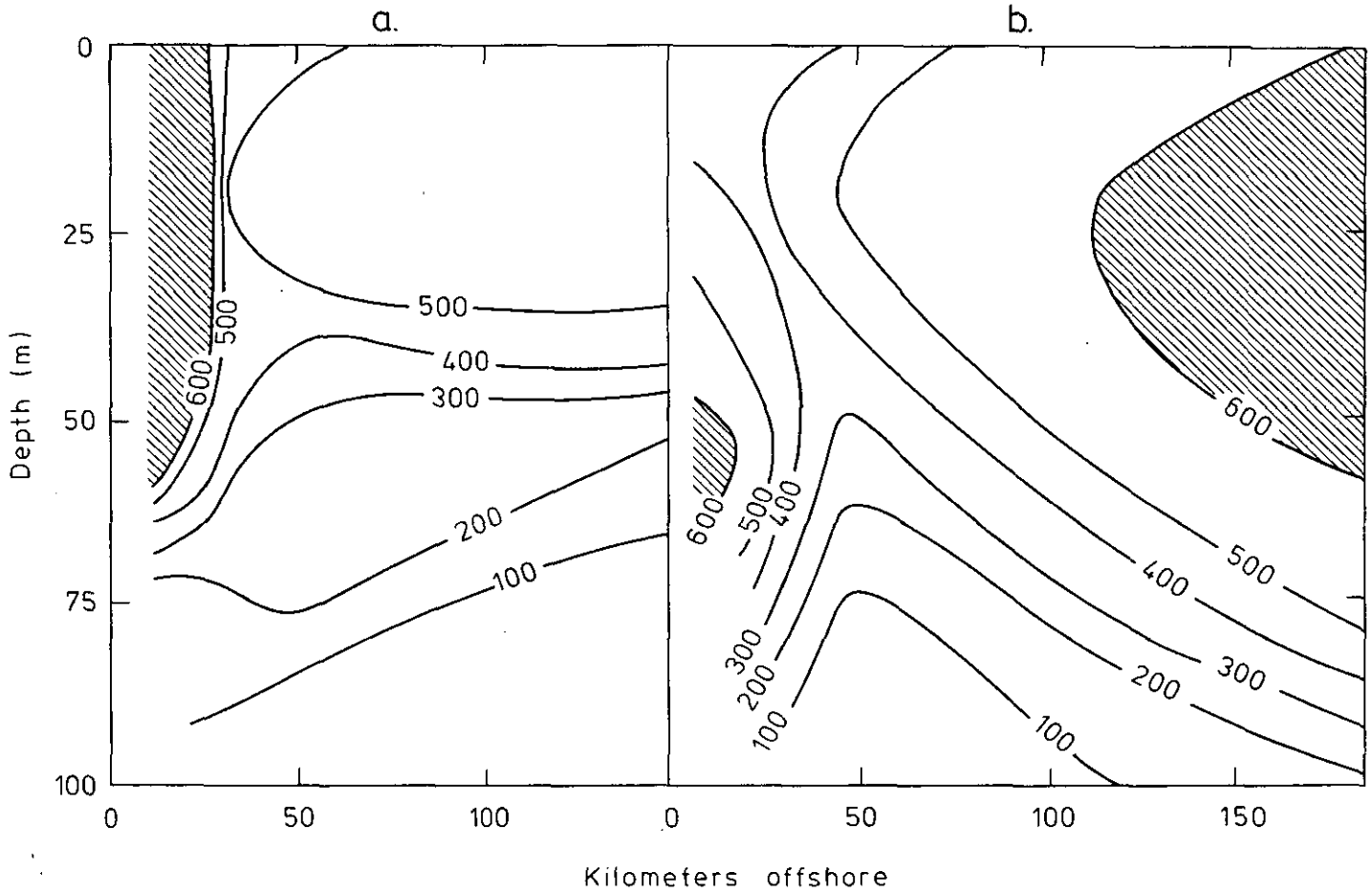

Fig. 11. Vertical isopleths of F_M along the 39°S section (Eden) (A), stations 2-5, and the section extending E x S from Jervis Bay (B), stations 6-9. Water of high F_M is shown by hatching. The 60 m deep, high F_M, water found off Eden may extend northward as a submerged water mass as suggested by the bottom water found off Jervis Bay. The water characterized by high F_M at station 6 is the closest available profile to eddy "F".

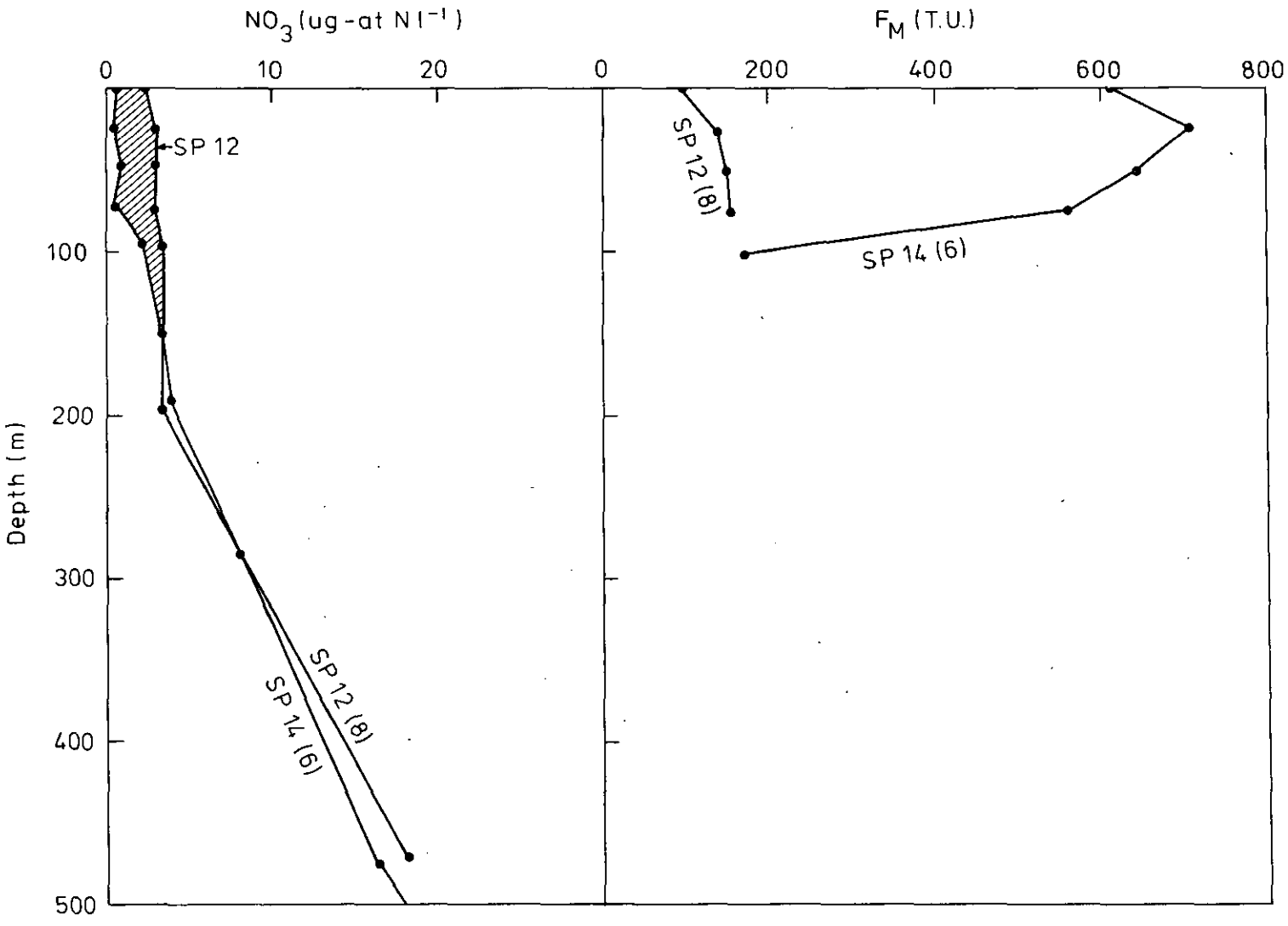

Fig. 12. Vertical profiles of (a) Nitrate and (b) F_M in eddy "F" ($T_{250} > 16^{\circ}C$) in September and October 1978 (SP12/78 station 8, SP14/78, station 6). The increase in standing crop between September and October is associated with reduction in nitrate concentration.

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