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MEMORANDUM



**Atlantic Inflow Experiment
GIN Sea
Cruise '87**

**Data Report
Part I: 'Tydeman' hydrography**

**T.S. Hopkins, G. Baldasserini,
P. Povero, M. Ribera
and P. Zanasca**

December 1991

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NORTH ATLANTIC TREATY ORGANIZATION

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GIN Sea Cruise '87

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Executive Summary: This memorandum summarises the results of the Atlantic Inflow Experiment in the form of an oceanographic data report. Its purpose is to provide a complete data summary that serves as a reference for the experiment itself and for subsequent analysis of portions of the data pursuant to ASW applications.

The Atlantic Inflow Experiment was designed to provide information on the entrance of Atlantic waters into the Arctic Ocean through the Faeroe-Shetland Channel. The sampling design was unique and the instrumentation was more advanced technologically than that used in previous oceanographic samplings of the area.

Detailed sampling of the oceanographic environment provides information to researchers on three levels: exploration of the environment in both space and time frames not yet observed; confirmation of our understanding of the physical laws governing the ocean environment; and utilisation of these data and laws in quantitative assessments (models) that allow environmental prediction. Such descriptions and assessments of the ocean environment are a primary goal of ASW research.

Hydrographic data are the observations of water properties taken from a ship by means of a conductivity-temperature-depth instrument (CTD) that rapidly samples these and other variables as it is lowered through the water, and transmits the data to a computer system on board. On returning to the surface, the CTD records time-averages of these variables at selected depths; in addition attached bottles take water samples for the analysis of other variables.

This memorandum is the first in a sequence of reports from the 1987 Field Programme: a hydrographic cruise conducted on board the HNLMS *Tydeman* in May. Part II presents the observations obtained from seven current meters on three moorings, two sub-surface acoustic floats, and one ARGOS drifting meteorological/drifted buoy deployed between the two hydrographic cruises. Part III reports on the hydrographic data taken later in September on board the R/V *Belgica*.

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**Atlantic Inflow Experiment
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Abstract: The hydrographic data from the GIN 87-T cruise on board the HNLMS *Tydeman* are summarised in this data report. This cruise constituted the first cruise of the 1987 portion of the Atlantic Inflow Experiment, which was designed to investigate the causes and effects of the inflow of Atlantic Water into the Greenland-Iceland-Norwegian (GIN) Sea. The cruise was conducted 29 April-26 May 1987, in the vicinity of the Faeroe Channel and in the Norwegian Sea. Pressure, temperature, conductivity, dissolved oxygen, and light transmittance were recorded in situ via a CTD sample. Water samples were taken for the analysis of salinity, dissolved oxygen, nitrate, nitrite, silicate, oxygen-18, particulate organic carbon, chlorophyll-a and phaeophytin fluorescence, and phytoplankton composition. This memorandum describes the methods used in the data acquisition and reduction and presents the data in a selected sequence of plots and tables.

Keywords: Atlantic Inflow ◦ chemical oceanography ◦ Faeroe channel ◦ GIN Sea ◦ Greenland-Iceland-Norwegian Sea ◦ hydrography ◦ plankton

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1

Introduction

1.1. GIN SEA PROJECT

The GIN Sea observational programme was initiated in 1985 by the Applied Oceanography Group (AOG) to acquire an extensive set of oceanographic data in the Greenland–Iceland–Norwegian (GIN) Sea. The data was subjected to state-of-the-art quantitative analyses to serve the purposes of SACLANTCEN and the NATO scientific communities. The responsibility for the acquisition, implementation and maintenance of the instrumentation belongs to the Ocean Engineering Department. The GIN Sea field experiments attempted to employ as many techniques as feasible in order to maximize the potential for interpretation and assessment. To achieve this, the observational programmes have employed a high-quality standard instrumentation (e.g. CTDs, current meters) and new or experimental instrumentation (e.g. acoustic doppler current profilers, SOFAR subsurface floats, meteorological/thermistor chain ARGOS buoys). These were augmented with biological and chemical sampling techniques (e.g. chemical tracers, planktonic species counts). Both the experimental instrumentation and biological and chemical sampling open avenues of collaboration with other research institutions and enlarge the potential for utilization of the latest techniques in interpretative analysis. The data obtained from the moored and floating instrumentation is presented in Part II of this data report.

The SACLANTCEN GIN Sea project proposed two major observational experiments: the Atlantic Inflow Experiment (AIE) in 1986–87 and the Icelandic Boundary Current Experiment (ICE) conducted in 1988–89. The AIE deals with the water-mass input to the GIN Sea via the Faeroe–Shetland Channel and its subsequent transitions northward within the Norwegian Current System. The ICE deals with the large-scale forcing controlling the Icelandic Current which transports waters of the Denmark Strait to the Faeroe Channel and which establishes the dynamic boundary forming the Iceland–Faeroe Front. The two experiments were designed to provide a substantial database and a more complete physical understanding of this important region.

1.2. ATLANTIC INFLOW EXPERIMENT

The Arctic Ocean receives large quantities ($\sim 4-8$ Sv) of North Atlantic surface waters. Most of this inflow derives from a portion of the North Atlantic Current which crosses the Wyville-Thomson Ridge and flows through the Faeroe-Shetland Channel. Smaller inflows arrive via the Iceland-Faeroe Ridge and the Denmark Strait. Virtually all of the salt and heat input to the Arctic Ocean enters with this input. Considerable observational effort has been spent in attempting to quantify this input with inconsistent results that are not in accord with the input values deduced from thermohaline balances of the Arctic Ocean (see Hopkins, 1988a). In part, these inconsistent results have been explained by the historical need to rely on the dynamic method, which uses an unknown reference level, i.e. Tait (1957). The more recent use of current meters has provided better direct information on the flow field (i.e. Dooley and Meincke, 1981). No comprehensive data set exists that provides a satisfactory description of the inflow and its temporal variability. Hopkins (1988a) reviews observational attempts to establish this inflow and its general relevance to Arctic oceanography.

The GIN Sea project was undertaken to enhance the data bank with observations concerning the behaviour of this input water, the Norwegian Sea*. The purpose was to better describe the frontal interface and its variability between this water mass and the Arctic waters. This observational effort is called 'The Atlantic Inflow Experiment'. This data report summarises the hydrographic data taken on board the HNLMS *Tydeman* from 29 April to 26 May 1987 in the Faeroe-Shetland Channel and southern Norwegian Sea regions, the first cruise of the Atlantic Inflow Experiment. For information concerning the preceding cruises (1986), see Hopkins (1988b); Hopkins, Giannecchini, Gualdesi and Zanasca (1990); and for the remaining 1987 cruises see Part II, Hopkins, Giannecchini, Gualdesi, Mouchet and Zanasca (1991) and Part III, Hopkins, Baldasserini, Goffart, Povero and Zanasca (1991).

1.3. COLLABORATION

The GIN Sea project is unclassified and open to collaboration with oceanographic research institutions of NATO member nations. This policy is intended to encourage participation and scientific exchange within the NATO community.

The GIN '87-T cruise was assisted by collaborating institutes as follows:

- Zoological Station, Naples; M. Ribera
 - loan of fluorometer and vacuum pumping apparatus
- University of Genoa; P. Povero
- University of Bergen
 - analysis of ^{18}O samples

* Atlantic Water, within the southern portions of the GIN Sea.

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Cruise track

The cruise hydrography (Fig. 1) consisted of CTD/rosette and XBT casts designed to satisfy the primary observational objective: a sampling of the water mass properties across the inflowing North Atlantic Water and across the Icelandic Current. The primary transects were taken orthogonal to the major bathymetry at the locations of the current meters. The B2-B8, B3-B7 and Faeroe-Shetland transects (Sts. 114-123, Sts. 130-139 and Sts. 147-154, respectively) were repeated; and a tidal time series was taken in the vicinity of Buoy 2 (Sts. 146.01-.13). Other complementary transects were taken to complete the sampling domain, which extended from the Wyville-Thomson Ridge to the Lofoten Basin and from the Norwegian Shelf to the Icelandic Plateau (St. 107). The stations were organized to provide a sampling sequence along the 2000 m and 800 m isobaths, corresponding with the current meter placement. The station spacing varied to provide better resolution over large gradients in the bottom depth and/or in frontal regions, e.g. across the Icelandic Current (Sts. 39-46 and 32-38) and near the current meter moorings. XBT casts were made between CTD casts and where greater temperature resolution was required.

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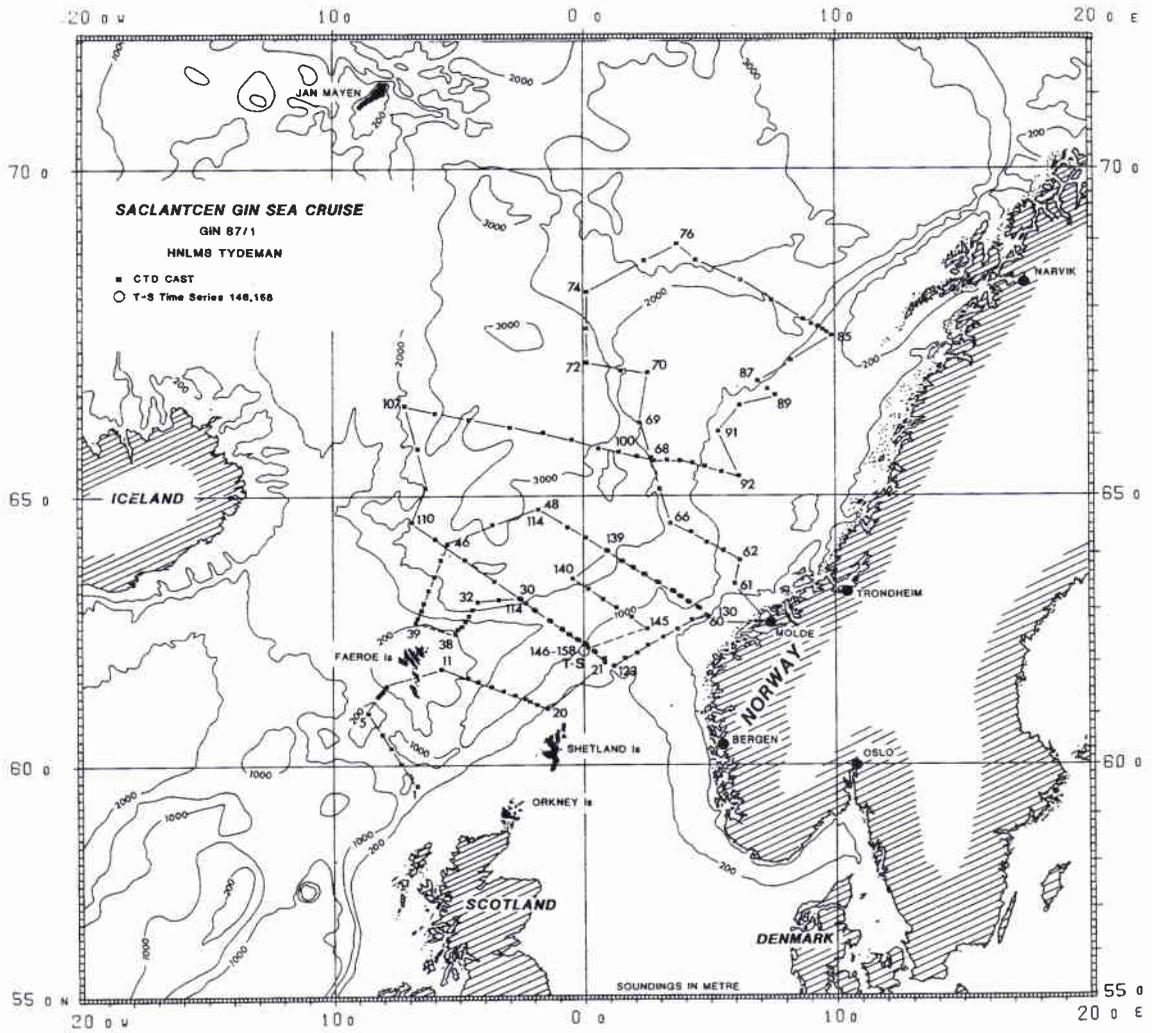


Figure 1 *Hydrographic stations of the cruise of HLNMS Tydeman.*

3.1. DATA ACQUISITION

CTD/rosette The CTD package was a Neil-Brown Mark III conductivity-temperature-pressure (CTD) sensor probe together with a General Oceanics rosette sampler (5 litre, 12 bottles). The CTD included a Sea Tech 25 cm transmissiometer and a Beckman dissolved oxygen sensor. This system was mounted in a protective stainless steel cage, on which were attached four leads of 20 kg and two vanes to prevent rotation. The package had been tested to descend, without kiting, at speeds of 1.9 m/s. Descent speeds were restricted to ~ 1 m/s to avoid problems with the response times of the sensors. An identical package was available as a spare and was used from Sts. 129-154 when problems developed with the thermistor on the primary unit.

A new single conductor cable (4000 m, $\frac{1}{4}$ inch) was acquired for the cruise in order to extend the sampling capability to the depths of the Norwegian Sea. The use of a large rosette frame necessitated fairleading the cable to the forward hydroframe from the winch amidships. This unusual arrangement created a torque in the cable which ultimately resulted in several cable accidents and a considerable number of spikes in the data. The effect of the torque was minimized by mounting a vane and the CTD/rosette package was suspended via four cable straps to a safety grip in order to avoid strain on the electrical cable termination.

Hydrographic cast A hydrographic cast consisted of the lowering of a CTD/rosette package to just below the surface, where it was left to stabilise for a few minutes, and then lowered to within 30-50 m of the bottom depth as indicated by the ship's depth recorder. During this downcast, the data stream was interfaced to a MicroVAX II computer. The data stream was duplicated onto a backup cassette. At the conclusion of the downcast an upcast was initiated, that is, data acquisition stops were made at specified water sample depths. At each stop, the CTD was allowed to stabilise for 1 min before acquiring data for 30 s and before closing the Niskin bottle.

The CTD deck unit was equipped with a digital monitor to control the data stream which was routed directly to a MicroVAX computer. The acquisition commands were entered via the MicroVAX terminal, and provided for screen plot of the raw data and a routing to a Calcomp 1044 printer for an on-line 3-pen plot of the temperature, conductivity, and transparency variables. These plots were used to monitor and evaluate the data quality and to determine the depths for the sampling of particular vertical features. The CTD data stream was duplicated on a 'backup'

cassette. A decimated printout of certain raw and derived variables was made in between casts for the onboard scientific assessment of the data. XBTs (type T7) were interfaced with an HP-85 for an on-line plot/print and for registration onto a data cassette.

Shipboard data The HNLMS *Tydeman's* on-line system provided the ship's position, water depth, sea surface temperature, wet/dry air temperatures, and wind speed/direction on a print-out every 15 min and recorded on magnetic tape. This data was later transferred and made available to SACLANTCEN. An HP-21 MX computer was interfaced to a satellite receiver to provide visual and infrared images of the region.

Water samples The number of bottle depths was adjusted to 12 or less according to the depth of the particular station to obtain a reasonable vertical distribution. The surface and intermediate (salinity minimum) layers were favoured. In all cases, the following standard depths were used, i.e. 3, 25, 40, 65, 100, 200, 350, 500, 650, 800, 1000, 1500, and 2000, 2500, and 3000 and/or the depth of the bottom less 50 m. Water samples were drawn from every cast in the following quantities:

- salinity samples at one to three depths into 250 ml glass rubber-stoppered bottles,
- dissolved oxygen samples at two to four depths into volume-calibrated dark glass bottles,
- nutrient samples from every depth into 25 cm³ plastic bottles,
- chlorophyll samples at bottle-depths 65 m or less into 500 cm³ plastic bottles,
- particulate organic carbon samples from selected depths filtered into 2 l bottles,
- ¹⁸O samples at occasional depths into 500 ml plastic bottles.

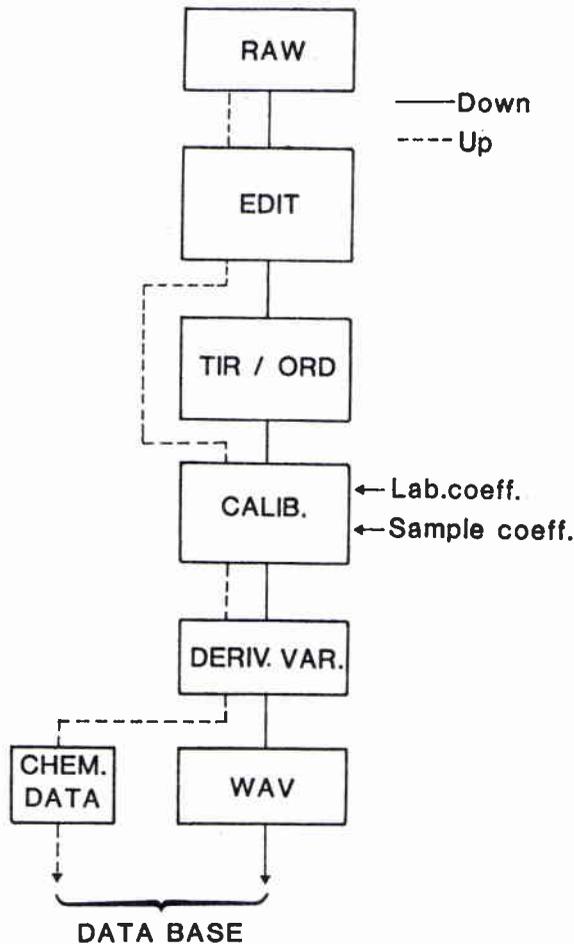
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Figure 2 Sequence of data reduction by SAACLANTCEN's oceanographic profiling system.

3.2. CTD DATA REDUCTION

Processing Processing of CTD data was accomplished by the SAACLANTCEN oceanographic profiling system (OPS) which runs on a VAX. Generally, OPS is used on board for acquisition and for both data-quality and scientific assessments. OPS performs a complete sequence of data reduction (Fig. 2) which involves the following subroutines:

- (a) **RAW.** The CTD raw data were recorded on board onto MicroVAX cassettes. On return to SAACLANTCEN these were translated to the mainframe VAX. At this stage the casts were renumbered to correspond with the station numbers, the headers were completed and their information checked. Upcast files were treated similarly.
- (b) **EDIT.** All six of the raw data variables (temperature, conductivity, pressure, oxygen current, oxygen temperature, transparency) were edited for obvious, large-amplitude spikes. These are usually single data points created by noise or intermittency in the cable transmission and cause a spike in all variables;

occasionally they are found in only one variable due to sensor noise. The routine allows for blow-up plots over any pressure range and for cursor identification. Spiky points are removed and replaced by a linear interpolation at 32 Hz. Gaps greater than 0.5 m are treated differently, see step g) below. As a final step, the salinity values are calculated to see if any prominent spikes were missed.

- (c) **TIR/ORD.** The pressure sensor has a resolution of 5 cm. To create a smooth pressure signal relative to the other variables, the pressure signal is first passed through a filter with a 50-ms time response. The variable of time exists implicitly because of the sampling at 32 Hz; using the pressure signal, a descent speed w is calculated for each meter of depth. Following a method described by Giles and McDougall (1986), the descent speed w and the manufacturer's response times for the 'fast response' thermistor and for the conductivity cell are used in the following filter:

$$C^s(t) = e^{-\Delta t/\tau} C^s(t - \Delta t) + \frac{1 - e^{-\Delta t/\tau}}{1 - e^{-\Delta t/\tau^c}} (C^m(t) - e^{-\Delta t/\tau^c} C^m(t - \Delta t))$$

where Δt is the sampling rate (32 samples per second), C^s the smoothed conductivity, C^m the measured conductivity, τ and τ^c the sensor response times of the fast response thermistor and the conductivity sensor, respectively. This operation reduces the spikes caused in the calculation of salinity due the mismatch in the response characteristics of these two sensors. At this point we have brought the response of the pressure, fast-response temperature, and conductivity to ~ 50 ms.

The descent speed w is checked for values much less than the mean, zero, or negative and the corresponding raw variables are cut at a certain pressure $P(z)$ and resumed at the next greater value of pressure $P(z + \Delta z)$. This eliminates the data corresponding to pressure reversals (ship heaving) and reduces the inertial effect caused by the slowing of the sensor package relative to the water carried with it.

- (d) **CALIB.** The data are calibrated using two sources of information: the calibration data from the laboratory tests at SACLANTCEN and the in situ samples taken during the cruise. Pre- and post-calibrations were made on the CTD unit employed in a 800 litre thermally stable bath ($\pm 0.003^\circ\text{C}$), with a salt content controlled within the operating salinity range (see De Strobel and Montanari, 1984).
- (e) **DERIV.VAR.** At this point a set of oceanographic variables are derived from the calibrated data files using algorithms from Fofonoff and Millard (1983).
- (f) **WAV.** Depth-integrated weighted averages for each current meter (centred about an integer depth) were then calculated for each of these variables. This file was then used to produce the plots and listings included in this data report.
- (g) **FUL.** A CTD downcast is always missing a certain portion of data at the beginning and end of the cast. A complete file is essential for certain depth

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integrations of data. The FUL file is identical to the WAV file except that the temperature, salinity and related derived variables are extrapolated upwards from the first depth to the surface and downwards from the last depth to bottom. A cubic polynomial is used that matches the adjoining slope of the WAV data and that is also normal to the surface and bottom boundaries. The surface portion, which is usually only a few meters, is effectively an extension of the surface mixed layer. The bottom portion varies in depth and therefore requires careful editing in order that density and water mass characteristics are conserved relative to the surrounding waters.

Archiving Both the WAV and another file (CHEM DATA), created from the upcast data, were then exported for archiving and further analysis to the SACLANTCEN AOG GIN Sea database. Raw data and backup tapes of the EDIT file (see (b)) are also maintained at the Centre.

Sensor calibration Sensor calibration was performed in the OED laboratory facility (De Strobel and Montanari, 1984). For each of the sensors a regression and calibration correction formula resulted from a mean of the pre- and post-cruise laboratory measurements, using the following relationships:

(a) Pressure:

$$P_{\text{CTD}} = \begin{cases} P_{\text{stand.}} \times 0.9990 - 1.46, & \text{for Casts 1-128 of CTD2,} \\ P_{\text{stand.}} \times 1.001 - 4.87, & \text{for Casts 129-154 of CTD1,} \end{cases}$$

where P_{CTD} and $P_{\text{stand.}}$ refer to the pressure measured by the CTD and the laboratory standard, respectively. The two regressions had a standard deviation of ± 0.56 and 1.07 dBar, respectively. Note, the offset of the latter regression was estimated from average of surface-depth value from the Sts. 129-154.

(b) Temperature:

$$T_{\text{CTD}} = \begin{cases} T_{\text{stand.}} \times 1.001 - 0.009, & \text{for Casts 1-128 of CTD2,} \\ T_{\text{stand.}} \times 0.9978 - 1.776 \times 10^{-5} P_{\text{CTD}} + 0.006, & \text{for Casts 129-154 of CTD1,} \end{cases}$$

which had standard deviations of ± 0.001 and 0.002°C , respectively. The regression for CTD1 was obtained by applying first the laboratory corrections and then bringing it into agreement with duplicate deep water casts of CTD2.

(c) Conductivity:

$$C_{\text{CTD}} = \begin{cases} C_{\text{stand.}} \times 1.000 - 0.001, & \text{for Casts 1-128 of CTD2,} \\ C_{\text{stand.}} \times 0.9993 + 0.027, & \text{for Casts 129-154 of CTD1,} \end{cases}$$

which had standard deviations of ± 0.006 and 0.003 mmhos/cm, respectively.

(d) The oxygen current and oxygen temperature sensors were not calibrated in the laboratory. In between CTD casts the oxygen sensor was washed in fresh water and kept sealed.

- (e) The transmissometer was not calibrated in the laboratory. Blank readings of the transmissometer were taken daily during the cruise and the instrument was washed with fresh water after every cast. The data was recorded in volts. Conversion to percent of transparency is made with the relation

$$OP = 100 - [\text{reading}(\text{volts}) \times 20].$$

Data calibration In situ samples of salinity and oxygen were taken during the bottle casts. The procedure for applying this information was as follows:

- (a) The upcast data file was acquired for the 30 s prior to the closure of the bottle. The pressure signal was used to decide on the length of data to be used for in situ data comparison. Normally, the entire set was used to form an upcast data average of all the raw variables. However, in some cases the depth of the CTD varied more than a predetermined 3 m tolerance, invariably in the form of waves and/or trends, in which case the last full wavelength or the last $\sim 1/3$ of the sampling, respectively, was averaged to obtain the value for that depth.
- (b) A data-quality check was made by computing the means and standard deviations of the differences between successive values for all variables in this upcast file. If these standard deviations exceeded those from a large statistical reference set of such samplings, the upcast file for that variable was edited to exclude spikes or erratic data. In cases in which the file was judged unacceptable, a value was created from the equivalent depth of the downcast file and a data-quality flag was appended to the data value.
- (c) The laboratory calibration values (P , T and C) were used to calculate salinity values from these upcast data files. At each depth where a bottle salinity was taken, the CTD upcast salinities were subjected to a multi-regression analysis against the bottle salinity, the temperature, and the pressure. This resulted in the salinity offset formula, for different CTDs and groups of stations:

$$S_{\text{CTD}} = \begin{cases} S_{\text{bottle}} \times 9.80786 \times 10^{-1} + T_{\text{CTD}} \times 1.23156 \times 10^{-3} \\ \quad + P_{\text{CTD}} \times 3.92702 \times 10^{-6} + 6.783 \times 10^{-1}, \\ \quad \text{for Casts 1-128 of CTD2,} \\ \\ S_{\text{bottle}} \times 1.02578 - T_{\text{CTD}} \times 3.95258 \times 10^{-3} \\ \quad + P_{\text{CTD}} \times 1.71649 \times 10^{-6} - 8.895 \times 10^{-1}, \\ \quad \text{for Casts 129-136, 142-146 of CTD1,} \\ \\ S_{\text{bottle}} \times 9.34057 \times 10^{-1} + T_{\text{CTD}} \times 1.88527 \times 10^{-3} \\ \quad + P_{\text{CTD}} \times 2.02318 \times 10^{-5} + 2.3007, \\ \quad \text{for Casts 137-141 of CTD1,} \\ \\ S_{\text{bottle}} \times 1.05995 - T_{\text{CTD}} \times 3.22947 \times 10^{-3} \\ \quad + P_{\text{CTD}} \times 2.61792 \times 10^{-5} - 2.0976, \\ \quad \text{for Casts 147-154 of CTD1,} \end{cases}$$

SACLANTCEN SM-249**Table 1** *Results of linear regression*

Cast	Coefficients					Stand. Dev.	
	a ($\times 10^{-1}$)	b ($\times 10^{-1}$)	c ($\times 10^{-5}$)	d ($\times 10^{-2}$)	e ($\times 10^1$)	(deeper water)*	
<i>Downcast - CTD2</i>							
1-60	2.9315	-10.6420	9.1182	1.7148	4.1965	± 0.14	± 0.05
61-128	1.1677	-3.1370	-0.9251	-2.1399	1.7134	± 0.15	± 0.09
<i>Downcast - CTD1</i>							
129-145	0.3118	-7.8754	-1.9760	-0.1006	3.4176	± 0.13	± 0.04
146-154	1.0992	-3.7106	-15.2086	-0.3655	1.9200	± 0.15	± 0.05
<i>Upcast - CTD2</i>							
1-60	16.6304	0	0	0	-0.3922	± 0.16	n.a.
61-74	18.7312	0	0	0	-0.4972	± 0.12	n.a.
75-96	14.3755	0	0	0	-0.1088	± 0.16	n.a.
97-120	13.4673	0	0	0	-0.0558	± 0.14	n.a.
121-128	11.0171	0	0	0	+0.0074	± 0.09	n.a.
<i>Upcast - CTD1</i>							
129-154	1.7520	-4.1503	9.6880	0.3385	2.03186	± 0.15	n.a.

* n.a.: not available.

which had standard deviations of ± 0.006 , 0.004 , 0.004 , 0.002 , respectively. Note, that for the downcast, the salinity is first derived using the laboratory regression corrections above and then adjusted according to the results of the bottle calibration.

- (d) Using the corrected salinity and temperature values from the upcast, CTD values of oxygen were calculated from the averages of oxygen current and oxygen temperature values using the manufacturer's formula

$$O_{CTD} = (O_C \times A) \times \exp(T_0 \times C_T + P C_P) \times O_{sat.}$$

These were then compared with the corresponding bottle data values using a linear regression,

$$O = a \times O_{CTD} + b \times S + c \times P + d \times T + e,$$

with different coefficients, depending on the CTD and cast, applied to the up and downcast data. The coefficients are listed in Table 1.

3.3. CHEMICAL ANALYSIS

Salinity Salinity samples were analysed on a Guildline AutoSal at SACLANTCEN several weeks after the cruise. The results were used for CTD calibration and data quality control. The data listed in Appendix C are the calibrated CTD values.

Dissolved oxygen Sample bottles were volume calibrated (~ 75 ml). The Winkler method of analysis was used. Samples were fixed immediately and titrated later with an automated burette (DOSIMAT). Blanks were run once a day, approximately every 10 stations. The data listed in Appendix C are given in ml/l. The values from the CTD at each of the bottle depths are also given.

Oxygen-18 Oxygen-18 isotope samples were analysed by the Geology Department, University of Bergen using a mass-spectrometric technique (cf. Gat and Gonfiantini, 1981). The data in Appendix C are given as $\delta^{18}\text{O}$ from the relation

$$\delta^{18}\text{O} = \frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - (^{18}\text{O}/^{16}\text{O})_{\text{SMOW}} \times 1000}{(^{18}\text{O}/^{16}\text{O})_{\text{SMOW}}}$$

where $^{18}\text{O}/^{16}\text{O}_{\text{SMOW}}$ is the stable-isotope ratio for standard mean ocean water.

Nutrients Nutrient samples were prefiltered on a Whatman GF/F filter, copiously rinsed with reagent-grade water and using a syringe equipped with a swinnex filter support. The samples were analyzed soon after using an ALPKEM Rapid Flow Analyzer. The procedure for silicate analysis followed that of Strickland and Parsons (1968) using the absorption value at 820 nm in a 10 mm flow cell. For the nitrate/nitrite analysis, a modified procedure of Grasshoff, Ehrhardt and Kremlig (1983) was used with an absorption of 540 nm and a 10 mm flow cell. A salt correction for the silicates was computed but not applied to the data set. It will be applied in subsequent analysis of the total nutrient data set from the other cruises (contact authors for further information). The peak heights on the graphic output from the analyzer were measured with a ruler with a resolution of 1 mm, i.e. $\pm 0.1\mu\text{M}$. The data listed in Appendix C are given in μM only for the silicates, since the nitrate and nitrite data needed further editing and correction caused by frequent problems with the analyzer on the nitrate channel.

Chlorophyll Chlorophyll-a and phaeopigments were measured fluorometrically using a Turner Designs Model 110 fluorometer. Water sample volumes of either 200 or 500 ml, depending on the sample depth, were filtered through a Whatman GF/F glass-fibre filter. The filters were then finely ground in a 10-ml tissue-grinder with 90% neutral acetone, centrifuged, and left for 20–24 h under refrigeration at 0°C for complete pigment extraction prior to observing their fluorescence.

Particulate organic carbon One litre samples were filtered on precombusted (4 h at 450°C) glass-fibre filters (Whatman GF/C). After filtration the filters were dried at 60°C for 3 h and were stored in a freezer until post-cruise laboratory processing. There, the filters were dried at 60°C, placed in acid-washed aluminium boats,

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and then burned in a Carlo Erba Elemental Analyzer Model 1106. A solution of cyclohexanone was used as a standard. The data were not available for this publication but will follow in a joint publication with the Marine Science Environmental Institute, University of Genoa.

4

Data presentation

The data are presented in three Appendices. Appendix A consists of hand-contoured cross-sections from the cruise track of Fig. 1. The data are from 1 m averages of the FUL file from the CTD downcasts. The contour intervals have been chosen to highlight various water-mass features (cf. Hopkins, 1988a). The 35 ppt isohaline defines the low-salinity boundary of the Norwegian Atlantic Water; the boundary in temperature is taken as $\sim 2^\circ$, but is not as clearly defined since the thermocline extends deeper than the halocline. The hatched portion of the salinity contours represents the salinity minimum water that is identified as the Arctic Intermediate Water. Below the Arctic Intermediate Water is found the fairly uniform upper Norwegian Deep Water having potential temperatures of $\sim -1^\circ\text{C}$ and salinities of ~ 34.9 ppt. In some cases a deeper secondary salinity maximum (>34.913 ppm) is also hatched.

Appendix B consists of plots and prints from the downcast data of each station. Three two-variable depth profiles are shown of salinity and potential temperature, of potential density and sound velocity, and of transparency and oxygen saturation. A T-S plot is also displayed. Finally, a listing is given of 1 m average values at selected depths of the variables: temperature, potential temperature, salinity, potential density, density at 1000 m, integrated density (0,T,S), steric height, sound velocity, transparency, oxygen concentration, oxygen saturation, and the Brunt-Väisälä frequency.

Appendix C consists of a tabulation of the upcast data for each station. In the header is included the station number and depth, date and time, geographical position at the end of the downcast, and the wind speed and direction. The variables listed from the CTD are the bottle depths, pressure, temperature, salinity, sigma-t, opacity, and oxygen concentration and from the water samples are the silicate, oxygen, oxygen-18, chlorophyll-a and phaeophytin-a.

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Appendix A

Transect contours

Potential temperature and salinity contours of the various sections of the GIN '87-T Cruise are presented in Figs. A1–A27. Sections can be identified from the station numbers given at the top of the section and the cruise track of Fig. 1.

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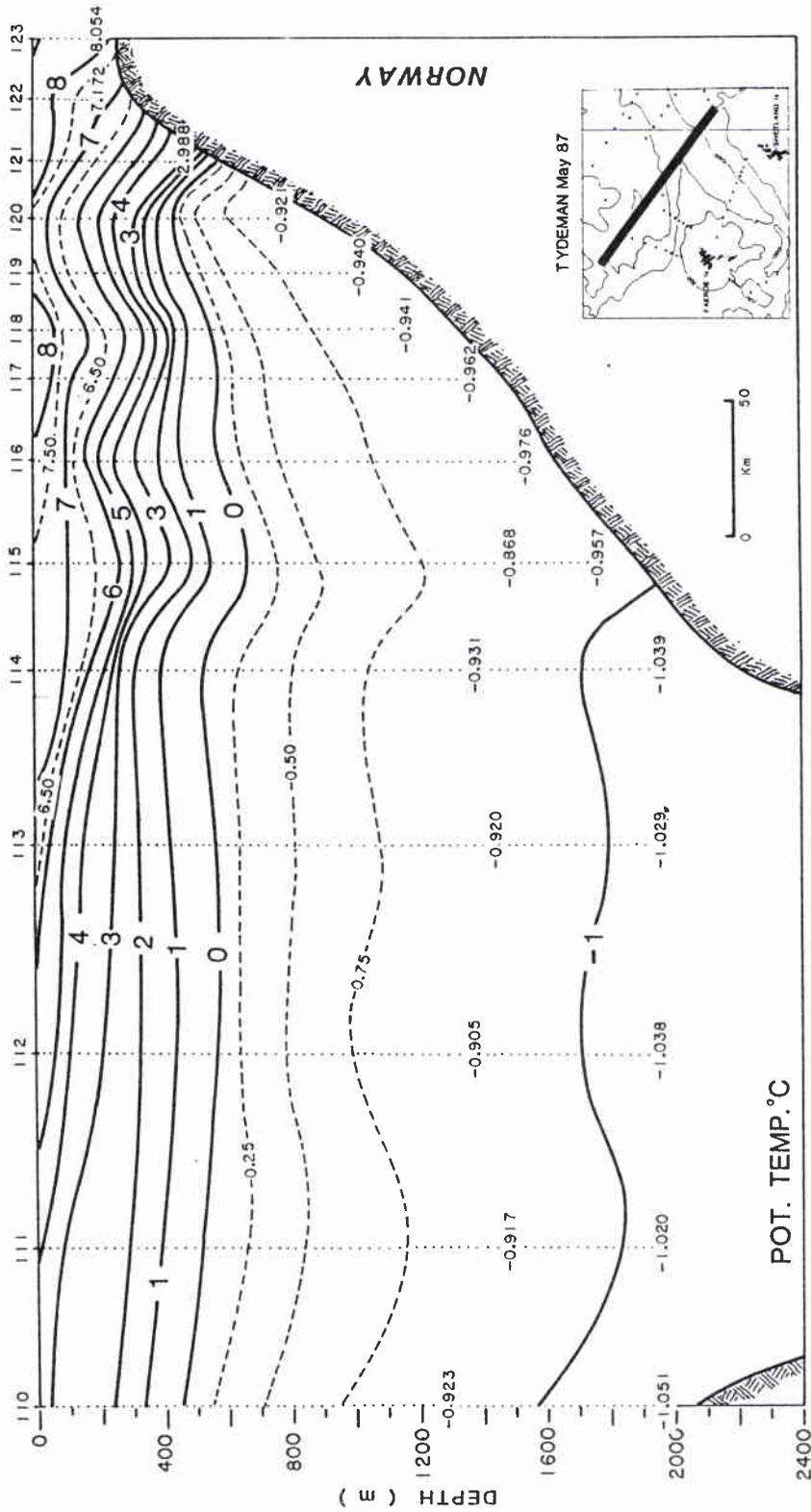


Figure A4

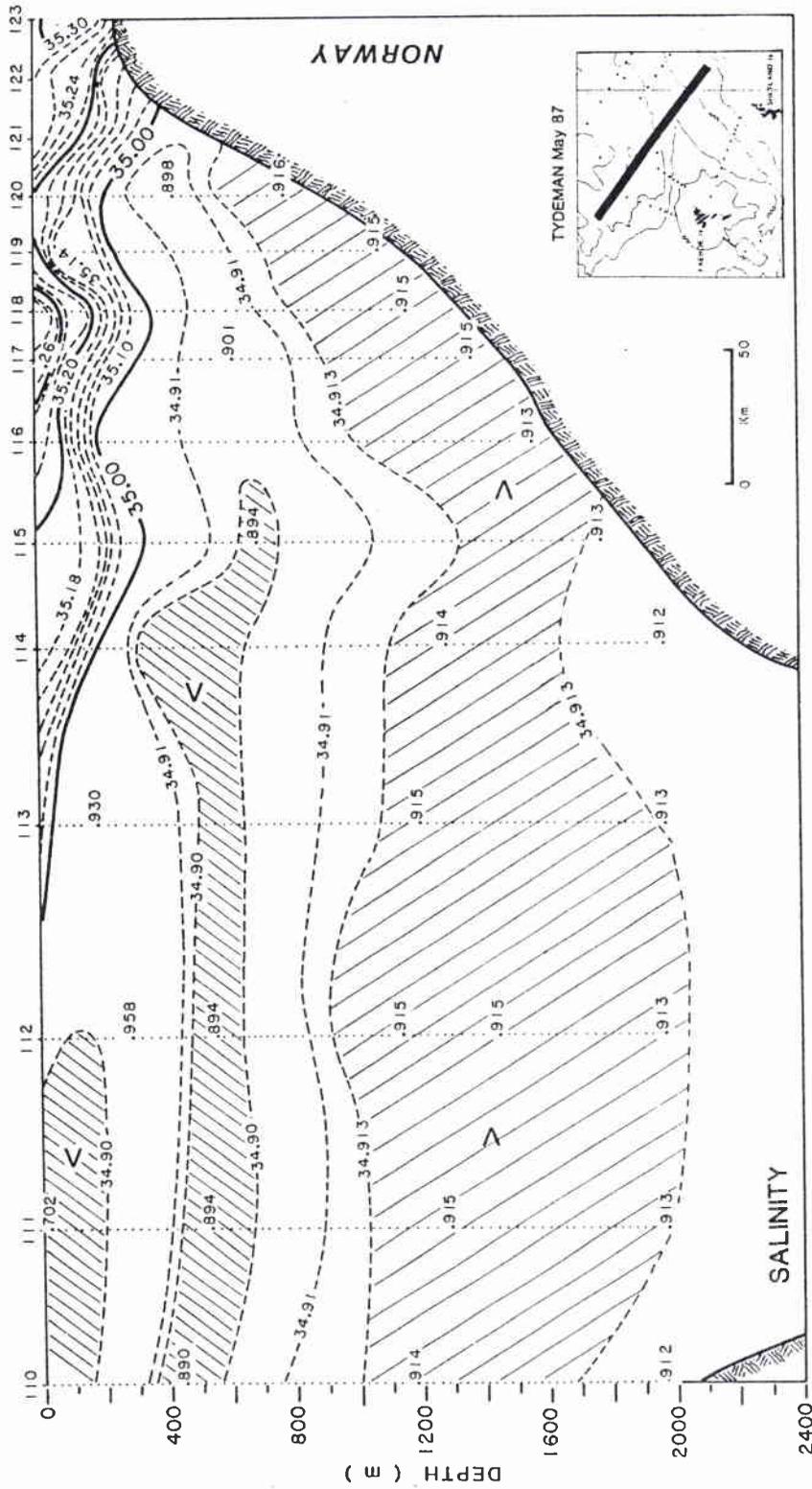


Figure A5

SACLANTCEN SM-249

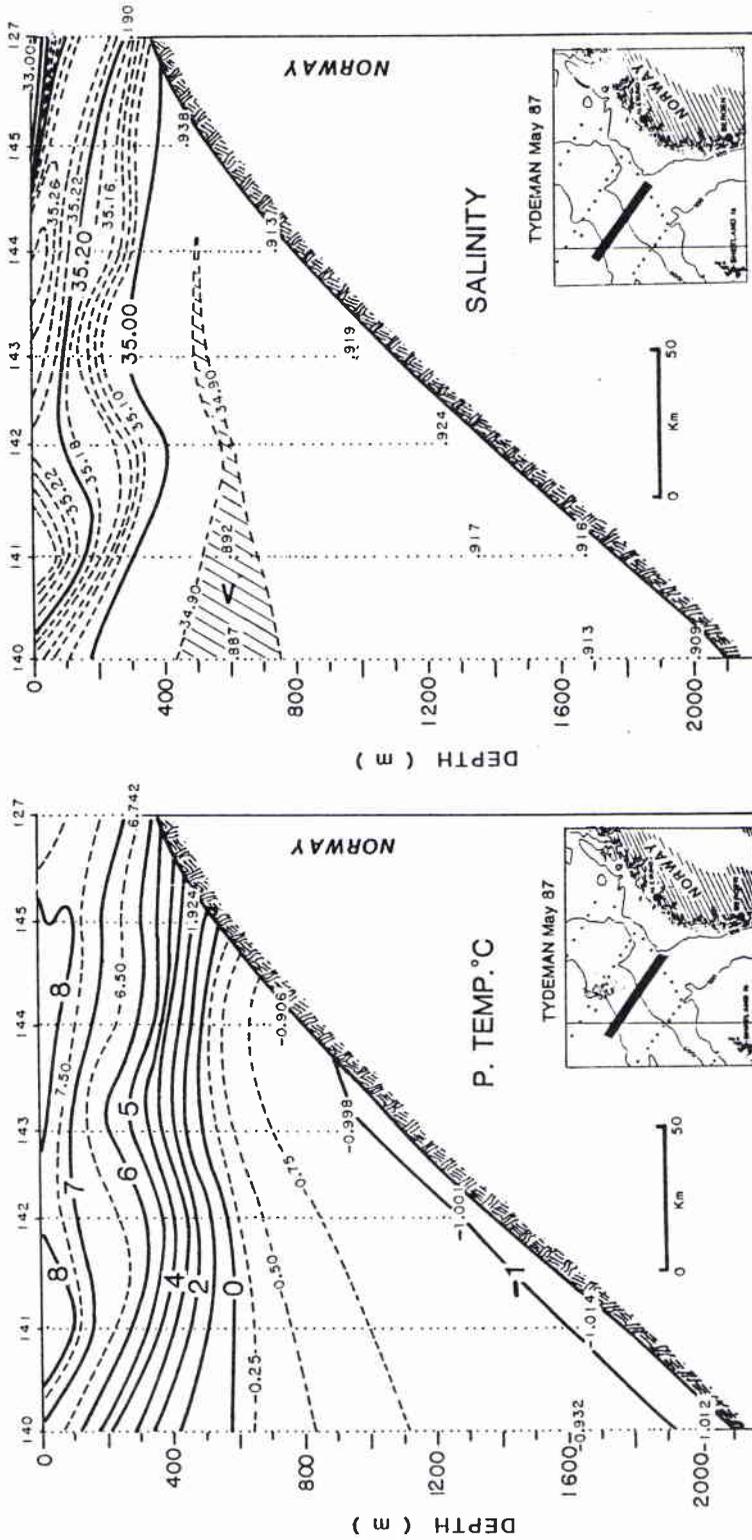


Figure A6

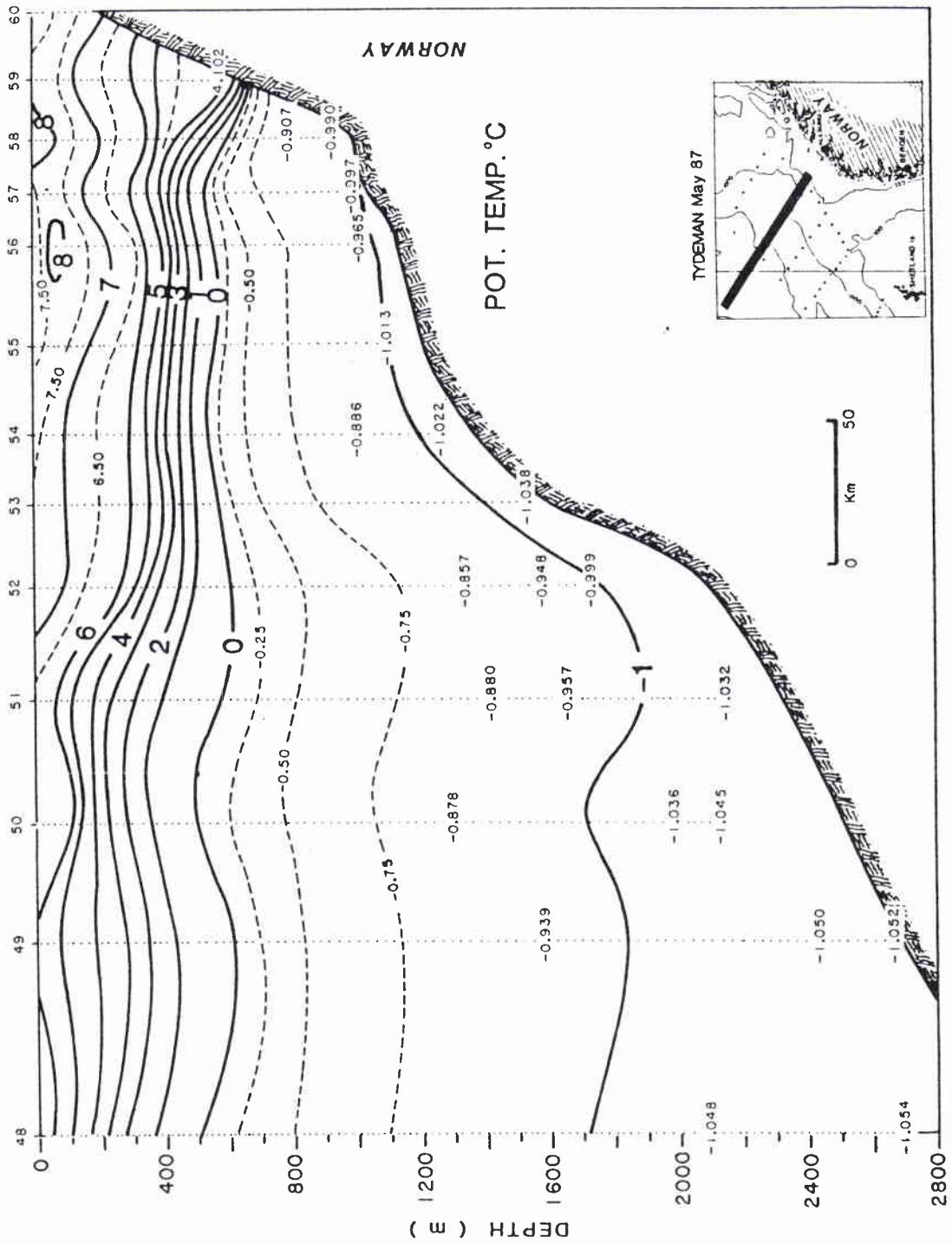


Figure A7

SACLANTCEN SM-249

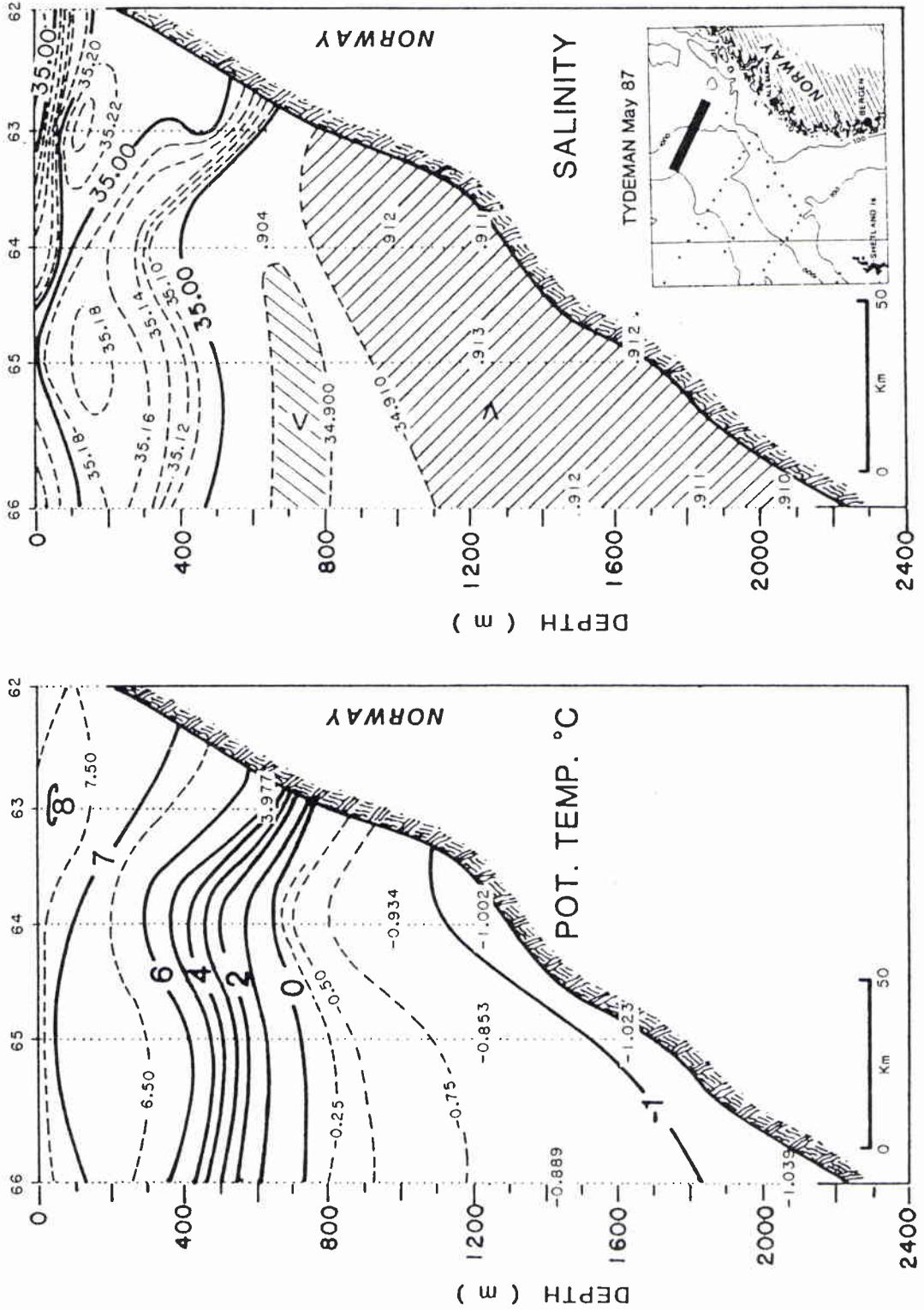


Figure A10

SACLANTCEN SM-249

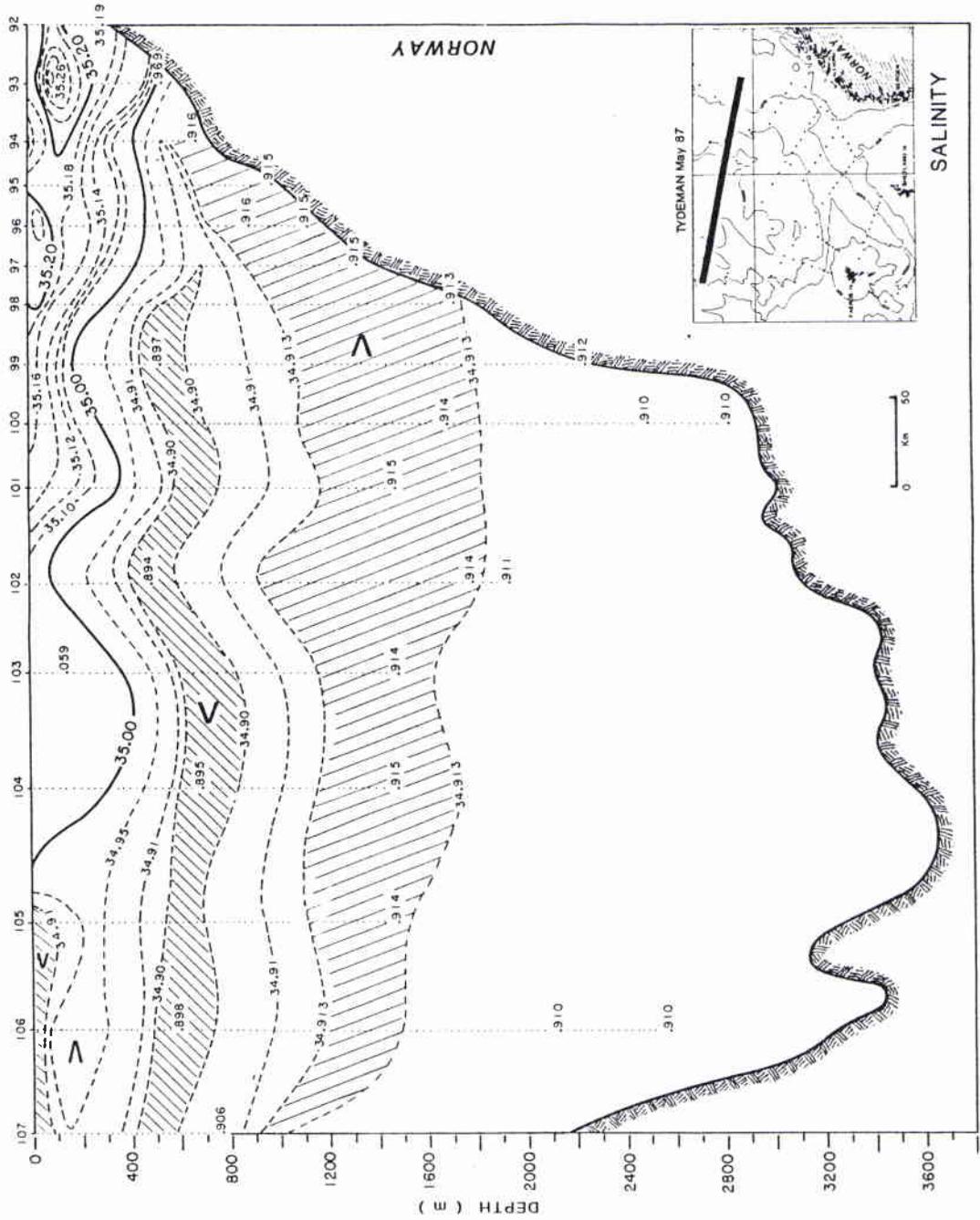


Figure A12

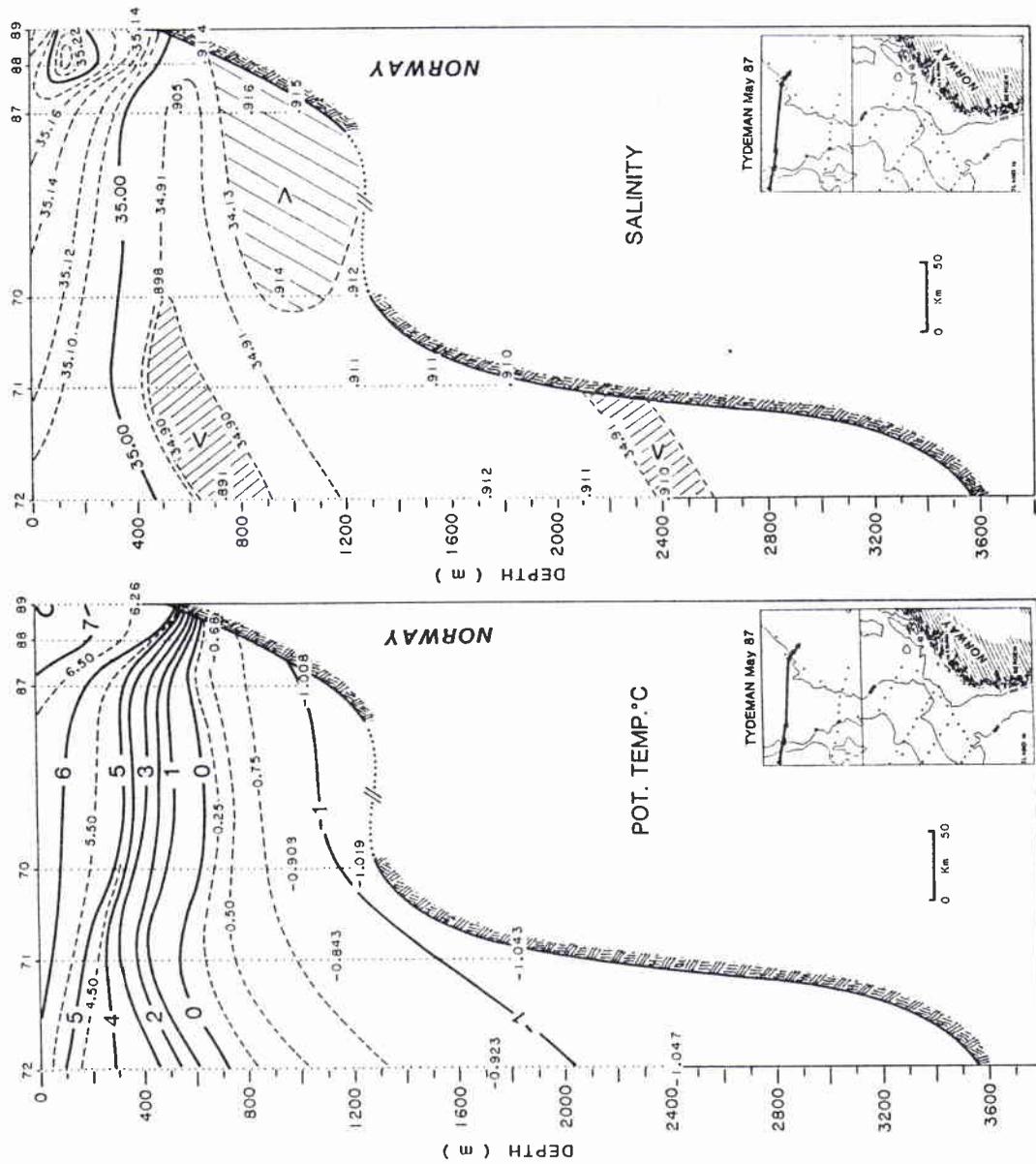


Figure A13

SACLANTCEN SM-249

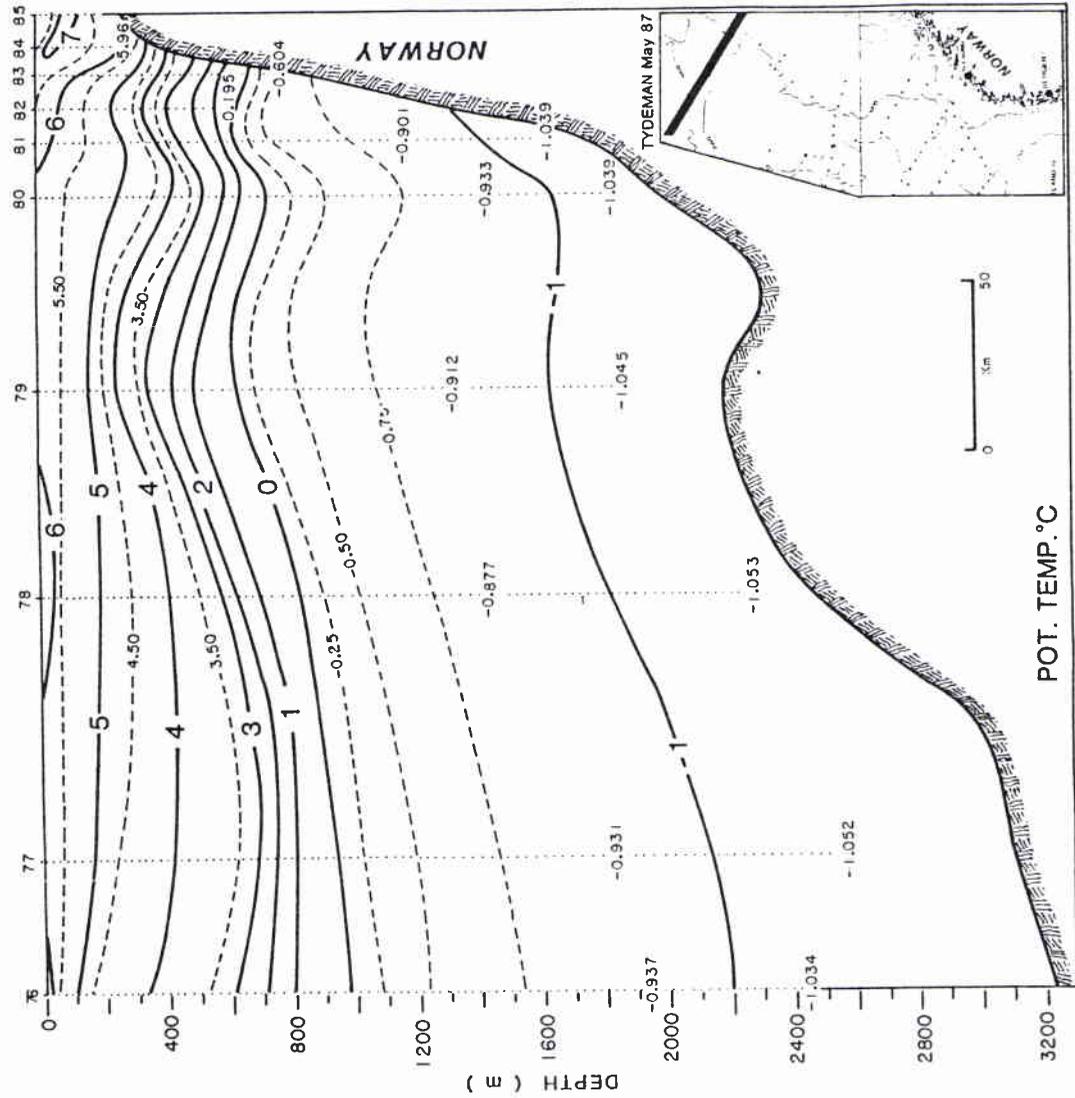


Figure A14

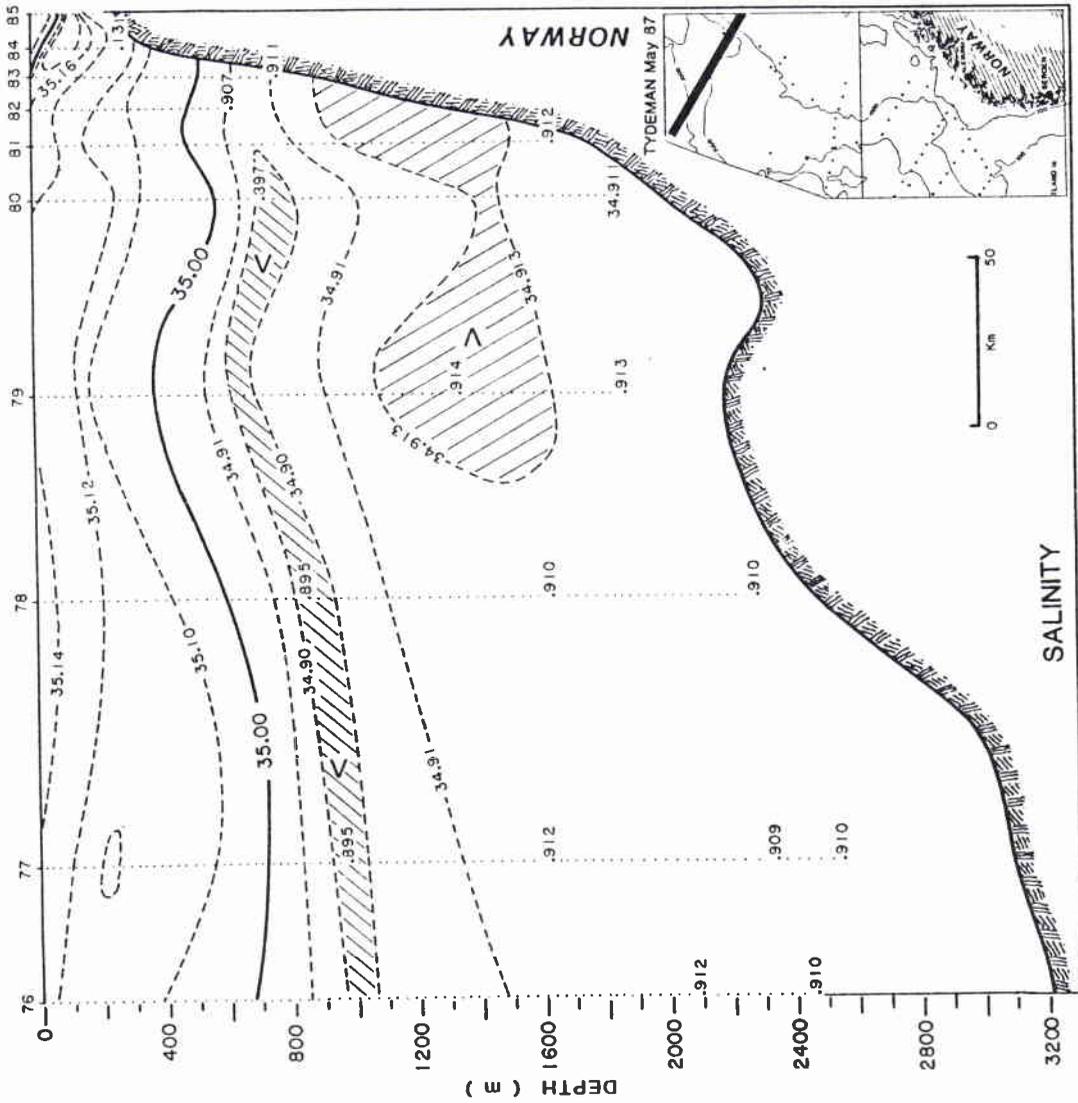


Figure A15

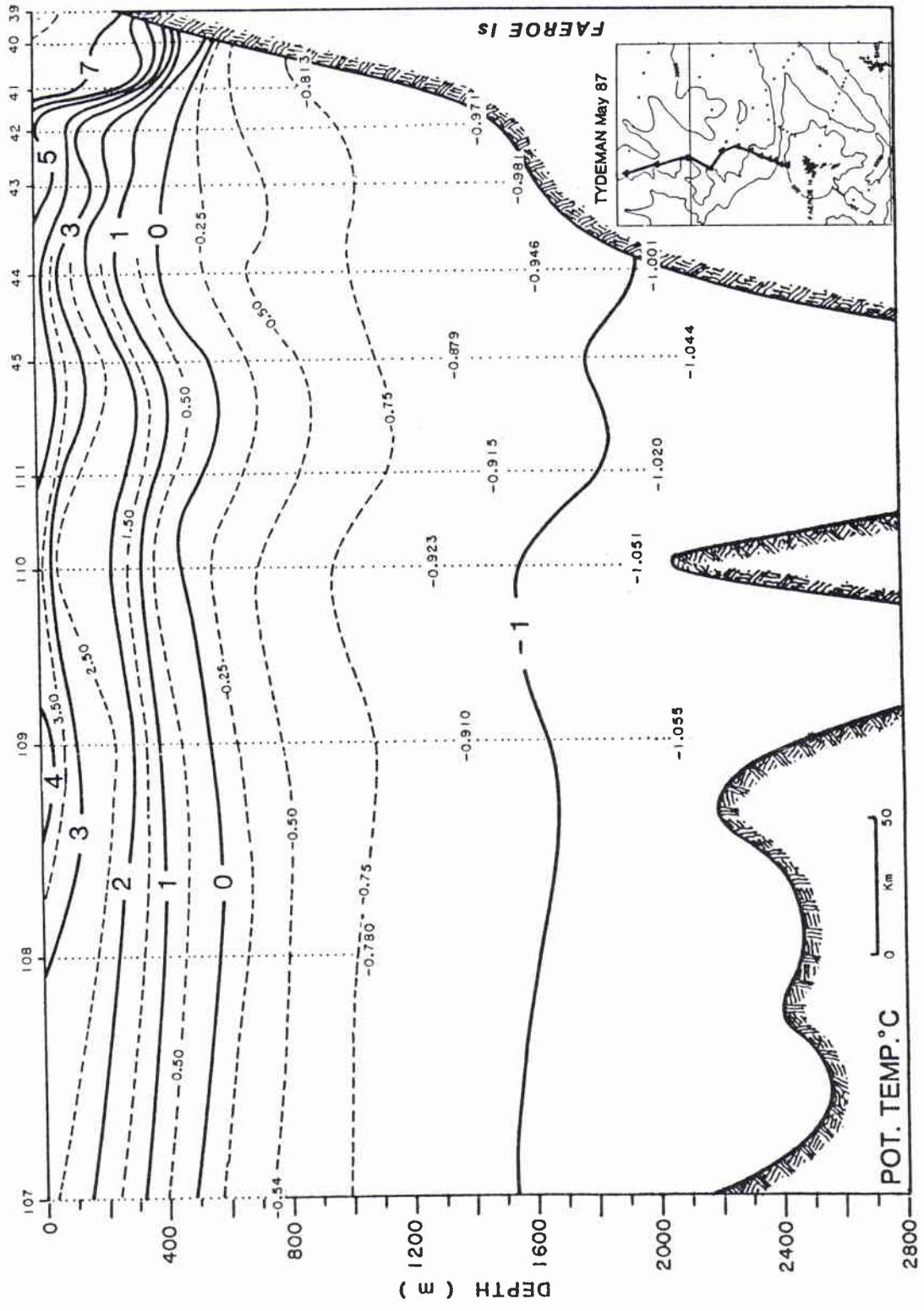


Figure A17

SACLANTCEN SM-249

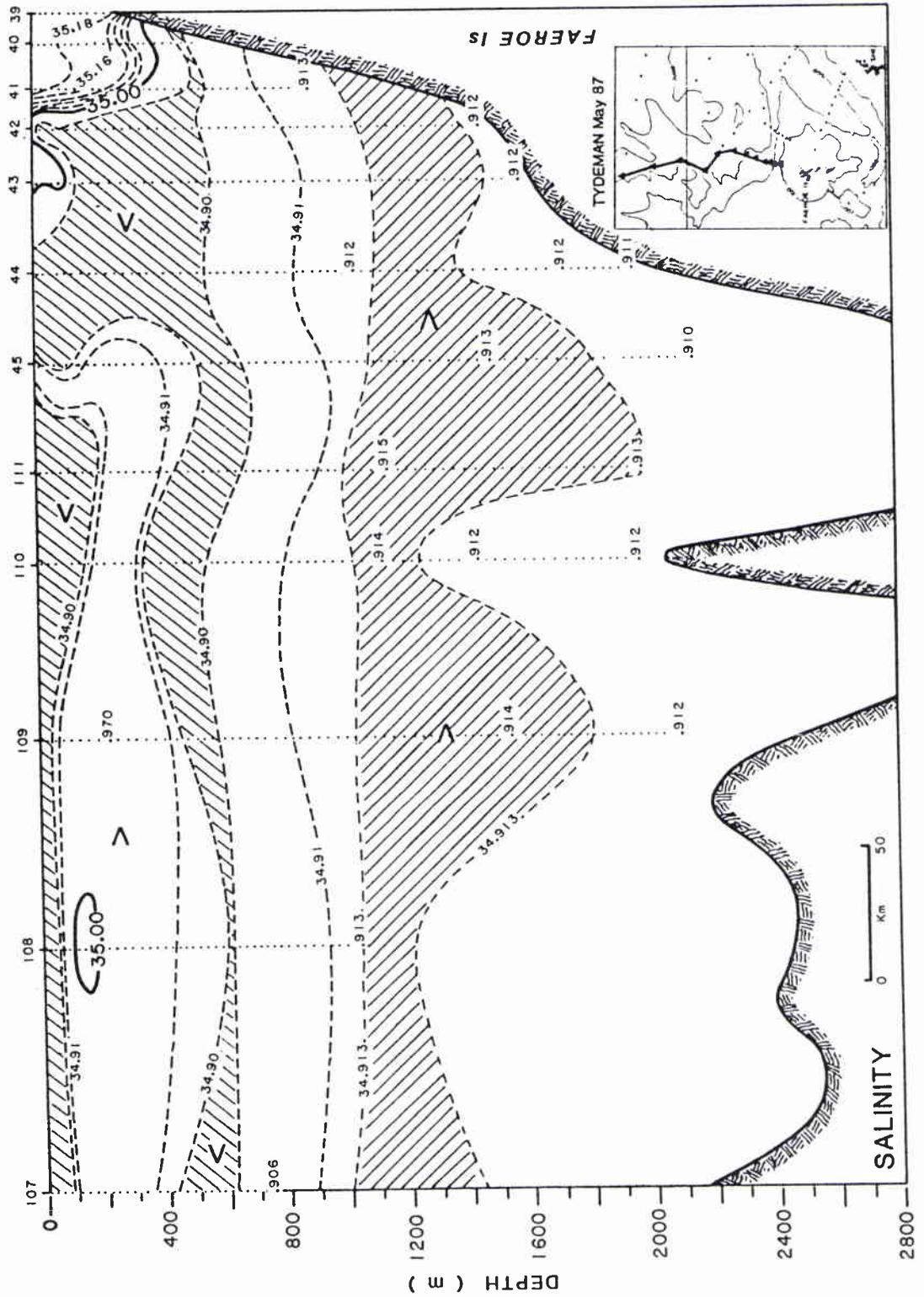


Figure A18

SACLANTCEN SM-249

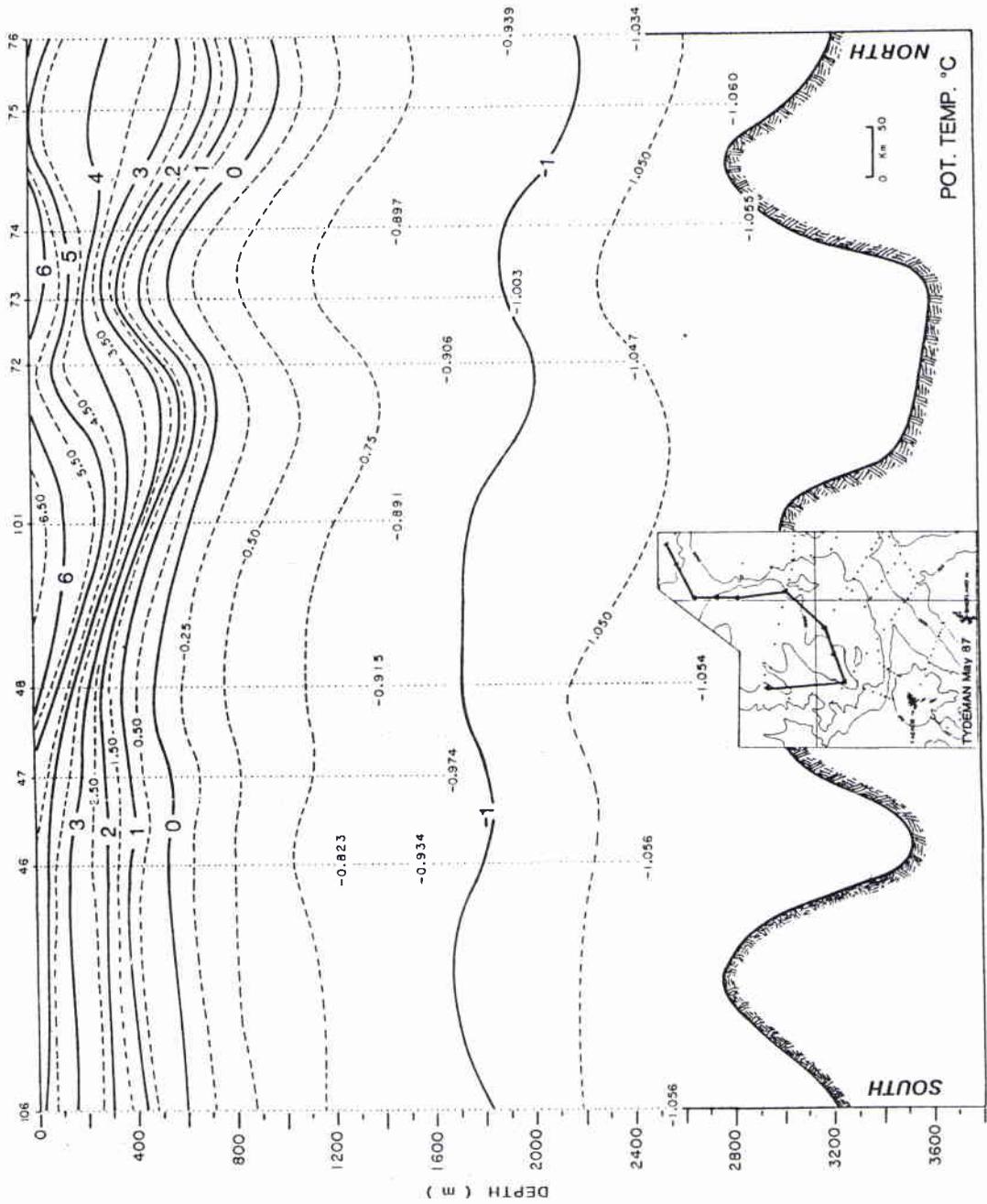


Figure A20

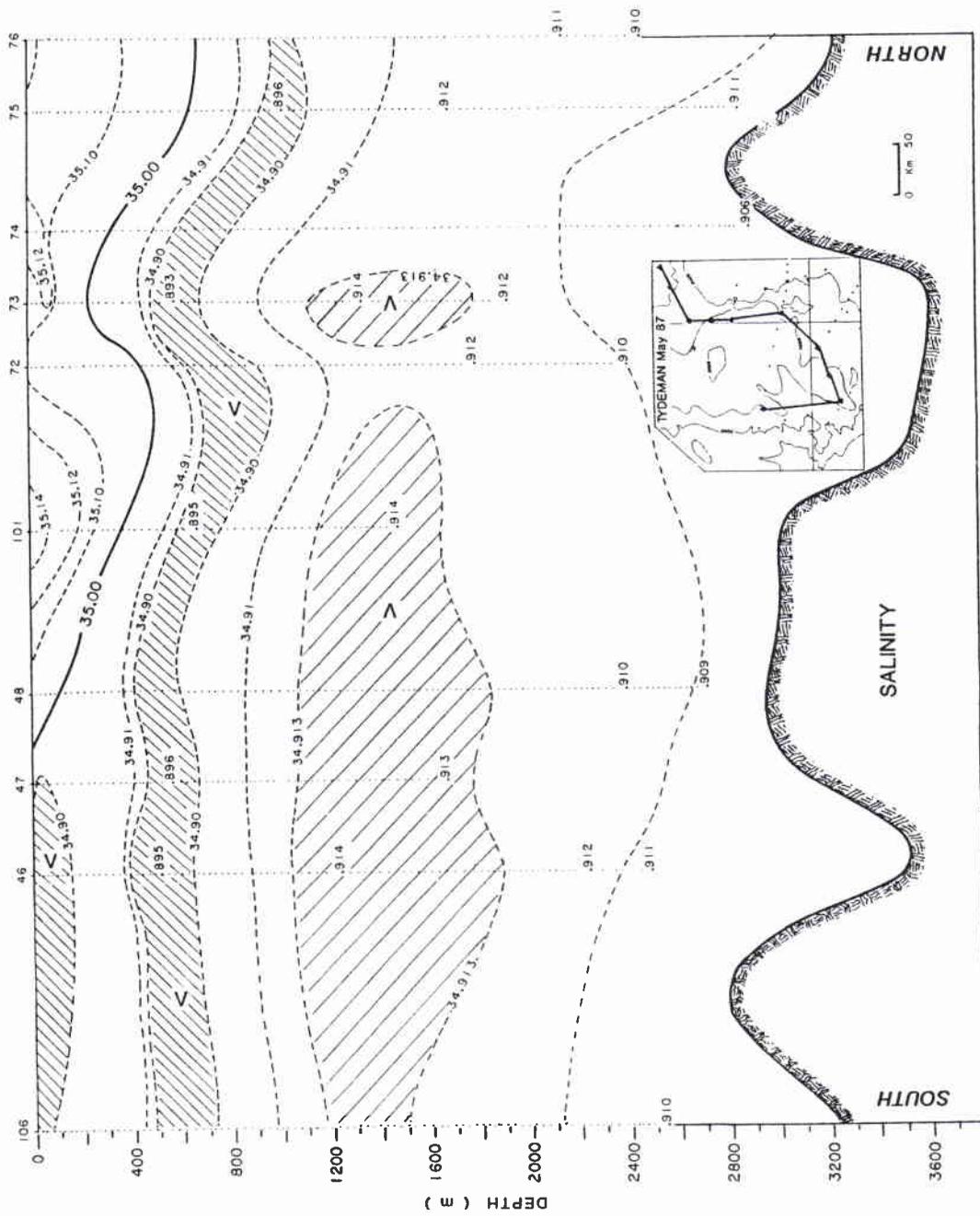


Figure A21

SACLANTCEN SM-249

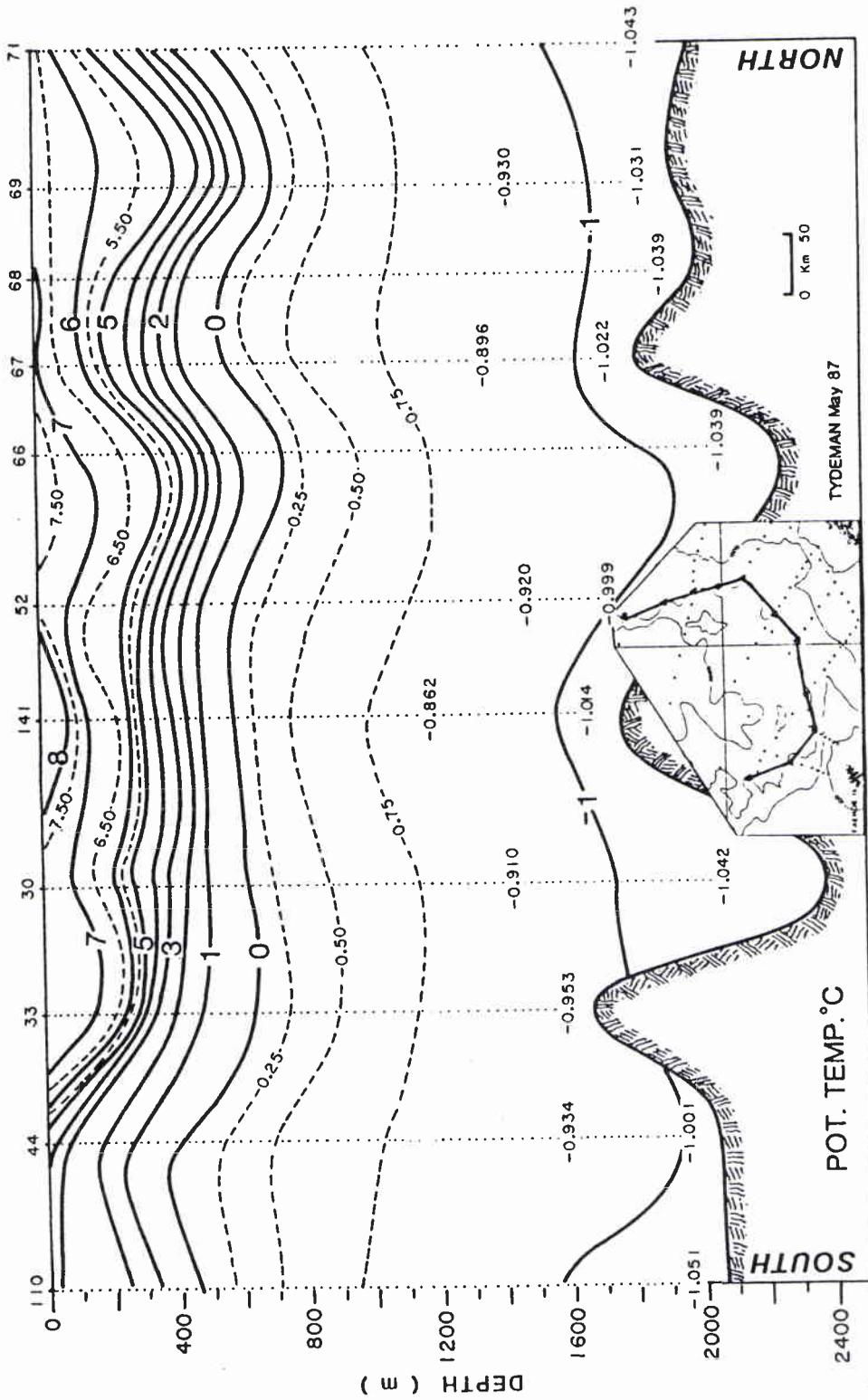


Figure A22

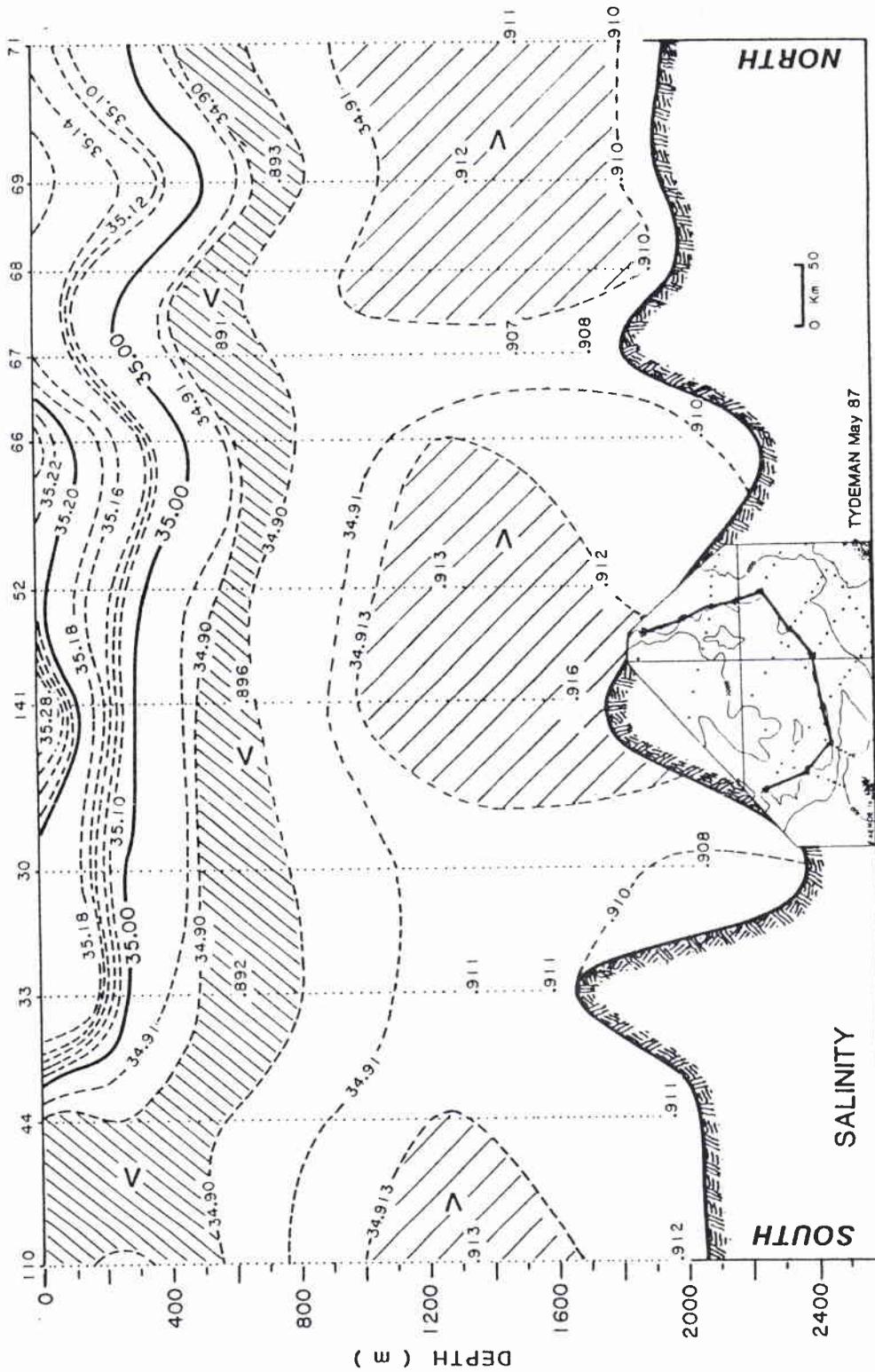


Figure A23

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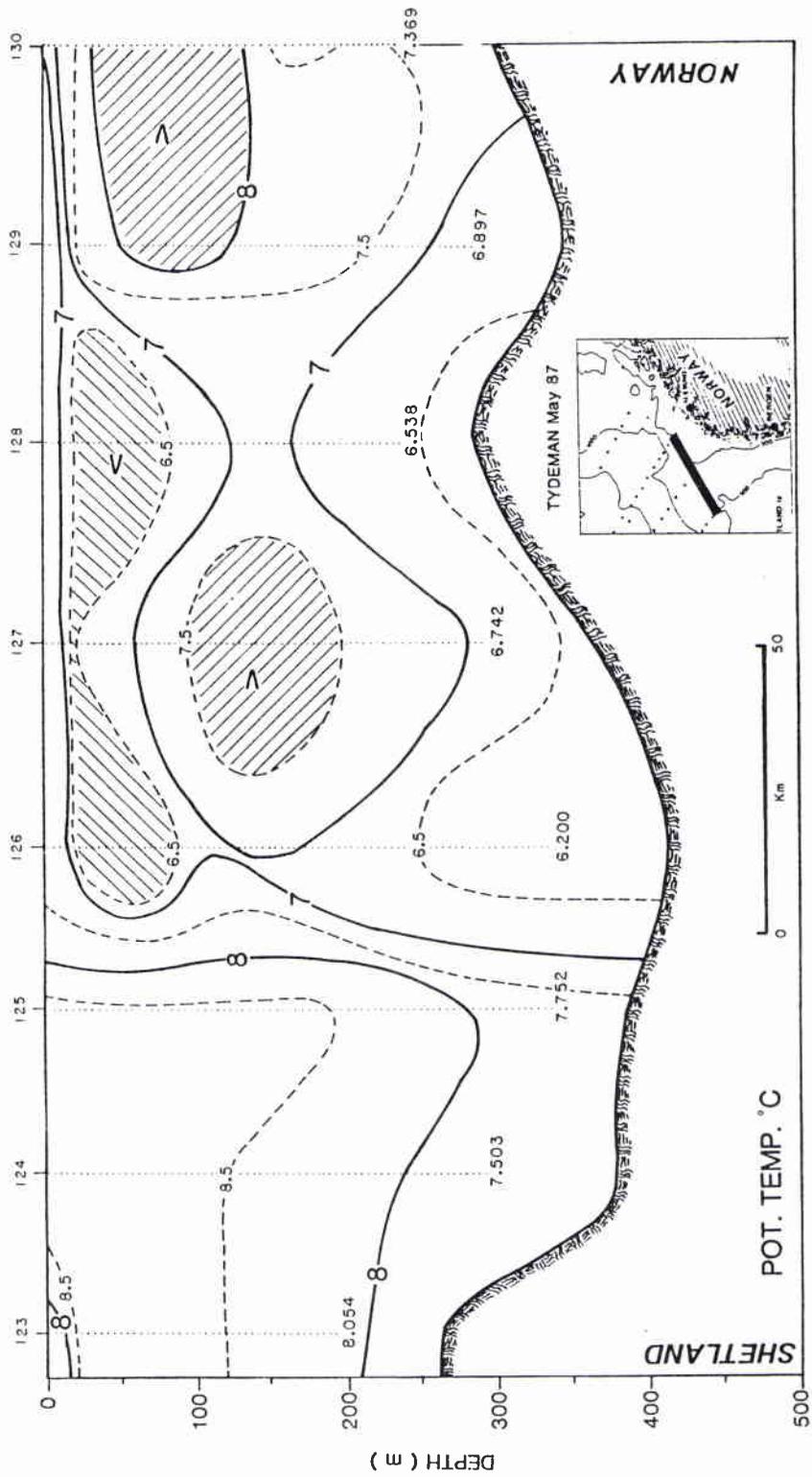


Figure A24

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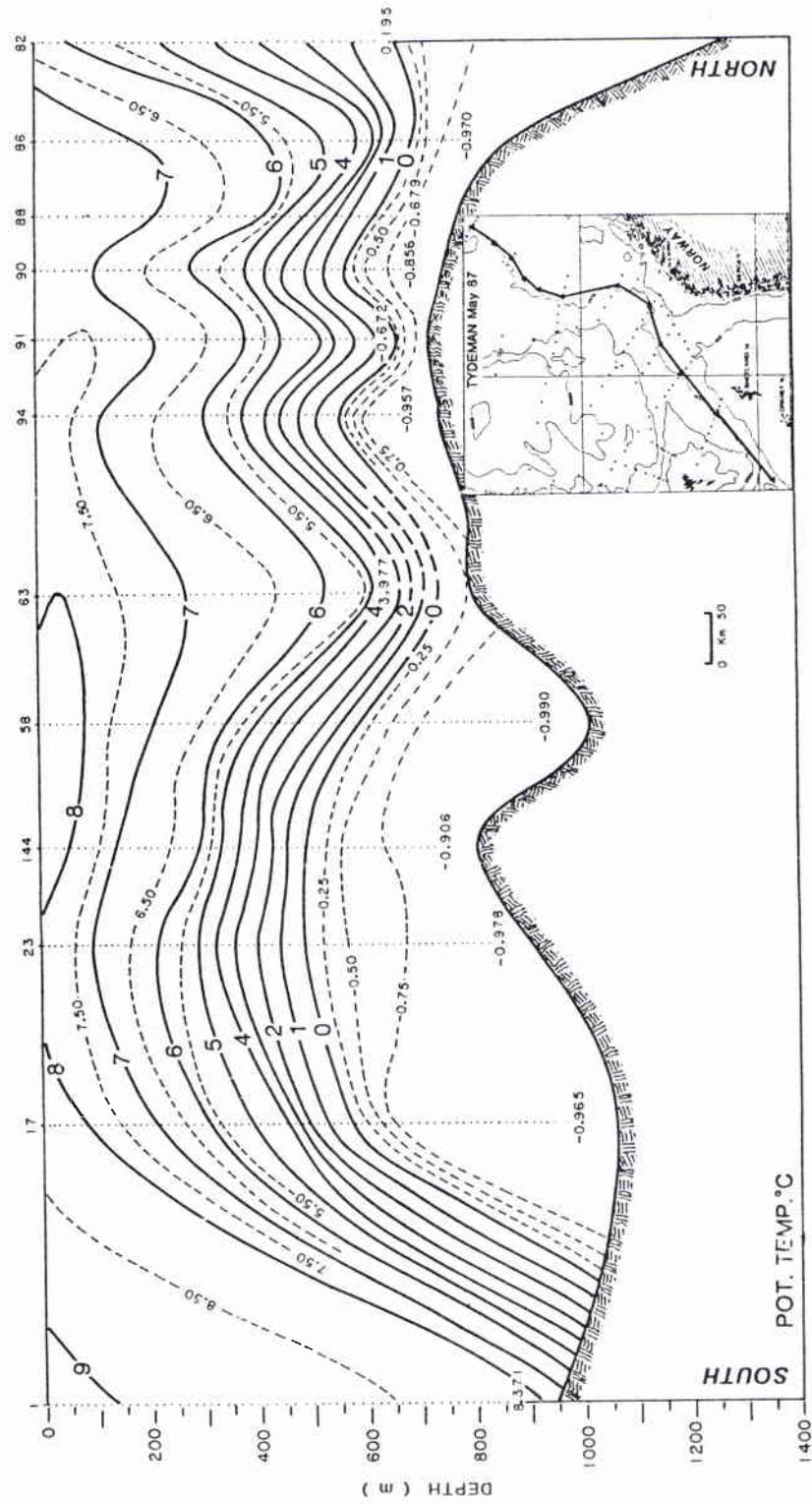


Figure A26

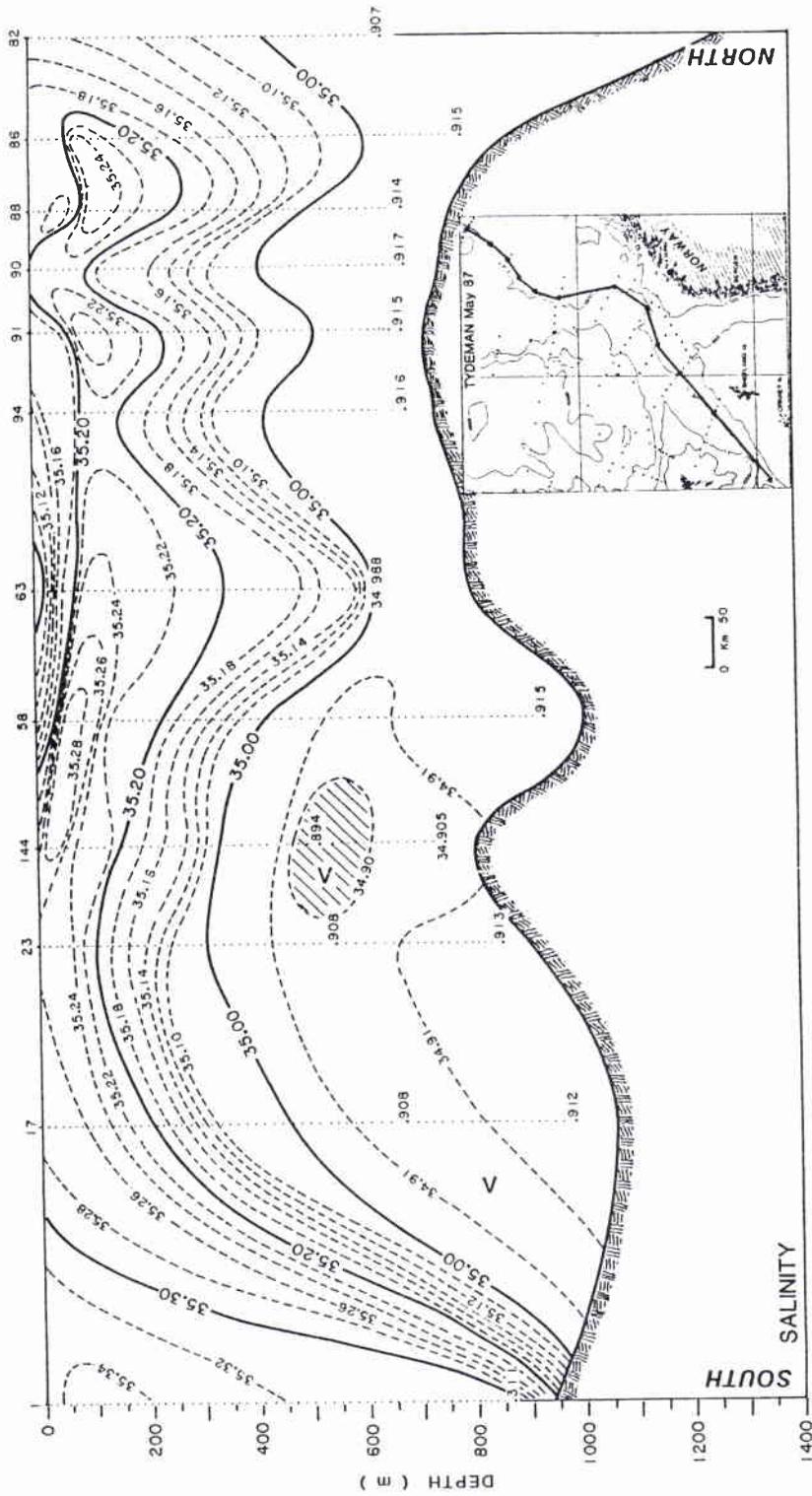


Figure A27

Appendix B

CTD data from the downcasts

CTD data from the downcasts are presented in Figs. B1–B167. For each downcast, four plots are presented in four panels as follows:

- upper left, vertical profiles of salinity (in ppt) and potential temperature (in °C);
- upper right, vertical profiles of transparency (in %) and oxygen saturation (in %);
- lower left, vertical profiles of sigma-t density (in gm/cm³) and sound velocity (in m/s);
- lower right, potential temperature *vs* salinity diagram. The points corresponding to the pressures of 100, 200, 300 dB etc. are indicated and the isopleths of sigma-t are drawn on the diagram.

These stations profiles are followed (Figs. B168–B265) by data listings from the WAV file of one-meter averaged variables at selected depths.

SACLANTCEN SM-249

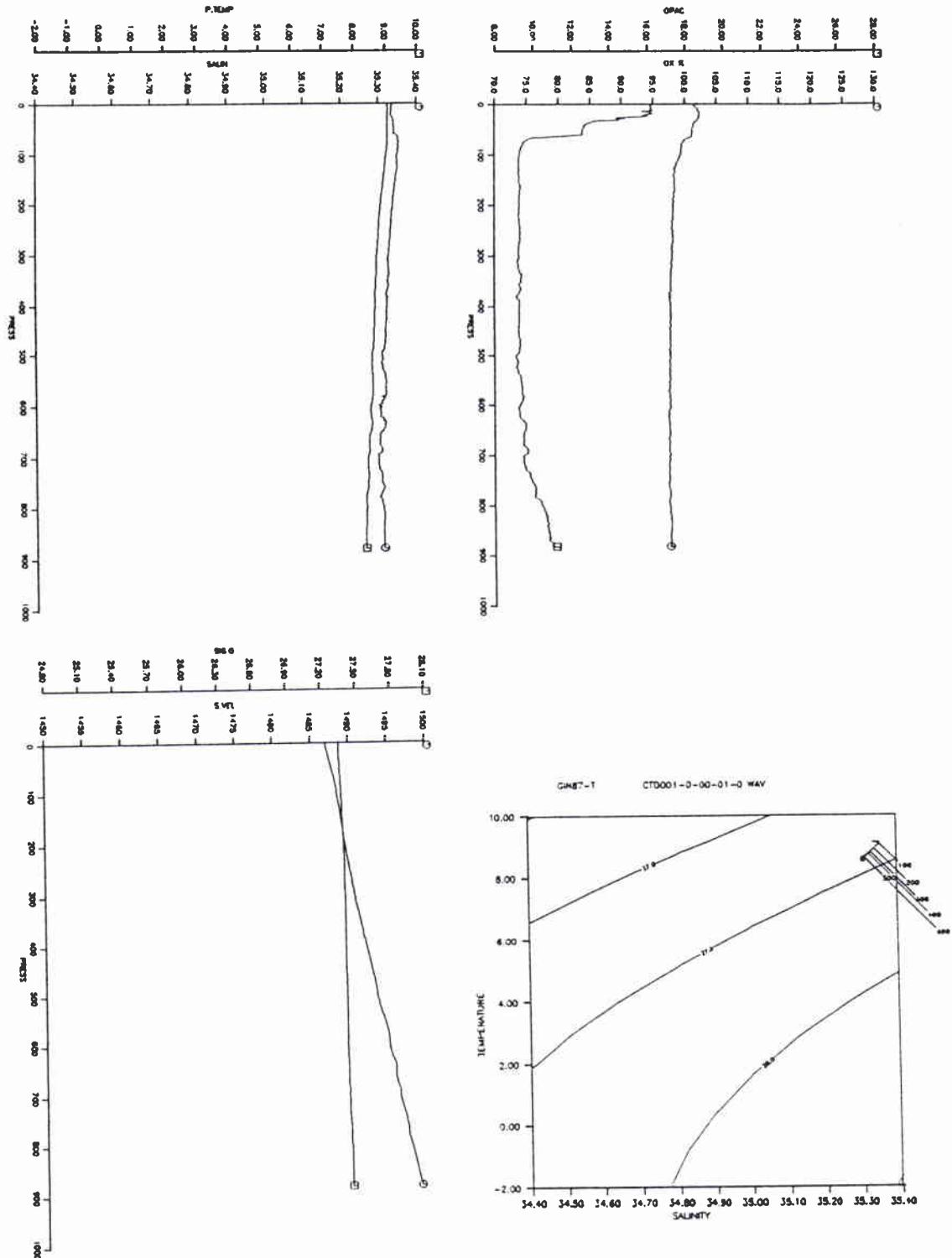


Figure B1

SACLANTCEN SM-249

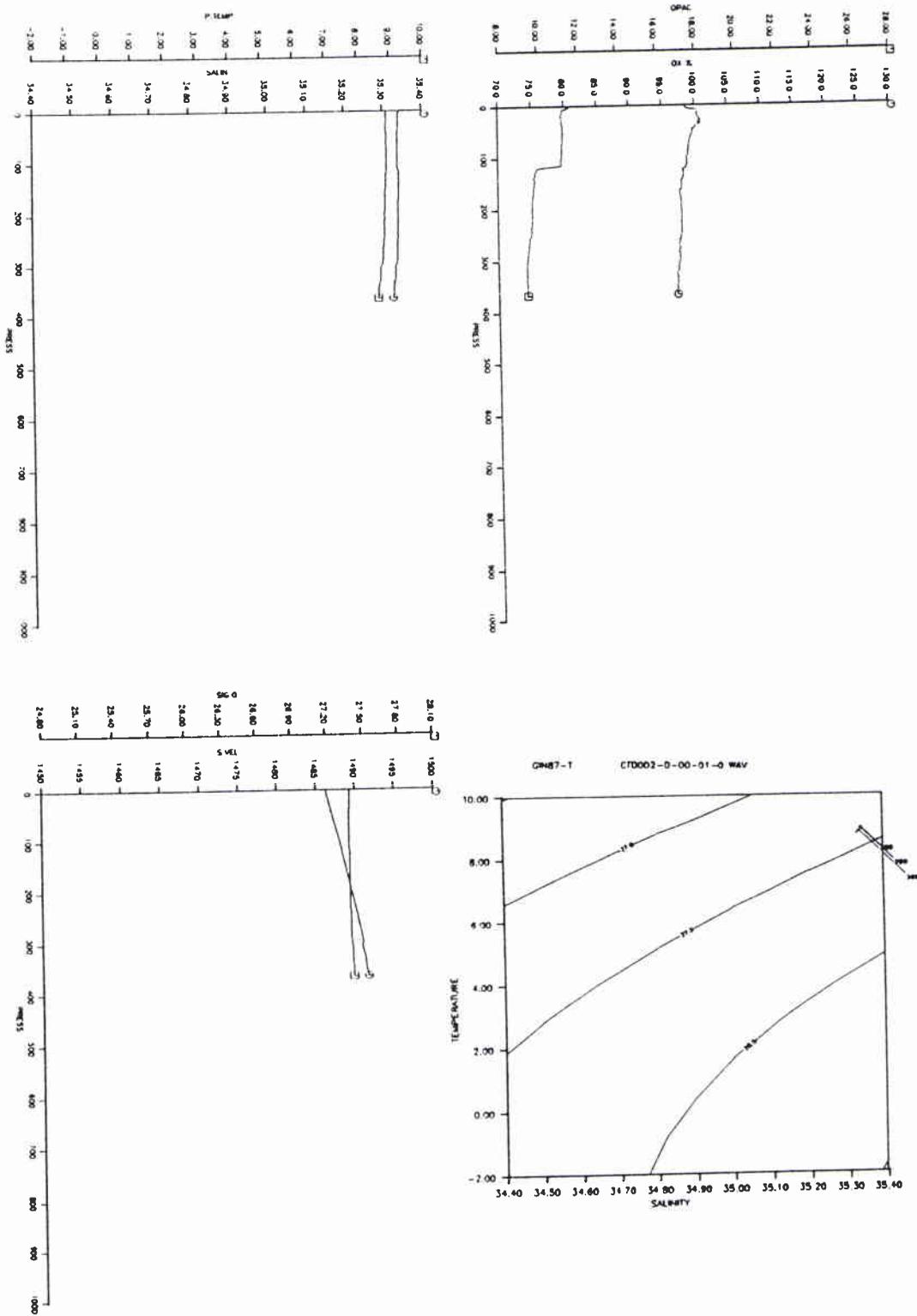


Figure B2

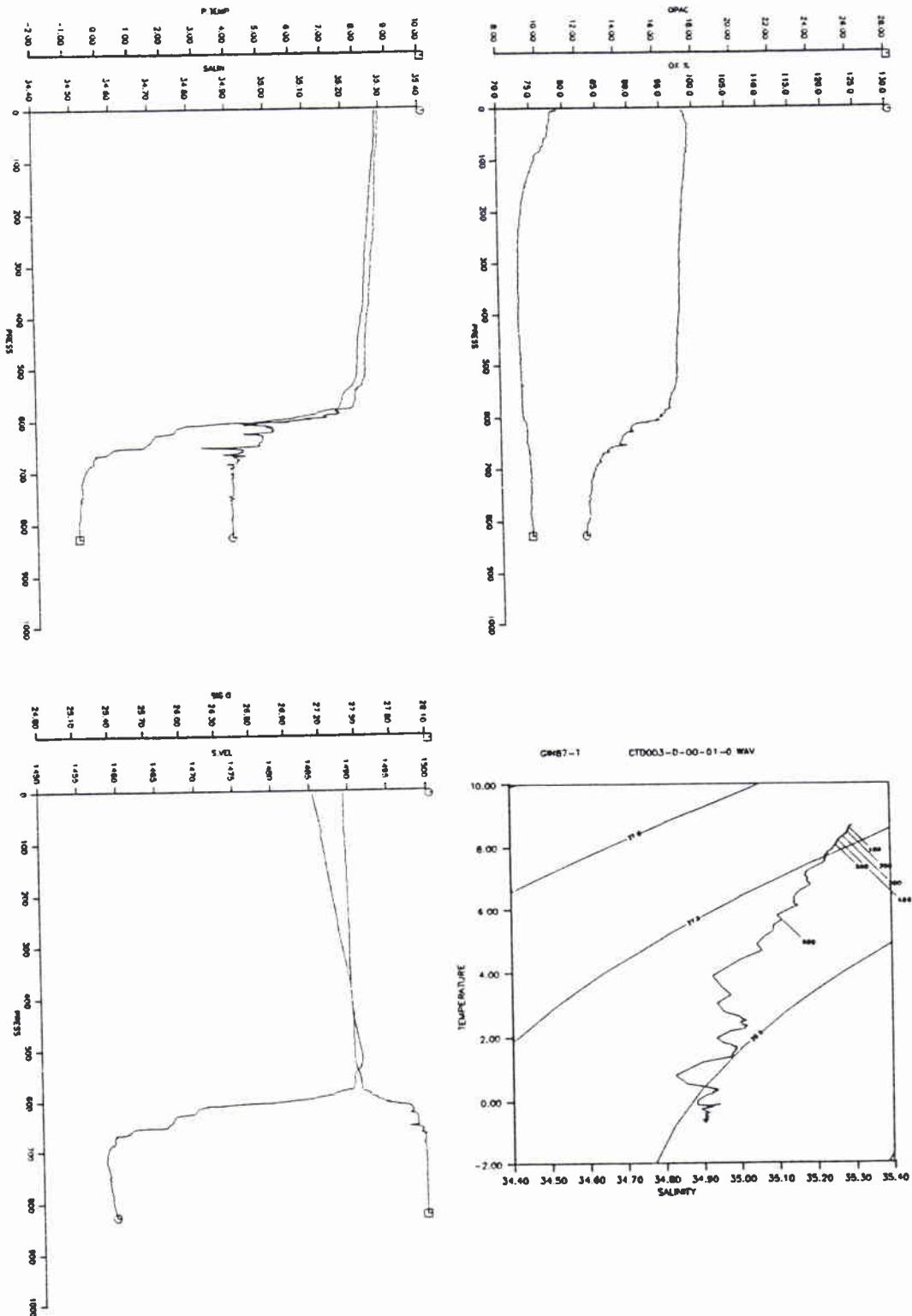


Figure B3

SACLANTCEN SM-249

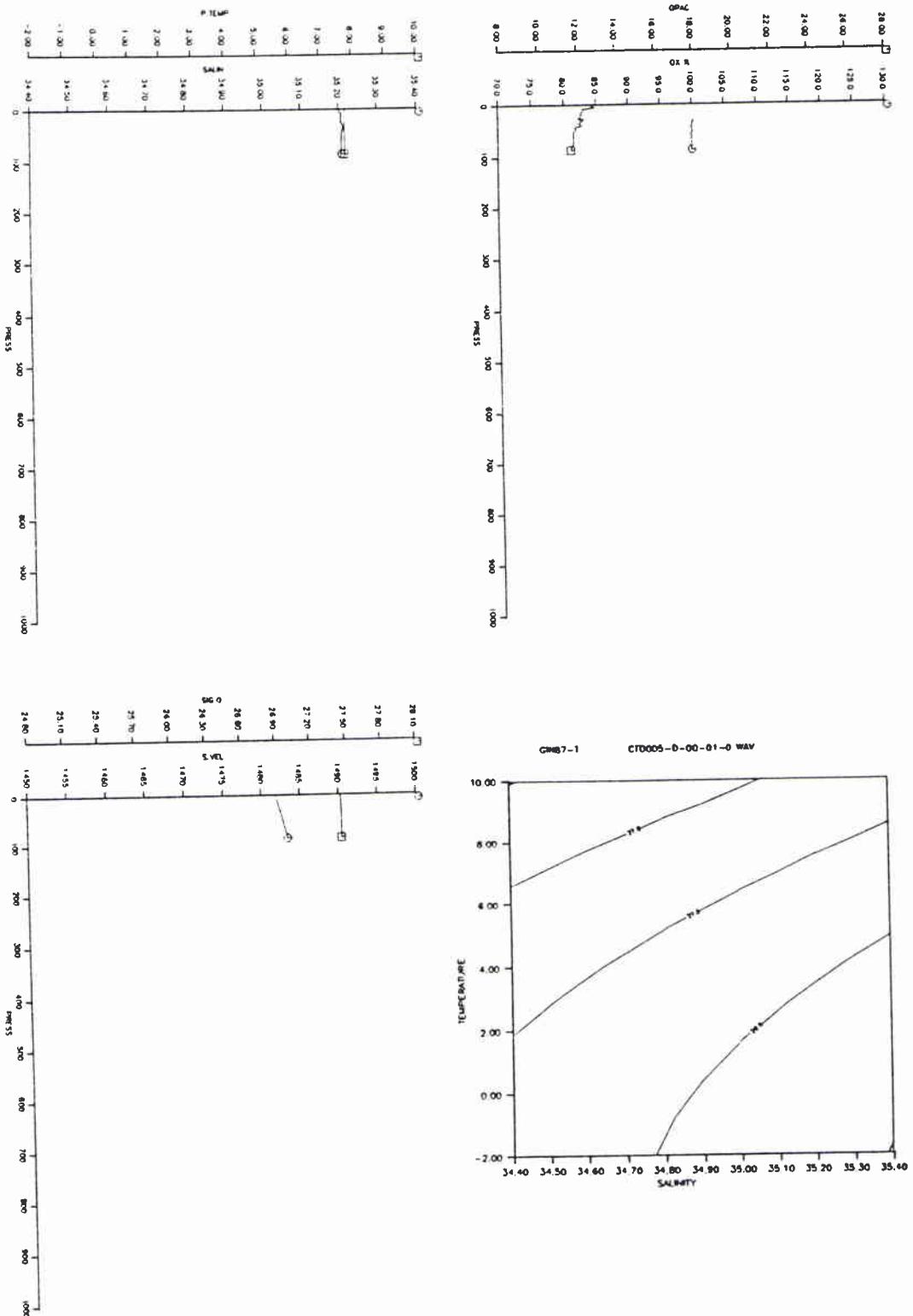


Figure B4

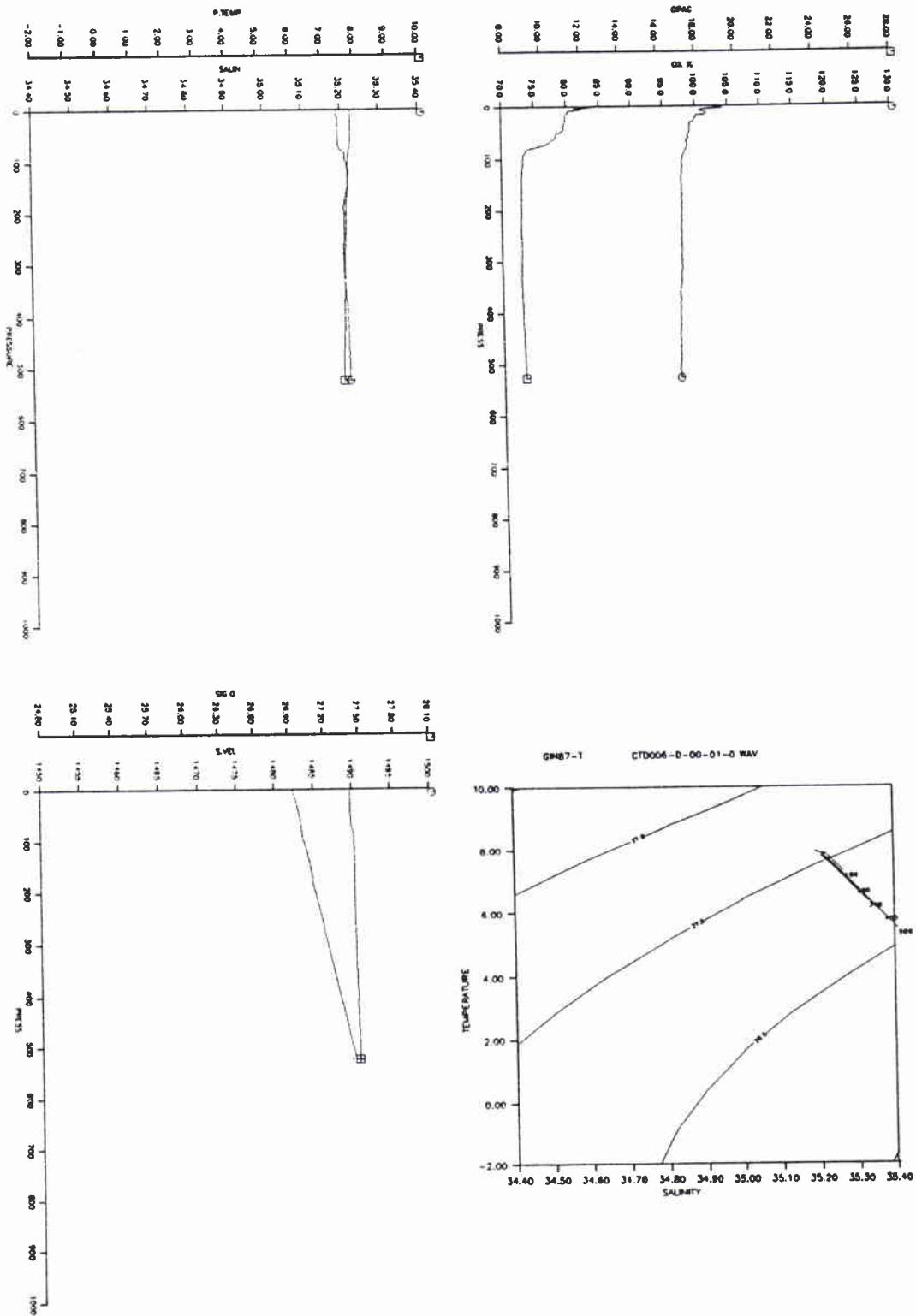


Figure B5

SACLANTCEN SM-249

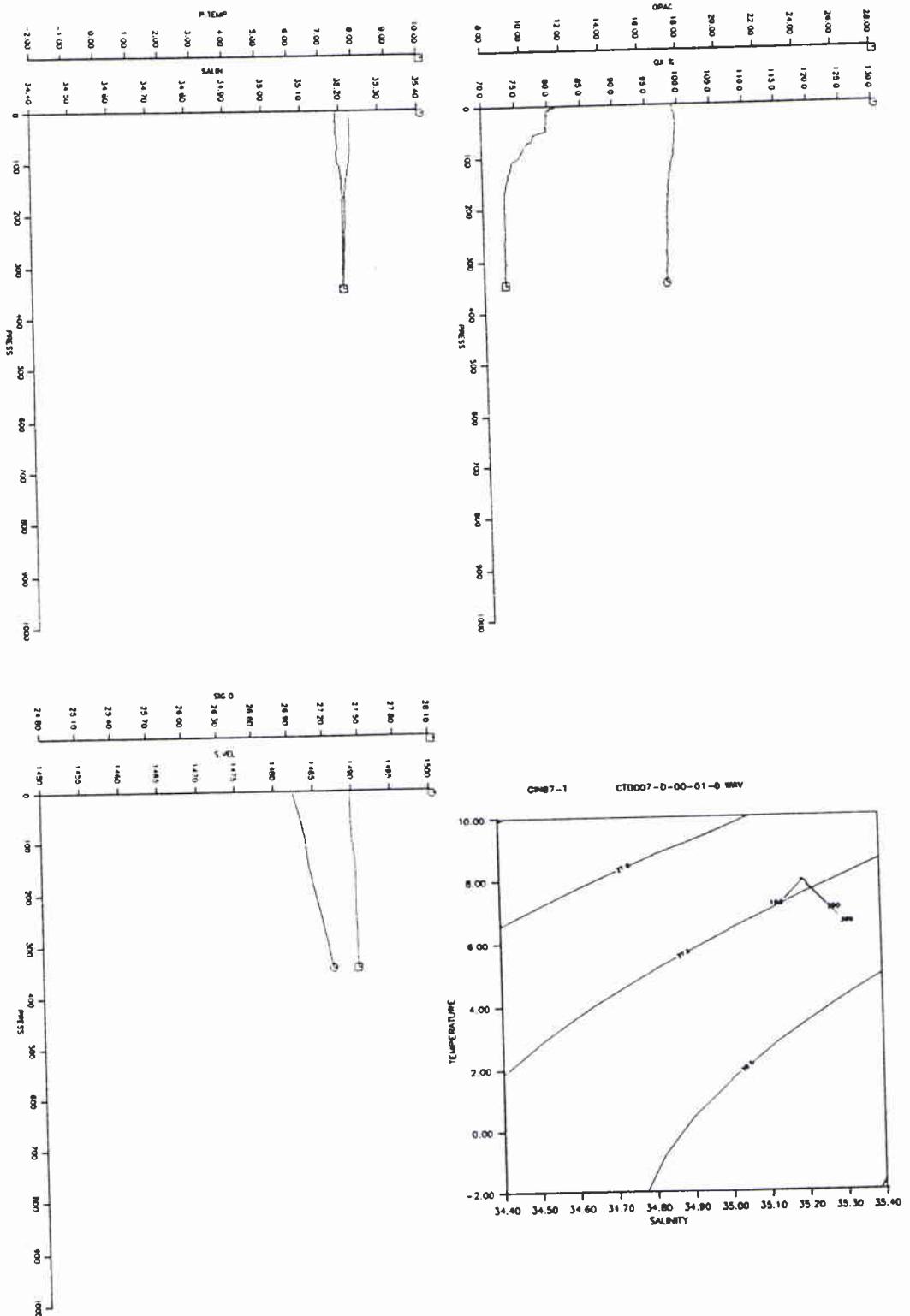


Figure B6

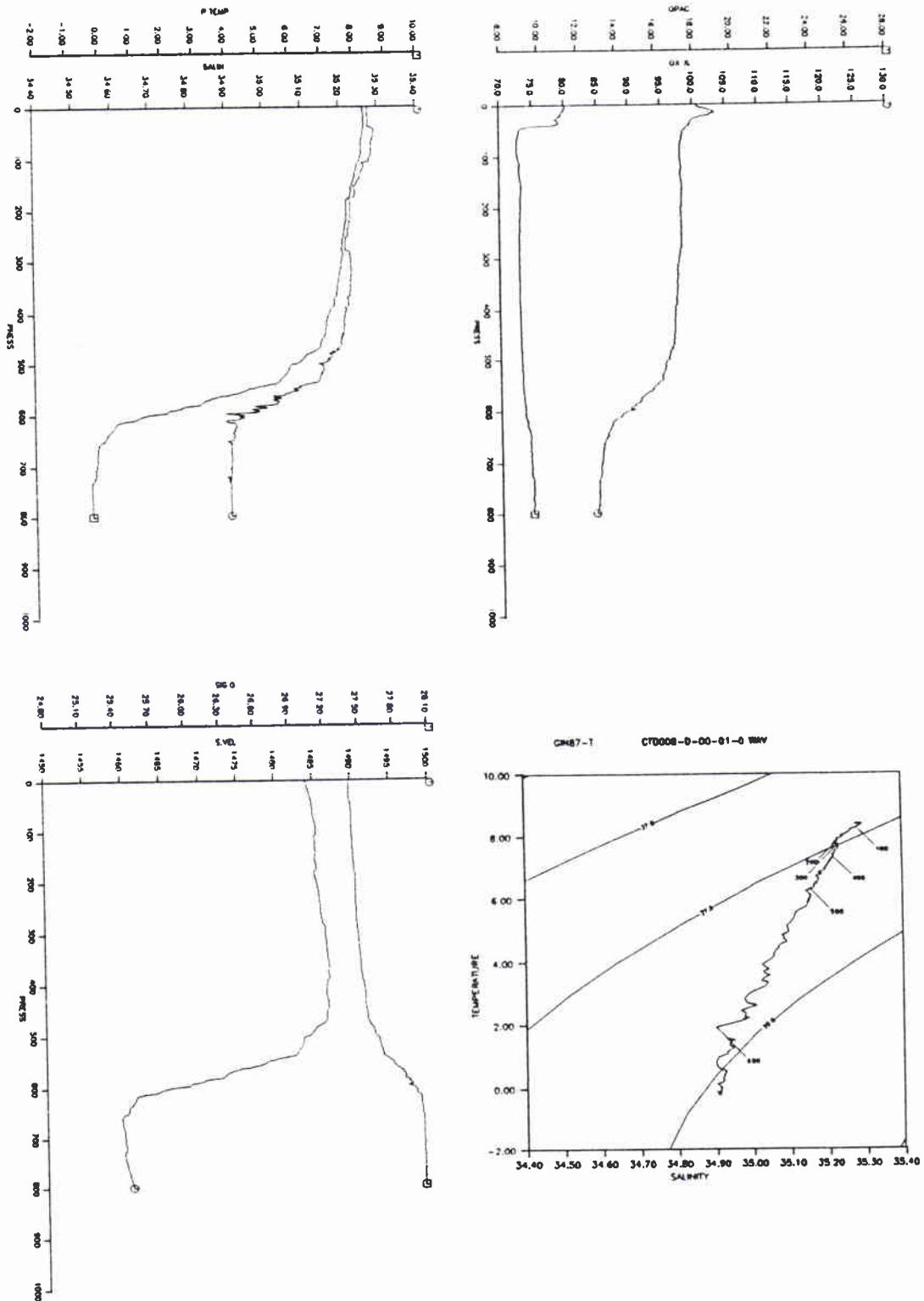


Figure B7

SACLANTCEN SM-249

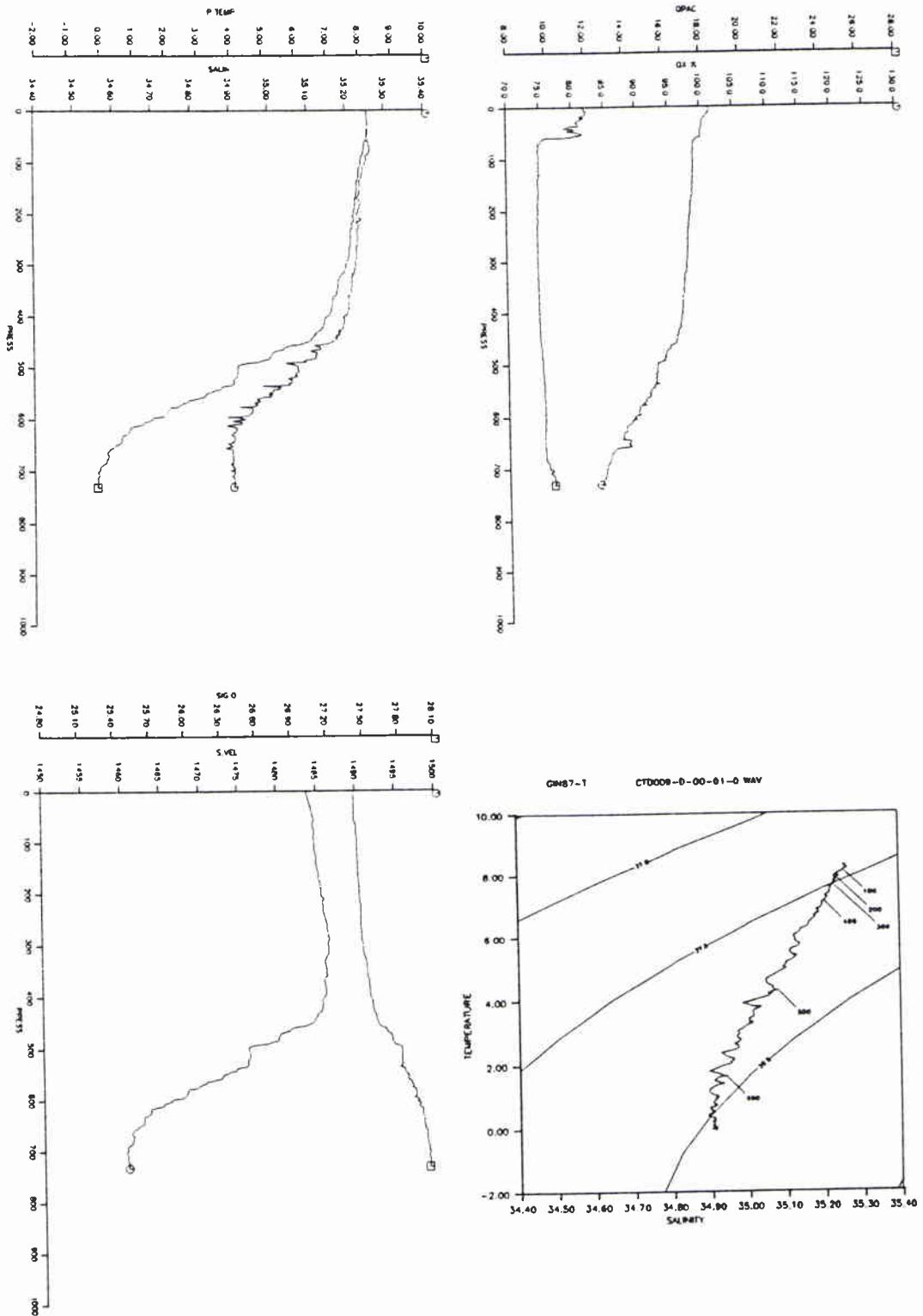


Figure B8

SACLANTCEN SM-249

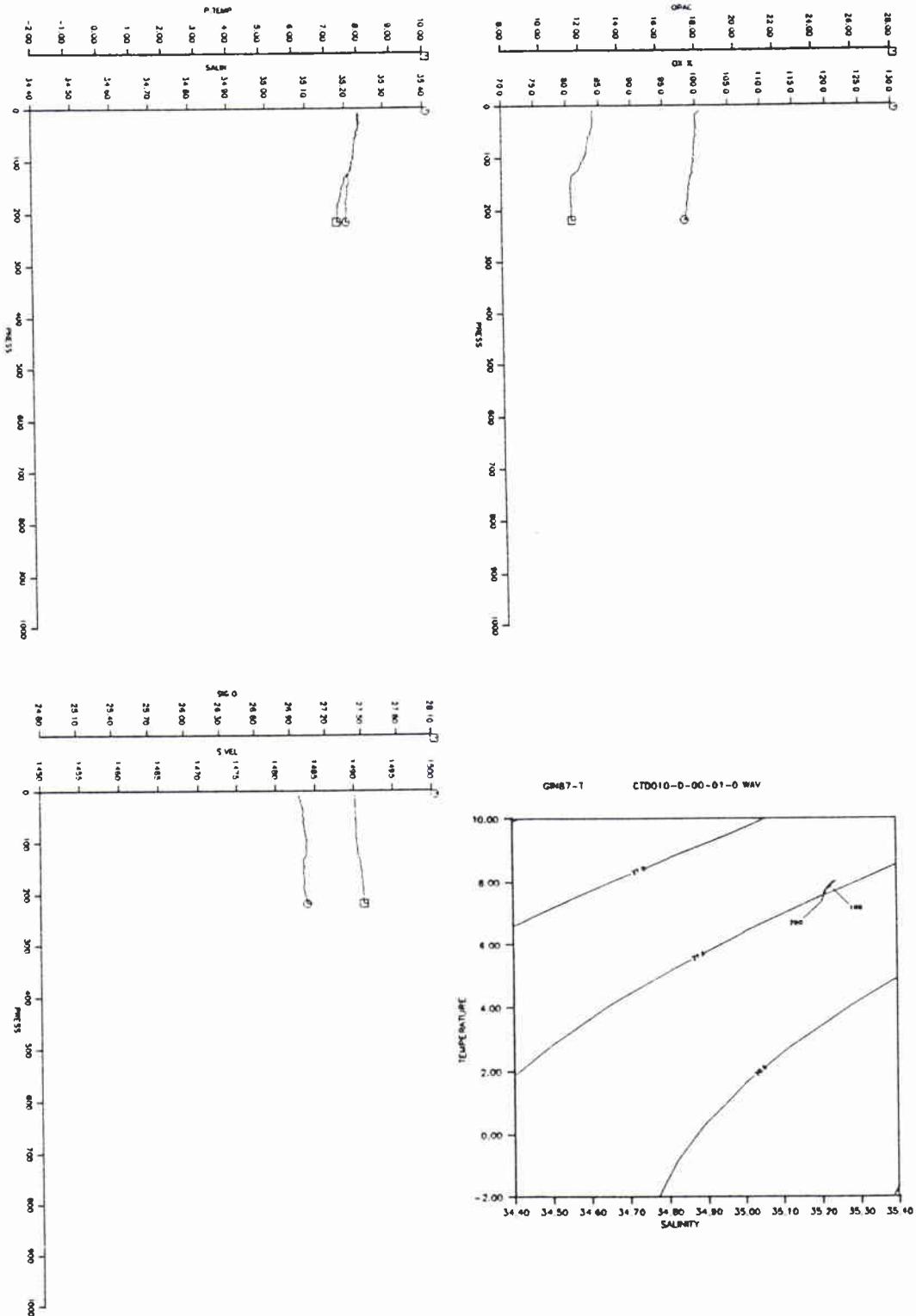


Figure B9

SACLANTCEN SM-249

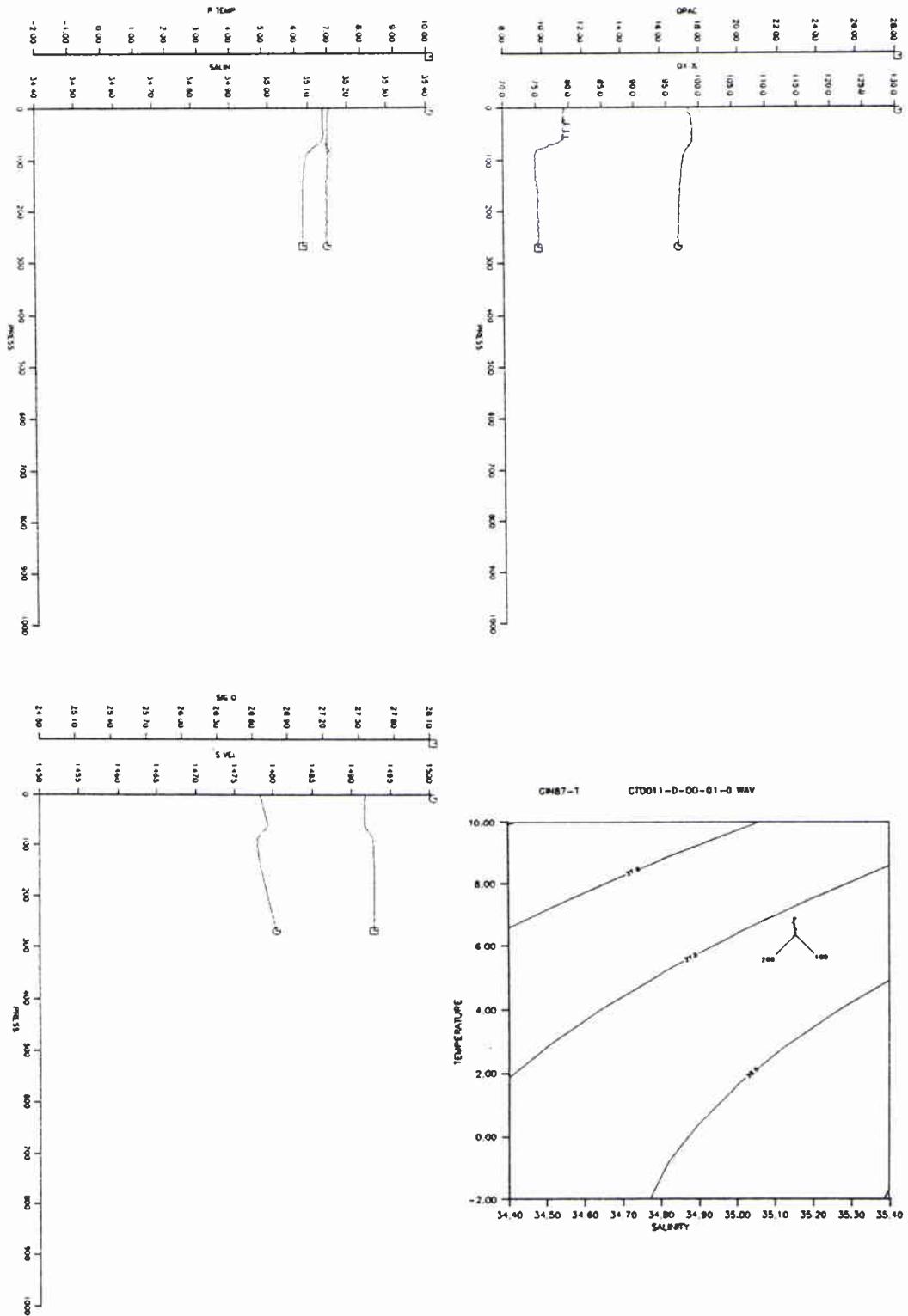


Figure B10

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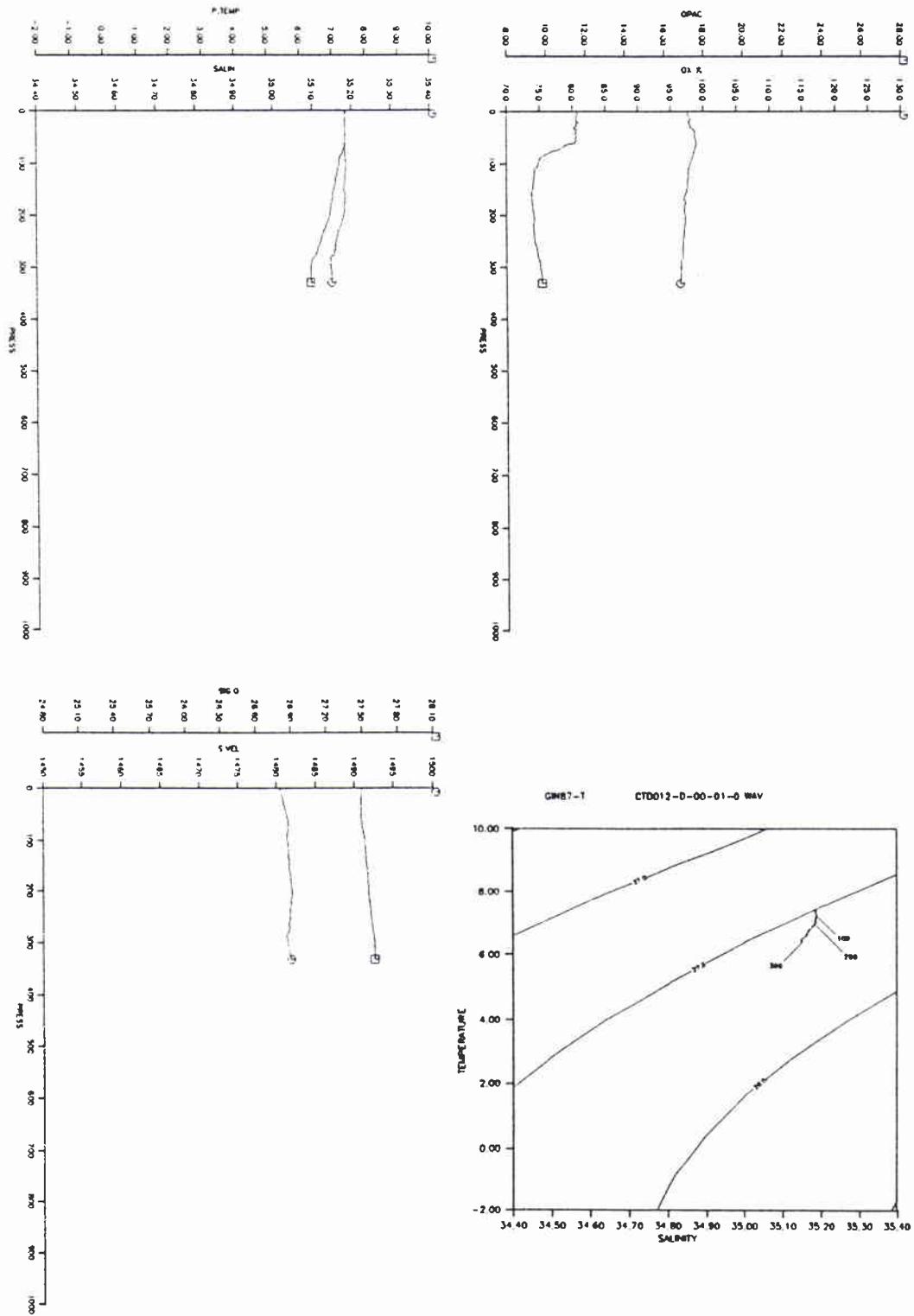


Figure B11

SACLANTCEN SM-249

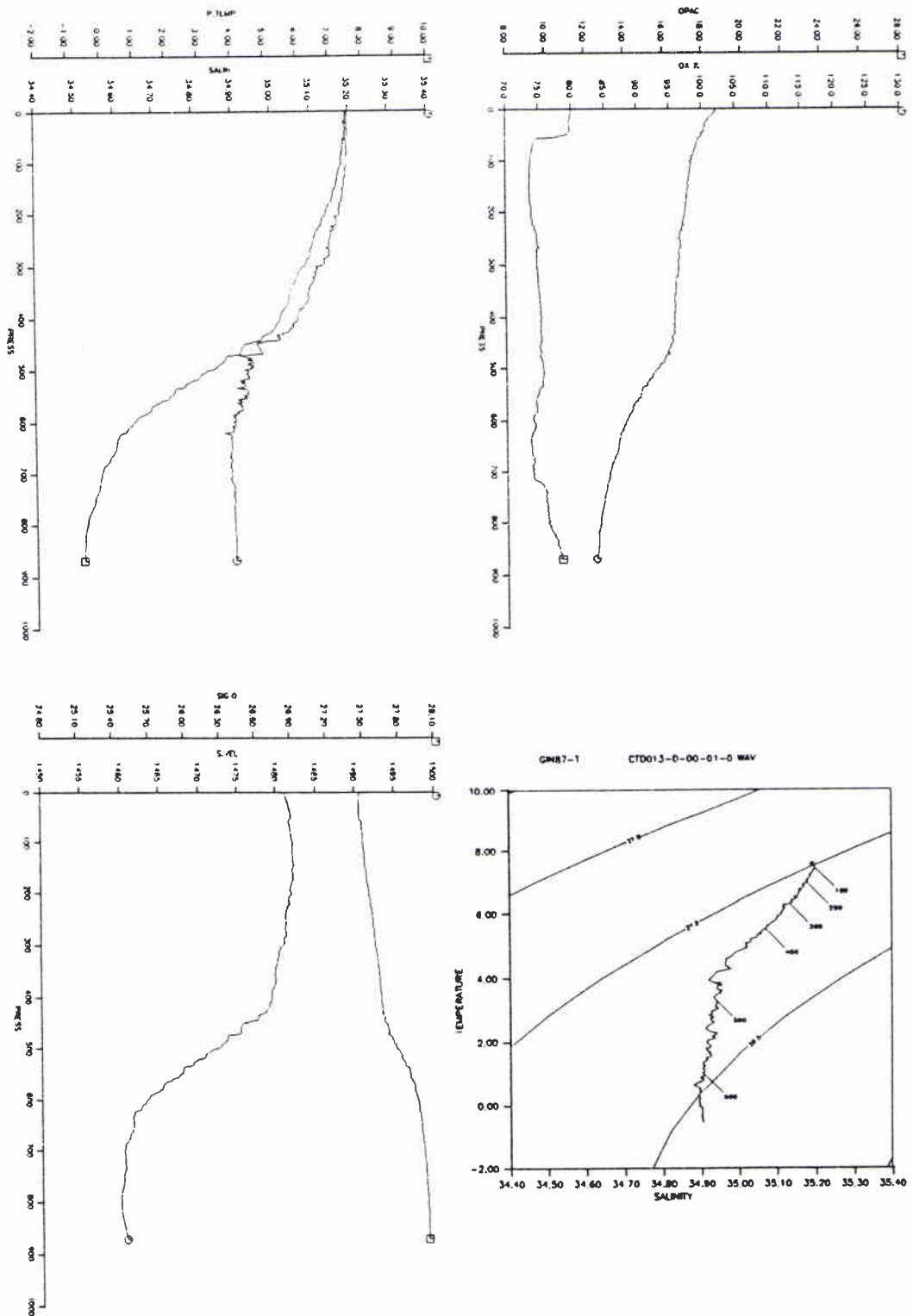


Figure B12

SACLANTCEN SM-249

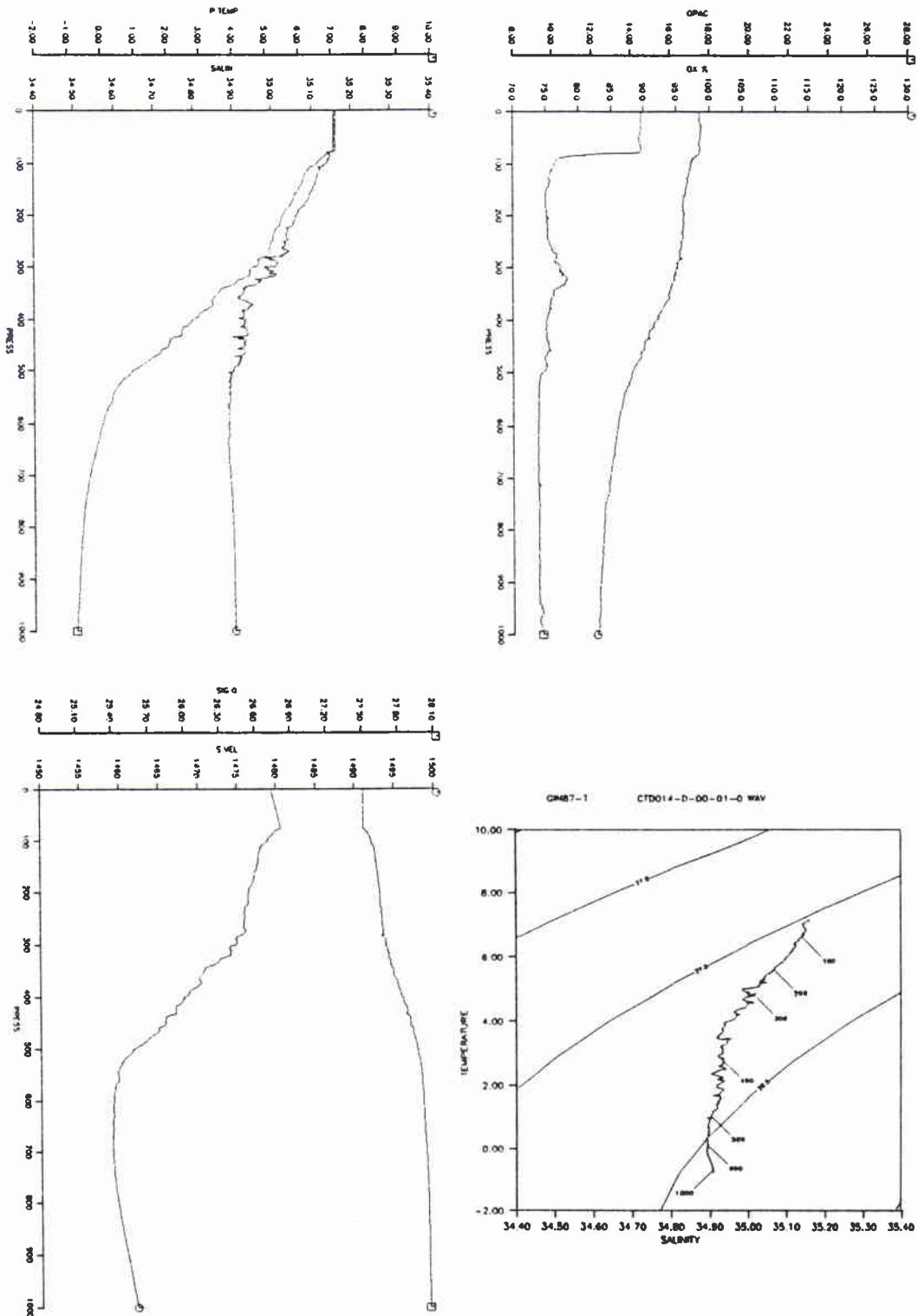


Figure B13

SACLANTCEN SM-249

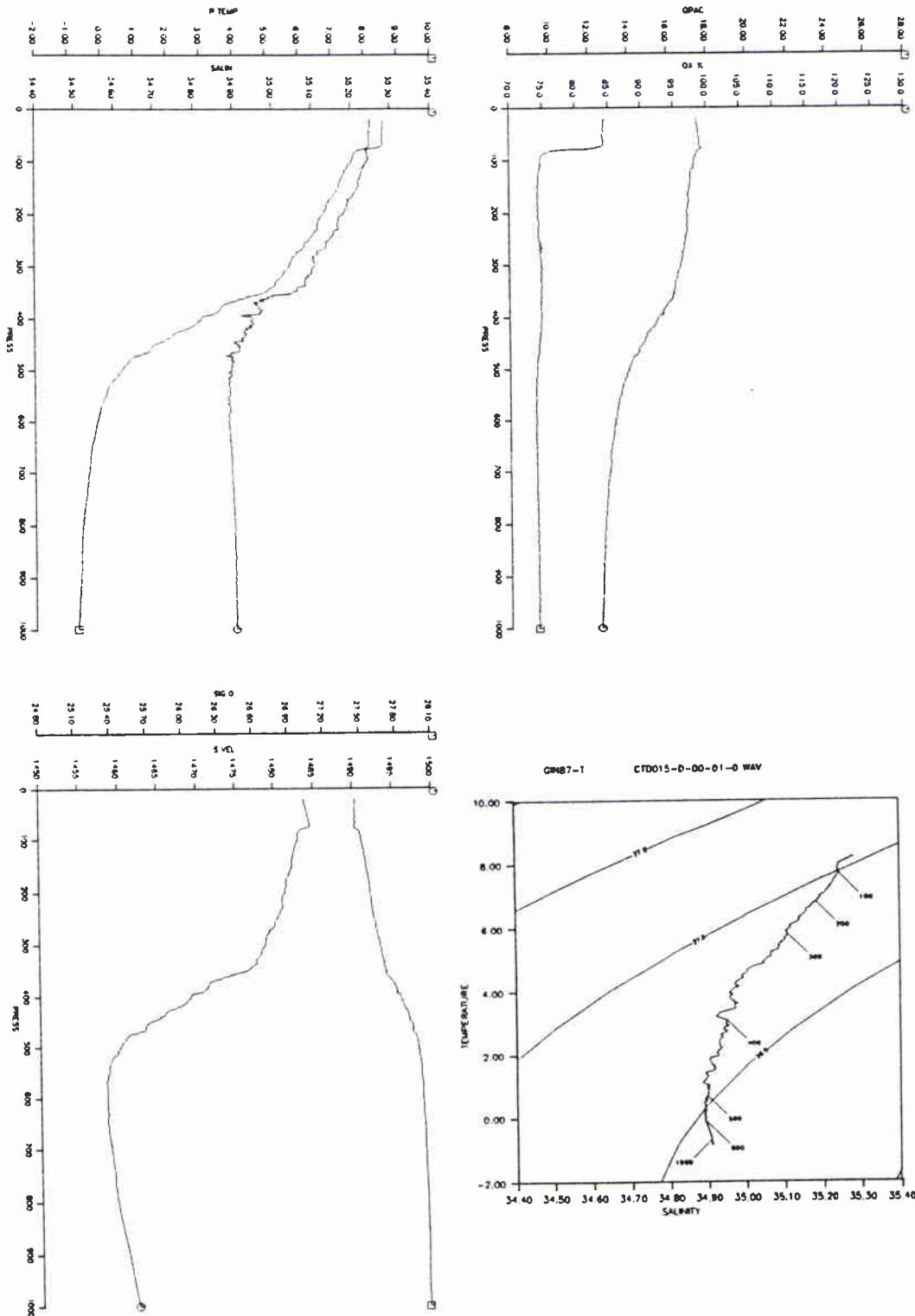


Figure B14

SACLANTCEN SM-249

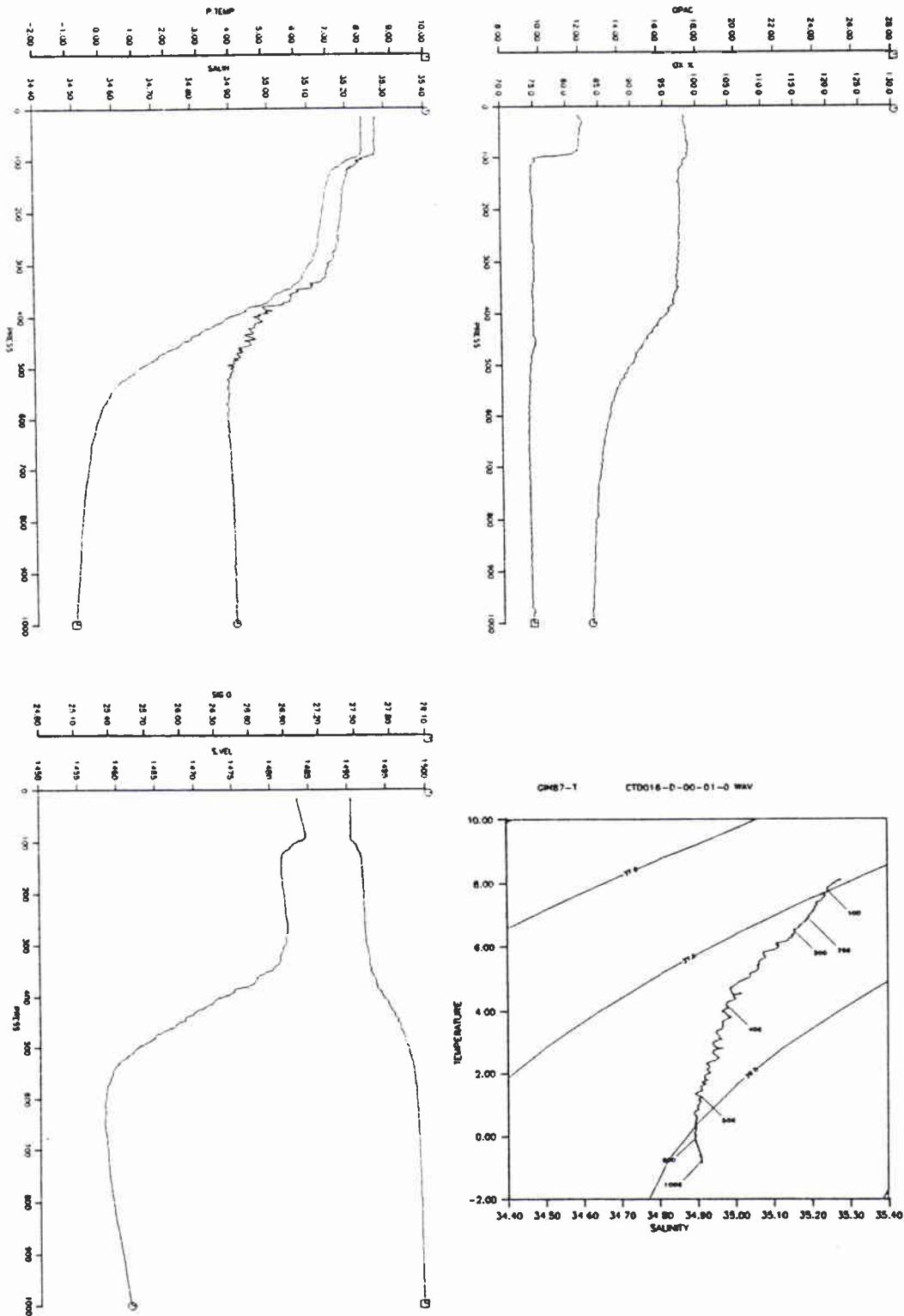


Figure B15

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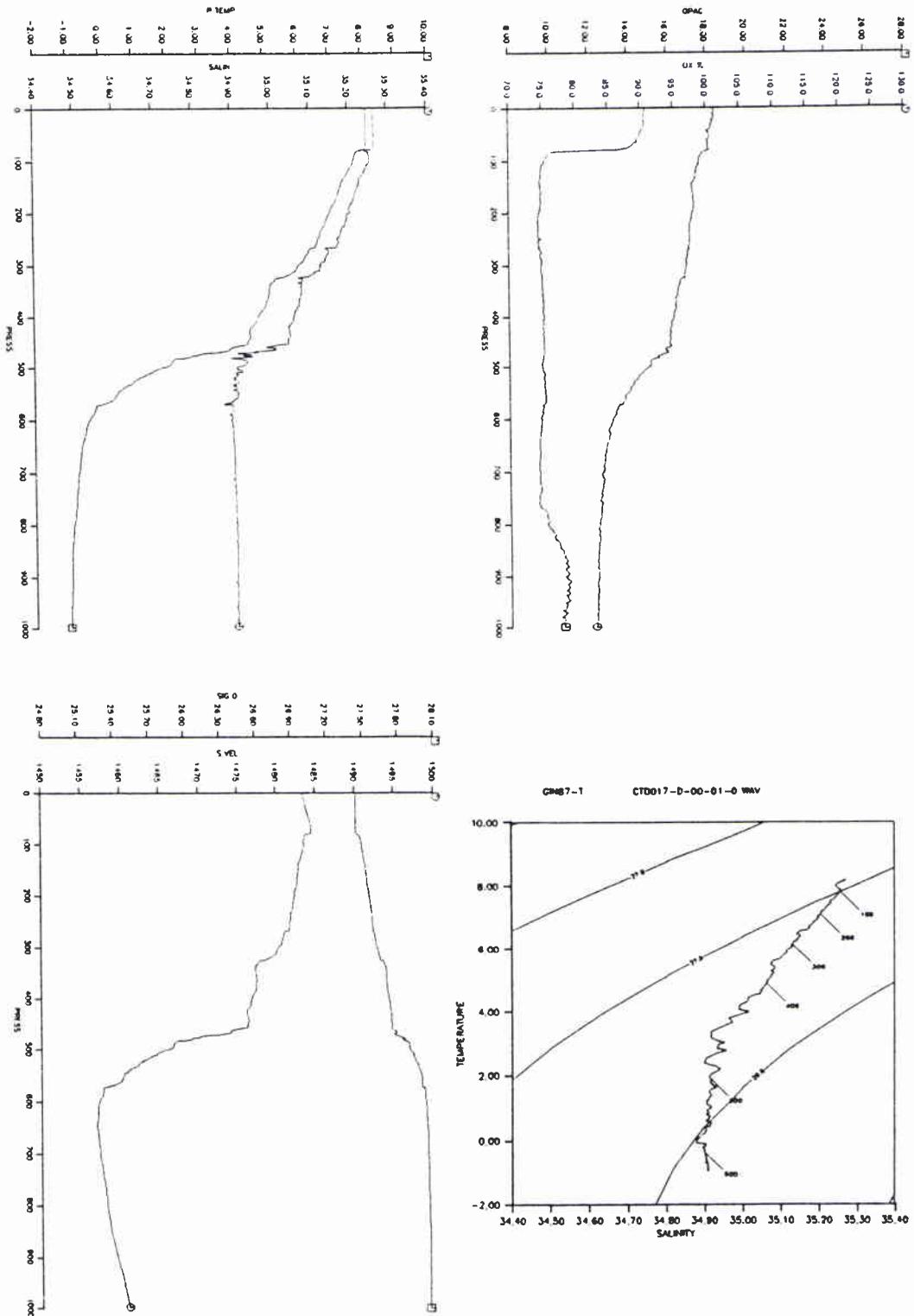


Figure B16

SACLANTCEN SM-249

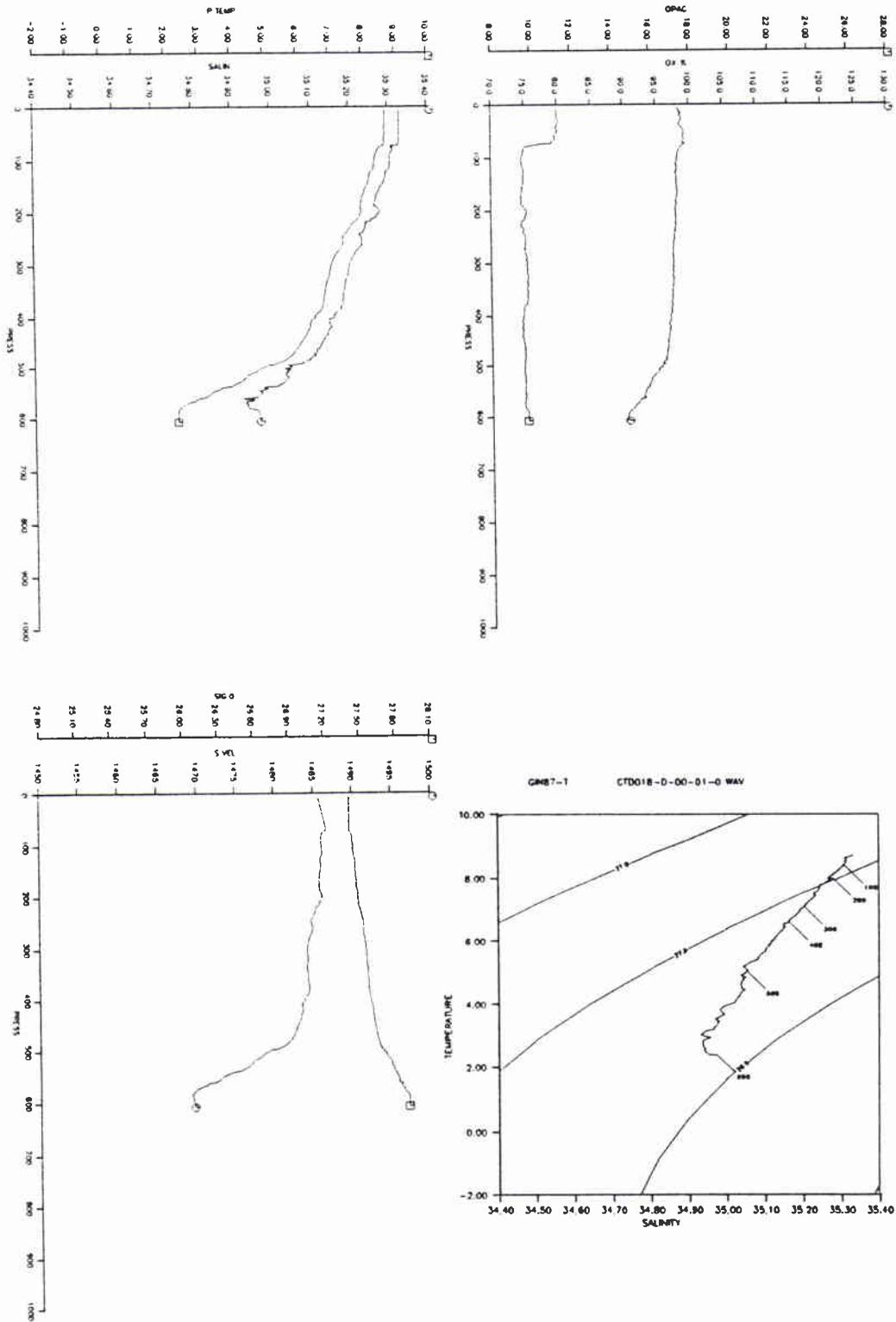


Figure B17

SACLANTCEN SM-249

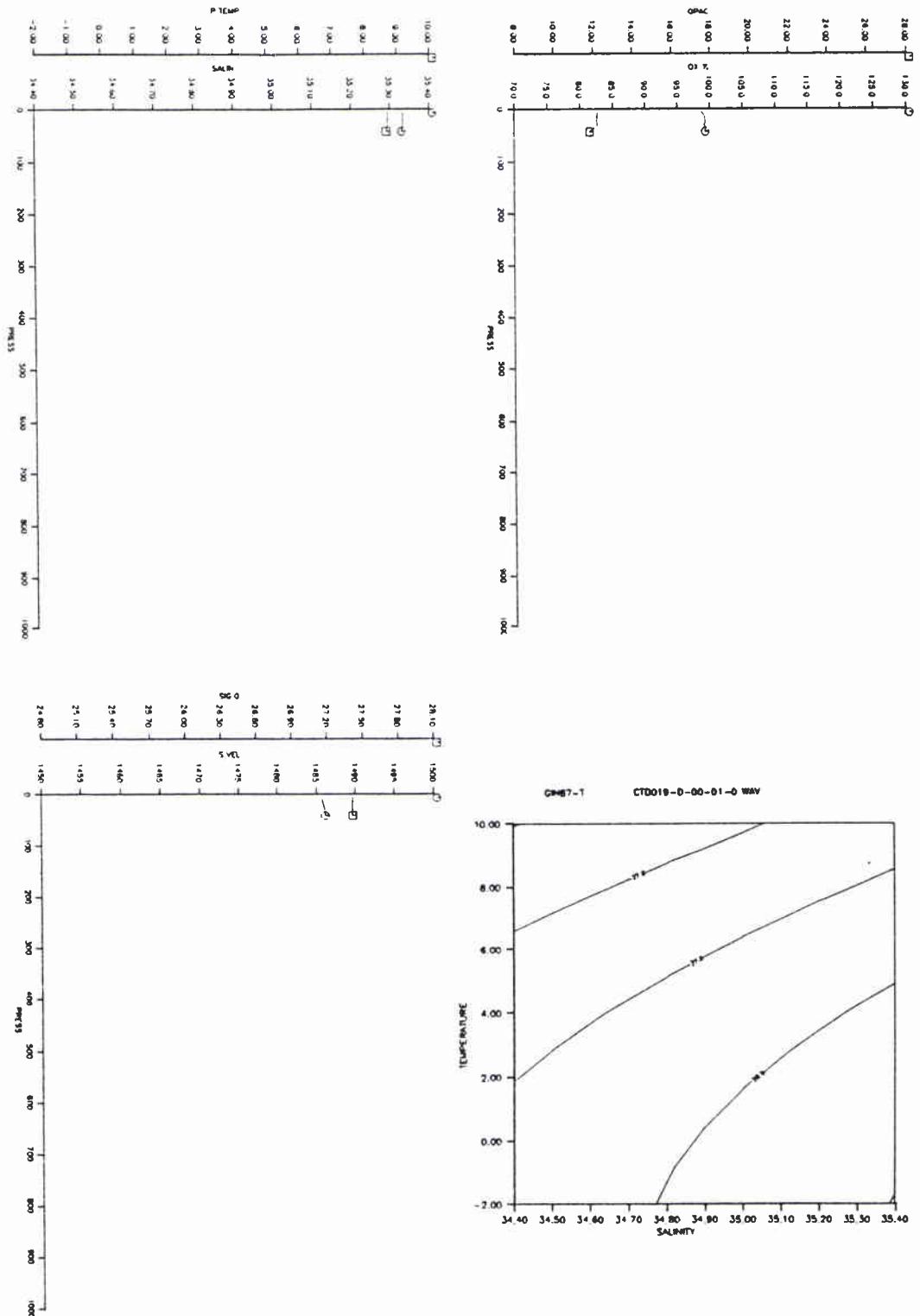


Figure B18

SACLANTCEN SM-249

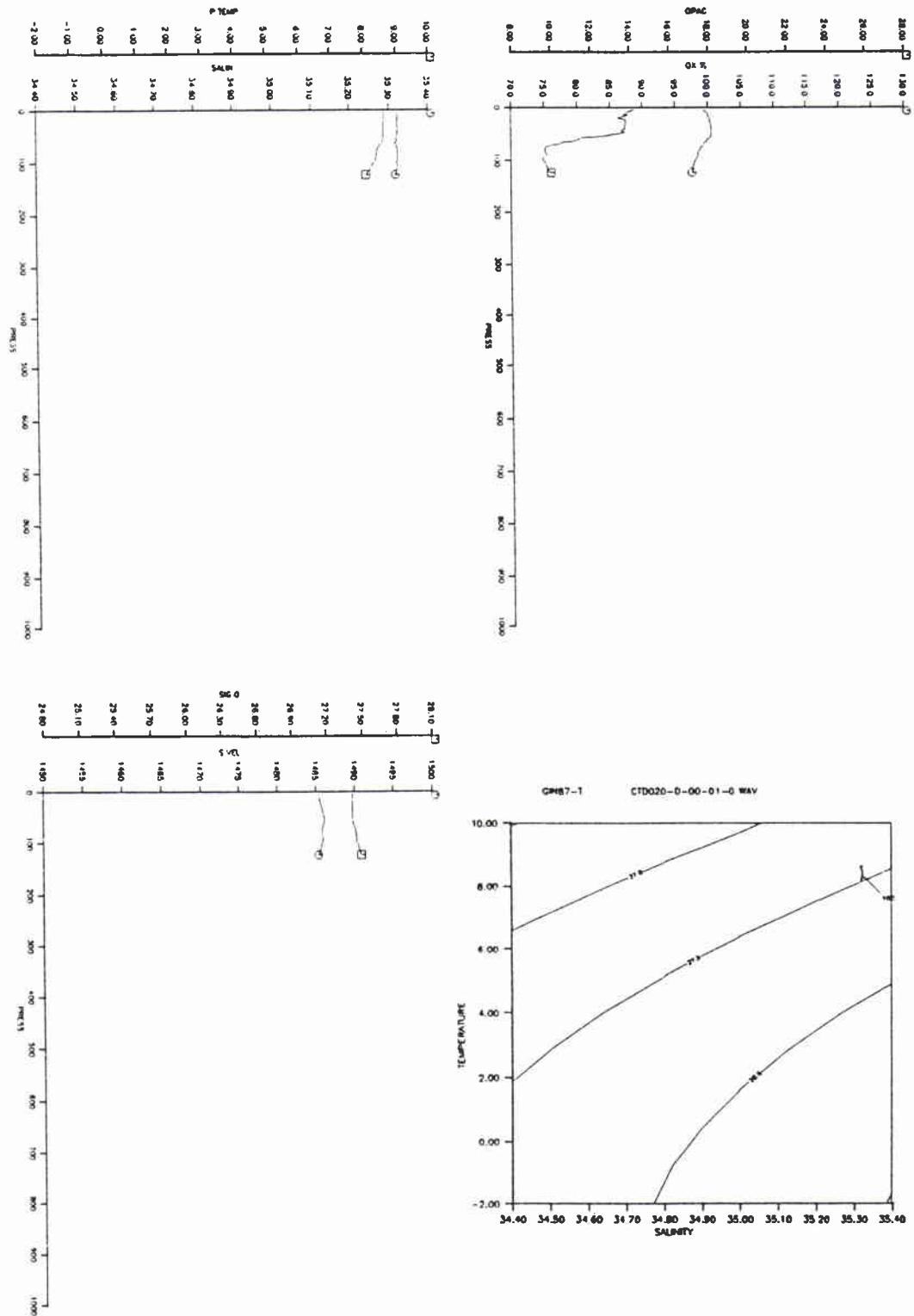
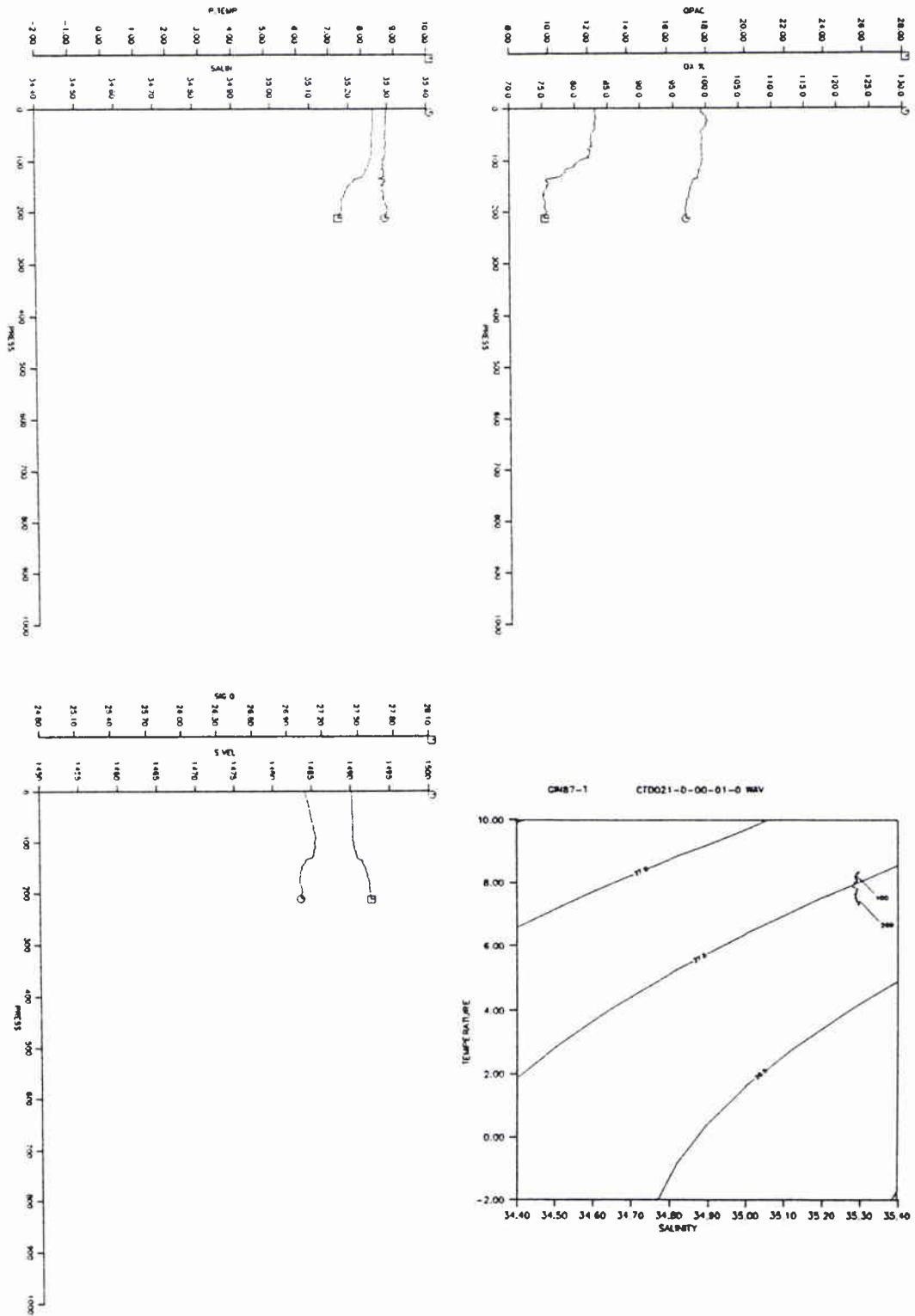


Figure B19

SACLANTCEN SM-249



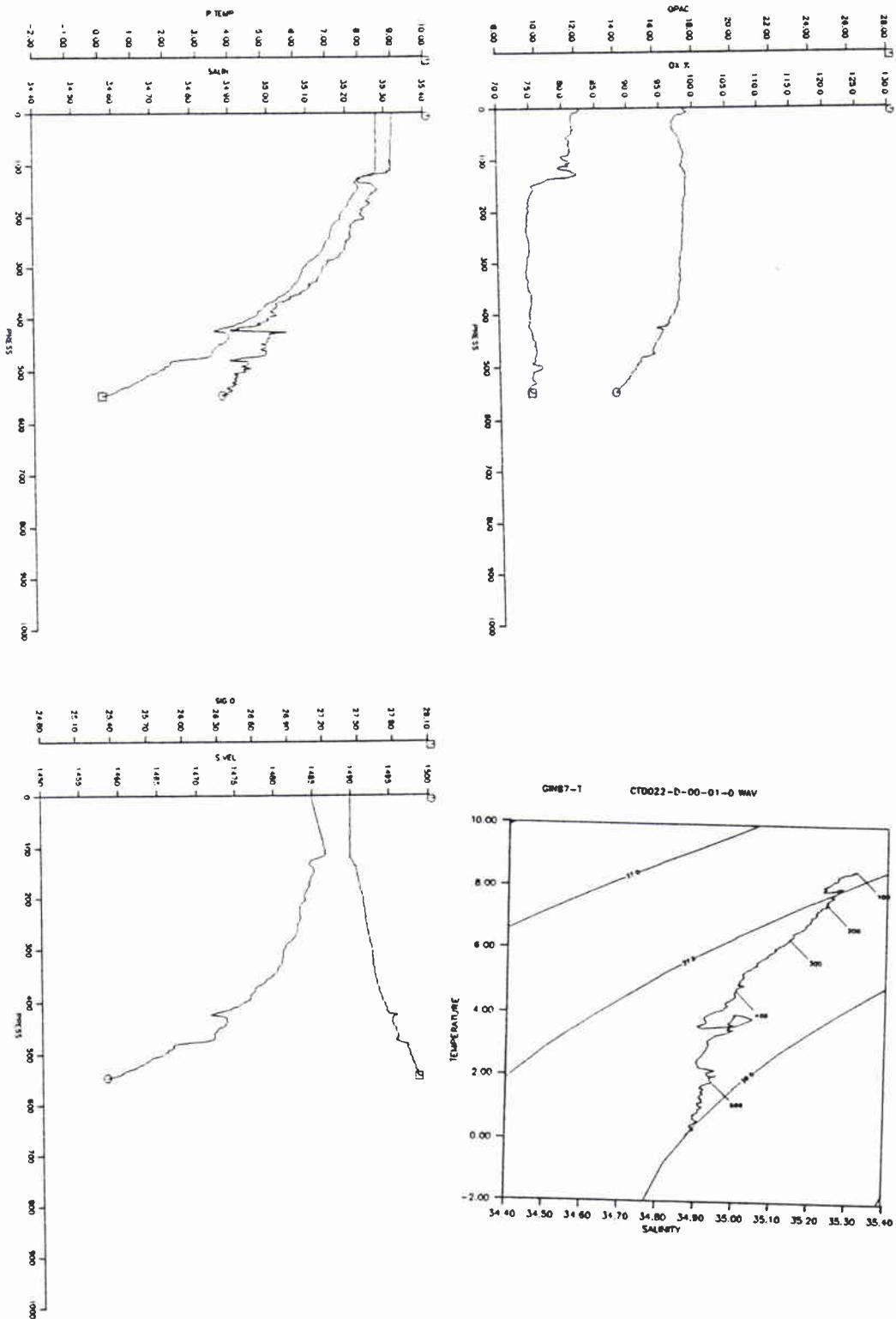


Figure B21

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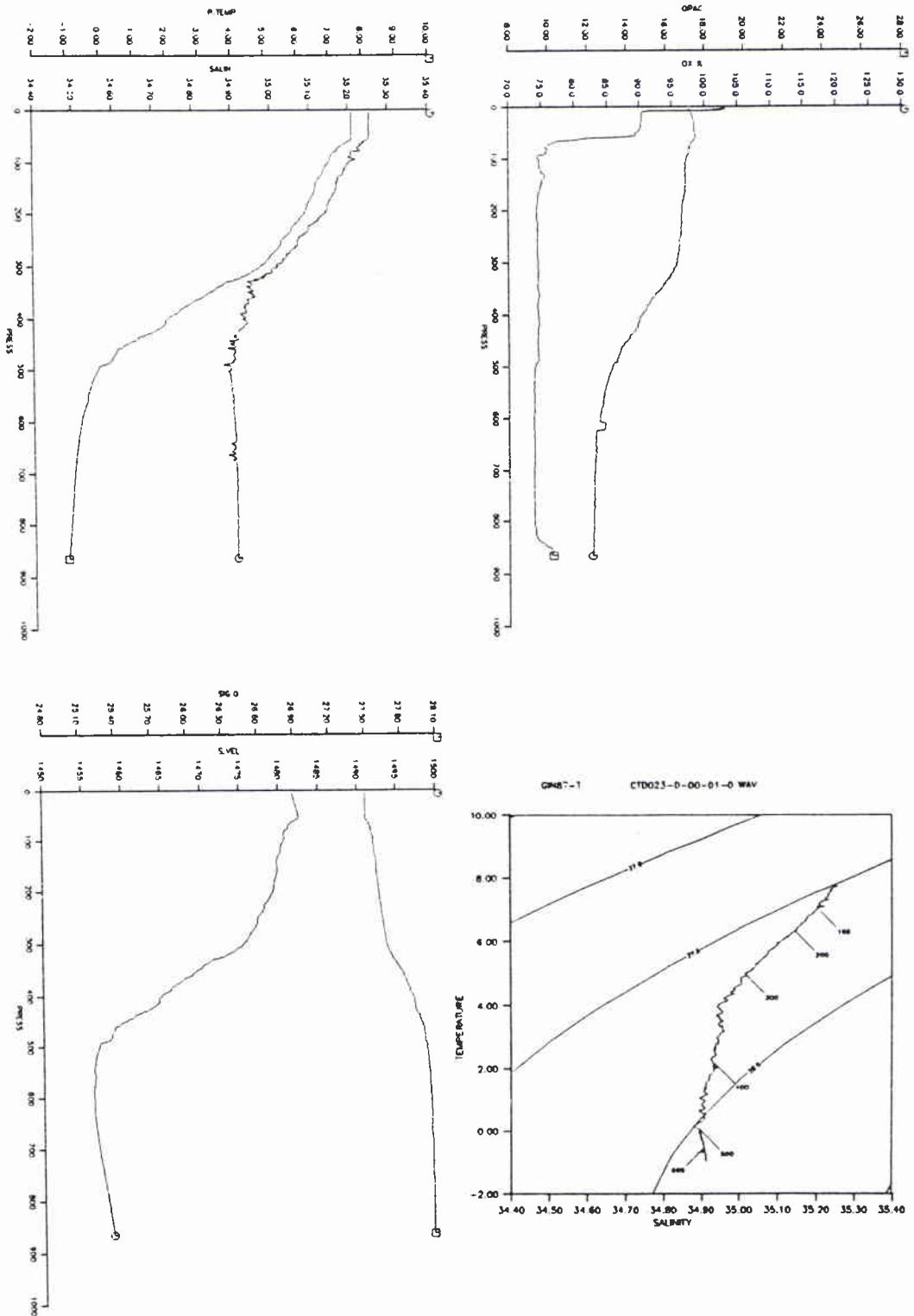


Figure B22

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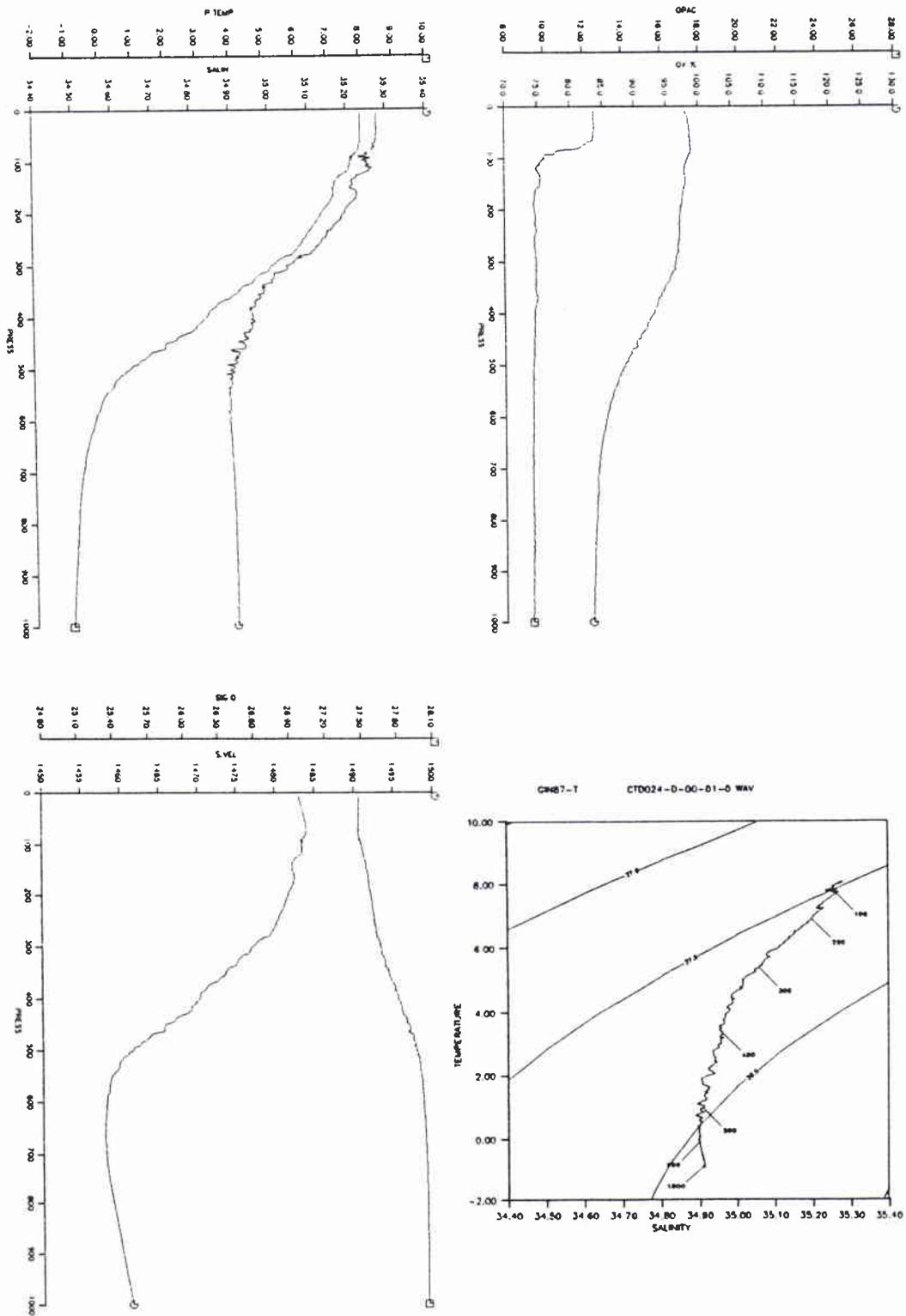


Figure B23

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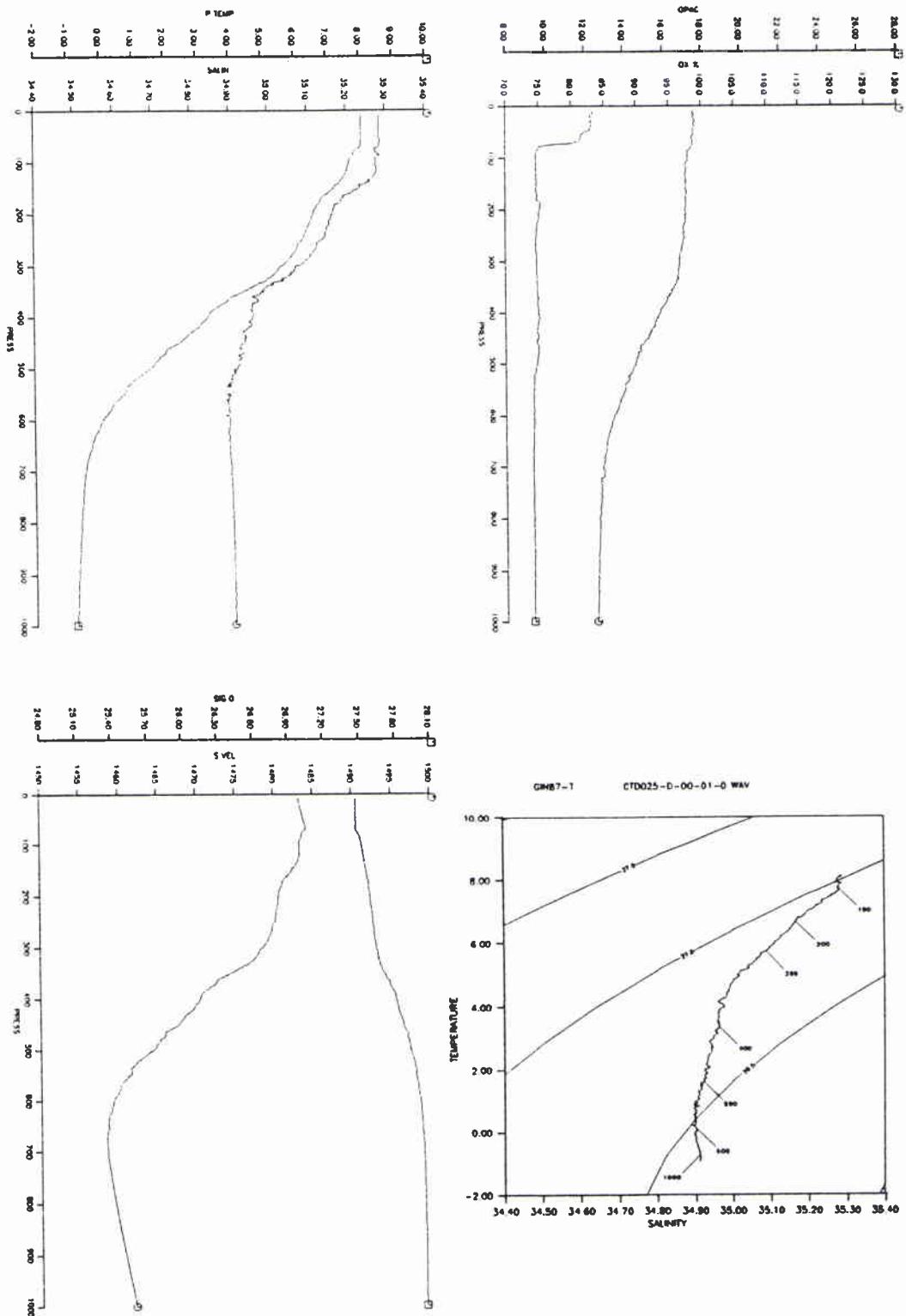


Figure B24

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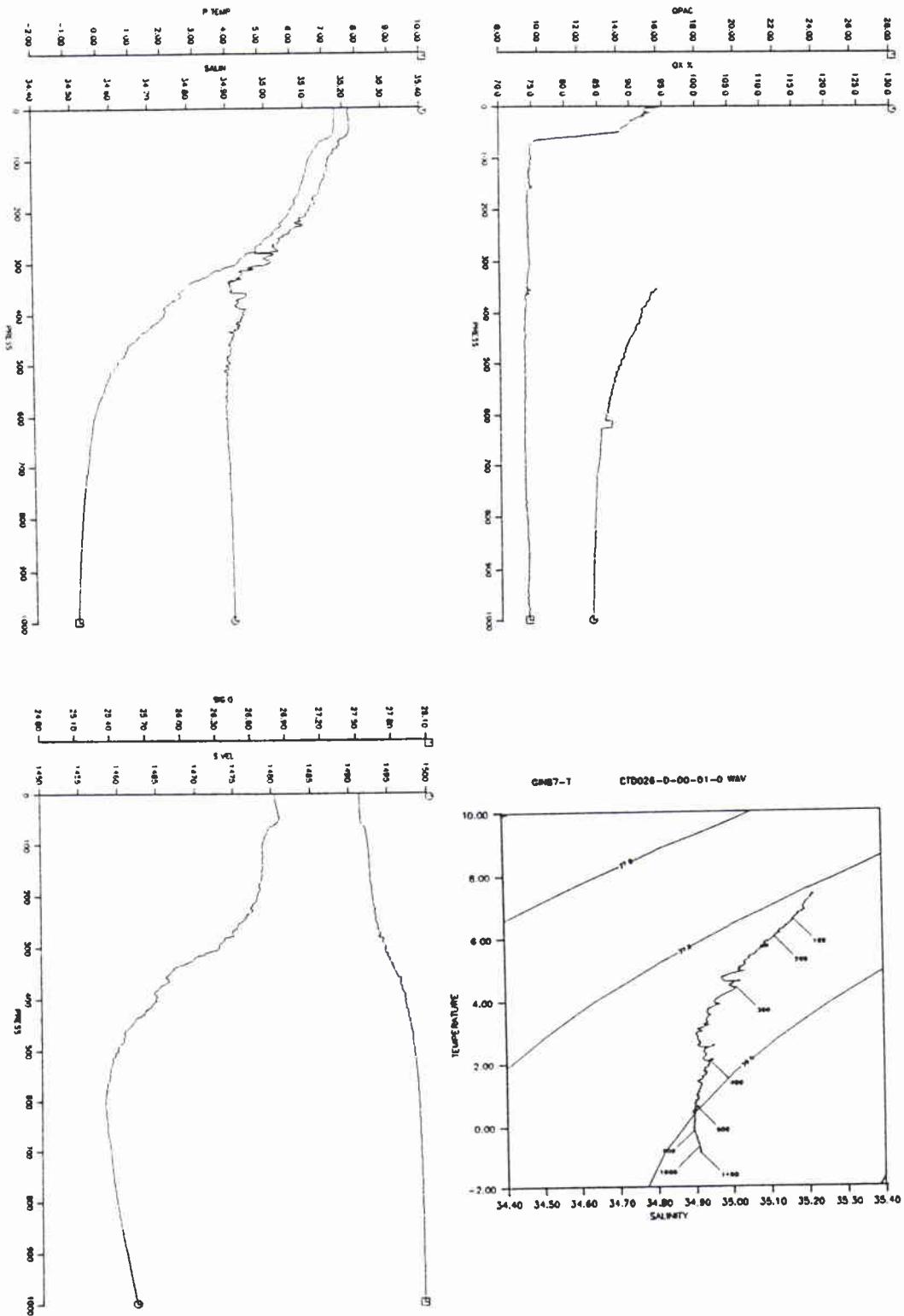


Figure B25

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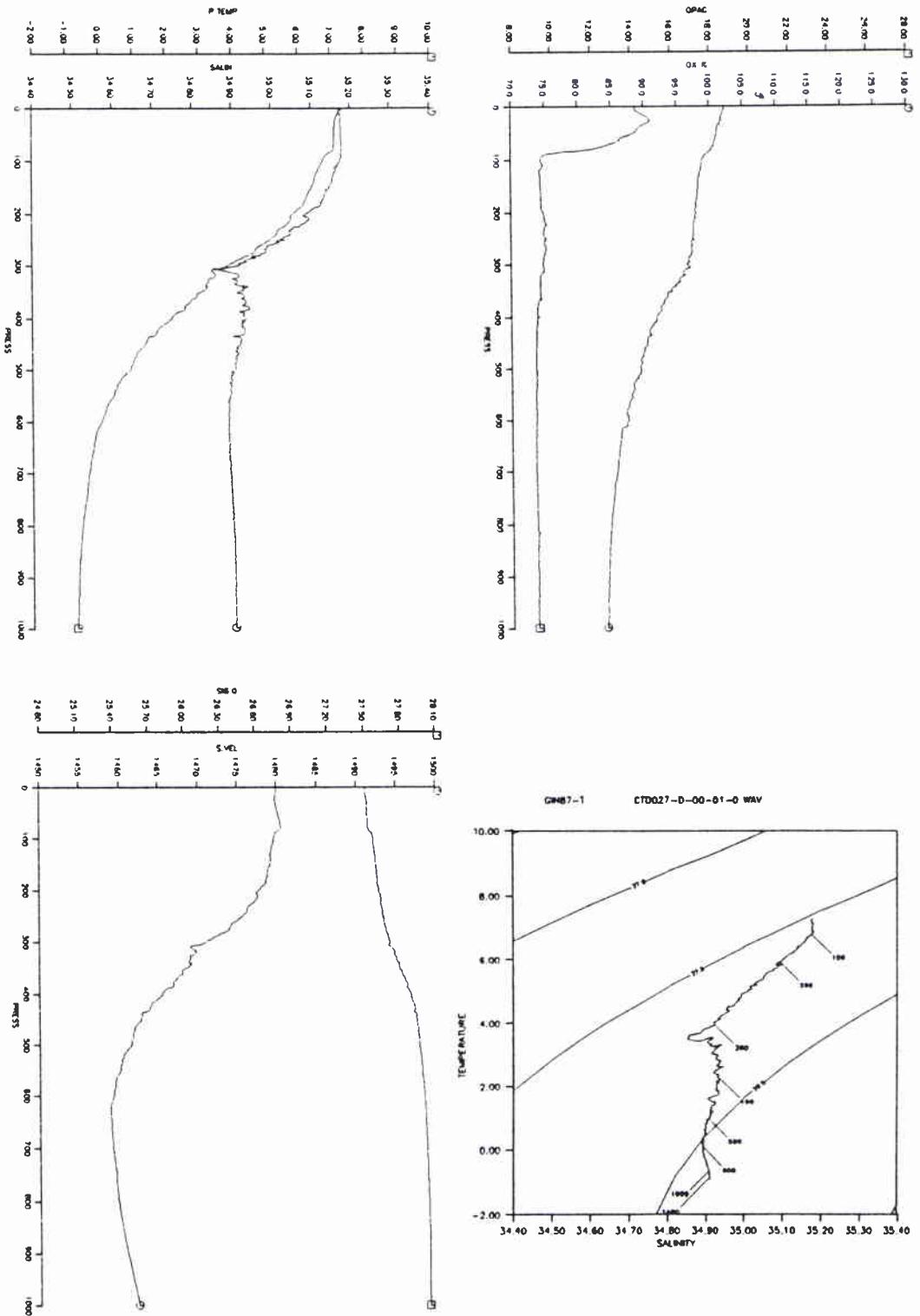


Figure B26

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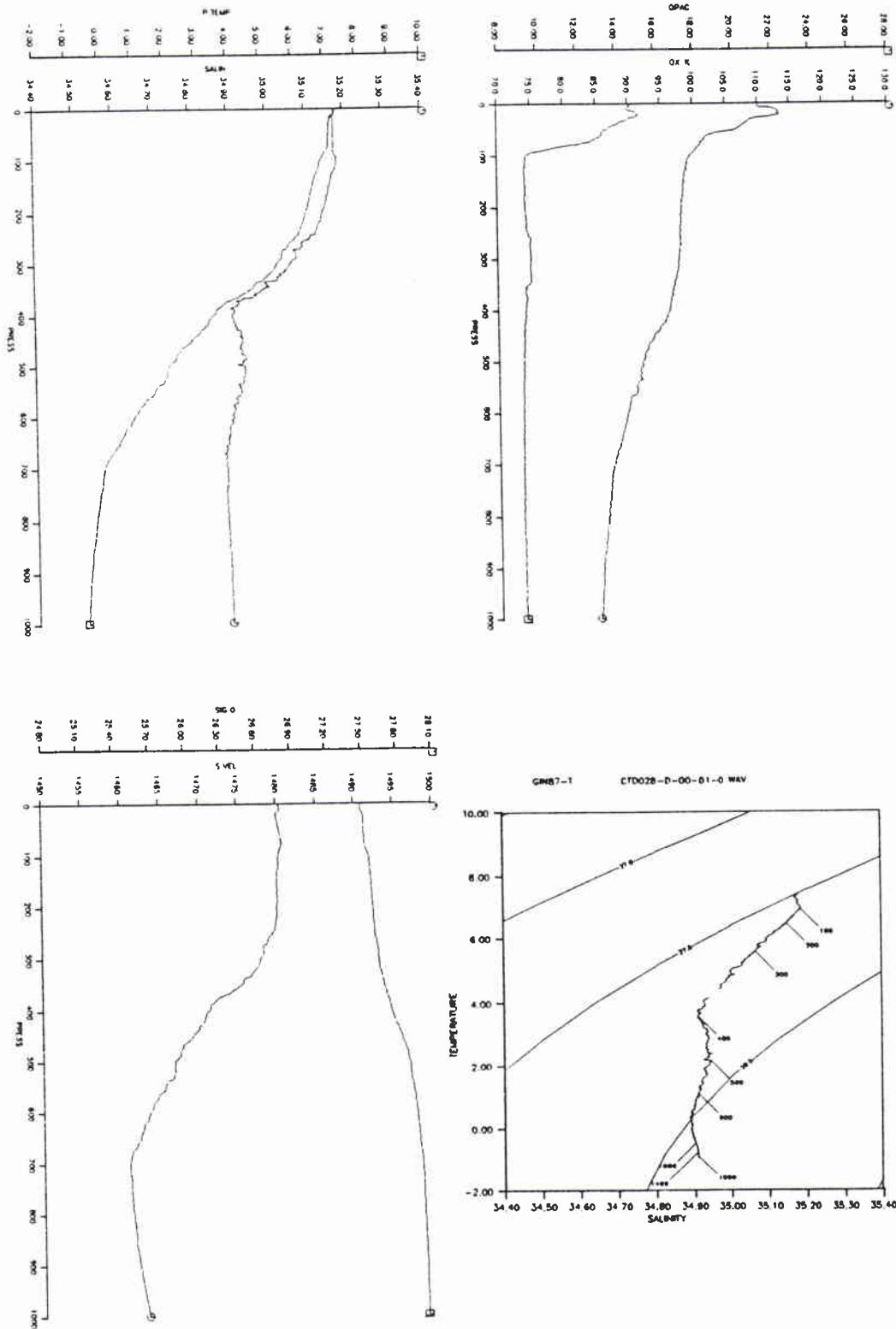


Figure B27

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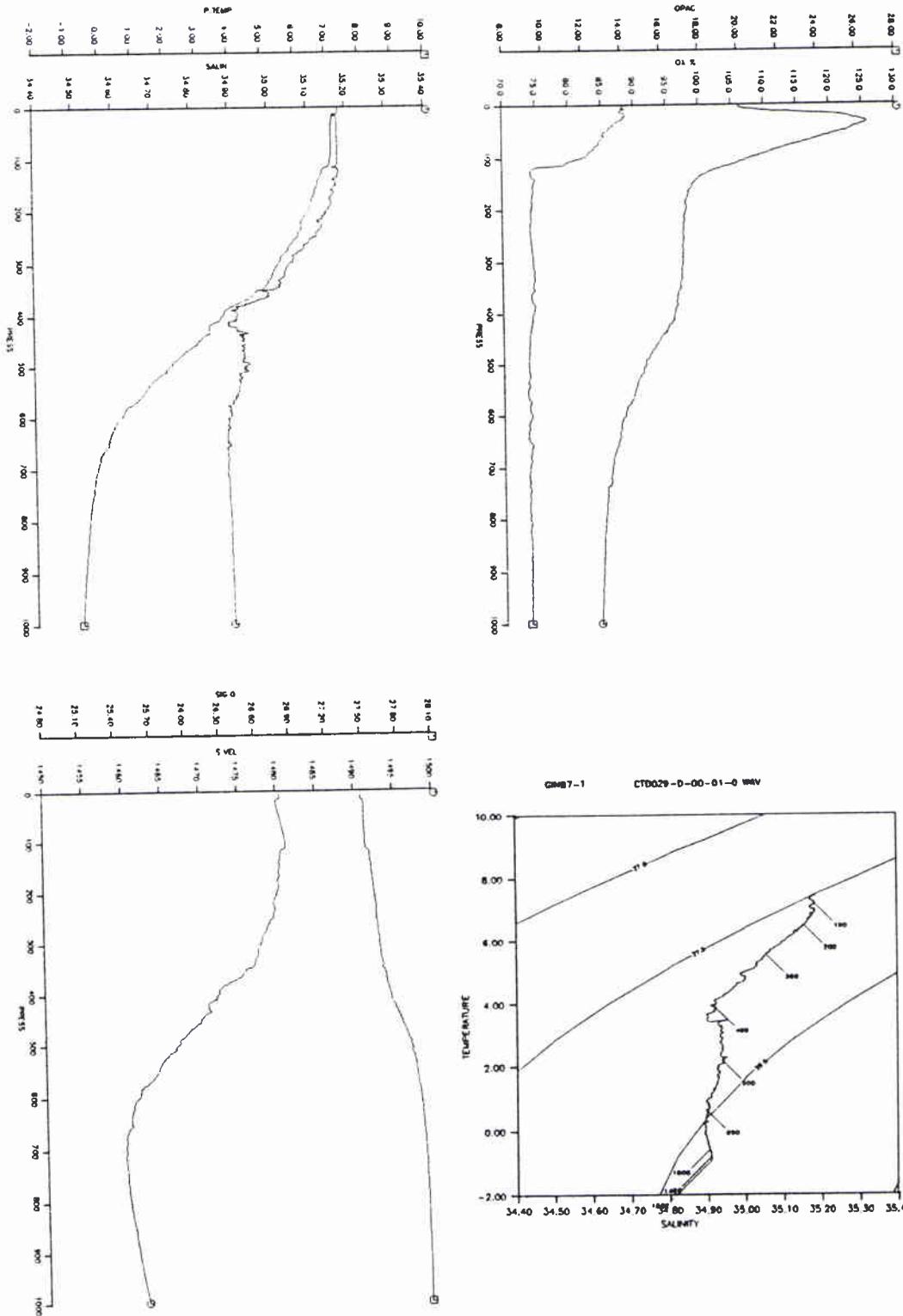


Figure B28

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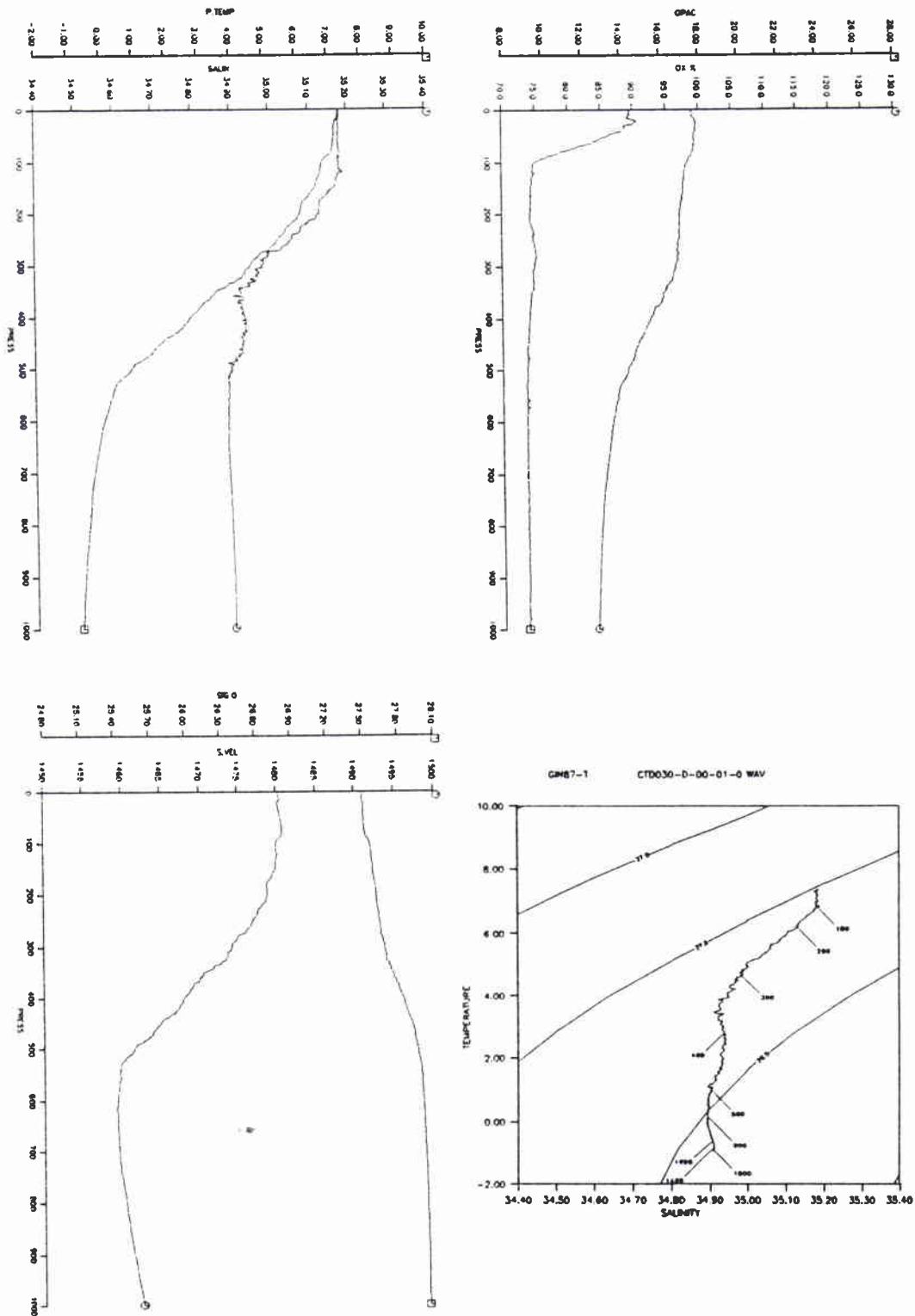


Figure B29

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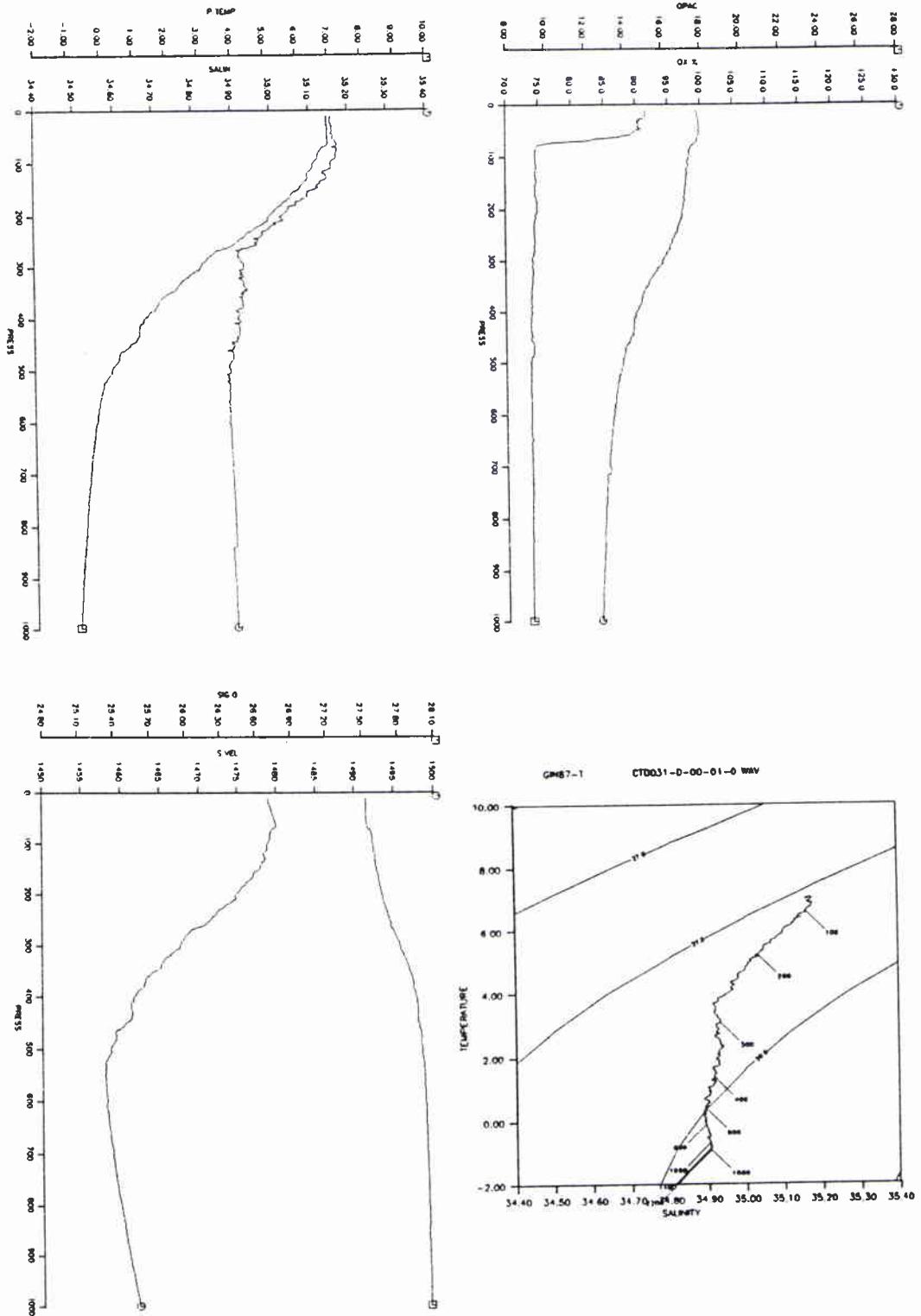


Figure B30

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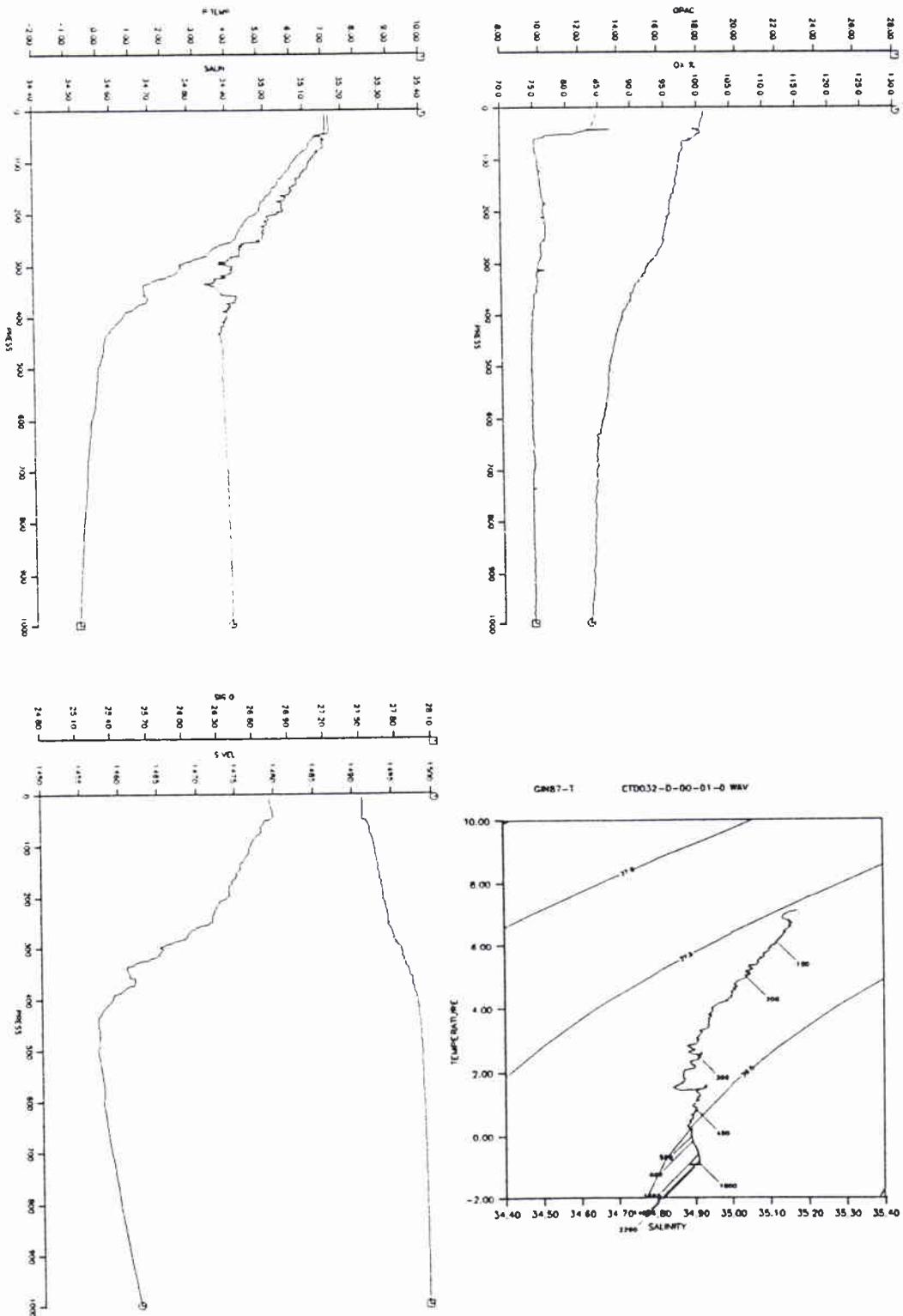


Figure B31

SACLANTCEN SM-249

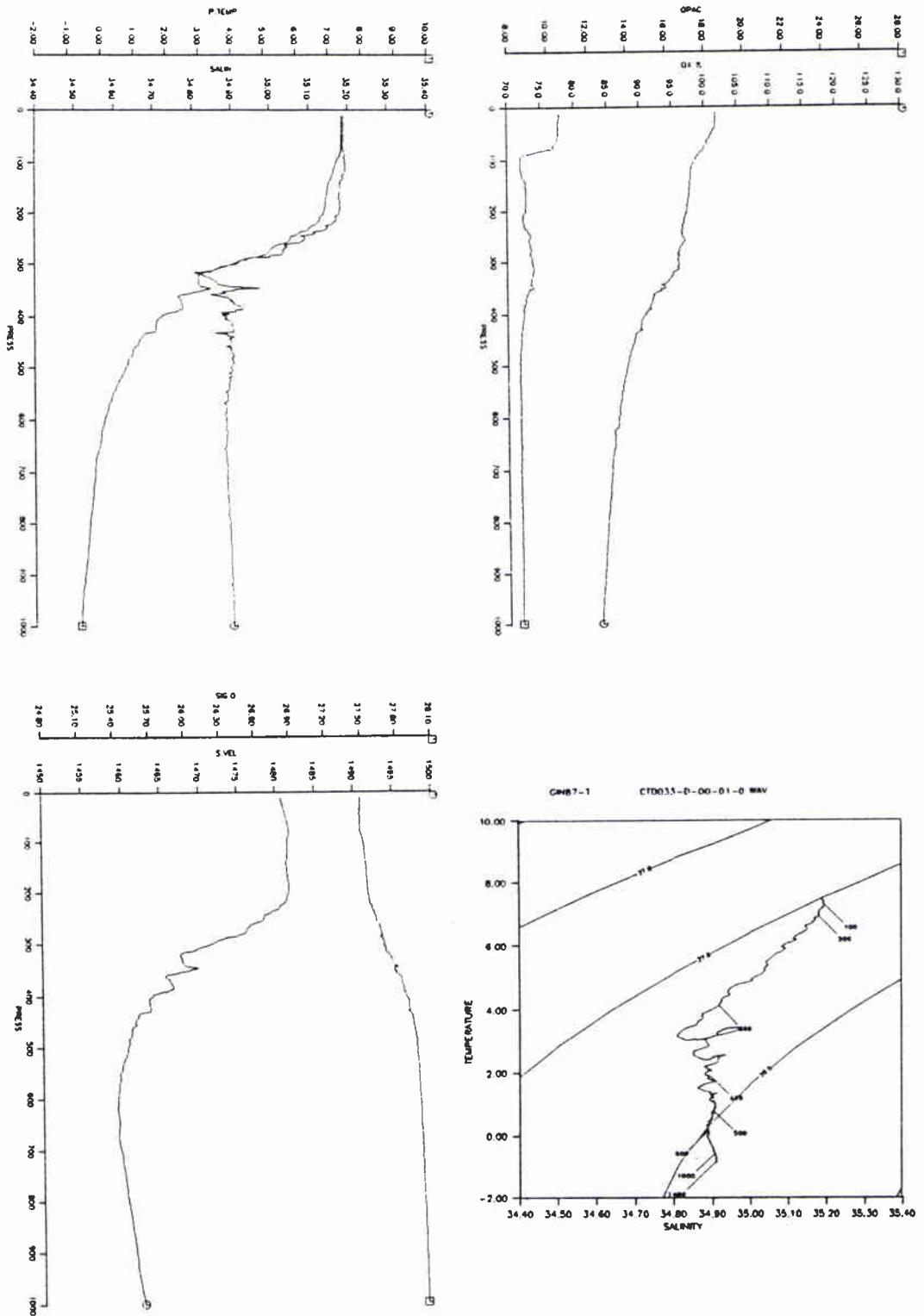


Figure B32

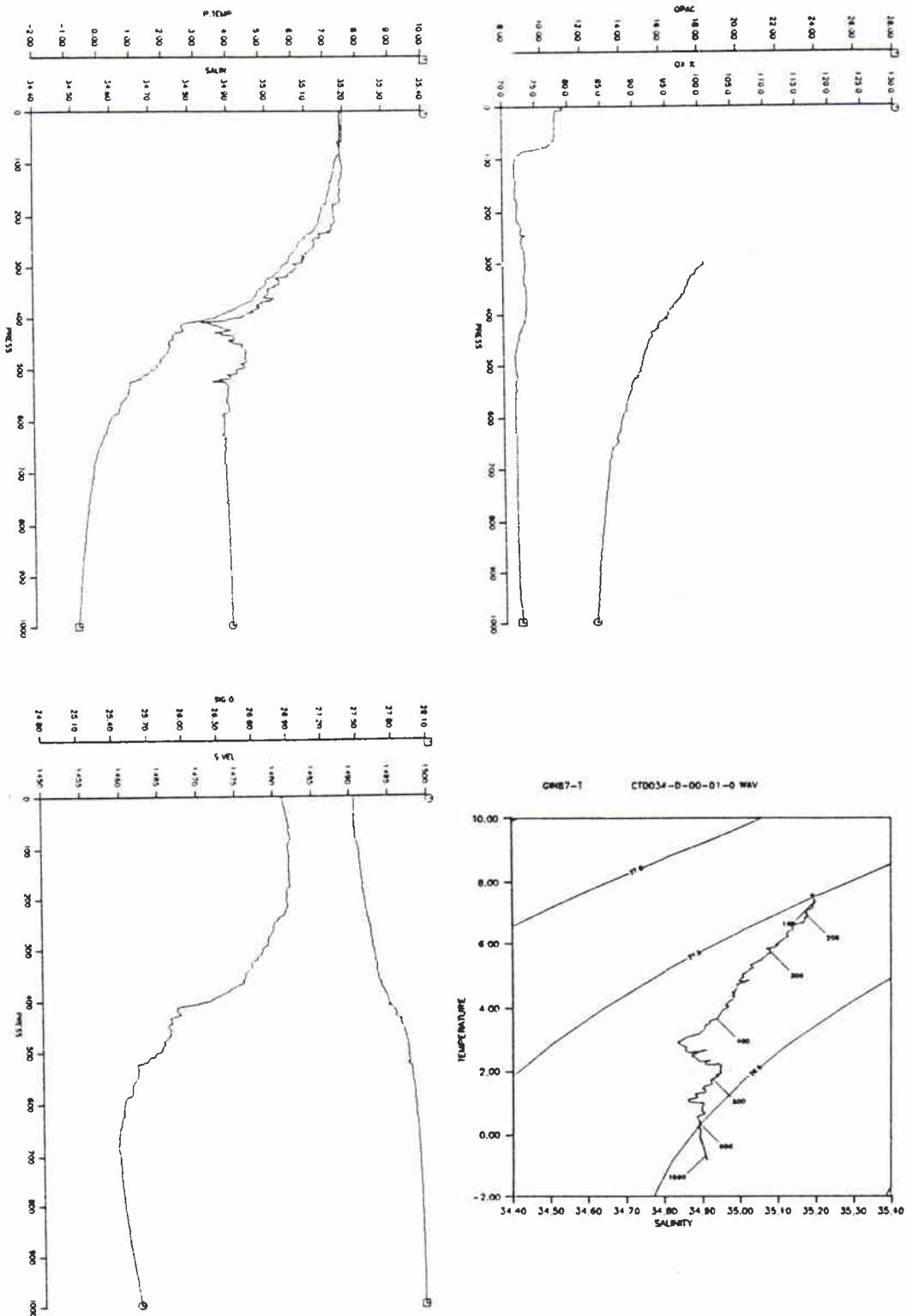


Figure B33

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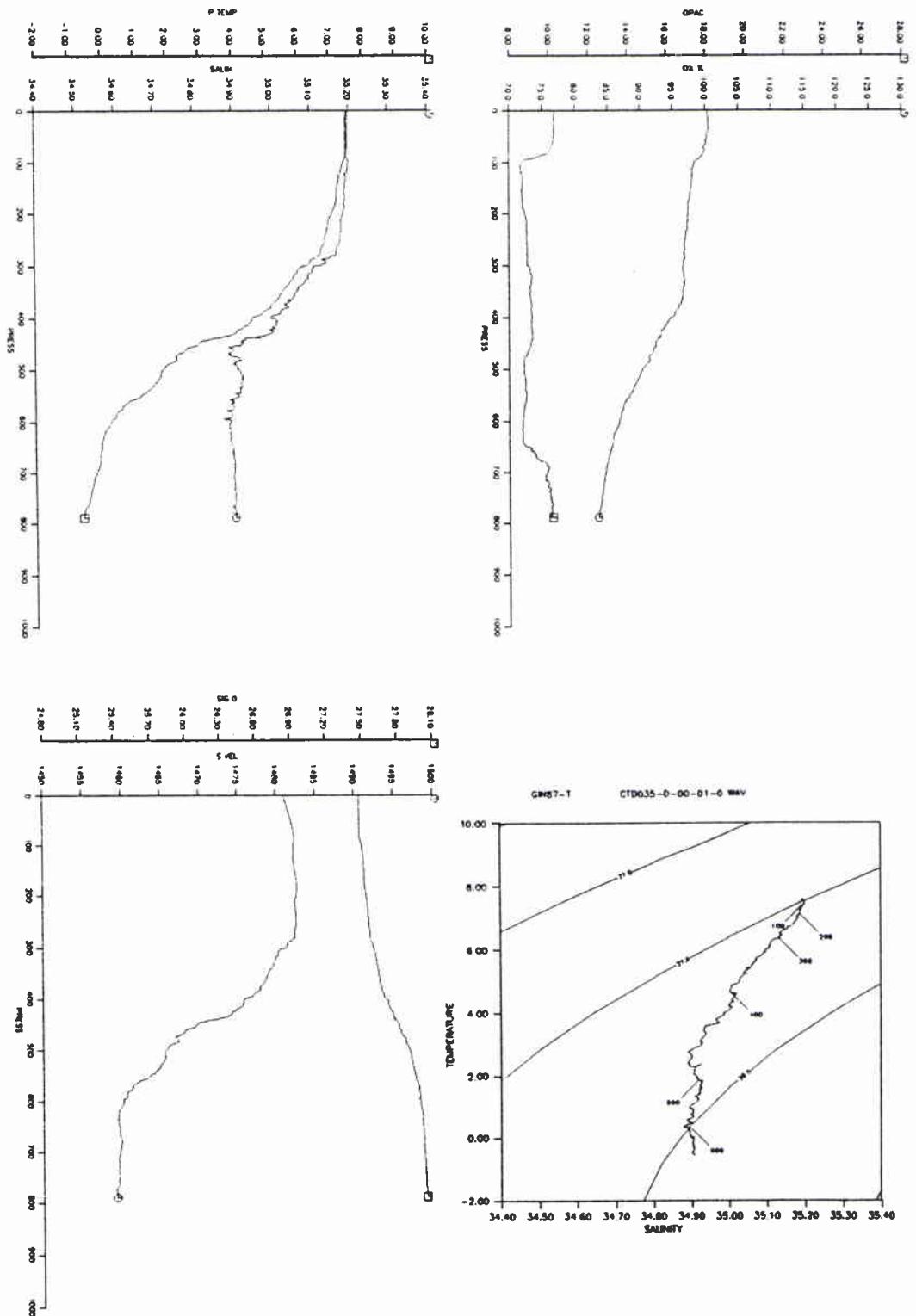


Figure B34

SACLANTCEN SM-249

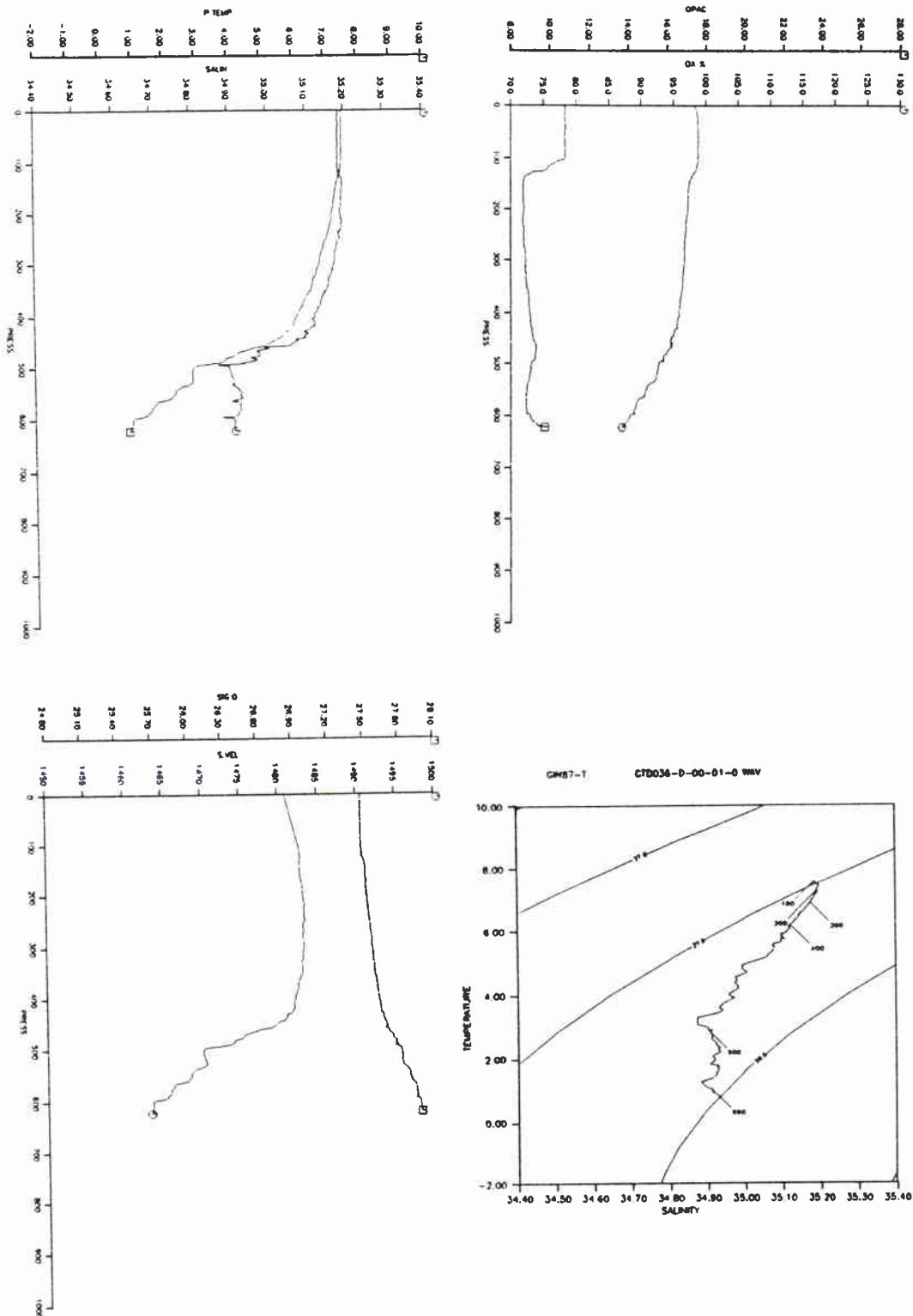


Figure B35

SACLANTCEN SM-249

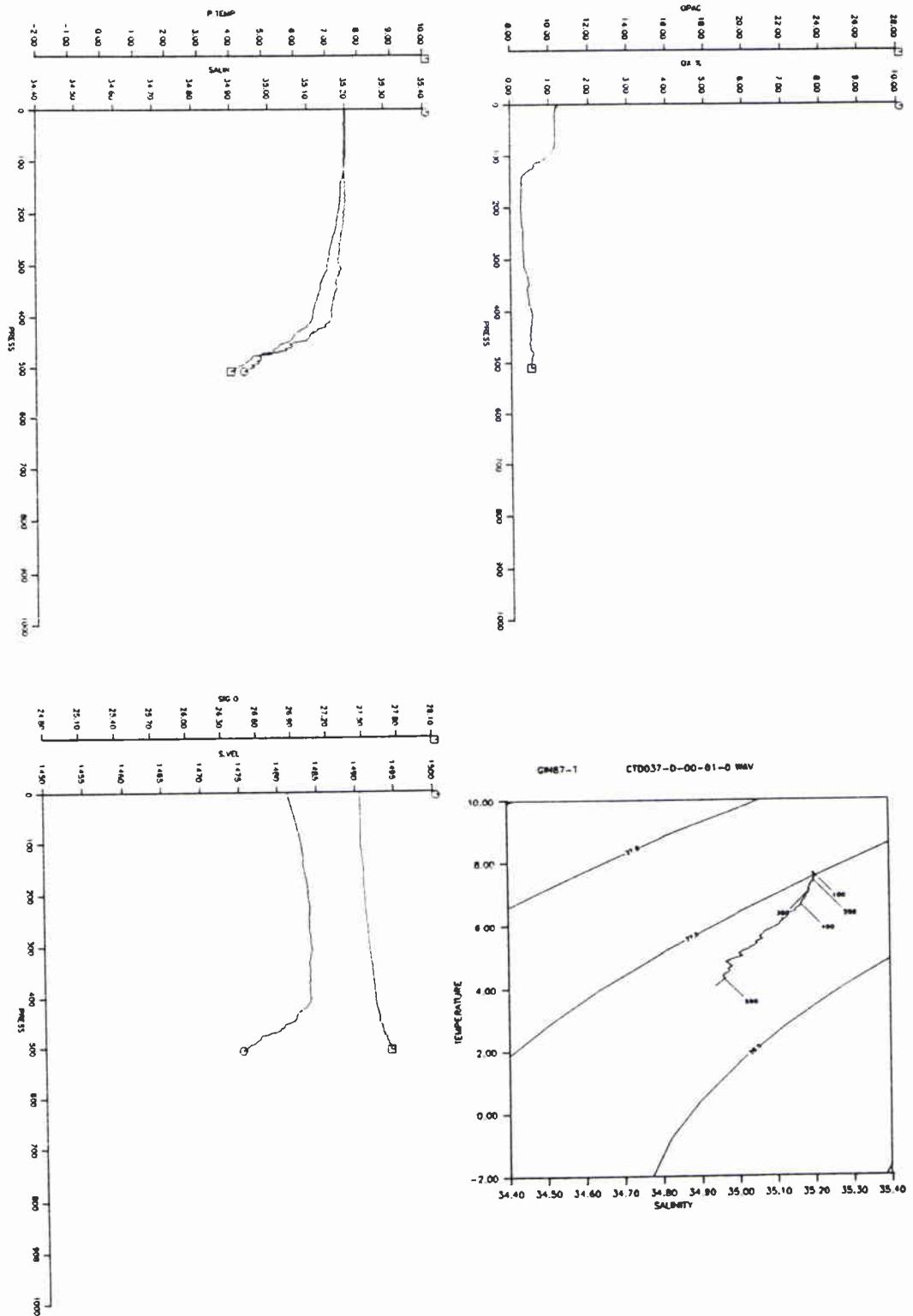


Figure B36

SACLANTCEN SM-249

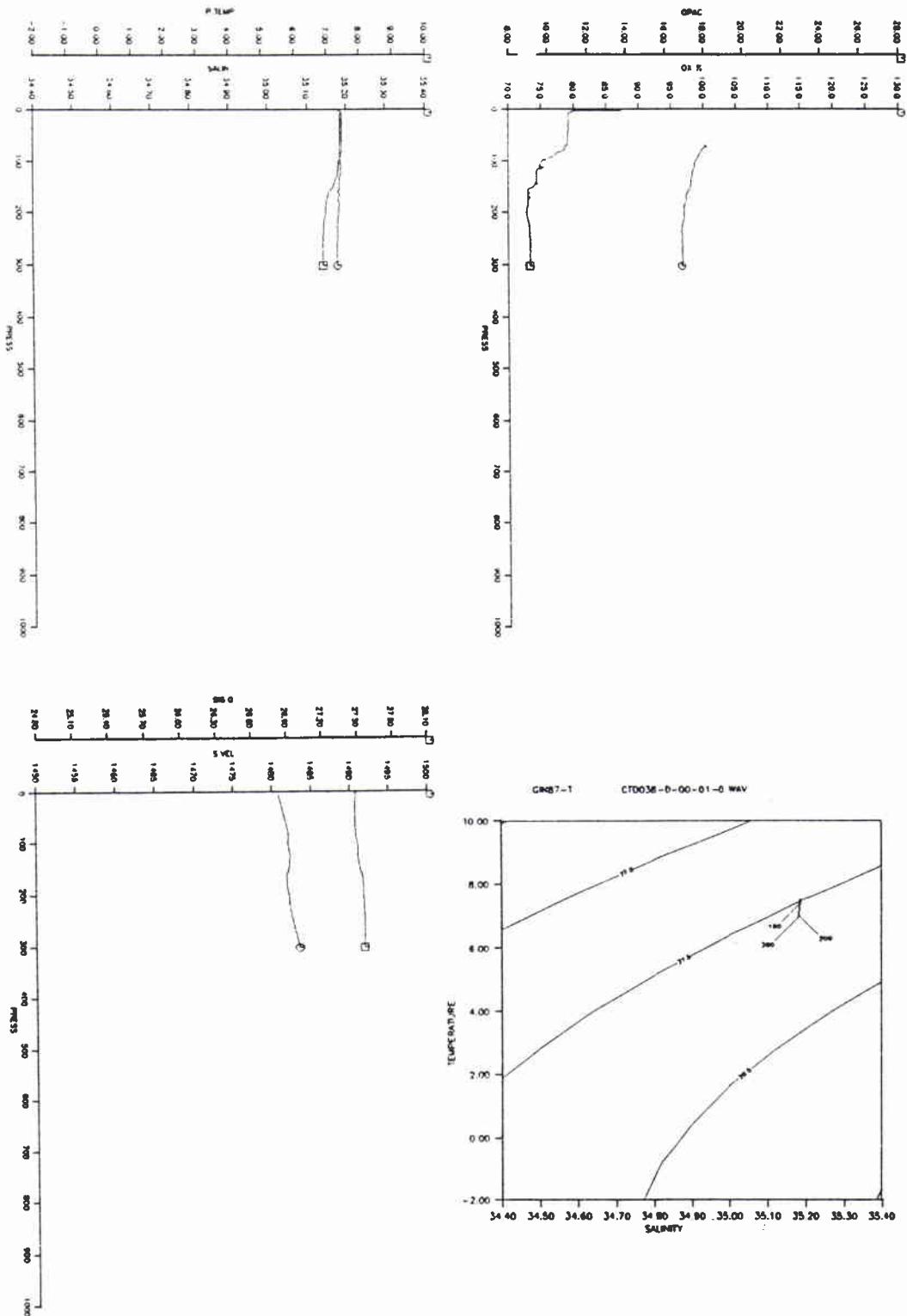


Figure B37

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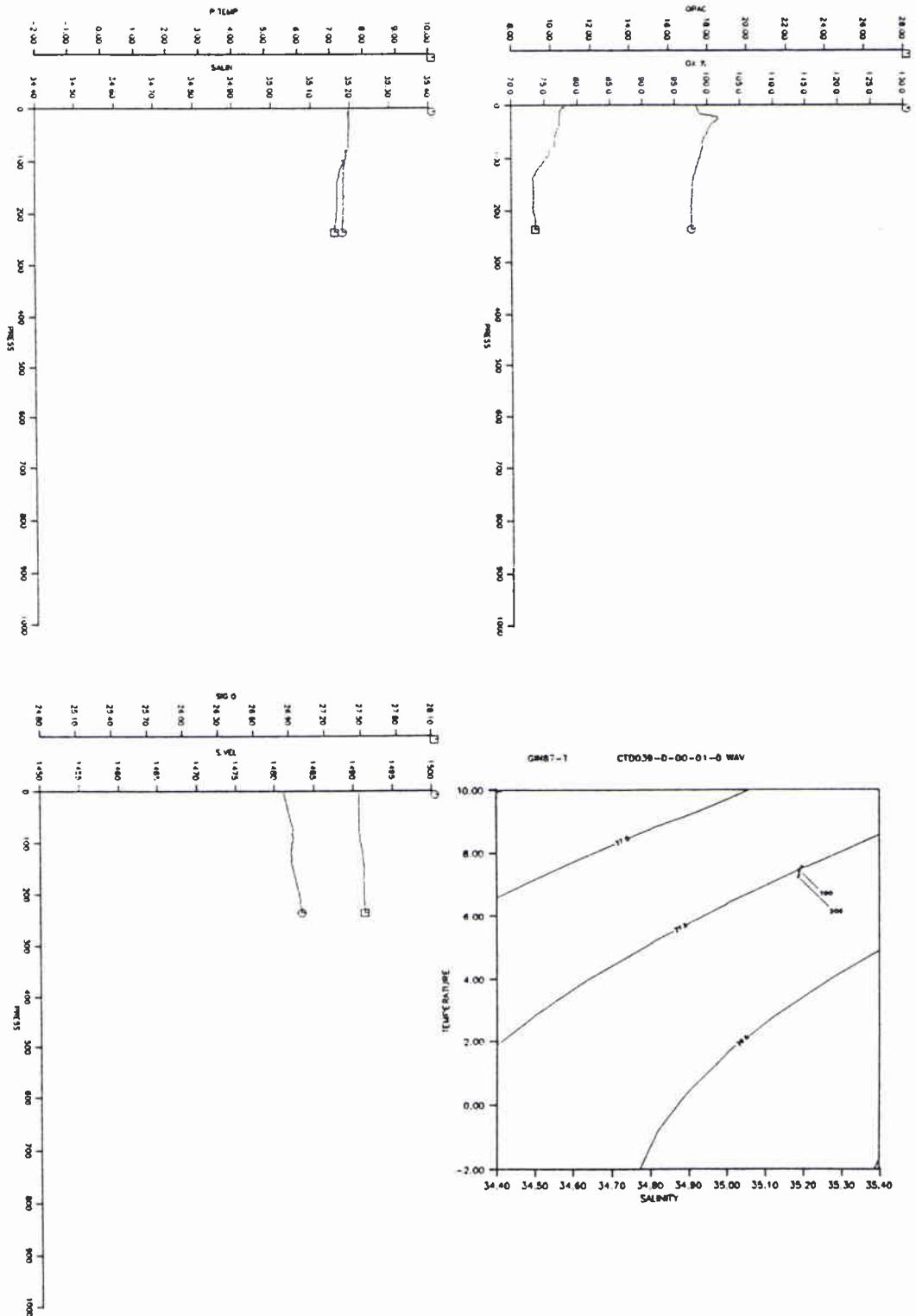


Figure B38

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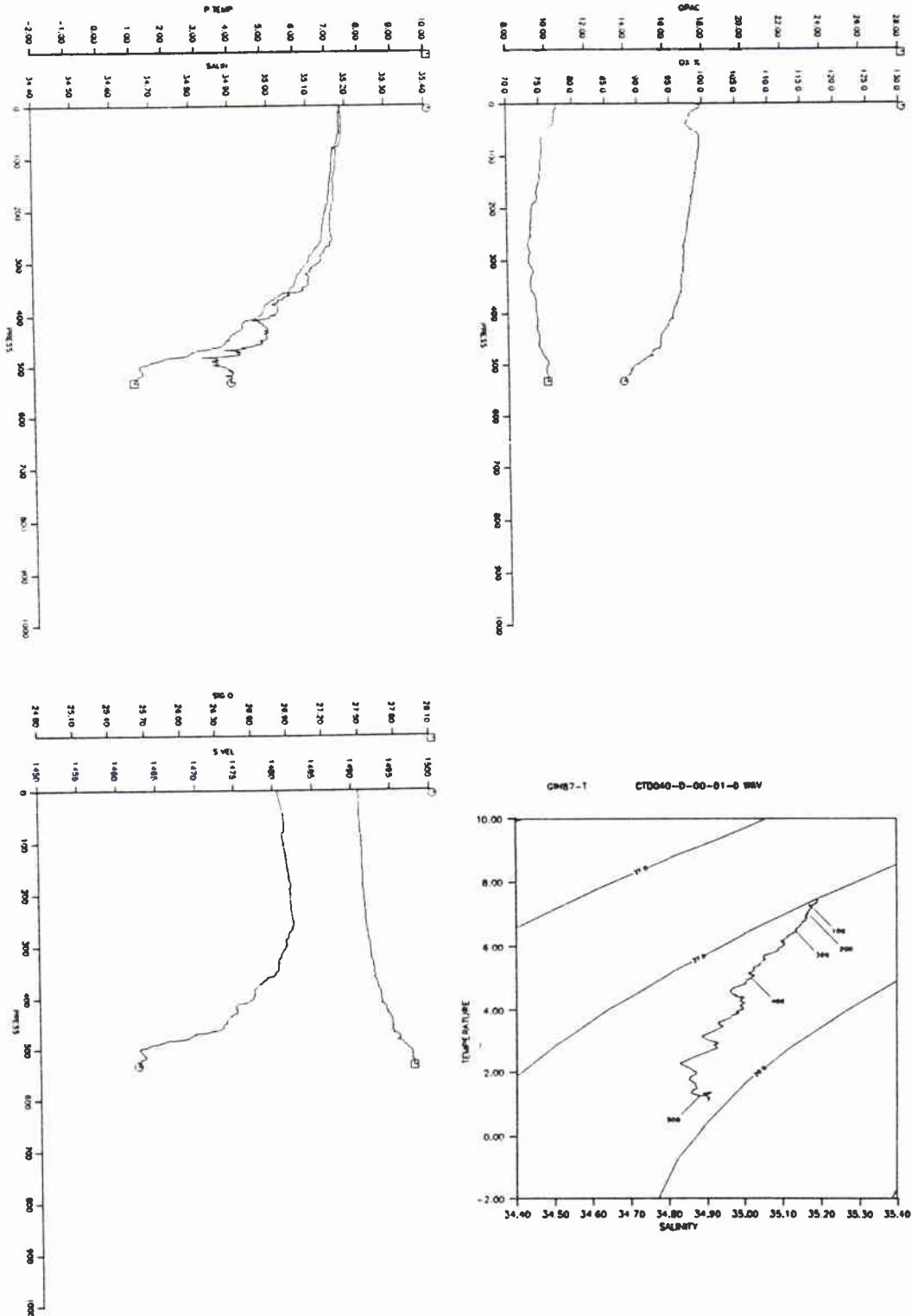


Figure B39

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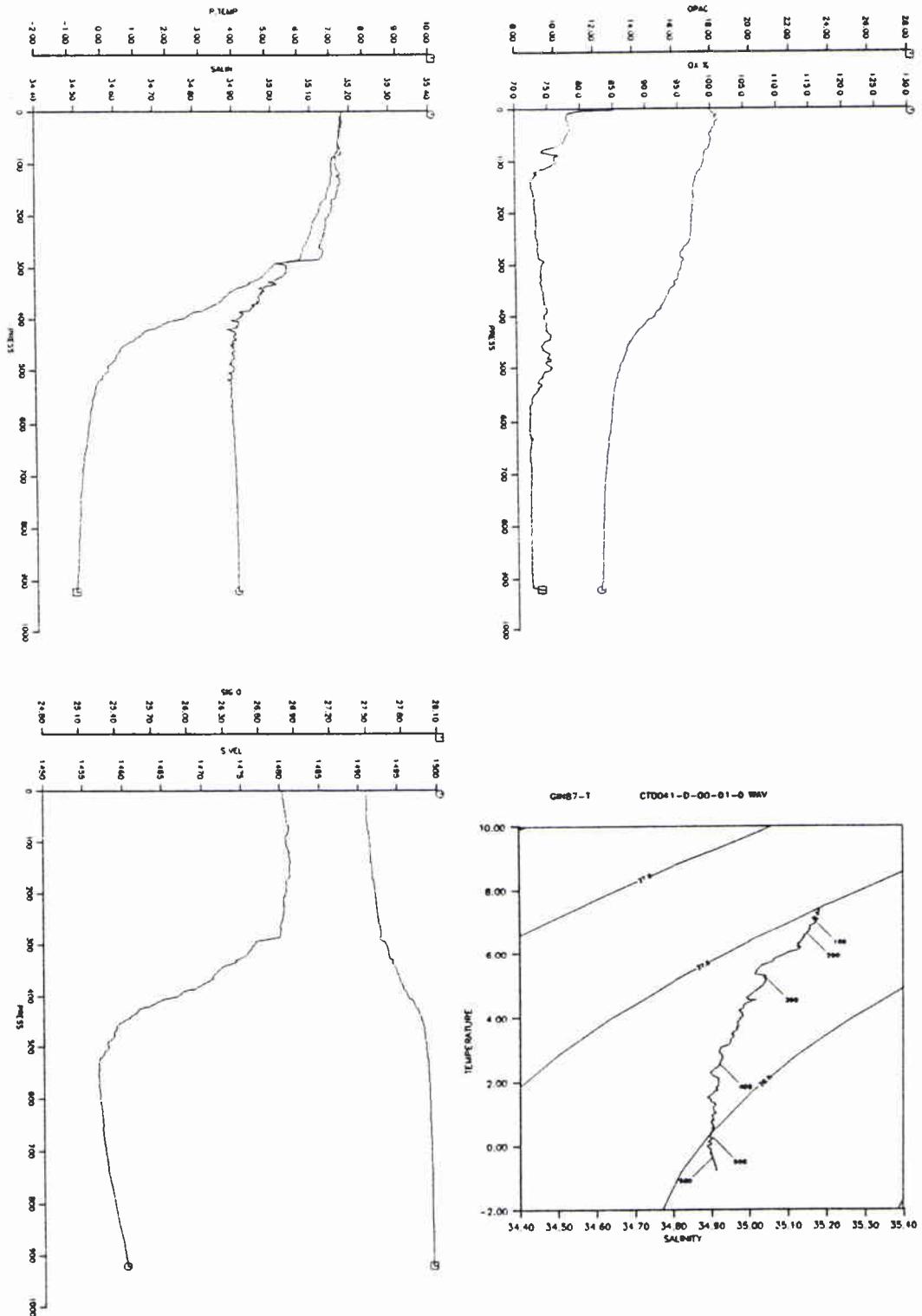


Figure B40

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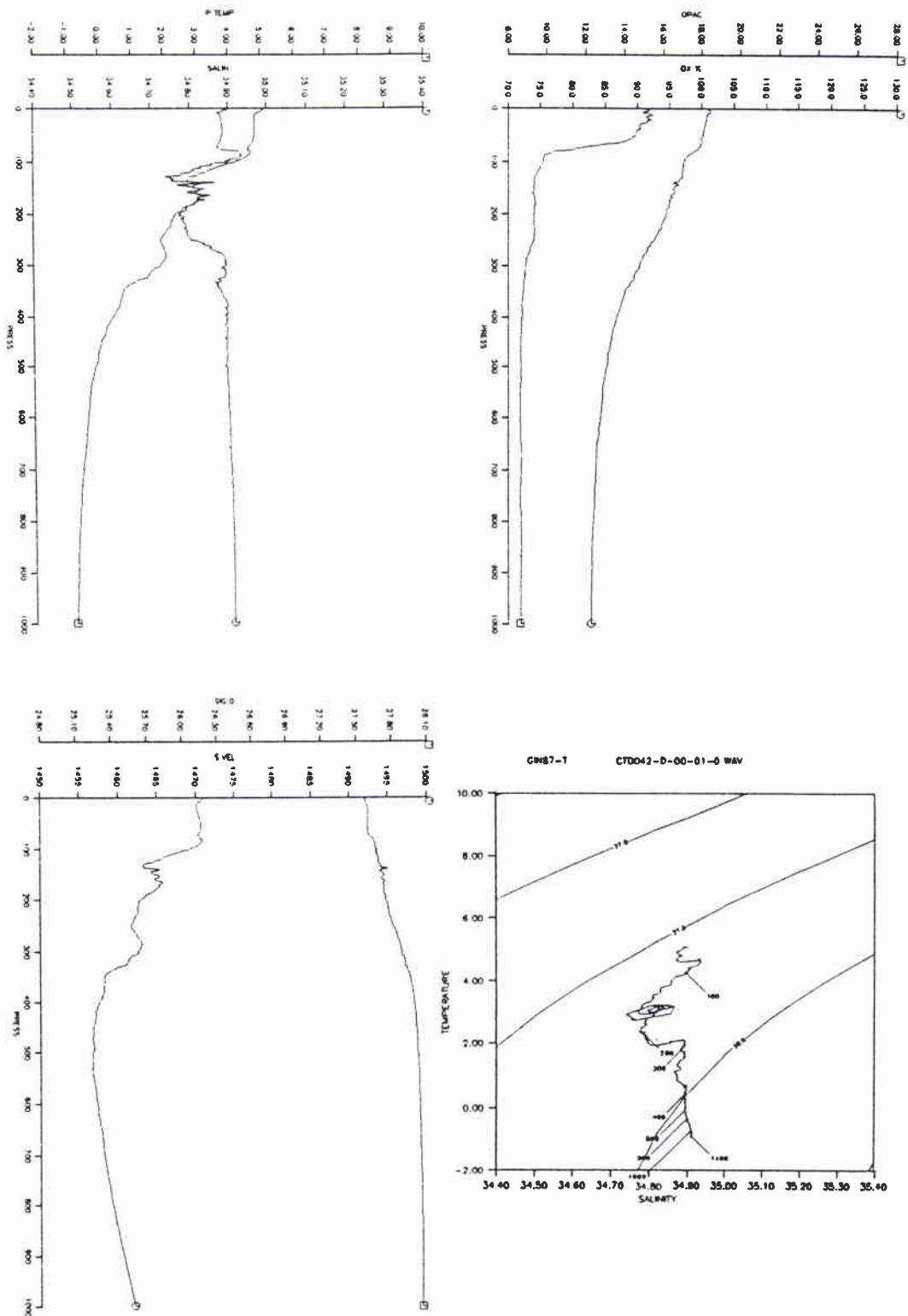


Figure B41

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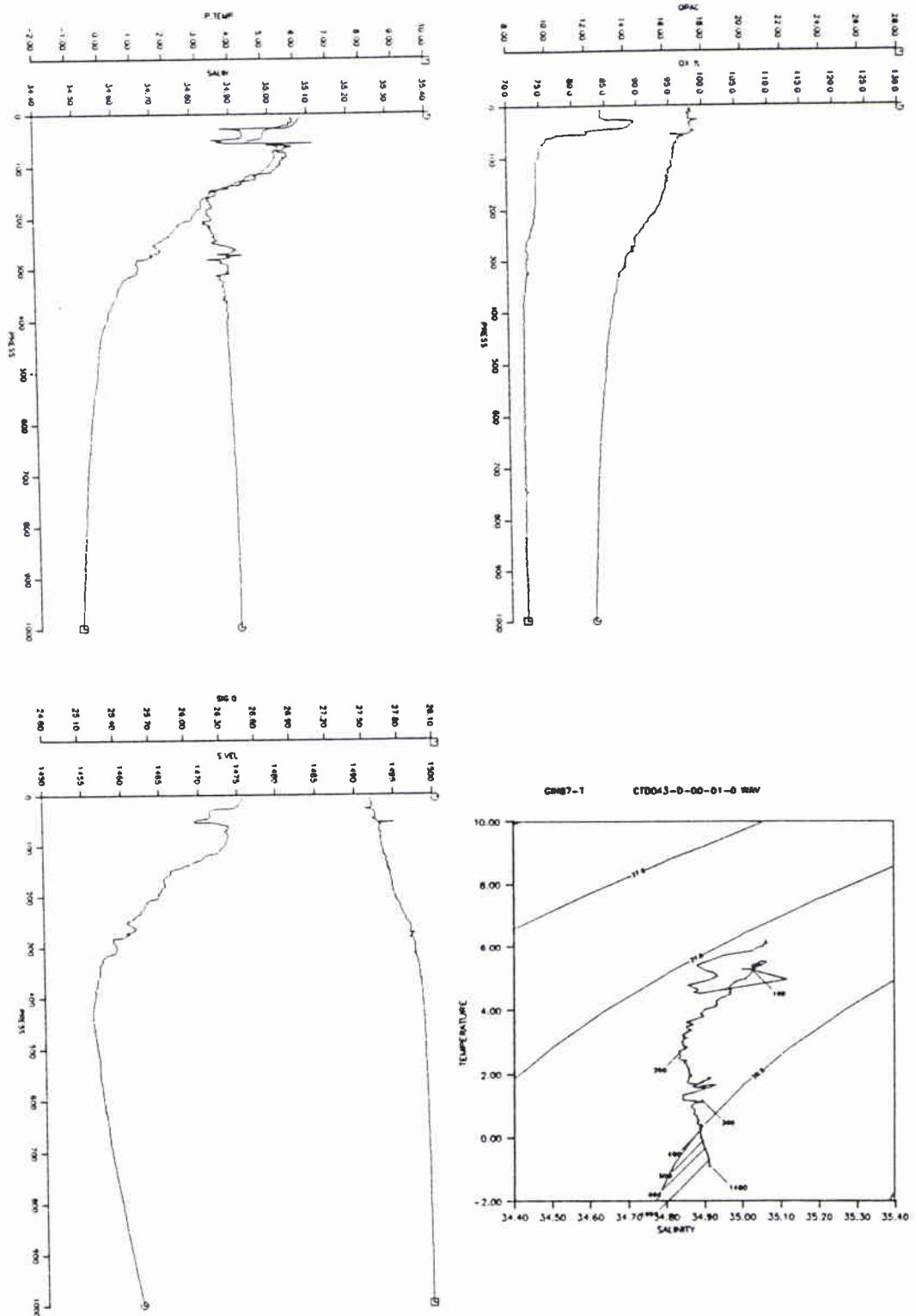


Figure B42

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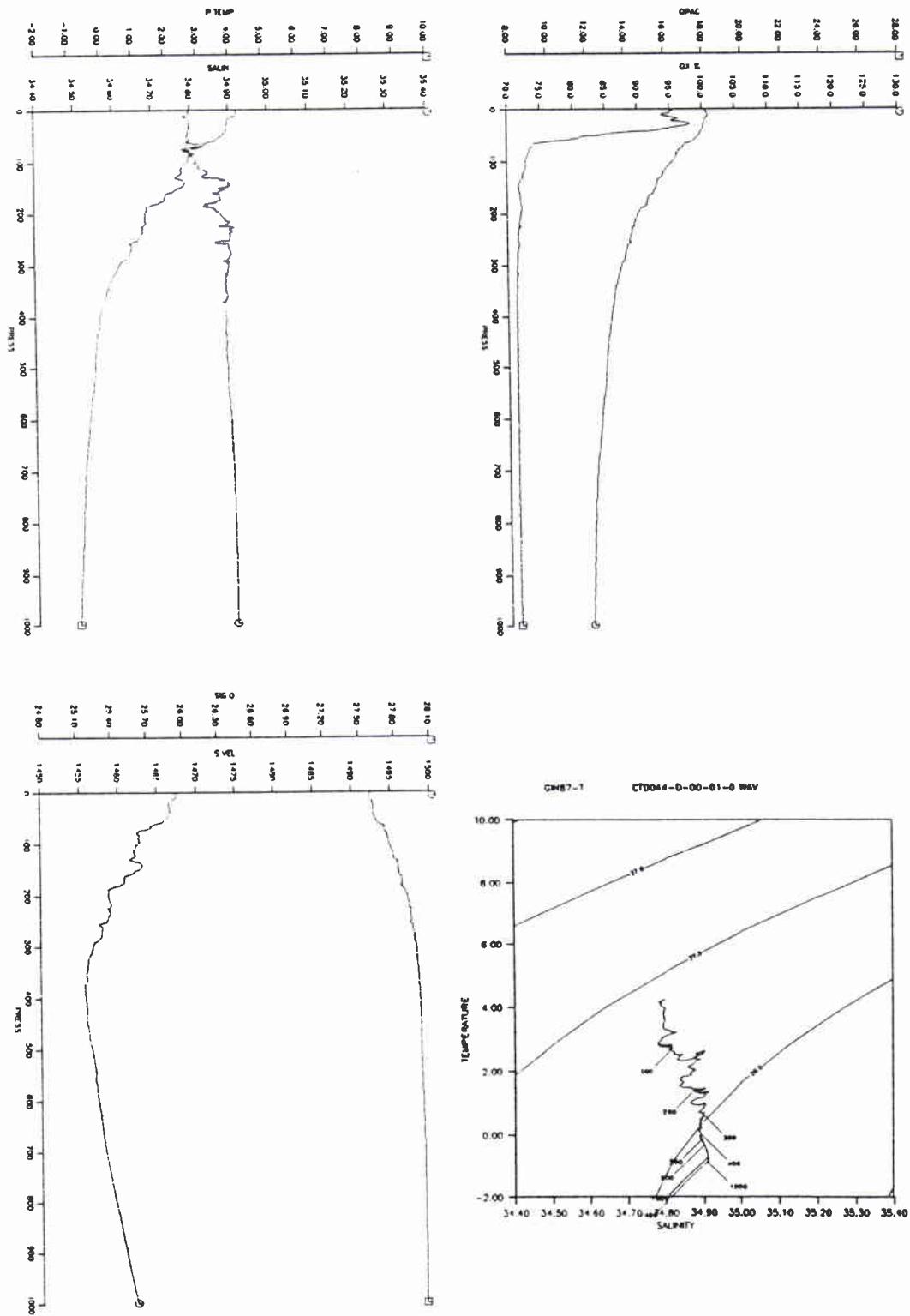


Figure B43

SACLANTCEN SM-249

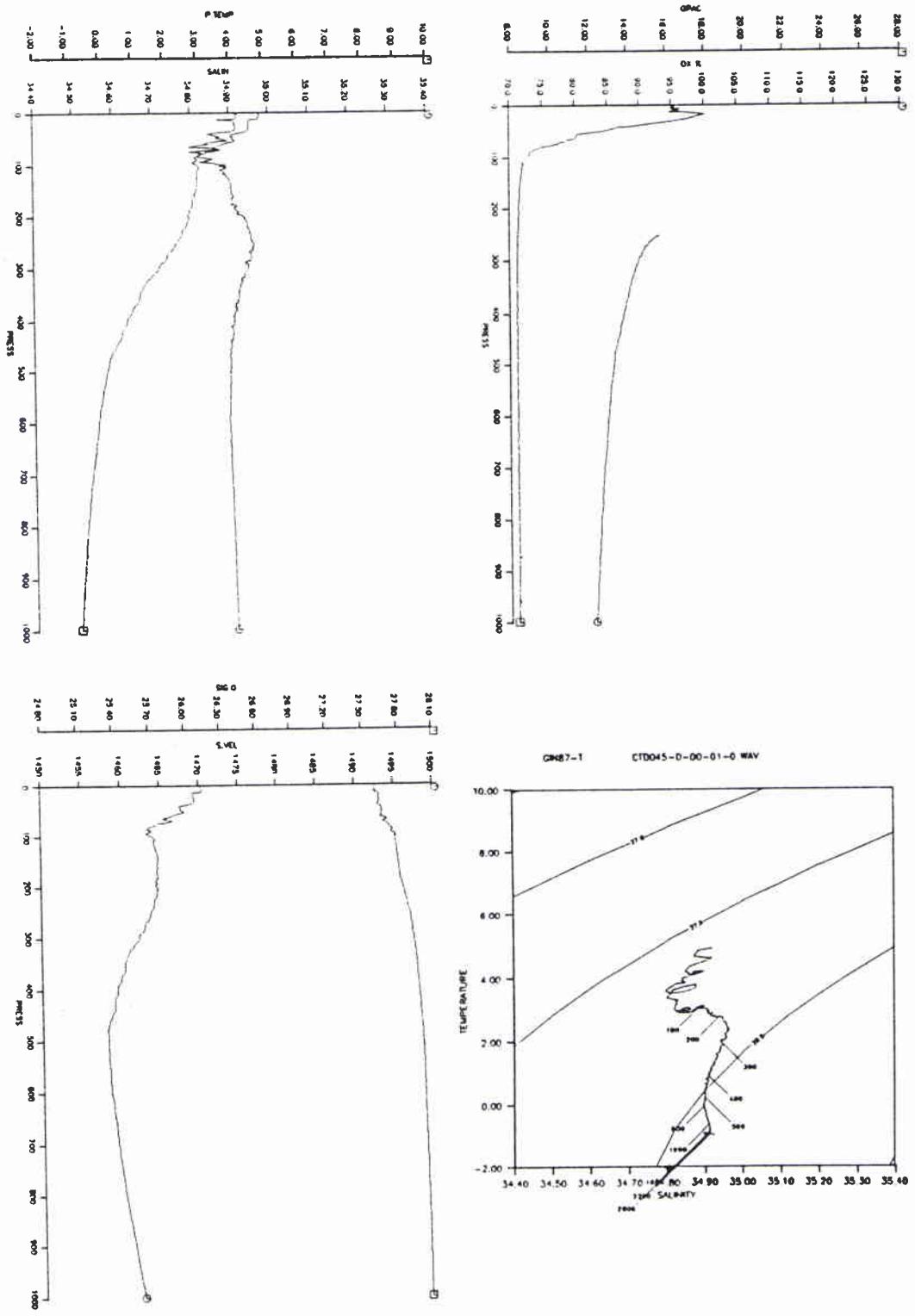


Figure B44

SACLANTCEN SM-249

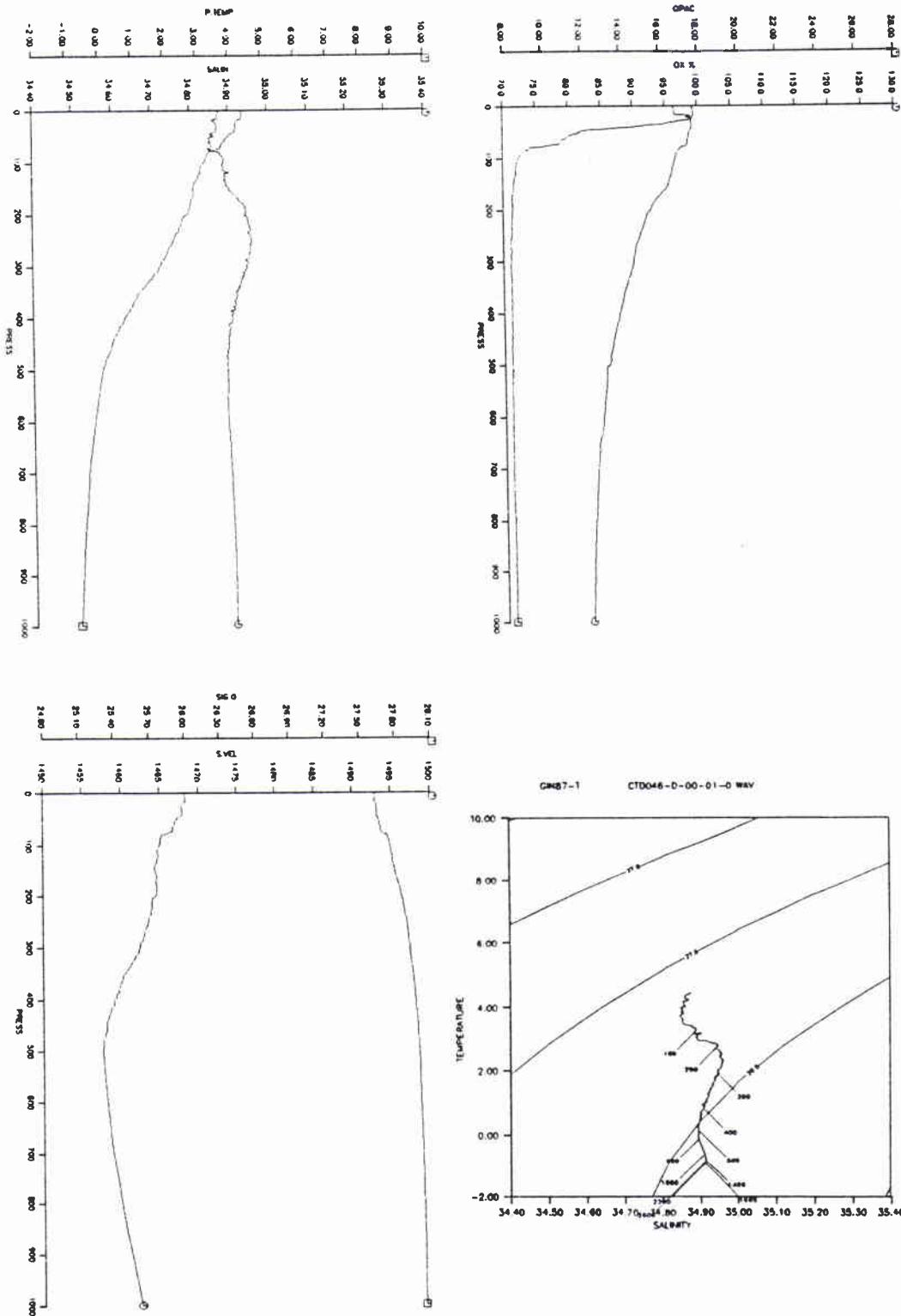


Figure B45

SACLANTCEN SM-249

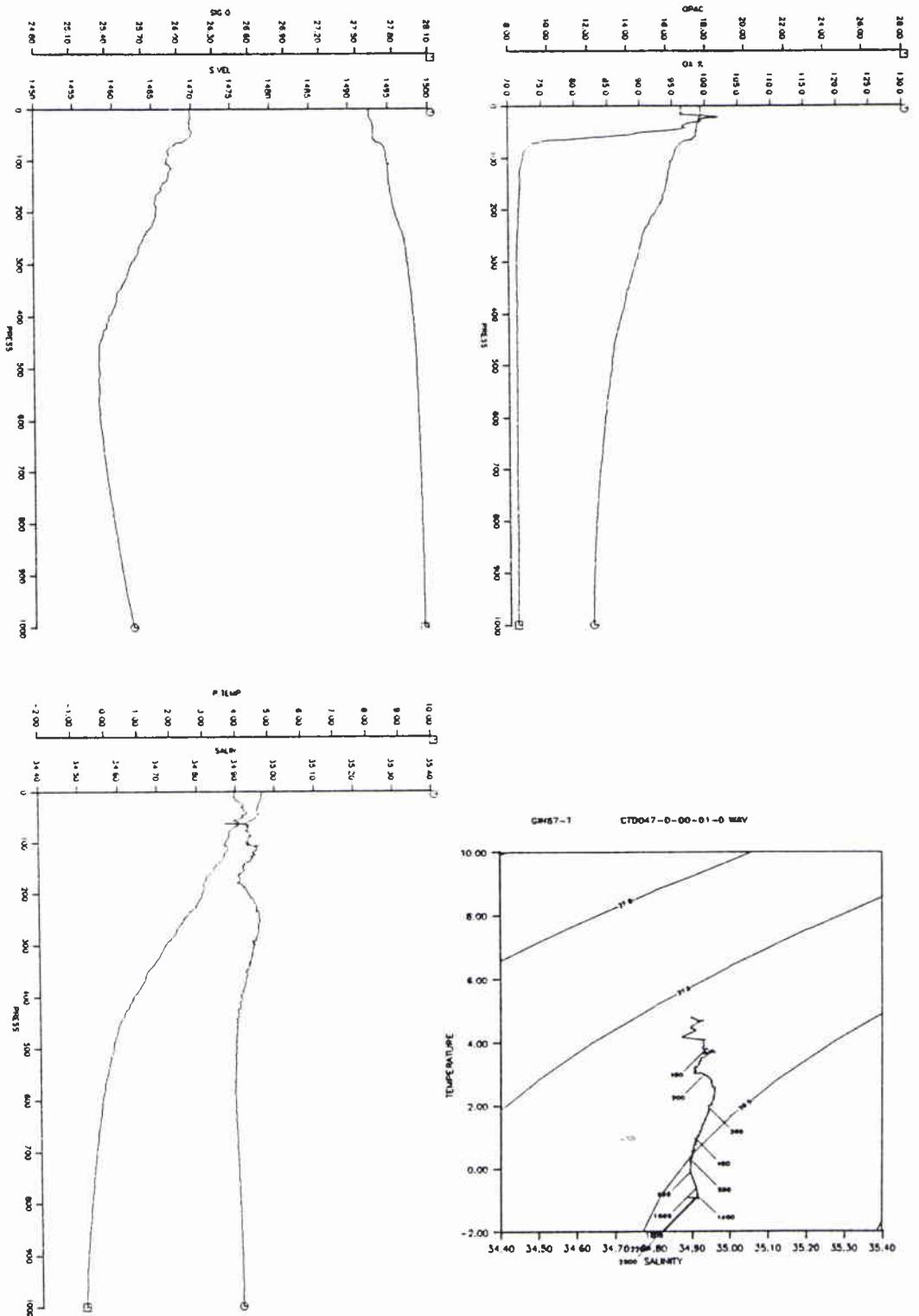


Figure B46

SACLANTCEN SM-249

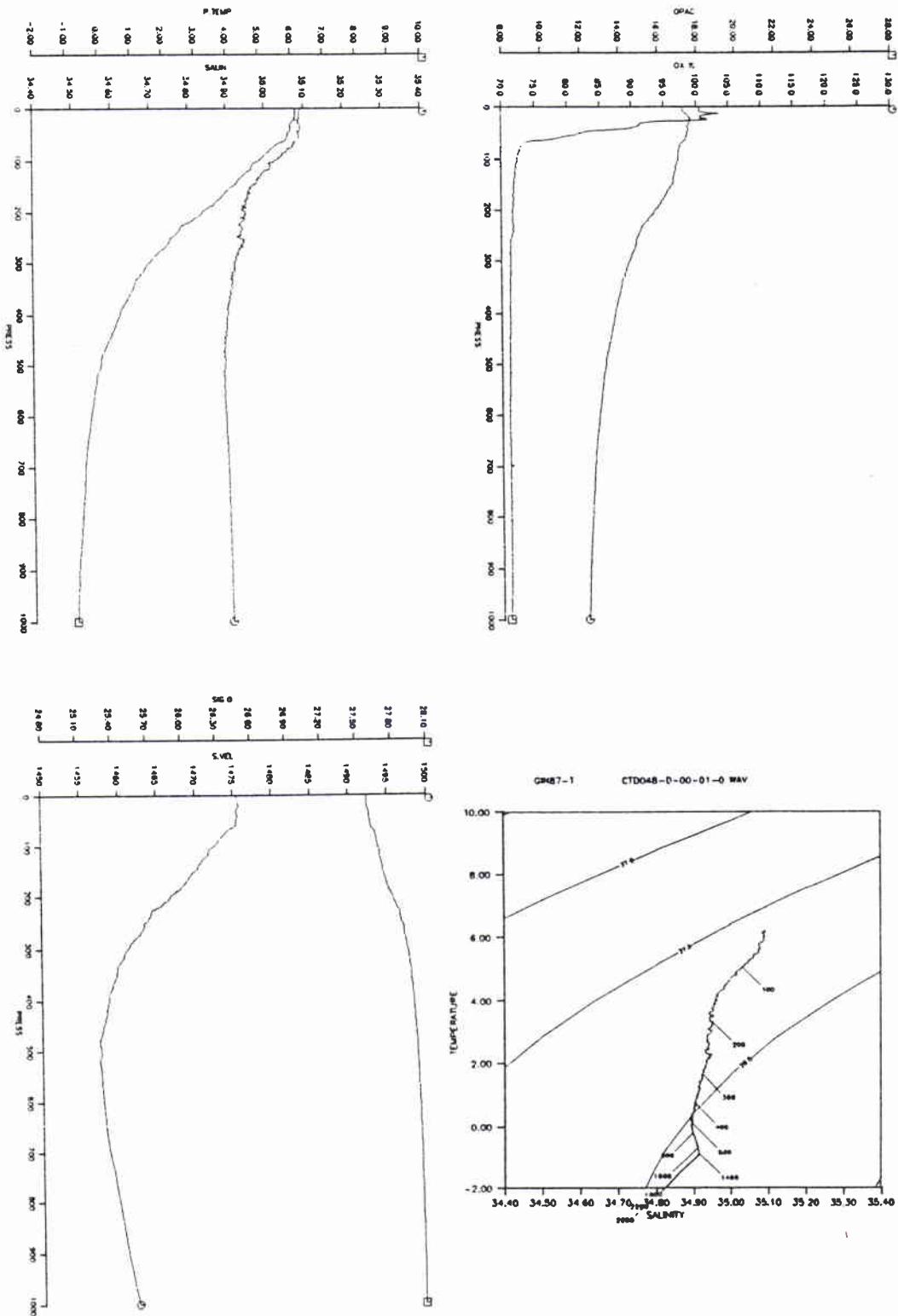


Figure B47

SACLANTCEN SM-249

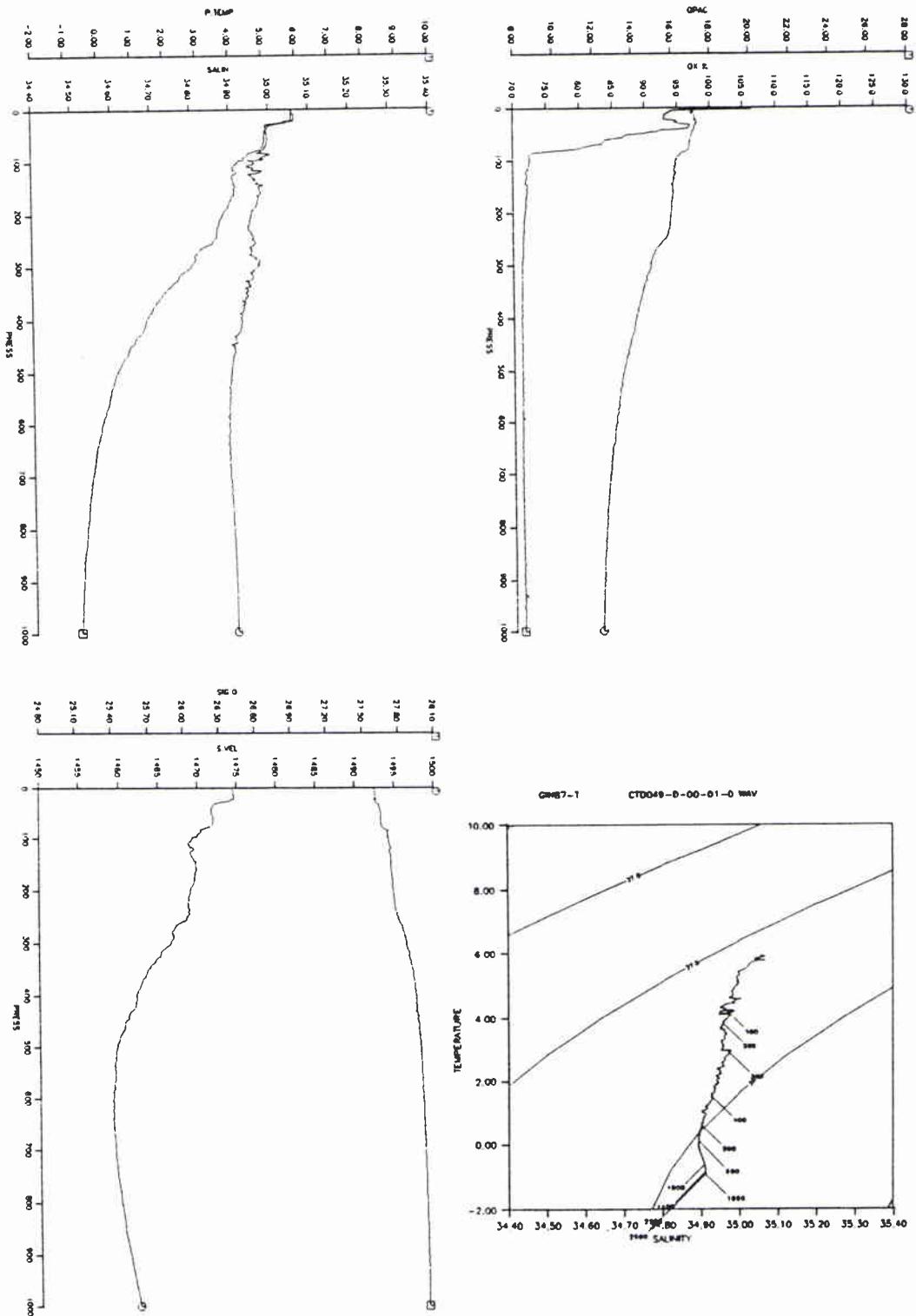


Figure B48

SACLANTCEN SM-249

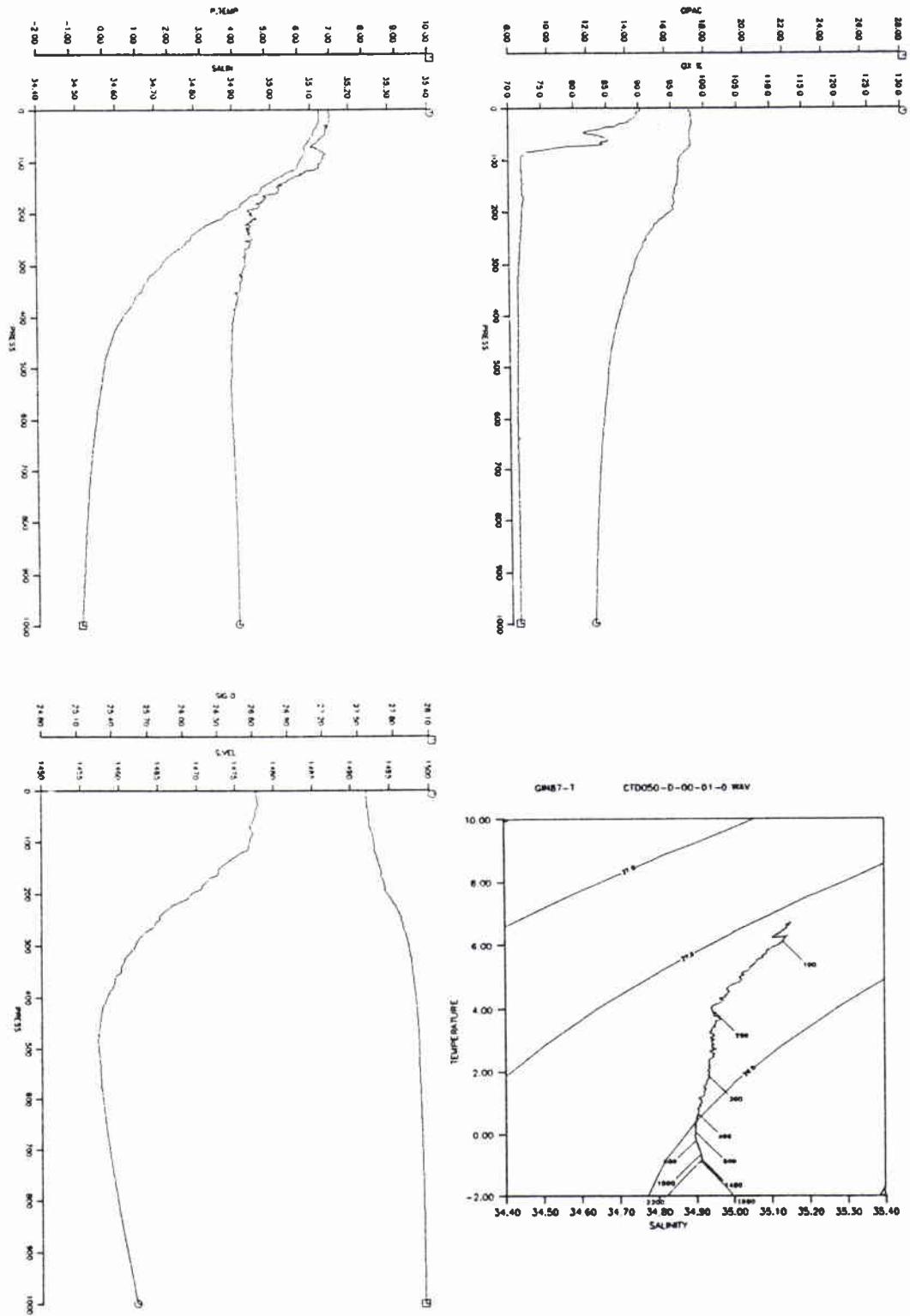


Figure B49

SACLANTCEN SM-249

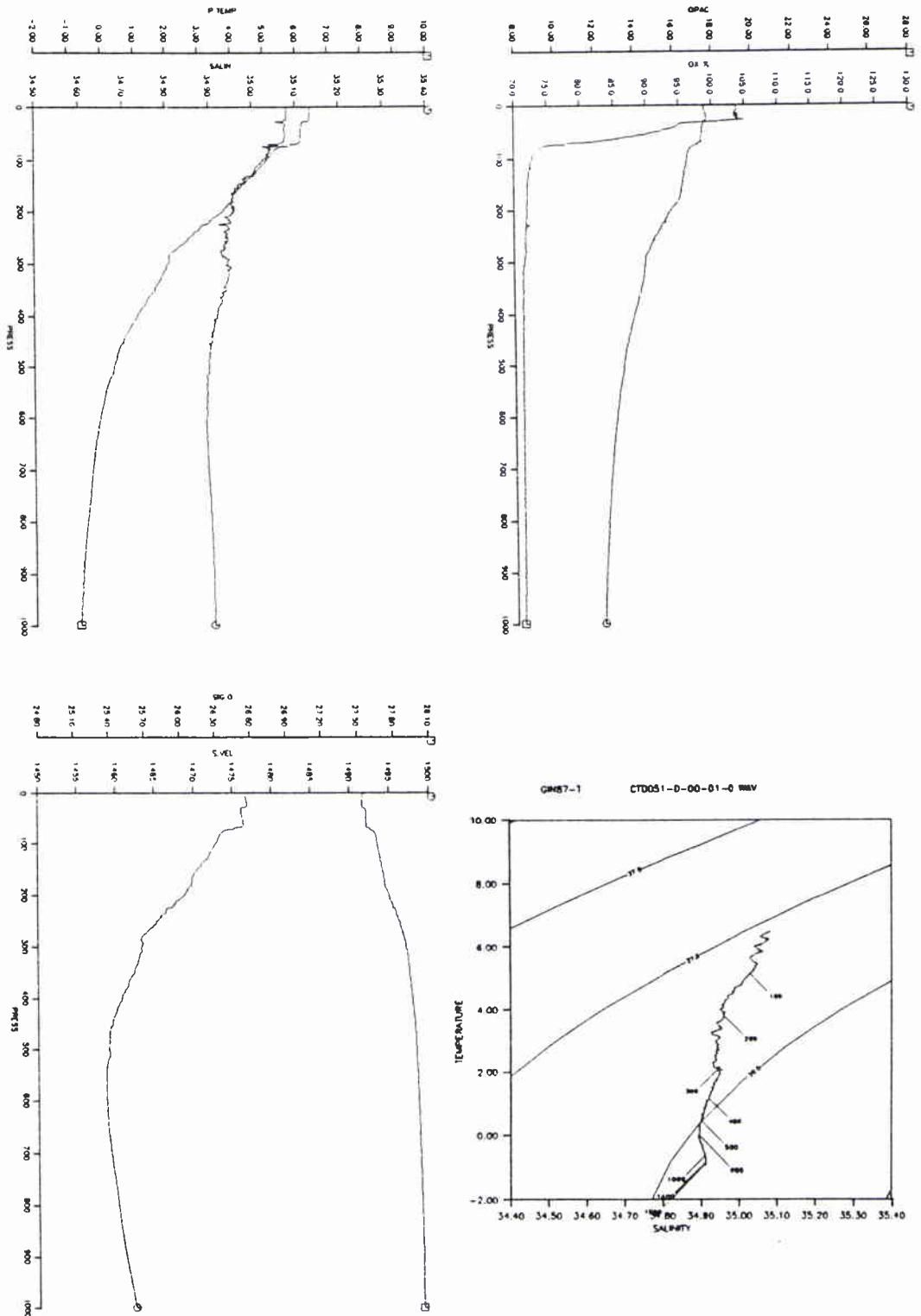


Figure B50

SACLANTCEN SM-249

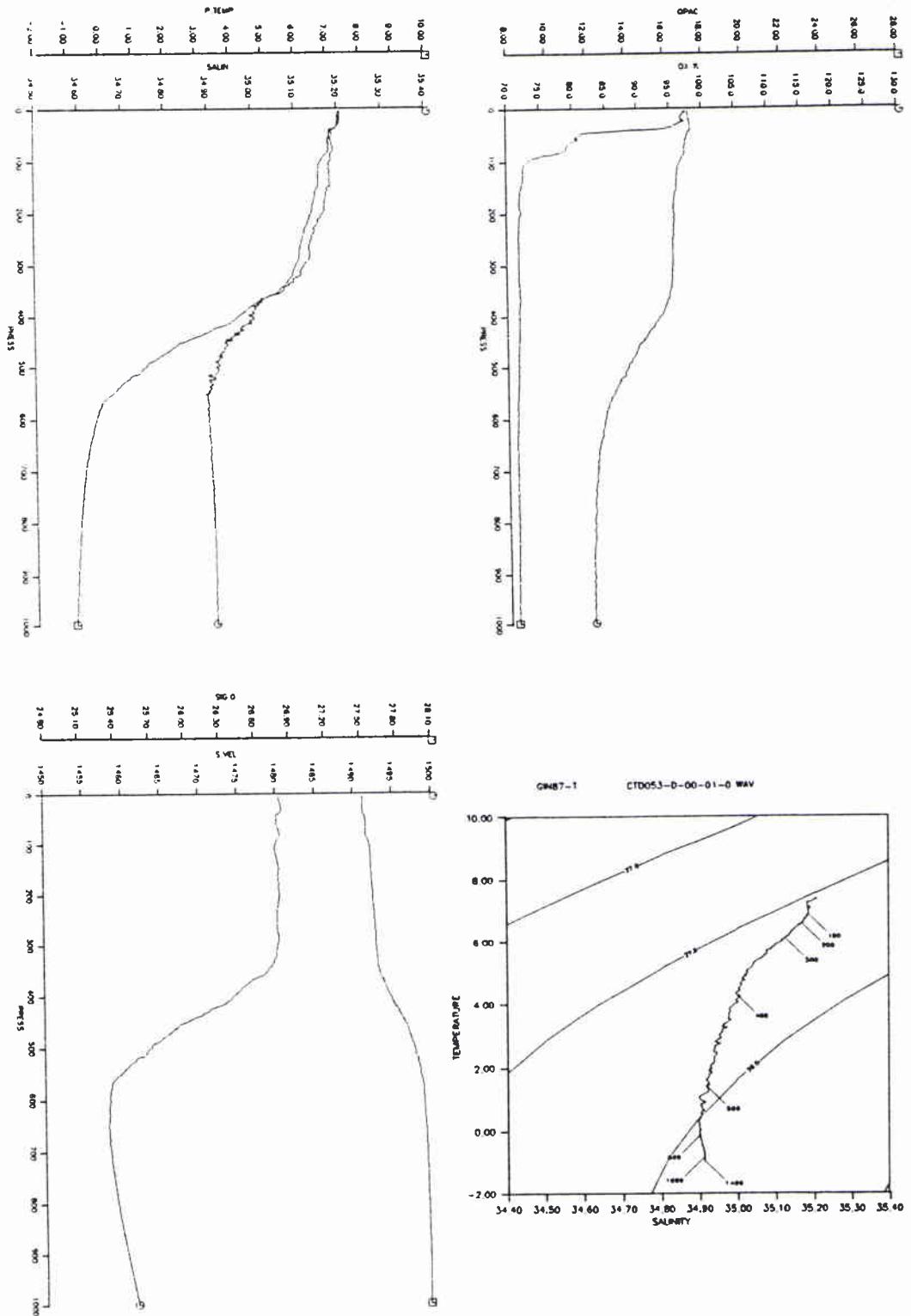


Figure B52

SACLANTCEN SM-249

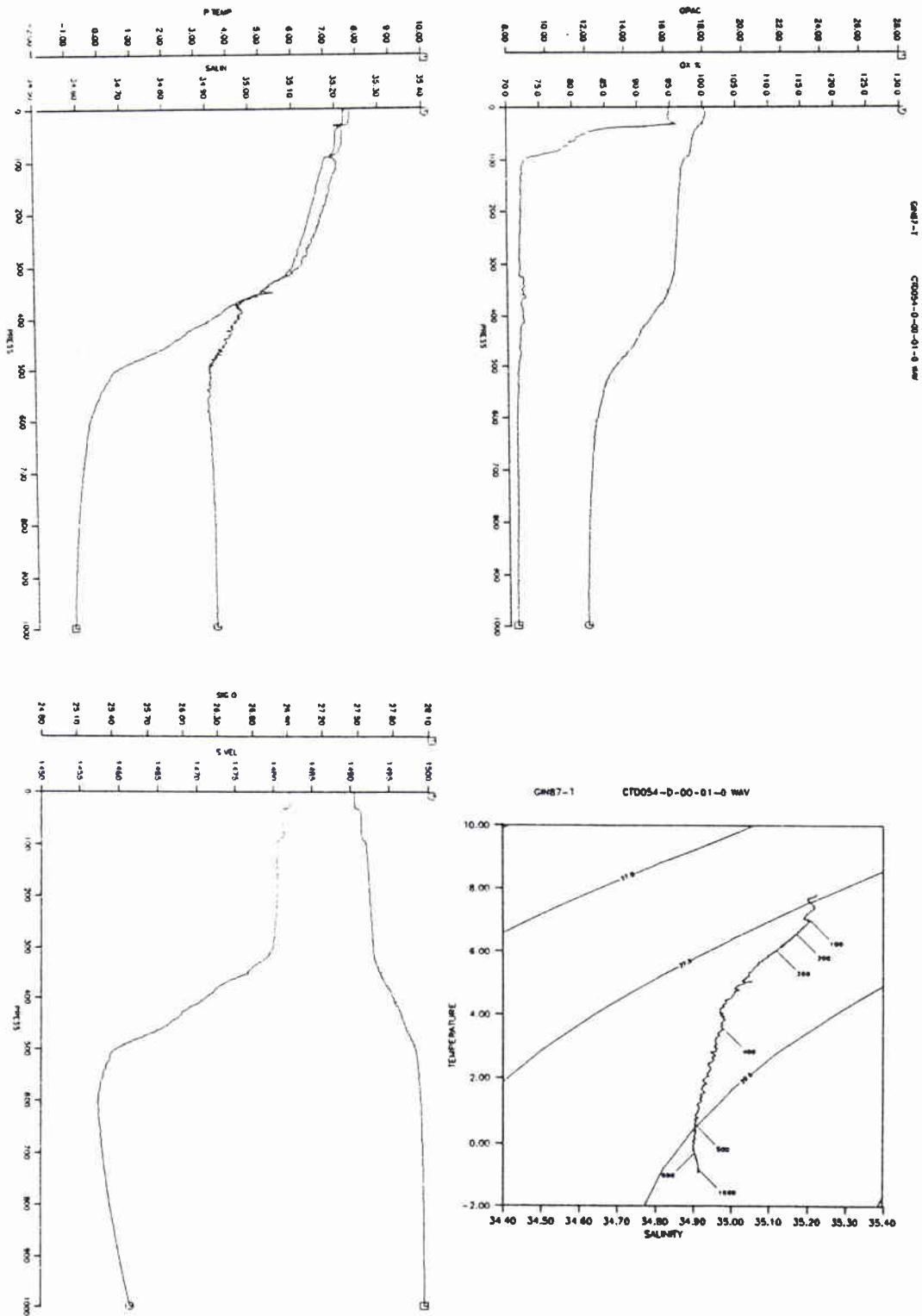


Figure B53

SACLANTCEN SM-249

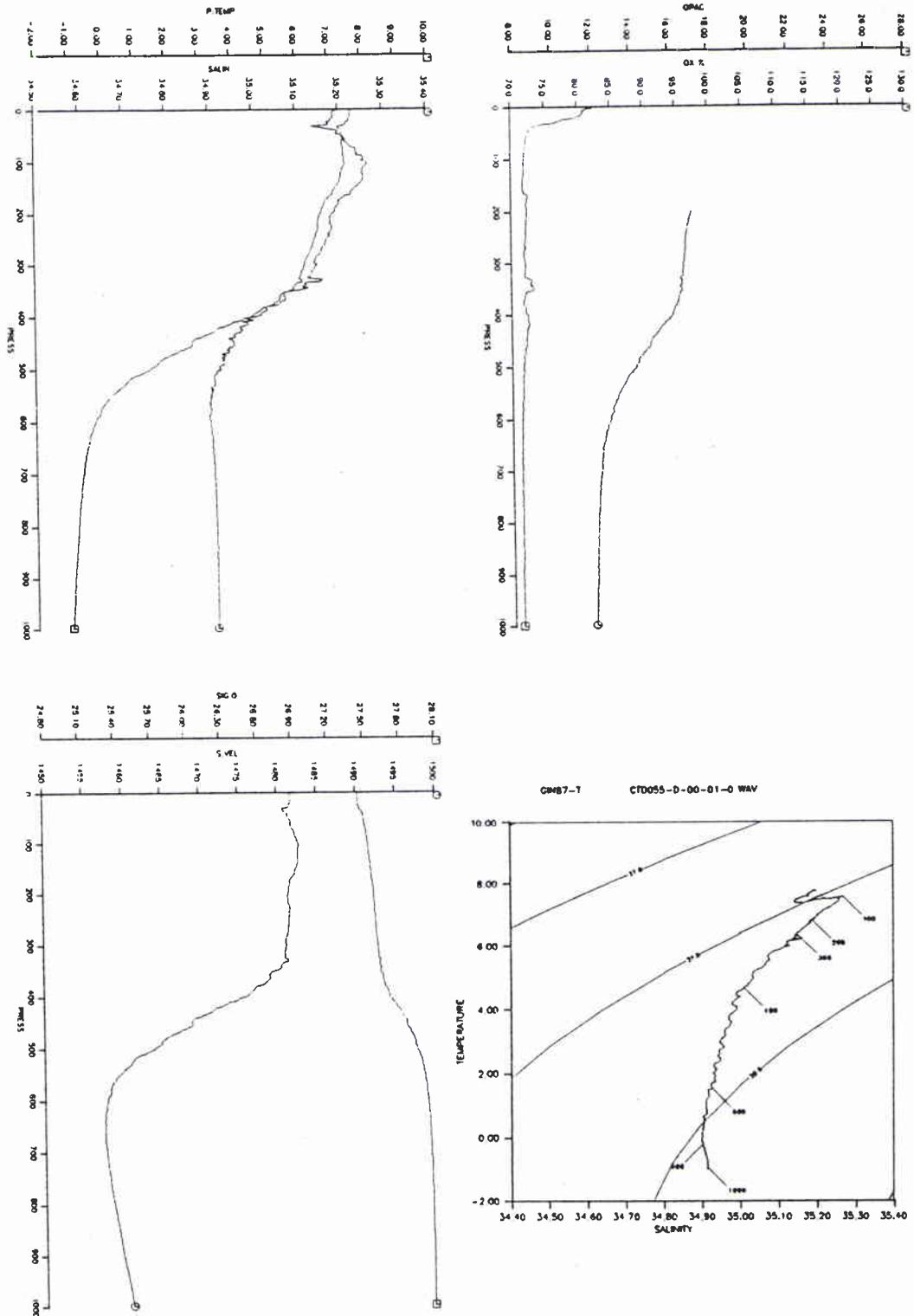


Figure B54

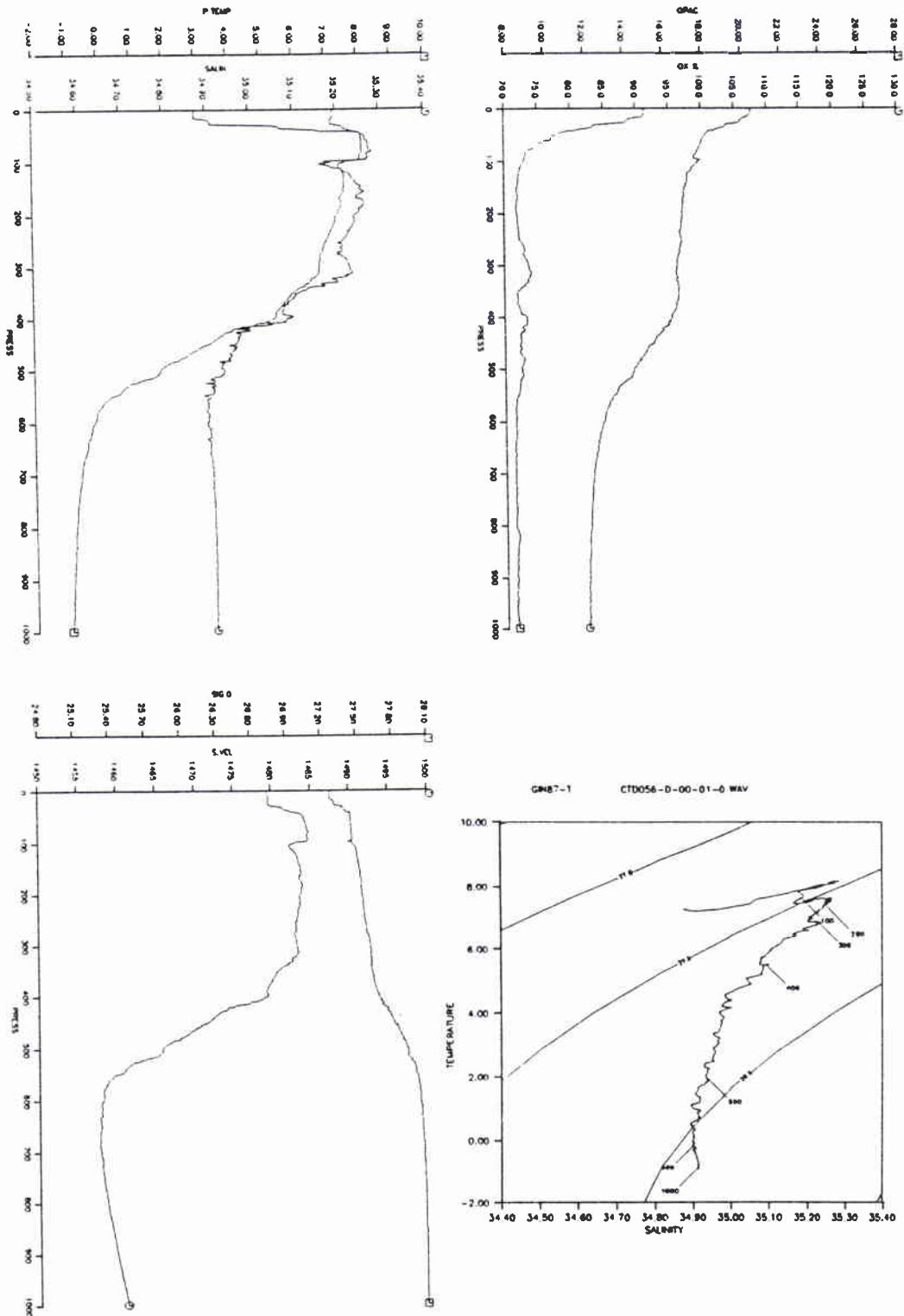


Figure B55

SACLANTCEN SM-249

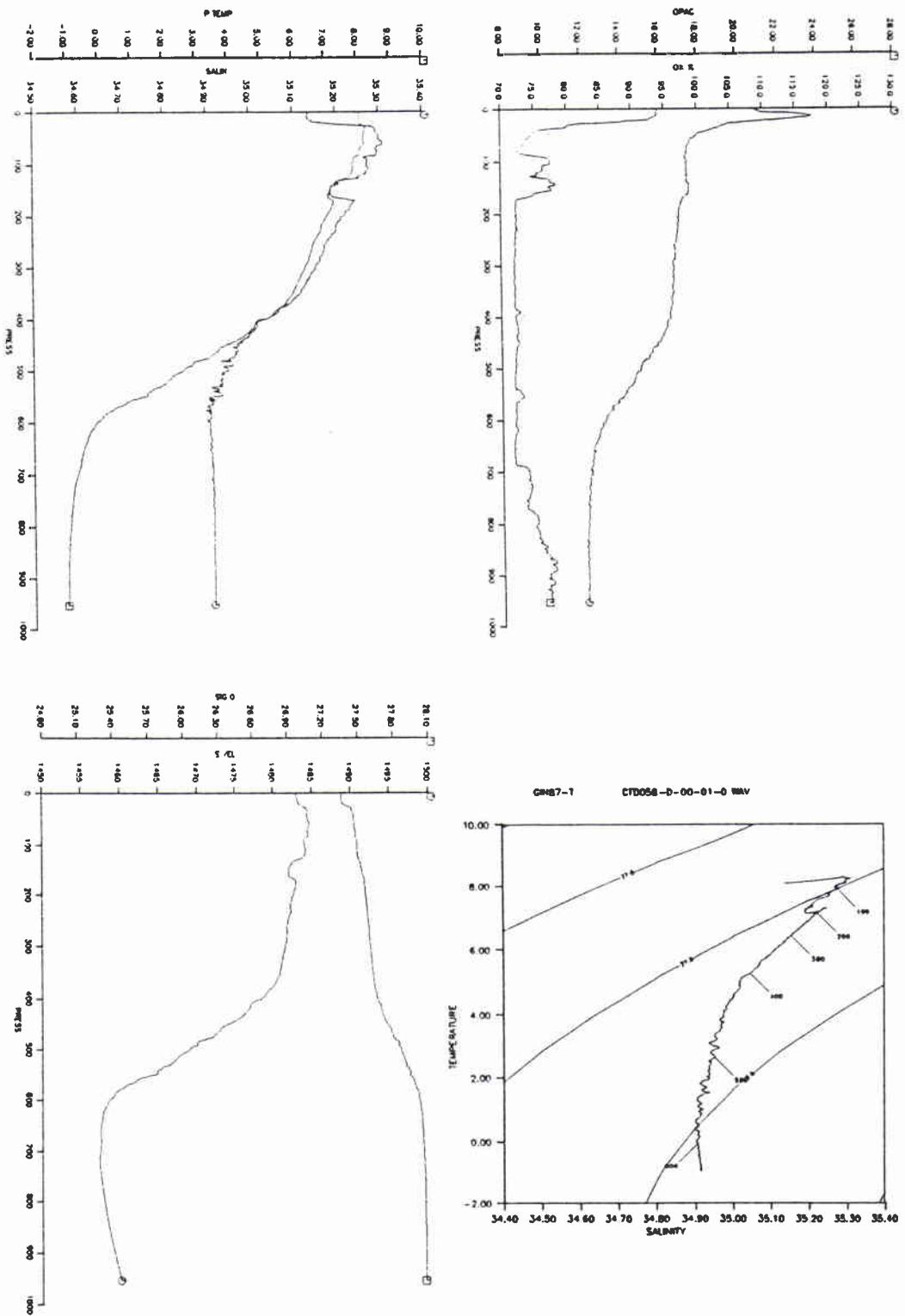


Figure B57

SACLANTCEN SM-249

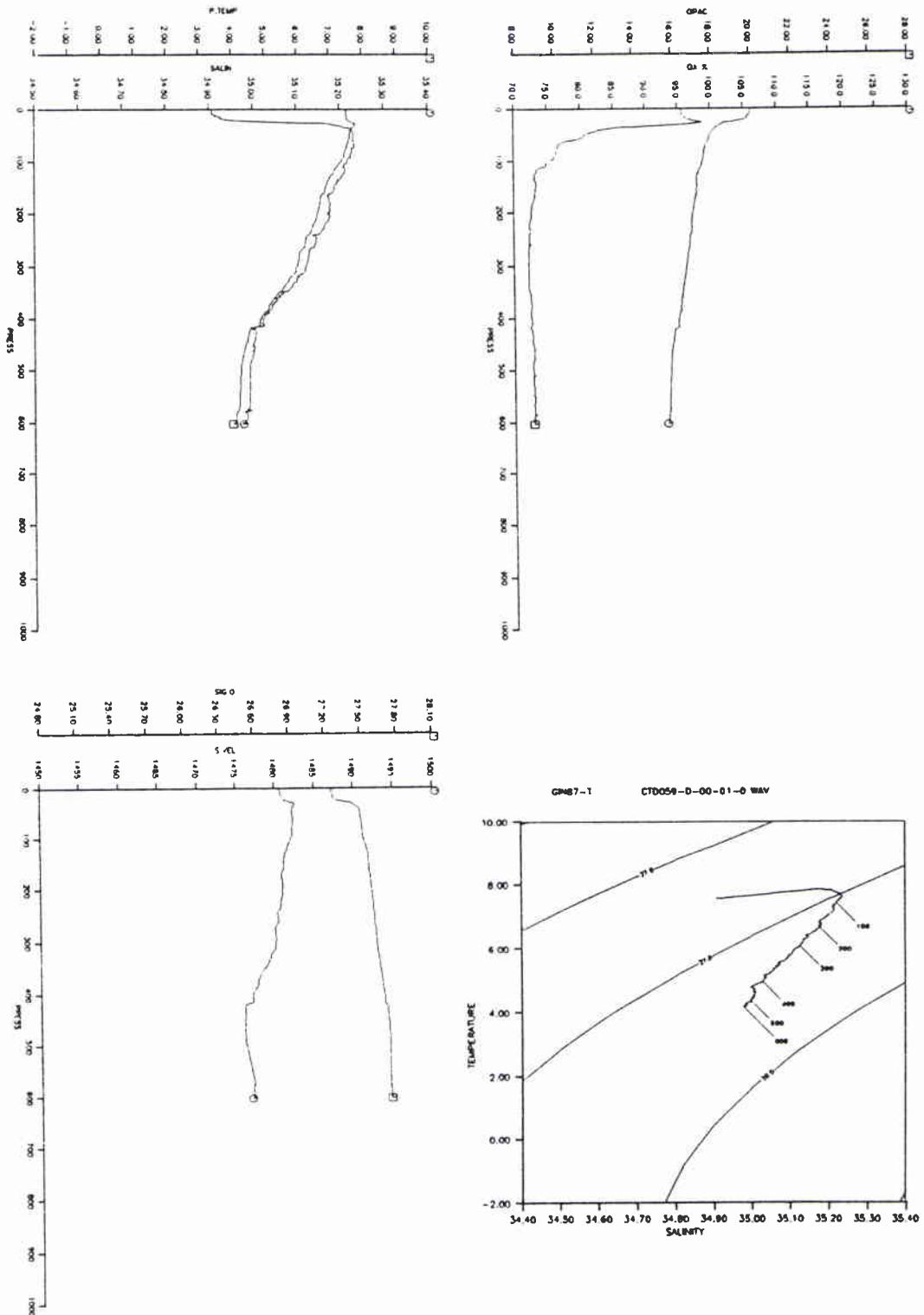


Figure B58

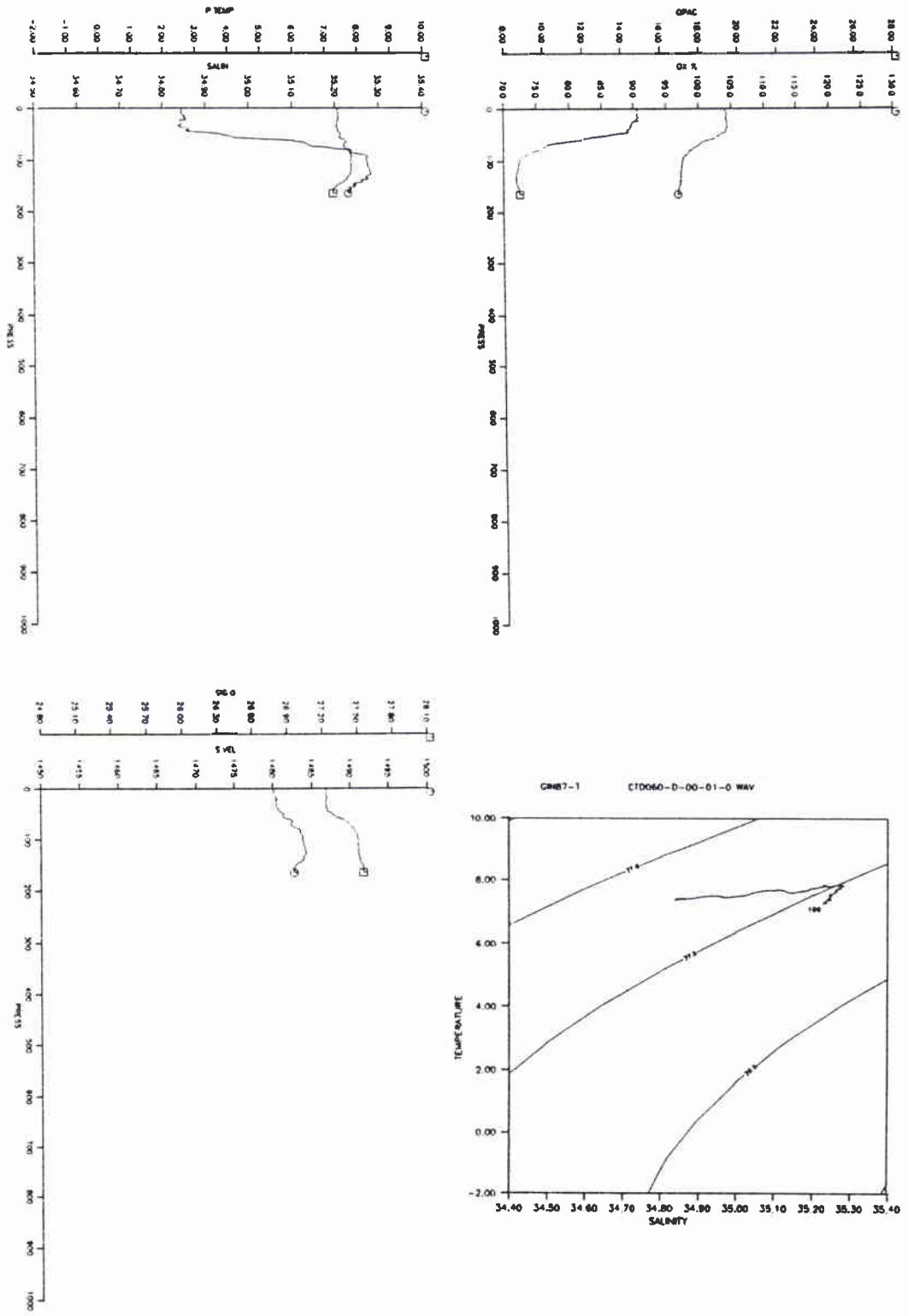


Figure B59

SACLANTCEN SM-249

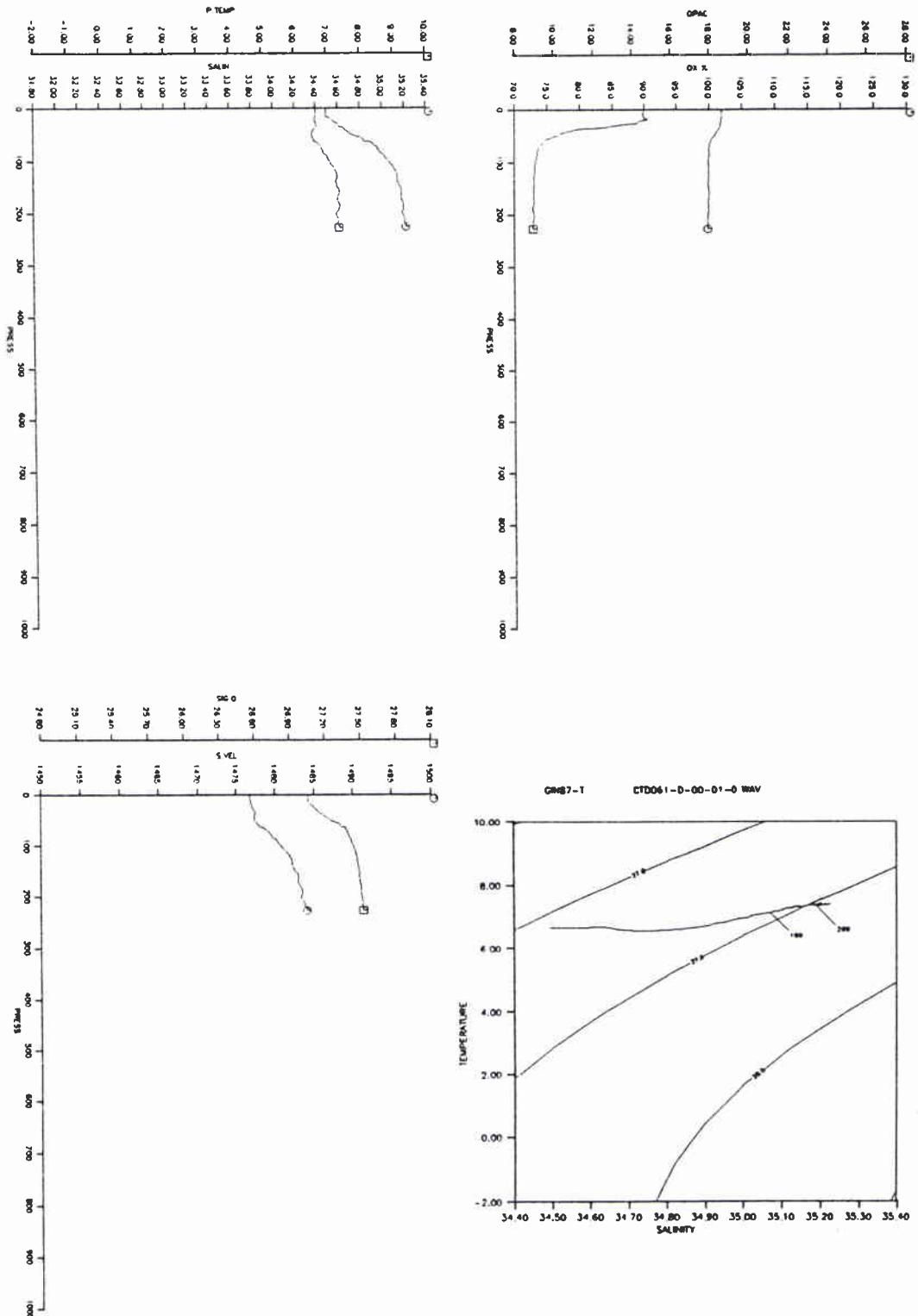


Figure B60

SACLANTCEN SM-249

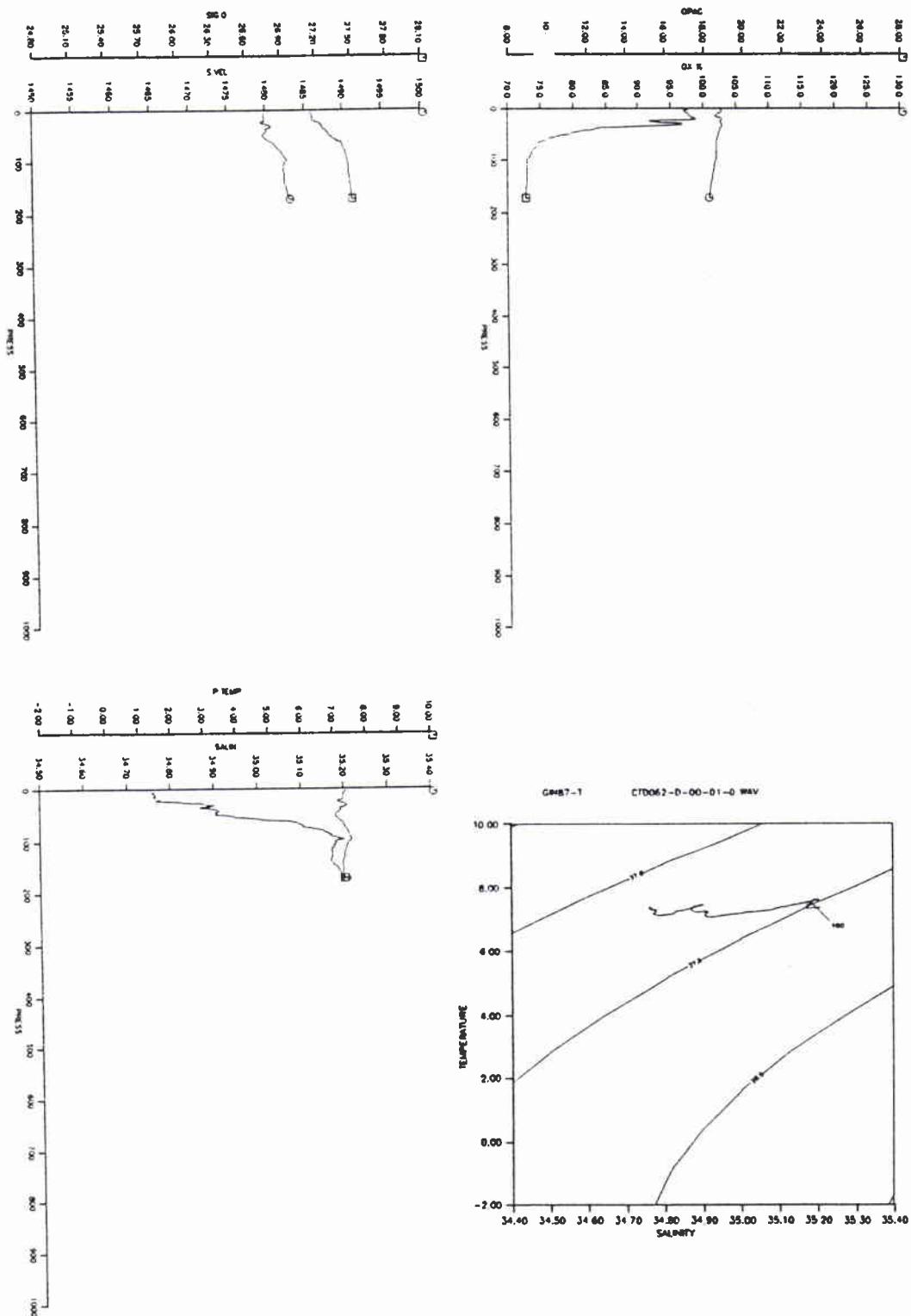


Figure B61

SACLANTCEN SM-249

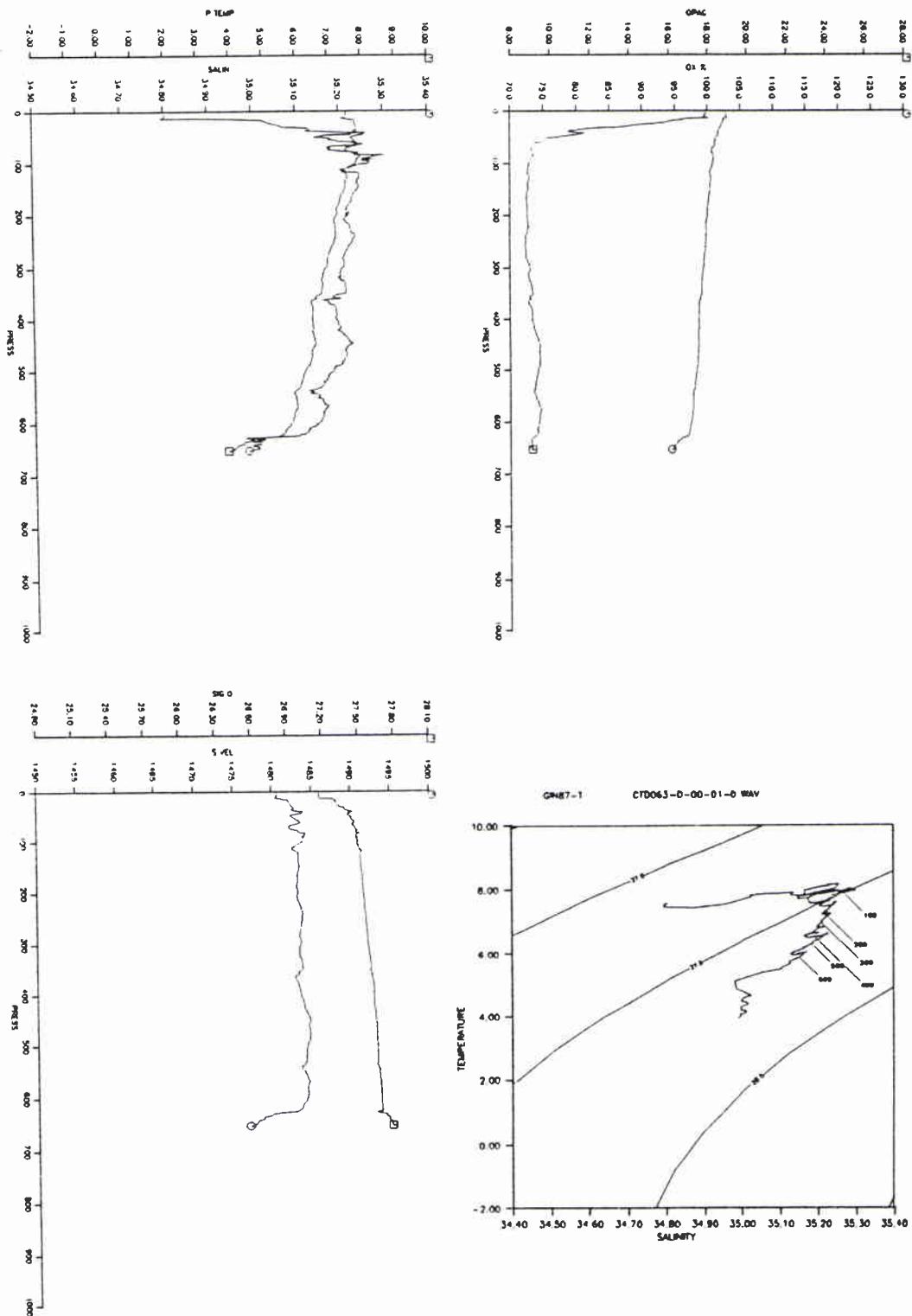


Figure B62

SACLANTCEN SM-249

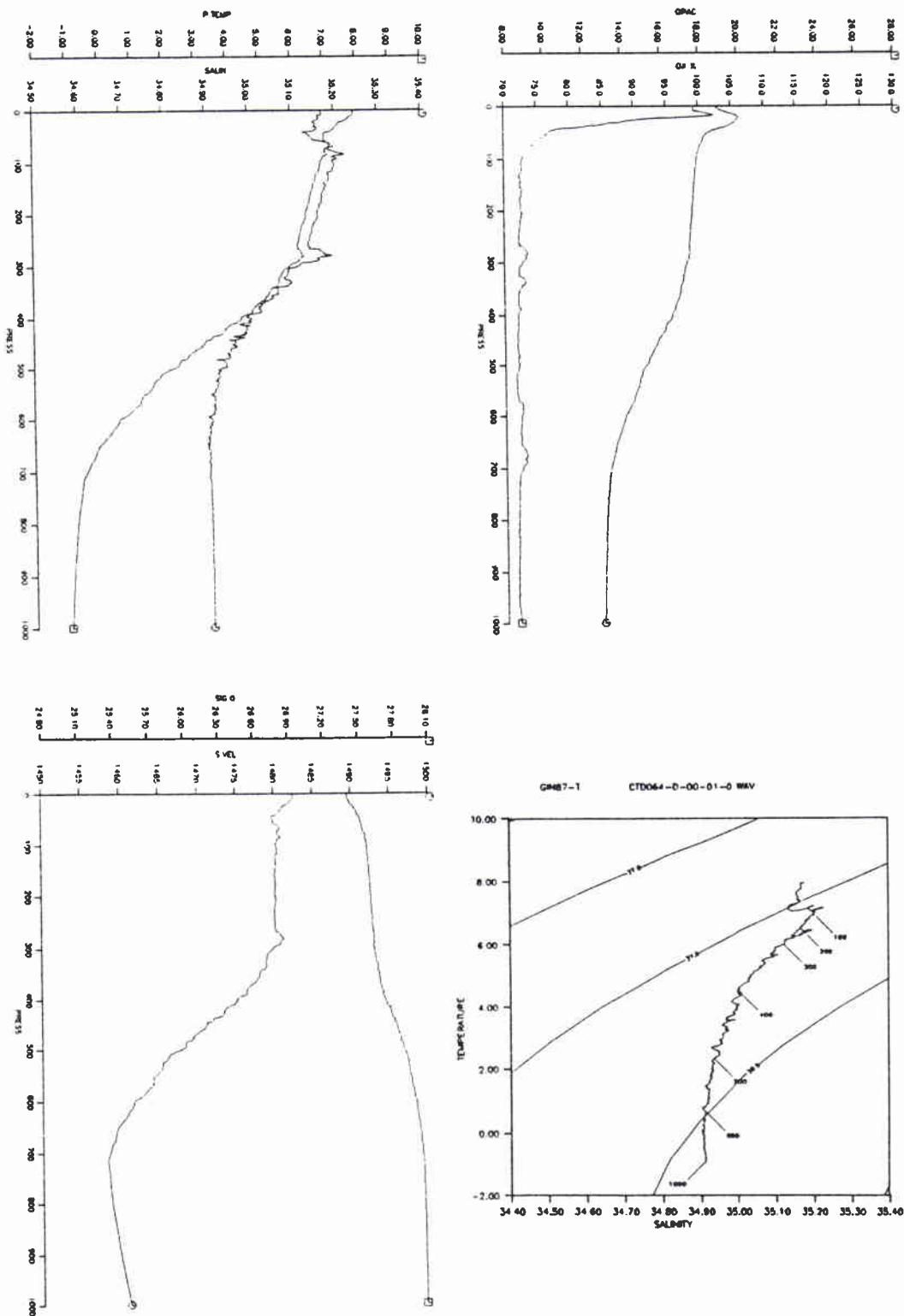
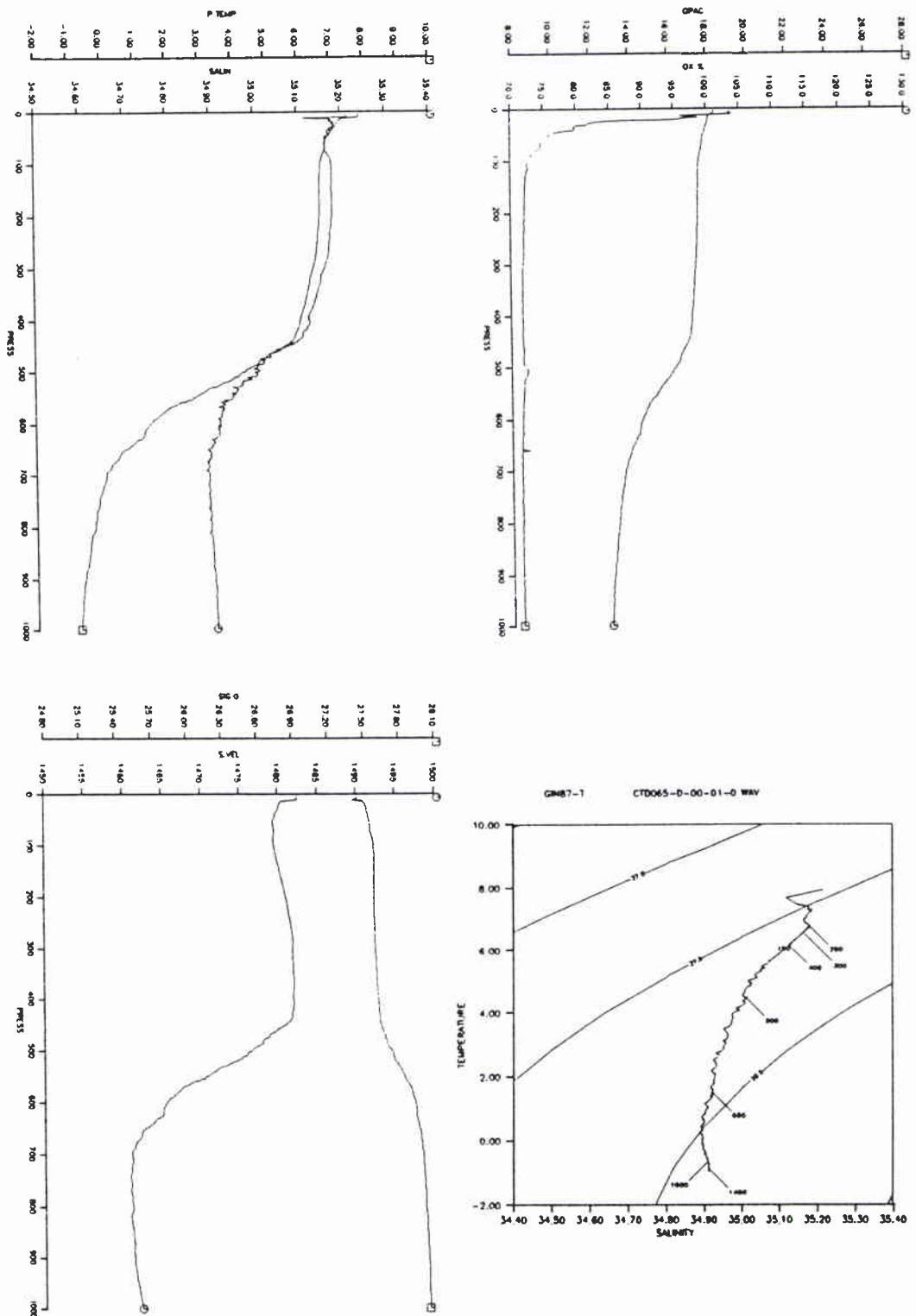


Figure B63

SACLANTCEN SM-249



SACLANTCEN SM-249

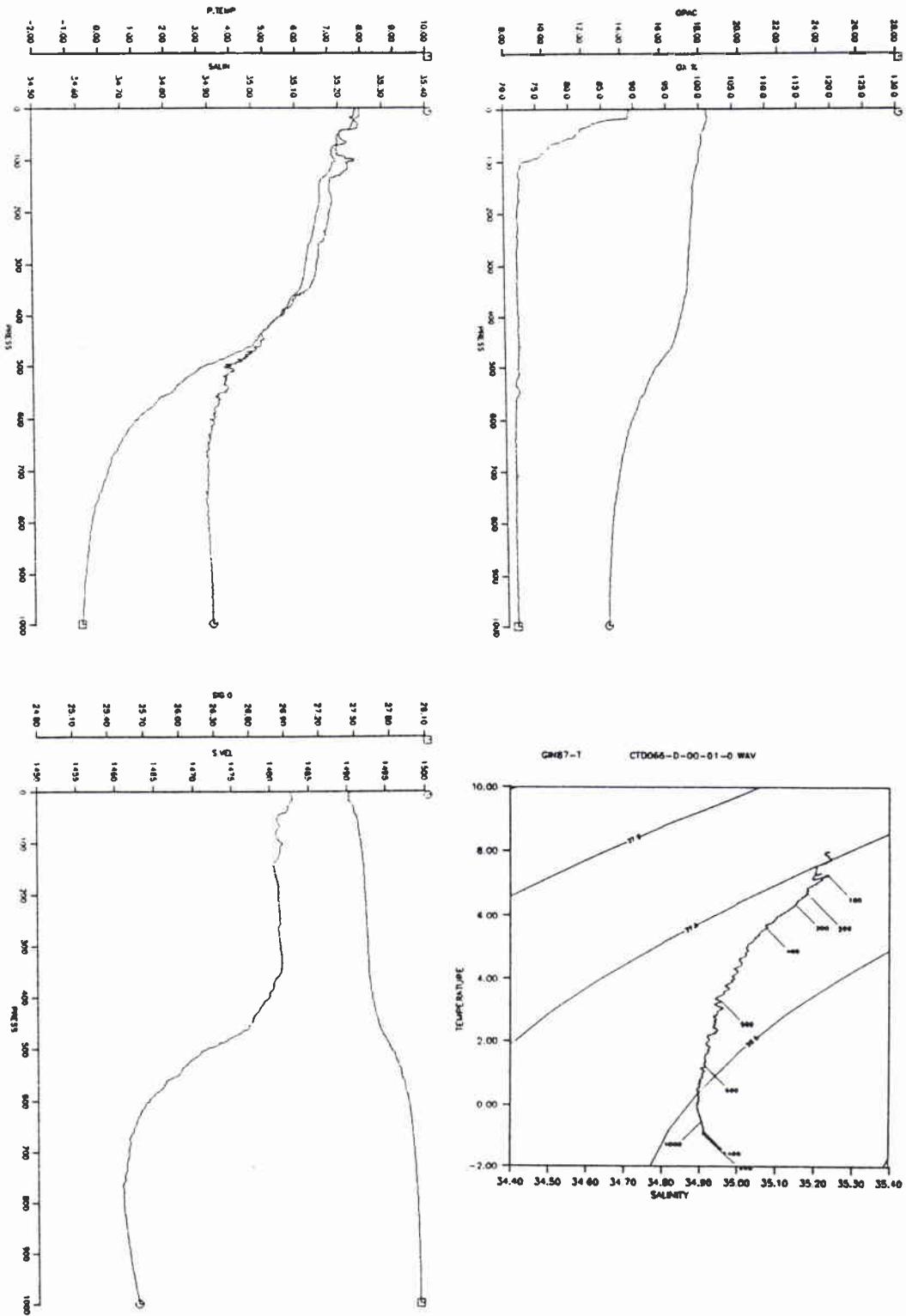


Figure B65

SACLANTCEN SM-249

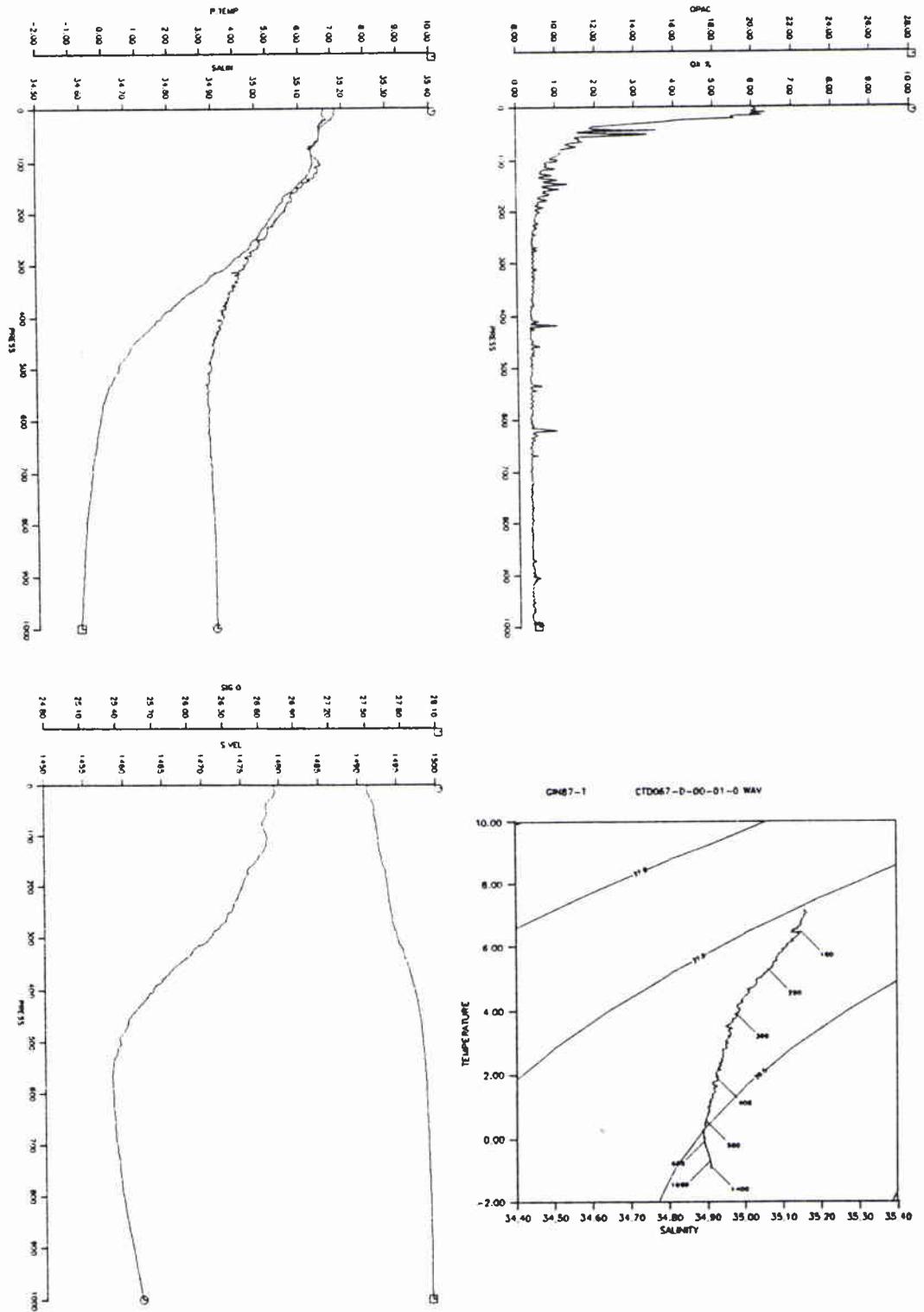


Figure B66

SACLANTCEN SM-249

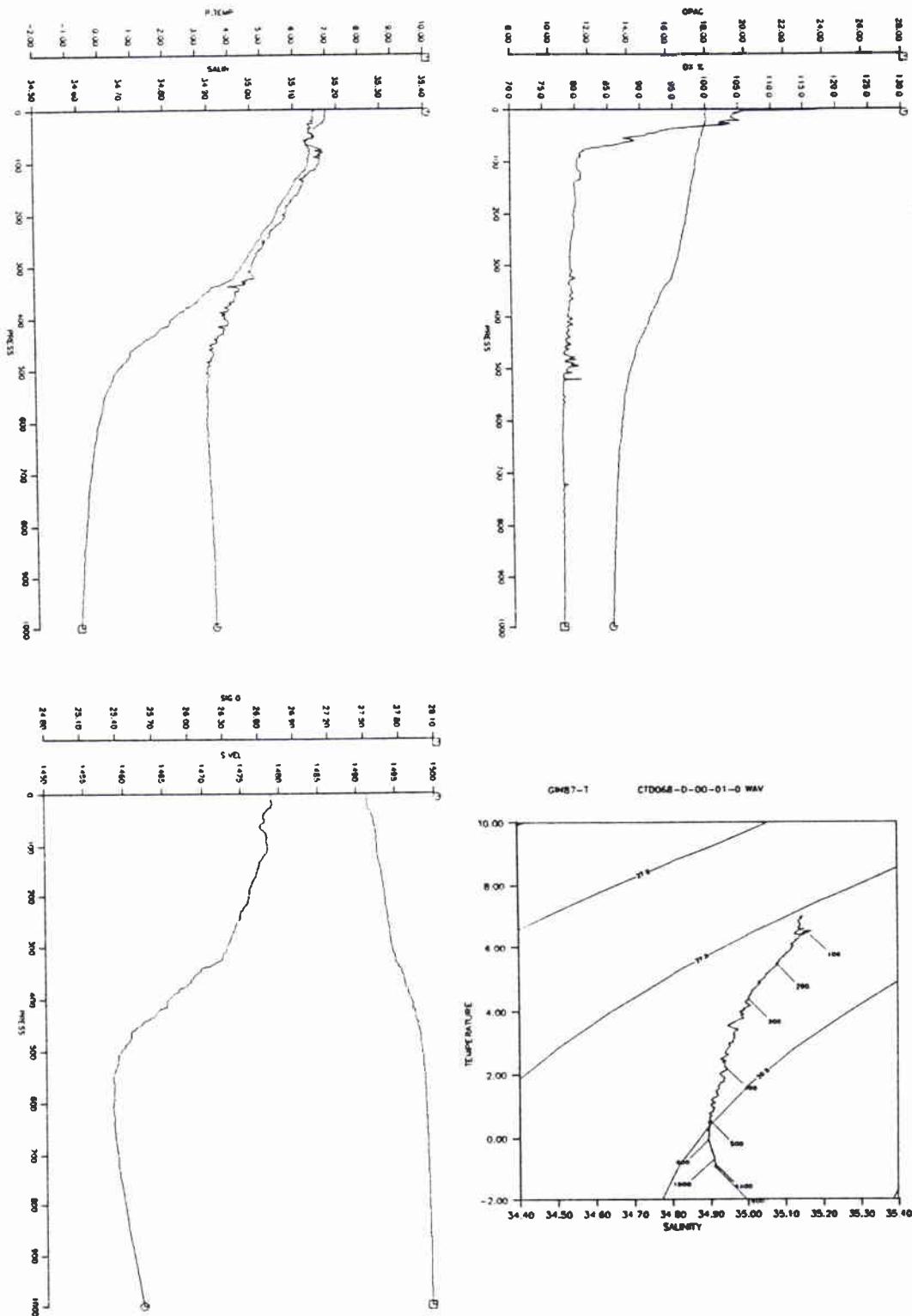


Figure B67

SACLANTCEN SM-249

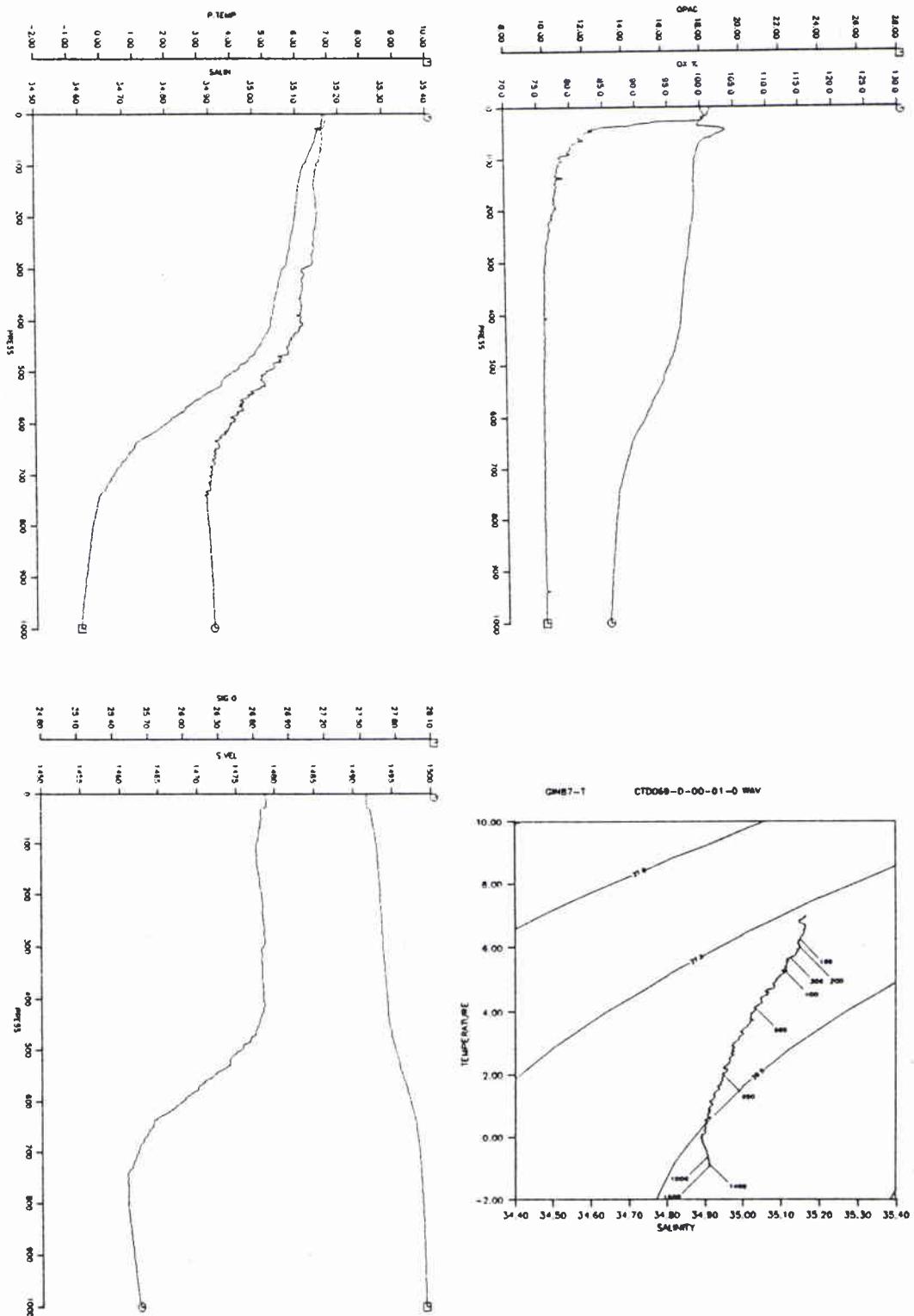


Figure B68

SACLANTCEN SM-249

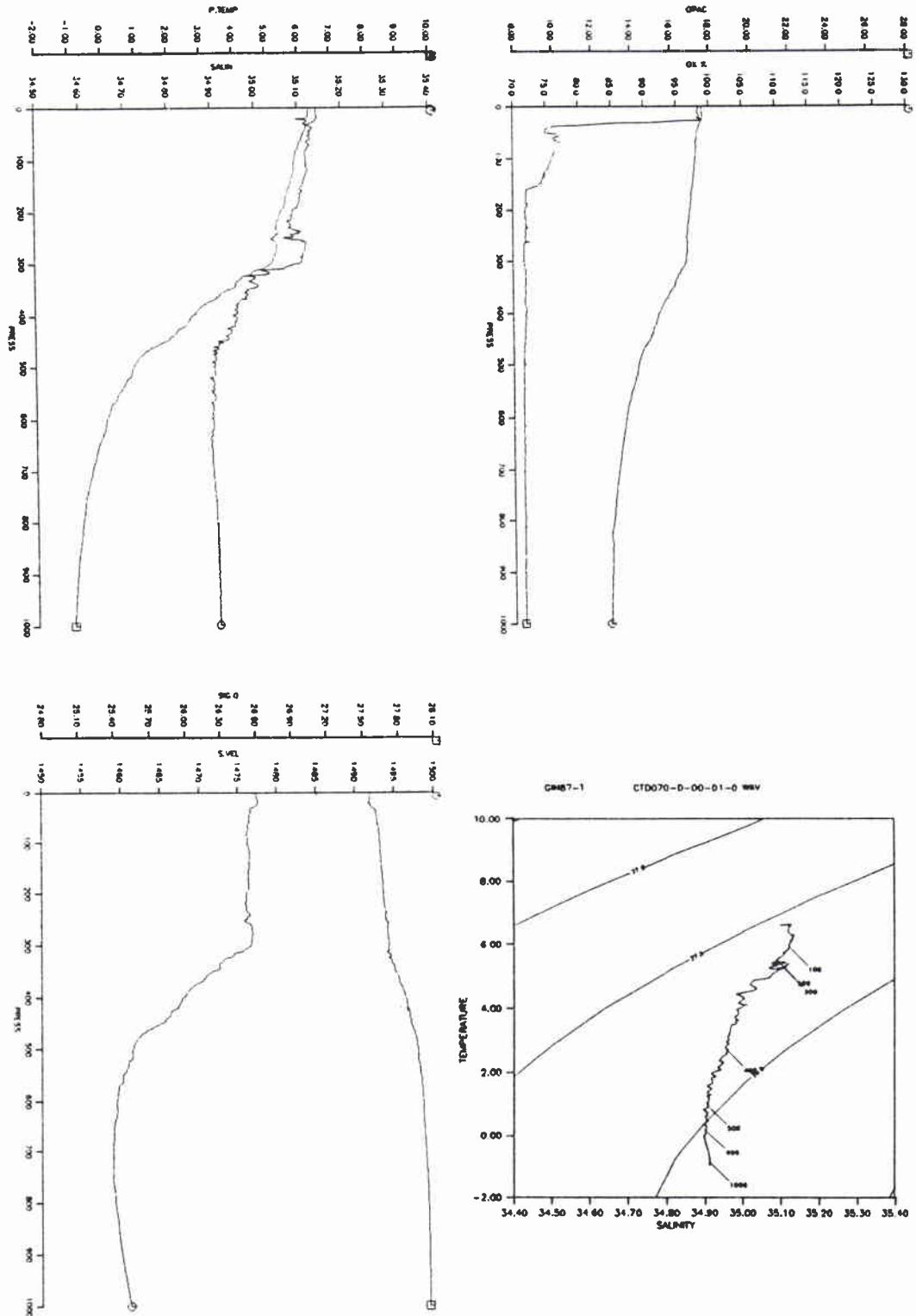


Figure B69

SACLANTCEN SM-249

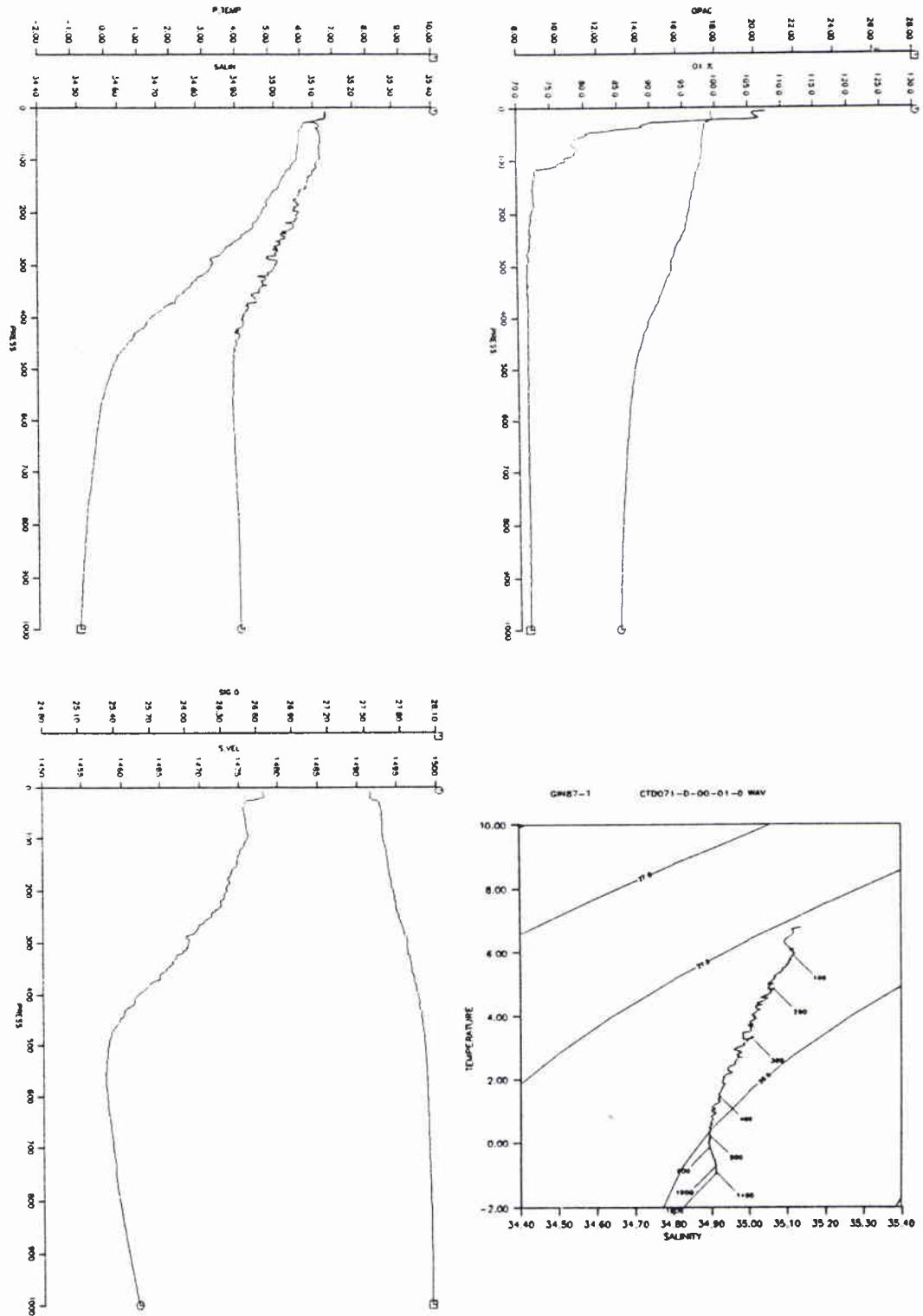


Figure B70

SACLANTCEN SM-249

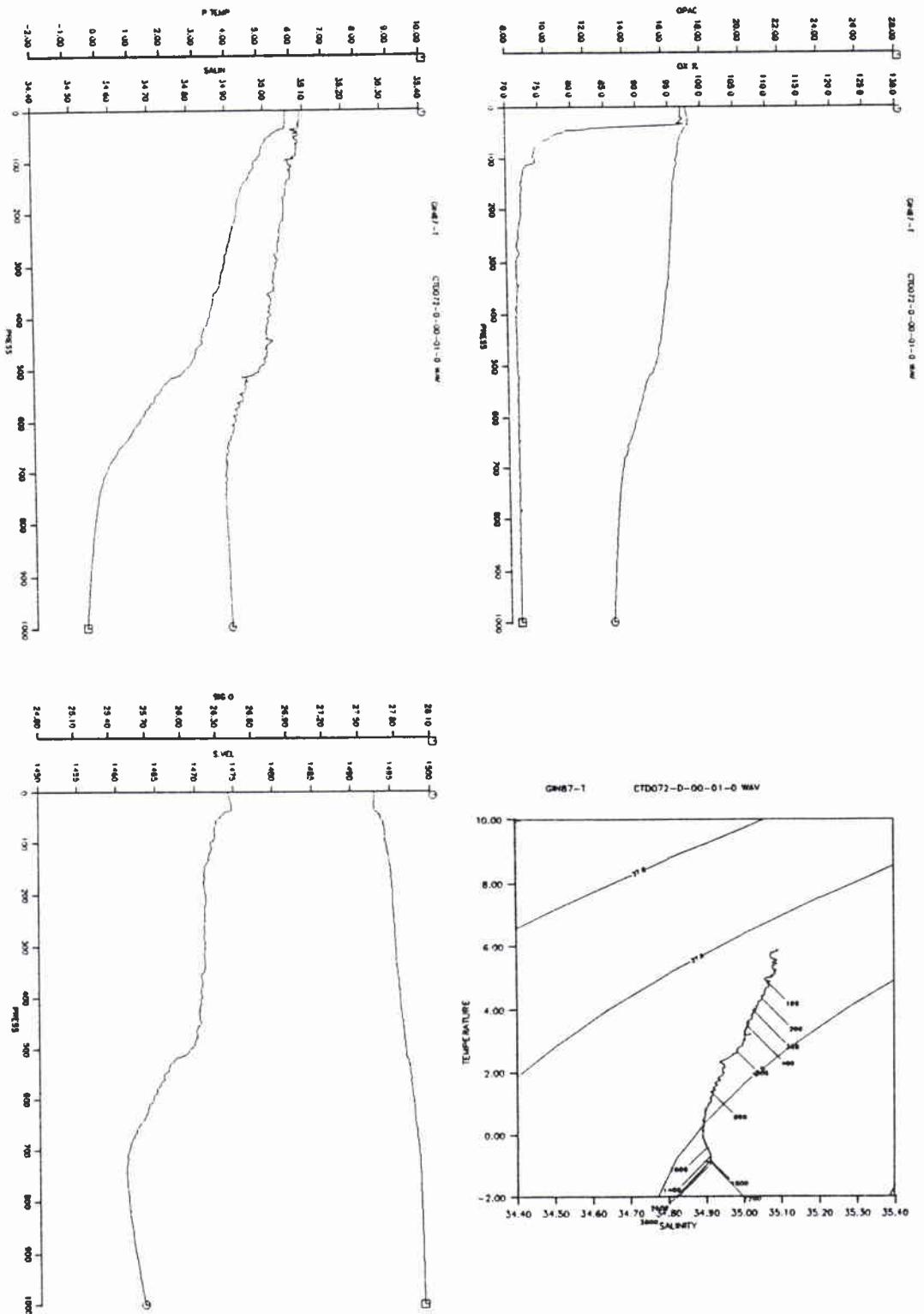


Figure B71

SACLANTCEN SM-249

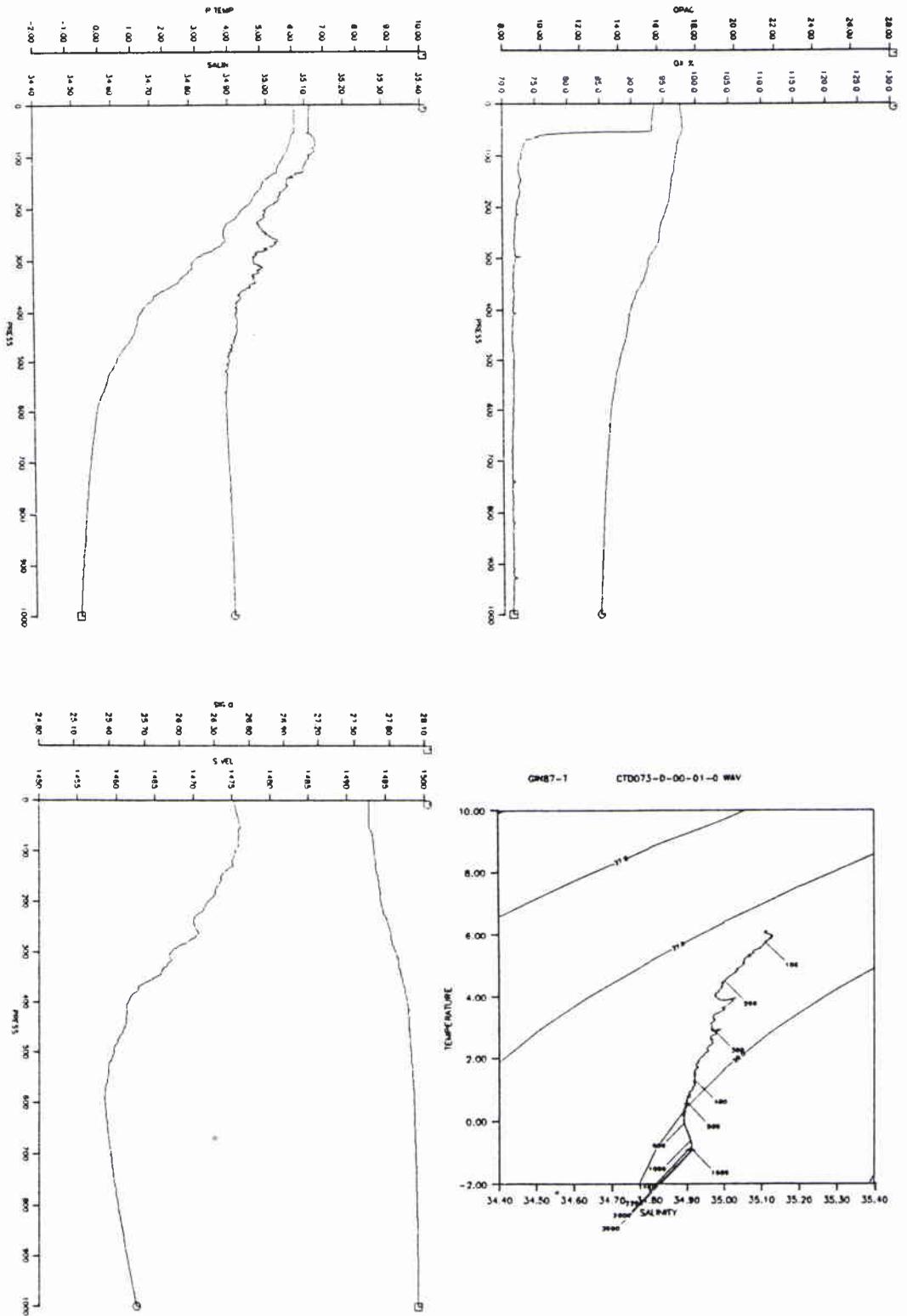


Figure B72

SACLANTCEN SM-249

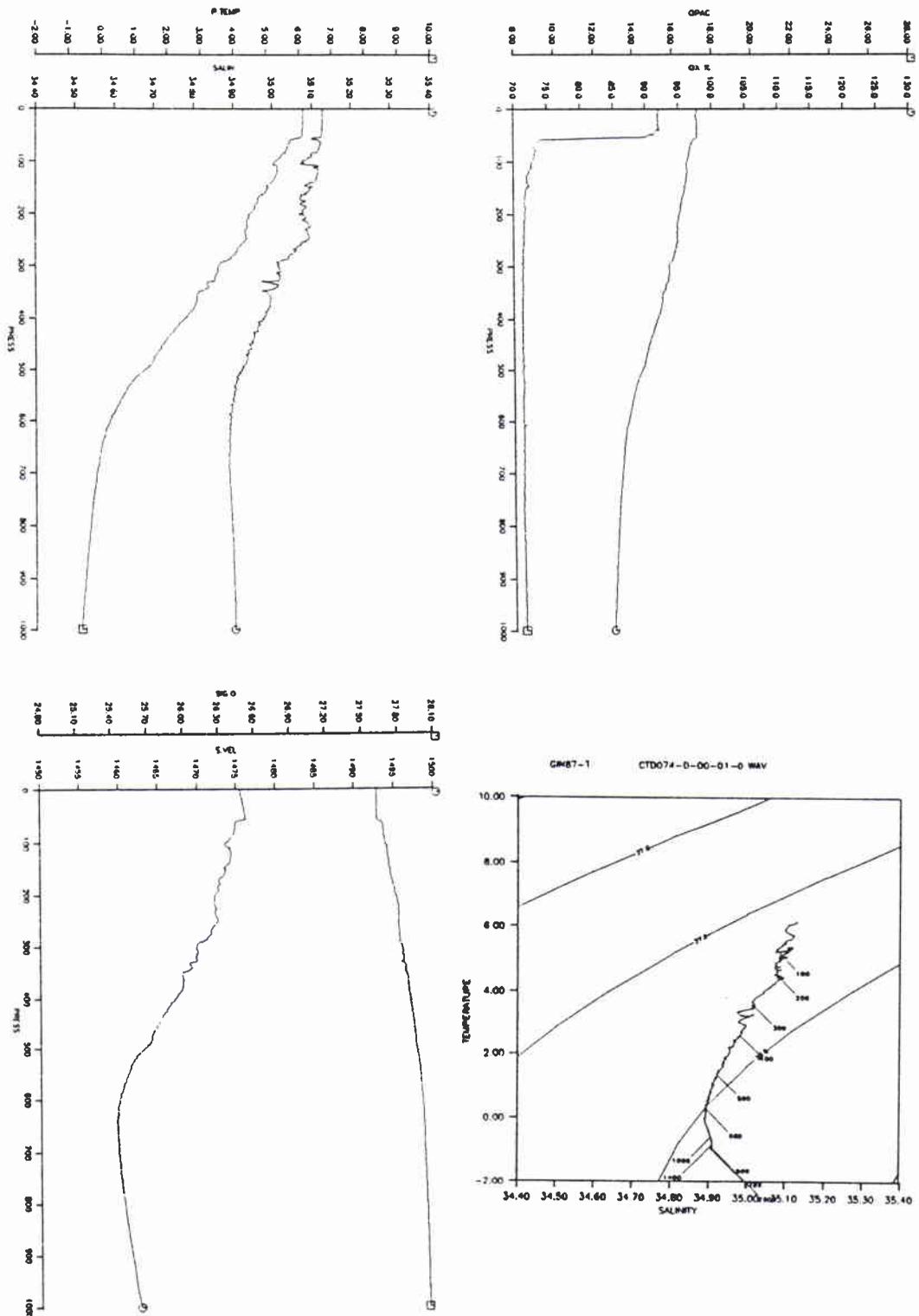


Figure B73

SACLANTCEN SM-249

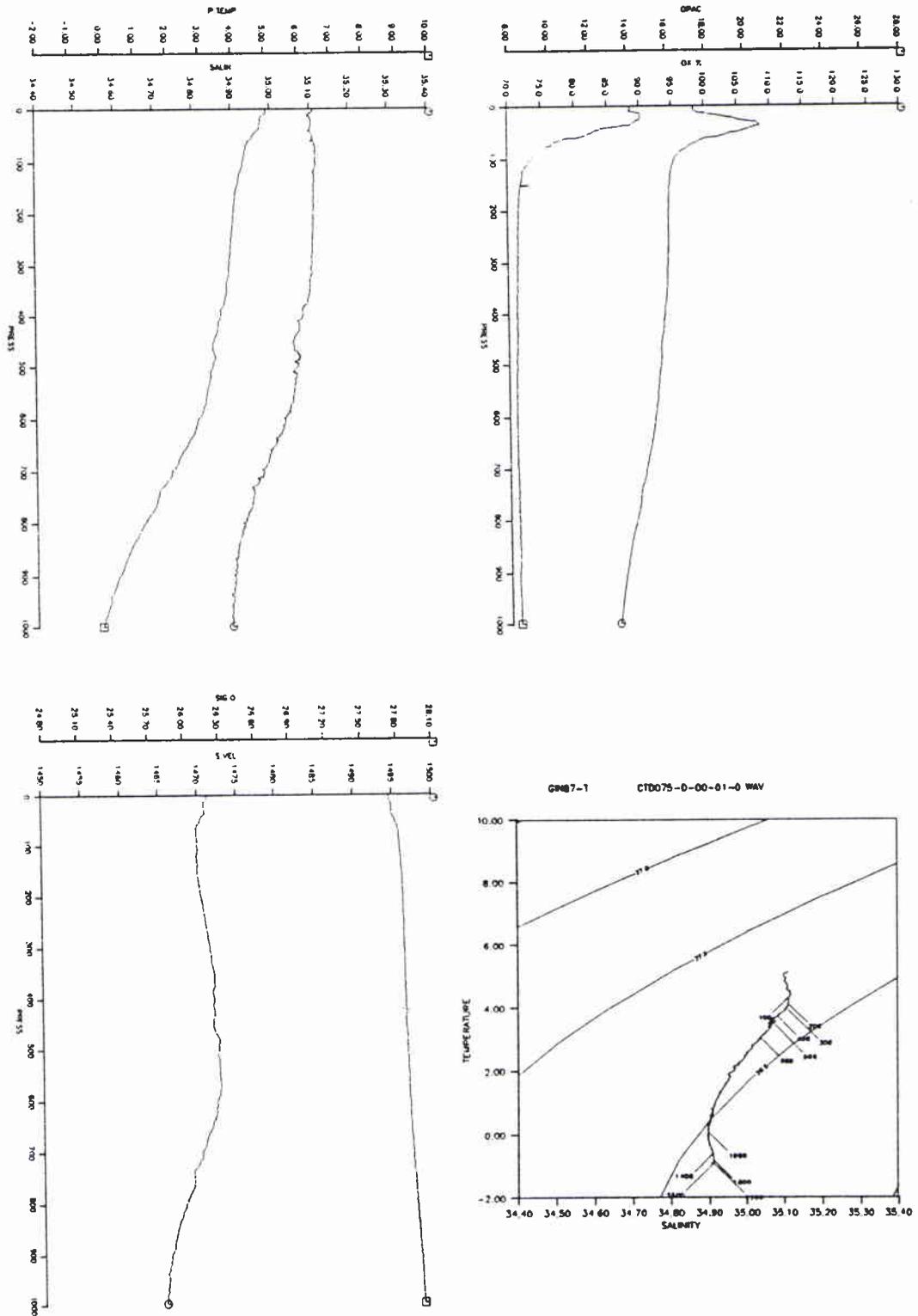


Figure B74

SACLANTCEN SM-249

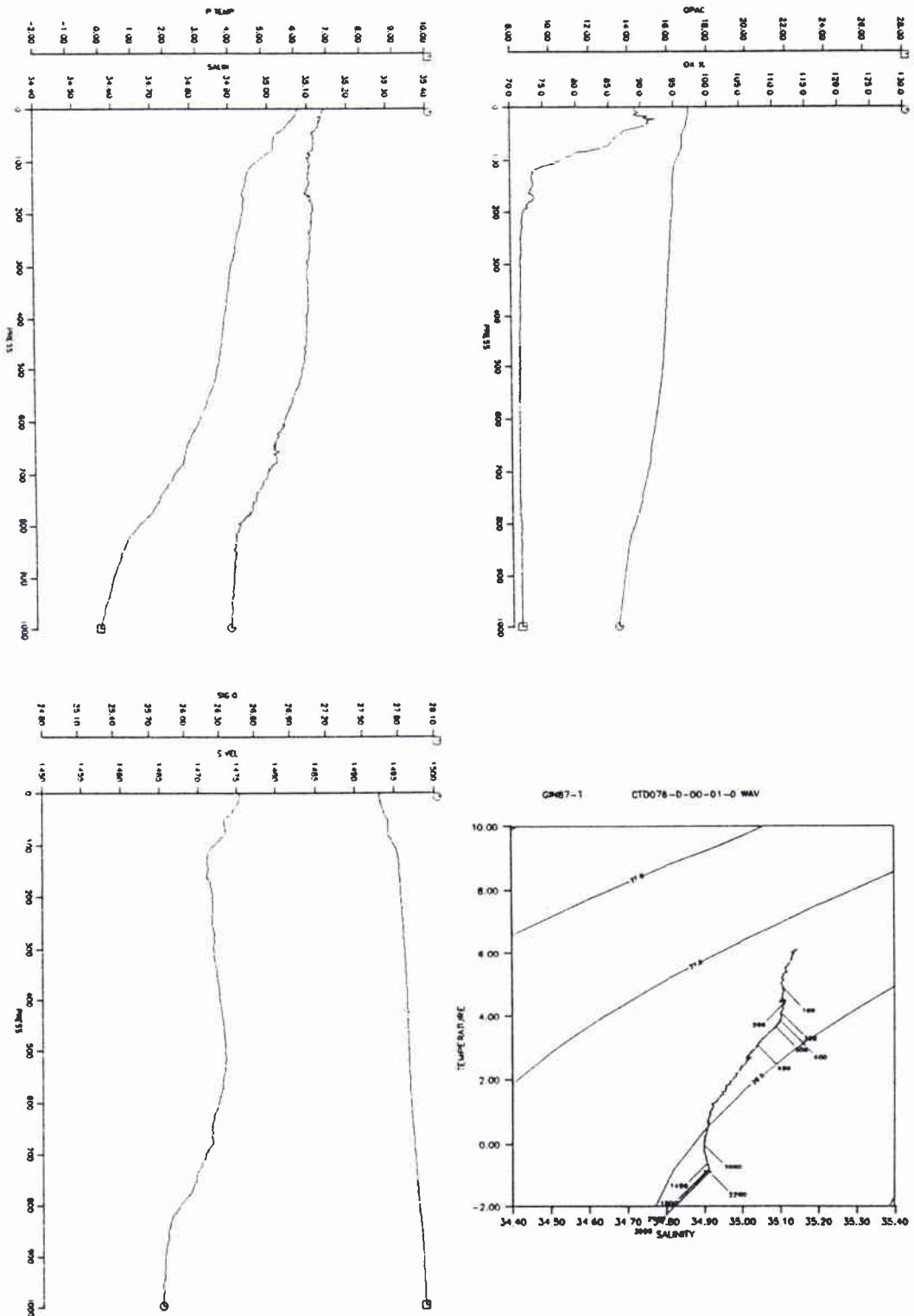


Figure B75

SACLANTCEN SM-249

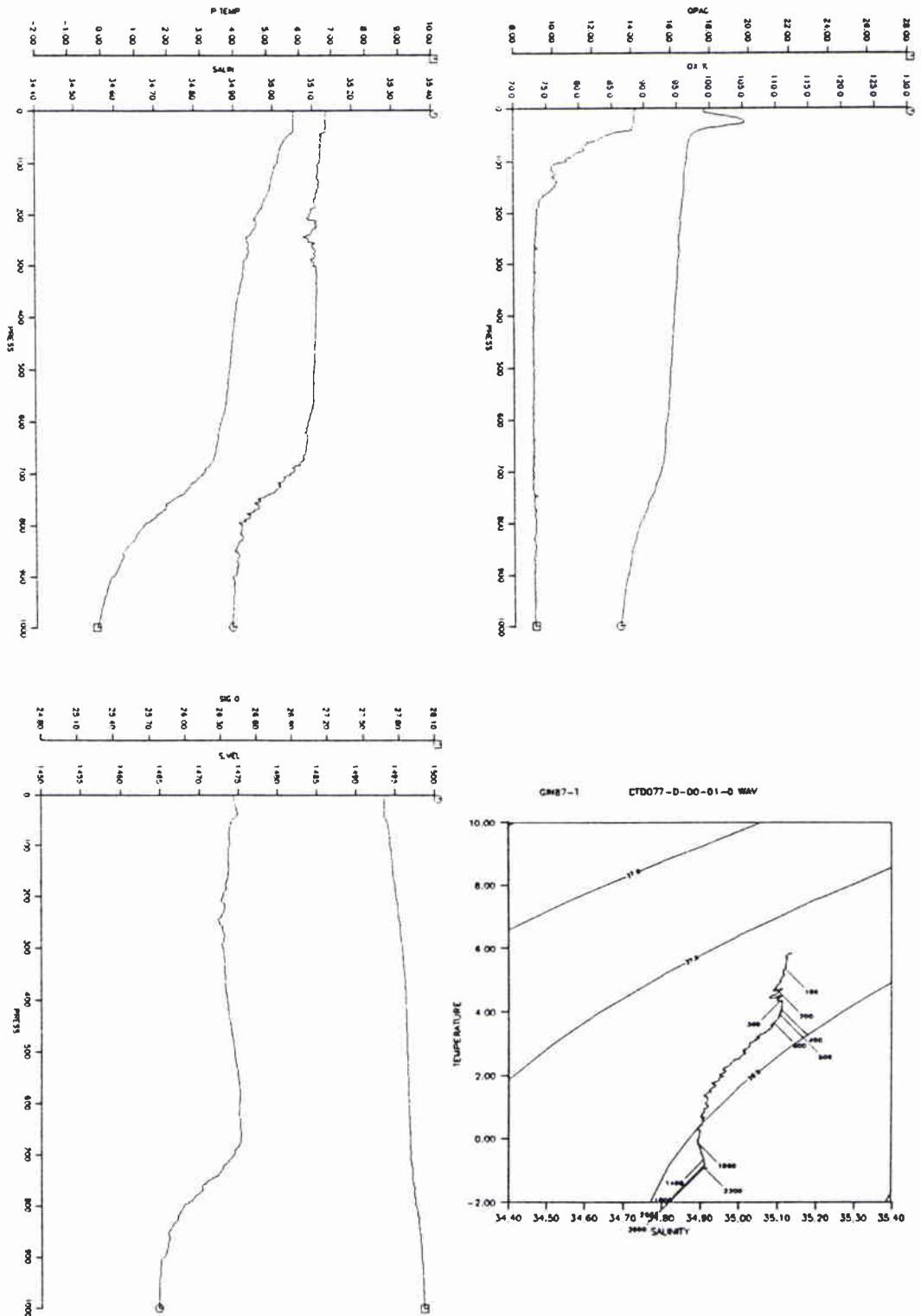


Figure B76

SACLANTCEN SM-249

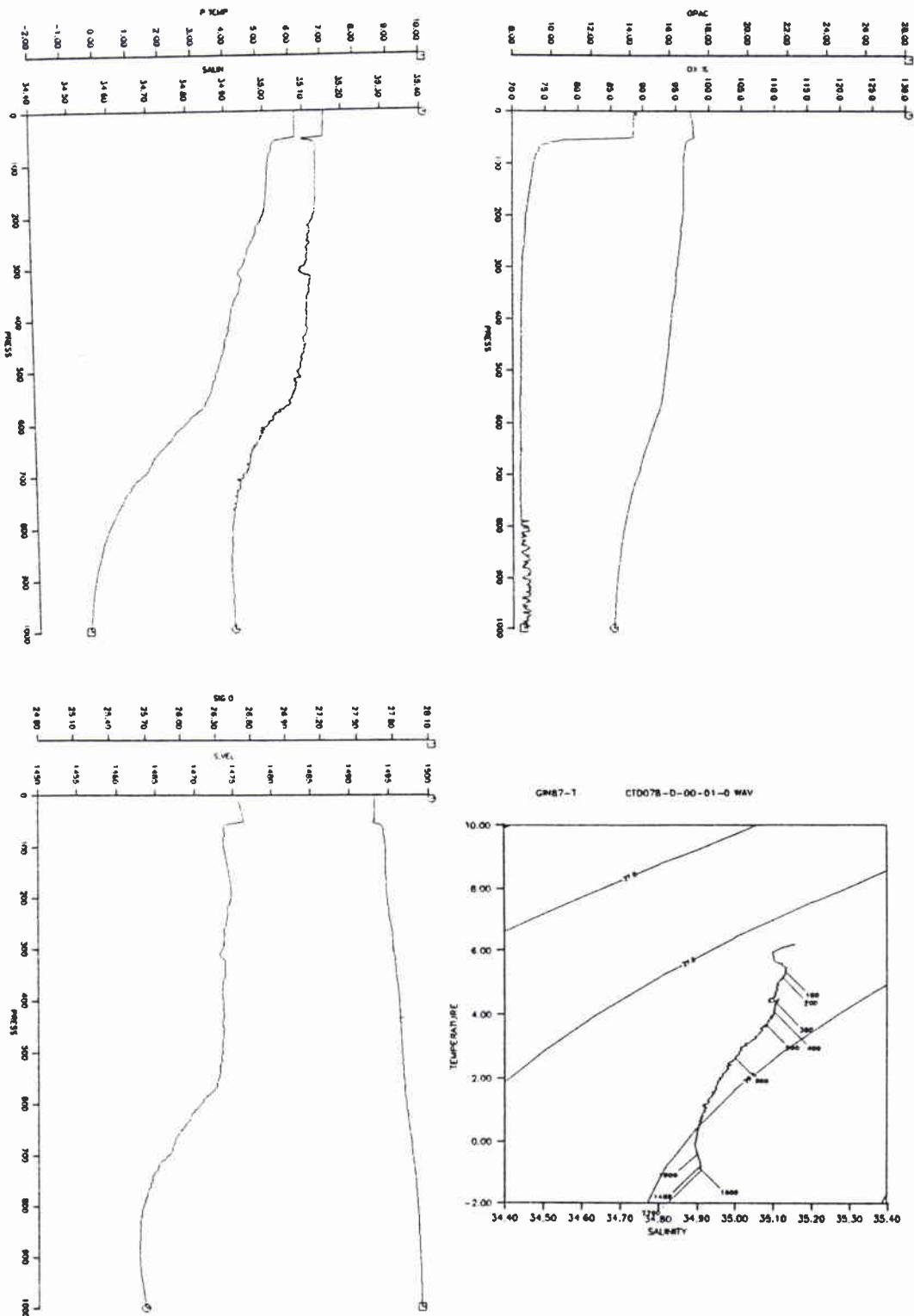


Figure B77

SACLANTCEN SM-249

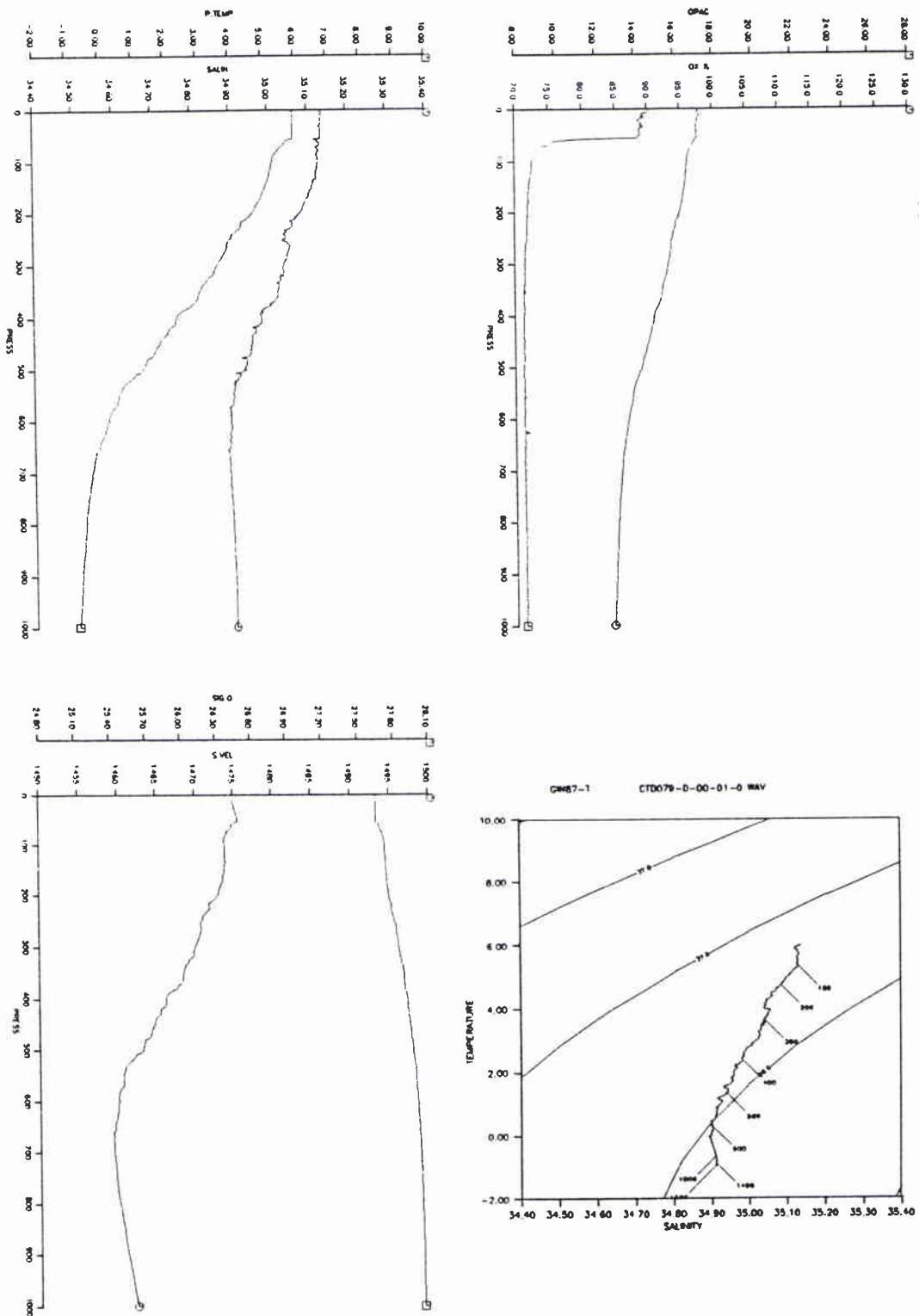


Figure B78

SACLANTCEN SM-249

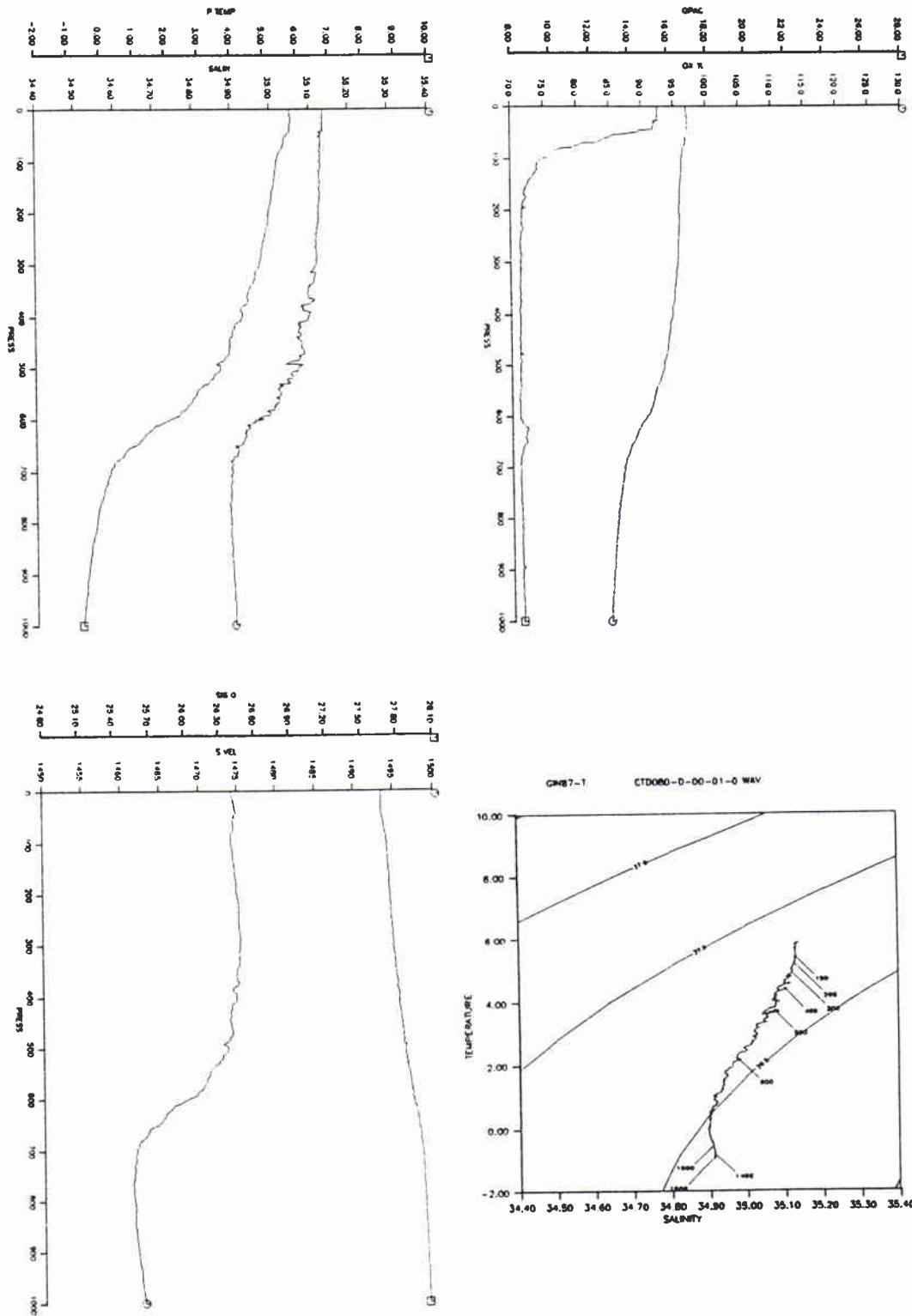


Figure B79

SACLANTCEN SM-249

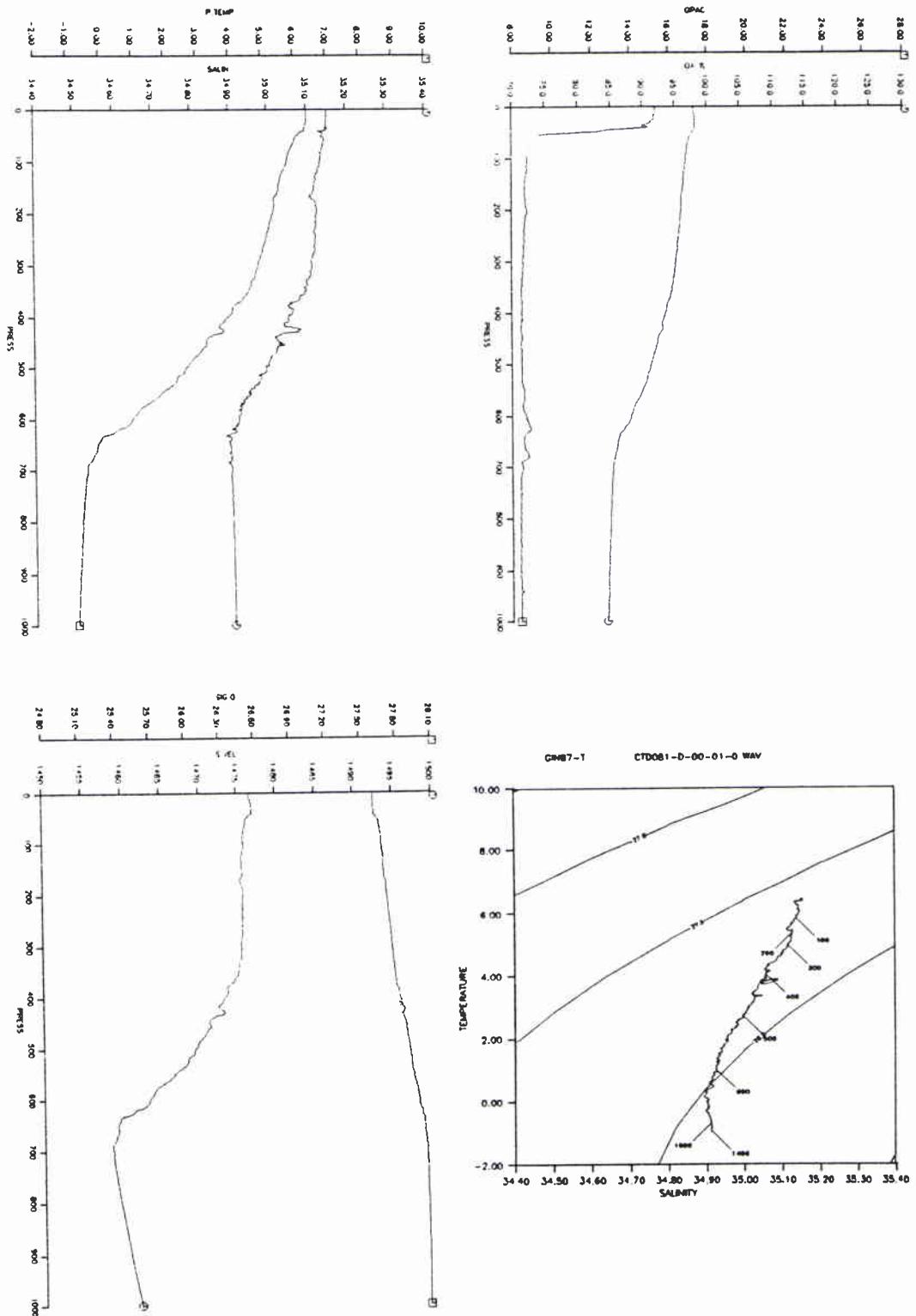


Figure B80

SACLANTCEN SM-249

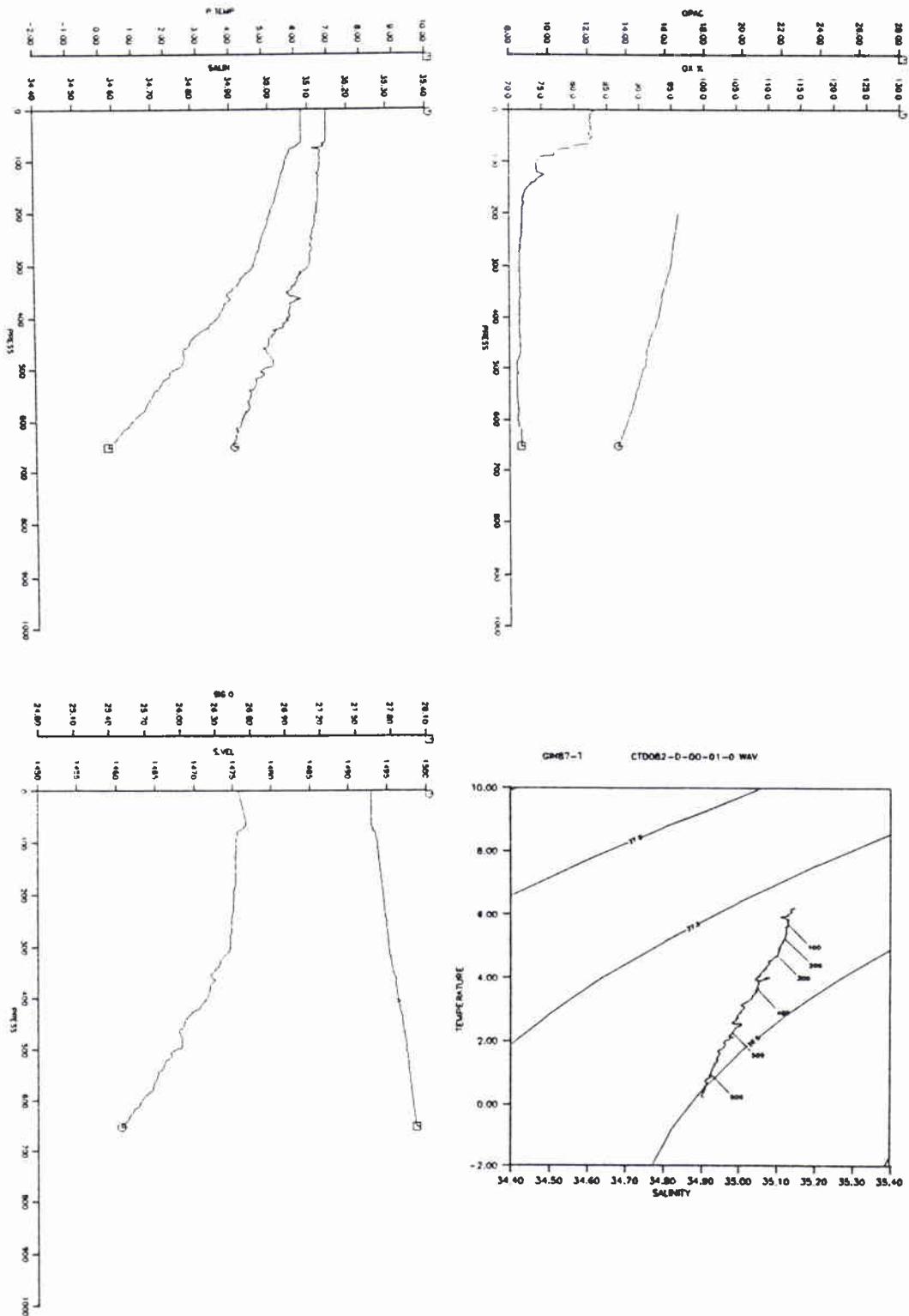


Figure B81

SACLANTCEN SM-249

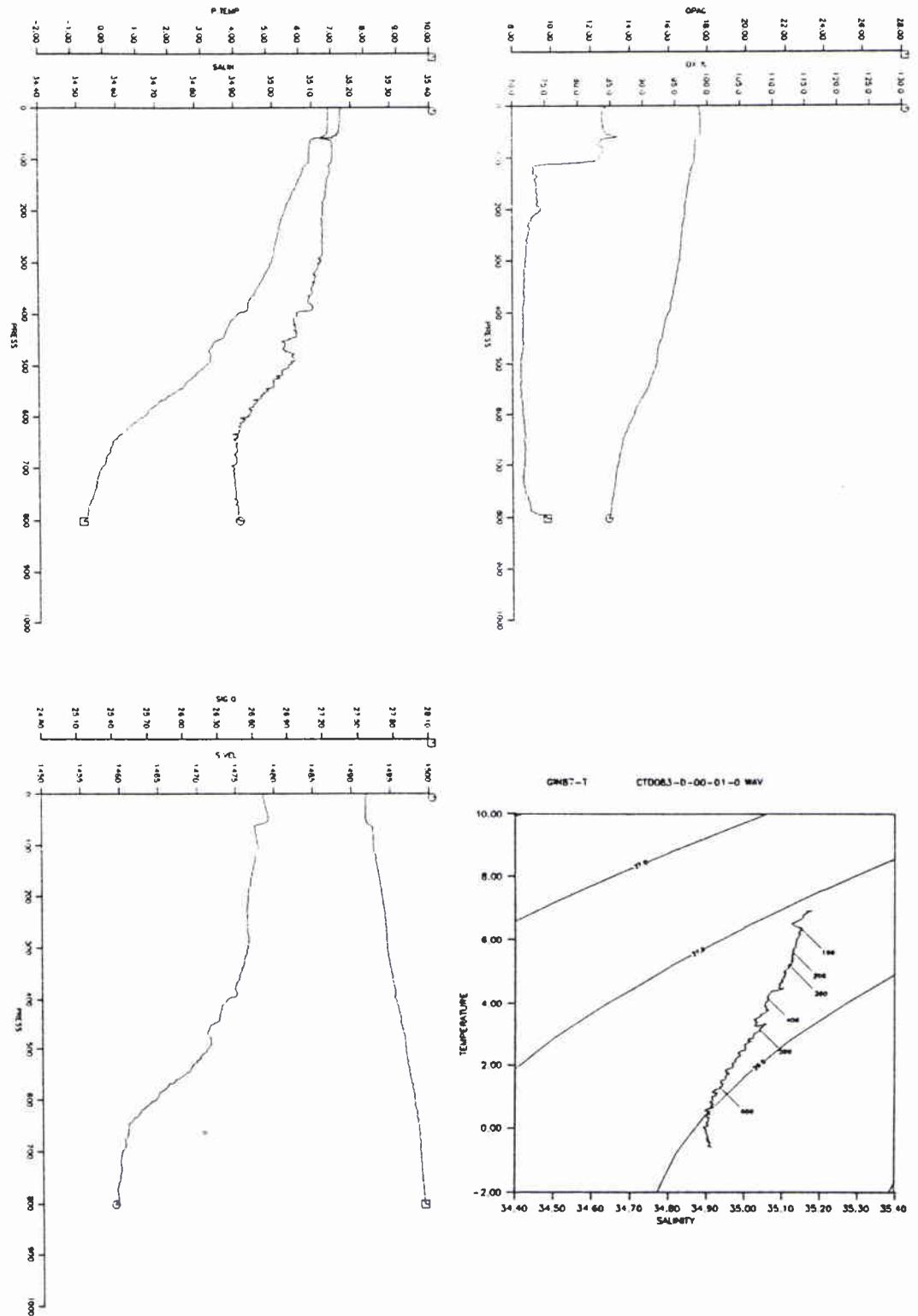


Figure B82

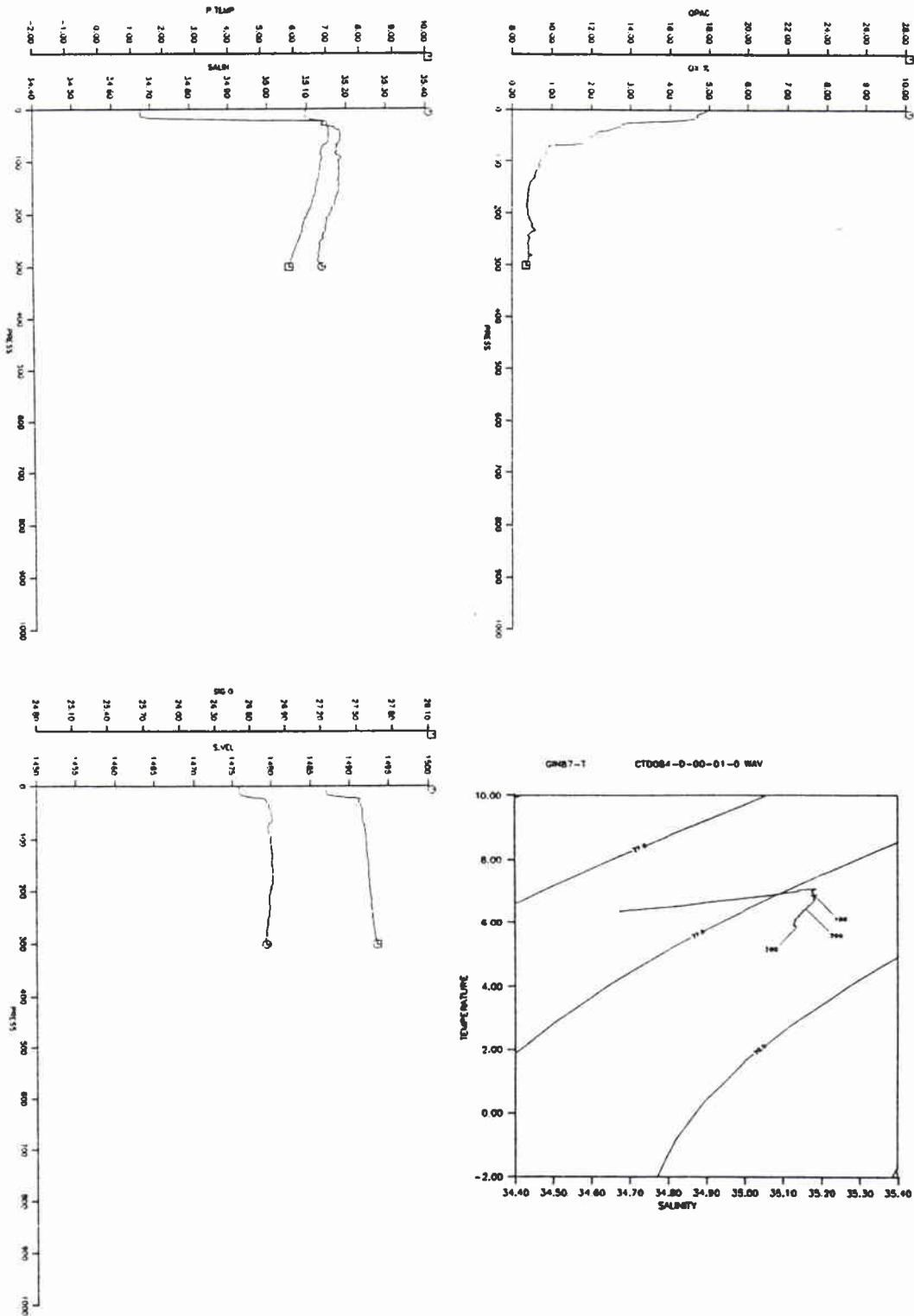


Figure B83

SACLANTCEN SM-249

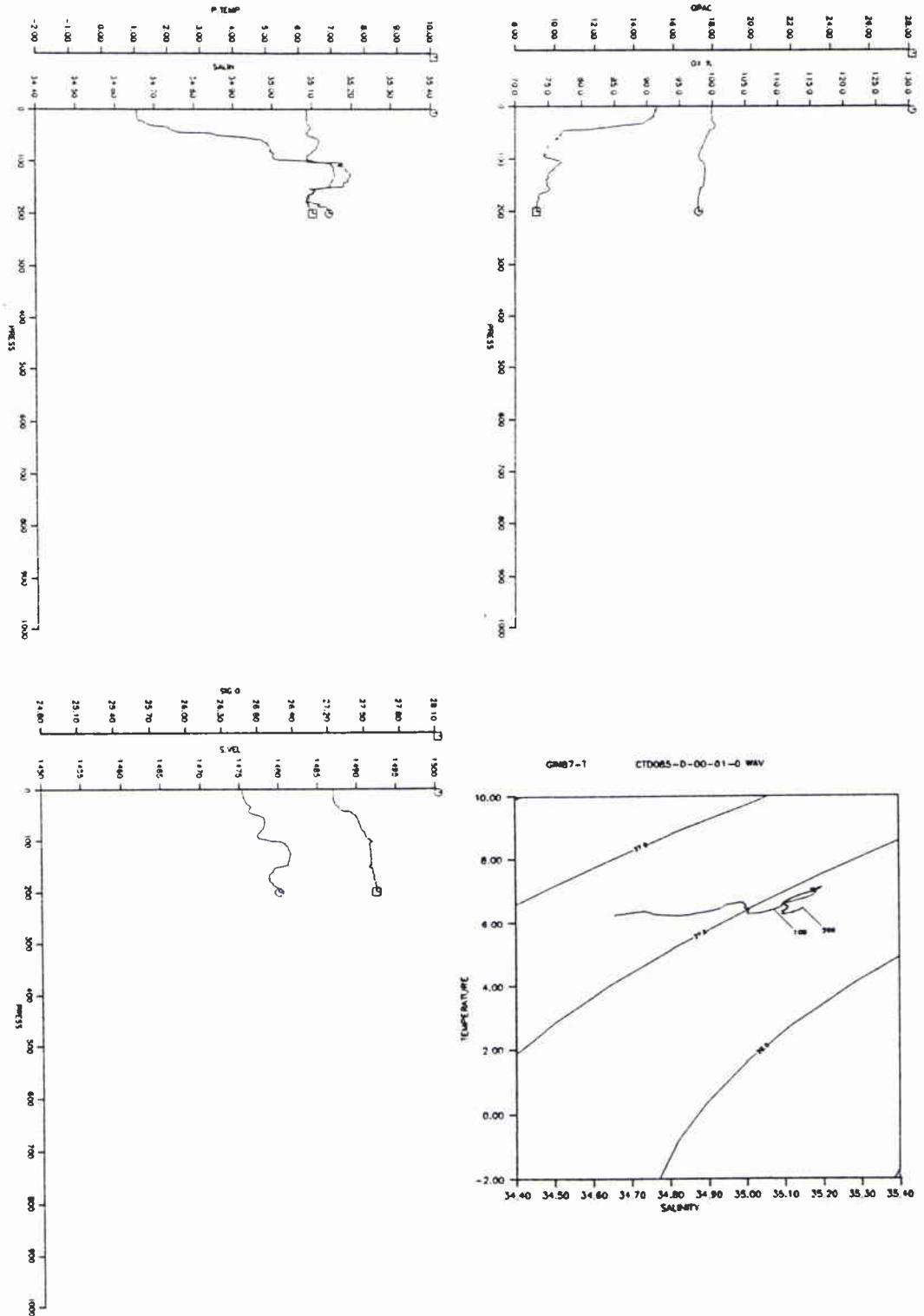


Figure B84

SACLANTCEN SM-249

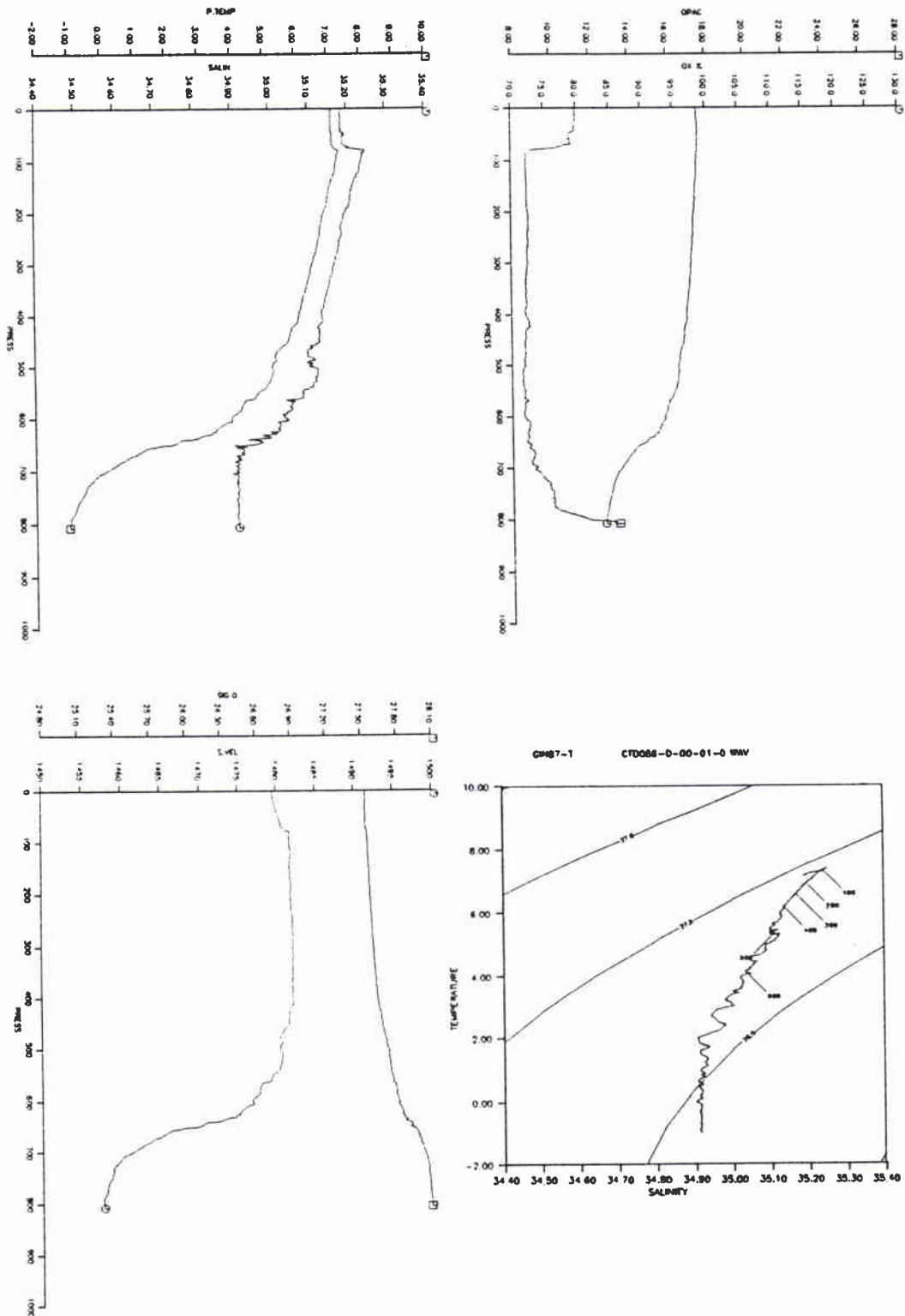


Figure B85

SACLANTCEN SM-249

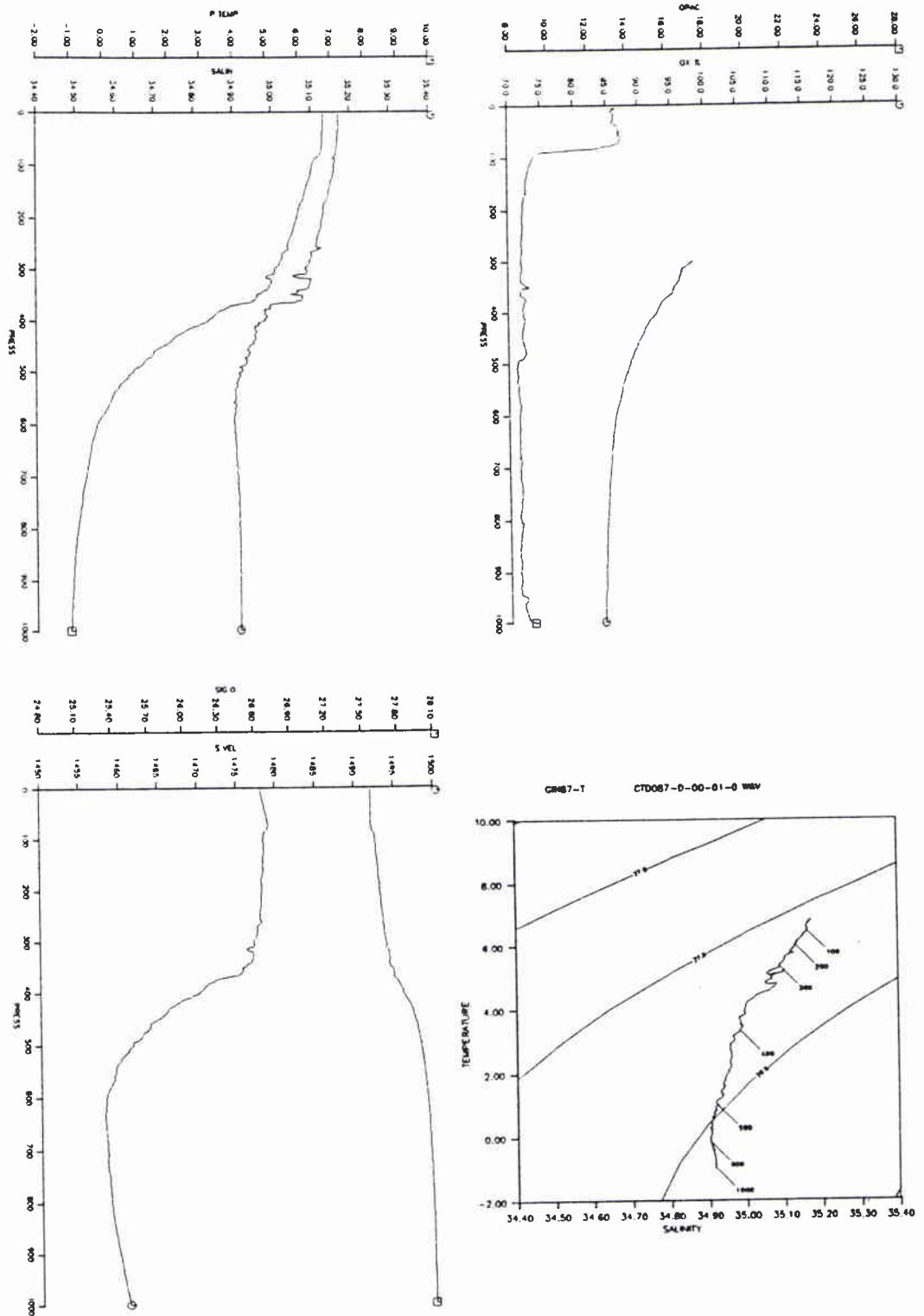


Figure B86

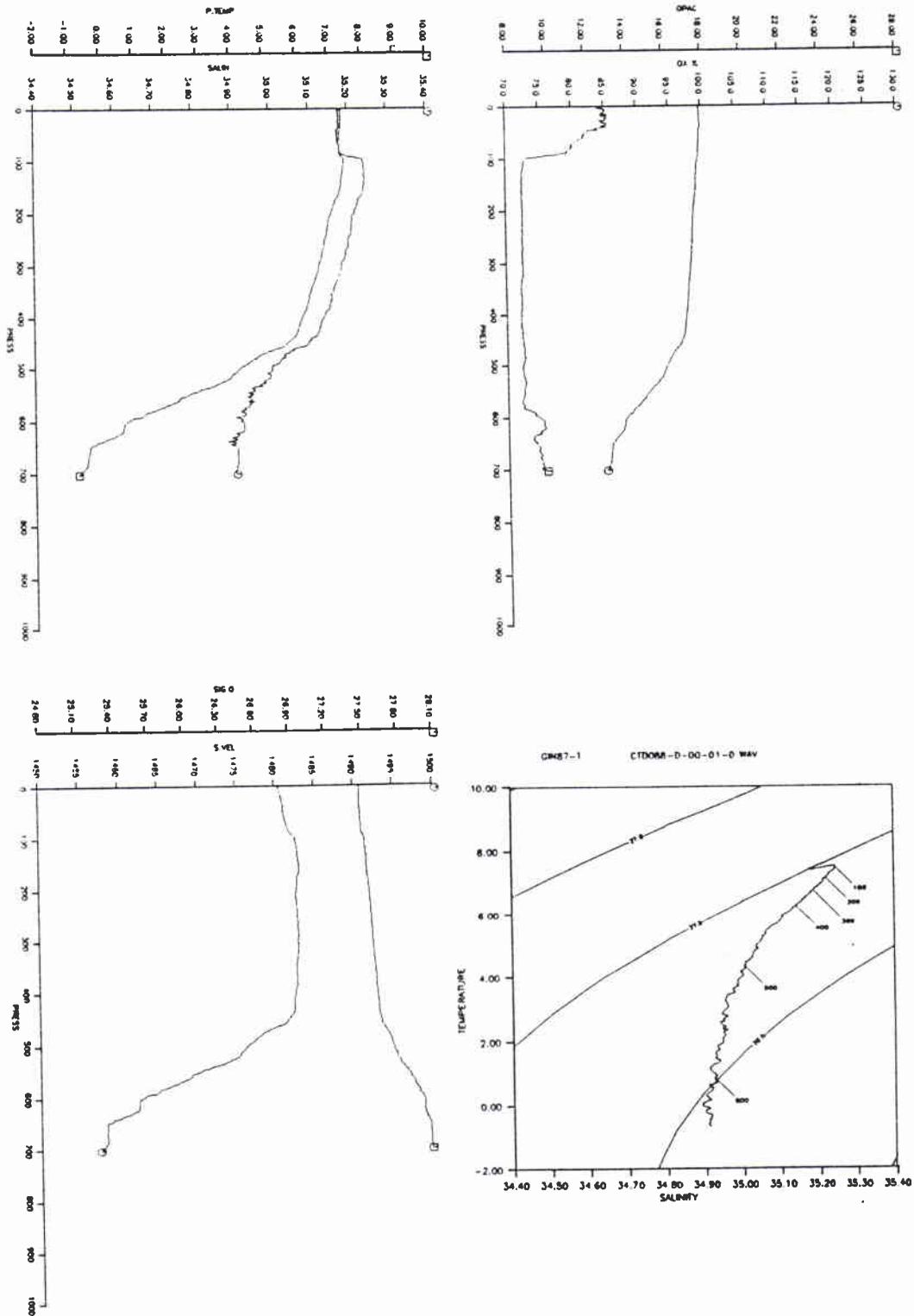


Figure B87

SACLANTCEN SM-249

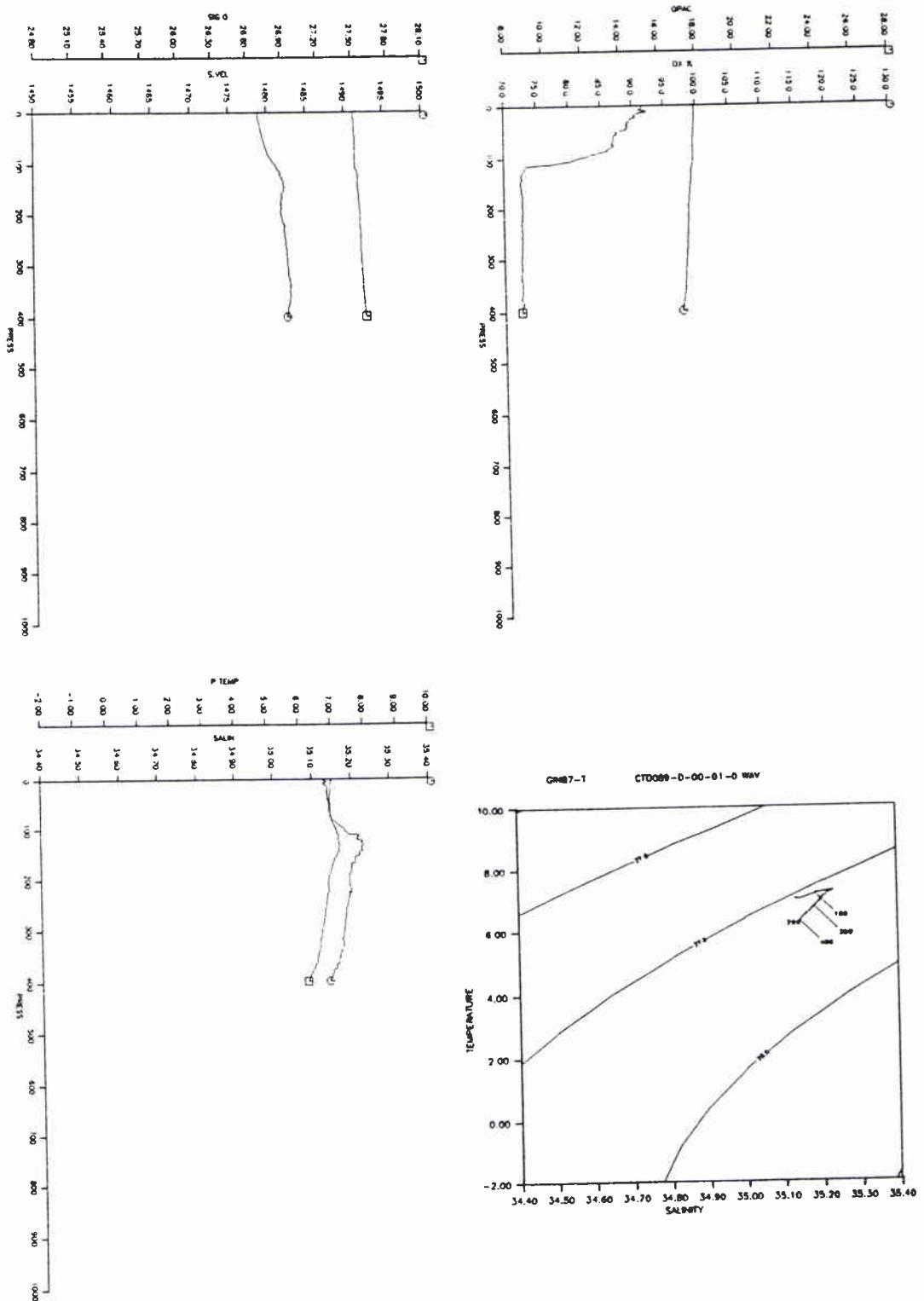


Figure B88

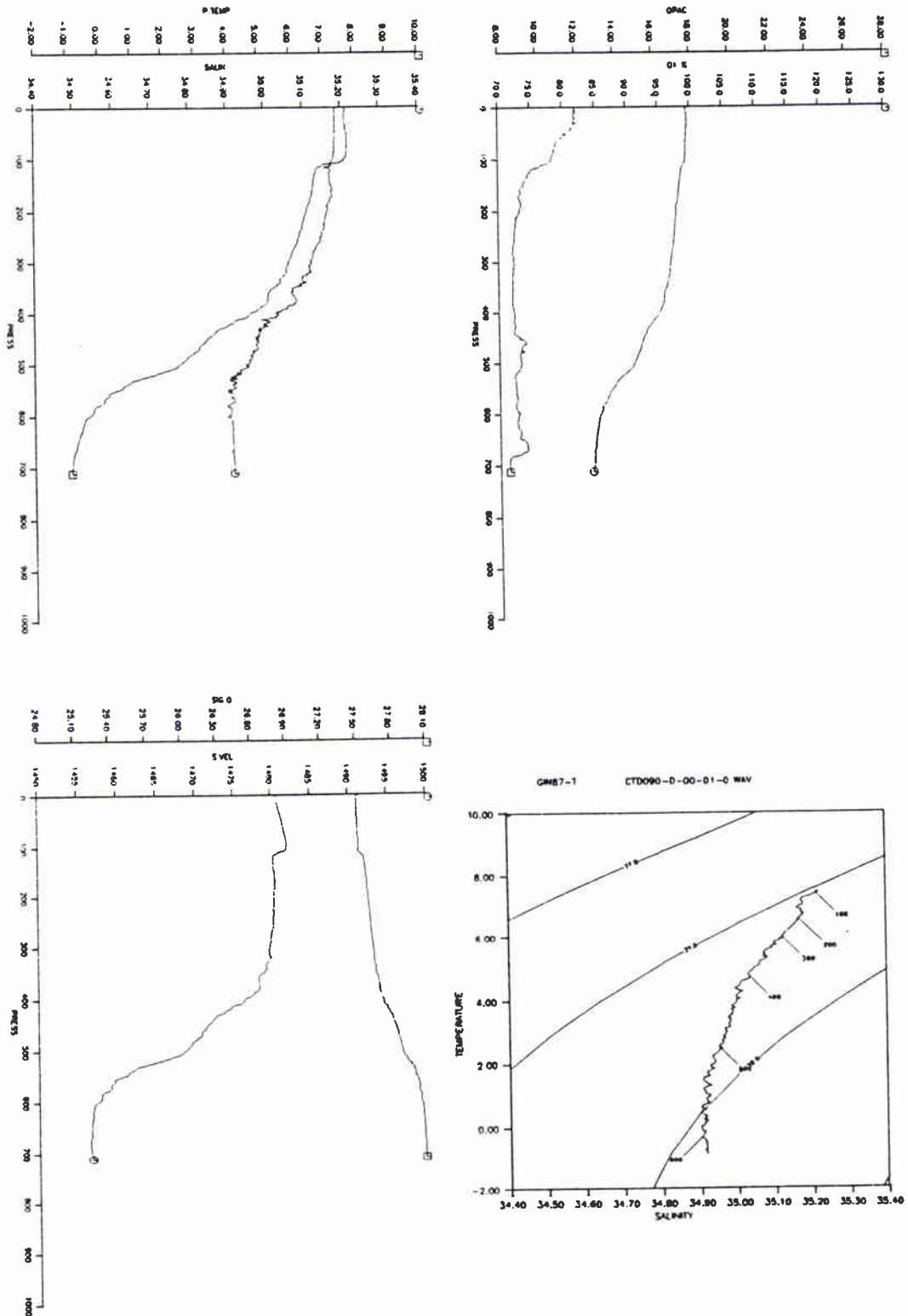


Figure B89

SACLANTCEN SM-249

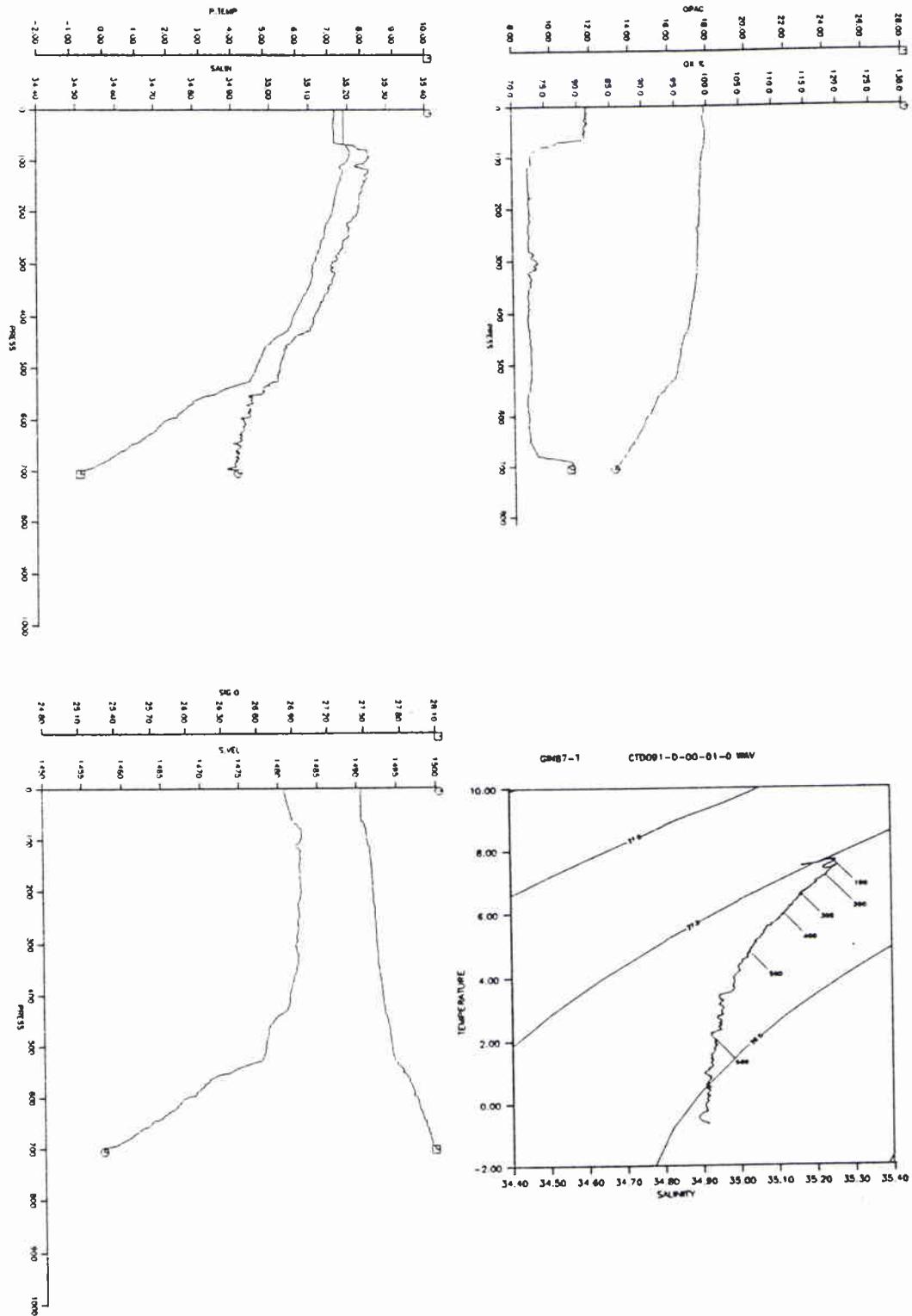


Figure B90

SACLANTCEN SM-249

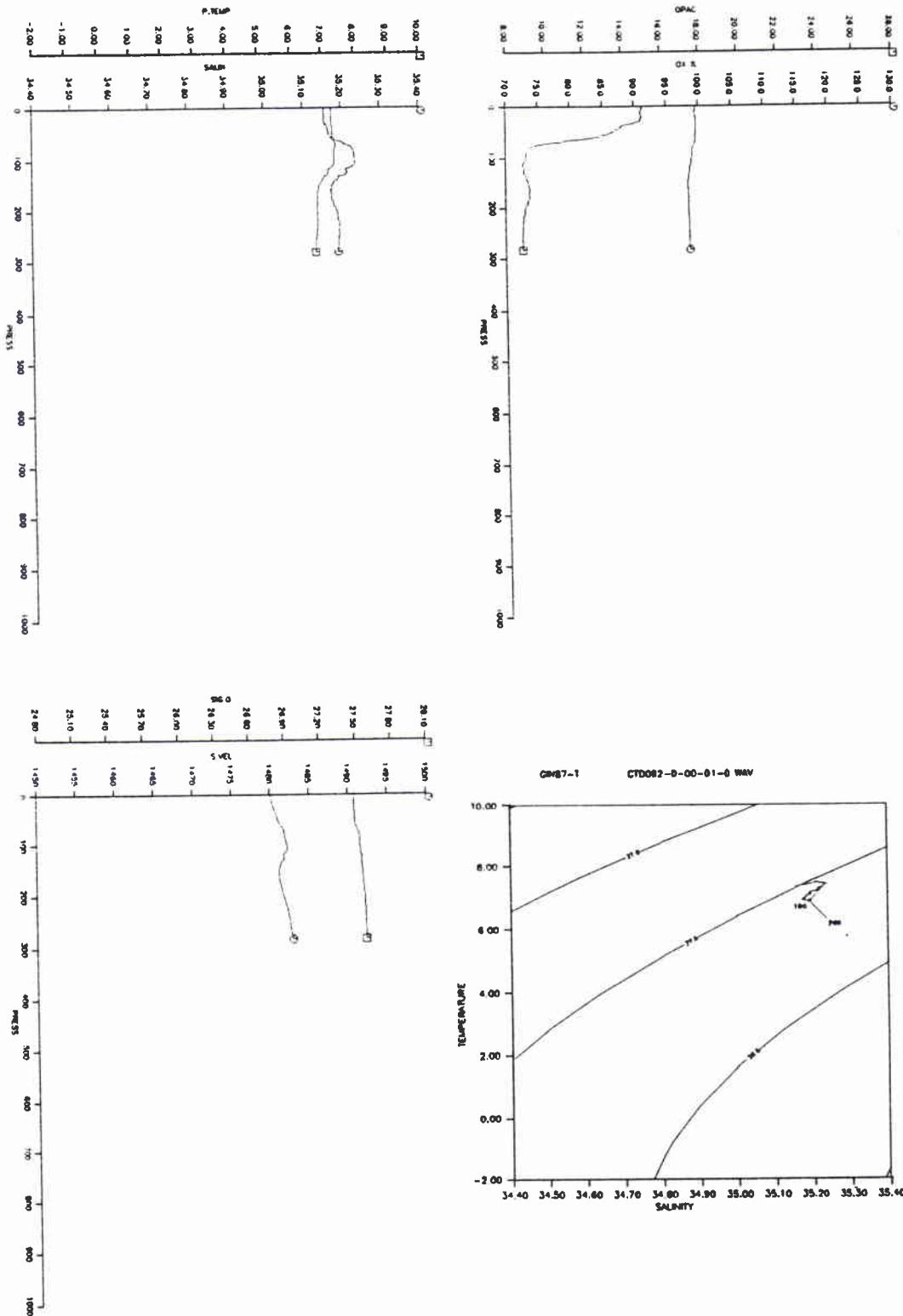


Figure B01

SACLANTCEN SM-249

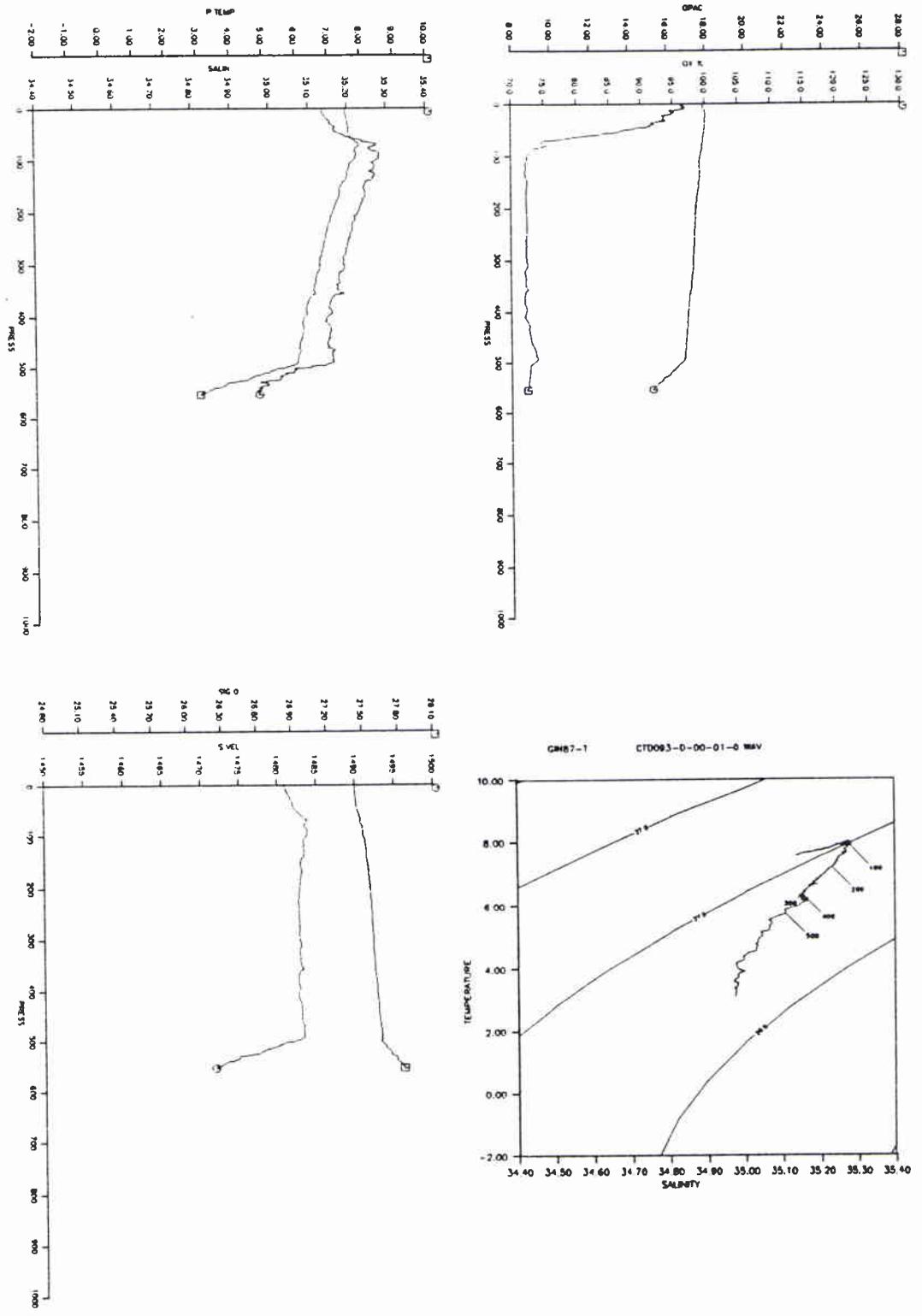


Figure B92

SACLANTCEN SM-249

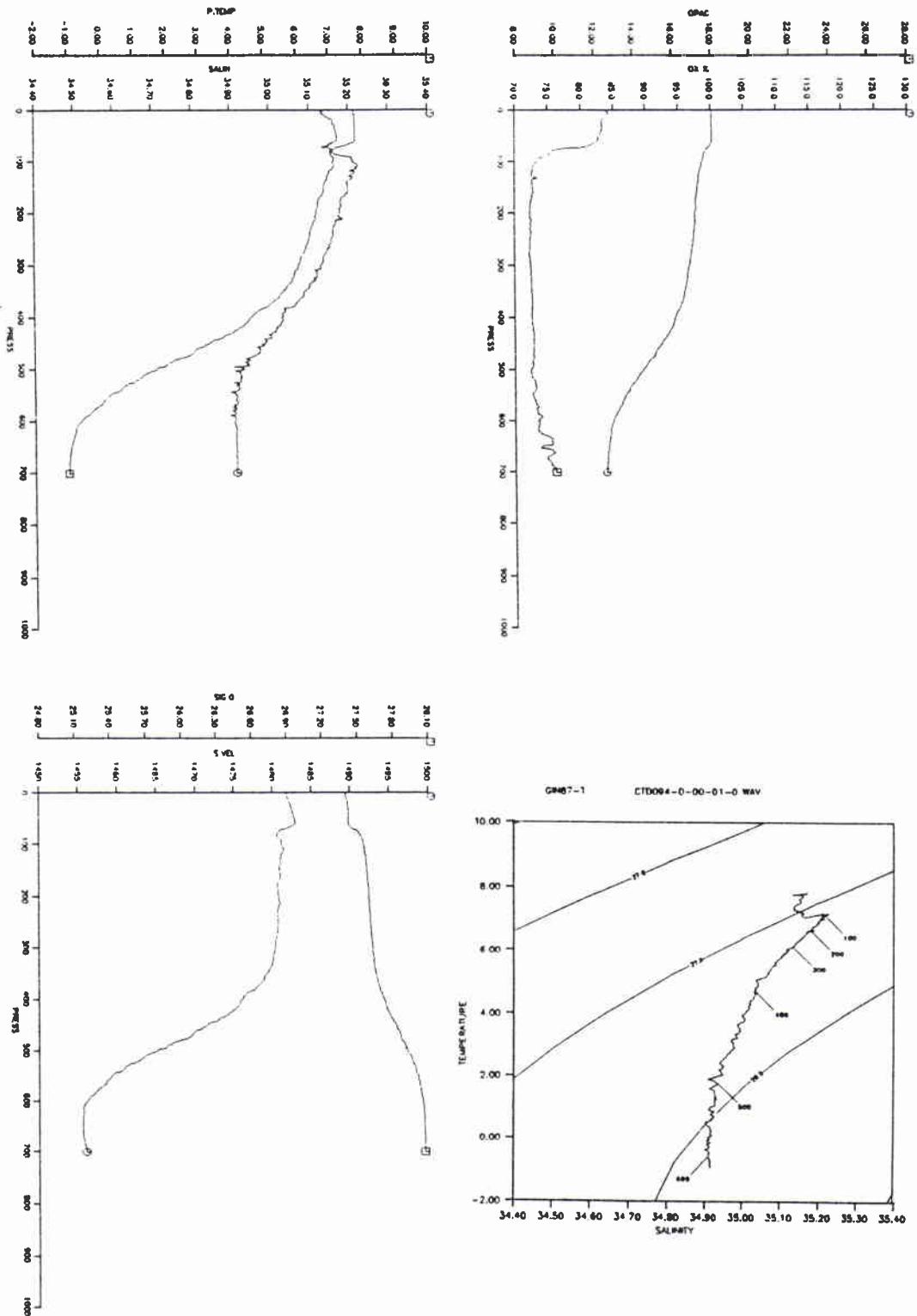


Figure B93

SACLANTCEN SM-249

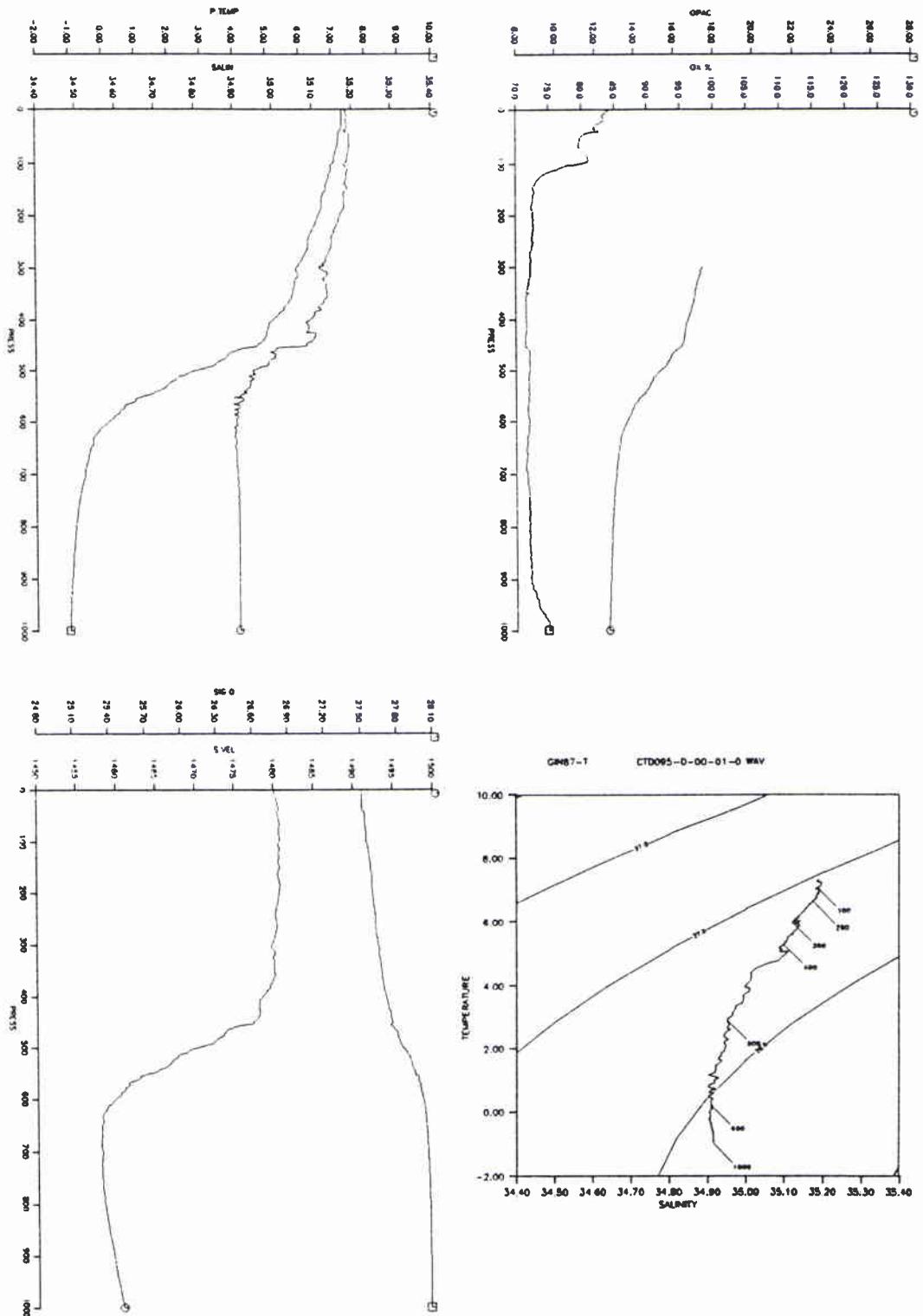


Figure B04

SACLANTCEN SM-249

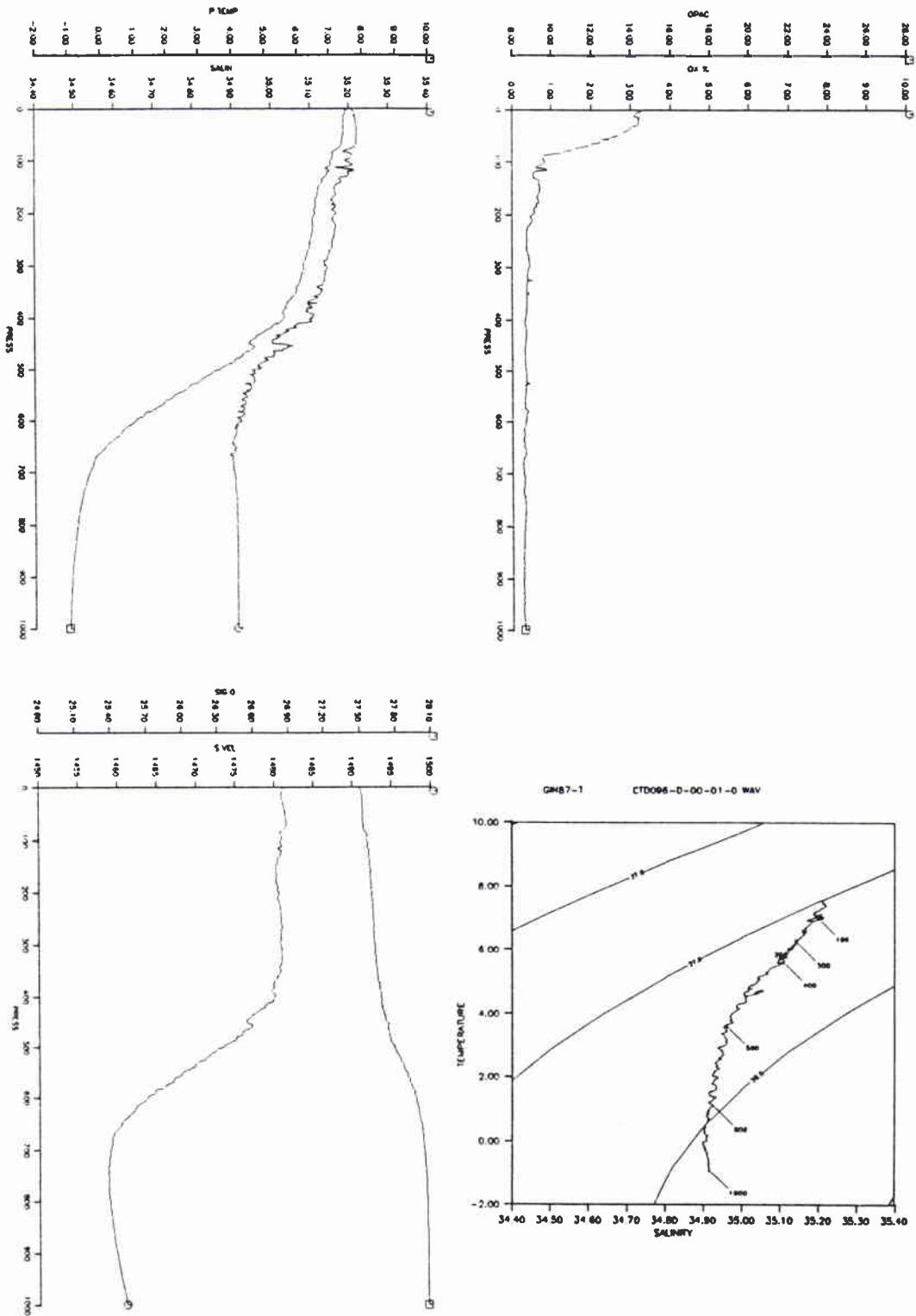


Figure B95

SACLANTCEN SM-249

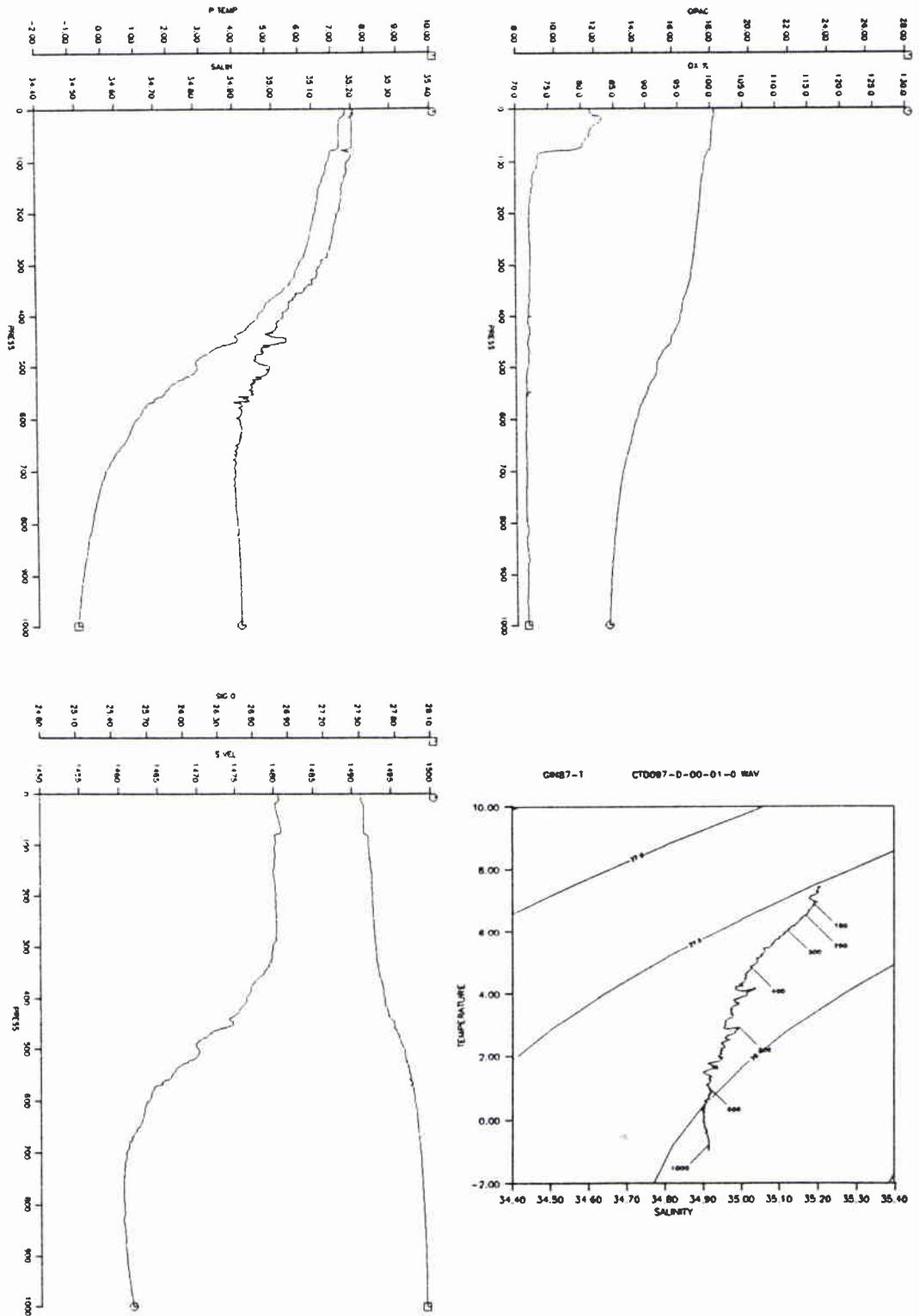


Figure B96

SACLANTCEN SM-249

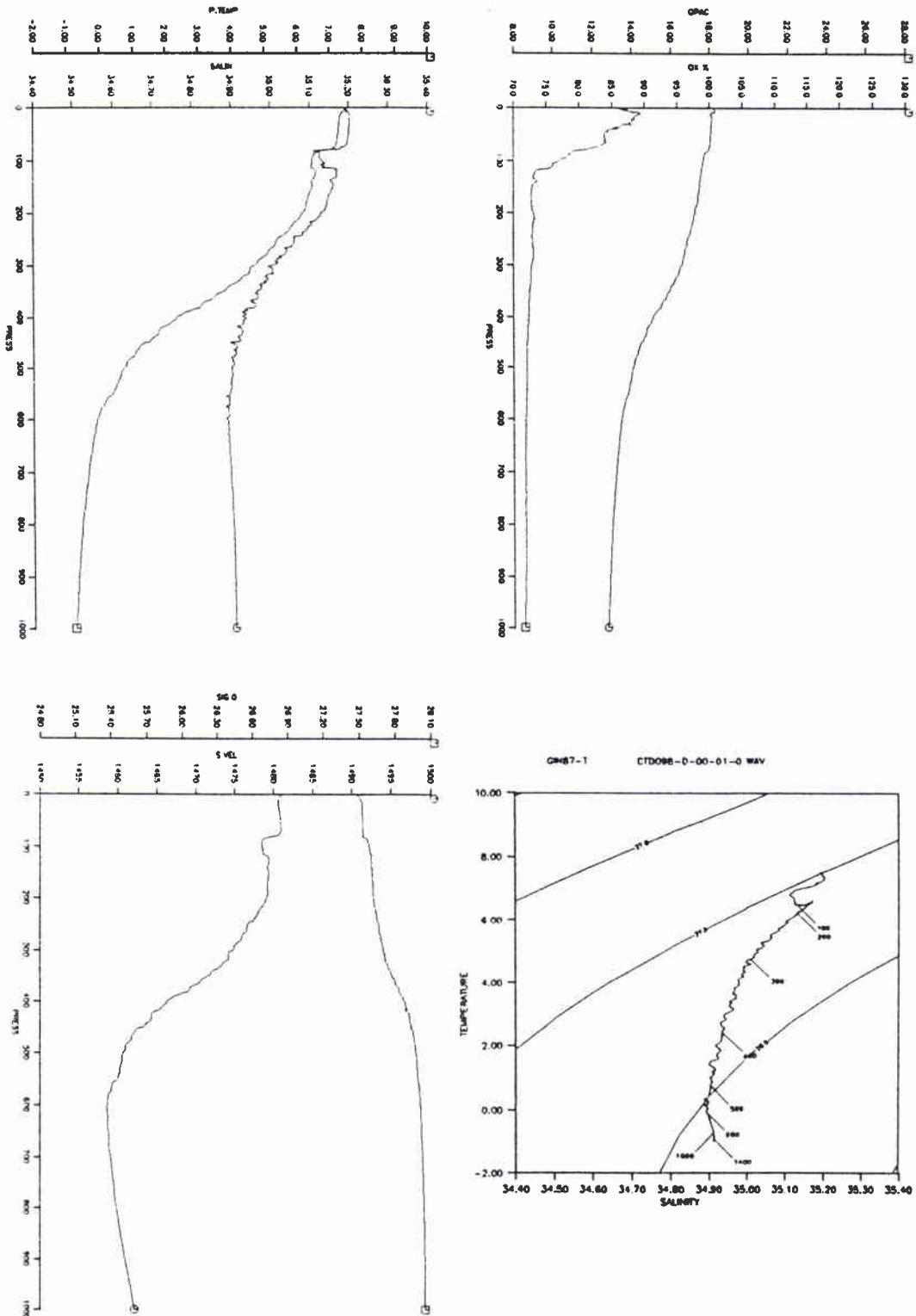


Figure B97

SACLANTCEN SM-249

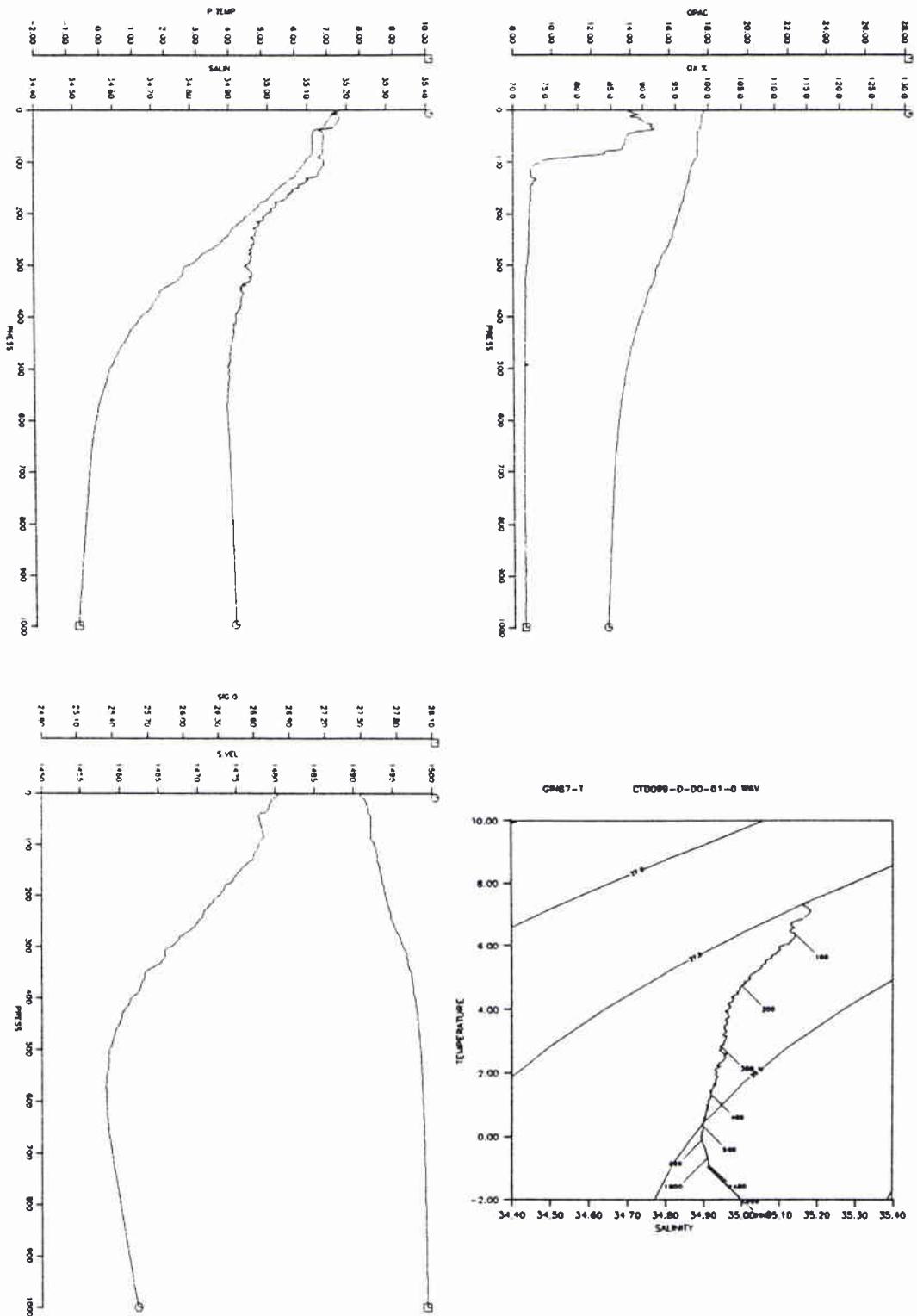


Figure B98

SACLANTCEN SM-249

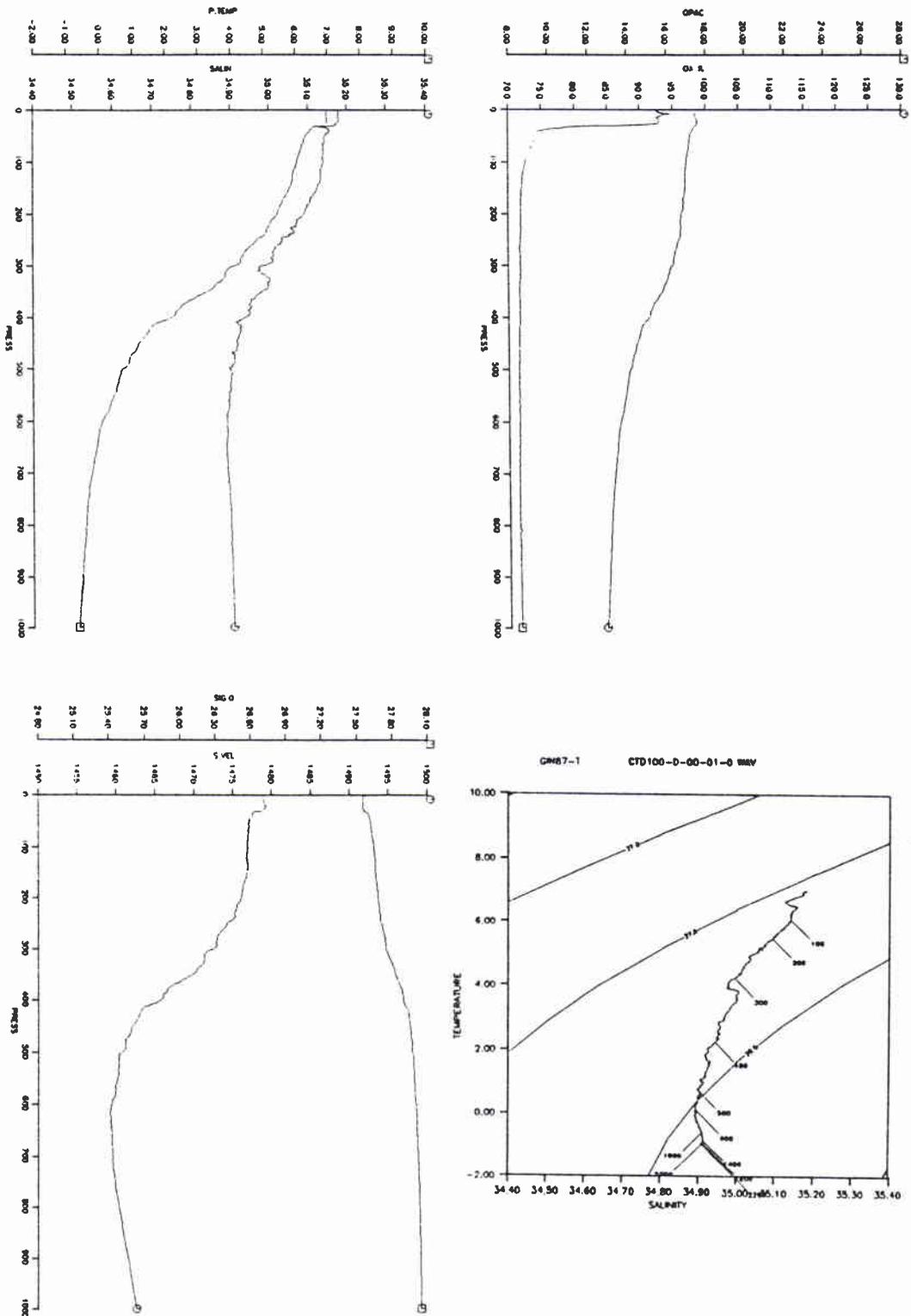


Figure B00

SACLANTCEN SM-249

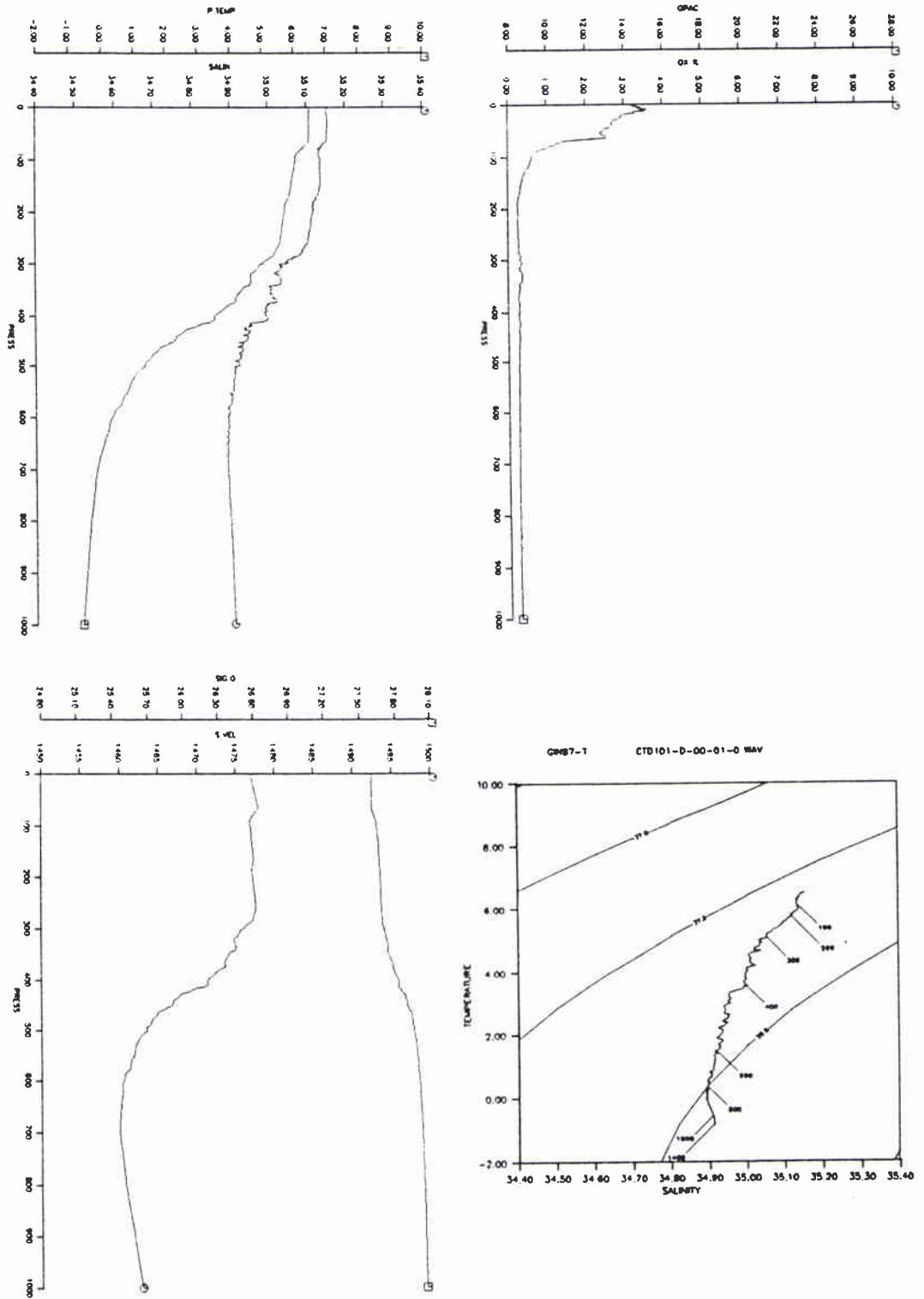


Figure B100

SACLANTCEN SM-249

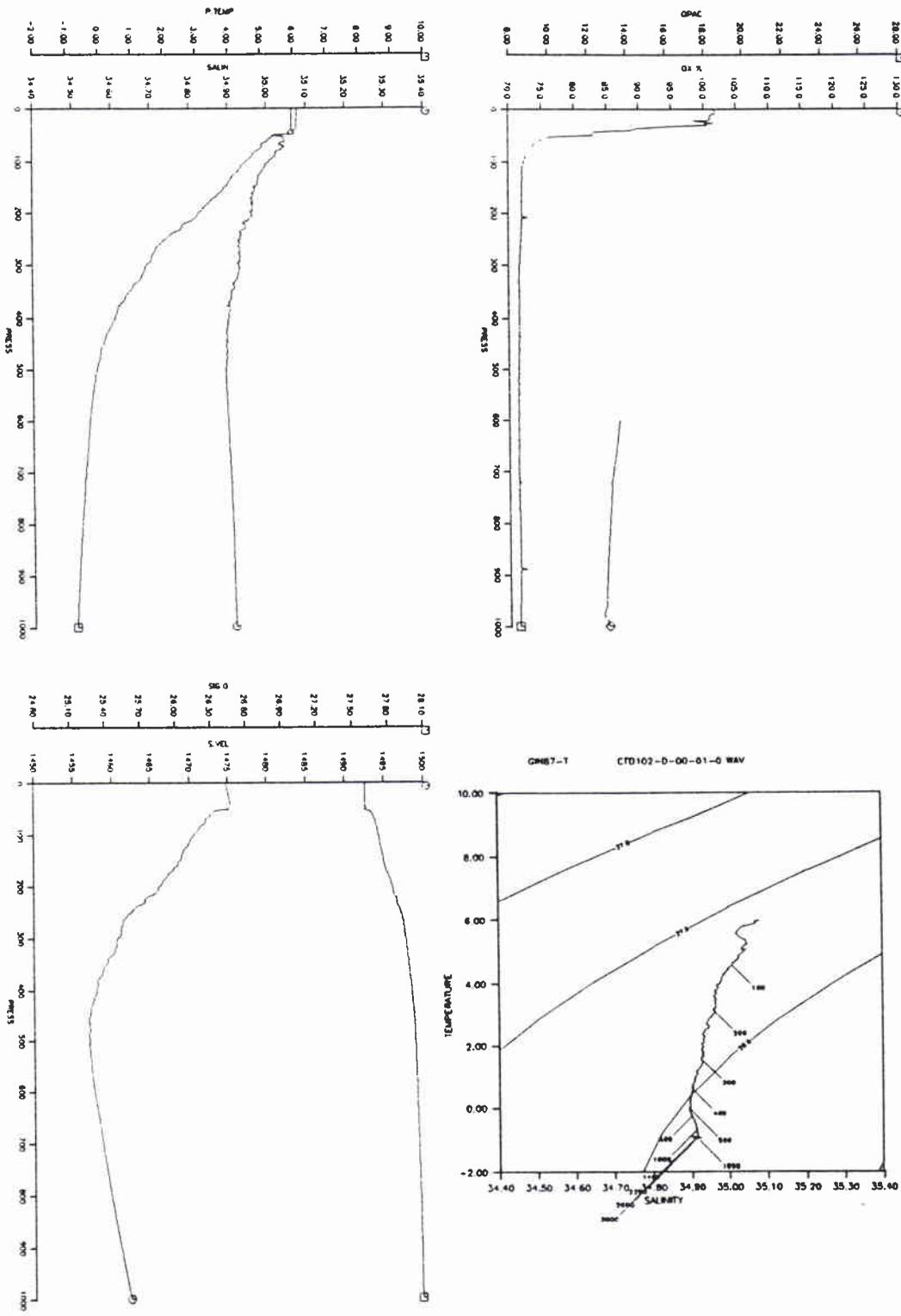


Figure B101

SACLANTCEN SM-249

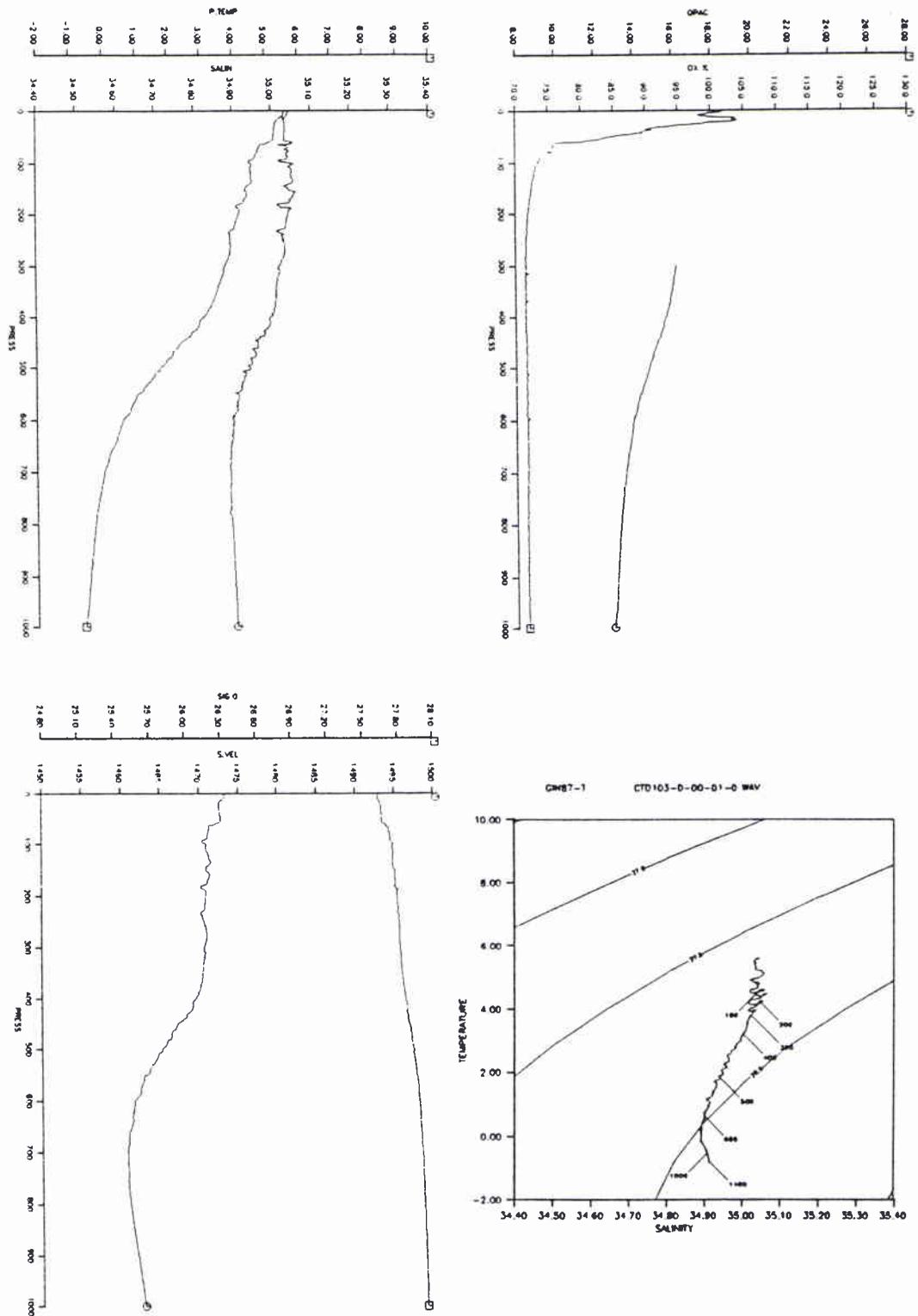


Figure B102

SACLANTCEN SM-249

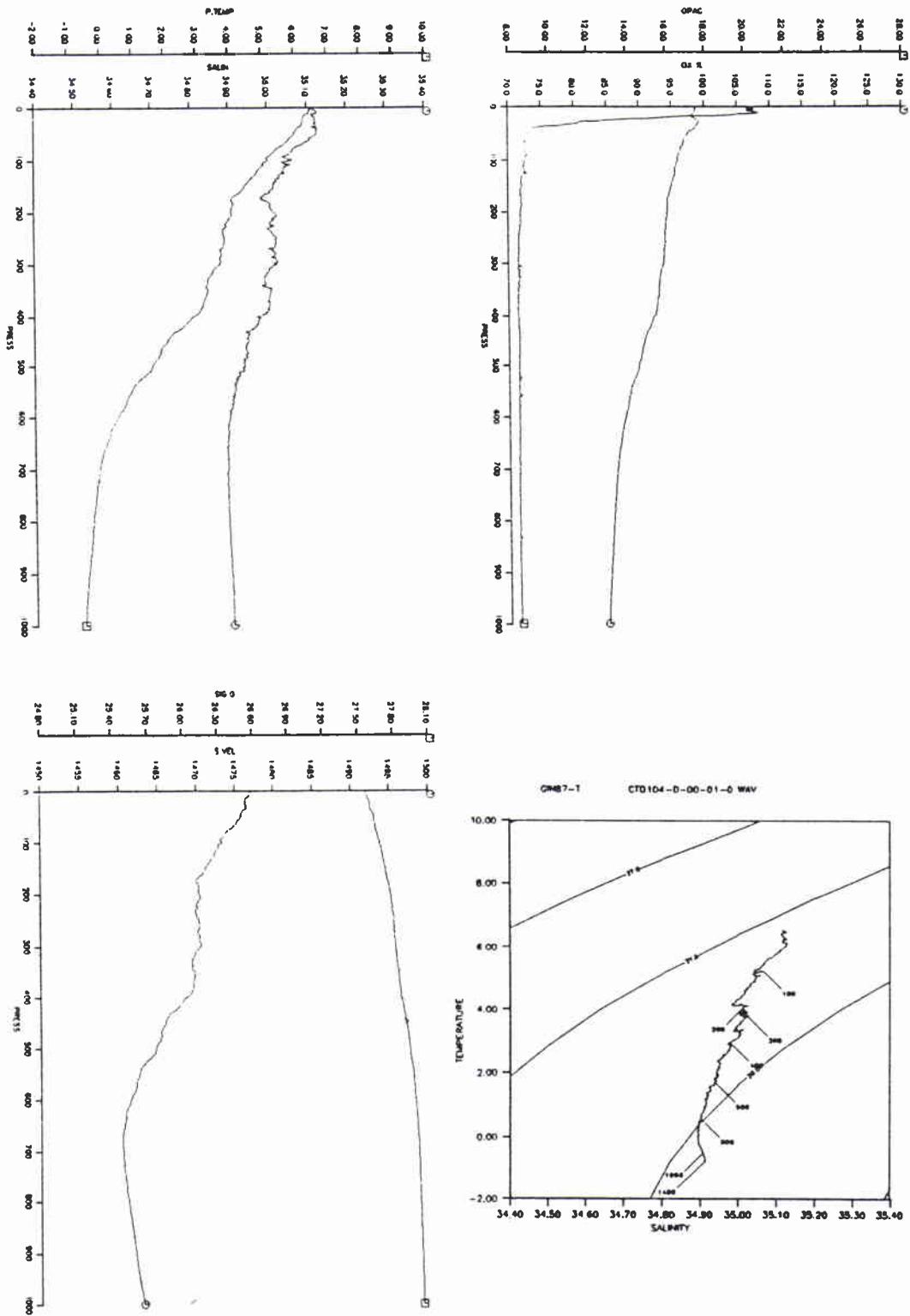


Figure B103

SACLANTCEN SM-249

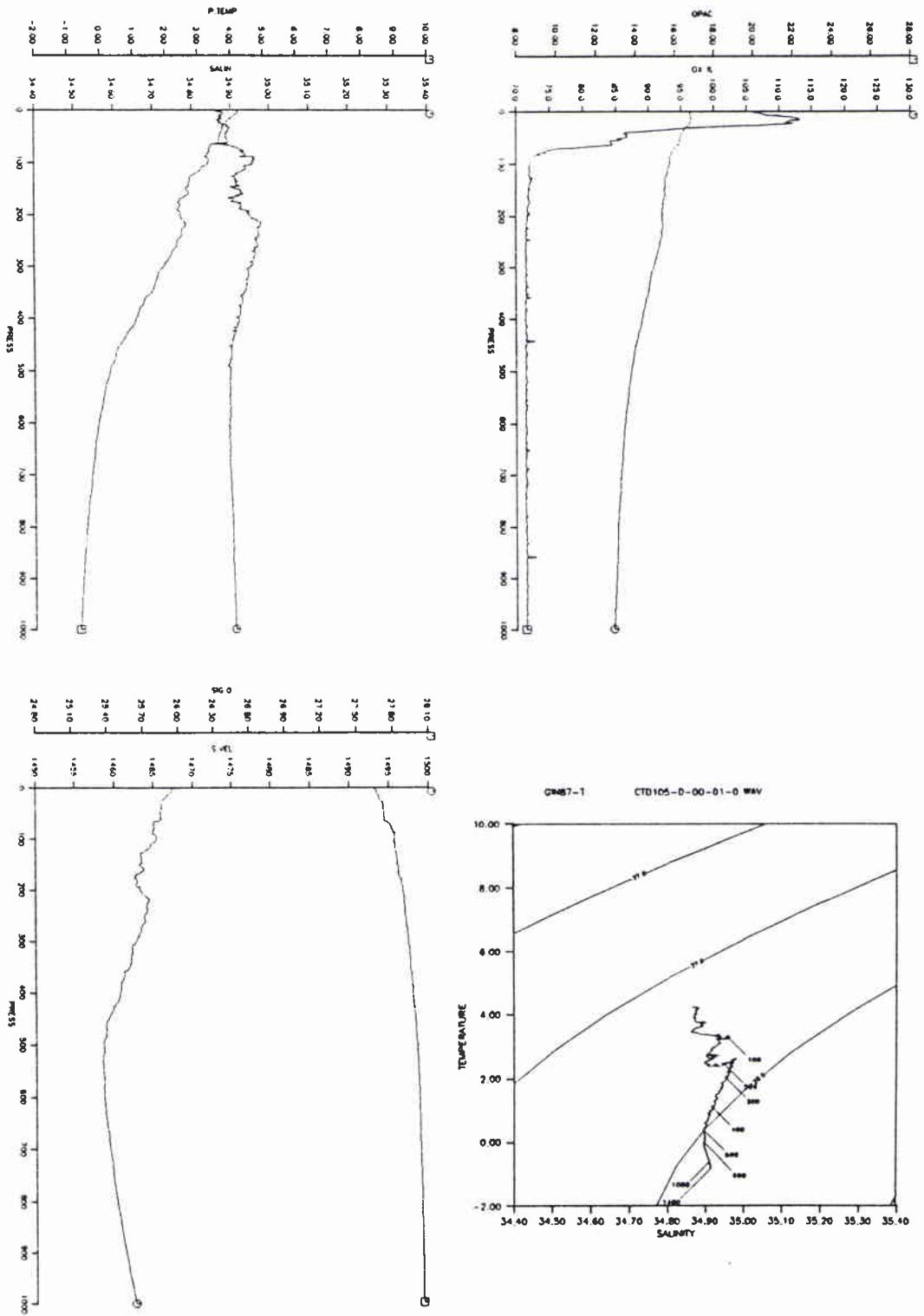


Figure B104

SACLANTCEN SM-249

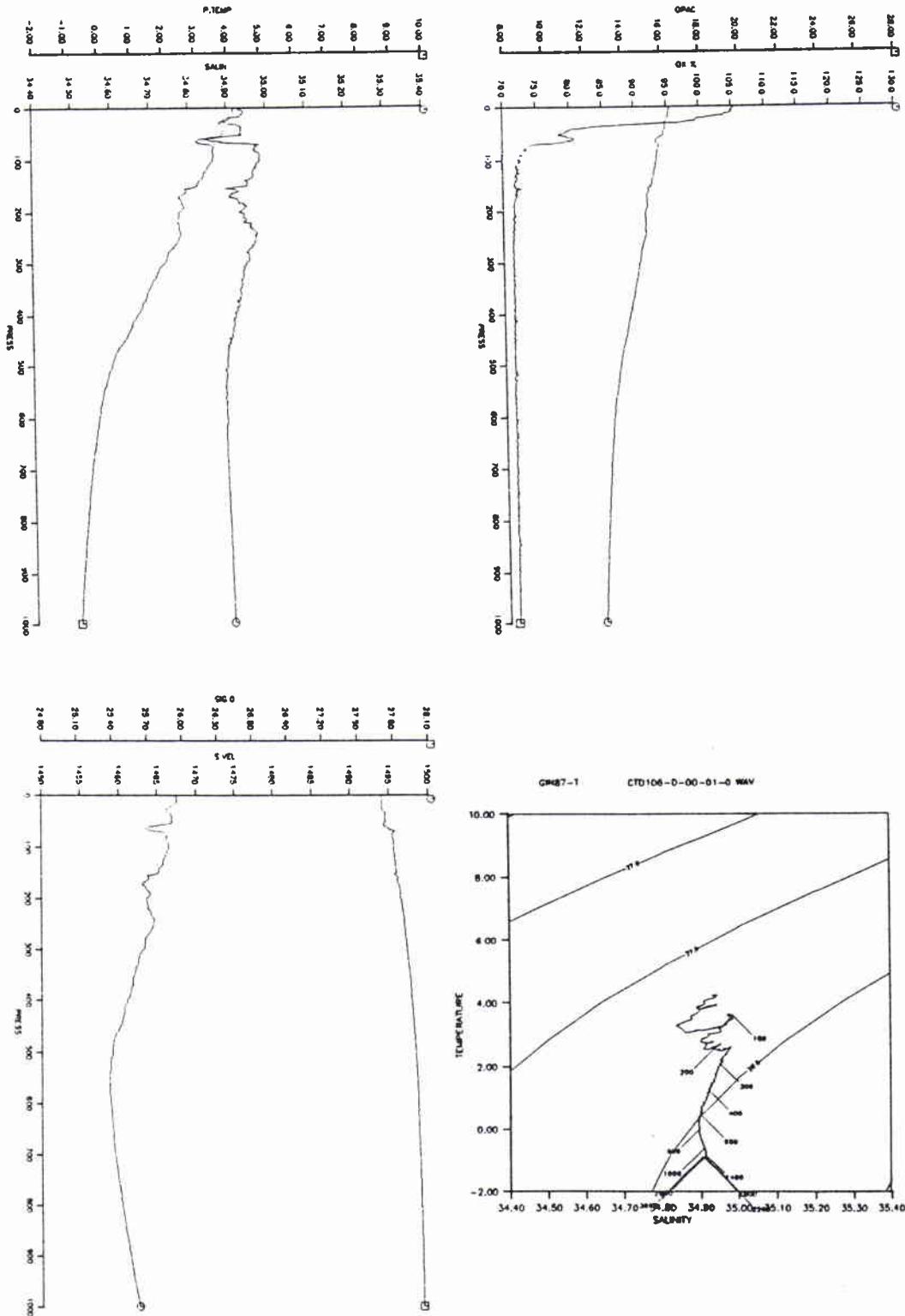


Figure B105

SACLANTCEN SM-249

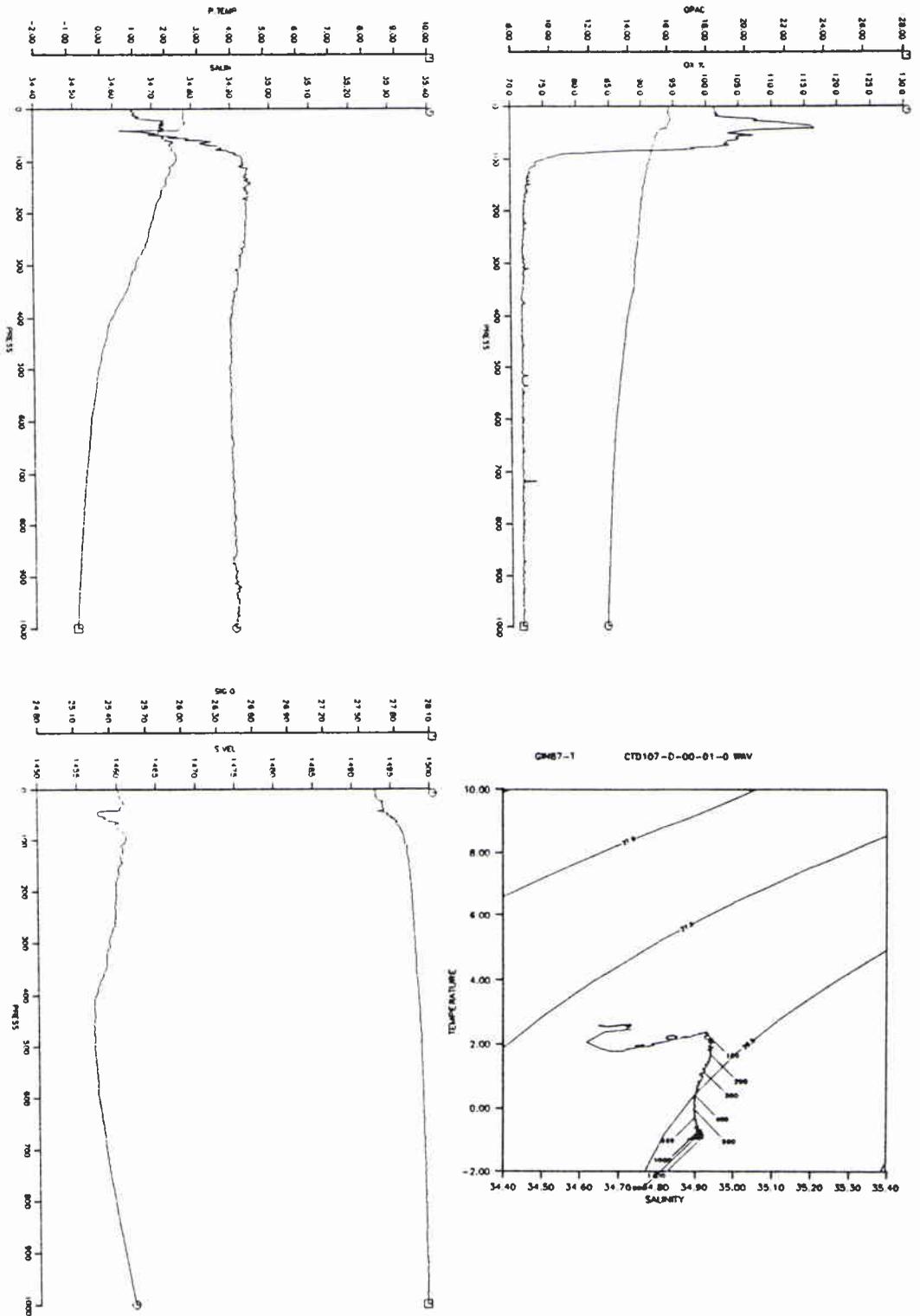


Figure B106

SACLANTCEN SM-249

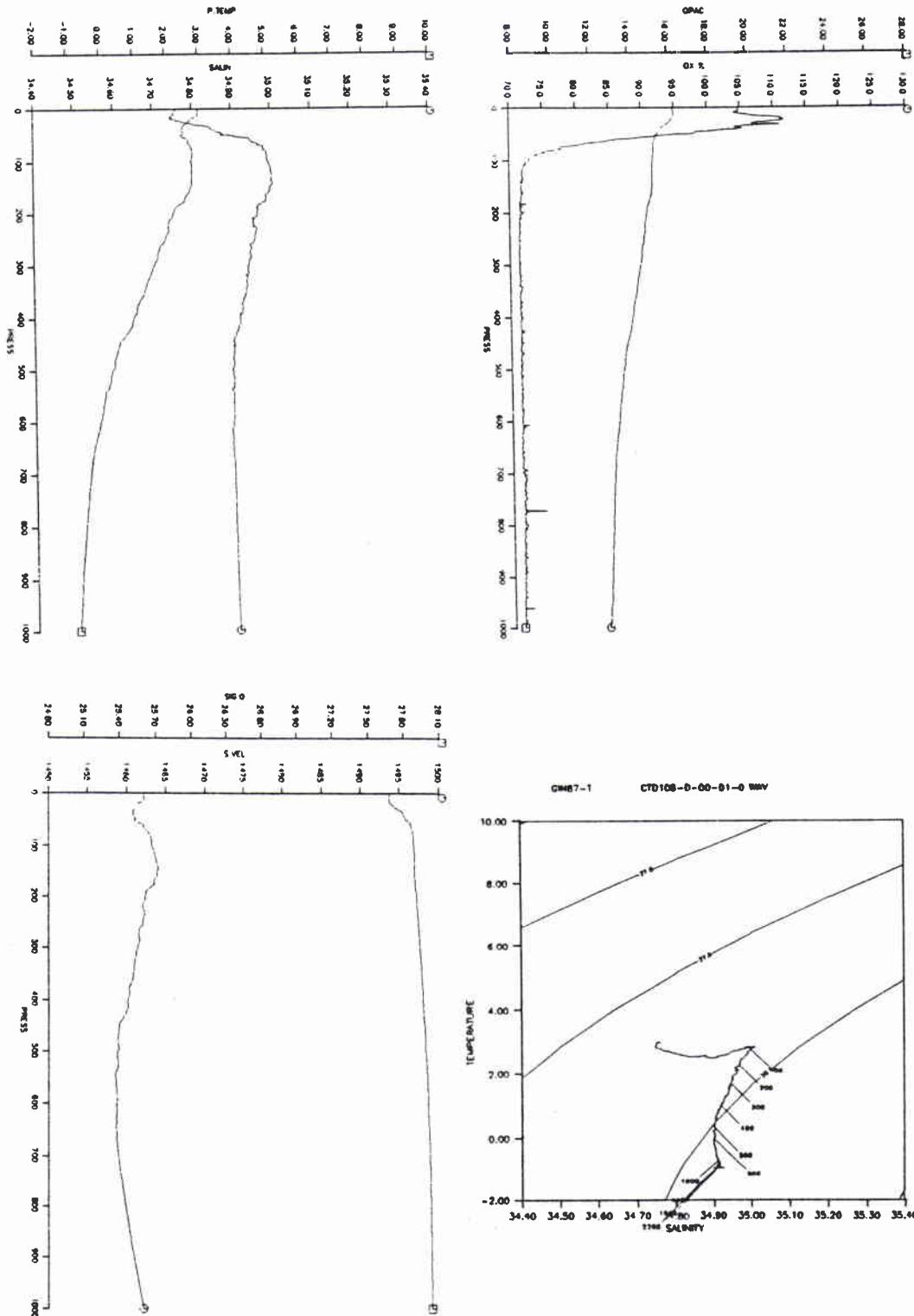


Figure B107

SACLANTCEN SM-249

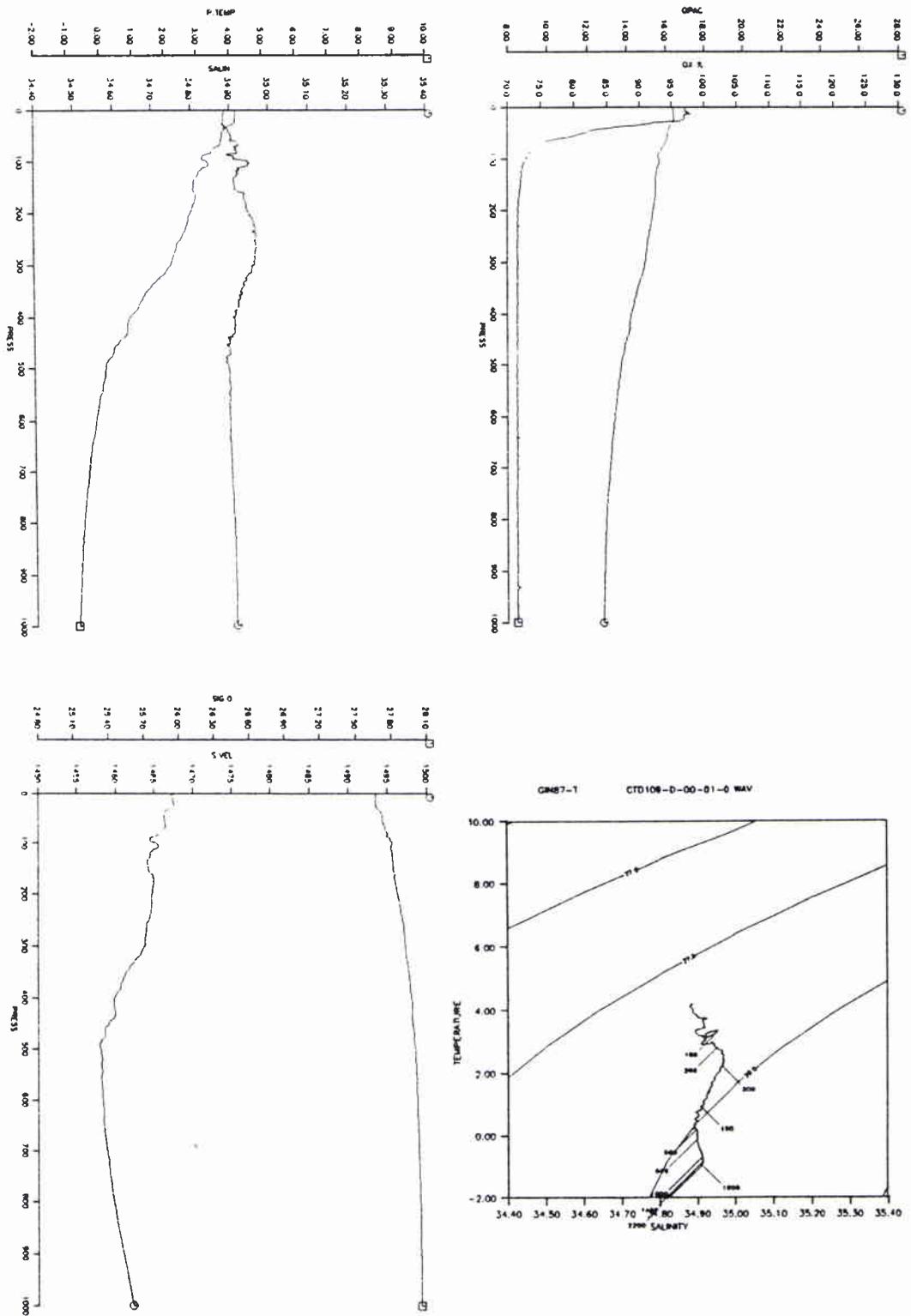


Figure B108

SACLANTCEN SM-249

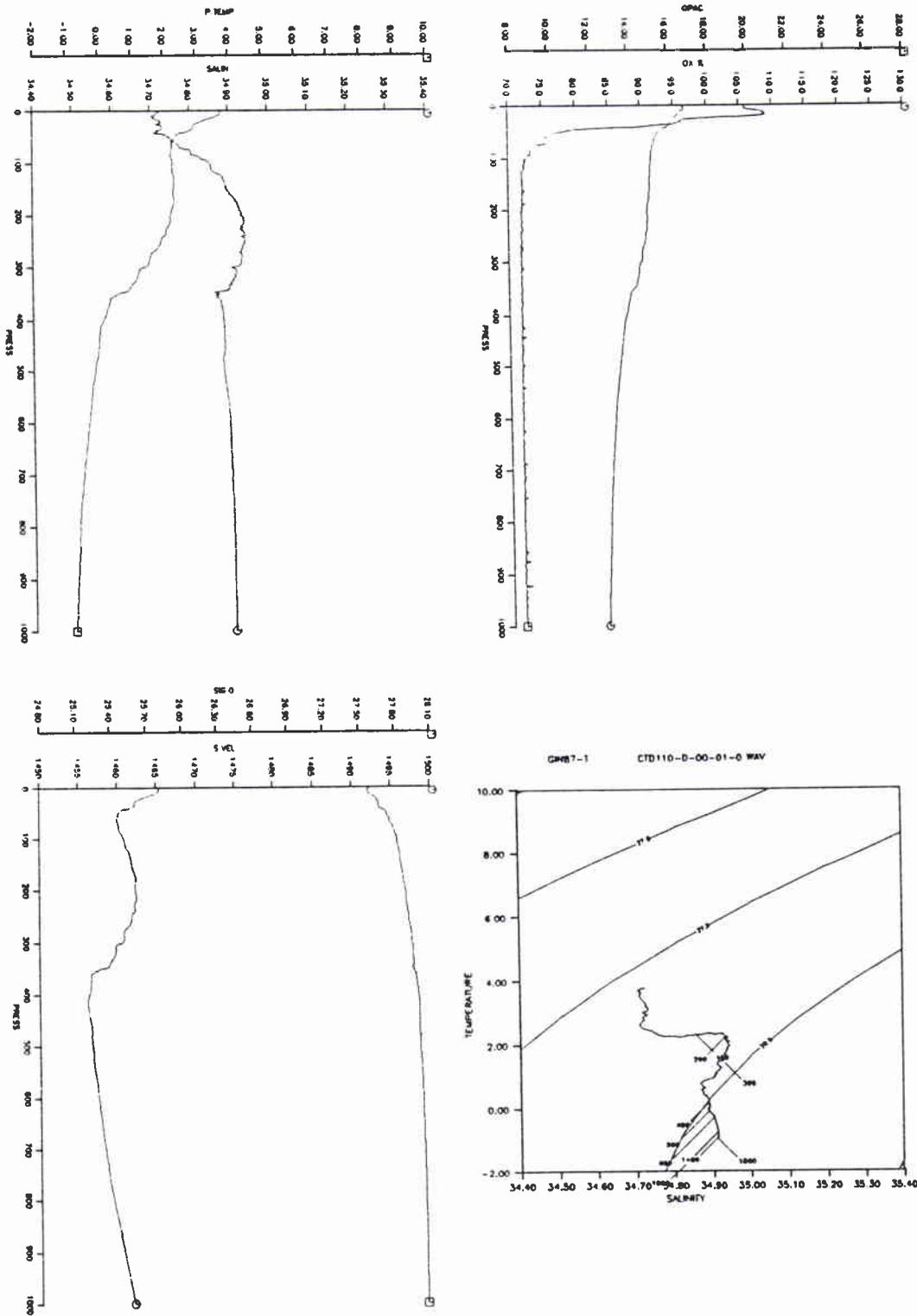


Figure B109

SACLANTCEN SM-249

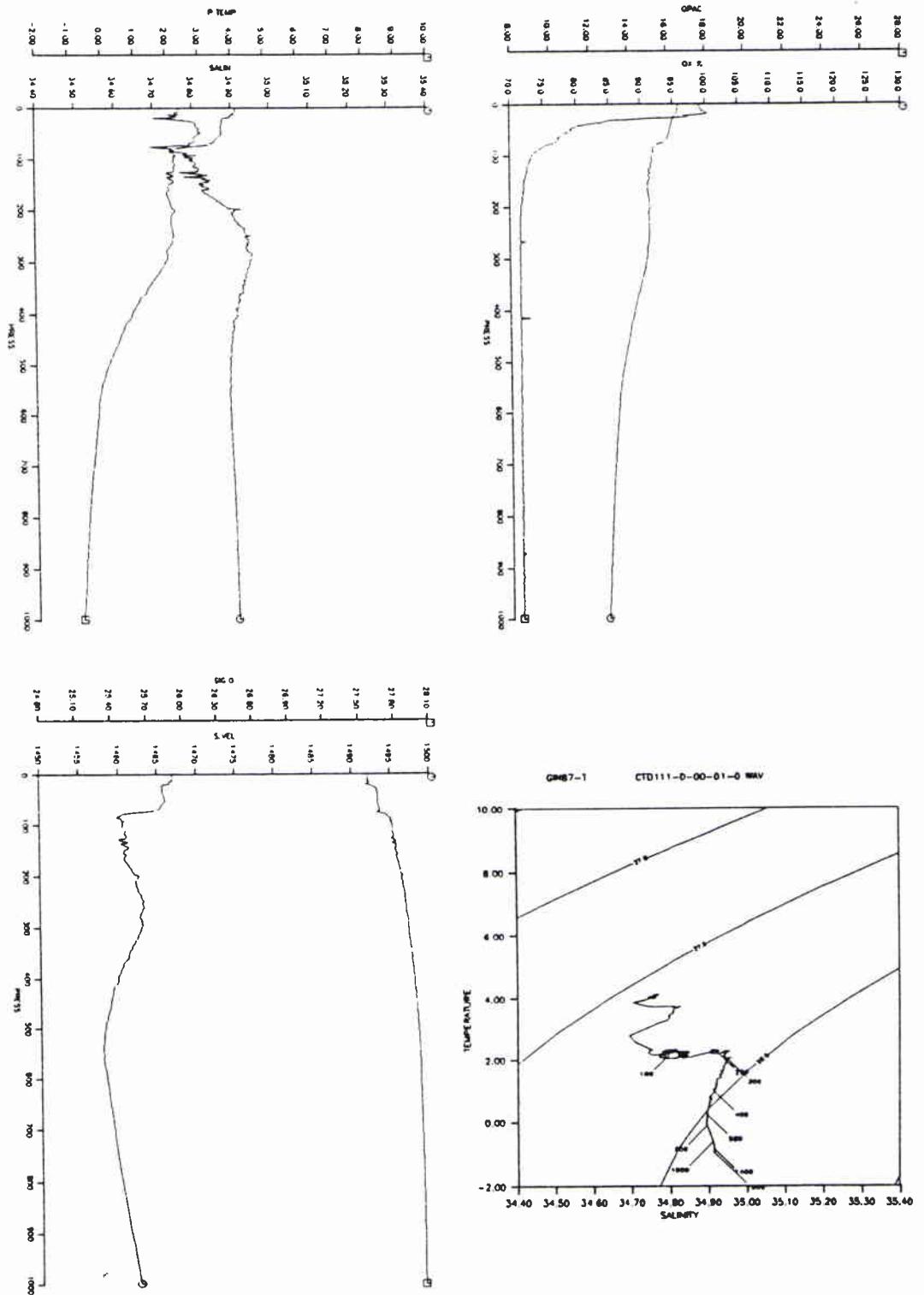


Figure B110

SACLANTCEN SM-249

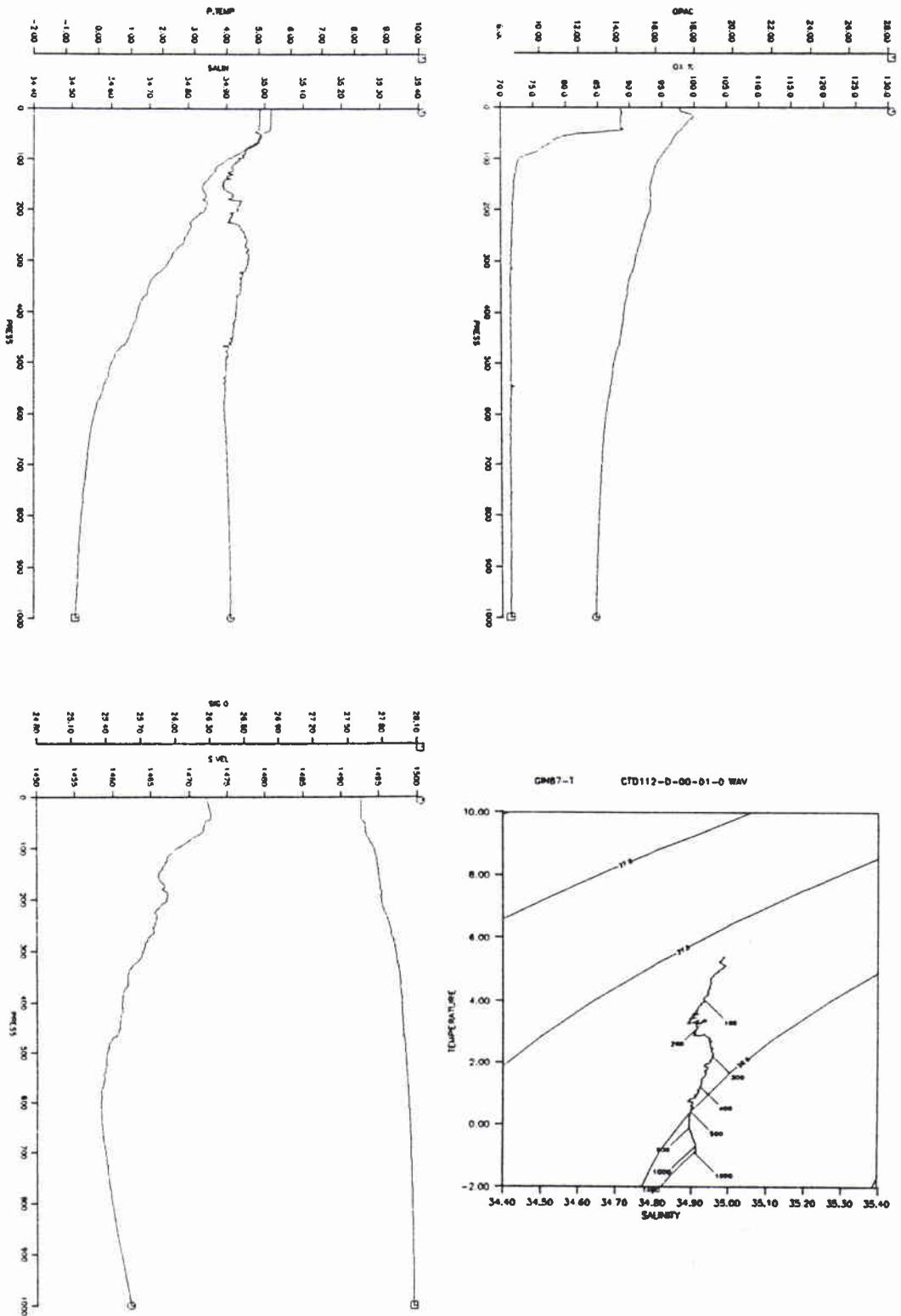


Figure B111

SACLANTCEN SM-249

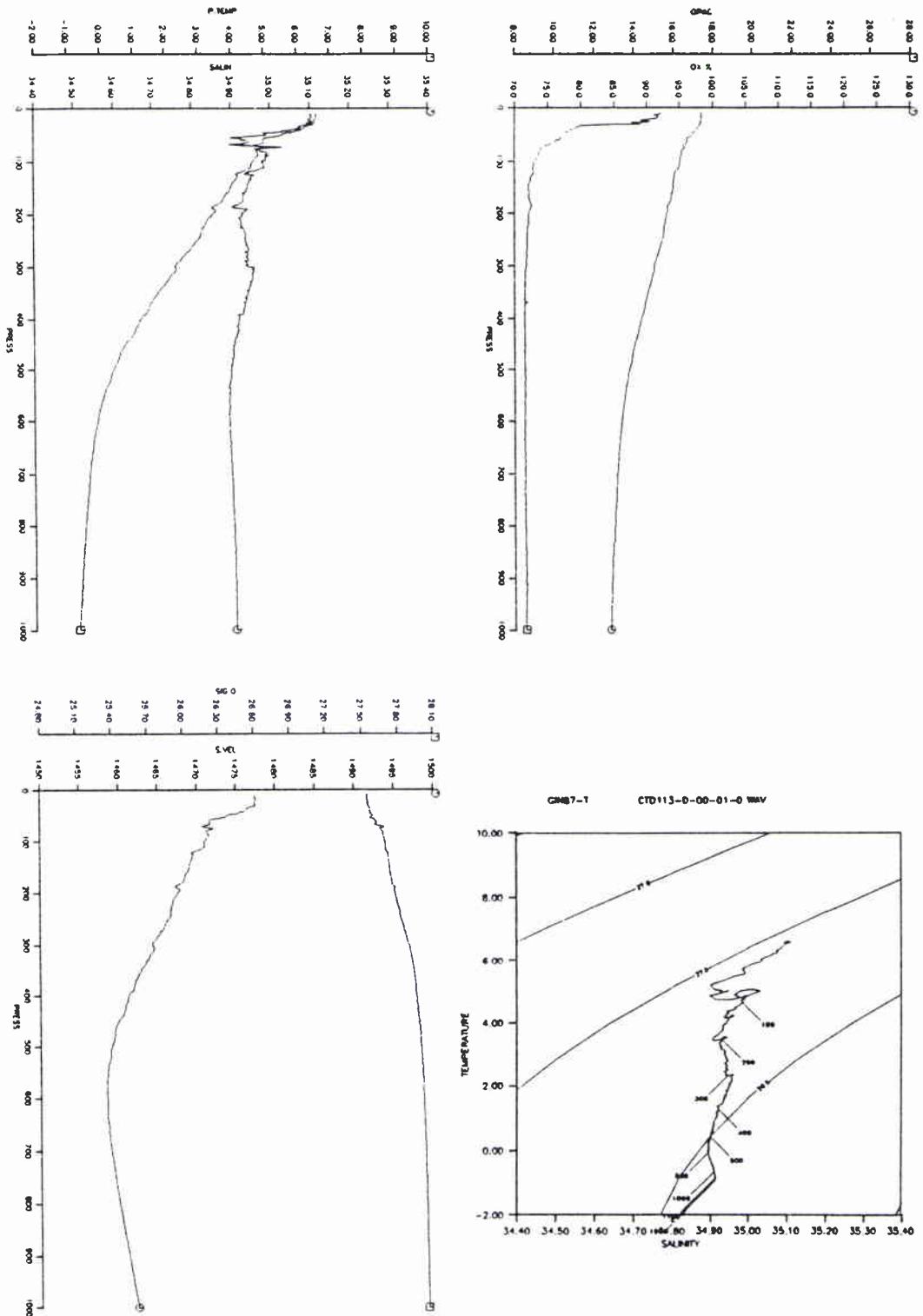


Figure B112

SACLANTCEN SM-249

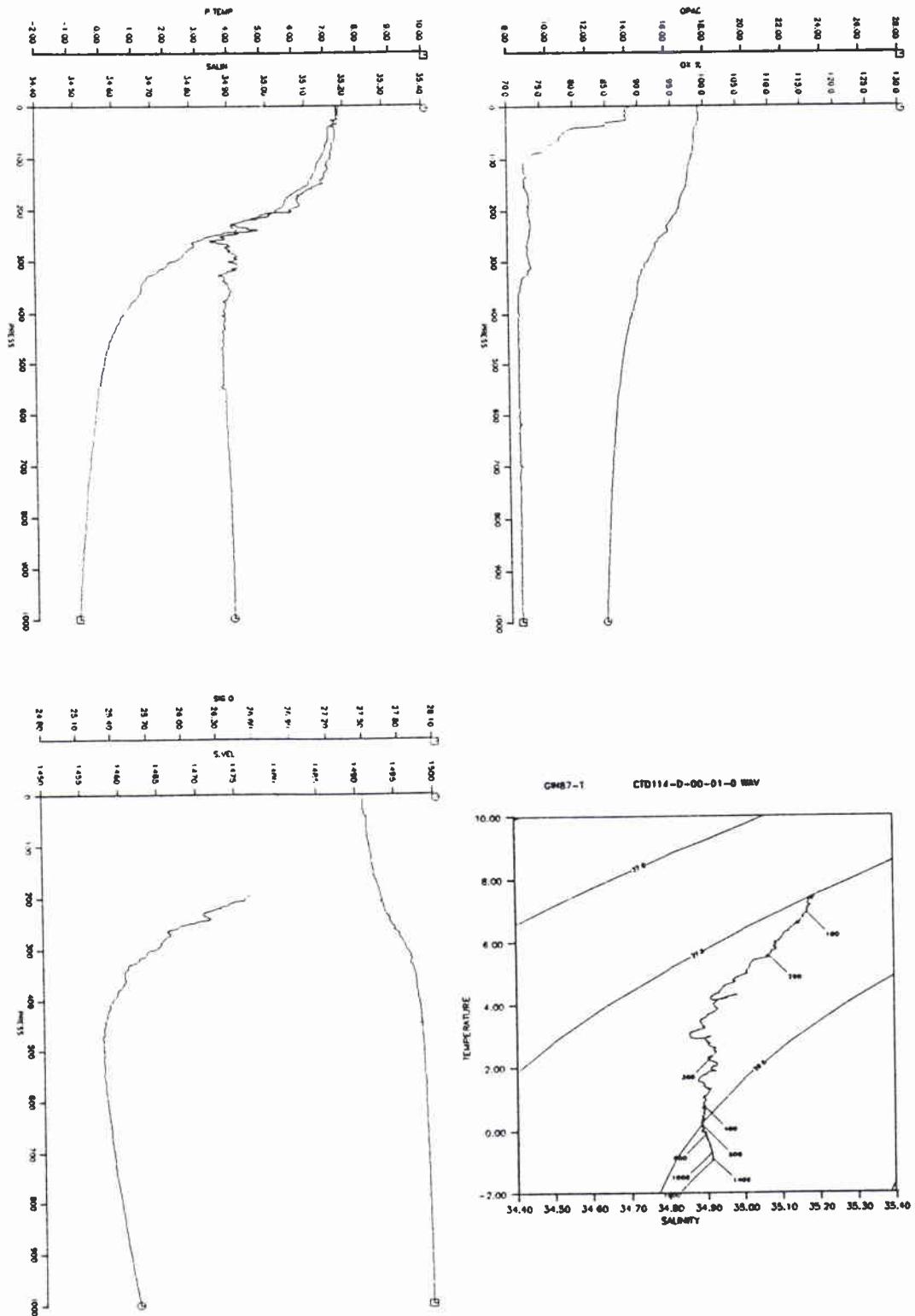


Figure B113

SACLANTCEN SM-249

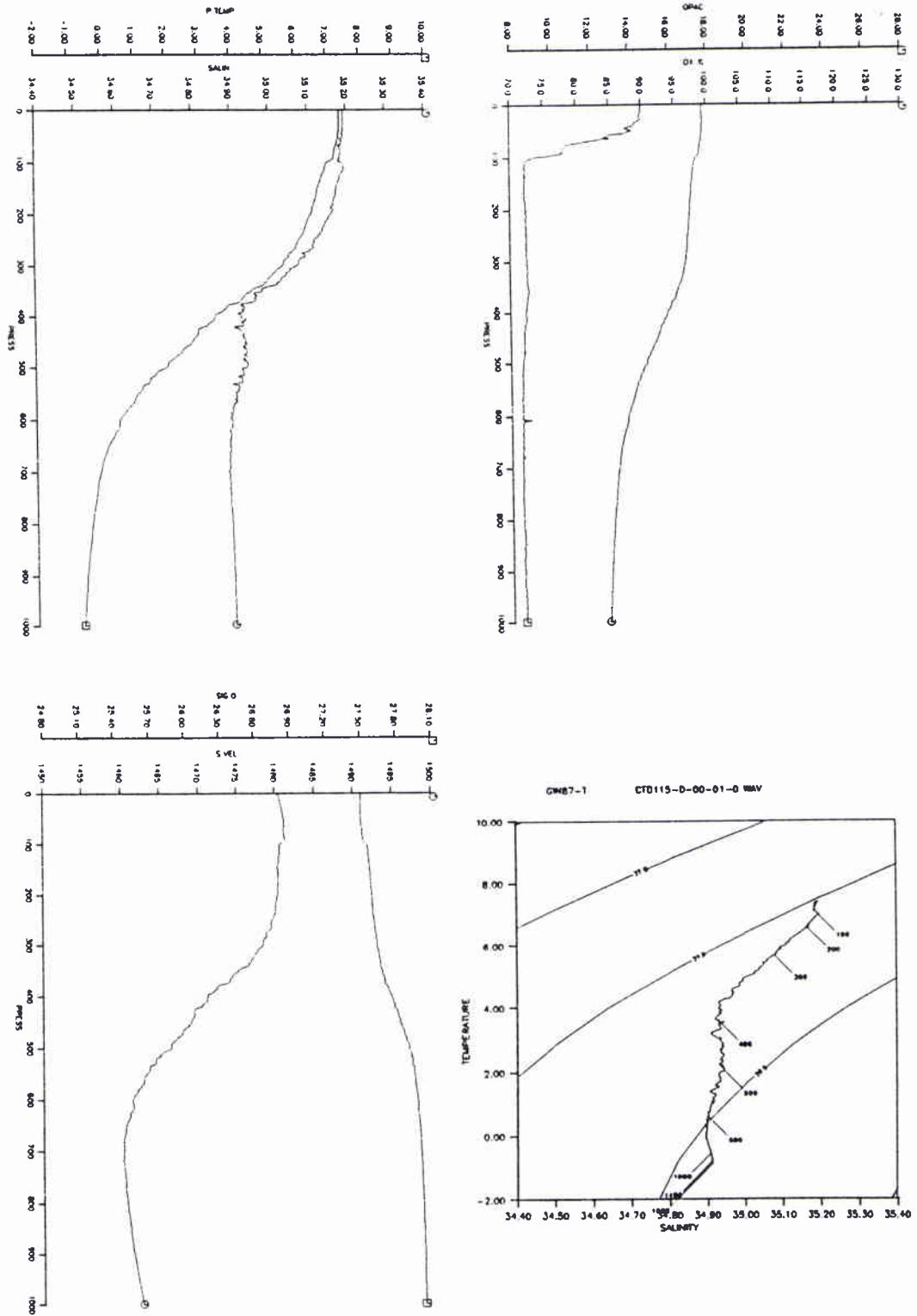


Figure B114

SACLANTCEN SM-249

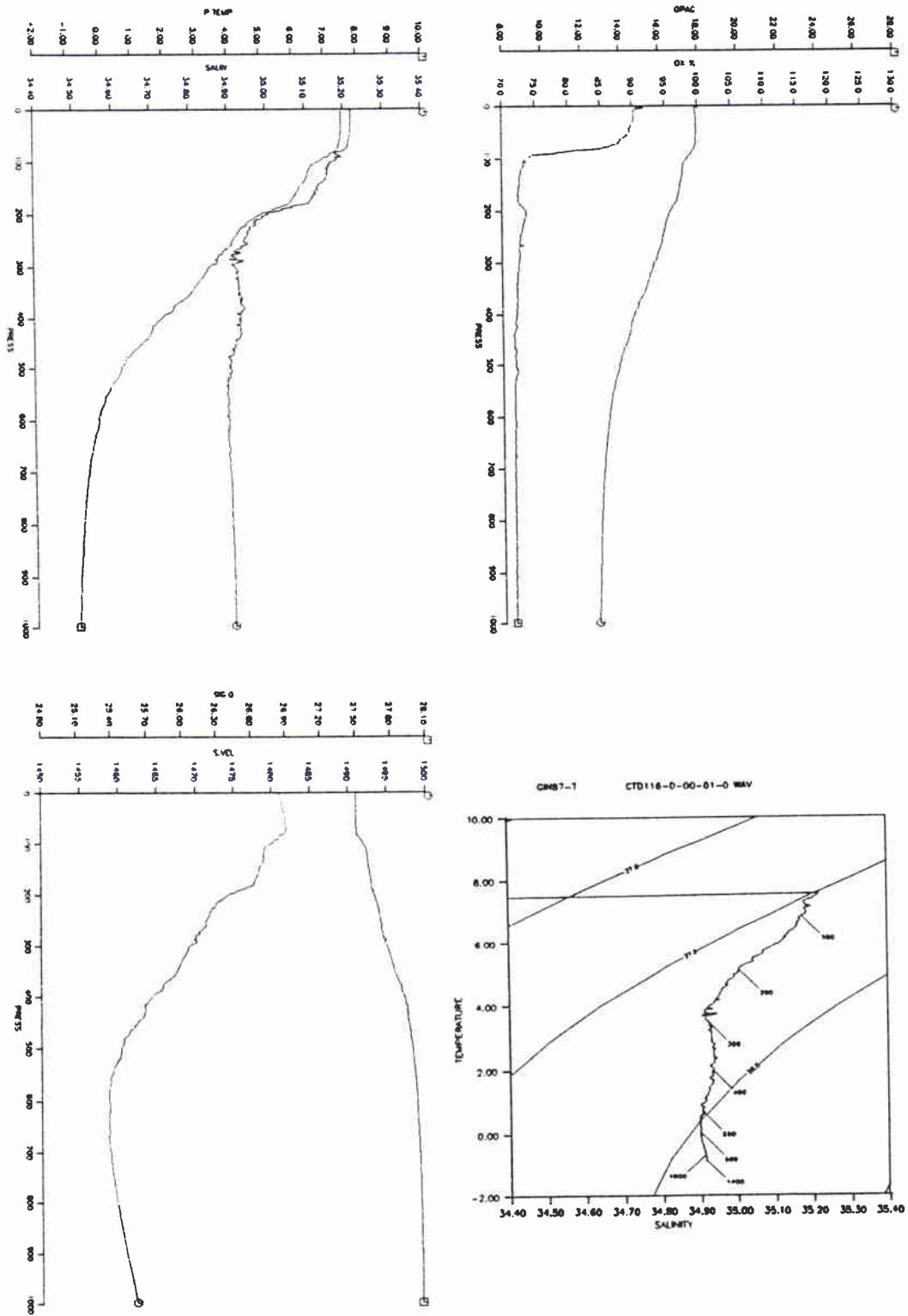


Figure B115

SACLANTCEN SM-249

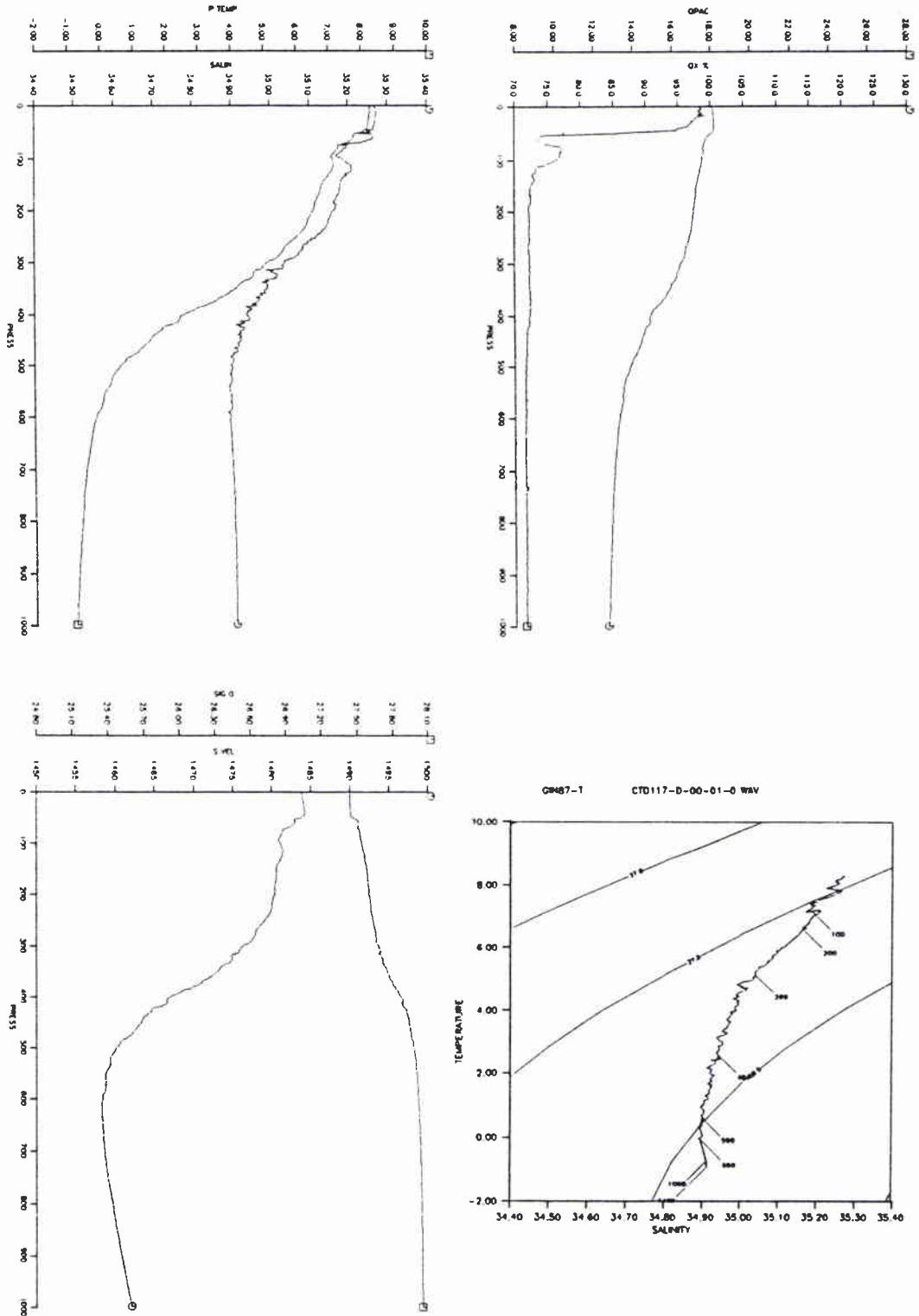


Figure B116

SACLANTCEN SM-249

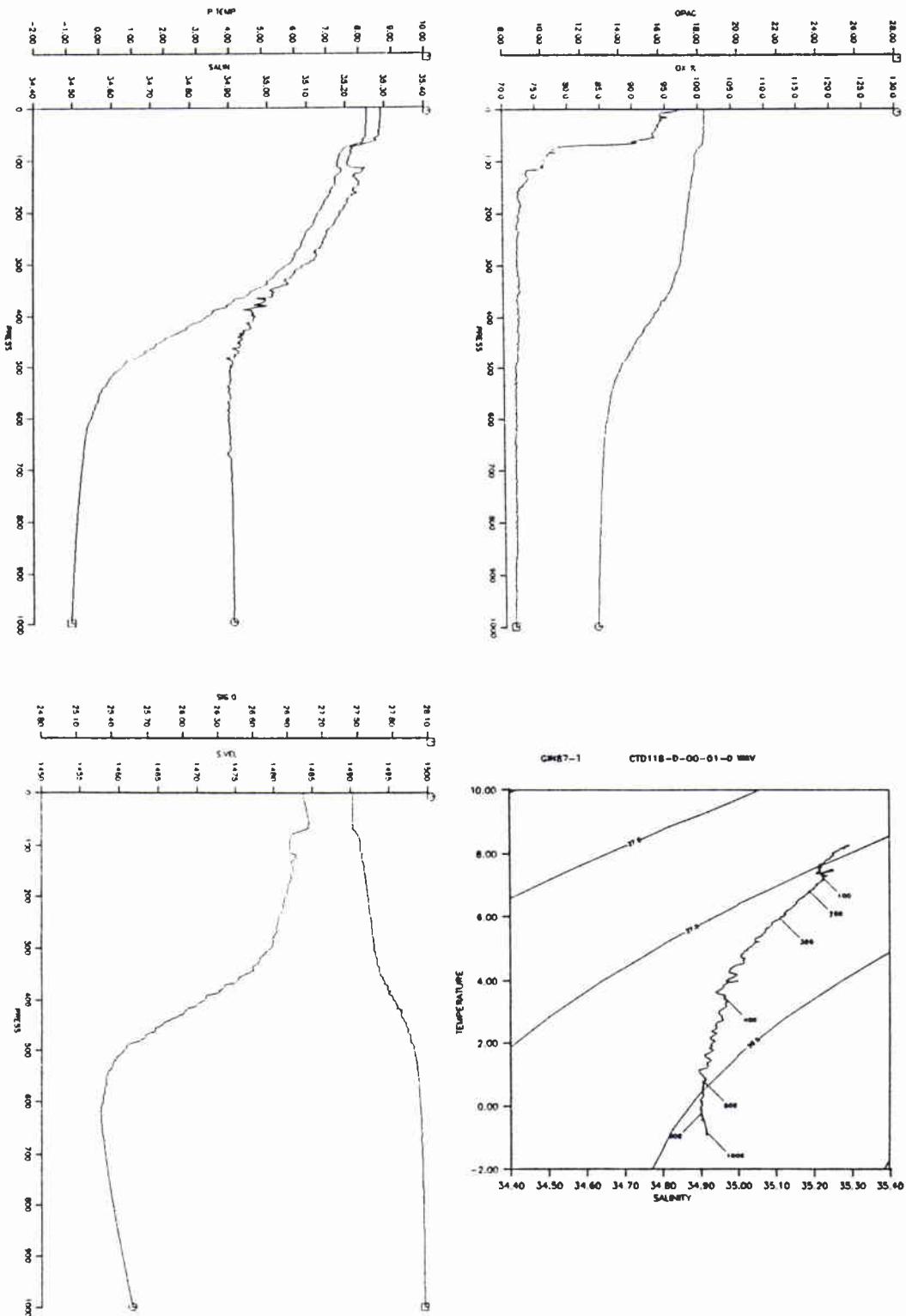


Figure B117

SACLANTCEN SM-249

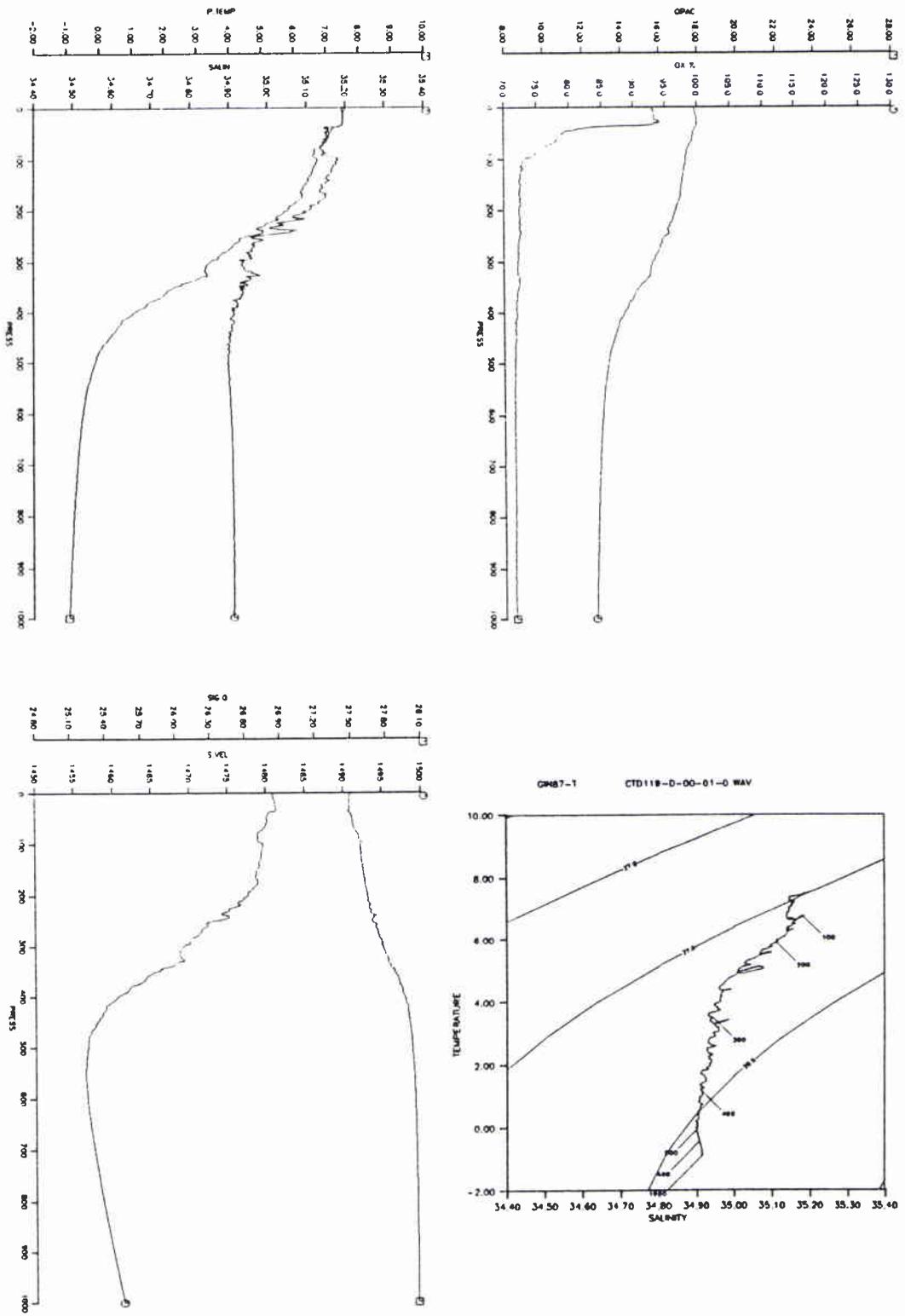


Figure B118

SACLANTCEN SM-249

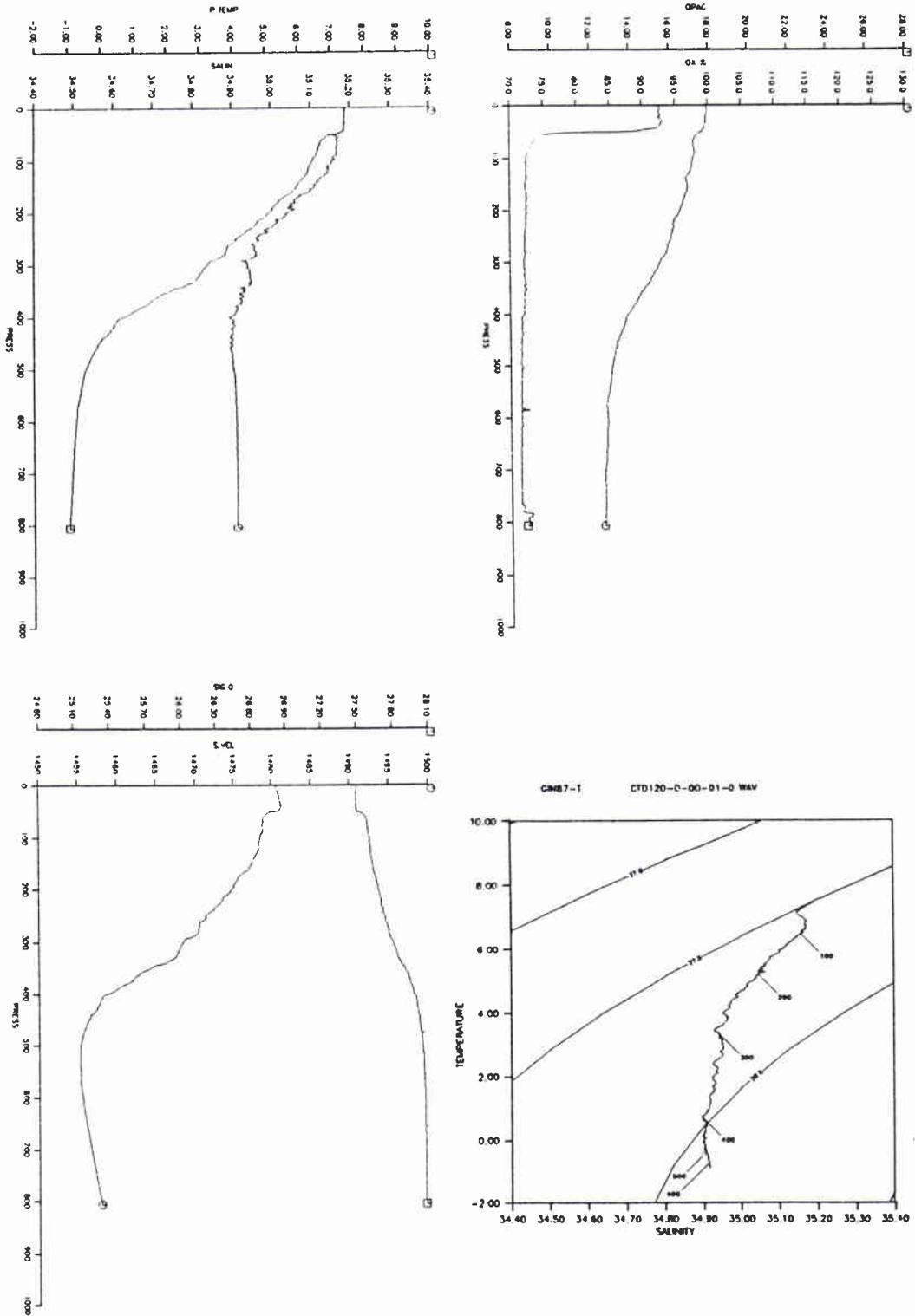


Figure B119

SACLANTCEN SM-249

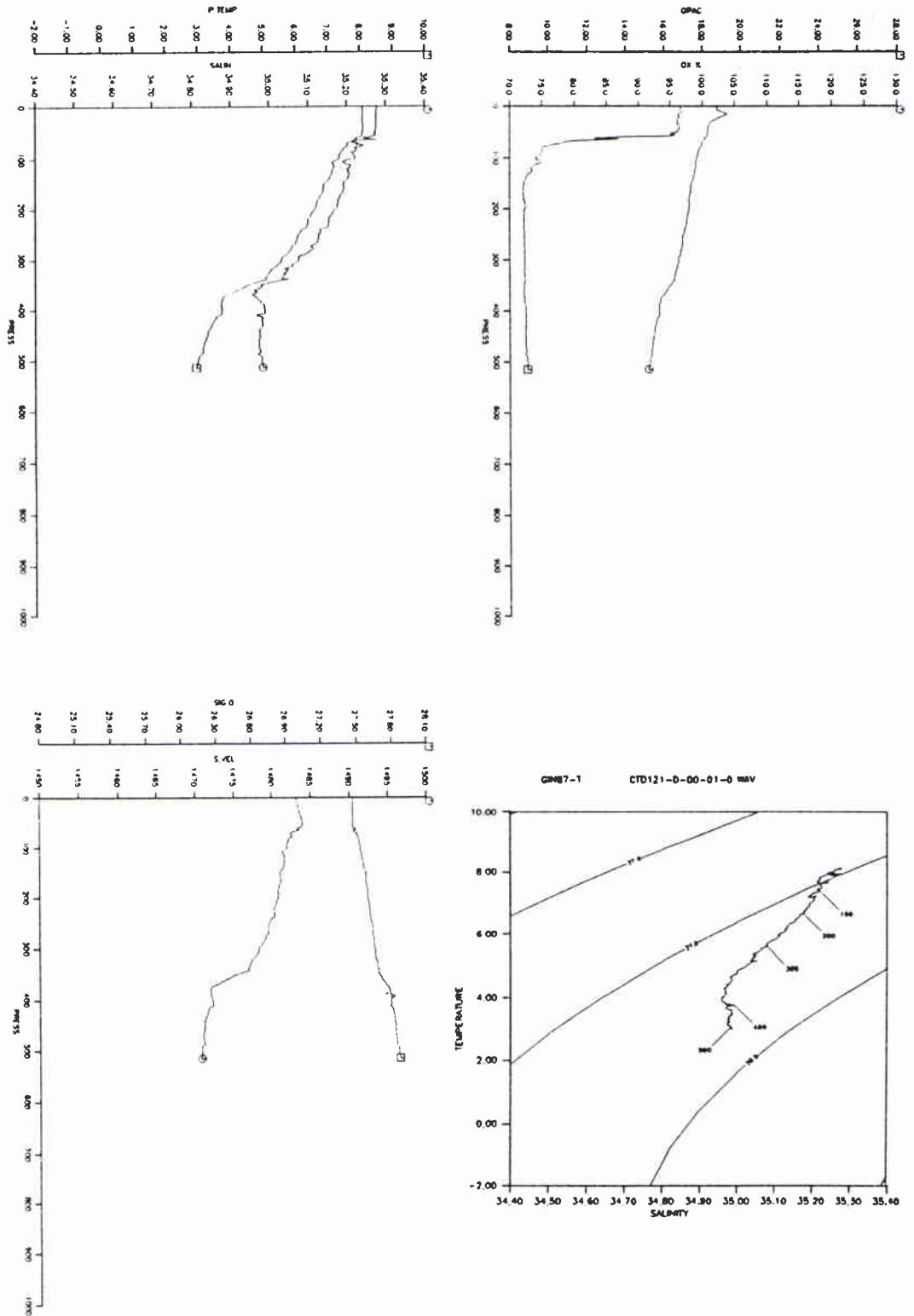


Figure B120

SACLANTCEN SM-249

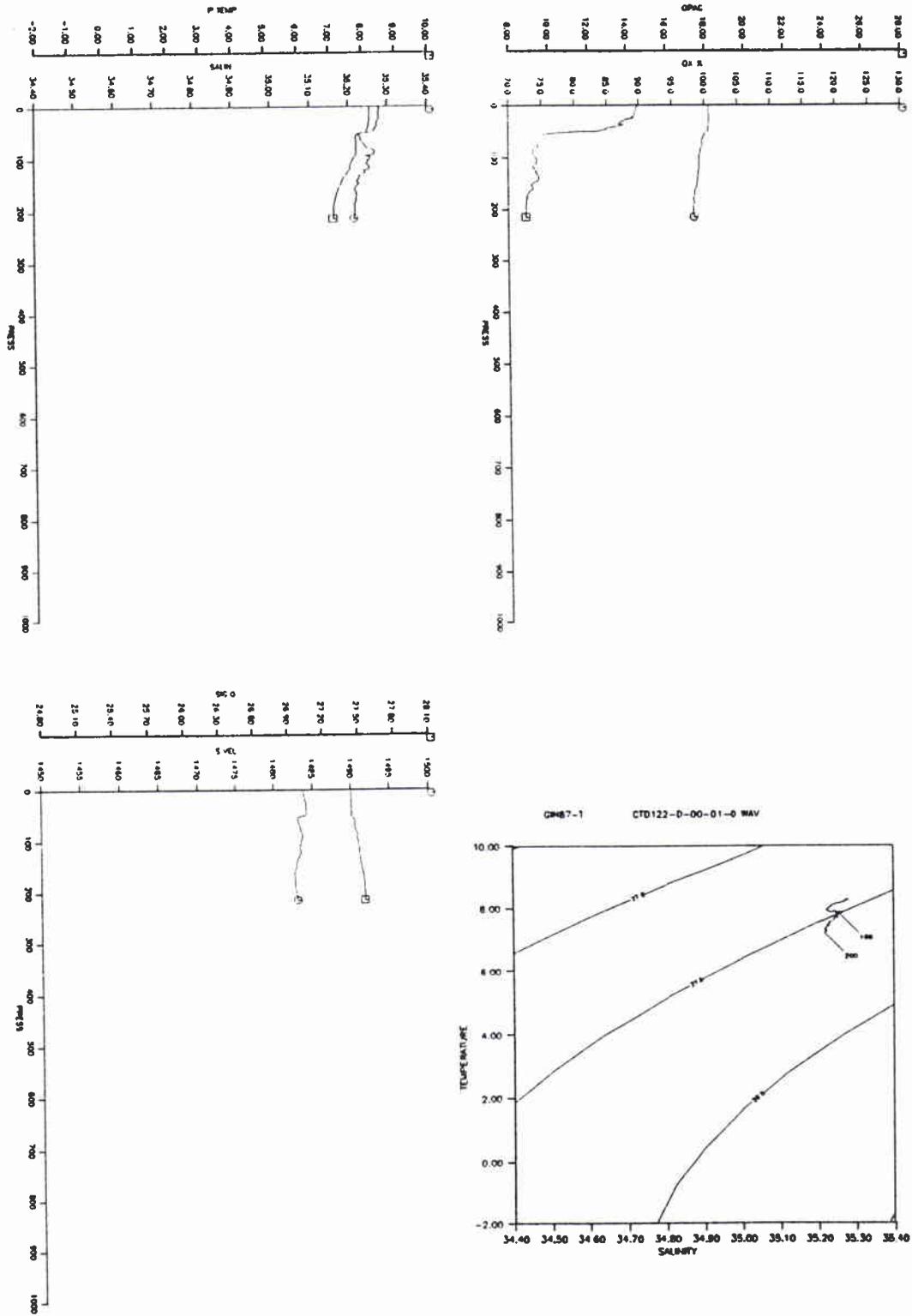


Figure B121

SACLANTCEN SM-249

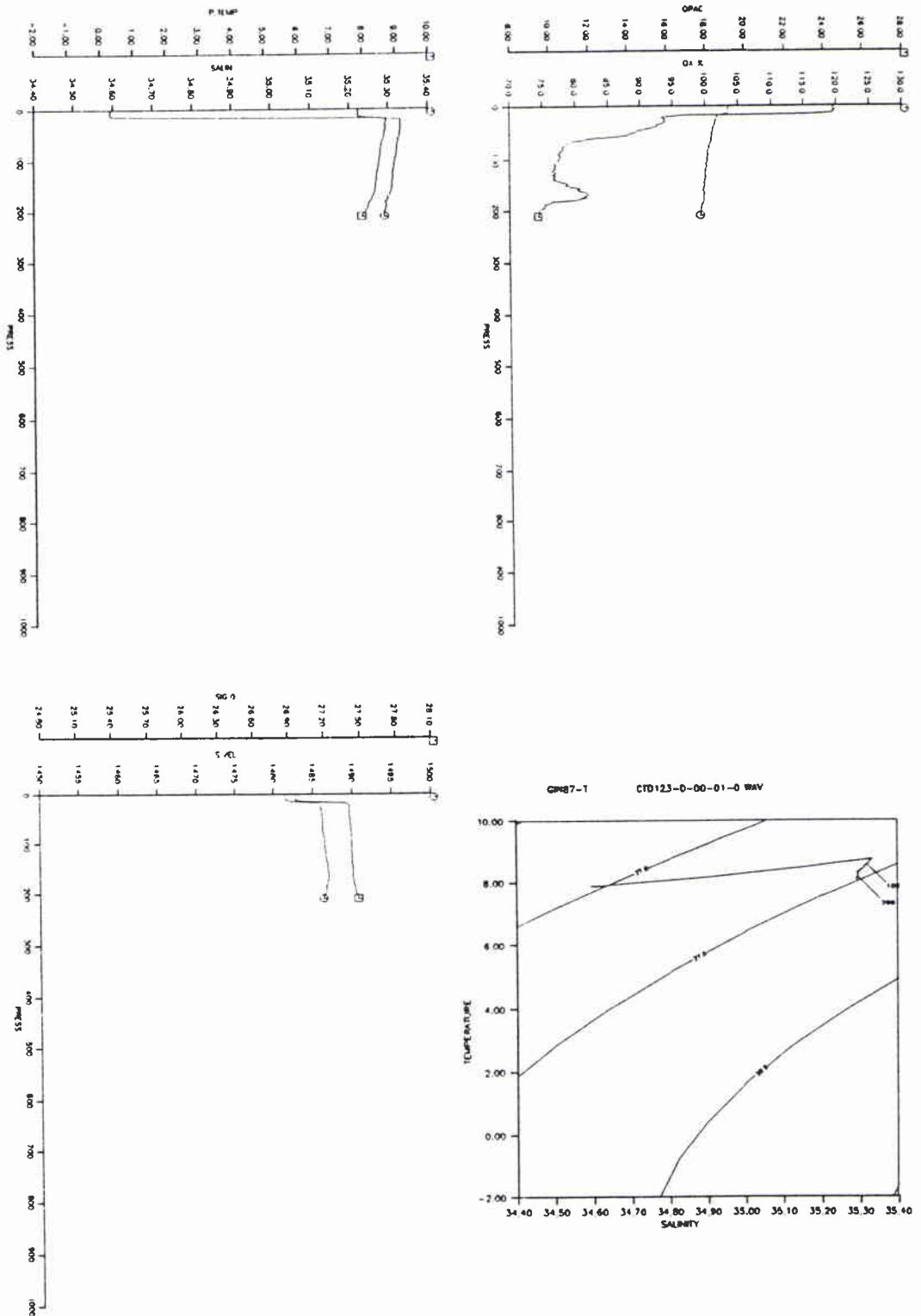


Figure B122

SACLANTCEN SM-249

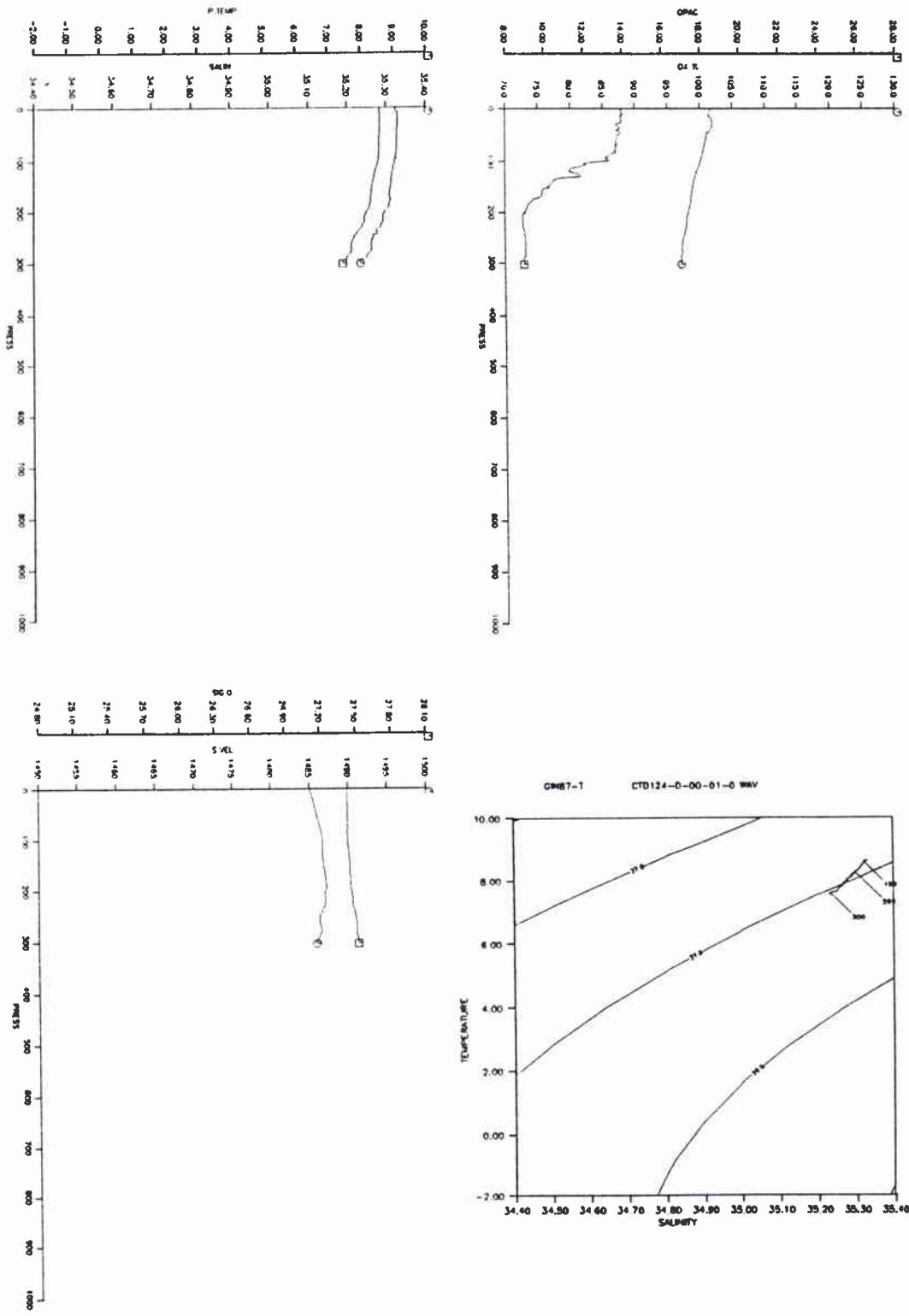


Figure B123

SACLANTCEN SM-249

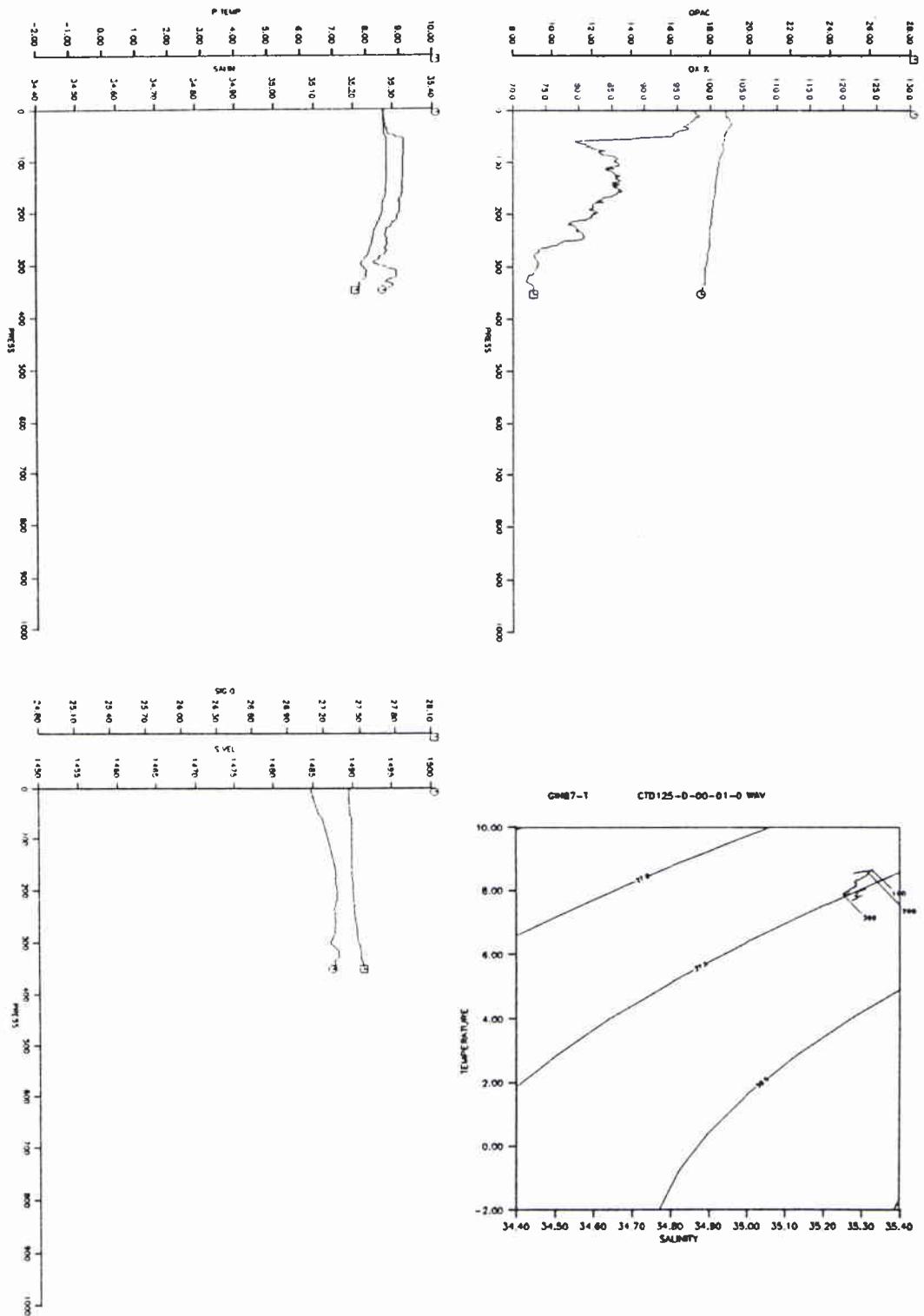


Figure B124

SACLANTCEN SM-249

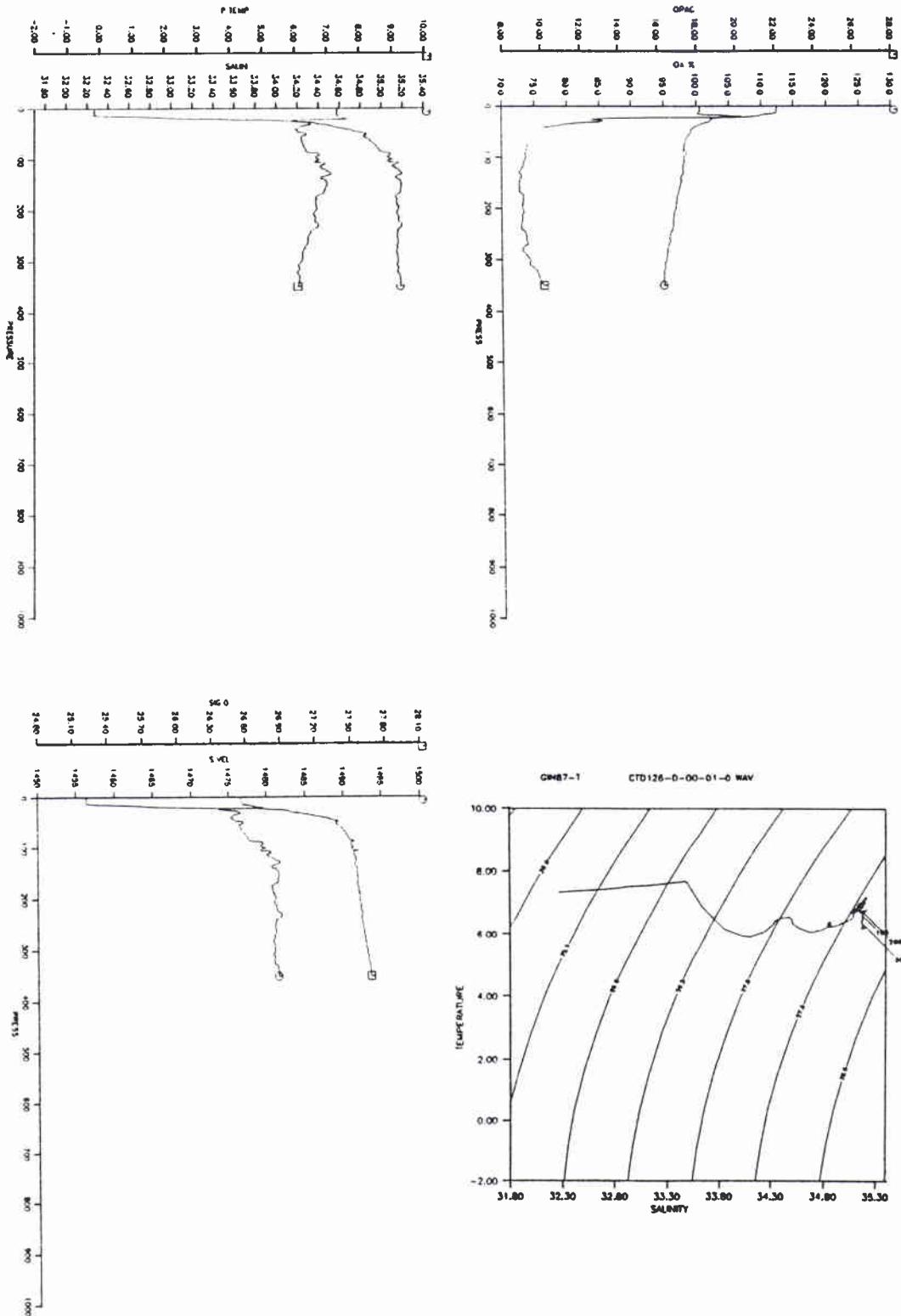


Figure B125

SACLANTCEN SM-249

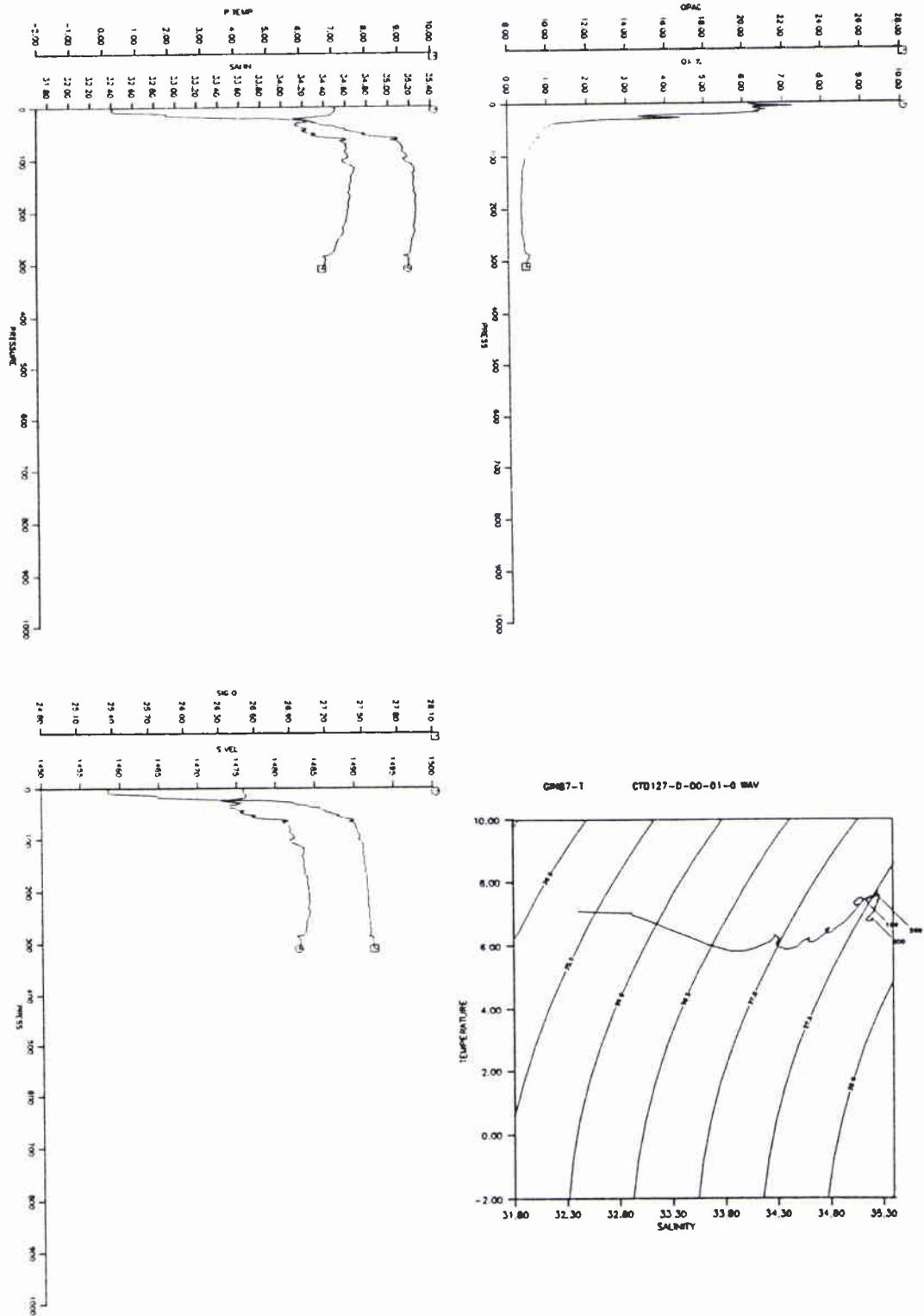


Figure B126

SACLANTCEN SM-249

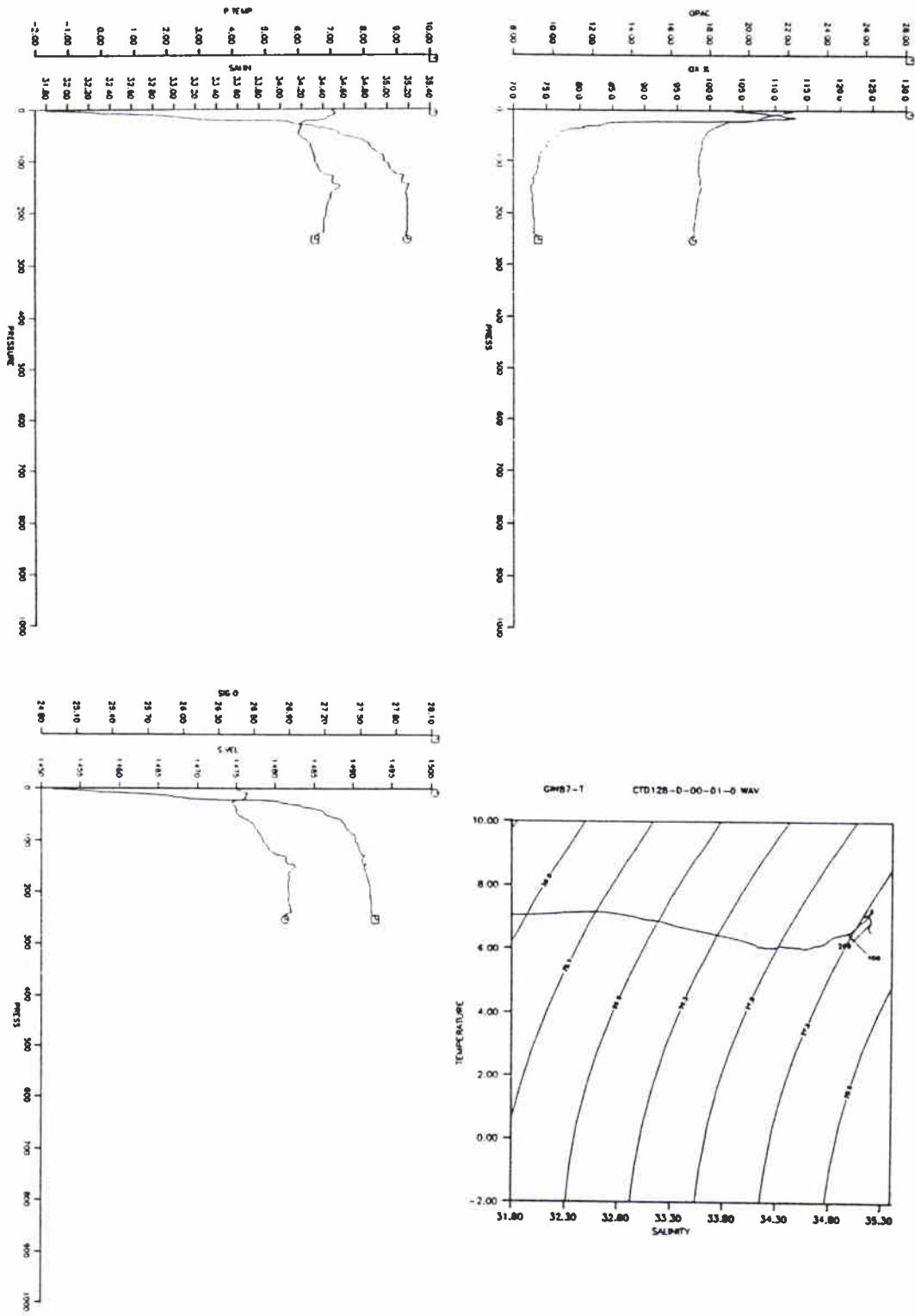


Figure B127

SACLANTCEN SM-249

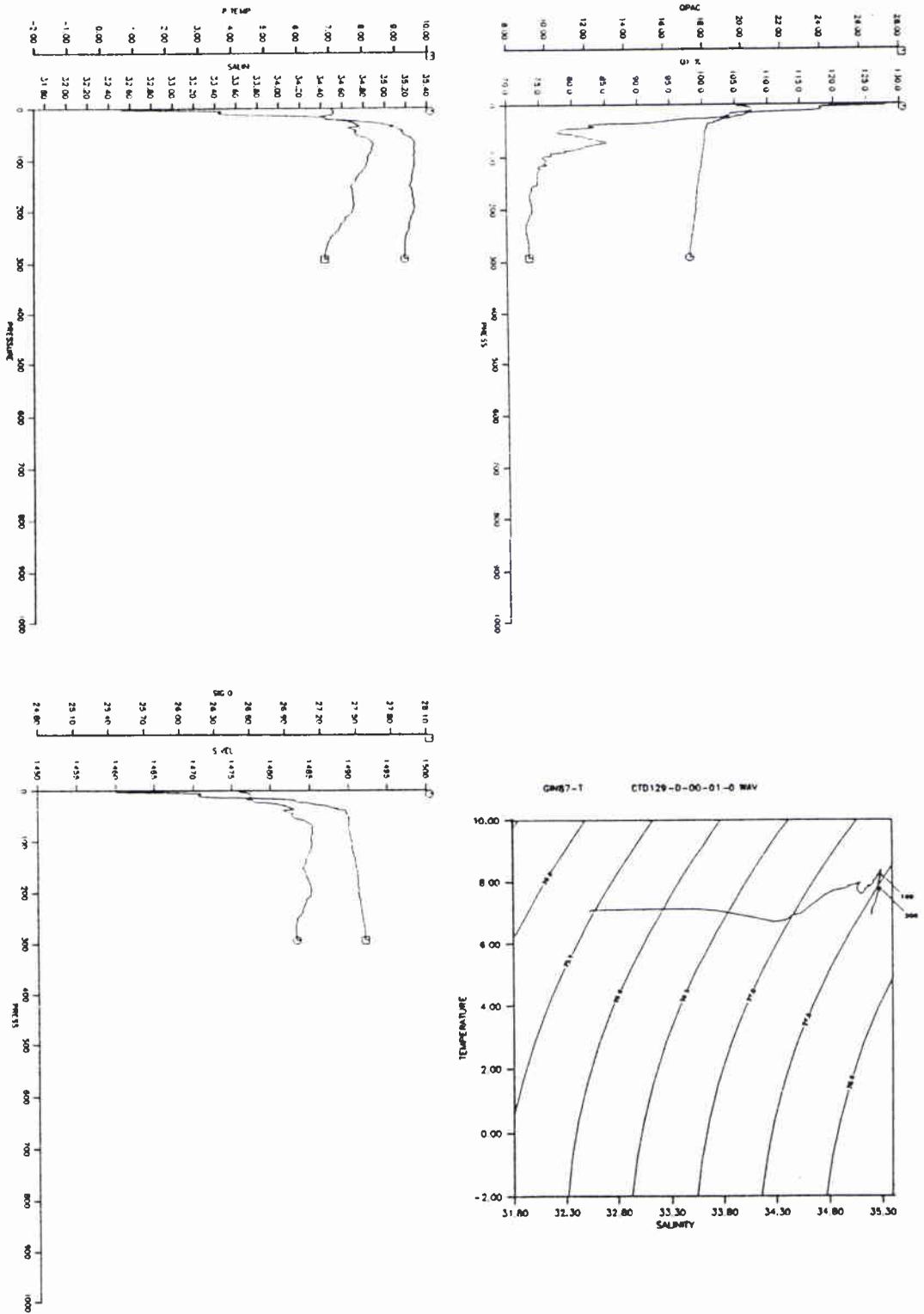


Figure B128

SACLANTCEN SM-249

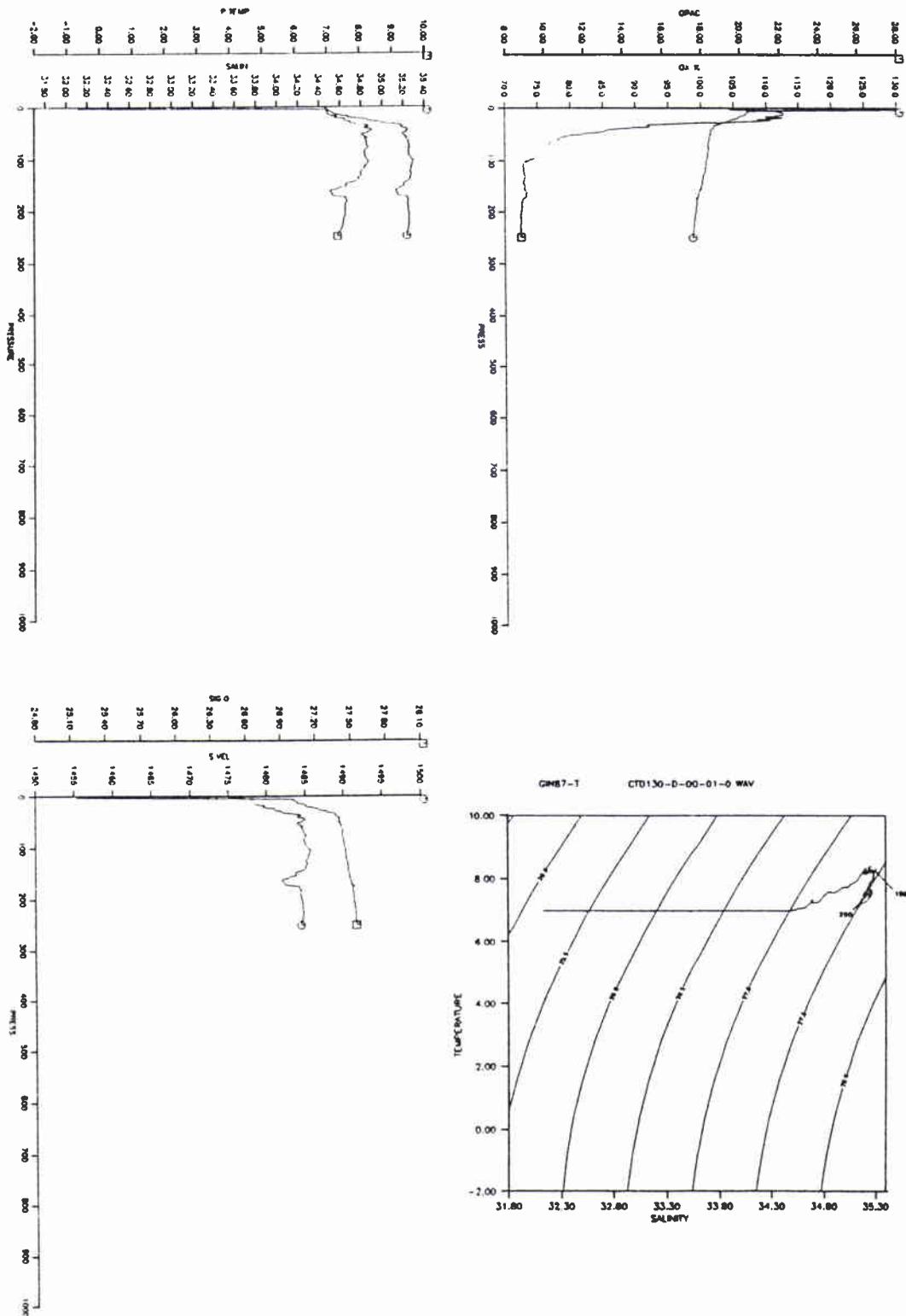


Figure B120

SACLANTCEN SM-249

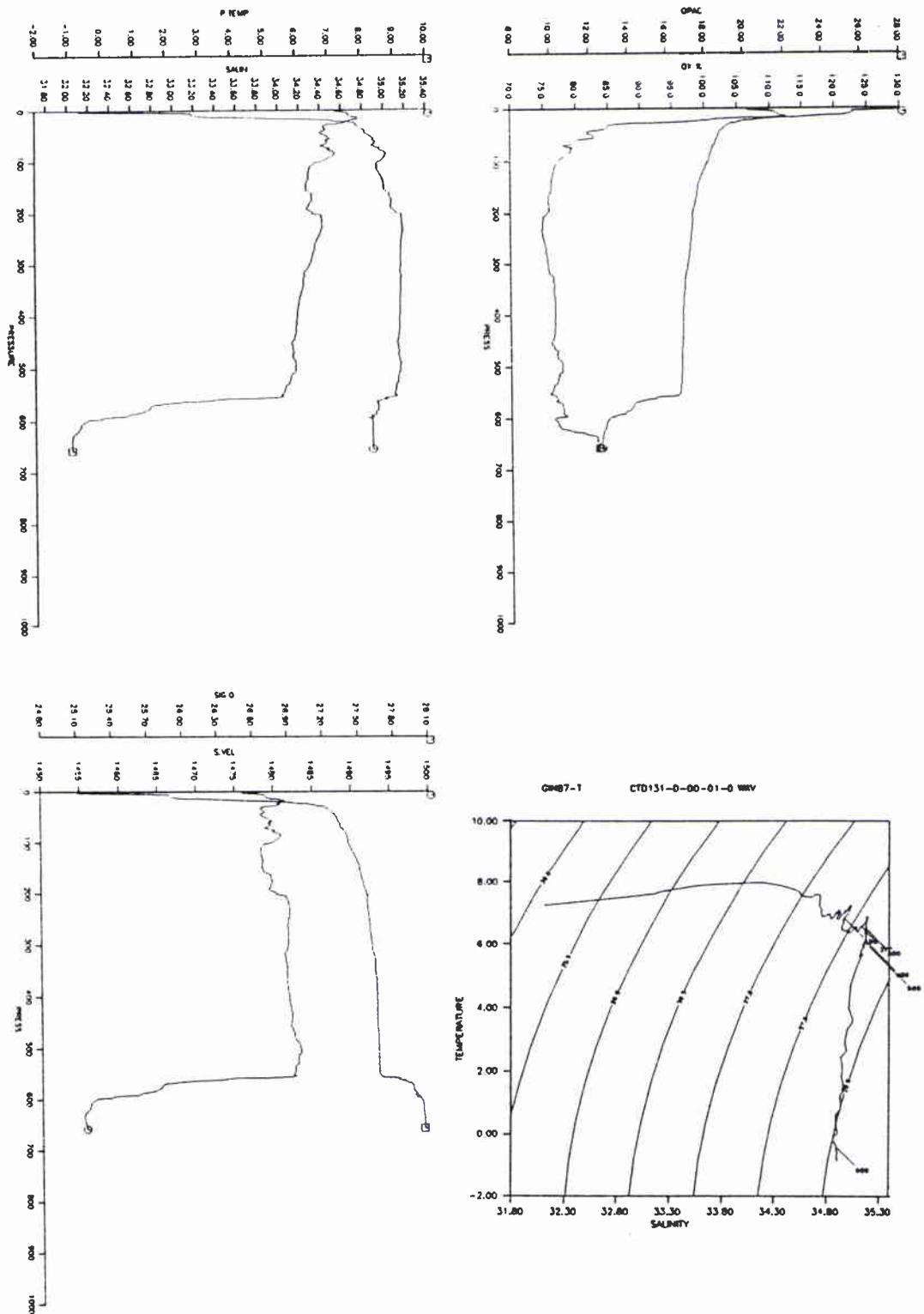


Figure B130

SACLANTCEN SM-249

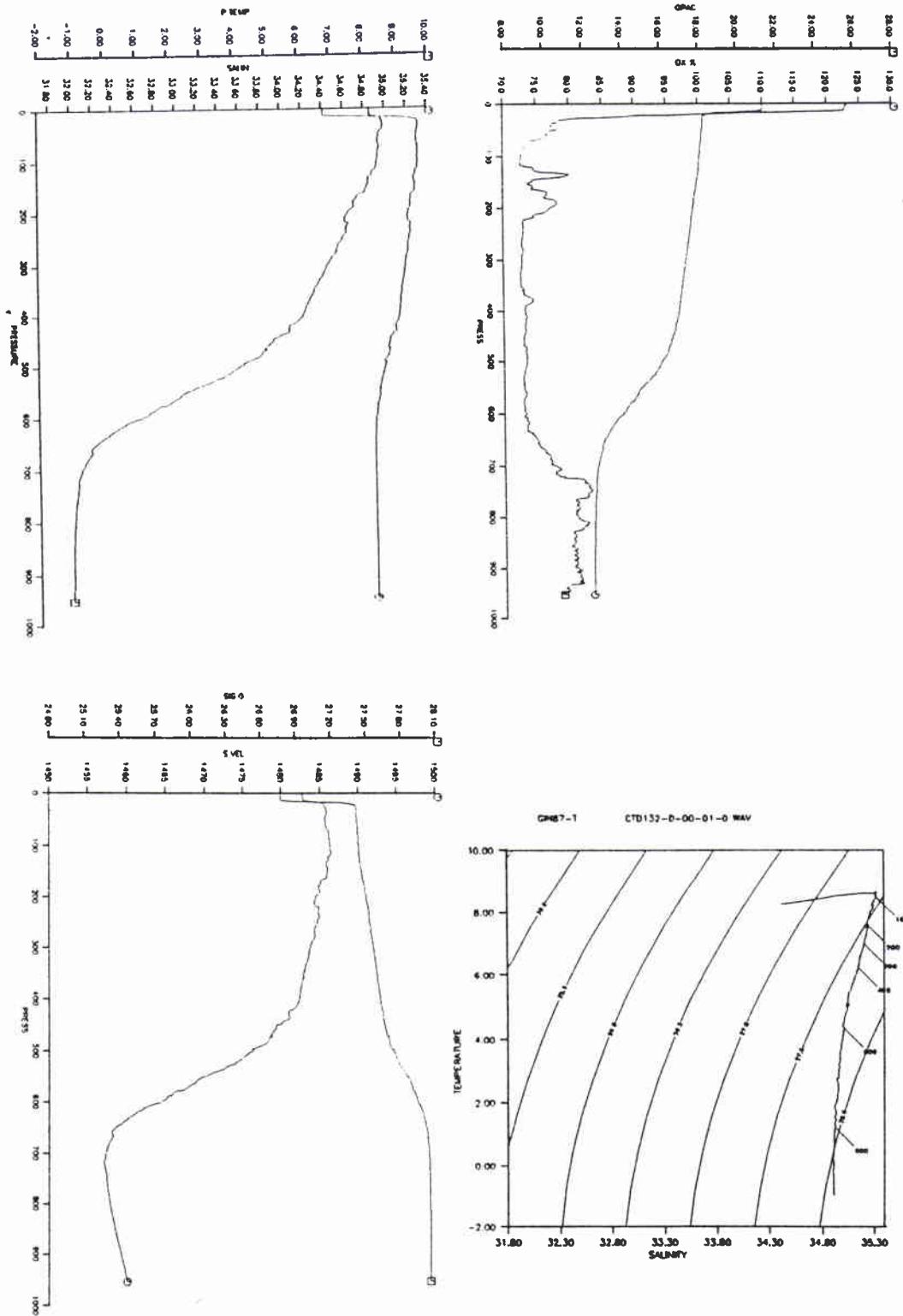


Figure B131

SACLANTCEN SM-249

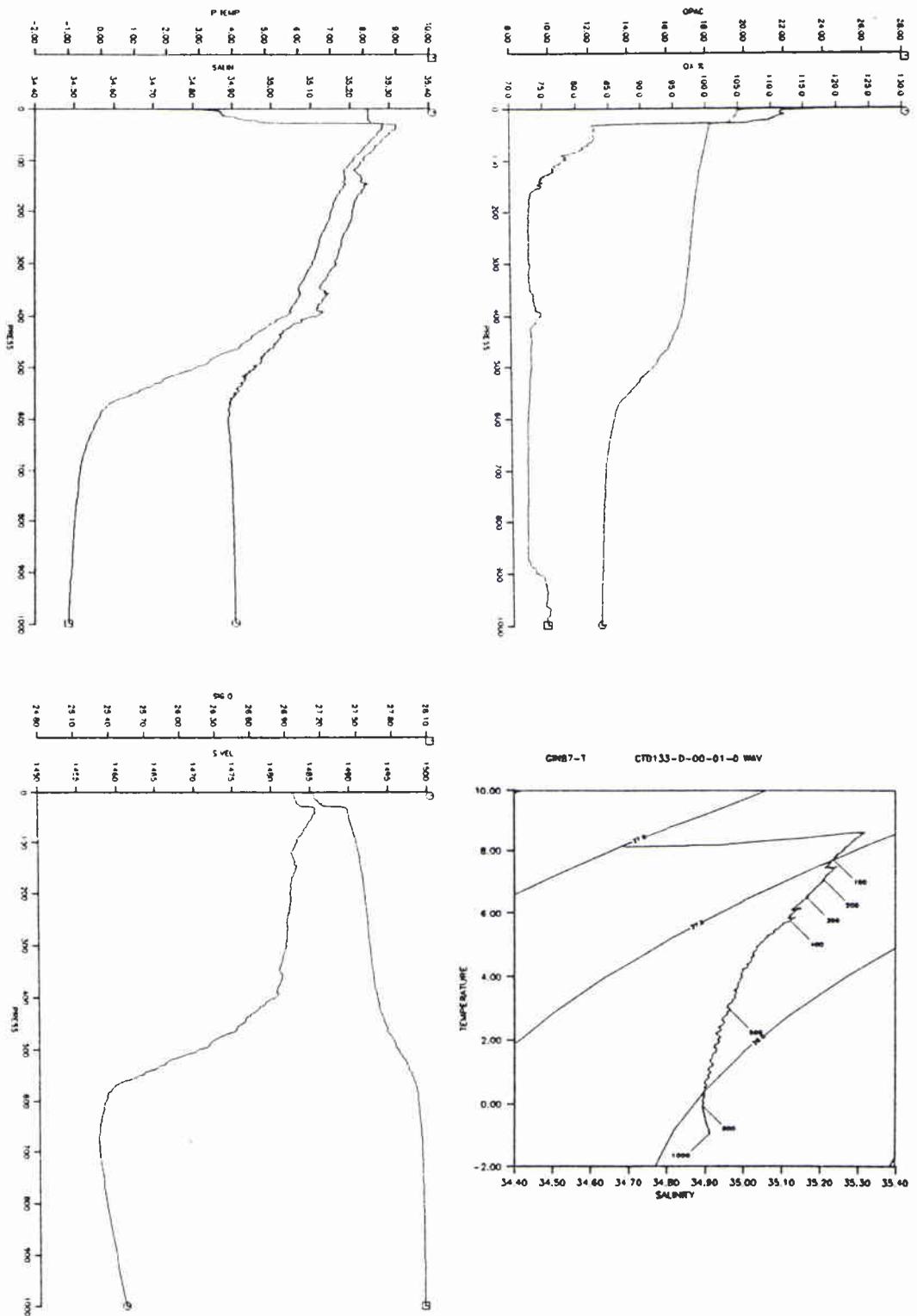


Figure B132

SACLANTCEN SM-249

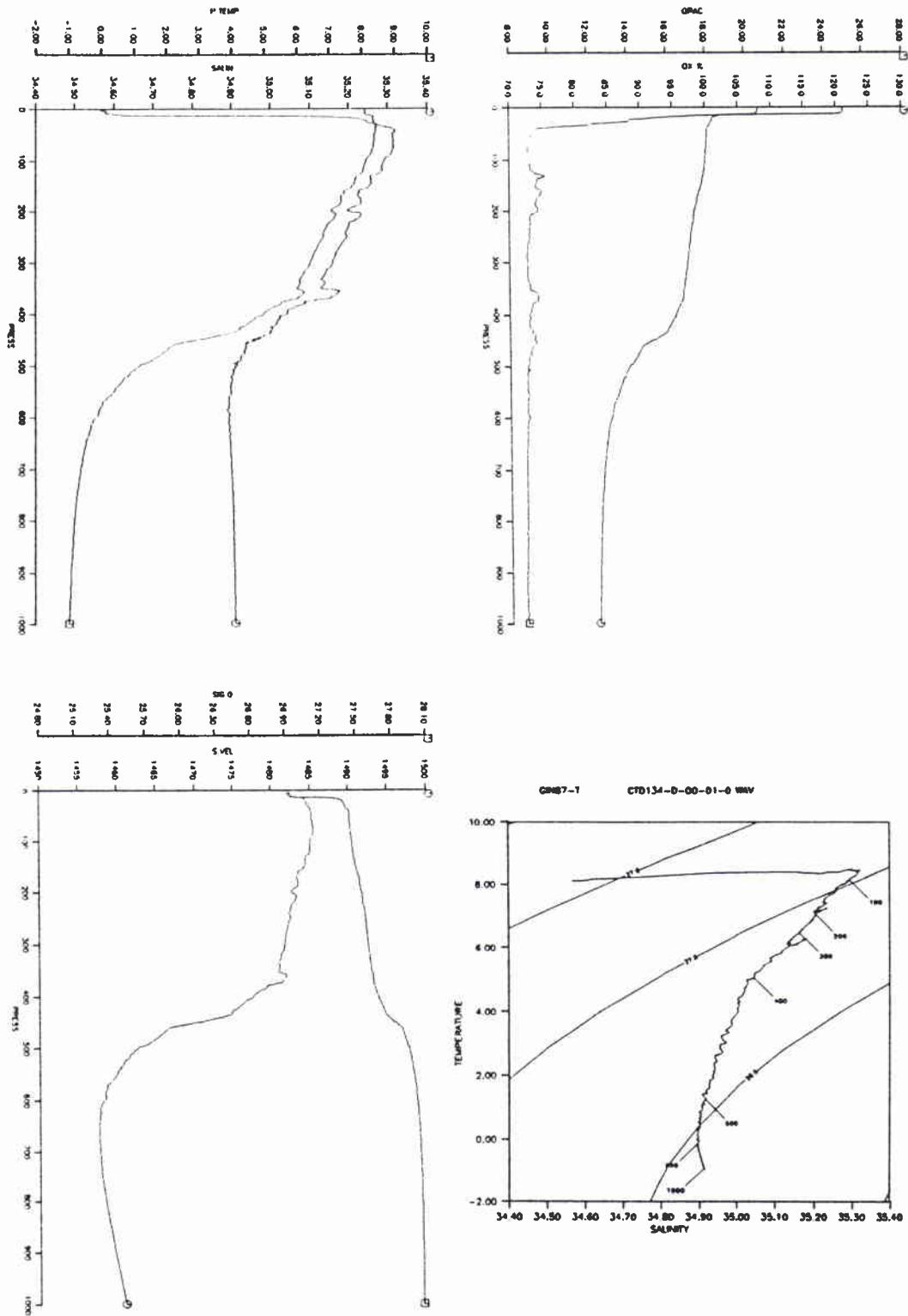


Figure B133

SACLANTCEN SM-249

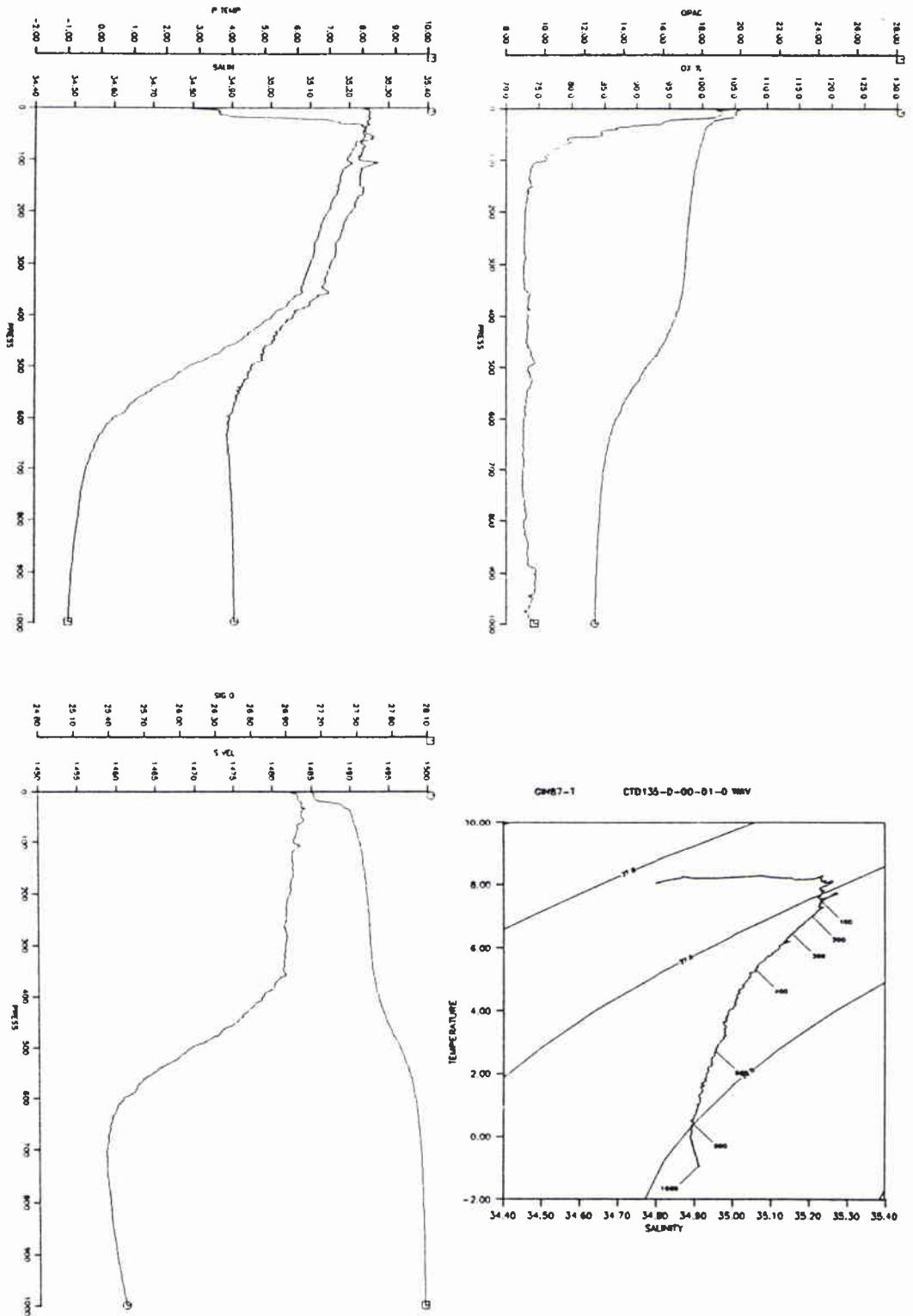


Figure B134

SACLANTCEN SM-249

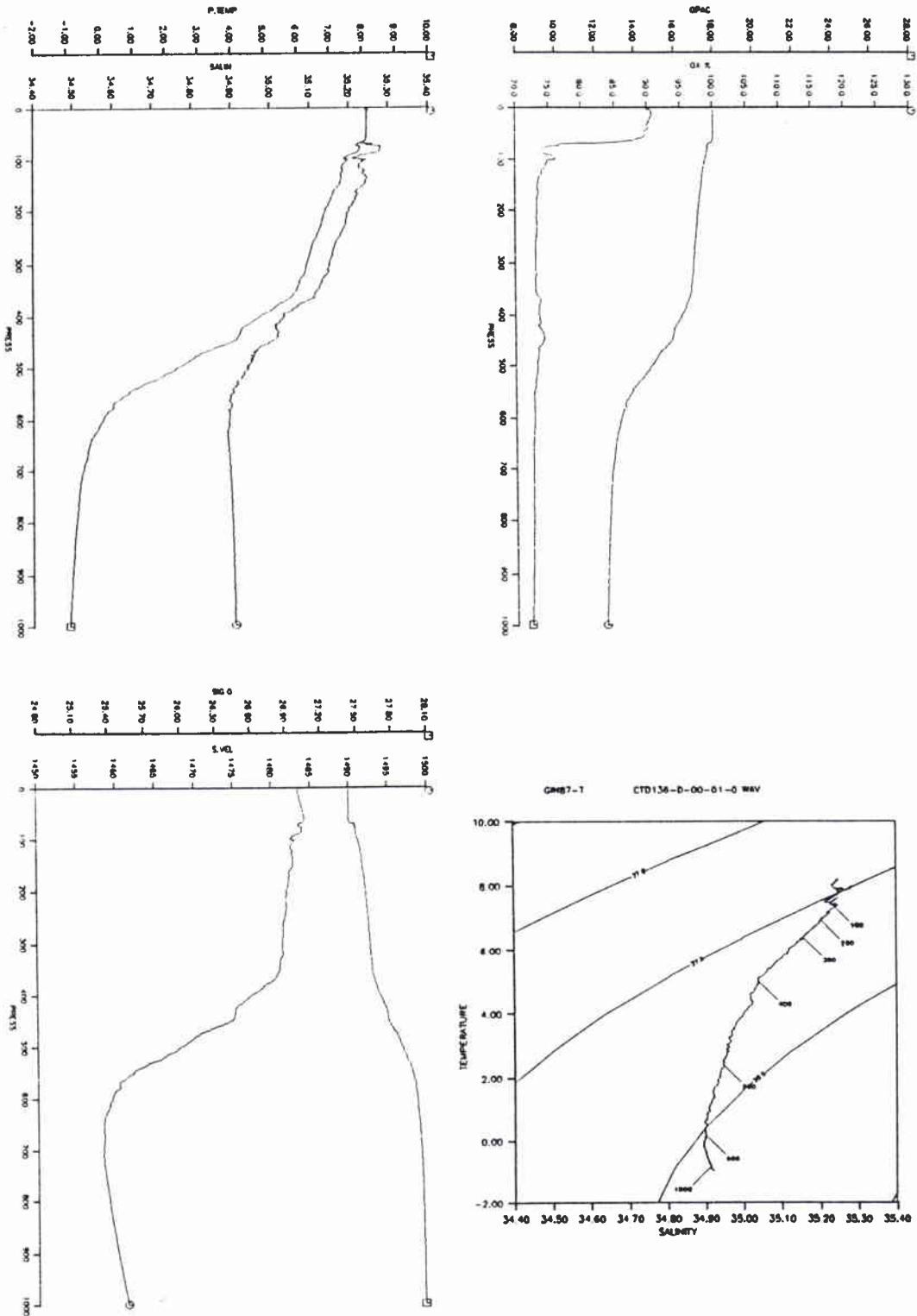


Figure B135

SACLANTCEN SM-249

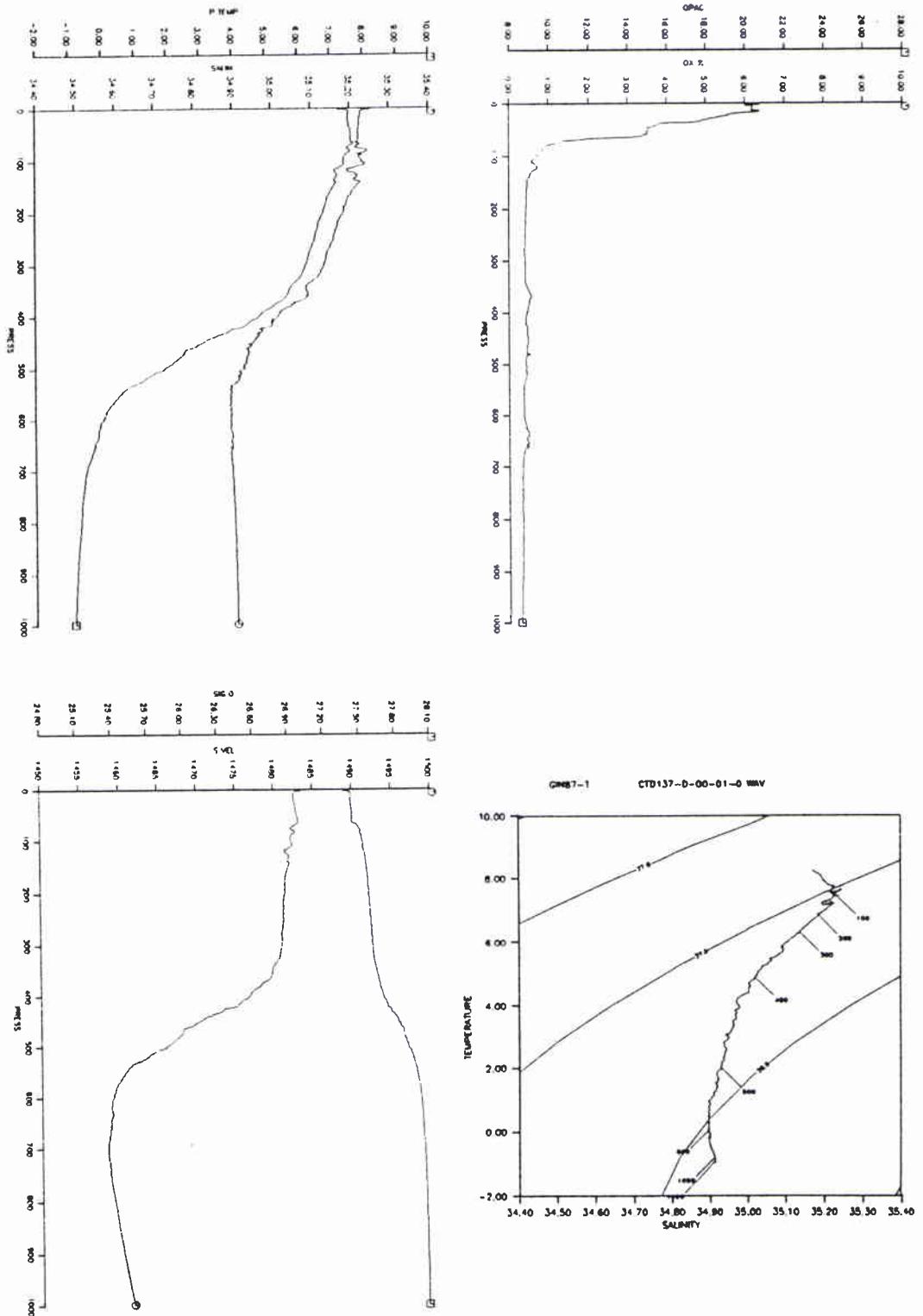


Figure B136

SACLANTCEN SM-249

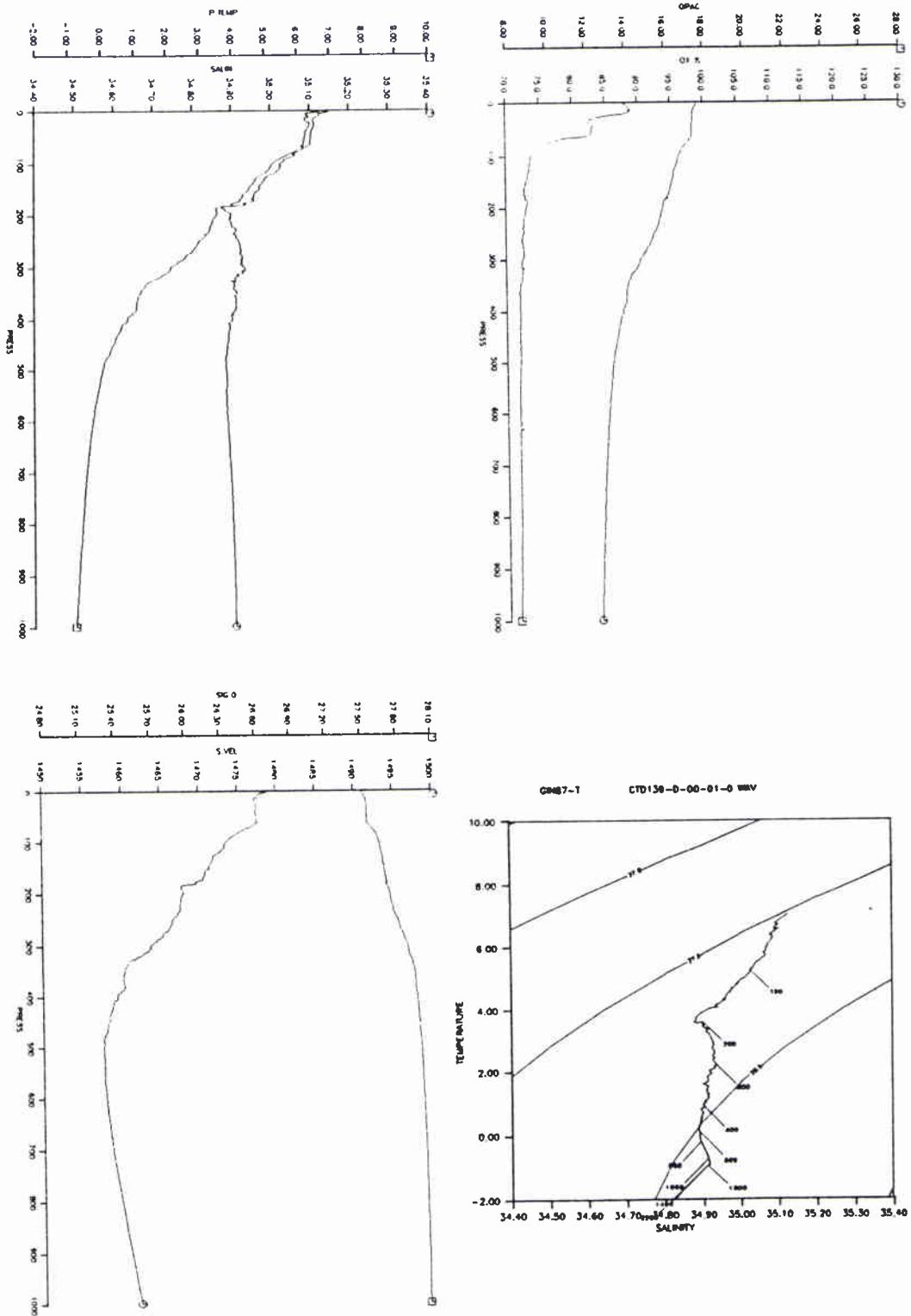


Figure B138

SACLANTCEN SM-249

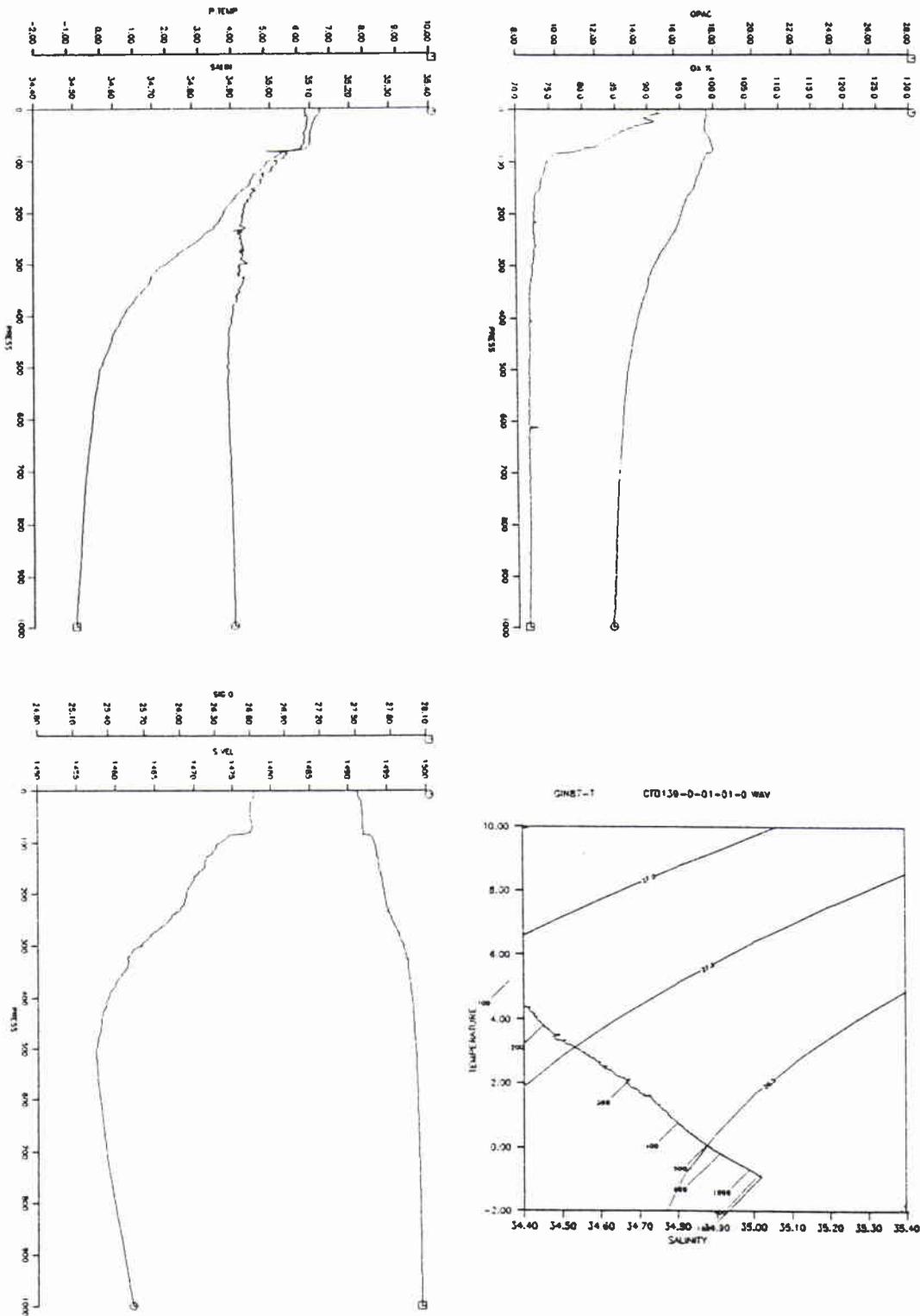


Figure B139

SACLANTCEN SM-249

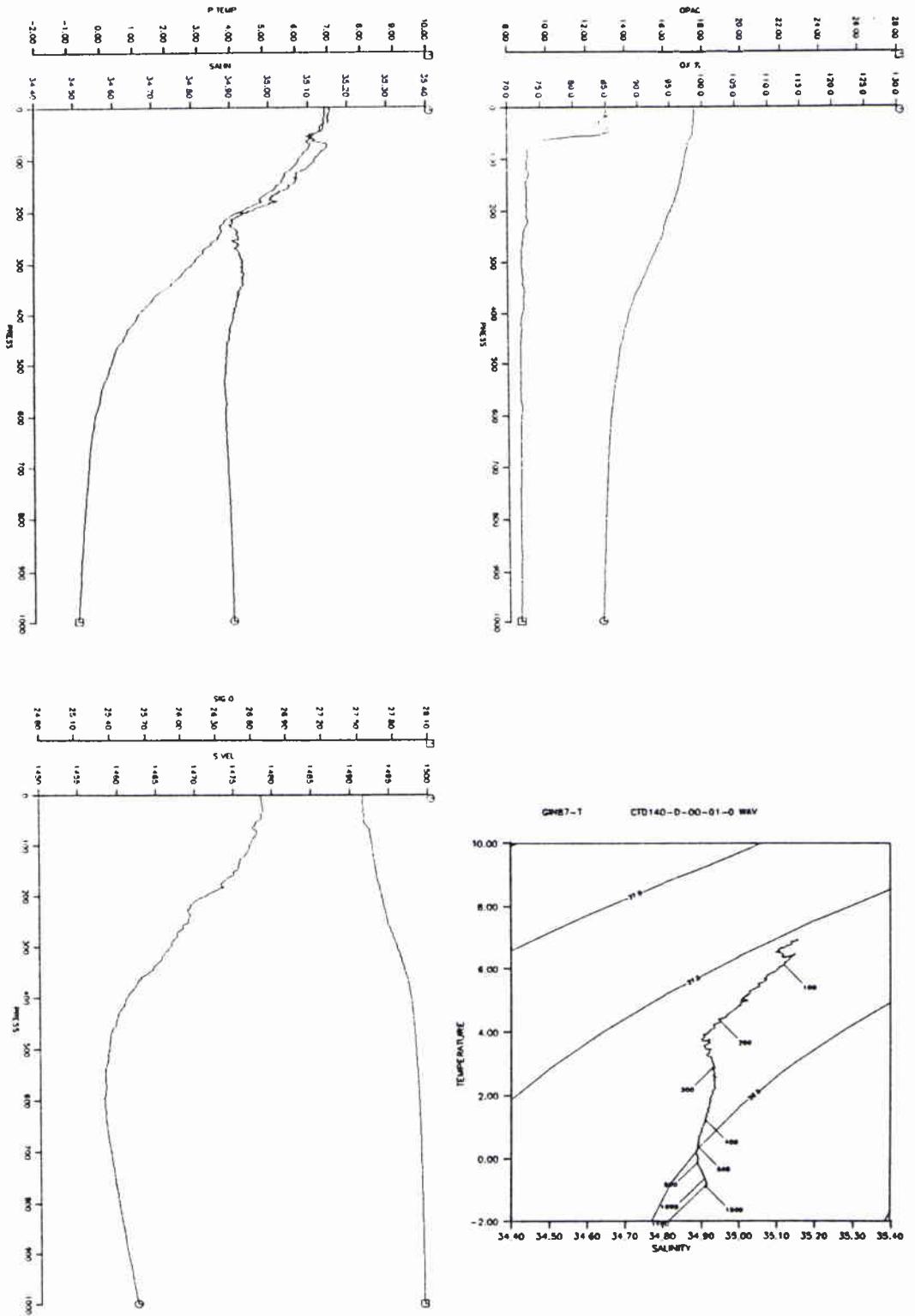


Figure B140

SACLANTCEN SM-249

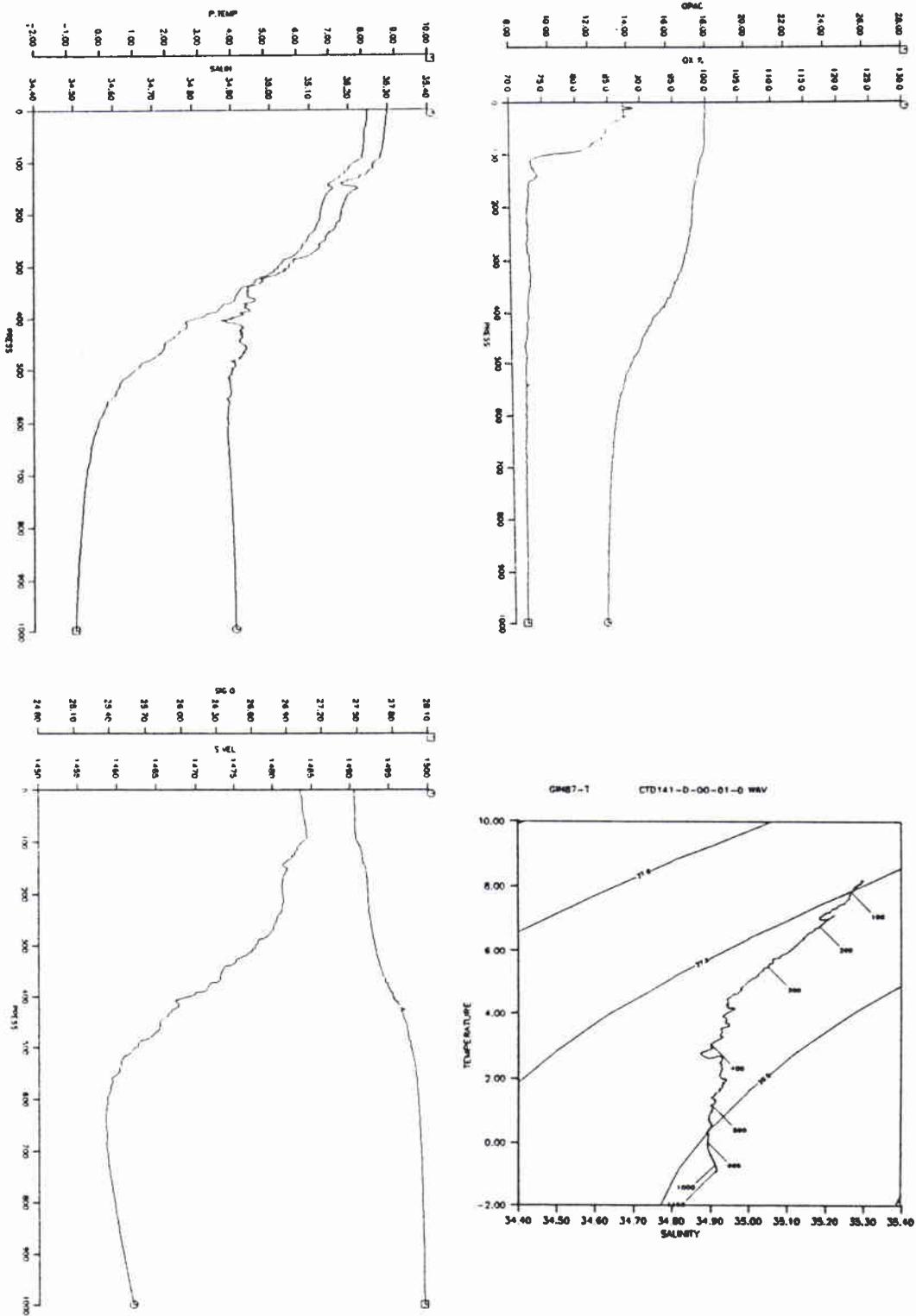


Figure B141

SACLANTCEN SM-249

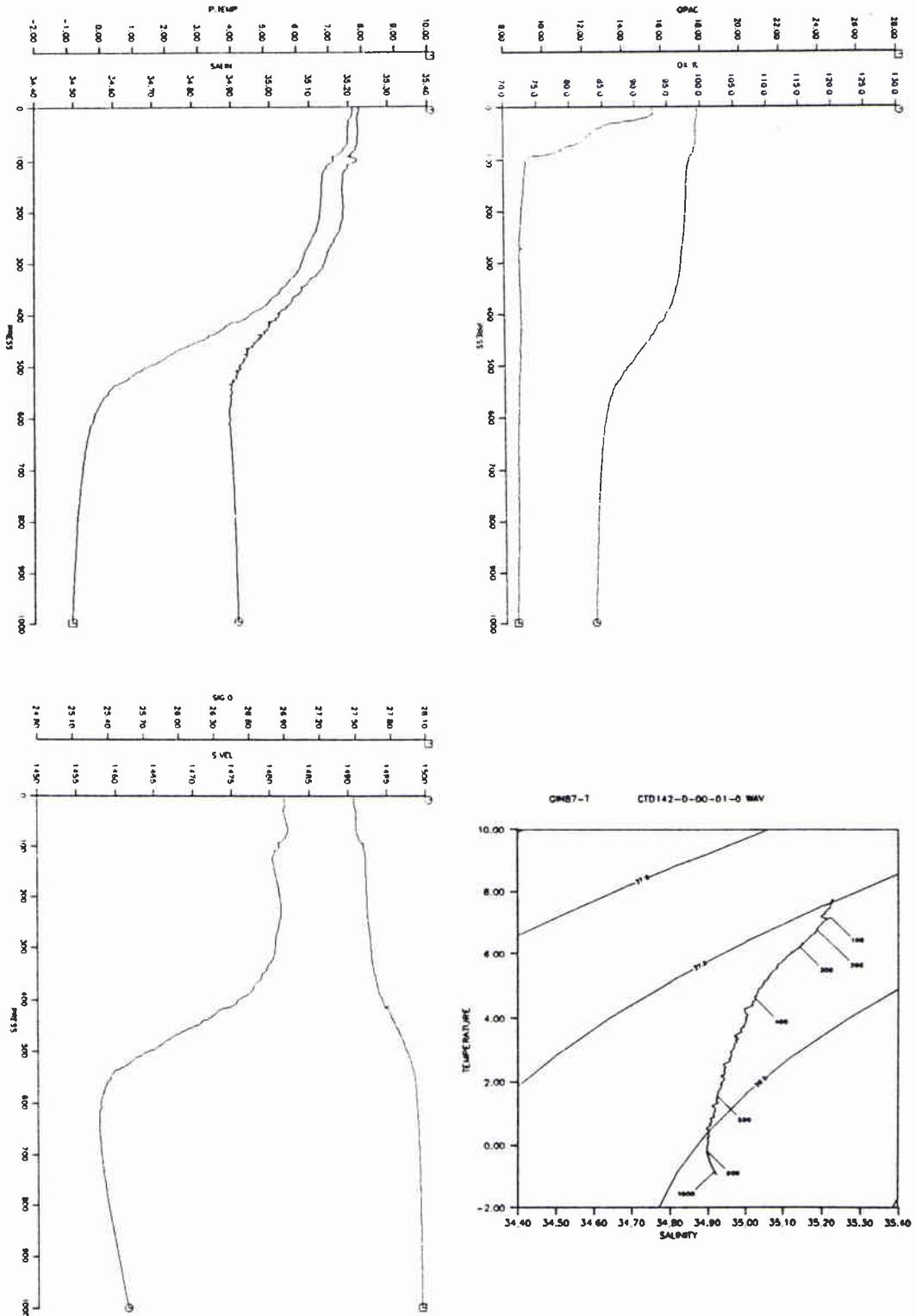


Figure B142

SACLANTCEN SM-249

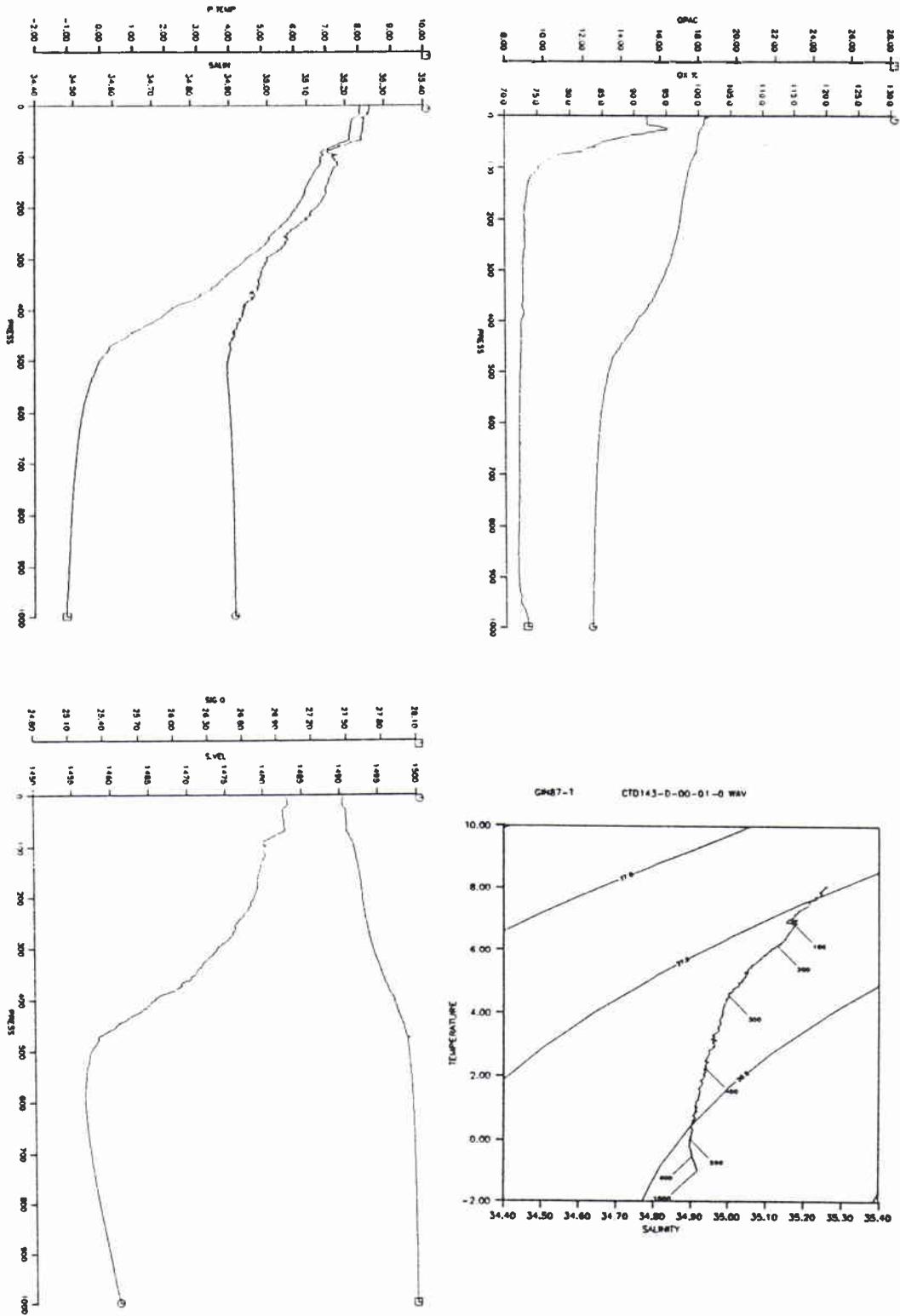


Figure B143

SACLANTCEN SM-249

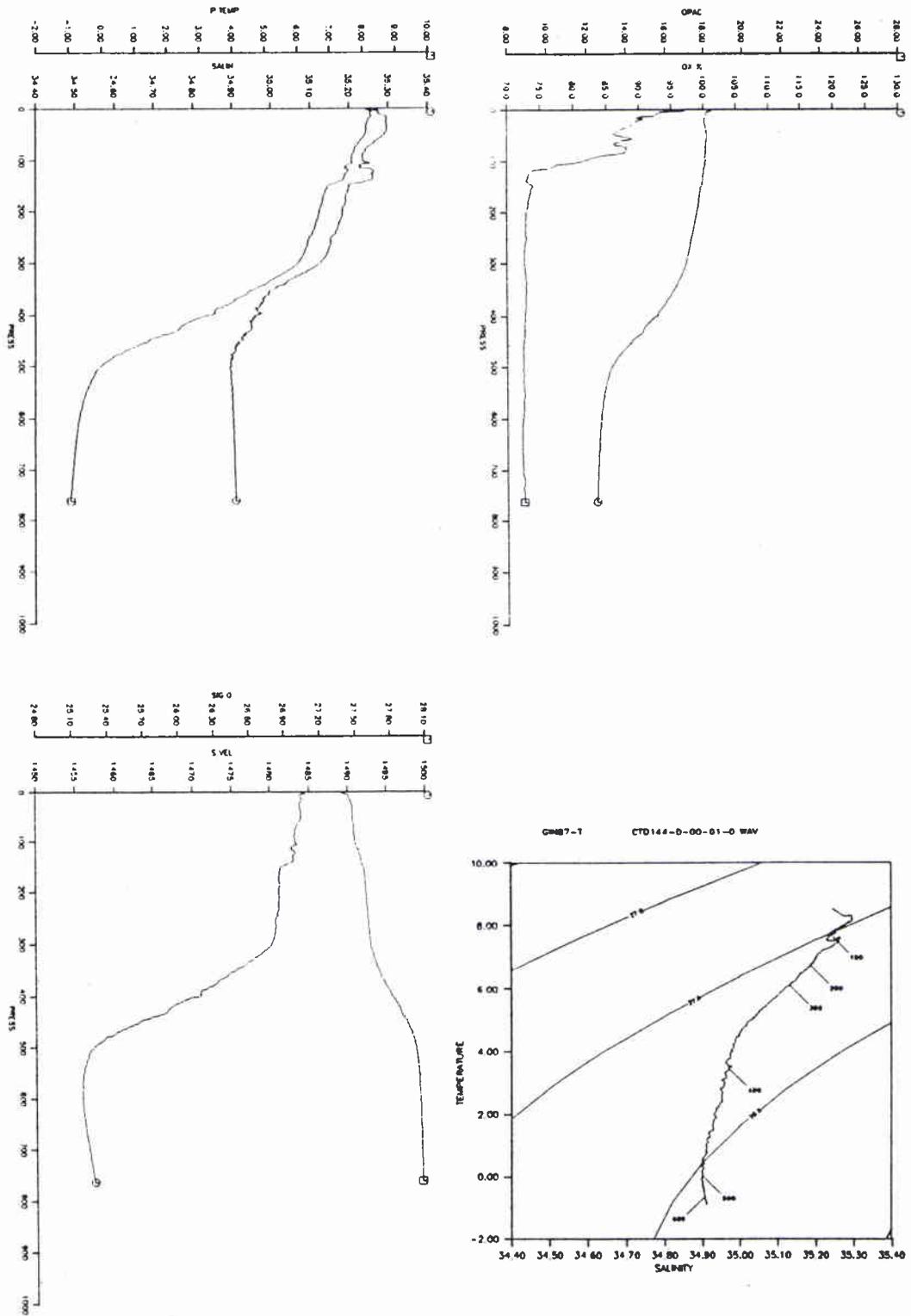


Figure B144

SACLANTCEN SM-249

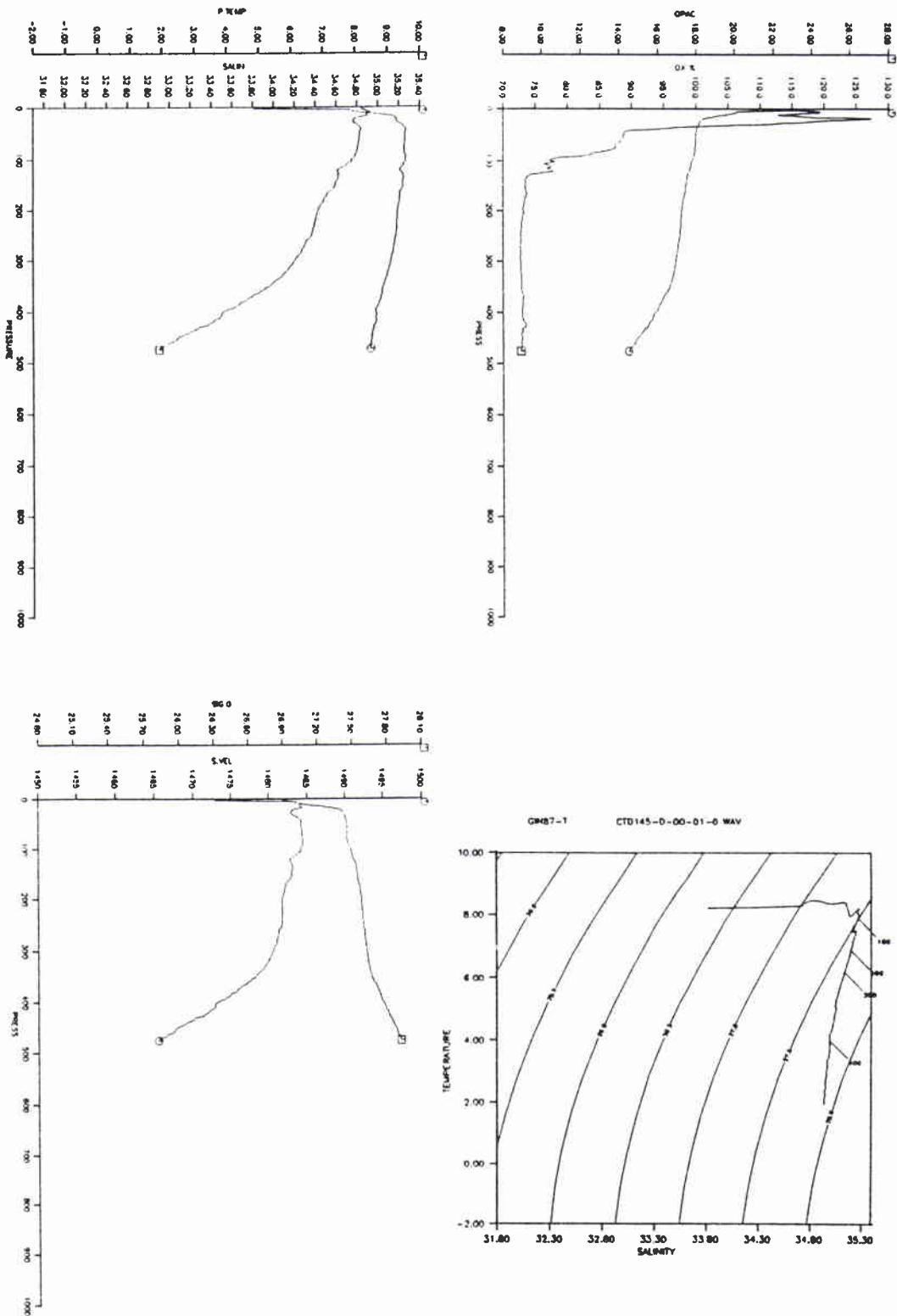


Figure B145

SACLANTCEN SM-249

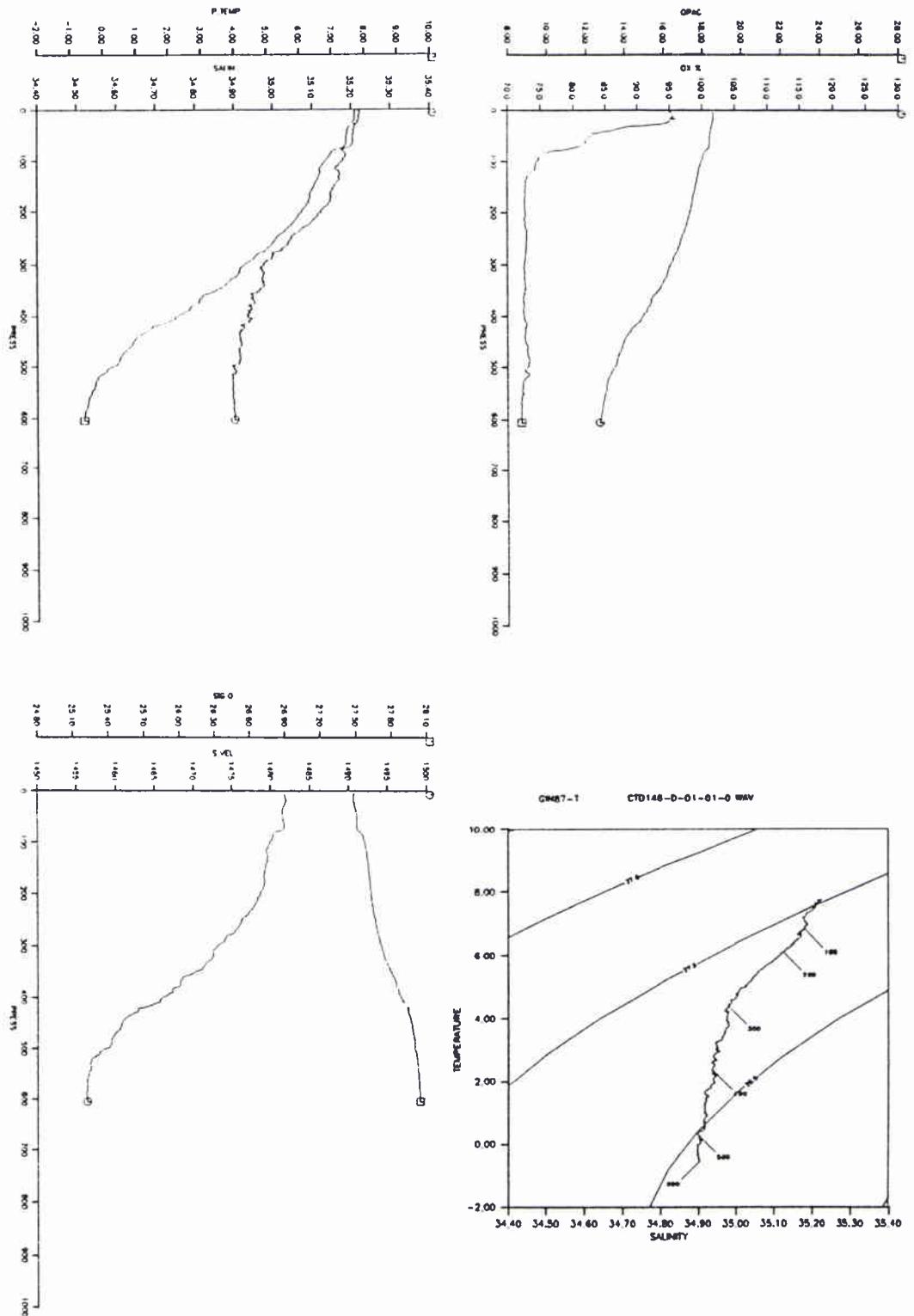


Figure B146

SACLANTCEN SM-249

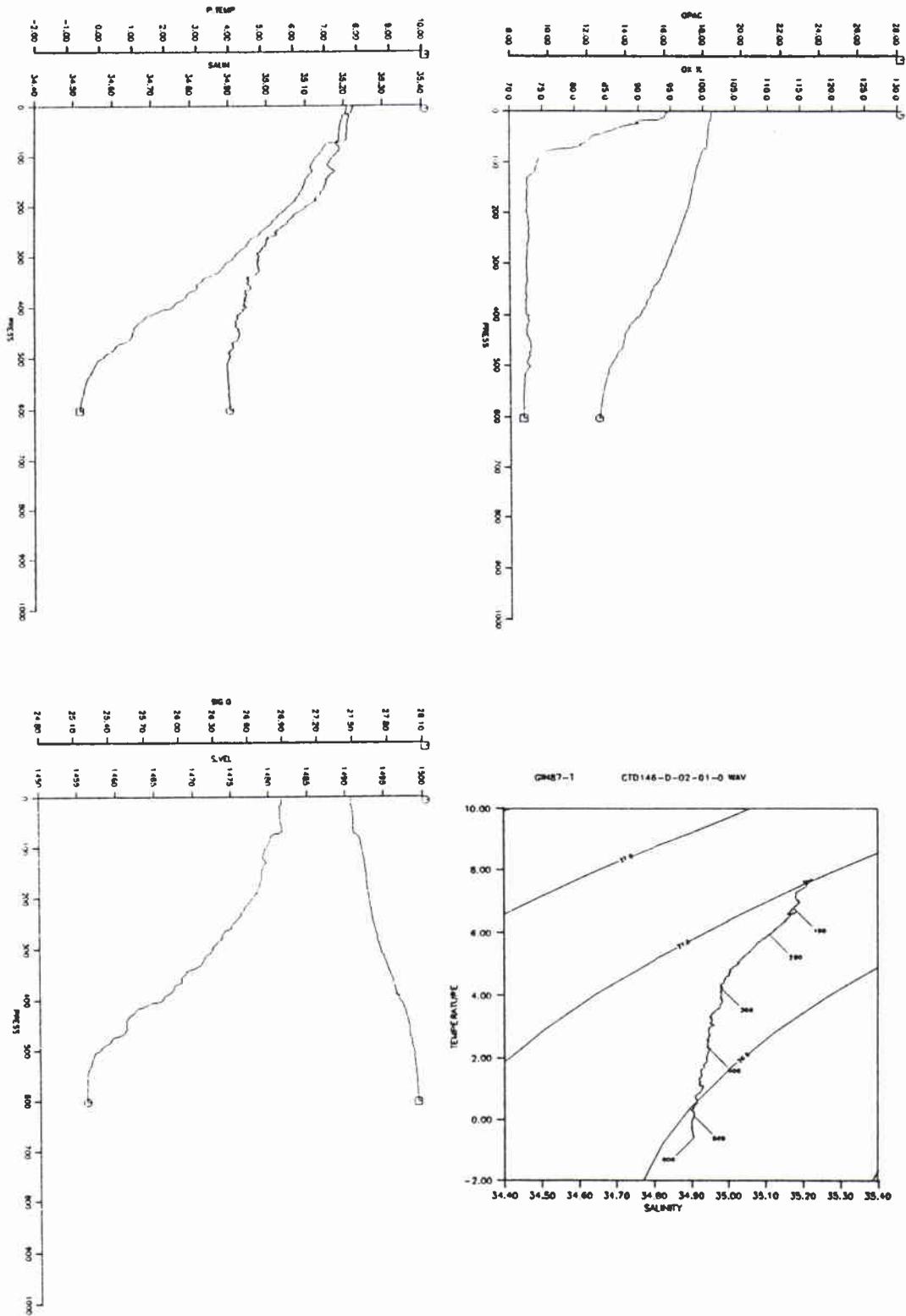


Figure B147

SACLANTCEN SM-249

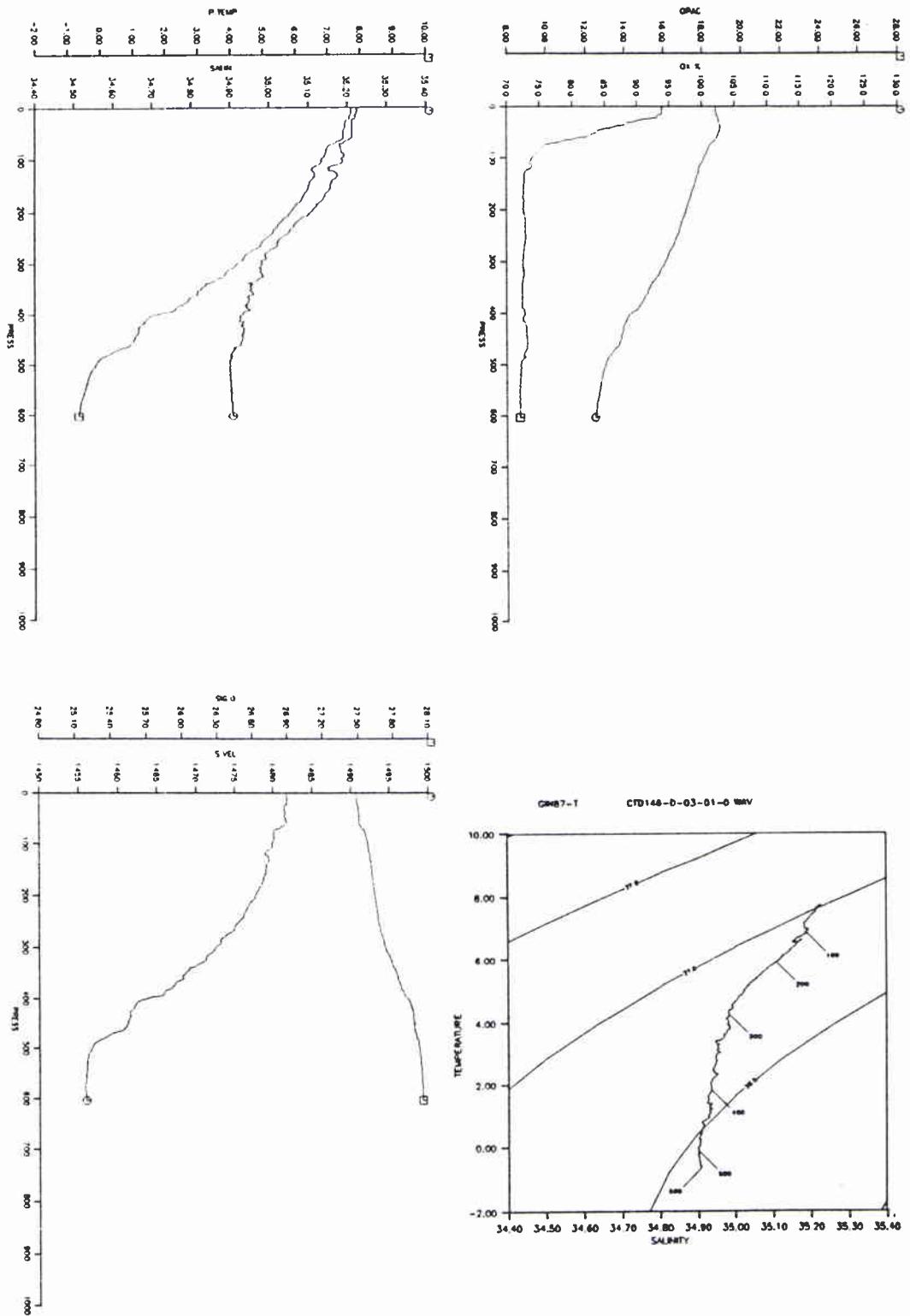


Figure B148

SACLANTCEN SM-249

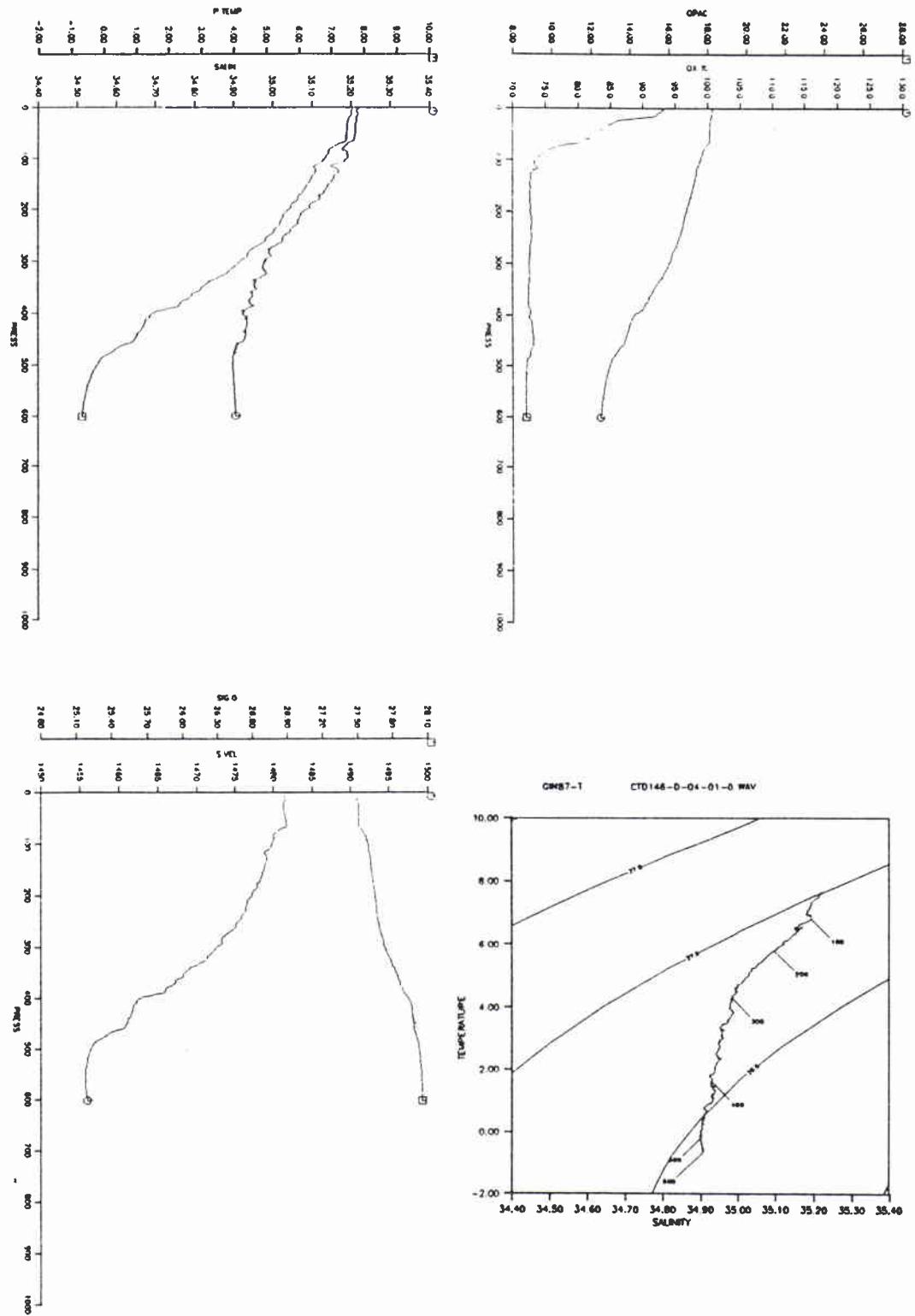


Figure B149

SACLANTCEN SM-249

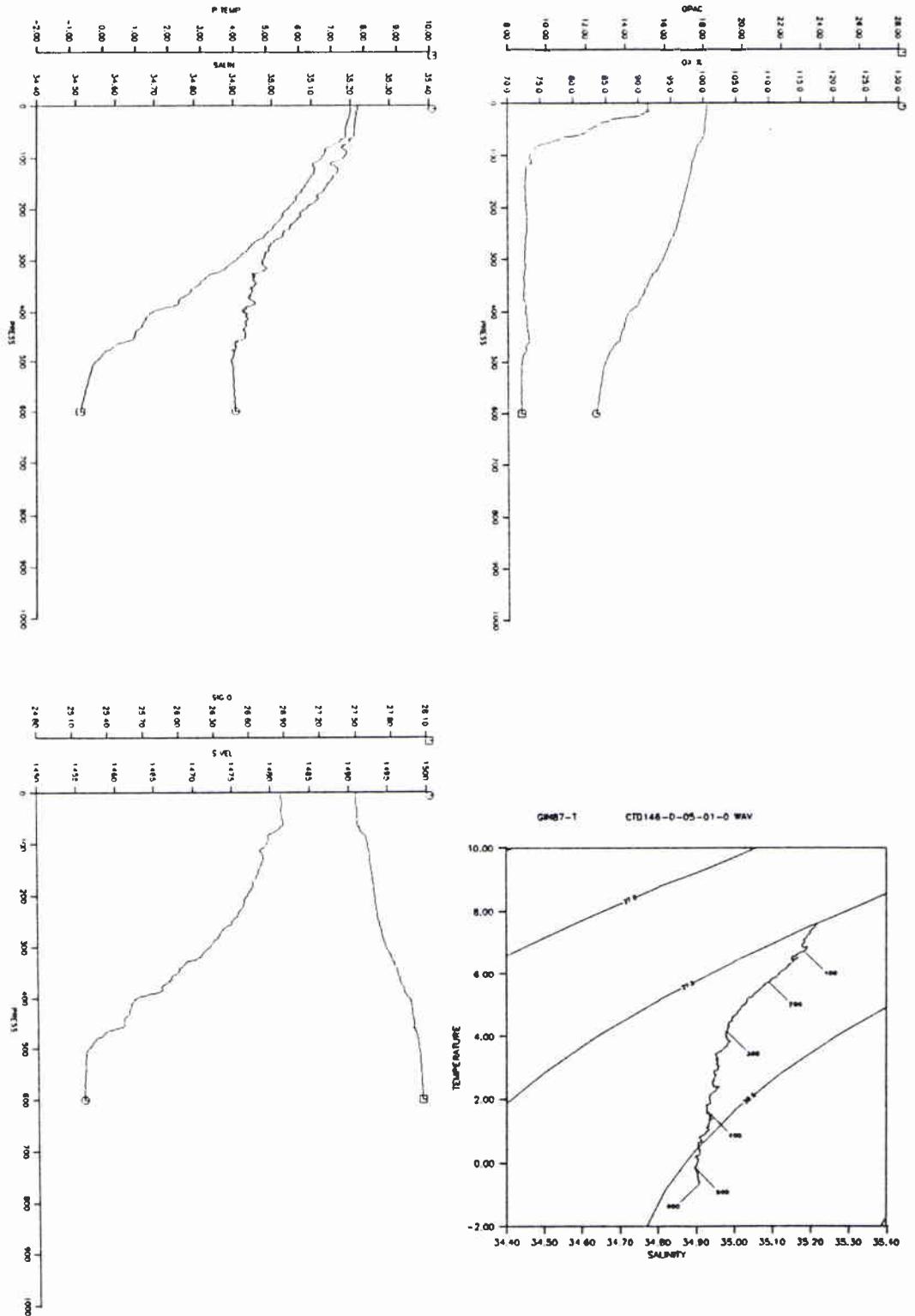


Figure B150

SACLANTCEN SM-249

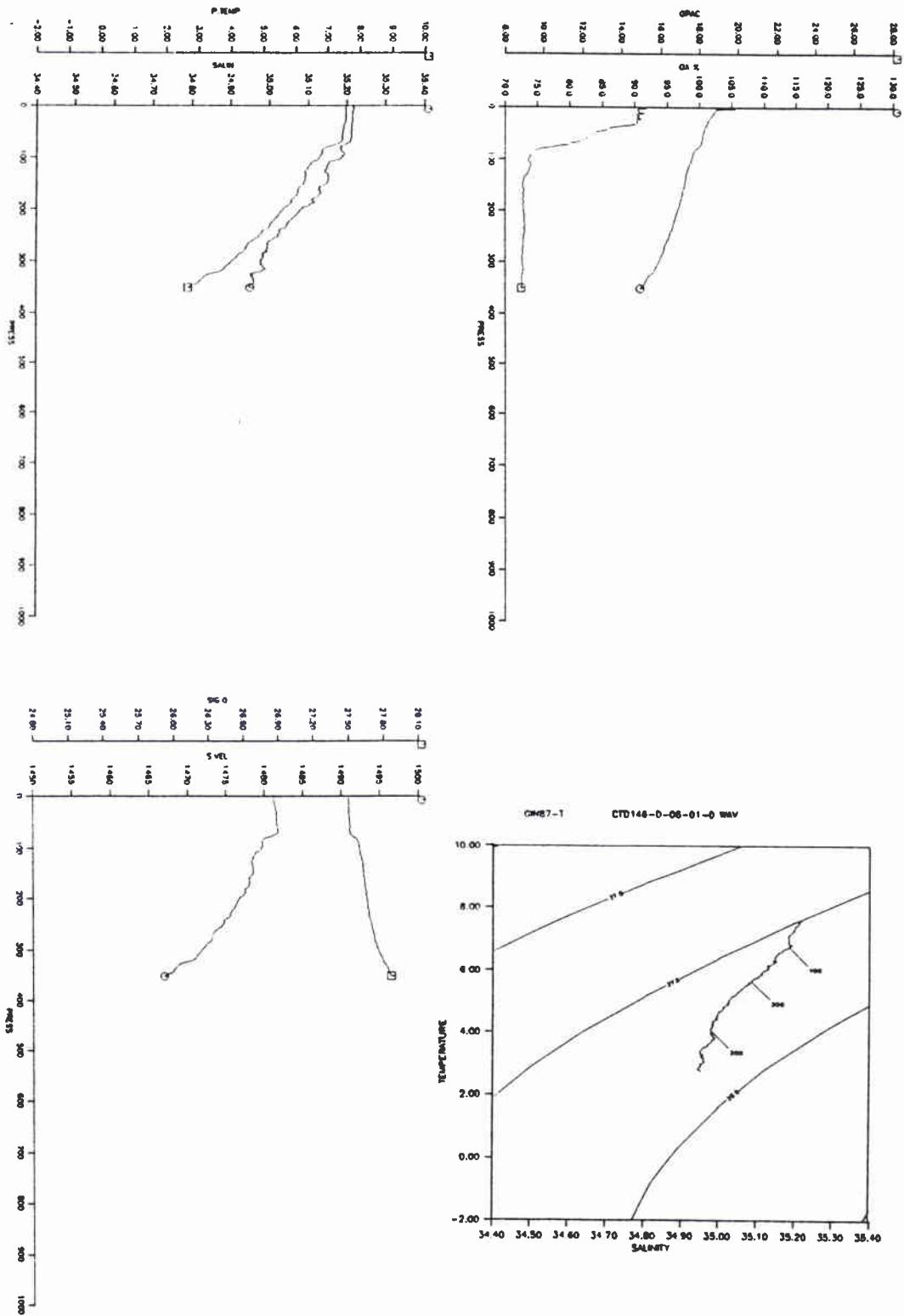


Figure B151

SACLANTCEN SM-249

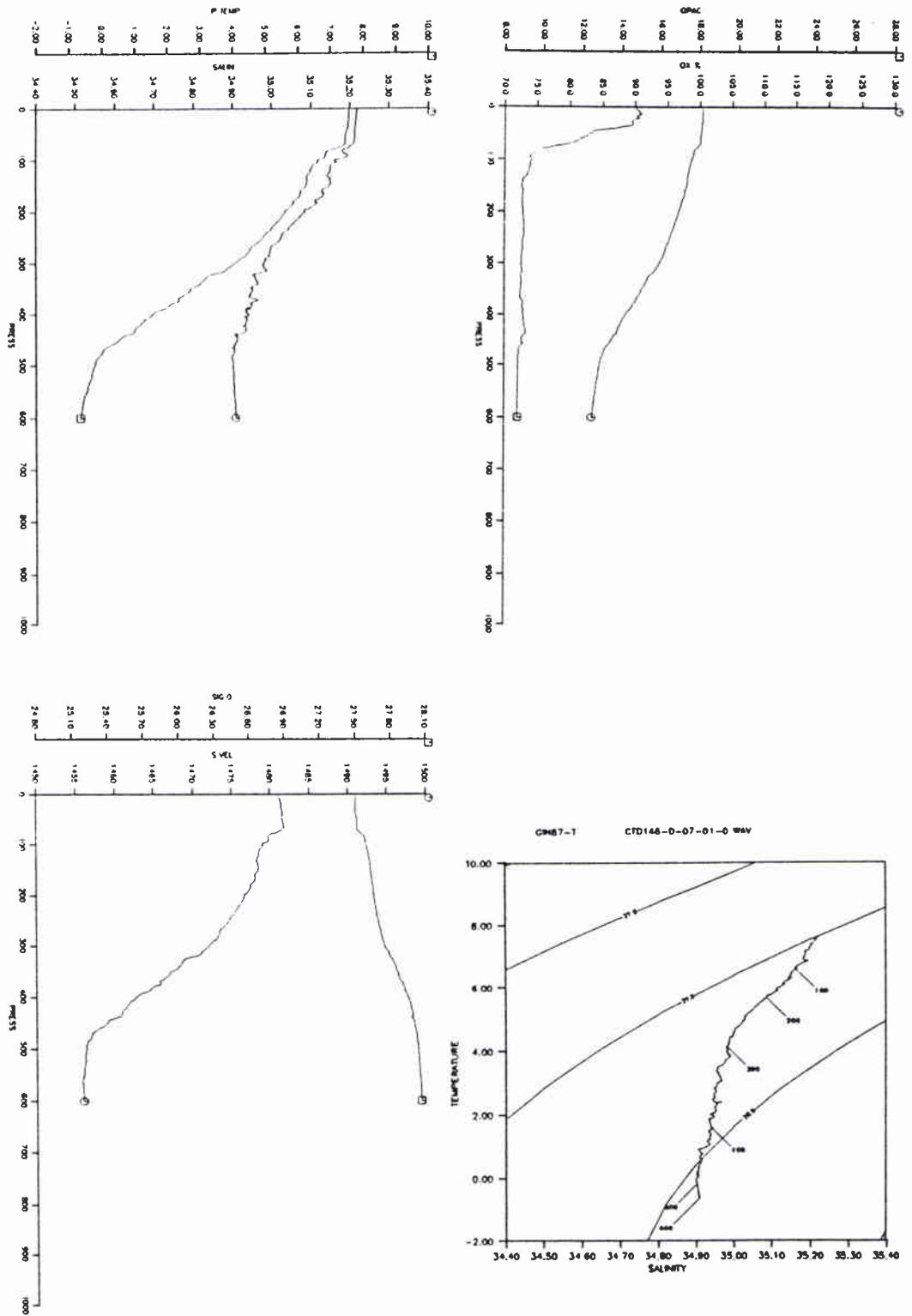


Figure B152

SACLANTCEN SM-249

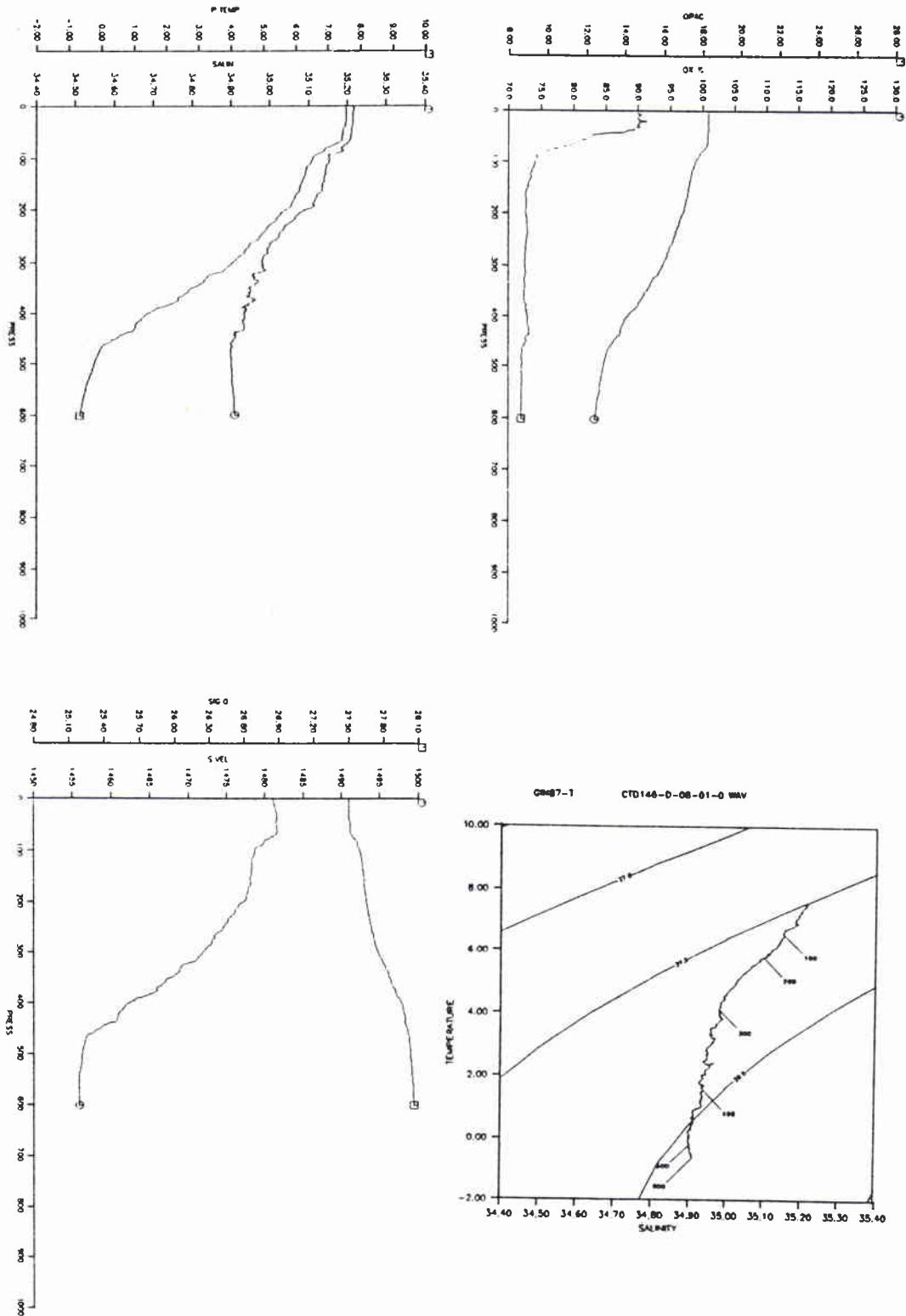


Figure B153

SACLANTCEN SM-249

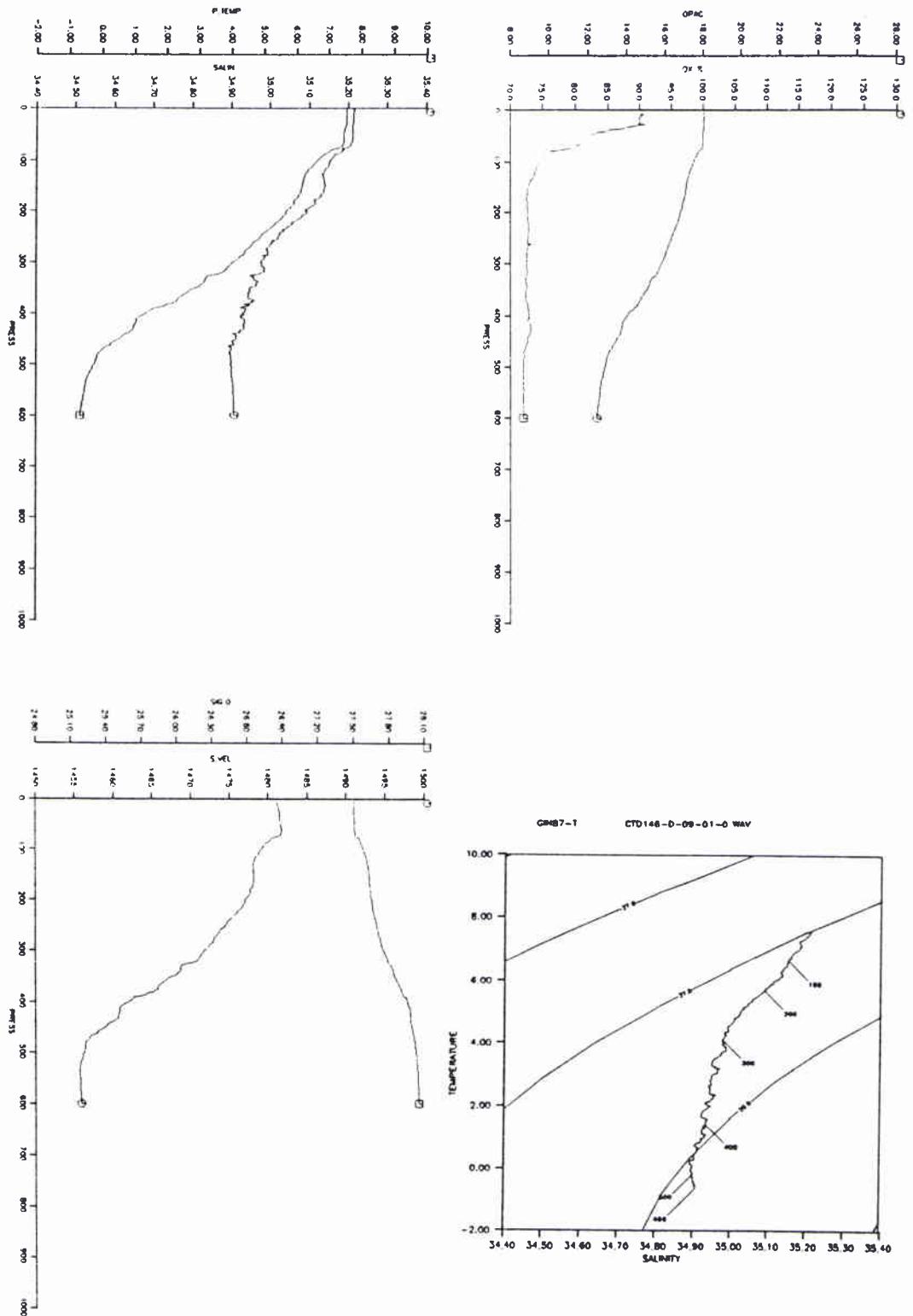


Figure B154

SACLANTCEN SM-249

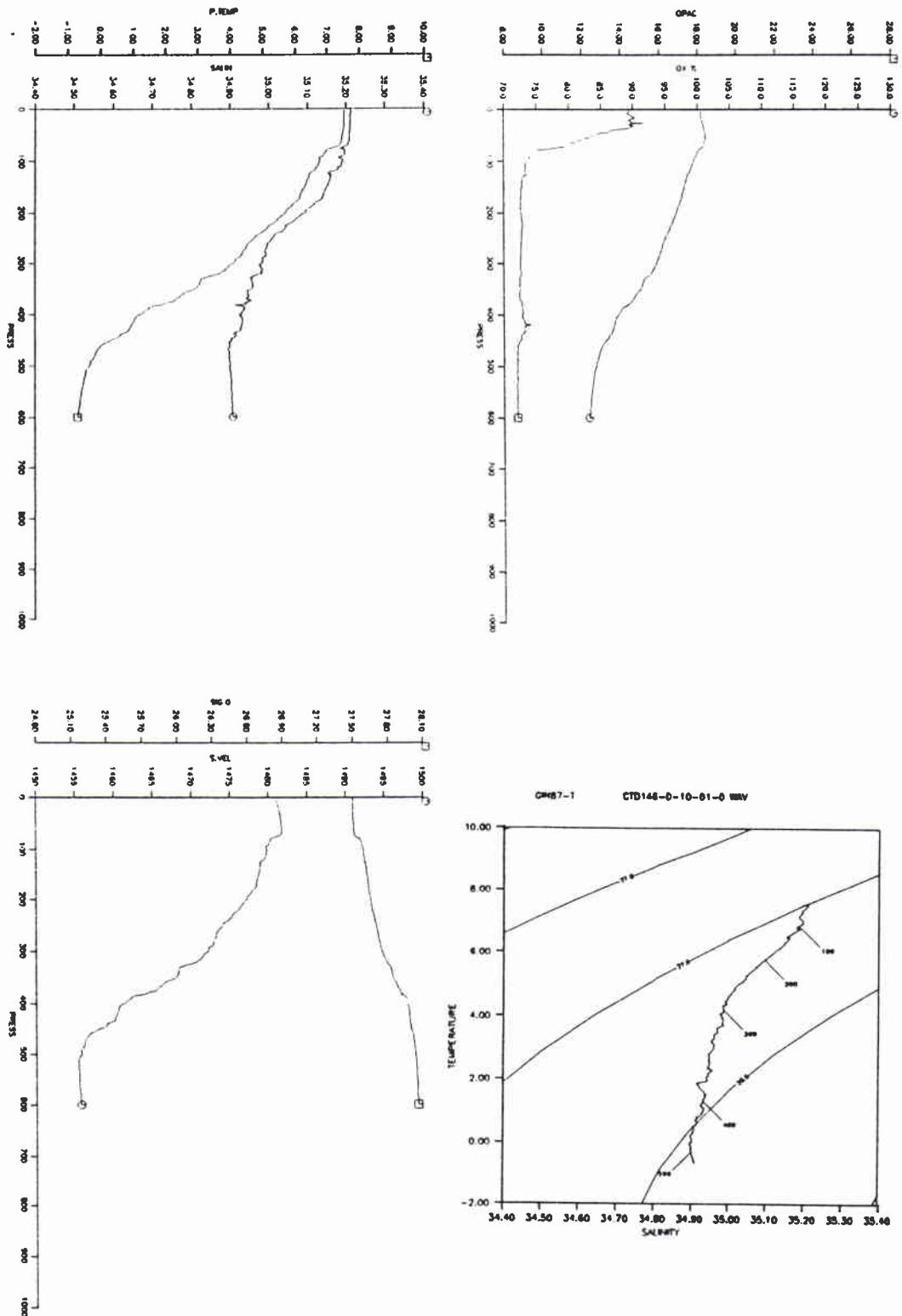


Figure B155

SACLANTCEN SM-249

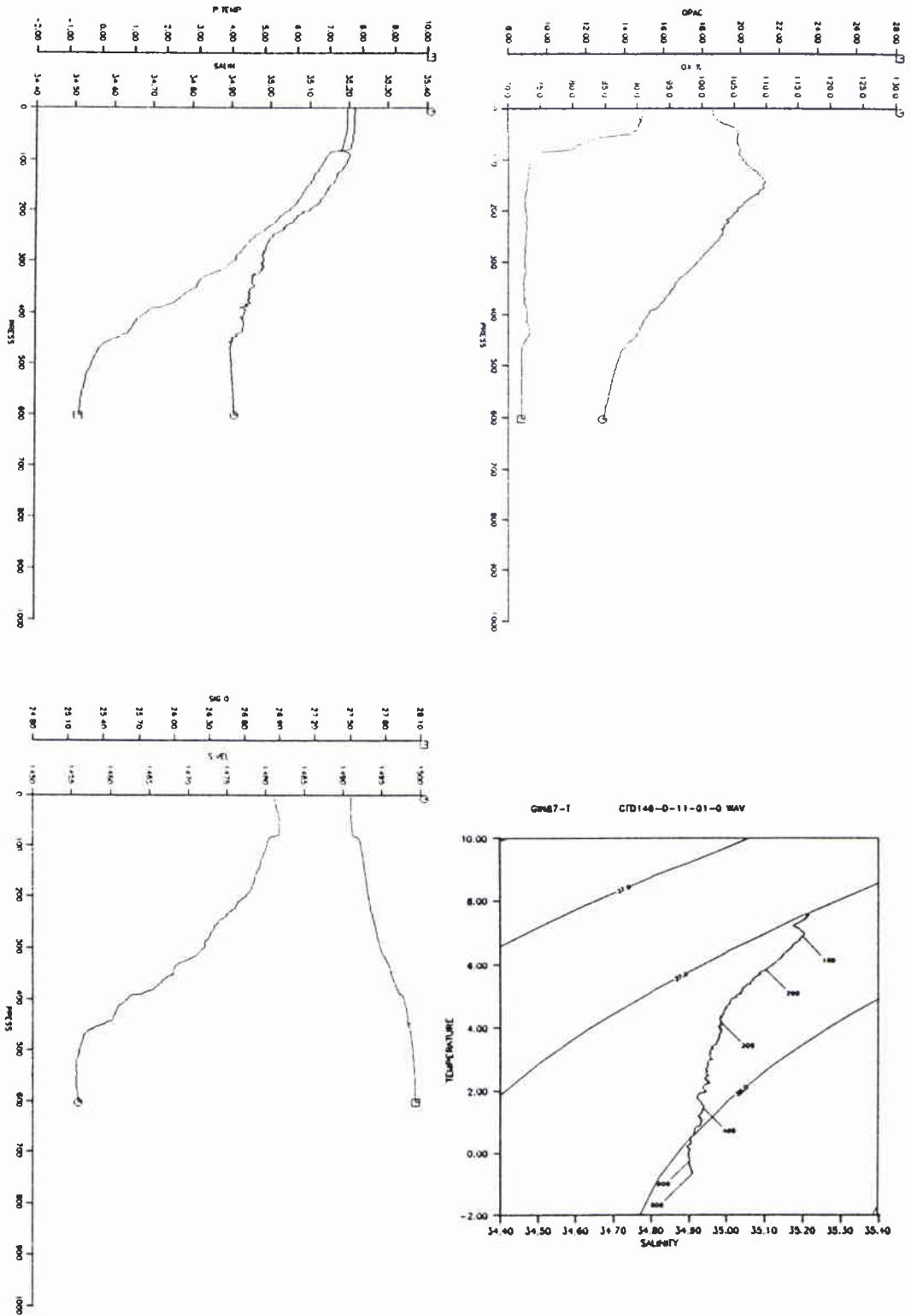


Figure B156

SACLANTCEN SM-249

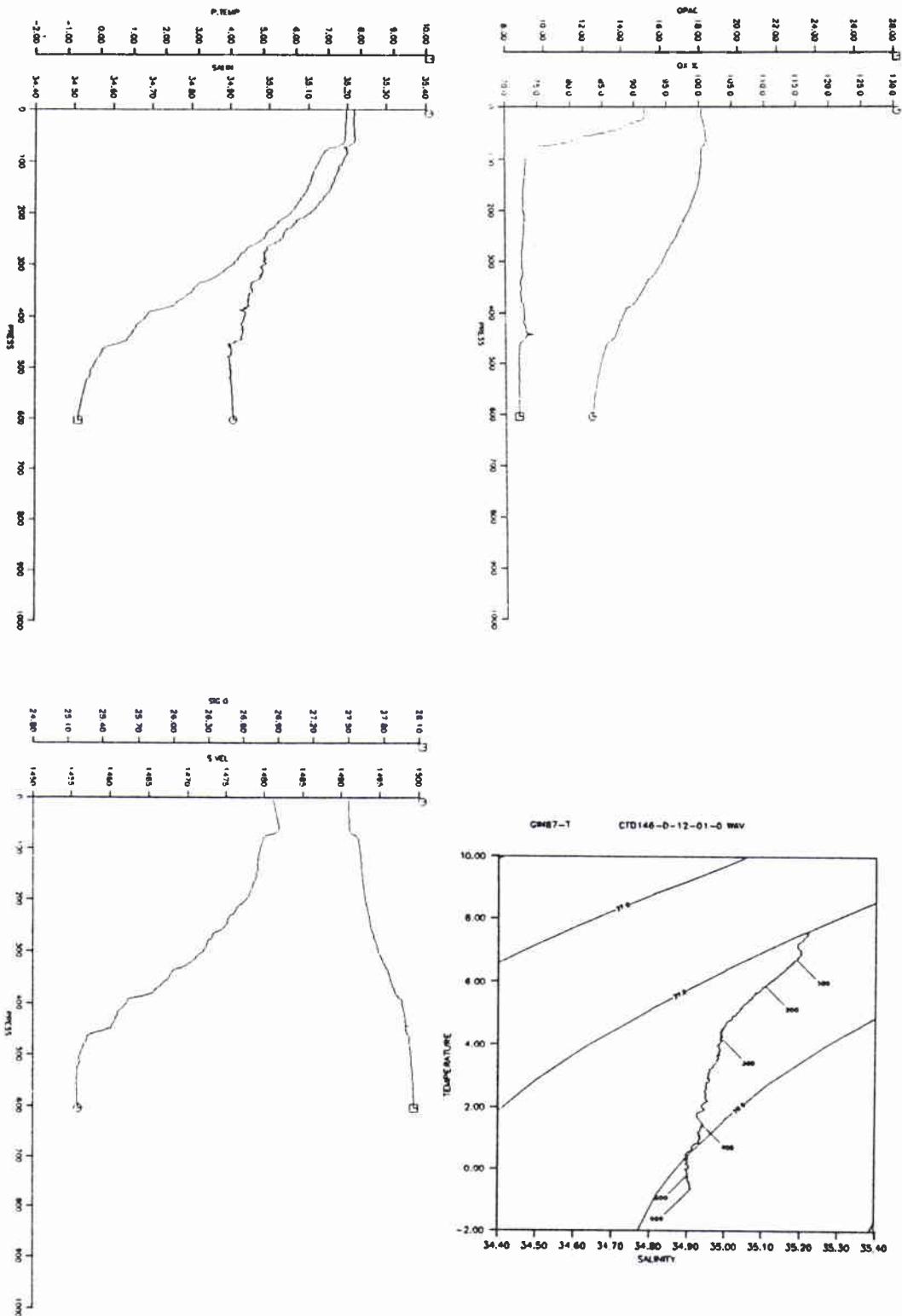


Figure B157

SACLANTCEN SM-249

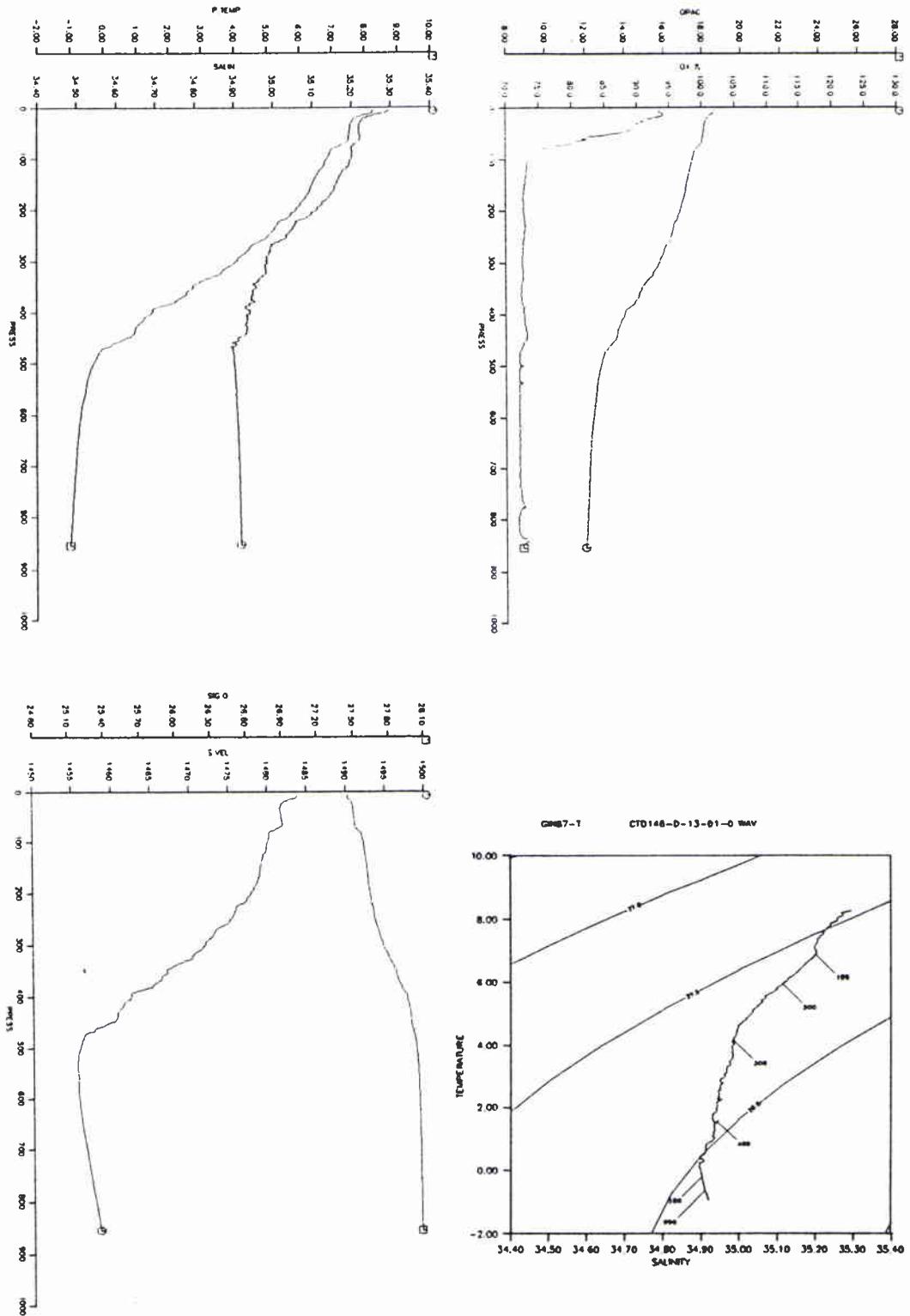


Figure B158

SACLANTCEN SM-249

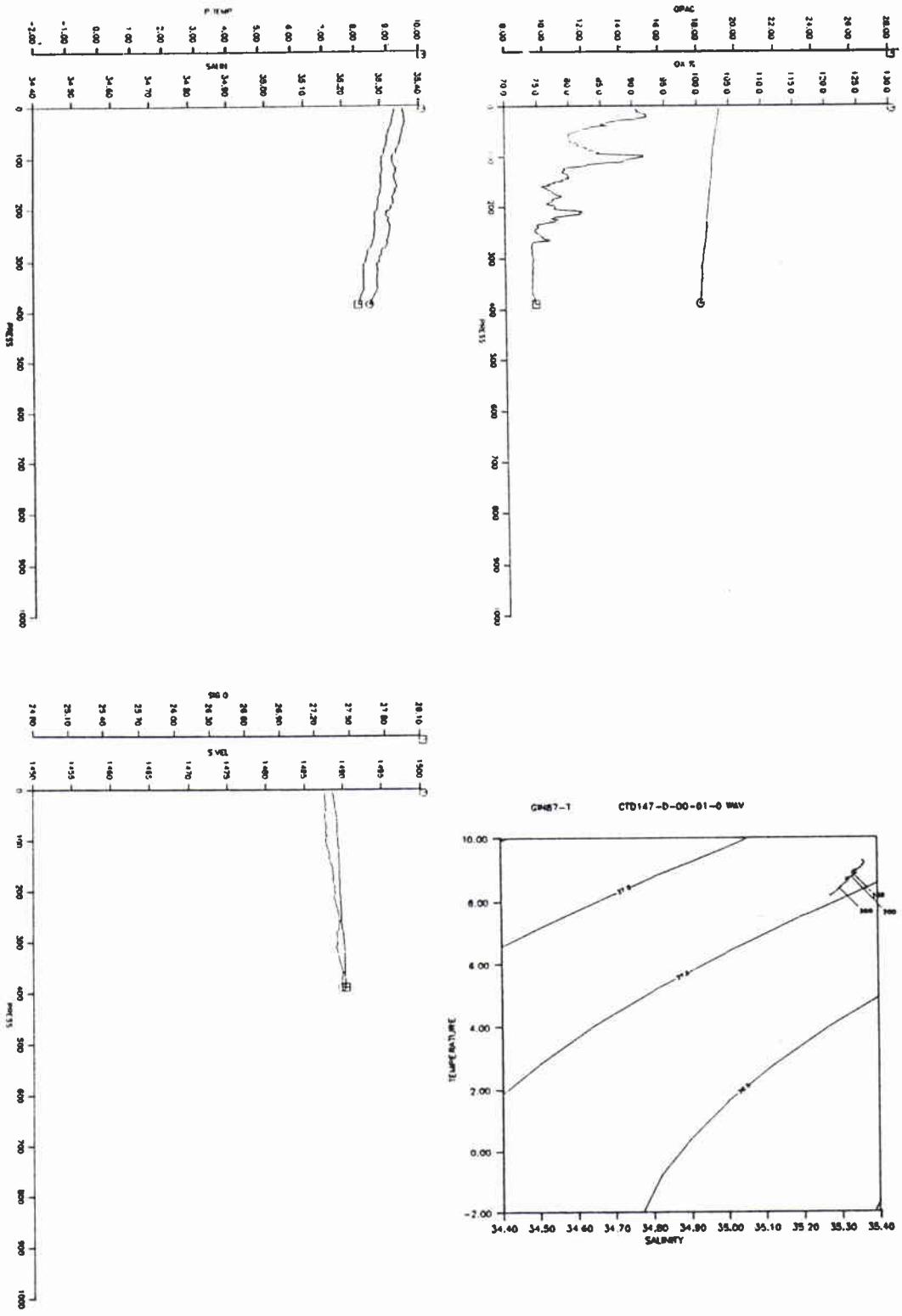


Figure B150

SACLANTCEN SM-249

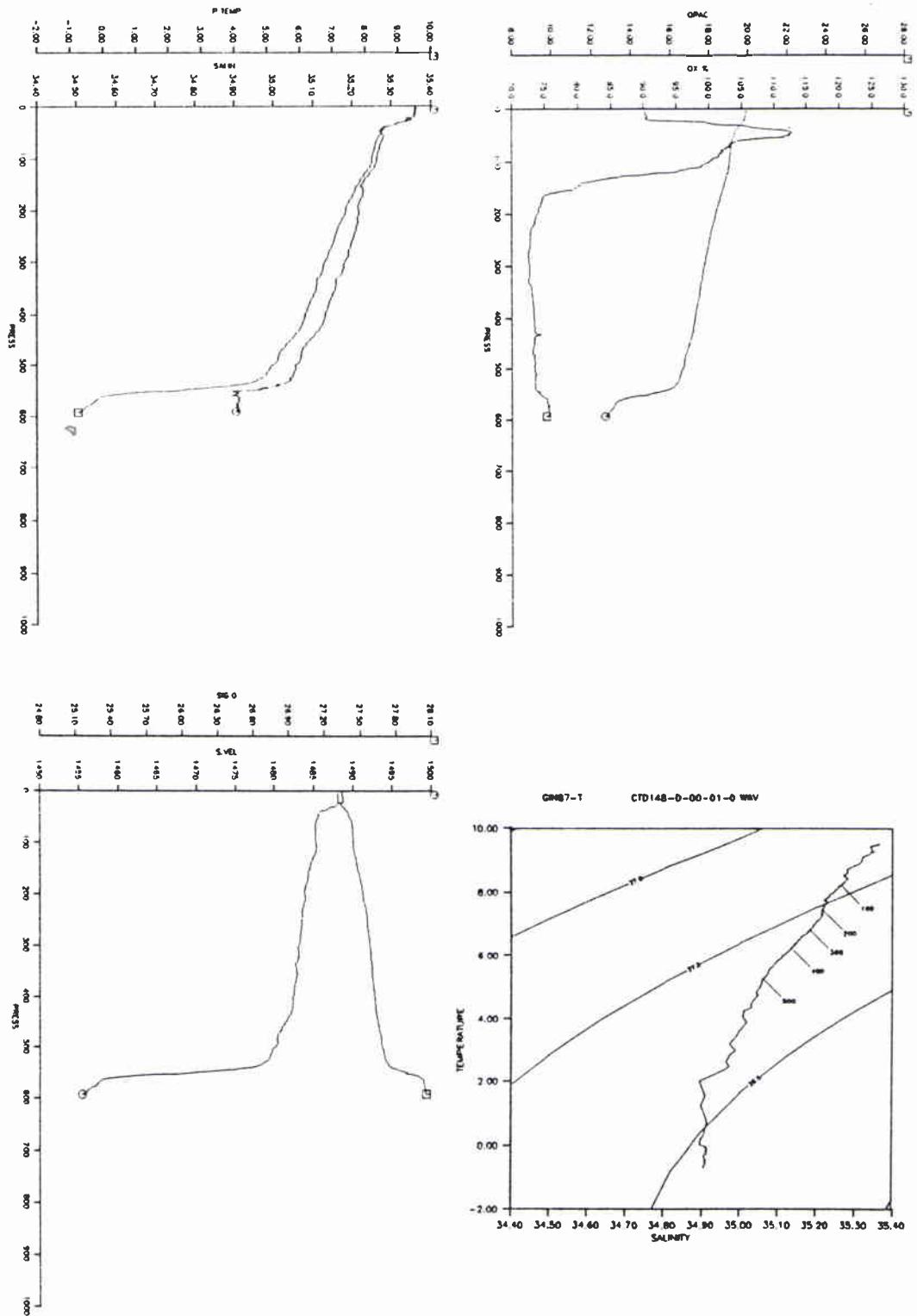


Figure B160

SACLANTCEN SM-249

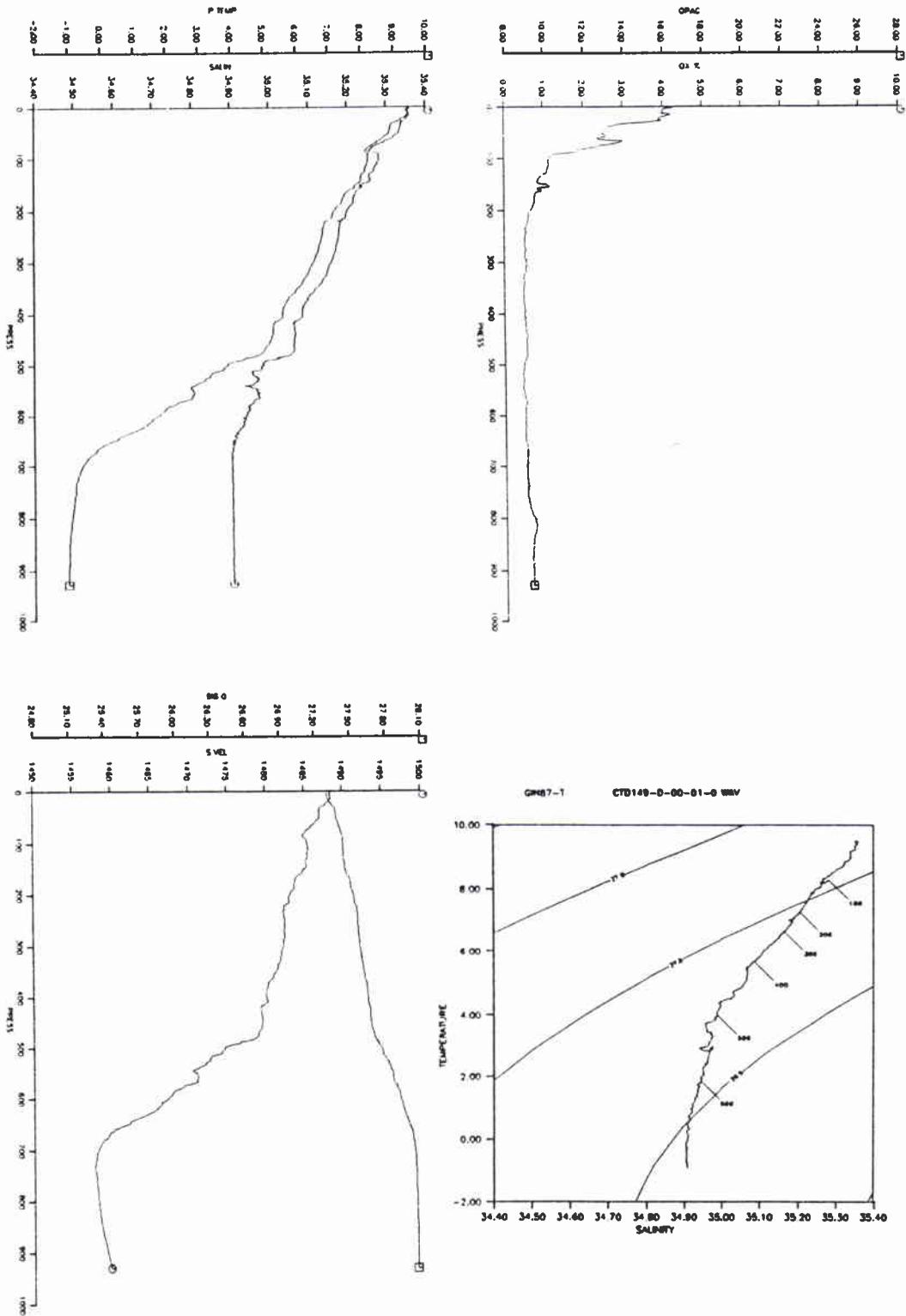


Figure B161

SACLANTCEN SM-249

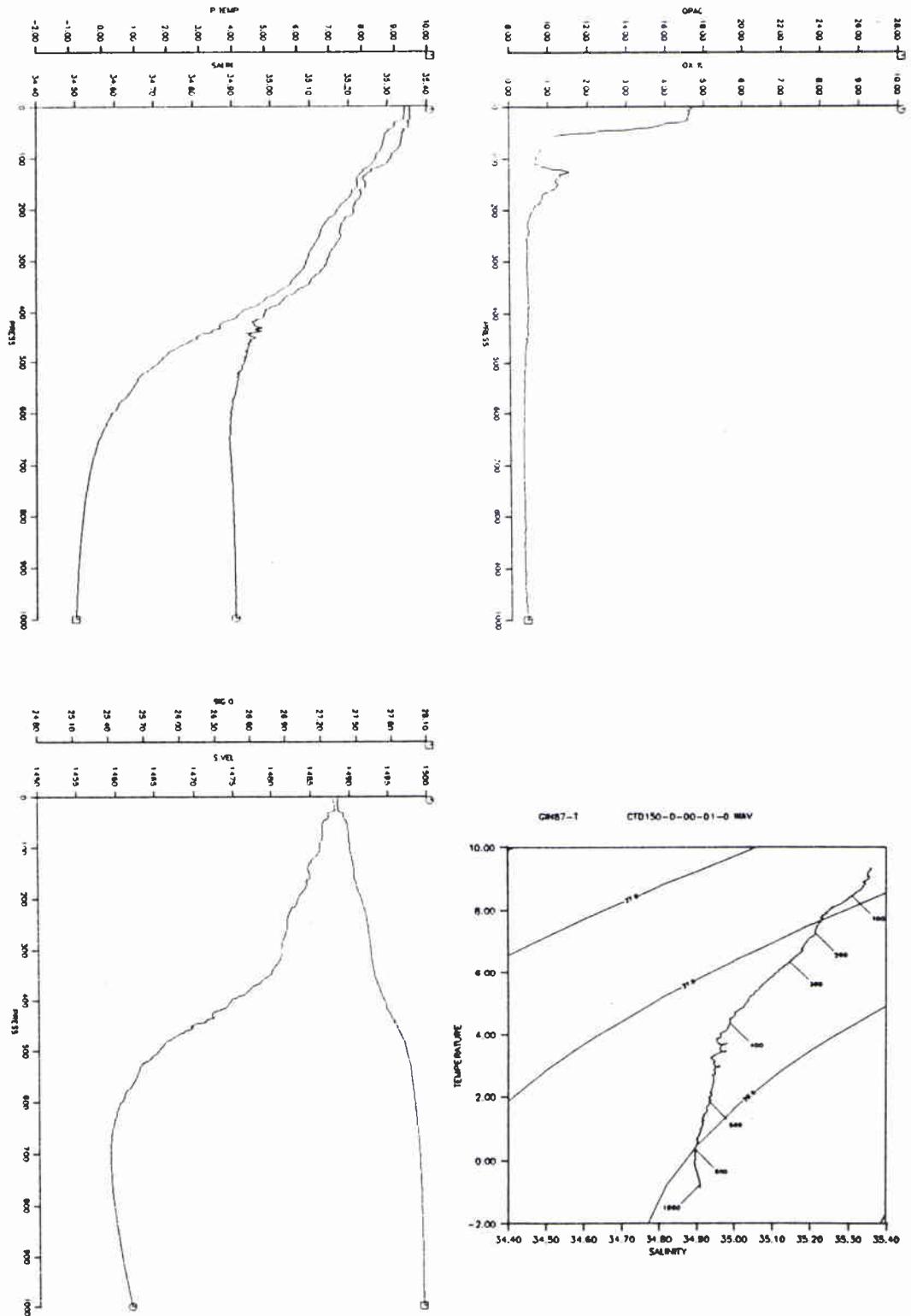


Figure B162

SACLANTCEN SM-249

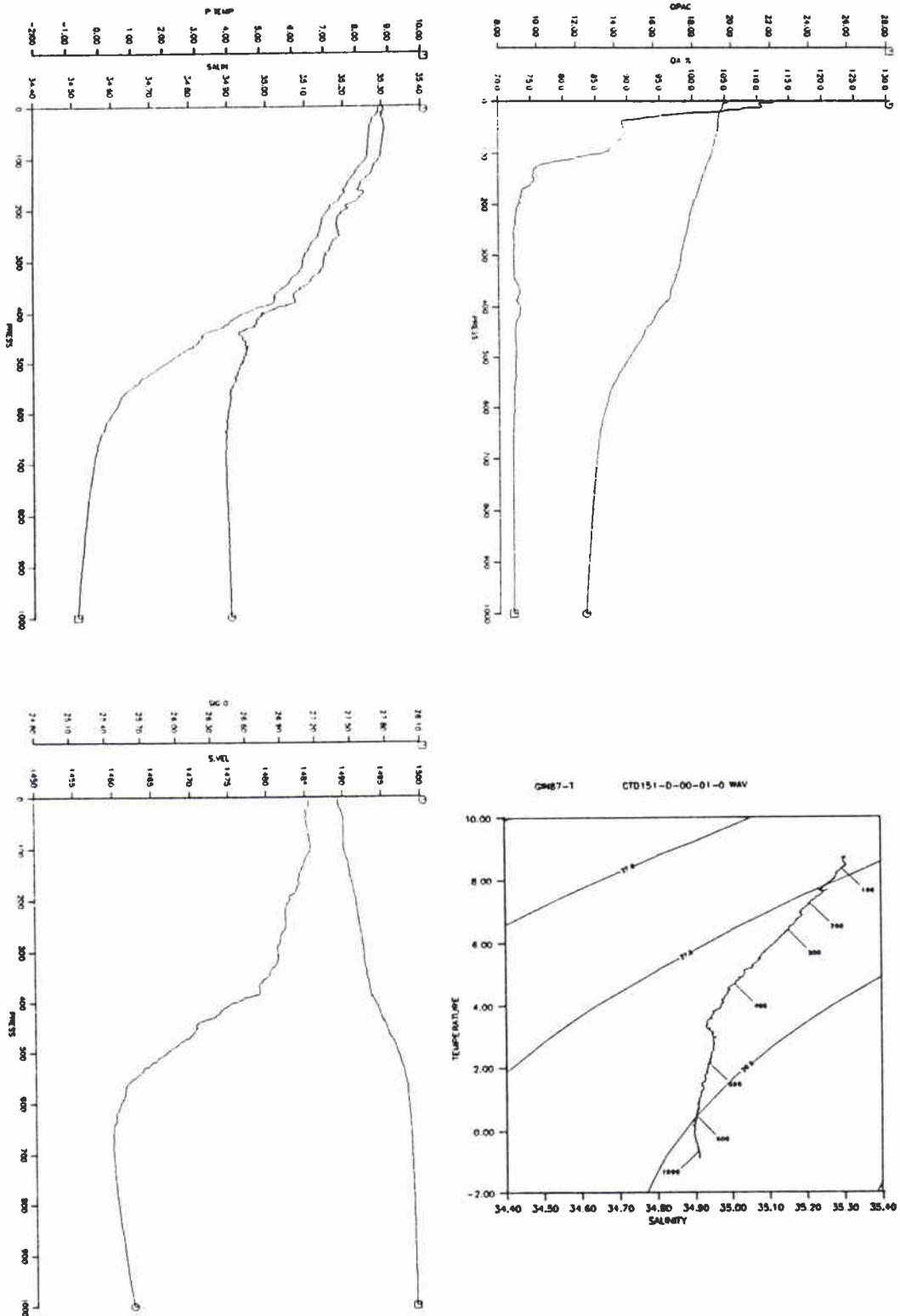


Figure B163

SACLANTCEN SM-249

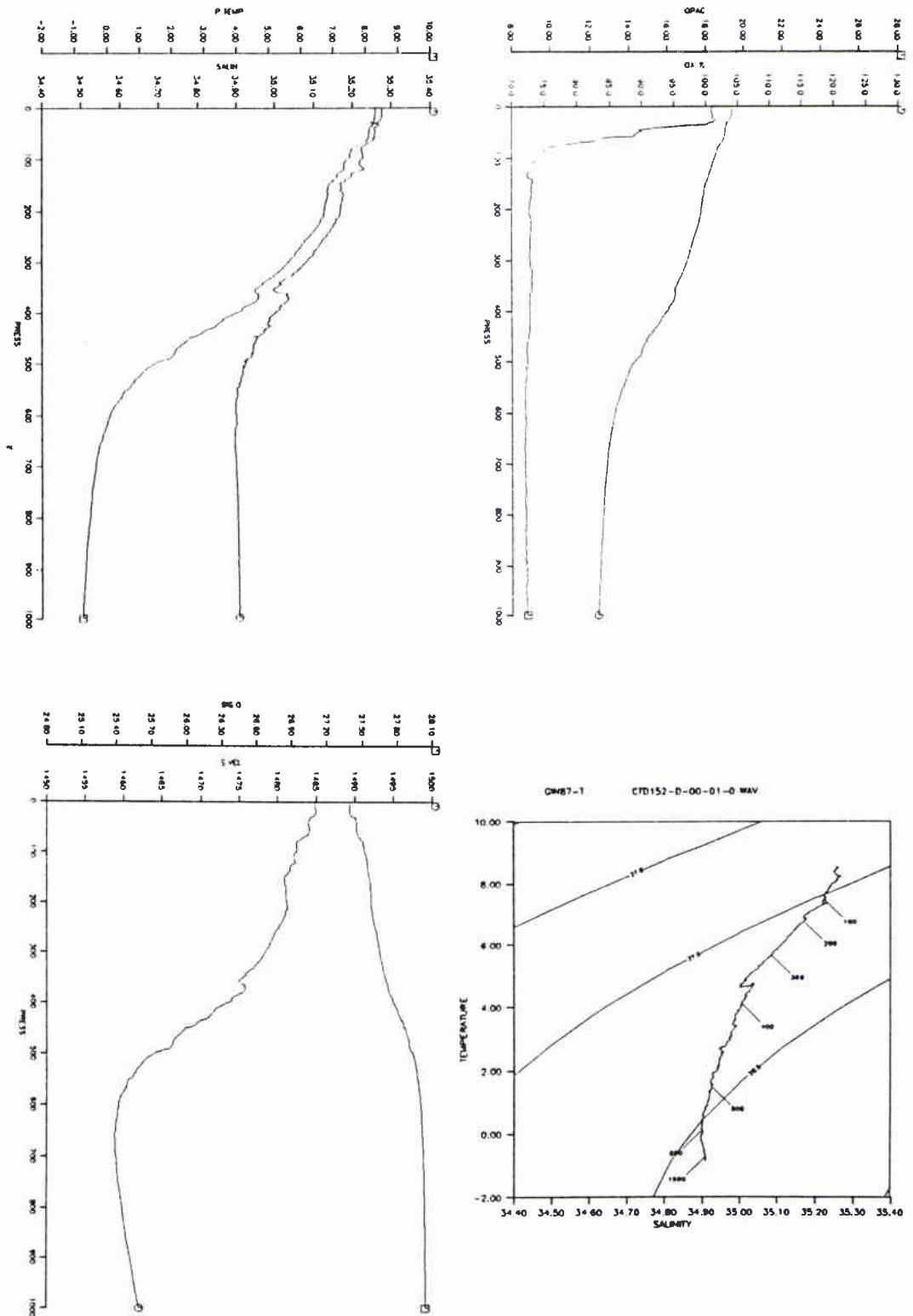


Figure B164

SACLANTCEN SM-249

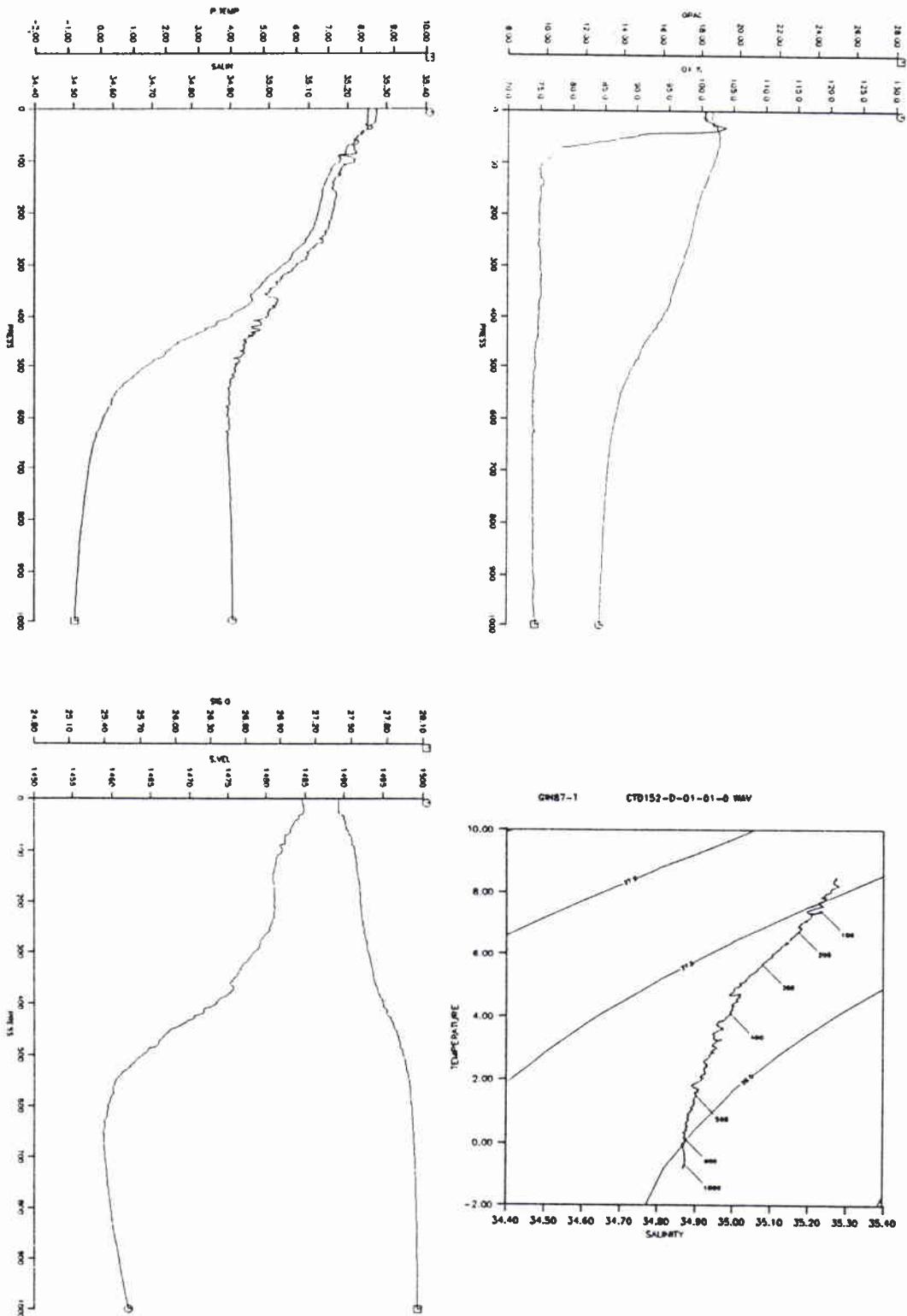


Figure B165

SACLANTCEN SM-249

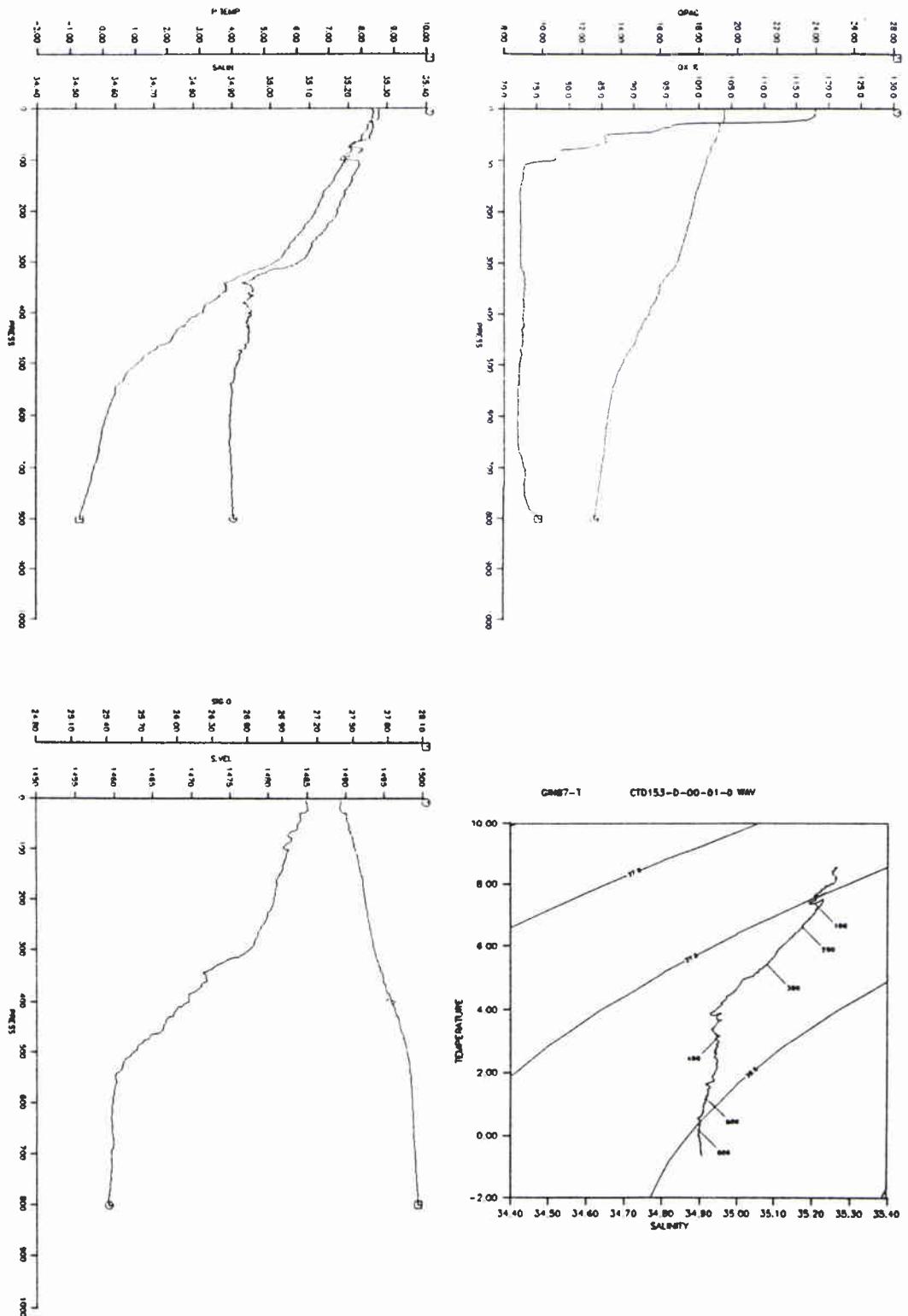


Figure B166

SACLANTCEN SM-249

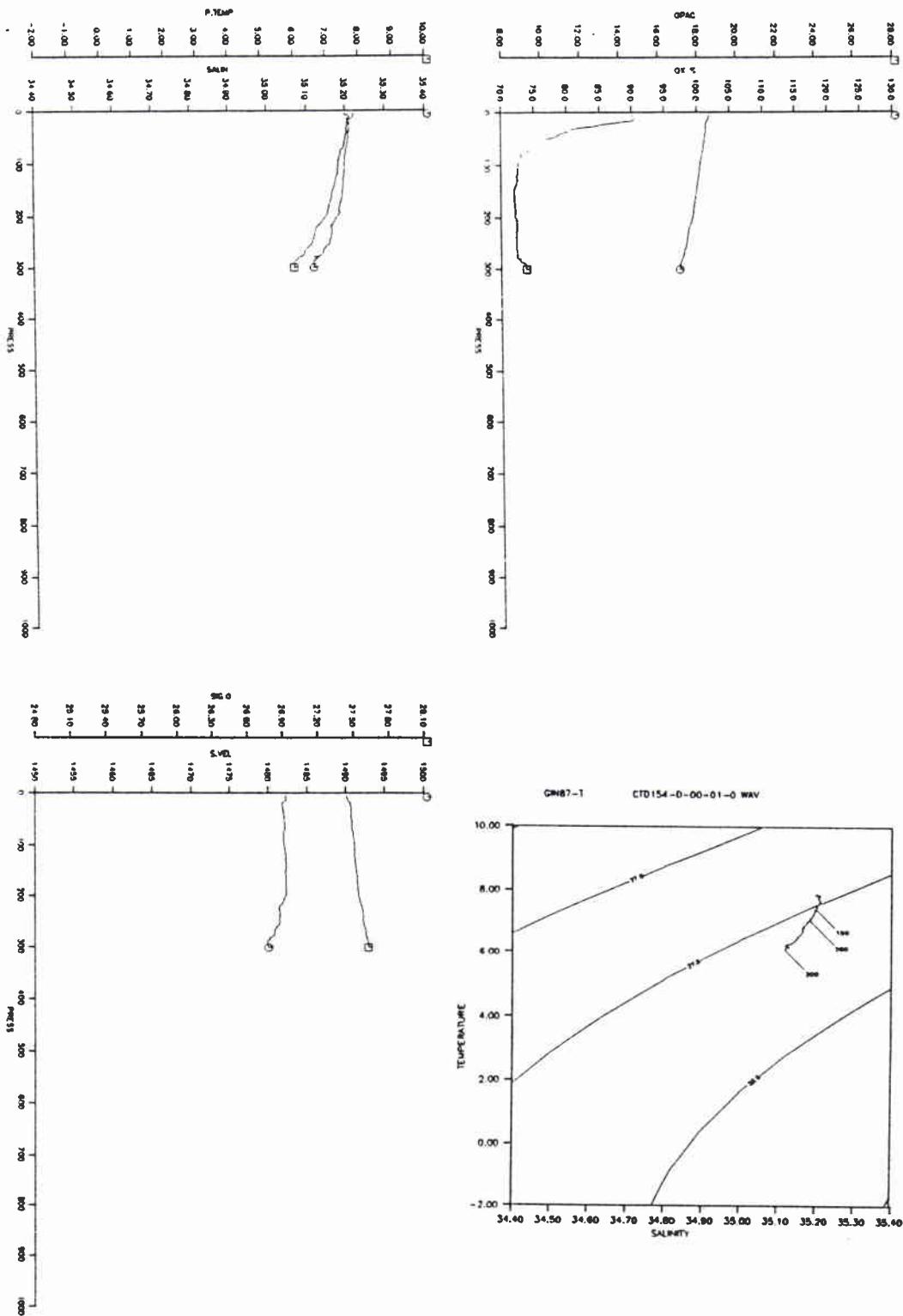


Figure B167

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