R.V. FRANKLIN

NATIONAL FACILITY
OCEANOGRAPHIC RESEARCH VESSEL

RV FRANKLIN

RESEARCH SUMMARY

CRUISE FR 2/89

Sailed Adelaide 0900 Tuesday 17 January 1989
Arrived Adelaide 1030 Wednesday 8 February 1989

Principal Investigators

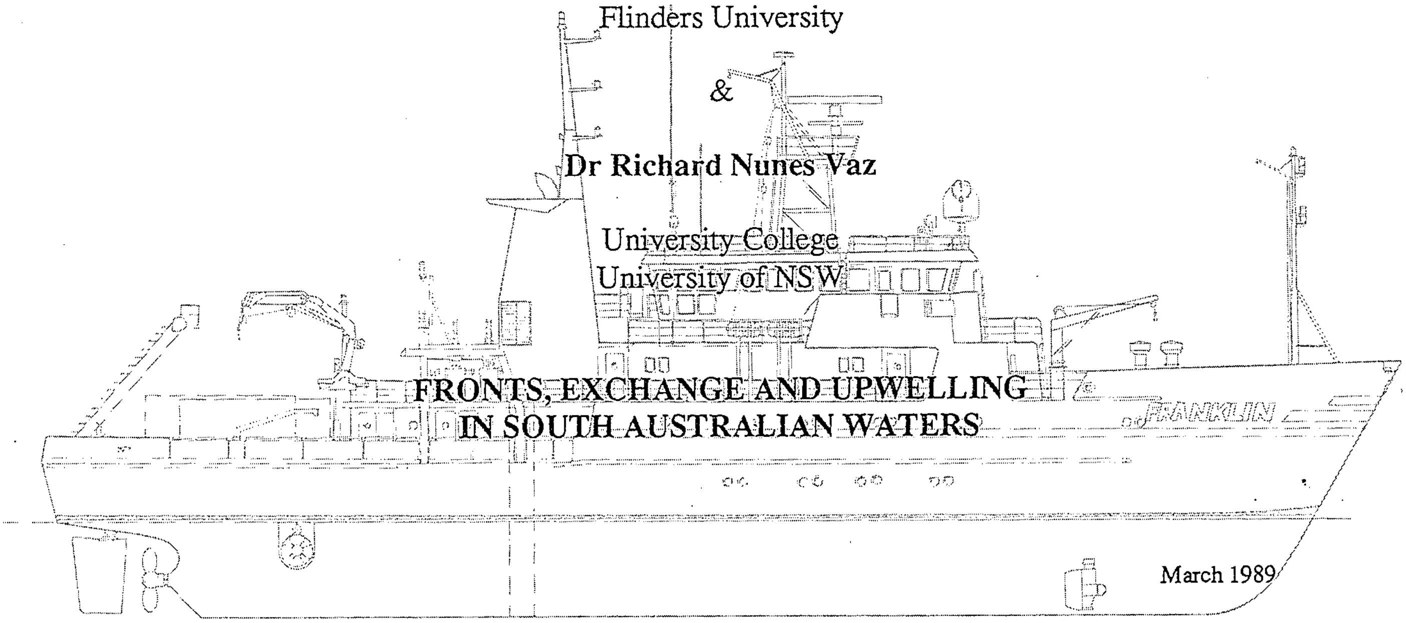
Prof Geoff W. Lennon

School of Earth Sciences
Flinders University

&

Dr Richard Nunes Vaz

University College
University of NSW



FRONTS, EXCHANGE AND UPWELLING IN SOUTH AUSTRALIAN WATERS

March 1989

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AUSTRALIA

R.V. FRANKLIN IS OWNED AND OPERATED BY CSIRO

1. ITINERARY

Sailed: ADELAIDE 09:00 Tuesday 17th January 1989.

Arrived: ADELAIDE 10:30 Wednesday 8th February 1989.

2. SCIENTIFIC PROGRAMS

Assisted by the guidance of up-to-the-minute infra-red imagery of sea-surface-temperature, to conduct a systematic observational program in the South Australian upwelling zone, using the CTD and acoustic doppler current profiler. This aspect of the program is linked to the previous Franklin cruise (FR01/89) of Hunter and Hearn (Lennon/Nunes Vaz).

The retrieval of two current meter moorings deployed by Hunter and Hearn within the upwelling zone (Lennon/Nunes Vaz).

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). This work was again to be guided by indications from infra-red imagery of the region provided by the Flinders University remote sensing facility.

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).

The collection of water samples for trace element and isotope detection, as a means of tracing fluid exchange between Spencer Gulf and the adjacent shelf. This part of the program was cancelled prior to the voyage due to the unavailability of a vital item of equipment (Veeh).

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,
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Dr. H. Veeh,
School of Earth Sciences,
Flinders University,
Bedford Park, South Australia, 5042.

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 fluid between Gulf and shelf) and the detailed nature of mixing (i.e. interleaving etc.).

The cruise was very successful, and the intentions were very largely met, due, in part, to flexibility in the timing and nature of Franklin tasks afforded us by the Master, Neil Cheshire, and the Cruise Manager, Neil White. There was no time lost due to bad weather, and all instrumentation performed very well, (despite more rapid use of the CTD than normal in order to provide the necessary temporal and spatial resolution). Work in the region was guided, in some degree, by indications from NOAA-11 imagery received by the Flinders remote sensing facility. In the early stages of this work the Fisheries' research vessel successfully received images transmitted from Flinders. This was useful in directing effort to resolving the correspondence between sea-surface-temperature distributions and their underlying structures. It also demonstrated the feasibility of optimising the observational work using remotely sensed data. However, following the early successes, antenna problems prevented the reception of subsequent transmissions to the vessel. The station network, for this part of the cruise, is shown in figure 1. More detailed exercises were conducted within specific parts of the grid.

The network of CTD stations at the mouth of the Gulf was completed in the first two days, after which a sub-section of the pattern was surveyed in finer detail.

It was apparent that many interesting and complex mixing processes were taking place close to the frontal zone. Interleaving layers were commonly seen, some associated with instabilities that persisted for more than an hour. On the western side of the Gulf entrance the vertical regime of the Gulf waters butted directly against the two-layer structure of the shelf, apparently bringing three water masses into close proximity (figure 2). On the eastern side the two regimes were separated by some 10 - 20 km within which the density was largely uniform.

Figure 3 shows a composite T-S diagram in which all 2-m averages from all 316 CTD stations have been combined as percentage frequencies of occurrence of particular T-S characteristics. There are clearly 3 identifiable water sources in the region, corresponding to Gulf (warm, salty), surface shelf (cooler, fresher) and ocean (cold, relatively fresh) waters. It is apparent that the connection between Gulf and ocean waters is strong, and mixed products along this line are common. Again, mixed products of surface shelf and ocean waters are common, and are presumably found in the thermocline. What is notable in the diagram, and though it is consistent with the notion of upwelling and surface divergence in the density minimum zone, is nevertheless surprising to find so graphically demonstrated, is the absence of a significant connection between

Gulf and surface shelf waters. The diagram suggests that very little direct contact between these two water masses occurs.

Alongside the CTD profiling, the acoustic doppler current profiler logged currents throughout the cruise. The instrument appeared to function well, giving very plausible consistent data. Vectors from the ADCP during the more detailed CTD mapping (around a box completed in just over 24 hours) showed a distinct diurnal inflow/outflow pattern (figure 4) consistent with the diurnal nature of tides at the time.

Two separate 24h periods of repetitive CTD profiling at a fixed station in the region of the front proved to be extremely informative. The frontal zone was subject to substantial tidal advection placing the station into both the Gulf and the shelf regimes at various times. This work revealed some very persistent interleaving structures which remained identifiable through several successive profiles (implying a length scale as well as a time-scale). The zone was extremely rich in intrusive features.

In the original proposal for this work it was intended that a microstructure probe (from Professor Imberger's group in Western Australia) would be deployed in this area. Unfortunately the loss of certain parts of the system during its use in Western Australia late in 1988 precluded this aspect of the program. It seems likely that this would have been very rewarding.

The fixed station exercises were conducted for a full 24 hours to enable later removal of most of the tidal signal in the acoustic current profile data. In this way, as the frontal zone drifted to either side of the station, some sense of the cross-frontal shear should be resolvable.

Following these exercises the South Australian Fisheries' research vessel, Ngerin, joined the Franklin for periods of simultaneous, coordinated activity. The use of the CSIRO National Facility and the South Australian Fisheries' research vessels in joint work of this nature is notably unique in the Australian marine science scene. Both vessels were used to combine acoustic doppler current data with water structure observations along a repeated track. The availability of two vessels permitted a significant cross-frontal line to be sampled at a frequency sufficient to allow subsequent removal of the tidal signal, to reveal the non-tidal shear across the frontal zone. This work would not have been possible without the opportunity to work with two such research vessels dedicated to the exercise, and accordingly should be considered an important step forward in the management of coastal oceanographic research.

Nutrient analysis of the waters in the frontal zone showed potentially significant differences between Gulf and surface shelf waters in phosphate, and considerable differences between these and the ocean waters, particularly in nitrate/nitrite. These data, alongside filtered chlorophyl samples which were also taken, will be used to investigate the extent of productivity associated with the mixing of waters in the frontal zone.

Shelf Transects Across The Eastern Great Australian Bight

Two days were spent in CTD work along the two cross-shelf transects also shown in figure 1. In December 1988, the S.A. Fisheries' vessel Ngerin had deployed two current meter moorings on the shelf, one on each of the transects. These are to be recovered during Franklin cruise 04/89, and are intended to provide some information as the direction and rate of along-shelf flow from, or to, the Great Australian Bight. Earlier data, from work done by Flinders University, indicate that the general south-easterly shelf flow is interrupted and possibly reversed during the summer. Interest is focussed on the role of the shelf waters in the dynamics of the Gulf frontal zone.

The CTD profiling along transects A and B was to provide water property structure within which the current meter data will be placed. The opportunity was taken to check on the continuing operation of the moorings, as these waters are often busy and the hardware may well have been lost. The mooring on transect A was not seen, but the sea state conditions were very difficult at the time. The mooring on transect B was found without difficulty in the correct location.

Summertime Upwelling In South-Eastern South Australia

The south-eastern part of the S.A. coast has a narrow continental shelf and, subjected to south-easterly winds, the surface waters move to the north-west and offshore, to be replaced by deep, cold, nutrient-rich waters from offshore. In the process the thermocline rises to the surface and progresses offshore until the south-easterlies cease. Following such an event the thermocline relaxes back to its normal horizontal configuration.

The second part of this cruise, after work in the entrance to Spencer Gulf, follows on from the Hunter/Hearn cruise in early January (FR01/89). The Hunter/Hearn cruise defined a Seasoar/CTD grid network of cross-shelf transects from Portland, in the south, to Beachport, in the north. During the early part of their cruise, winds were unfavourable to upwelling. A weak event was monitored during the second half of the exercise, but because of the limited duration of the event (and remaining cruise time) effort was concentrated in the southern half of the proposed network.

Two shelf moorings were also deployed during the Hunter/Hearn cruise (see figure 5), to monitor the incidence of signals (shelf waves etc.) entering the upwelling zone from the north-west. Such long period waves would contaminate the currents recorded by the ADCP and, without knowledge of their existence or absence, would make the interpretation of ADCP data questionable.

Work in the region during this cruise began on Sunday 29th January. In this case, effort was concentrated in a number of cross-shelf transects in the northern half of the proposed CTD network (figure 5). Again, data were gathered using the Neil-Brown CTD at specific stations, and with the ADCP at all times during the cruise.

On arrival in the area winds were unfavourable to upwelling, being mostly onshore. During the first two days, the structure along 5 transects was observed in order to establish a baseline from which the occurrence of upwelling would be apparent. The inner three transects were designated as the primary observation sections. The outer two were monitored less frequently in order to be aware of the properties of water that might be advected into the primary site.

On the evening of the 31st January winds swung round to the south-east, in the sense to promote upwelling (figure 6). The three primary transects were sampled approximately once each day in order to note the differences at intervals of approximately one inertial period. Five days into the event, as the cruise end approached, a full south to north survey of six cross-shelf transects was undertaken, one to the south and two to the north of the main three. (This was interrupted by 12 hours of east/south-easterly winds averaging 35 knots, gusting to 50 knots, when work had to be stopped.)

As with the first part of the cruise, this exercise was extremely successful. The timing was very fortunate, and a strong upwelling event was recorded in great detail. The central cross-shelf transect was sampled on a regular basis some 8 times during the evolution of upwelling and substantial changes were seen. All instruments performed without fault, including the ADCP which ran continuously throughout the exercise.

On arrival in the area the initial surveys showed surface temperatures throughout the region of 16 to 17 degrees. A largely horizontal thermocline was present at approximately 20m depth over the mid-shelf region, deepening to 40-60m over the outer shelf. This was underlain with waters of approximately 14 degrees. The 26.5 isopycnal was horizontal at a depth of ~80m (figure 7). During the final survey of the cruise, the same transect showed waters of 13 degrees at the surface nearshore, increasing abruptly (the contouring program has smoothed the gradient which the thermosalinograph indicated as sharp) to nearly 15 degrees offshore (figure 8). Ocean waters of 10 degrees (normally below 250m off the shelf) had upwelled onto the shelf during the event. The 26.5 isopycnal had also reached the surface nearshore.

During the evolution of the event, as the isopycnals were rising to the surface, the ADCP indicated strong west-north-westerly currents alongshore in the direction of the wind, with a slight offshore component in the surface 20m-30m, with a tendency for a weak onshore component at greater depth. These currents had a distinct cross-shore variation, strengthening on approaching the shore, and then weakening as surface temperatures rose in a slightly warmer inshore zone next to the coast.

Following completion of the CTD work in the upwelling zone, the two Hunter/Hearn moorings were recovered.

5. CRUISE NARRATIVE

Franklin left Port Adelaide at 0900 on Tuesday 17th January, as scheduled.

The degree of flexibility built in to the cruise plan, and afforded by the ship's master and cruise manager, meant that a decision had to be made as to whether to begin the cruise in the region of Spencer Gulf, and conclude with the south-eastern upwelling investigation, or vice versa. For two reasons it was decided to go initially to Spencer Gulf. Firstly, the Hunter/Hearn cruise (FR01/89) had returned at the tail end of a weak upwelling event and another event was not thought to be imminent. Secondly, the South Australian Fisheries' research vessel Ngerin was scheduled to take part in joint work with the Franklin but was only available for segments of the first two weeks of the 23 days planned for the Franklin, and only within the Spencer Gulf region. It was therefore felt that, to take full advantage of the invaluable opportunity of simultaneous observations from two research vessels, the Spencer Gulf exercise should commence the cruise.

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 42 CTD profiles, was completed at 03:20h on Thursday 19th January.

Prior to departure from Adelaide, Flinders University had provided a NOAA-11 infra-red image of the Gulf entrance area which showed a strong surface frontal feature extending westward across the mouth of the Gulf, but diffusing slightly and turning north-westward on approaching the western side.

The survey, in contrast, indicated a significantly stronger frontal zone on the western side of the Gulf entrance, in a position somewhat south of that indicated in the image a few days prior to our departure. This immediately suggested a degree of mobility and variability that was unexpected.

The frontal zone was located by the first survey, and from 05:00h on the 19th until 08:30h on the 20th of January, a near-rectangular box of approximately 50 closely spaced CTD stations was used to look at the zone in detail.

The box survey proved to be of great value. It clearly identified the limits of each type of water mass and indicated that the part of the front on the western side of the mouth was much sharper than that on the east. In this area the shelf thermocline was butted squarely against the vertically mixed regime of the Gulf (figure 3). The region showed clear indications of active interleaving and, in view of the change in position from the initial large-scale survey, it indicated that the zone undergoes considerable longitudinal movement, presumably due to tidal advection. The ADCP data clearly showed the diurnal nature of tidal currents at the time (figure 2).

At 10:00h on Friday 20th, 24 hours of half-hourly CTD profiling was initiated at a fixed station (35 13.6'S, 136 19.6'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. The 24h period was chosen to assist the later removal of much of the tidal component from the ADCP data, to reveal something of the nature of cross-frontal shear.This was an extremely useful exercise as the region was rich in intrusive features which were, in some cases, associated with instabilities in the vertical density structure.

At 10:45h on Saturday 21st January the Ngerin was available for the first joint exercise with the Franklin. For a 24 hour period the two ships steamed almost together, back and forth along a 21km line through the frontal zone. While Franklin logged ADCP data continuously and profiled with the CTD at each end of the line, Ngerin filled in the physical structure between the end points. The resampling period for each transect was approximately 2.25 hours which again 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.

An oil leak in the engine room necessitated anchoring the Franklin for some hours following the joint exercise on the 22nd January (during which time Ngerin commenced a period of Fisheries' committments). At 22:00h Franklin departed from the Gulf, conducting a CTD transect across the shelf at the eastern end of the Great Australian Bight. The CTD work continued in a pattern along the shelf break towards the east, and a northward transect to rejoin one of the detailed lines through the frontal zone of Spencer Gulf on Wednesday 25th January.

Two moorings had been deployed on the shelf by the Flinders group in December 1988 - one on each of the cross-shelf CTD transects. These should provide the speed and direction of the residual flow and clues as to the origins of shelf waters in the vicinity of the Gulf frontal zone. The shelf CTD transects were intended to reveal the cross-shelf physical structure, to place the mooring data into context, and to locate the moorings' surface markers as a check of their continued survival and operation in the area.

The mooring on the western transect was not found, but this was probably due to the sea state at the time which made visual spotting of buoys very difficult. The mooring on the eastern transect was readily found in position.

On returning to the Gulf a second large-scale survey was completed at 16:00h on Thursday 26th January, from which it was evident that there had been some considerable changes since the initial survey. The frontal zone on the eastern side had tightened appreciably. The first survey was conducted at a time of neap semi-diurnal tides, the second at springs.

A second 24 hours of half-hourly fixed station CTD profiling, this time on the eastern side of the front, was completed at 21:00h on Friday 27th January. At this time the Ngerin joined the Franklin for a second 24h ADCP/physical structure exercise. This kind of detailed work proved to be very informative with regard to the nature of mixing and exchange processes within the Gulf frontal zone. Subsequent analysis of the ADCP data in front-based coordinates will be carried out upon receipt of the calibrated data from CSIRO, Hobart.

Franklin left Spencer Gulf at approximately 22:00h on Saturday 28th January for the south-east upwelling region, arriving, off Beachport, for the first station in a set of cross-shelf transects, at about 20:00h on Sunday 29th. A high pressure cell was approaching the Bight from the west, somewhat squeezed between cyclones to the north and cold fronts to the south. The cell, nevertheless, managed to establish itself within the Bight and south-easterly winds, favourable to upwelling, began during the evening of 31st January.

An initially coarse network of five cross-shelf transects were covered in the days prior to the south-easterlies in order to establish a baseline from which re-organisation due to upwelling would be apparent.

CTD profiling on the inner three transects continued, on approximately a daily basis, during the first 5 days of the event. Winds were sustained at 10 to 20 knots from the south-east throughout this period. The ADCP data indicated a developing alongshore coastal jet current as the isopycnals shoaled inshore.

On Saturday 4th February a six-transect survey of the shelf was begun, from Cape Northumberland in the south, to Robe in the north. This was interrupted by 12 hours of east/south-easterlies averaging 35 knots, gusting to 50 knots. The survey was completed at 05:00h on Tuesday 7th February, some 12 hours after winds had turned to become weaker and easterly.

At approximately 07:00h on Tuesday 7th the inshore mooring of the two Hunter/Hearn moorings was acoustically triggered to release, and recovered. The offshore mooring was similarly recovered at approximately 10:30h on the 7th.

6. SUMMARY

In all aspects of the program, the cruise should be considered to have been extremely successful. The data gathered in both main sites of interest are comprehensive, and provide a thorough coverage of most physical parameters, and additional biological characteristics over a wide area and for a substantial time. The data set from the upwelling area of the south-east should be considered particularly valuable covering, as it does, the entire evolution and onset of a substantial event. In 23 days only 12 hours were lost due to bad weather, and virtually no losses occurred due to vessel or equipment problems.

The entire cruise, as it unfolded, tested the instrumentation and winch systems, as over 500 CTD casts were performed, and the ADCP was run continuously throughout. The operation of the ship in relation to the scientific program was smooth and efficient at all times.

A number of software facilities which were made 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 great value in planning specific tasks, enabling optimum use to be made of the cruise time available. 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
Richard Schahinger		Flinders Uni
Robert Gardiner-Garden		UNSW
Paul Hutchinson		Flinders Uni
Pat Bishop		Flinders Uni
Adam Clark		Flinders Uni
Neil White	Cruise Manager	CSIRO - ORV
Phil Adams		CSIRO - ORV
Ron Plaschke		CSIRO - ORV
Mark Rayner		CSIRO - ORV

8. ACKNOWLEDGMENTS

Our program of measurements, being confined almost entirely to the shallower regions of the South Australian shelf seas where the time-scales of significant changes are measured in hours rather than days, necessitated much more rapid and continuous use of the CTD than was usual for the vessel. Without the flexibility allowed by both Neil Cheshire and Neil White, and without the patience of so many in the face of continuous CTD work, much less would have been achieved. The success of the cruise, and the quality of data collected owe a *great deal* to the supervision and efforts of CSIRO personnel. These are greatly appreciated, as are the efforts of the entire Franklin crew.

FIGURE 1

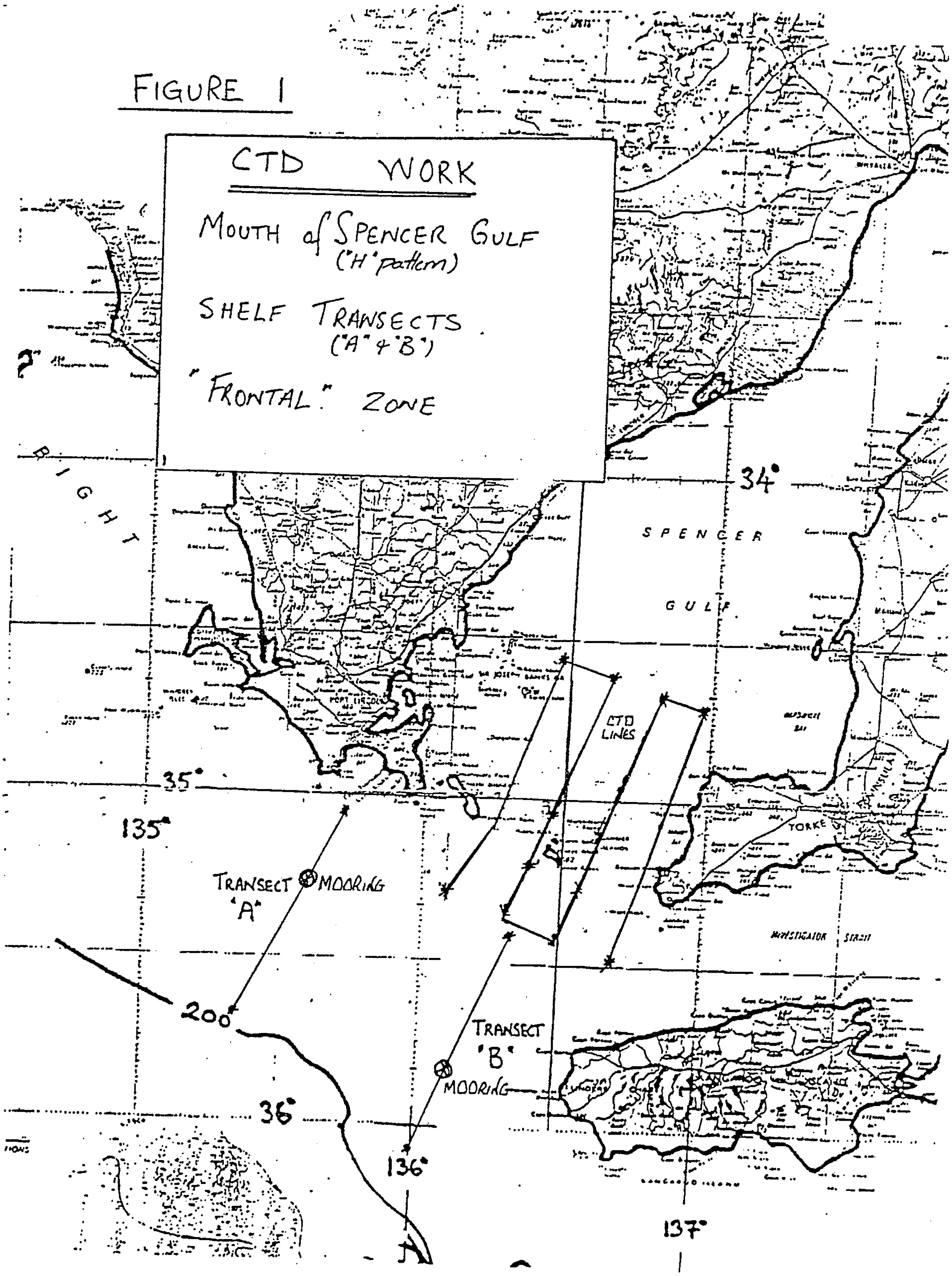
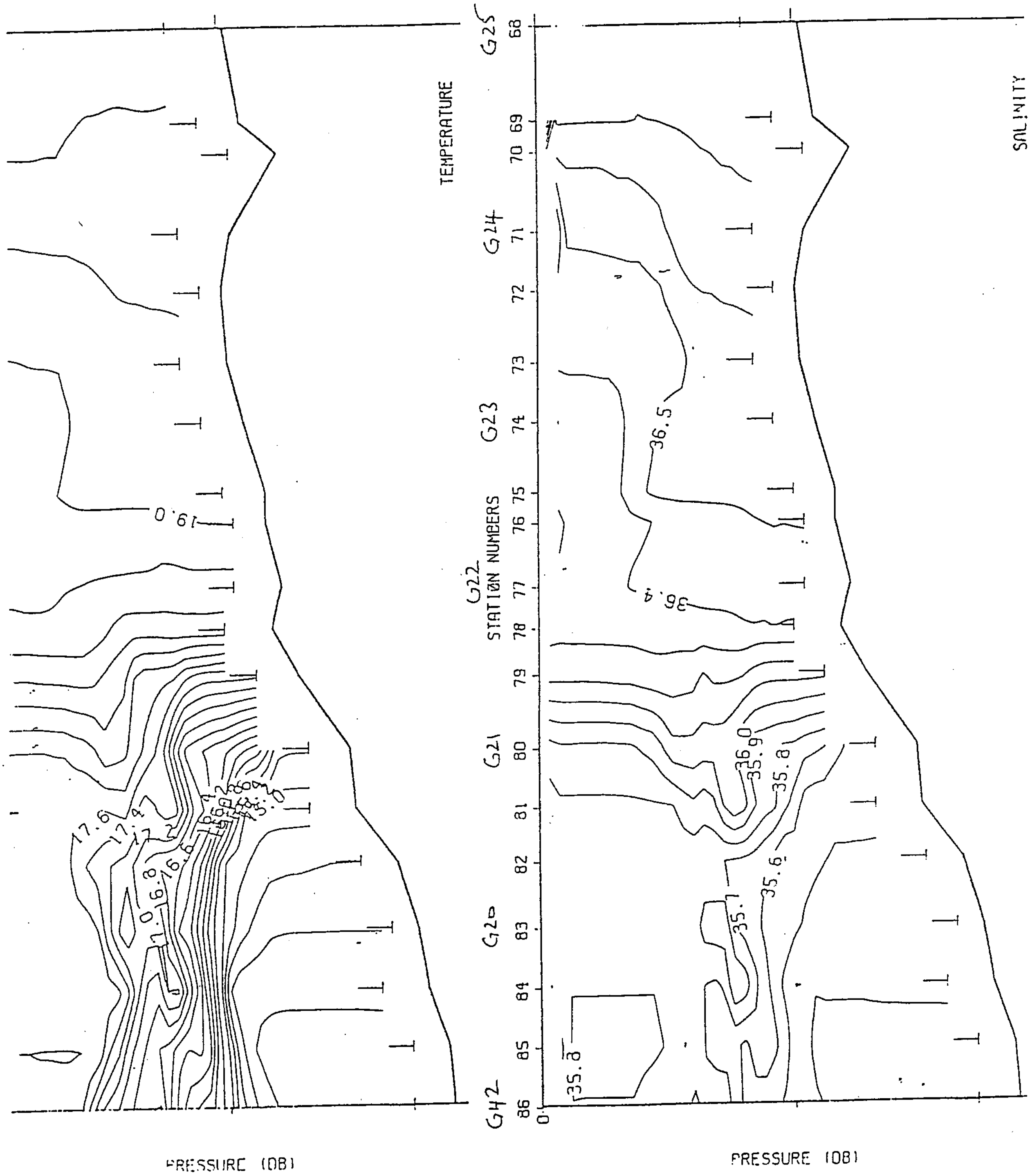

CTD WORK
MOUTH of SPENCER GULF
("H" pattern)
SHELF TRANSECTS
("A" & "B")
"FRONTAL" ZONE
BIGHT
SPENCER
GULF
CTD LINES
34°
35°
135°
TRANSECT "A"
MOORING
200
TRANSECT "B"
MOORING
36°
136°
137°
PORT LINCOLN
YORKE
INVESTIGATOR STRAIT

FIGURE 2



TEMPERATURE
SALINITY
STATION NUMBERS
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PRESSURE (DB)
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G14
G23
G22
G21
G42
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69
70
71
72
73
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75
76
77
78
79
80
81
82
83
84
85
86
19.0
17.6
17.4
17.2
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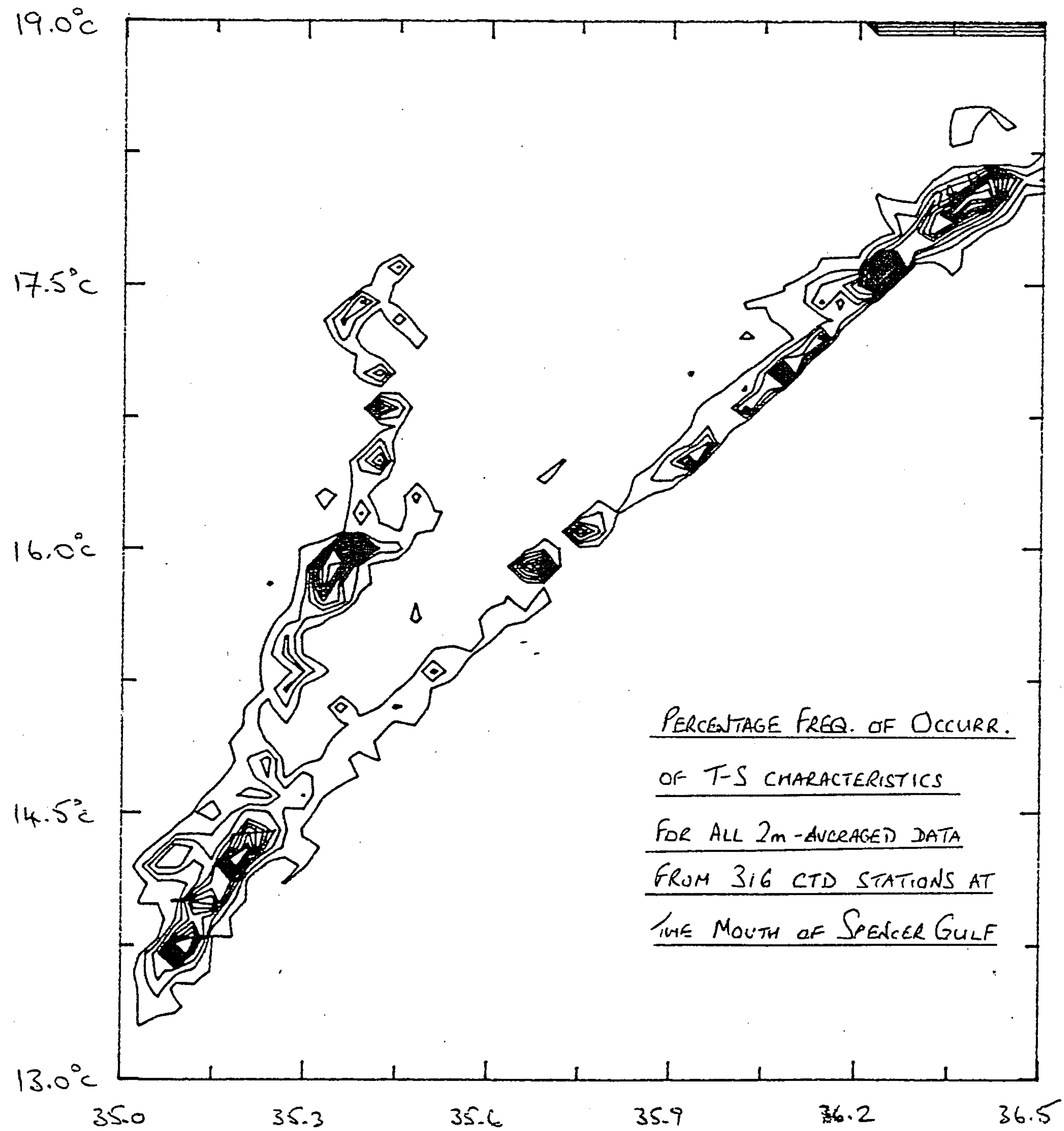
35.9
35.8
35.6
35.7
35.8

FIGURE 3.



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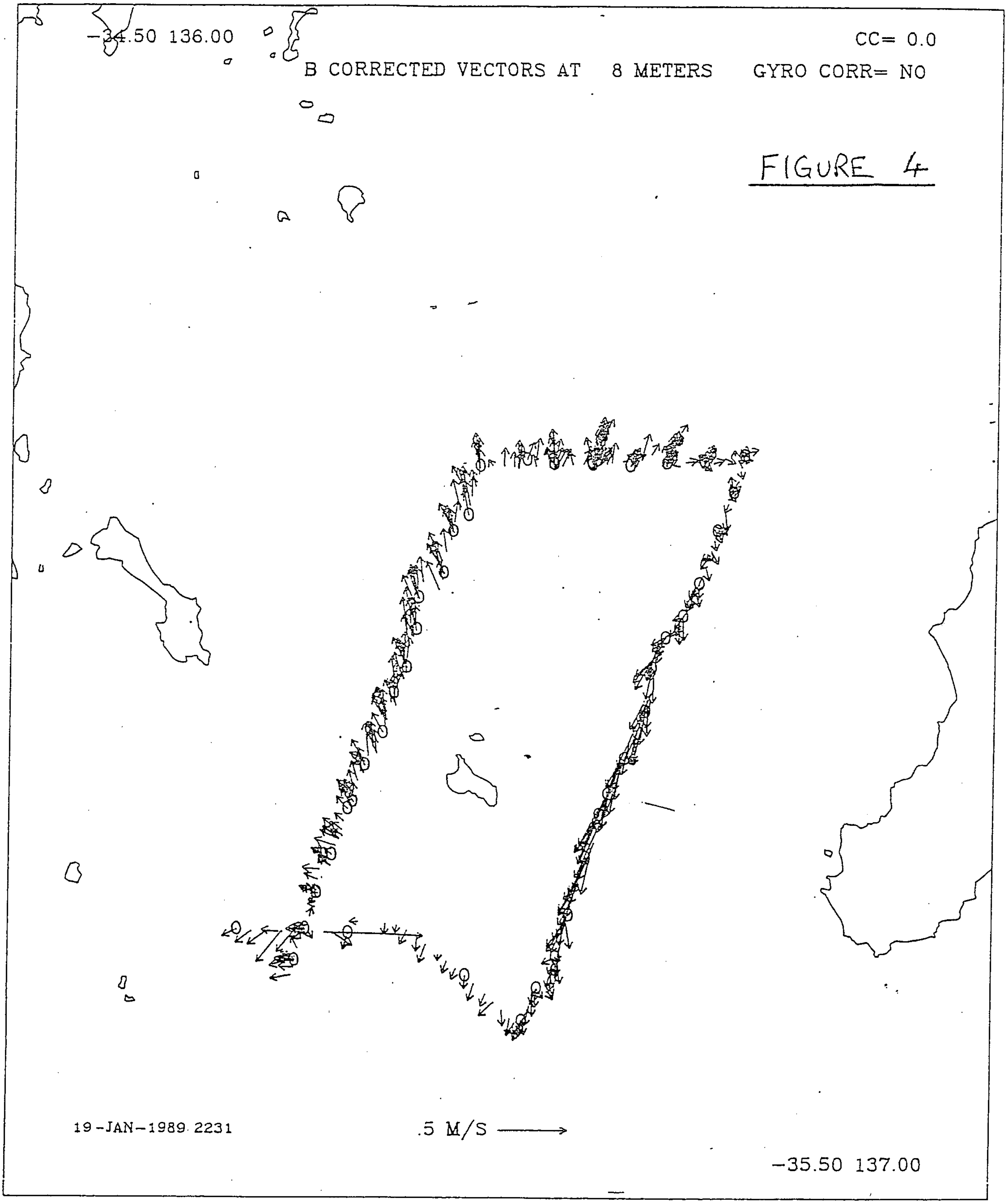
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19-JAN-1989 2231
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FIGURE 4

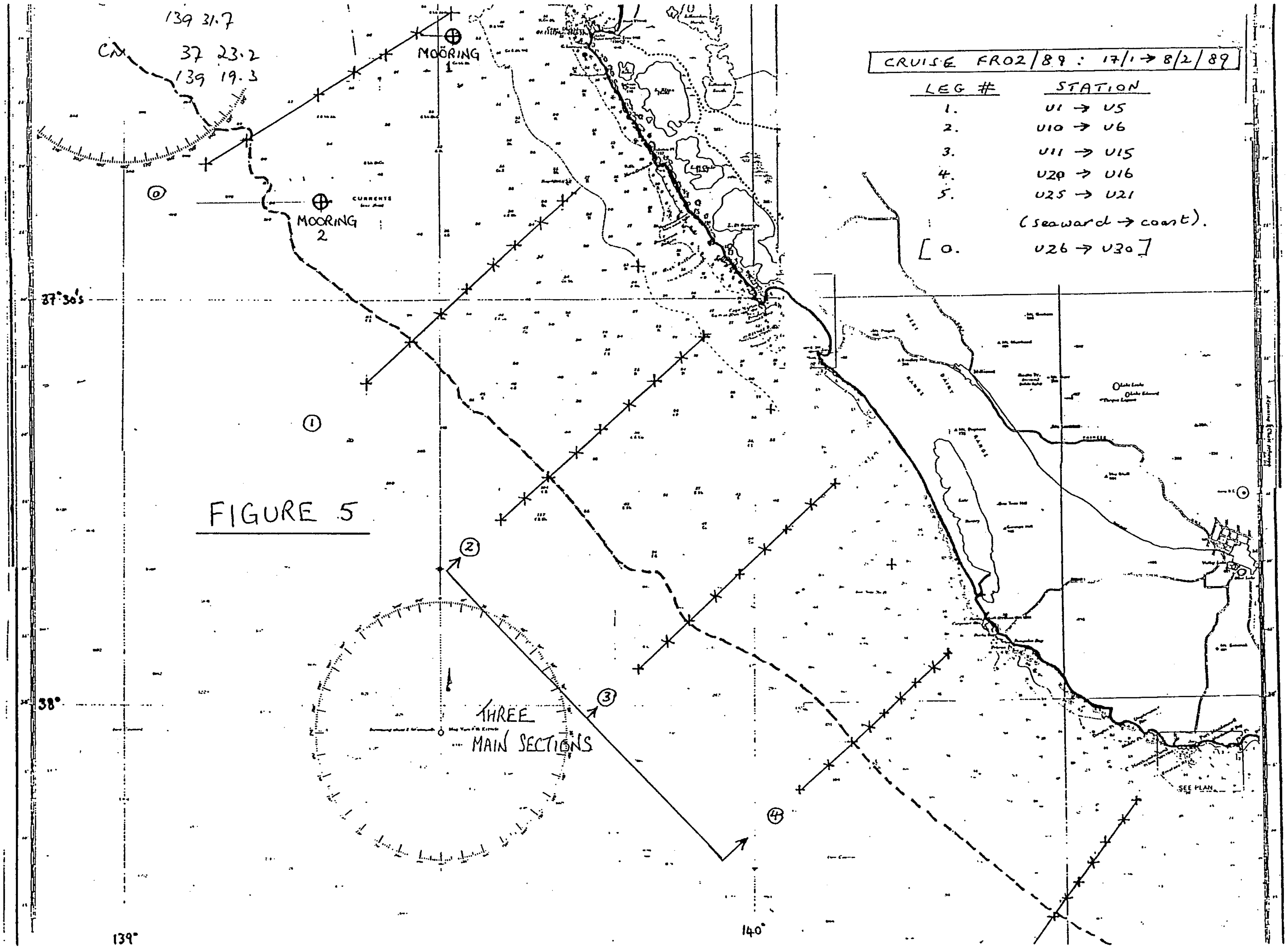

CRUISE FR02/89 : 17/1 → 8/2/89
LEG #
STATION
1.
U1 → U5
2.
U10 → U6
3.
U11 → U15
4.
U20 → U16
5.
U25 → U21
(seaward → coast).
[0. U26 → U30]
139 31.7
CN
37 23.2
139 19.3
MOORING 1
MOORING 2
CURRENTS
37°30'S
38°
139°
140°
THREE MAIN SECTIONS
SEE PLAN

FIGURE 5

Along-shore (red, pos. from south), cross-shore (blue, pos = offshore)

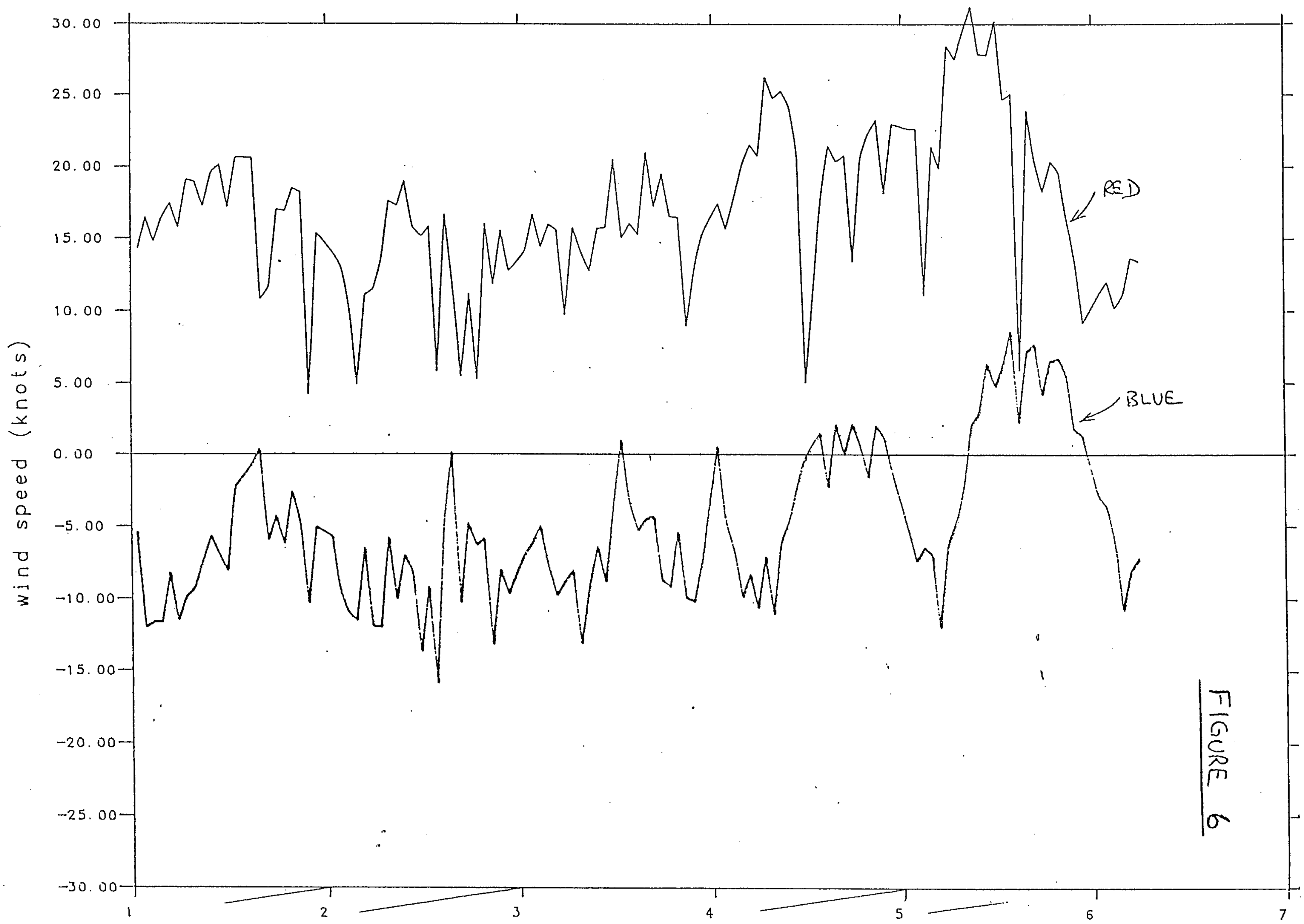


FIGURE 6

30/1/89 UTC

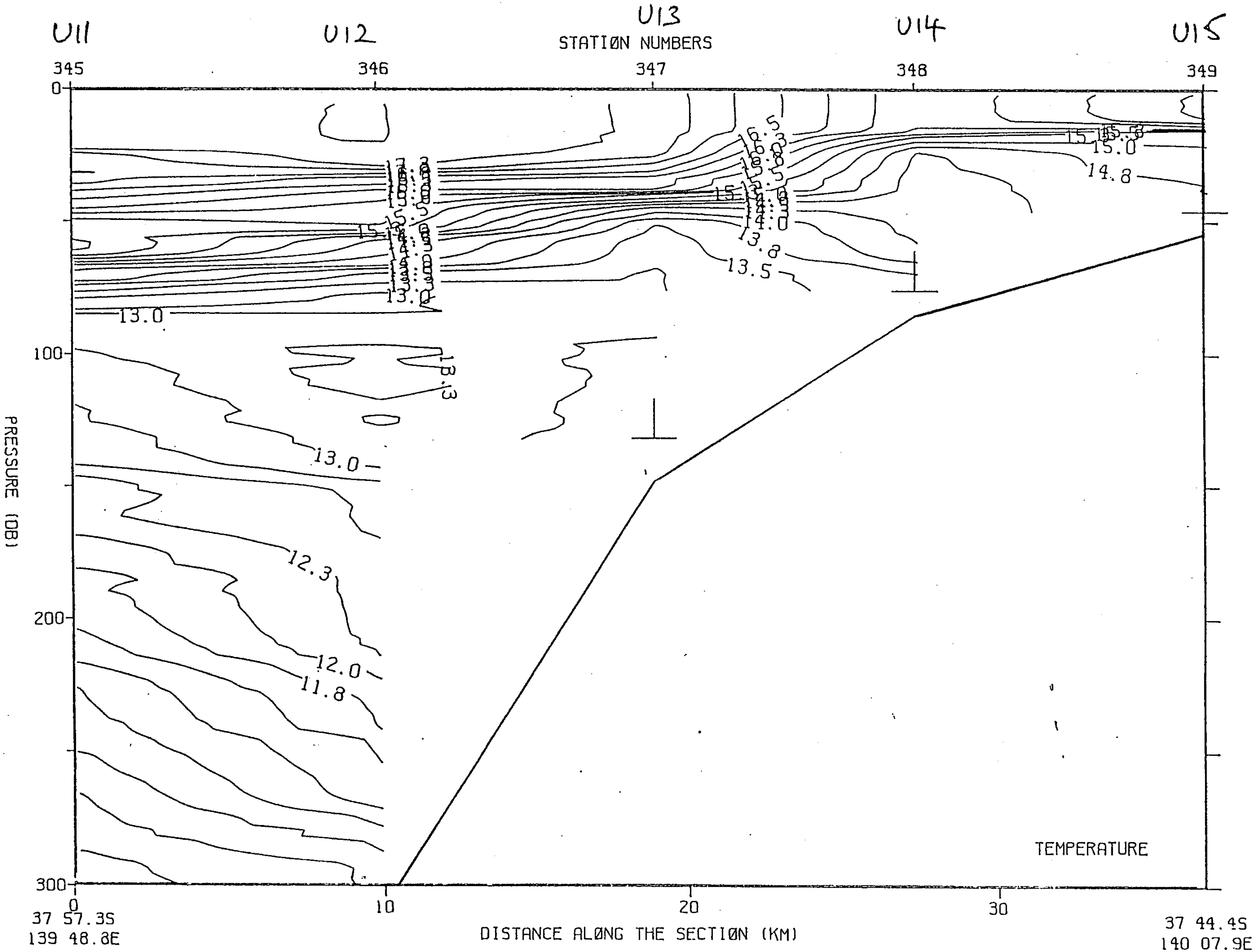
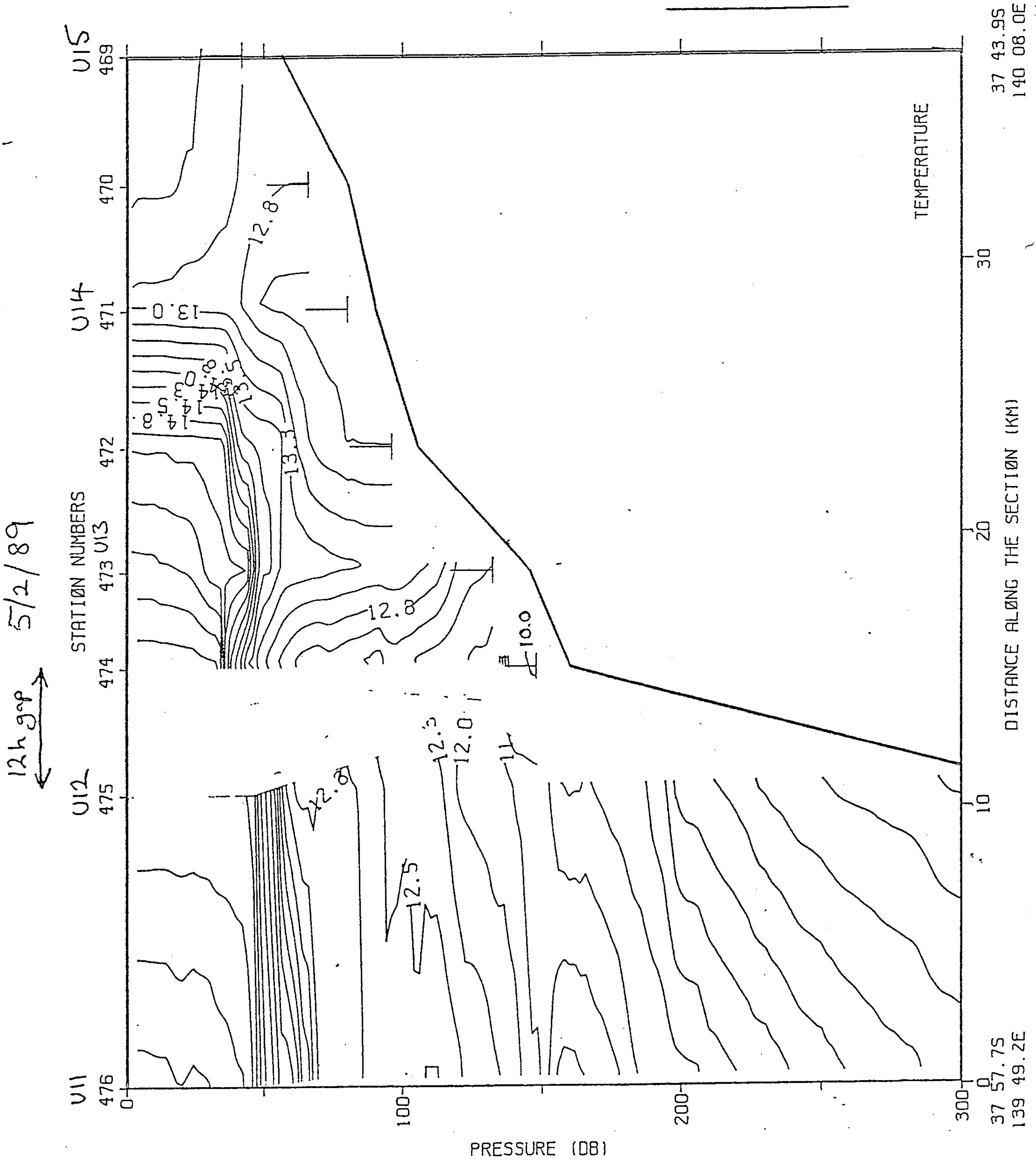


FIGURE 7

FIGURE 8



TEMPERATURE
STATION NUMBERS
476
475
474
473
472
471
470
469
U11
U12
U13
U14
U15
12h gap
5/2/89
PRESSURE (DB)
0
100
200
300
DISTANCE ALONG THE SECTION (KM)
0
10
20
30
37 57.7S
139 49.2E
37 43.9S
140 08.0E
12.8
13.0
12.8
10.0
12.5
12.0
11
12.5