R.V. FRANKLIN

NATIONAL FACILITY
OCEANOGRAPHIC RESEARCH VESSEL

RV FRANKLIN

RESEARCH SUMMARY

CRUISE FR 4/89

Sailed Adelaide 0900 Thursday 23 March 1989
Arrived Melbourne 1300 Saturday 1 April 1989

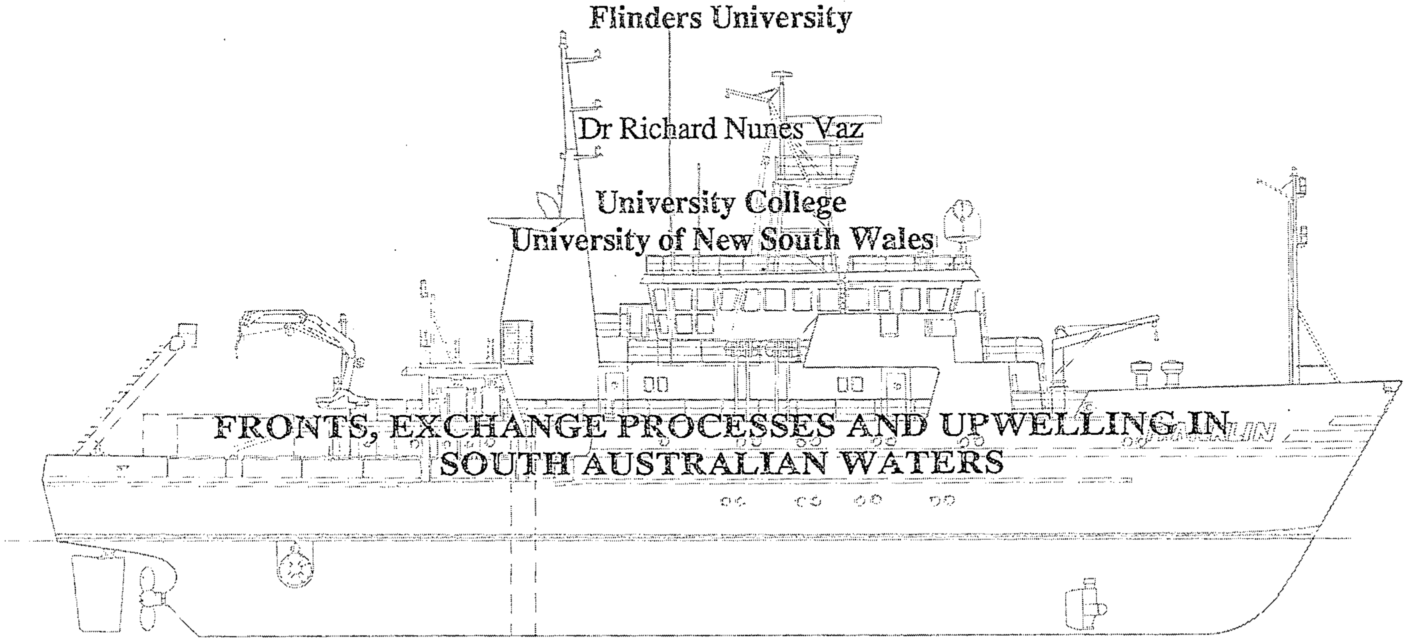
Principal Investigators

Prof Geoff W. Lennon

School of Earth Sciences
Flinders University

Dr Richard Nunes Vaz

University College
University of New South Wales



FRONTS, EXCHANGE PROCESSES AND UPWELLING IN SOUTH AUSTRALIAN WATERS

May 1989

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R.V. FRANKLIN IS OWNED AND OPERATED BY CSIRO

1. ITINERARY

Sailed: ADELAIDE 09:00 Thursday 23rd March 1989.

Arrived: MELBOURNE 13:00 Saturday 1st April 1989.

2. SCIENTIFIC PROGRAMS

The investigation of frontal activity at the mouth of Spencer Gulf, and its bearing on the apparent inhibition of fluid exchange across the Gulf entrance during the summer (Lennon/Nunes Vaz).

Survey of shelf waters to evaluate the extent of Bight water intrusion into the Gulf/shelf zone, and its role in the dynamics of the frontal zone (Lennon/Nunes Vaz).

3. PRINCIPAL INVESTIGATORS

Professor G. W. Lennon,
School of Earth Sciences,
Flinders University,
Bedford Park, South Australia, 5042.

Dr. R. A. Nunes Vaz,
Geography and Oceanography,
University College,
ADFA, Campbell, A.C.T. 2600.

4. RESULTS

Frontal Zone In The Mouth Of Spencer Gulf

The high salinity of Gulf waters (due to an all-year-round excess of evaporation) enhances density such that, for most of the year, a dense, saline bottom current flows from the Gulf, across the shelf and over the shelf break. In summer, however, the higher temperatures of Gulf waters offset the excess salinity at which time the density contrast across the Gulf entrance, between Gulf and surface shelf waters, virtually disappears. The Gulf entrance is then characterised by the meeting of 3 water masses (vertically mixed Gulf, and upper and lower shelf waters, separated by a seasonal thermocline) of not dissimilar densities.

Historical data suggested that the transition zone is a turning point (minimum) of the longitudinal density gradient and, as such, would be a zone of near-bottom convergence. Assuming uniformity across the Gulf width implies that the converging waters upwell. Hence, the cruise aimed to address: the dynamics of the frontal zone, the fate of upwelled waters, the proportions of mixing across the zone (with respect to the exchange of salt, heat, nutrients fish larvae between Gulf and shelf) and the detailed nature of mixing (i.e. interleaving, etc.).

The program as outlined above has involved two cruises of the ORV FRANKLIN (FR02/89 & FR04/89) of which this is the second. It has also involved substantial complementary work with the South Australian Department of Fisheries' vessel, MRV NGERIN, including 10 days of joint activity in January, concurrent with cruise FR02/89, some 7 days of independent work in late February, and a further 7 days of joint activity during this cruise. The intention has been to monitor the evolution of the frontal system from its establishment in early summer, through a strengthening phase, to its disappearance in early autumn. (The autumn and winter behaviours, involving the discharge of accumulated brines in submerged dense gravity currents, have been reported previously.)

Briefly, the program timetable was as follows. In early December 1988, the NGERIN deployed a total of 9 moorings in the waters of the Gulf entrance and the adjacent shelf. Four current meter moorings, and four thermistor strings (one combined mooring) were laid in a line through the Gulf entrance along the Gulf axis. A current meter mooring was placed on the shelf mid-way from the Gulf to the shelf break to monitor the movement of oceanic waters onto the shelf, and another current meter mooring was placed on the shelf somewhat to the west of the working area to assess the extent of influx of Bight waters into the Gulf frontal region.

From 17th January to the 30th January 1989 (FR02/89) both the FRANKLIN and NGERIN conducted complementary observations of physical, chemical and biological properties in and around the frontal zone. The FRANKLIN conducted a comprehensive network of 316 CTD profiles, including the collection of a great many nutrient and chlorophyll samples. Together with the CTD data, the acoustic doppler current profiler continuously monitored surface-to-bottom currents throughout the zone. Alongside this activity the NGERIN conducted more than 200 CTD profiles while also performing fish larval trawls in and around the front. When conditions were favourable both vessels attempted fine-scale vertical resolution of physical properties, indicating the occurrence, but not the details, of layering and intrusions through the front, and the likelihood of salt fingering. Two days were spent in simultaneous repetitive coverage of two cross-frontal lines, by both vessels. The FRANKLIN gathered doppler current data while the NGERIN conducted discrete CTD profiles, in such a way as to allow later assessment and removal of the tidal currents, and thus revealing the relationship between frontal structure and residual currents.

The January exercise (FR02/89) was also assisted by the provision of satellite infra-red SST coverage from the Flinders remote sensing facility. Before departure from Adelaide the FRANKLIN received the most recent NOAA SST image, and during the early part of the activity the NGERIN received further imagery relayed by HF radio to a computer on-board which performed the image enhancement. (In the later stages the antenna on NGERIN suffered damage in difficult sea conditions, and no further images were received.). In this way, in addition to some ground truthing work, the investigation was to some extent guided and optimised by the SST indications of the frontal configuration.

In early February the FRANKLIN moved to the south-east coast of South Australia to observe the evolution of a wind-driven upwelling event. This work was performed in association with the Hunter/Hearn exercise (FR01/89) and successfully monitored the entire development, and initial stages of collapse of a strong upwelling event. It is believed that there is a connection between upwelling seen on this coast, and the intrusion of oceanic waters over the shelf south of the S.A. Gulfs. The connections between the intensity of upwelling activity in S.A. waters, and the dynamics of the Gulf frontal zone, are to be explored in the data sets acquired during these exercises.

NGERIN conducted a further week of CTD profiling in late February, in order to maintain observations of the evolution of the frontal system during the summer season. The HF radio antenna problems were corrected for this cruise, and the NGERIN successfully received up-to-the-minute SST imagery to guide their operation.

This cruise (FR04/89) involved a further 8 days of physical, chemical and biological monitoring of the frontal zone, alongside the NGERIN. It is known that the zone breaks down in early autumn. This is because Gulf temperatures fall, increasing the density and thereby promoting their discharge in the form of dense bottom gravity currents. The intention was, in addition to further assessing the roles of semi-diurnal, diurnal and spring/neap changes of the intensity of turbulence on the frontal zone, to determine the gross structure of the zone and the nature of its development through the summer season.

As was the case with cruise FR02/89, this cruise was extremely successful. All equipment performed reliably and well, there were no delays or losses of time due to bad weather, and the efficiency and conscientiousness of FRANKLIN and CSIRO personnel ensured the maximum return of high quality data.

Figure 1 shows the arrangement of the CTD network within the mouth of the Gulf, and across the shelf. It was, to some extent, surprising to note (for example, in figures 2 and 3) that the frontal zone was apparently stronger (larger gradients) than was the case in late January, despite the likelihood of its impending collapse at some time in May. Gradients were large across a concentrated near-botom front, involving changes of up to 3 C and 1.2 psu through a horizontal distance of approximately 10km. These gradients are twice as large as those observed in January. Again, the coincidence of temperature and salinity fronts acts on density in such a way as to form a density minimum at the front itself. It is believed that this density minimum, while promoting bottom convergence and probable upwelling at the front, also produces a separation zone for the longitudinal vertical circulation, and thereby inhibits exchange across the zone. Nutrient analysis, performed on-board the FRANKLIN, supports the physical evidence for the separation of properties, and a lack of cross-frontal exchange. Nitrate/nitrite within the Gulf waters was below detection limits, while on the shelf side it was present in small amounts, increasing substantially in the waters below the shelf thermocline (nutrocline). Chlorophyll filtration was performed on board the FRANKLIN once through the large-scale CTD grid. Analysis will be performed following the cruise, but the density of colour increased appreciably in the vicinity of the front. The colour was also somewhat stronger than that seen in January. Fish larval distributions will be assessed and reported subsequently by the S.A. Department of Fisheries.

The upward inclination of the pycnocline, in figure 3 for example, further implicates wind-driven upwelling in the convergence of water masses towards, and the dynamics of, the frontal zone. This figure also suggests a great deal of internal wave/internal tide activity with probable breaking of internal waves on the shoaling sea bed. Assessment of these aspects will be made on the basis of current meter time series from the shelf moorings, and acoustic doppler results tied to structure seen during both FR02/89 and FR04/89 cruises.

Each of the FRANKLIN CTD profiles (sampled at 30Hz) was processed to produce a reduced file of 2m-average values. Each profile therefore constituted a small number of discrete points within a T-S diagram. The result of plotting these discrete points from all CTD profiles on the same T-S diagram, and contouring percentage occurrence, is shown in figure 4. It indicates the presence of two well-defined water masses in the frontal region, associated with Gulf (warm salty) and shelf (cooler fresher) characteristics. A less prevalent third mass is seen as cold, relatively fresh waters of oceanic origin (lower left). In the corresponding figure from January the masses are strongly linked by mixed waters of intermediate characteristics, although the mixing line between shelf and Gulf water masses was unexpectedly absent. In this latest cruise, the masses were apparently more distinctly separate, with less evident mixing. The increased gradients observed during this cruise, compared with those seen in January, appear to be associated with reduced mixing in the area. It was also noted that interleaving of masses across the frontal zone was almost entirely absent in the latest results, while a great deal of fine-scale structure was seen in January. As before, however, the frontal zone is still subject to a substantial advection on tidal time scales.

Cruise FR04/89, in completing the 1989 program of observations in the frontal zone, assited the NGERIN in the recovery of the moorings. It was originally intended that NGERIN would recover all 9, but difficult sea conditions and the tight observational/sampling schedule necessitated FRANKLIN's recovery of the mid-shelf mooring south of the Gulf. All 9 moorings were safely recovered with all (bar one) instruments apparently intact and working.

Unfortunately, the entire cruise period was characterised by overcast conditions, and no satellite infra-red imagery could be of assistance in determining the optimum sampling strategy.

5. CRUISE NARRATIVE

Franklin left Port Adelaide at 09:00h (local time) on Thursday 23rd March, as scheduled.

Arriving, at 19:00h, at the first station of four axially-aligned transects through the mouth of Spencer Gulf, a large-scale survey of the physical structure, involving 43 CTD profiles, was completed at 09:40h on Saturday 25th March.

Having defined the frontal zone, from 11:00h until 18:30h on the 25th of March a more detailed assessment of cross-frontal contrasts was made on a line to the west of Wedge Island.

At 20:15h on Saturday 25th March, 12.5 hours of half-hourly CTD profiling was initiated at a fixed station (35 3.5'S, 136 25.1'E) in the centre of the frontal zone. The intention here was to look at the spatial and temporal coherence of interleaving and intrusive features as the tidal advection carried the zone northward and southward through the observation point and, with the acoustic doppler data, to assess the residual current field across the front after subsequent removal of the tidal contribution. On this occasion very little structure was observed to pass the station, and vertically homogeneous conditions persisted throughout the period.

At 10:00h on Sunday 26th March the NGERIN joined the FRANKLIN for 13 hours of repetitive tandem steaming along a north-south line through the frontal zone. Franklin logged ADCP data continuously while Ngerin filled in the physical structure at 6 CTD stations along the line. The resampling period for each transect was approximately 1.5 hours which was intended to allow subsequent removal of the tidal part of the signal, to reveal the residual current structure and its relationship to the physical system. The NGERIN then departed for associated larval trawls within the area.

A second detailed section across the zone to the eastern side of Wedge Island was completed at 08:30h on Monday 27th March. This was followed by 12.5 hours of half-hourly fixed station CTD profiling, completed at 23:45h on the 27th. During this second fixed station work, appreciable changes in water column structure were noted as the front was advected past the station.

Discussions with the NGERIN, following 4 days of strong south-easterly winds, prompted FRANKLIN's involvement in the recovery of one shelf mooring (at 35 50.1'S 136 5.4'E). FRANKLIN arrived at the mooring site at first light, conducted a CTD cast for mooring instrument calibration purposes, and commenced the recovery at 06:40h on the 28th March. This was a U-shaped mooring with a riser to a surface buoy, a ground line of 230m and a second riser, to which the instruments were attached, topped by a subsurface buoy. The recovery went very smoothly, and was completed by 07:20h. The instruments were in good condition and surprisingly free of fouling.

FRANKLIN then continued southwards, beyond the shelf break, to a depth of 2850m. For this deep cast, to 2000m, an antenna was attached to the CTD framework for pressure testing. A cross-shelf CTD transect with stations at approximately 5nm intervals was then completed, joining the grid pattern within the Gulf mouth, at 00:30h on Wednesday 29th March.

A final large-scale appraisal of the frontal region, covering most of the zone in a relatively coarse pattern, was completed at 07:30h on Thursay 30th March. This grid was observed at the time of neap tides, for comparison with the initial grid survey at the start of FR04/89 which was conducted during spring tides.

6. SUMMARY

As with cruise FR02/89, in all aspects this cruise should be considered to have been extremely successful. It completes a comprehensive, detailed study of a sharp temperature/salinity front. The front evidently acts as a substantial barrier to the exchange of properties across the zone, and its study here has important implications for the understanding of Gulf/shelf interaction in the local context, with regard to salt discharge and possibly passive larval advection, and in the wider context of similar density-compensated frontal systems that are known to occur in various parts of the world ocean (for example, the Antarctic polar front, and shelf break fronts along the eastern coast of the North America). The data gathered are of high quality and cover a range of physical, chemical and biological parameters through substantial spatial and time scales.

As before, the software facilities available during the cruise (packages for plotting contoured cross-sections or vertical profiles of water properties, vector plots of ADCP currents, temperature/salinity diagrams, and freedom to write personalised software on the Vax) were of considerable value in optimising the cruise plan, and in early appraisal of the oceanography. The availability of real-time meteorological data, and continuous surface temperature and salinity observations were also much appreciated.

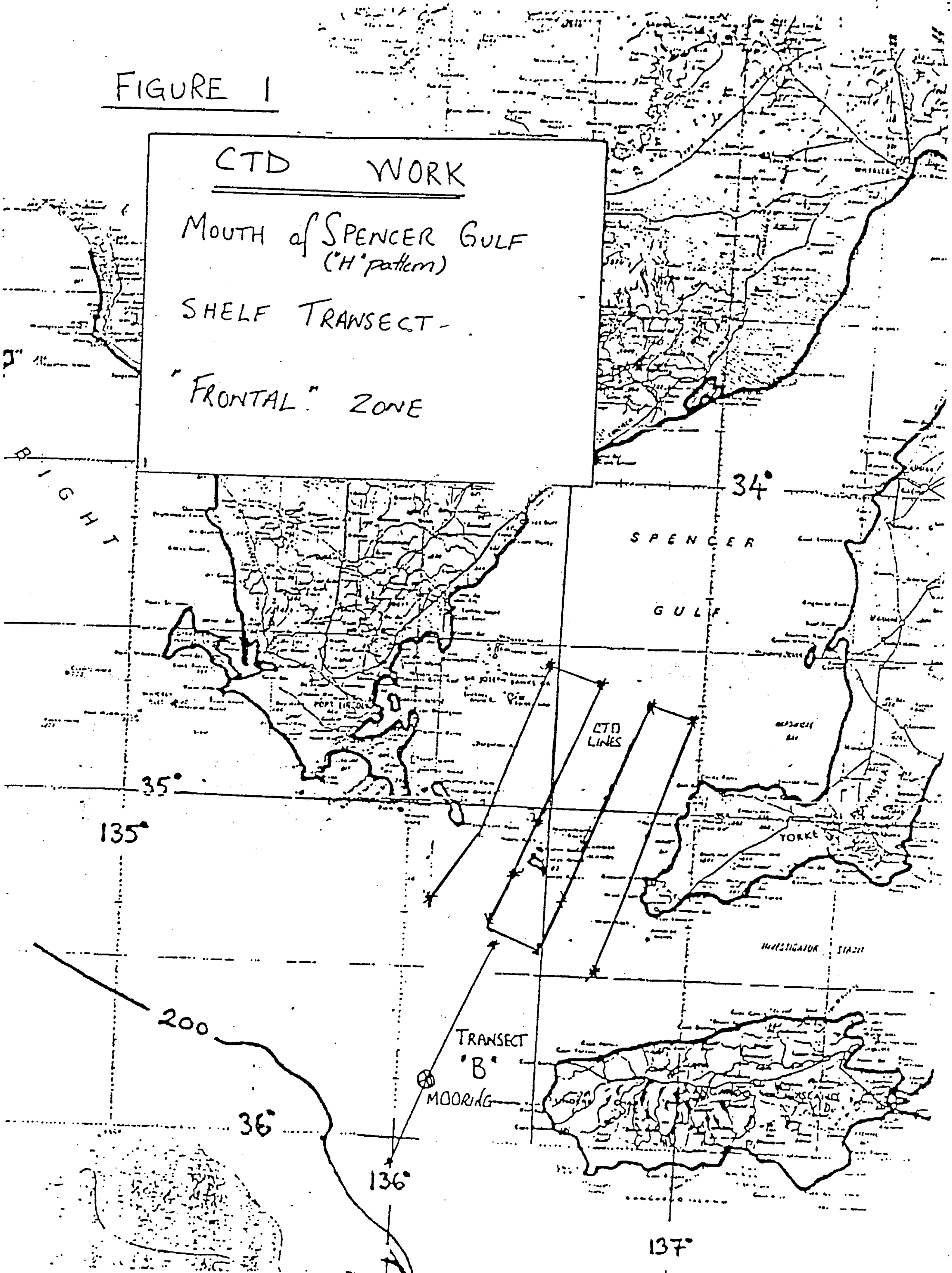
7. PERSONNEL

Rick Nunes Vaz	Chief Scientist	UNSW/Flinders Uni
Peter Petrusevics		S.A. Department of Fisheries
Guoy Tong Kiat		Flinders Uni
Jim Gunson		Flinders Uni
Mark Trenorden		Flinders Uni
Paul Chambers		Flinders Uni
Dave Vaudrey	Cruise Manager	CSIRO - ORV
Phil Adams		CSIRO - ORV
Gary Critchley		CSIRO - ORV
Bruce Barker		CSIRO - ORV
Brian Willey		Dept. of Transport & Communications

8. ACKNOWLEDGMENTS

It is a pleasure to thank the officers and crew of the Franklin, particularly the Master Neil Cheshire, and the CSIRO personnel, again in particular, Dave Vaudrey, for help and advice during the conduct of this cruise. The smooth efficiency of operations on the ship, the flexibility afforded in the final determination of the station plan, and the attention to maintenance of precision in data collection and analysis procedures, are very gratefully acknowledged. The quality of this very valuable data set owe a great deal to the supervision and efforts of CSIRO personnel.

FIGURE 1



CTD WORK
MOUTH of SPENCER GULF
("H" pattern)
SHELF TRANSECT -
"FRONTAL" ZONE
BIGHT
34°
SPENCER
GULF
CTD LINES
35°
135°
YORKE
TRANSECT 'B'
MOORING
200
36°
136°
137°

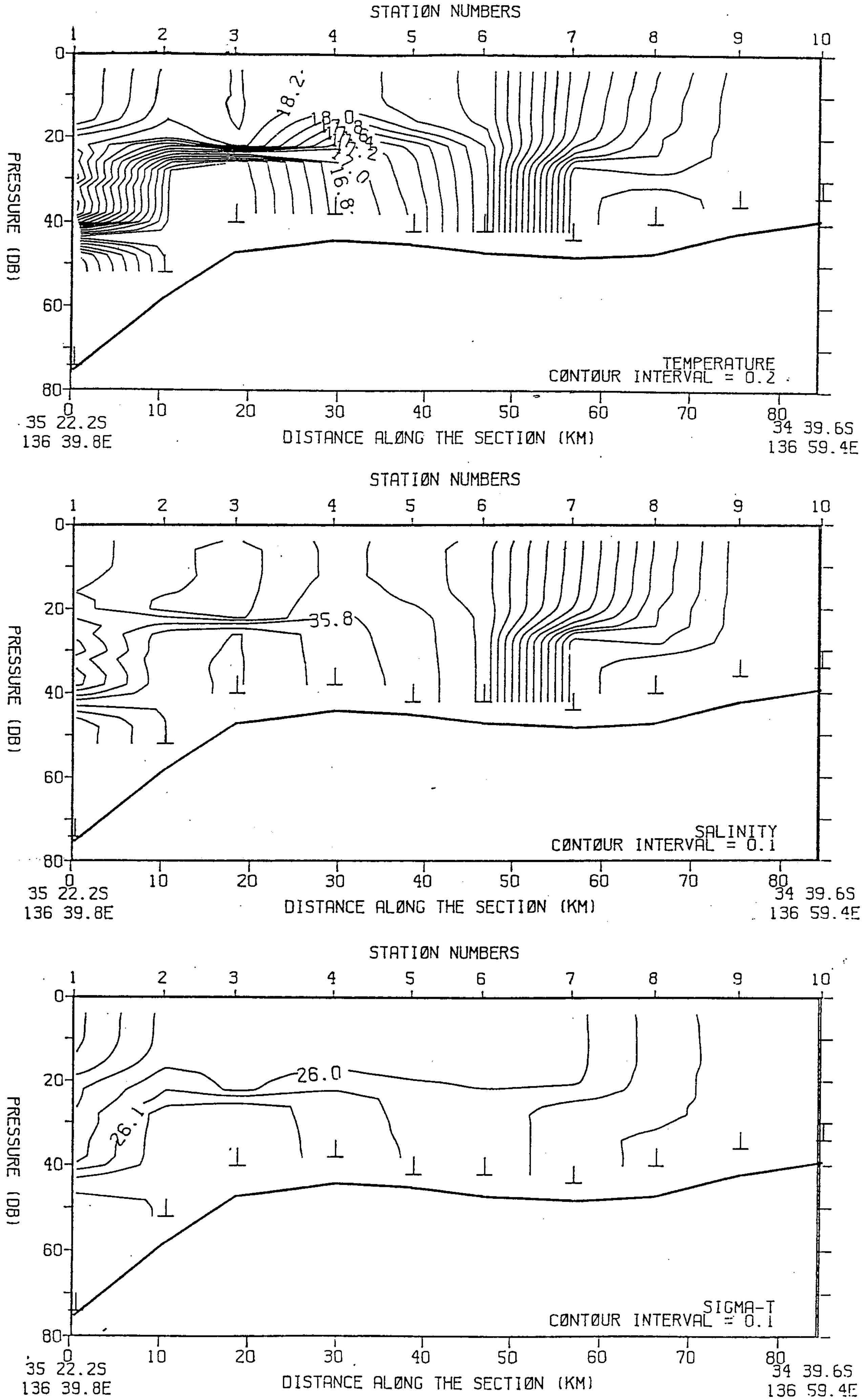

STATIØN NUMBERS
1 2 3 4 5 6 7 8 9 10
PRESSURE (DB)
0 20 40 60 80
18.2
18.0
17.8
17.6
17.4
17.2
17.0
16.8
TEMPERATURE
CØNTØUR INTERVAL = 0.2
0 10 20 30 40 50 60 70 80
35 22.2S
136 39.8E
DISTANCE ALØNG THE SECTIØN (KM)
34 39.6S
136 59.4E
STATIØN NUMBERS
35.8
SALINITY
CØNTØUR INTERVAL = 0.1
DISTANCE ALØNG THE SECTIØN (KM)
STATIØN NUMBERS
26.0
26.1
SIGMA-T
CØNTØUR INTERVAL = 0.1
DISTANCE ALØNG THE SECTIØN (KM)

FIGURE 2

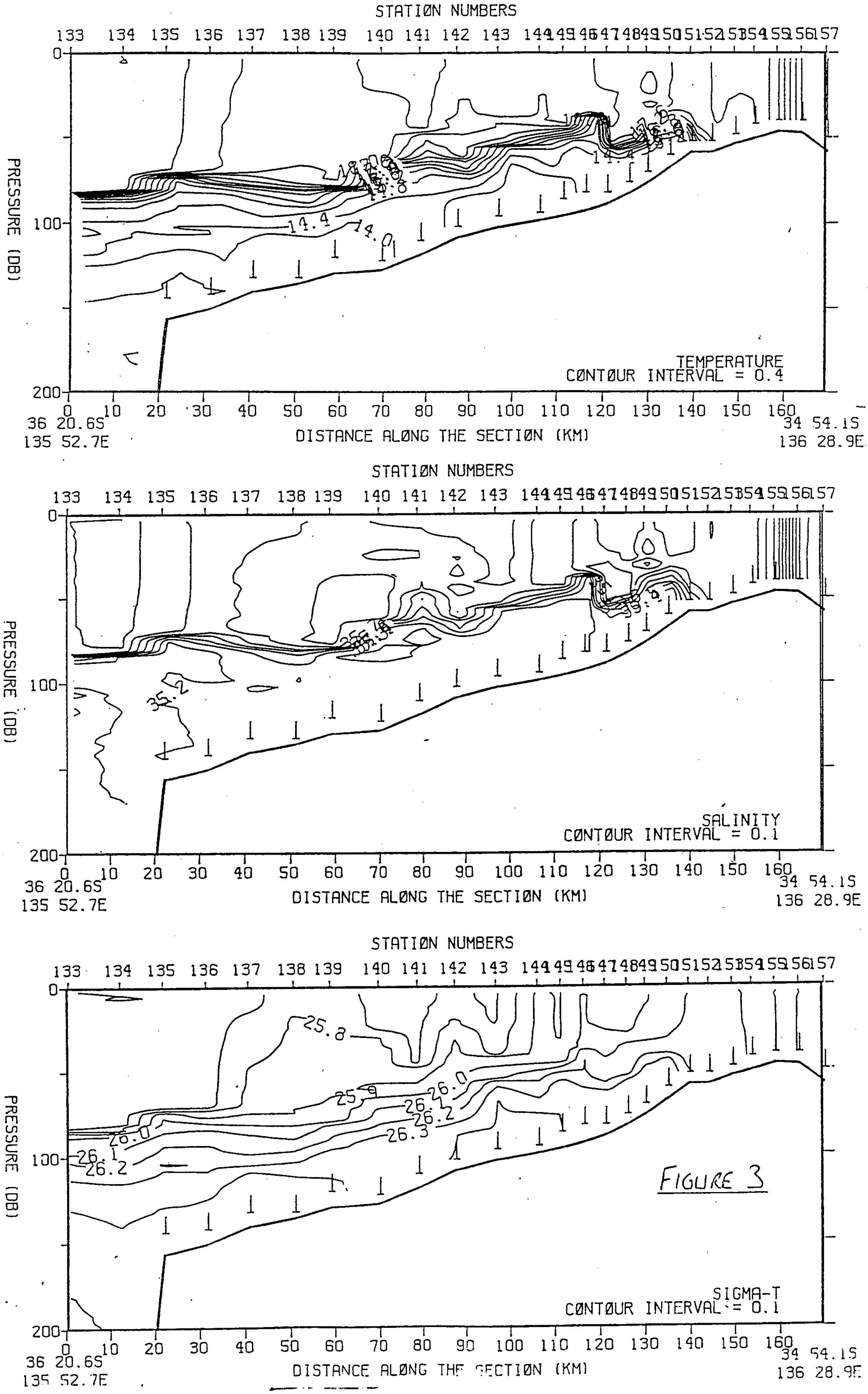
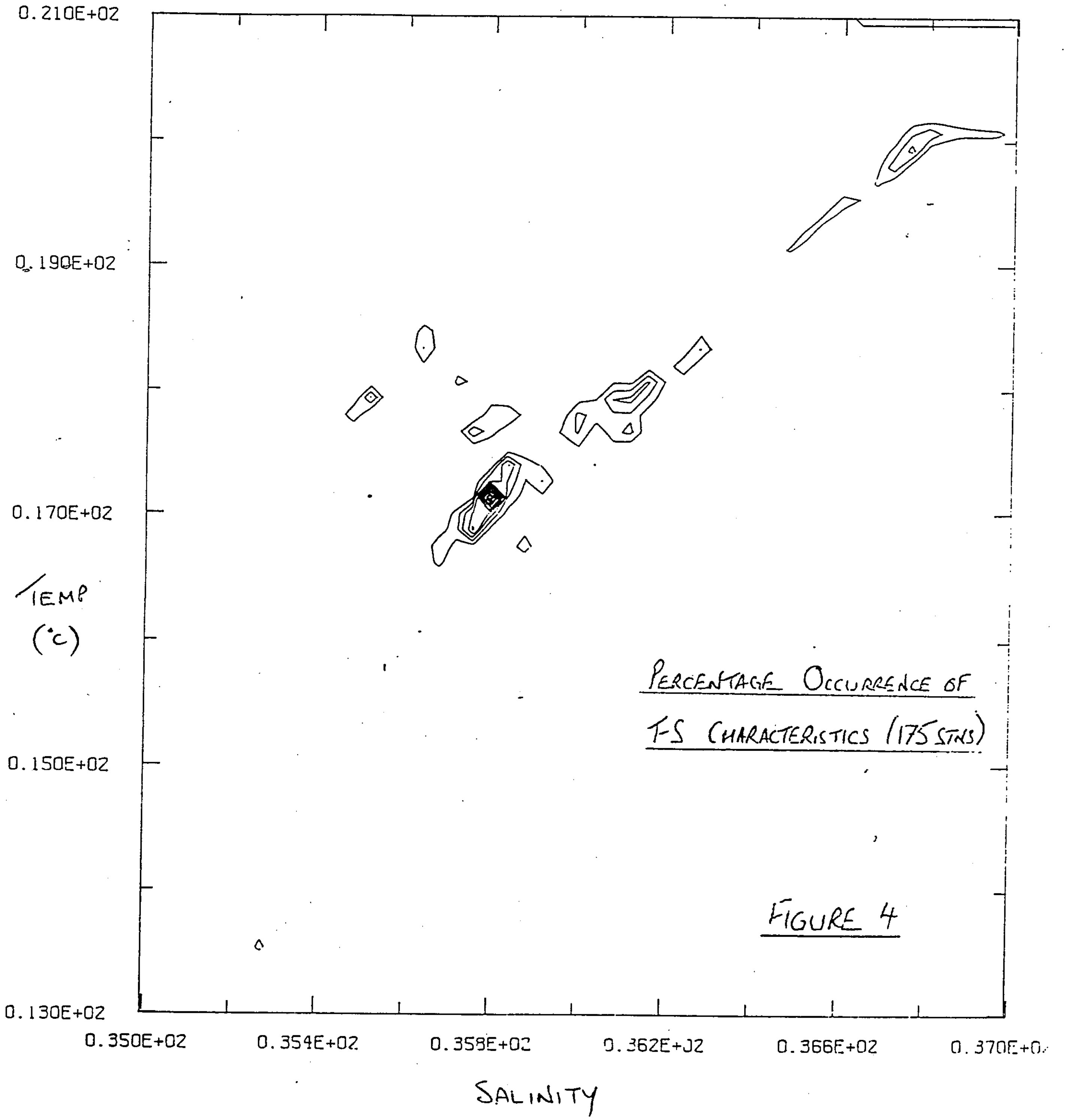

STATION NUMBERS
133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157
PRESSURE (DB)
0
100
200
14.4
14.0
TEMPERATURE
CONTOUR INTERVAL = 0.4
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
36 20.6S
135 52.7E
DISTANCE ALONG THE SECTION (KM)
34 54.1S
136 28.9E
STATION NUMBERS
133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157
PRESSURE (DB)
0
100
200
35.2
SALINITY
CONTOUR INTERVAL = 0.1
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
36 20.6S
135 52.7E
DISTANCE ALONG THE SECTION (KM)
34 54.1S
136 28.9E
STATION NUMBERS
133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157
PRESSURE (DB)
0
100
200
25.8
25.9
26.0
26.1
26.2
26.3
SIGMA-T
CONTOUR INTERVAL = 0.1
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
36 20.6S
135 52.7E
DISTANCE ALONG THE SECTION (KM)
34 54.1S
136 28.9E

FIGURE 3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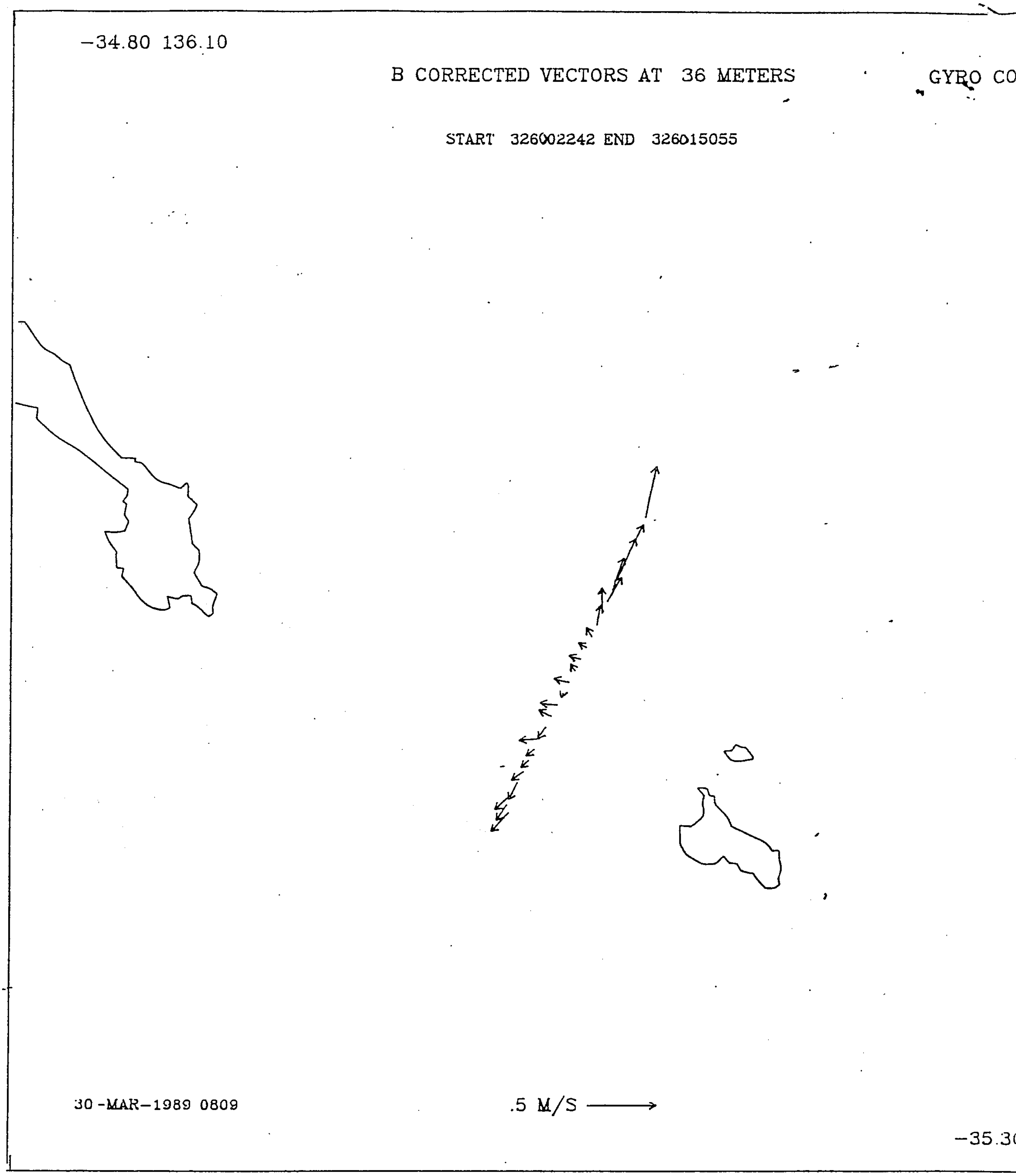
TEMP
(°C)
0.350E+02
0.354E+02
0.358E+02
0.362E+02
0.366E+02
SALINITY
PERCENTAGE OCCURRENCE OF
T-S CHARACTERISTICS (175 STNS)

FIGURE 4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