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**Technical Report  
on  
“Hydrographic features of the gas hydrate studies survey area of cruise  
AASGH4 in the Bay of Bengal”**

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## **AASGH4 (Bay of Bengal)**

### **1. Introduction**

Hydrographic data were collected from the research ship "A.A. Siderenko" in the Bay of Bengal in [(81.70°E, 82.90°E) x (15.75°N, 16.20°N)] grid at 9 selected stations, in between stn. Nos Ref. 03 to 65, to explore the possibility of occurrence of gas hydrates. The main source of data were using CTD observations in the Bay of Bengal upto near bottom during the period 22 December, 2002 to 26 January 2003. The physical and chemical parameters are temperature, salinity, dissolved oxygen and depth and also fluorescence. Contour maps of these parameters were prepared at depths 50 m, 100 m, 200 m, 811 m and at sea bed (or upto maximum depth of observation) to study their variability using surfer ver. 6.01 software. In the present technical report the hydrographic CTD profile diagrams and the derived contour maps are presented and described for the study area which are useful for gas hydrates exploration.

## 2. Methodology for CTD data collection

### i) The CTD System:

The CTD (conductivity, Temperature, Depth) system used in the gas hydrates study onboard AA “Siderenko” for water column hydrographic data collection consists of C,T,D primary sensors and auxiliary sensors for dissolved oxygen and turbidity in the underwater unit.

The CTD system used is SBE911plus, manufactured by M/S Seabird electronics Ltd , USA, which consists of an underwater unit and a deck unit and a single conductor wire rope connecting them. The winch used for lowering and hauling up the underwater unit by driving the wire wound drum is of M/S Dynacon, USA make. The configuration of the CTD unit system was tested individually and installed on board the ship. The single conductor wire is tested for electrical continuity by connecting underwater unit and deck unit through the slip ring and for mechanical strength by attaching a dead weight at the wire rope end without underwater unit and lowering upto approximately 4000m depth in the sea prior to actual CTD casts for data collection with underwater unit. A personal computer (PC) is connected to the deck unit via RS- 232 interface for data acquisition and storage. The underwater unit is fitted within a carousel to which Nansen / Niskin water samplers with lanyards are attachable for water sampling at different depths through a bottle closing mechanism controlled electronically from the deck unit.

### ii) Data Format:

The sensors are multiplexed and are digitized in the underwater unit at 24 Hz and the resultant data in Manchester code is transmitted to the deck unit via the single conductor armoured cable. Under water unit power is supplied by the deck unit via the same cable. A microprocessor in the deck unit decodes the incoming stream of under water unit data, converts to binary equivalents of frequencies, and presents the converted data to the IEEE –488 or RS-232C bus. The PC takes the data from the output bus, stores it on hard disk and converts to engineering units for real time display and /or plotting. In the data stream of 12 words, which are sampled at 24 Hz, the relevant word numbers for channels for primary sensors and auxiliary sensors and the

number of channels to suppress are appropriately chosen in the SEASOFT CTD software corresponding to sensor connections in the underwater unit. Each sensor has its own counting electronics circuit, so that all sensors are sampled simultaneously. Two 12 –bit counters are used for each sensor data.

iii) The Sensors:

In the 911plus CTD system the underwater unit primary sensors for temperature, electrical conductivity (for salinity measurements) and pressure and secondary sensors for dissolved oxygen, fluorescence and turbidity are well integrated with the electronic circuitry for sensor multiplexing and signal conditioning .

(a) Primary Sensors:

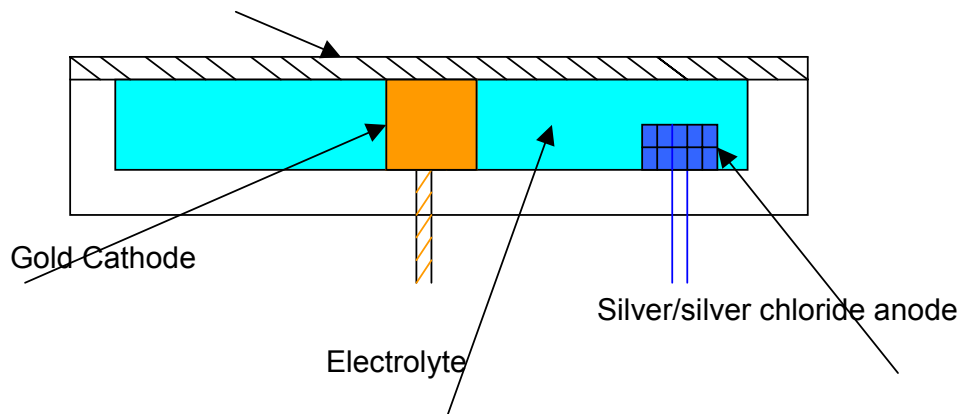
The temperature sensor (model SBE 3 plus) is a compact module containing a pressure-protected high-speed thermistor and “wien bridge oscillator” interface electronics. The conductivity sensor is a 3-electrode platinum two-terminal flow through device. The conductivity sensor (model SBE 4C) is similar in operation and configuration to the temperature sensor, except that the wien bridge variable element is the cell resistance. In the present SBE 9plus CTD underwater unit the temperature and conductivity sensors are equipped with the TC- duct, which provides uniform and constant flow of sea water past the two sensors which are enclosed in the TC – duct in which sea water is pumped in the duct by a motor pump in this present pumped CTD version. This pumped CTD version ensures that the same parcel of sea water at any particular location in the sea is sensed by T and C sensors. The pressure sensor is of digi-quartz type and is of model 410K-105, and paroscientific Inc , USA make. Embedded in pressure sensor is a semi-conductor temperature sensor used to compensate the small ambient temperature sensitivity of the digi-quartz. All the T,C,P sensors output in the form of frequencies and the calibration information for each sensor is contained in a series of numeric coefficients used in equations relating frequency to the measured parameter.

(b) Auxilliary Sensors:

Signals from the auxiliary sensors for dissolved oxygen, fluorescence and turbidity are acquired using conventional voltage-input multiplexed A/D converter. The A/D output is a binary number between 4095 and 0 corresponding to voltages in the range of 0 to +5 volts. The A/D binary values are incorporated into the CTD serial data stream and are available in unconverted form for display or transfer to the system computer. The chlorophyll fluorometer used of M/s SEAPOINT SENSORS Inc , USA make gives chlorophyll- $\alpha$  in seawater. The blue LED lamps direct light through the blue excitation filter/windows illuminating the sensing volume. Chlorophyll- $\alpha$  present in the sensing volume is excited with the blue light and fluoresces red light, a portion of which passes through the detector window. A lens system focuses the fluorescent light on to the photo detector. The fluorometer is of high performance, small size, very low power consumption, high sensitivity, wide dynamic range type and has good ambient light rejection and a low temperature coefficient. Exciting wave wavelength is 470nm peak, 30nm FBHM and emission wavelength is 685nm peak, 30nm FBHM for the fluorometer. The range of the fluorometer used is 0 to 150 $\mu$ g/litre with a gain setting of 1X. The turbidity meter used of M/S Seapoint Sensors Inc. USA make measures turbidity by detecting scattered light from suspended particles in water. The light sources are side-by-side 880nm light emitting diodes (LED). The light detectors are side-by-side silicon photo diodes with visible light blocking filters. Light scattered at angles between 15 and 150° from the sensing volume within 5cm of the sensor windows in sea water passes through the detector window and reach the detector. The amount of scattered light that reaches the detector is proportional to the turbidity or particle concentration in the water over a very large range. Sensitivities of 2,10,40 and 200mV/FTU are possible with arrange of 0-25-500 FTU (Formazin turbidity units) and a gain setting of 1X was used in the present observations.

## DISSOLVED OXYGEN SENSOR (SBE 43)

Teflon membrane



The dissolved oxygen sensor depends on the diffusion of oxygen through a Teflon membrane. Any surface coating that slows the diffusion will affect the sensor sensitivity and its time response (DO sensors are expected to drift in a similar manner to conductivity. For chemical reasons, they lose sensitivity overtime. The equation for calculating oxygen concentration from sensor output has a slope term,  $S_{oc}$ , and an offset term,  $B_{oc}$ . It is expected that  $S_{oc}$  will slowly increase with time, indicating a decrease in sensitivity. Fouling of the membrane by either oils or bacteria will result in a drift of a more episodic nature).

The dissolved oxygen sensor SBE 43 of M/S SeaBird Electronics, USA make measures flux of oxygen across a teflon membrane through electrolyte and in to a gold cathode. A silver/silver chloride anode is inbuilt in the sensor. The measurement is sensitive to the Teflon membrane permeability which is decreased by oil or bacteria coating and hence the sensor has to be rinsed in triton- X prior to beginning cast to protect membrane as it goes through sea surface. The range of the dissolved oxygen sensor SBE 43 used is 0 to 5 ml/litre. The maximum value of oxygen expected is 10.82 ml/liter. To compute oxygen in mg/liter units, the values of oxygen in ml/l has to be multiplied by 1.42903. A Benthos/Data Sonics altimeter is attached to the CTD frame looking downwards which helps in knowing the height of CTD underwater unit from seabed by using acoustic pulses reflected from sea bottom.

All the sensors were factory-calibrated by manufacturers and only calibration checks were done and the appropriate calibration constants for all the sensors were entered into SEACON program of the seabird SEASOFT software modules.

The temperatures are given in IPTS-90 units and the salinities are given in PSU units.

iv) THE CTD SYSTEM CONFIGURATION (FOR AASGH CRUISES)

SBE 9 plus CTD under water unit: S/N 09P25394 – 0646

Depth Capability (CTD and sensor housings) : 6,800meters.

Pressure Sensor Range: 0 – 10,000 psia

0 – 6885 decibar.

Digi-quartz Pressure Sensor (with temperature compensation) : S/N 83436

Modulo 12P: S/N MOD 12P –0601

AD 590 M (entered in SEACON ) : 0.01279181324.

AD 590 B ( entered in SEACON ) : -9.384090182

Temperature Sensor (3 plus 6800m) : S/N 032939.

Conductivity Sensor (4C 6800m) : S/N 042644.

Pump (SBE 5T) : S/N 053144

A/D input voltage range : 0 to 5 volts DC.

Logic Board EPROM Version 1.0

Modem Interface Installed

Modem Board Microcontroller Version 1.3 : P/N 11194.

Dissolved Oxygen Sensor (SBE 43) : S/N 430073

Fluorometer (Seapoint) : S/N 2376

Turbidity Sensor (Seapoint) : S/N 1767

Altimeter [ Benthos/Data Sonics (PSA – 916D)] : S/N 904

Sampling Rate : 24Hz

CTD deck unit : Model SBE 11 PLUS.

v) The CTD Sensor Specifications :



1. Conductivity Sensor :

Model : SBE 4

Serial No. : 2644

Range : 0 to 7 Siemens/meter (S/m)

Accuracy :0.0003 Siemens/meter

Repeatability : 0. 0003 S/m /month

Resolution : 0.00004 S/m @24Hz

Time Response : 0.060 seconds (pumped)

Settling Time : 0.7 seconds to within 0.0001 S/m

Supply Voltage : 6 to 24 Volts DC.

Supply Current : 18mA at 6 Volts; 12 mA at 10 to 24V

Signal output : 1V square wave capacitively coupled

Material : 6800m 7075 – T6 Aluminium

2. Temperature Sensor :

Model : SBE 3 plus

Serial No. : 2939

Range : -5° to +35°C

Accuracy (initial) : +/- 0.001°C

Resolution : 0.0003°C @ 24Hz (samples/second)

Response Time : 0.065 +/- 0.010 seconds.

Self Heating Error : < 0.0001°C in still water

Settling Time : < 0.5seconds to within 0.001°C

Stability : < 0.001°C drift during the initial 6 months

Temperature Scale : ITS – 90

Power required : 11 – 16 Vdc, 25mA

Signal Output : +/- 0.5V square wave

Housing (6800m) : 7075 Aluminium

3. Pressure Sensor :

Model : 410K- 105 (Digiquartz) make : Paroscientific Inc; Washington,  
USA

Serial No. : 83436

Pressure Range : 0 to 10,000psia (0 to 6800m depth)

Temperature Range : 0 to 125°C  
Resolution : 0.01ppm  
Repeatability : 0.005 % FS.  
Hysteresis : 0.005 % FS.  
Pressure Conformance : 0.005 % FS  
Acceleration Sensitivity( 3 axis average ) : 0.008 % FS/g  
Port : oil field  
Supply Voltage Sensitivity : negligible  
Nominal Pressure Frequency : 34KHz to 38KHz (0 – FS)  
Nominal Temperature Frequency; 172KHz + 50ppm/ °C  
Power Requirements : 6 to 35Vdc; 2mA  
Signal Outputs : square wave, 4Vp-p  
Over Pressure : 12 \* Full scale

4. Dissolved Oxygen Sensor :

Model : SBE 43  
Serial No. : 0073  
Type : Teflon membrane  
Anode : silver/ silver chloride  
Cathode : gold  
Range : 0-10.82ml/l

5. Fluorescence Sensor:

Make: Sea point sensors, Inc, USA  
Type : chlorophyll measuring type  
Serial No. : 2376  
Sensitivity/ Range(1X gain) : 0.033V/(µg/l) ; 0-150µg/l  
Minimum detectable level : 0.02 µg/l  
Power Requirements : 0 – 20Vdc, 15 mA avg, 27mA peak.  
Output : 0 to 5 Vdc  
Output Time Constant : 0.1sec  
Power – Up transient : 0.6sec  
RMS noise (typical) : 1X gain : < 1mV

Excitation Voltage : 470nm peak, 30nm FBHM  
Emission wavelength : 685nm peak, 30nm FBHM  
Sensing Volume : 340mm<sup>3</sup>.  
Temperature Coefficient ; < 0.2 %/ °C  
Operating Temperature : 0 – 65°C  
Depth Capability : 6000m

6. Turbidity Sensor :

Make : Seapoint sensors Inc, USA  
Serial No. : 1767  
Light Source wavelength : 880nm  
Scatterance Angles : 15-150°  
Linearity : < 2% deviation 0- 750FTU  
Sensitivity/Range (1X gain) : 2mV/ FTU ; < 750 FTU  
(5X gain) : 10mV/FTU ; 500 FTU  
Temperature Coefficient : < 0.05 %/°C  
Operating Temperature : 0-65°C  
Depth Capability : 6000m  
Power Requirements : 7 –20 Vdc; 3.5 mA avg, 6mA peak  
Output : 0-5Vdc  
Output Time Constant : 0.1 sec  
RMS noise : < 1mV  
Power- Up Transient Period : <1 sec

7. Altimeter :

Make : Benthos/Data Sonics , USA  
Model : PSA-916D  
Serial No. : 904

vi) Data Acquisition Procedure using CTD:

The CTD system is checked for correct operation and the “seasoft” CTD software is loaded in the PC. The calibration constants pertaining to the sensors used are entered in SEACON file of SEASOFT programme. The underwater unit is lowered to approximately 10m in the sea by operating the

winch. The deck unit is powered "ON" and "SEASAVE" module is run whereby the underwater unit pump priming to remove air bubbles trapped in the conductivity sensor TC-duct is done and allowed about 2 minutes to stabilize. Then the underwater unit is heaved upto near sea surface (about 1m depth) taking care not to expose the sensors and sampling bottles in the air. Prior to the start of lowering underwater unit into the sea, it is ensured that all the water sampling bottles are opened, otherwise they will be crushed due to water pressure difference in the sea and within the sampling bottle.

Then the data acquisition command in the SEASAVE programme is given and the underwater unit is lowered at a constant rate (at about 1m/s) up to the required depth. In these AASGH cruises the underwater unit was lowered up to near bottom depths and the height of underwater CTD unit above seabed is closely monitored using altimeter output and precautions are taken for CTD sensors not to touch the seabed. Usually the CTD underwater unit is sent up to 20-5 m from the sea bottom. Then water sample is taken by closing a water sampling bottle by giving electronic triggering command from the CTD deck unit after stopping the lowering of the underwater unit at the maximum lowered CTD depth.

The water sampling is then done during up cast using electronic triggering at the required depths by closing the sampling bottles at appropriate depths and bottle marker files are obtained. The water sampling is done only during up cast. Water sampling is done for calibration as well as for physical and chemical analysis. When the CTD underwater unit is brought to sea surface the data acquisition is stopped and the deck unit is powered off. The data stored on the hard disk of PC is in turn stored on floppy disks or compact discs (CDs) as required and subjected to data processing

vii) Data Processing:

The CTD raw data in the form of .DAT binary files are processed using seasoft software modules and converted into .CNV , .ASC files (which are binary and ascii files) and used for plotting profiles of salinity, temperature, DO, fluorescence and turbidity v/s depth and respective contours as a function of space coordinates of latitude and longitude. These .CNV and .ASC files are obtained by subjecting raw .DAT data files to binaveraging (depth

averaging ), filtering to eliminate noise and spikes, derivation of computed variables like potential temperature,  $\sigma_t$ ,  $\sigma_\theta$ , sound velocity, stability, Brunt-vaisala frequency etc, splitting into up and down cast files, time advancement of sensors and cell thermal constants and so on by use of appropriate seasoft software modules.

In the present report CTD data profile plots at various stations are generated by using SEASOFT modules and the contours are obtained by using surfer ver. 6.01 software. The contours of parameters are obtained at 50 m , 100m , 200m, at average of maximum depths of stations, and at the seabed (which are at the maximum CTD depths and assumed to have the same parameter value at the sea bottom).

Appropriate contour intervals are chosen for contour plots. All the profile and contour plots are analyzed for the study of physical and chemical processes in the area where the data are collected. The results are also discussed and presented in this report.

### **3. Contours of physical & chemical parameters:**

Iso-contour maps of temperature, salinity, dissolved oxygen, fluorescence (chlorophyll concentration) are prepared at the water depths of 50m, 100m, 200m, 811 m and sea bed. These contour maps depict the distribution of physical and chemical parameters as a function of depths of water column. Since Bottom Simulating Reflectors (BSRs) noted on the seismic reflection records form parallel to the sea bed, the sea bed characteristics form an important parameter, the temperature at the sea bed was studied. The depth-limited properties are differentiated from the true special features that demarcate gas hydrates. The probable seabed features are highlighted. All the contours give in totality the water column hydrographic characteristics. The source of data is from CTD observations carried out both in Arabian Sea (off Goa) and Bay of Bengal (in Krishna-Godavari basin) which are probable potential sites for occurrence of gas hydrates. The geo-physical studies supplement these data.

### **4. Hydrographic Features:**

Observations from Isopleth contour plots of parameters (T, S, DO) & Horizontal sections at various depths (Refer Figs. 20 to 33).

#### **(a) Isopleths of horizontal sections**

##### **1. 50m depth:**

- (i) From the temperature contour it is seen that a warm core (27.6°C) occurred and is centred at  $\approx 16.00^\circ\text{N}$ ,  $81.75^\circ\text{E}$  at the middle of the surveyed area. Comparatively cold cores occurred at  $\approx 15.87^\circ\text{N}$ ,  $81.88^\circ\text{E}$  of 26.8°C at south western region and at  $16.17^\circ\text{N}$ ,  $82.04^\circ\text{E}$  of 26.3°C at the central north edge.
- (ii) Salinity contour at 50m shows a high salinity core of 34.14 psu at  $\approx 16.17^\circ\text{N}$ ,  $82.02^\circ\text{E}$  at central north edge and low salinity cores of 33.42 p.s.u. and 33.18 p.s.u. at  $\approx 15.87^\circ\text{N}$ ,  $81.88^\circ\text{E}$  and  $15.83^\circ\text{N}$ ,  $81.71^\circ\text{E}$  respectively near the southern edge of surveyed area.

(iii) Dissolved oxygen contour at 50m shows a suboxic low concentration core of 1.8 ml/l at  $\approx 16.17^\circ\text{N}$ ,  $82.02^\circ\text{E}$  at central north edge and a high concentration core of 3.00 ml/l at the southwest corner  $\approx (15.79^\circ\text{N}$ ,  $81.71^\circ\text{E})$ .

2. 100m depth:

(i) Though there are no explicit cores seen low temperature ( $< 21.0^\circ\text{C}$ ) exists north of  $16.15^\circ\text{N}$  and  $< 82.10^\circ\text{E}$ . Least temperature of  $20.80^\circ\text{C}$  is seen at southwest corner at  $15.79^\circ\text{N}$ ,  $81.71^\circ\text{E}$

(ii) A high salinity pocket (core) of 35.8 p.s.u. is seen at  $\approx (16.12^\circ\text{N}$ ,  $82.12^\circ\text{E})$  towards northern edge eastward of  $82.0^\circ\text{E}$ . The salinity at 100m depth ranged between 34.70 p.s.u. and 35.8 p.s.u.

(iii) DO contour at 100m not available.

3. 200m depth:

(i) It is interesting to observe that a cold core of  $12.40^\circ\text{C}$  is seen at  $\approx 16.17^\circ\text{N}$ ,  $82.03^\circ\text{E}$  at the central northern edge and a warm region of  $15.2^\circ\text{C}$  is seen around  $\approx 15.95^\circ\text{N}$ ,  $82.08^\circ\text{E}$ . The temperature at 200m depth ranged between  $12.40^\circ\text{C}$  and  $15.20^\circ\text{C}$  in the surveyed area.

(ii) A high salinity pocket of 35.00 p.s.u. is seen around  $\approx 16.17^\circ\text{N}$ ,  $82.02^\circ\text{E}$  at the central northern edge and low salinity pocket of 34.95 p.s.u. around  $\approx 16.01^\circ\text{N}$ ,  $82.07^\circ\text{E}$

(iii) A dissolved oxygen low concentration core of 0.21 ml/l centred around  $\approx 16.12^\circ\text{N}$ ,  $82.12^\circ\text{E}$ . High concentration cores of 0.24 ml/l and 0.25 ml/l were found located at  $16.00^\circ\text{N}$ ,  $81.96^\circ\text{E}$  and  $15.79^\circ\text{N}$ ,  $81.76^\circ\text{E}$  at the southwest corner of the surveyed area respectively. An intermediate core of 0.22 ml/l was found at  $\approx 15.87^\circ\text{N}$ ,  $81.89^\circ\text{E}$  near southern edge.

4. 811m depth:

(i) Comparatively warm pocket of  $8.00^\circ\text{C}$  is seen centred at  $\approx 15.87^\circ\text{N}$ ,  $81.91^\circ\text{E}$  towards south edge. Relatively low temperature of  $7.76^\circ\text{C}$  is seen around  $\approx 16.05^\circ\text{N}$ ,  $82.15^\circ\text{E}$ . Temperature of  $7.61^\circ\text{C}$  prevailed in

the south western corner of the surveyed region. Temperature ranged between 7.61°C and 8.00°C.

- (ii) Salinity at 811m ranged between 34.95 p.s.u. and 34.97 p.s.u. Relatively high salinity of 34.97 p.s.u. is seen centred around  $\approx 15.88^\circ\text{N}$ ,  $81.91^\circ\text{E}$  and at  $16.17^\circ\text{N}$ ,  $82.26^\circ\text{E}$ . Relatively low salinity of 34.95 p.s.u. prevails at  $\approx 15.79^\circ\text{N}$ ,  $81.71^\circ\text{E}$  at the southwestern corner of the surveyed region.
- (iii) Dissolved oxygen concentration levels ranged between 0.65 ml/l and 0.77 ml/l. High concentration of 0.77 ml/l prevailed at  $\approx 15.79^\circ\text{N}$ ,  $81.71^\circ\text{E}$  at the southwestern corner of the surveyed region. Relatively low concentration level of 0.65 ml/l lays centred around  $\approx 15.90^\circ\text{N}$ ,  $81.91^\circ\text{E}$ . 0.66 ml/l water was found around  $\approx 16.17^\circ\text{N}$ ,  $82.27^\circ\text{E}$  at the northern edge. Relatively high "DO" of 0.76 ml/l existed at around  $\approx 16.02^\circ\text{N}$ ,  $82.27^\circ\text{E}$ .

#### 5. Parameters at seabed:

- (i) Temperatures at seabed ranged between 4.5°C (at station S4) and 10.50°C (at stn. Ref 03). Lowest temperature of 4.50°C occurred at  $\approx 15.79^\circ\text{N}$ ,  $81.73^\circ\text{E}$  at the southwestern corner of the surveyed region. Highest temperature of 10.50°C occurred at  $\approx 16.17^\circ\text{N}$ ,  $82.02^\circ\text{E}$  at the northern edge. The wide variation may be due to depth-limited bottom topographic changes.
- (ii) Salinity at seabed ranged between 34.85 p.s.u. and 35.01 p.s.u., similar to temperature variations. Low salinity of 34.85 p.s.u. occurred at  $15.79^\circ\text{N}$ ,  $81.77^\circ\text{E}$ . High salinity of 35.01 psu occurred centred around  $\approx 16.17^\circ\text{N}$ ,  $82.02^\circ\text{E}$  at the northern edge.
- (iii) Dissolved oxygen at seabed ranged between 0.30 ml/l and 1.70 ml/l. High DO concentration of 1.70 ml/l occurred around  $\approx 15.79^\circ\text{N}$ ,  $81.76^\circ\text{E}$  at the southwestern corner of the surveyed region. Low concentration levels of 0.30 ml/l occurred centred around  $\approx 16.17^\circ\text{N}$ ,  $82.03^\circ\text{E}$  at the northern edge. It is seen that all the patterns of contours of temperature, salinity and dissolved oxygen are similar (in term of variations).



(b) Vertical profiles & their general trends:

The vertical profiles of temperature, salinity,  $\sigma_t$ , fluorescence and dissolved oxygen are plotted for stations (AASGH4) Ref.03, 1, 4, 24, 33, 43, 49, 60 & 65 (Total 9 nos) as shown in station location map (Refer Figs. 2 to 19).

Temperature: All the temperature profiles are not very similar and especially in the top 100m at the sea surface the mixed layer depth varies from station to station. The structure at the top 150m layer is similar for Ref. 03, 1, 4, but the mixed layer depth is not same (which varied from 30m to 60m and temperature inversions within this region are seen, may be due to turbulence). The general trend in temperature profile in top 60m in stations 24, 33, 43, 60 & 65 is similar with a shallow mixed layer of 30m followed by inversions (or fluctuations). Station 49 is peculiar w.r.t. temperature which shows no mixed layer and has only one inversion at about 75m depth.

The temperature ranged between  $\approx 25.8^\circ\text{C}$  (at surface) to a minimum of  $4.4^\circ\text{C}$  at a depth of 1470m (at station 4). The general trend in the temperature profile is that with a mixed layer from 30-60m, then a smooth thermocline followed by gradual decrement of temperature with depth.

Salinity: Salinity ranged between 28.8 psu (st stn. 4) and 35.05 psu (at stn. Ref. 03); but occasional peaks upto 36.20 psu (at stn. 49) which may be due to spikes in salinity (these are salinity spikes in the profile at this station). The general trend is that salinity from surface increases sharply with depth upto 35.0 psu and then this value remains constant (or very small change) upto the seabed.

Density: The  $\sigma_t$  varied between  $\approx 18.0 \text{ kg/m}^3$  (at stn 01) at surface to  $\approx 27.6 \text{ kg/m}^3$  (at stn 4) at the sea bottom. The general trend of variation in  $\sigma_t$  is that the variation from surface is gradual with depth upto about approx. 300m and then the value very slowly decreases with depth upto the bottom of the sea.

Spikes in  $\sigma_t$  profiles are seen in stns 49 & 60 which are attributed to spikes in salinity.

Fluorescence: The fluorescence data, obtained with seapoint sensor, shows a minimum threshold value at surface ( $\approx 0.04 \mu\text{g/l}$ ) to subsurface peaks with maximum peak at  $\approx 50\text{m}$  and upto a maximum depth of  $\approx 210\text{m}$  and then the data remains at minimum value of  $0.04 \mu\text{g/l}$  upto sea bottom. The surface value of fluorescence ranged between  $0.04 \mu\text{g/l}$  and  $0.1 \mu\text{g/l}$  (at stn 33). The sub-surface peaks occur with values 0.56, 0.6, 0.66, 0.5, 0.46, 0.44, 0.68, 0.52, 0.48, 0.38, 1.44, 1.23, 0.56, 0.39, 0.71, 0.8  $\mu\text{g/l}$ . The sub-surface maxima of peaks in the individual profiles occur with values 0.39, 0.68, 0.71, 0.8, 0.56, 1.23 and 1.44  $\mu\text{g/l}$ , 0.58  $\mu\text{g/l}$ .

Dissolved oxygen: The general trend of Dissolved Oxygen variation is that a very high surface concentration is followed by a drastic decrease upto a minimum at around 150m depth, which remains nearly constant with depth upto typically 500-600m depth, and then the concentration gradually increases upto sea bottom. Near sub-surface spikes are observed at few stations. Interestingly the surface DO concentration is almost the same at all stations in the surveyed region and ranged between 4.6 and 4.75 ml/l. The DO concentration at the sea bottom ranged between 0.25 ml/l (at stn. Ref. 03) at 320m depth and 1.88 ml/l (at stn. 4) at 1470m depth. The depletion of DO from the surface upto 150m will be due to biota especially phytoplankton and spikes may be due to variation in biomass.

The vertical profiles of CTD data along with the horizontal sections at various depths gives clues to the probable sites for the occurrence of gas hydrates in the Bay of Bengal within the surveyed area.

## **5. Conclusions**

The hydrographic features at 9 stations in the study area surveyed in the Bay of Bengal were described. Details of the parameters such as near bottom temperature, salinity and dissolved oxygen are given and presented as respective seabed parameter maps. Other horizontal sectional contour

maps of these parameters at depths 50m, 100m, 200m, 811m also were presented to delineate their spatial variability.

Although the data acquisition was continuous with depth upto seabed (upto a maximum of 1490 metres at station 04), the near bottom maps are important for the methane gas hydrate studies. The salient points are:

- a. Seabed temperatures varied between  $\approx 4.6^{\circ}\text{C}$  and  $10.6^{\circ}\text{C}$  in the area; DO (Dissolved Oxygen) ranged between  $\approx 0.23$  and  $1.86$  ml/l and the salinity ranged between  $34.843$  and  $35.018$  psu at the seabed. The variations may partly be attributed to the bathymetric changes and partly to the seawater property changes.
- b. The near bottom temperatures can be used as one of the important parameters in estimating the gas hydrate stability zone thickness map.
- c. Dissolved oxygen and salinity can be used in estimation of some of the microbial communities which serve as proxies for the occurrence of methane gas hydrates.

## **6. Acknowledgements**

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## AASGH4

Parameters from CTD data at the maximum depth of observation

Station No.	Latitude (°N)	Longitude (°E)	Depth of seabed (m)	Max. CTD Depth (m)	CTD ht. from seabed [altimeter(m)]	Temperature (°C)	Salinity (psu)	Oxygen (ml/l)
REF03	16.16	82.03	330	323	1.03	10.6261	35.0178	0.22906
01	15.82	81.72	1284	1270	98.02*	5.4694	34.8765	1.50189
04	15.78	81.75	1488	1473	15.38	4.5868	34.8435	1.86407
24	15.87	81.89	1127	1106	19.25	5.965	34.904	1.28218
33	16	81.96	954	929	18.26	7.1631	34.94	0.89737
43	16.04	82.06	930	908	14.08	7.2705	34.9446	0.87727
49	16.12	82.13	828	811	15.54	7.7553	34.9597	0.69823
60	16.07	82.25	1283	1252	16.39	5.5073	34.8783	1.50487
65	16.18	82.26	871	851	12.14	7.4535	34.9497	0.80199

\* : unreliable data due to altimeter and pinger interference.

**NOTE: latitude & longitude are purely in degrees.**

Table - 1

AASGH4  
STATION PLOTS

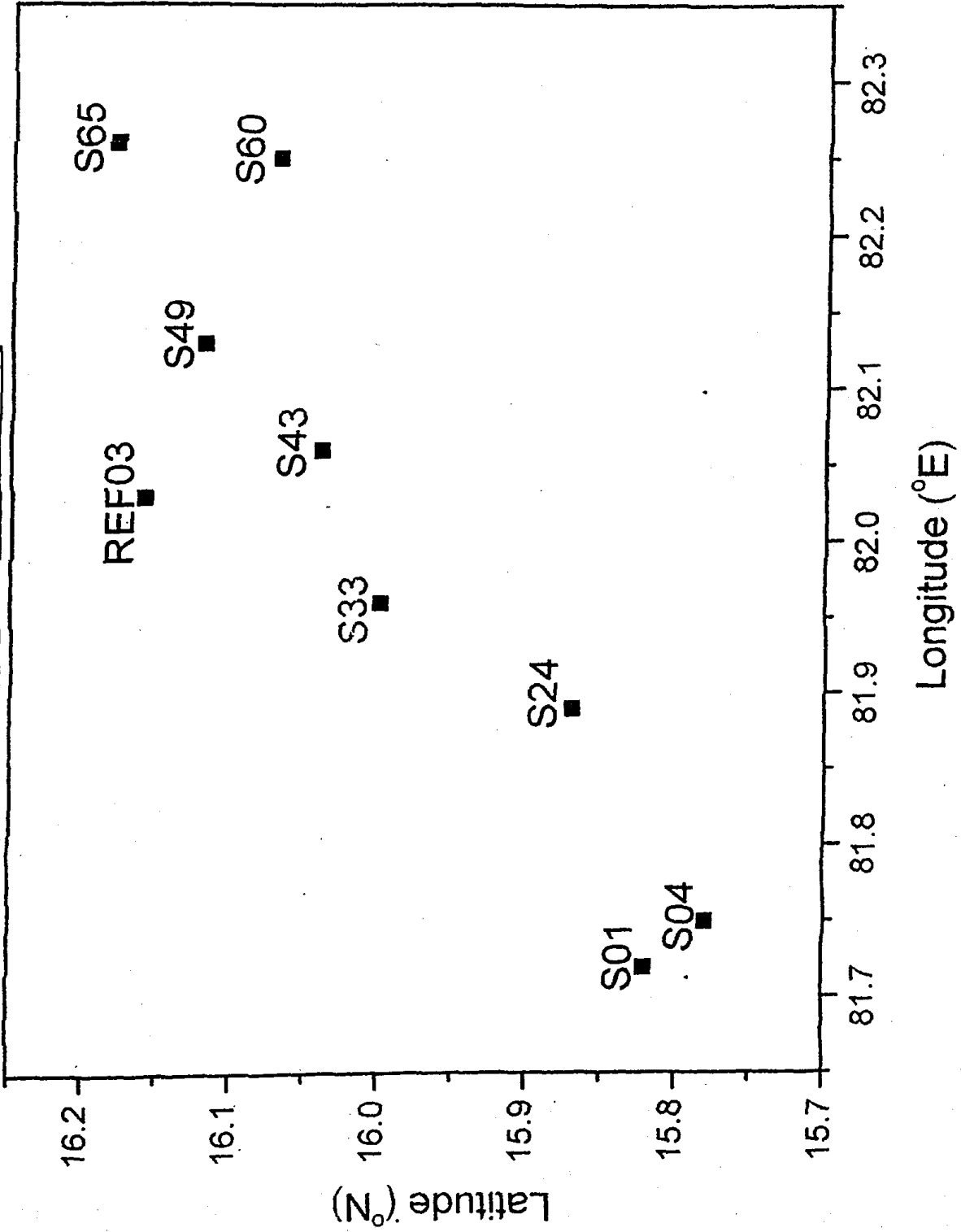


Fig-1

AASGH4, stat01

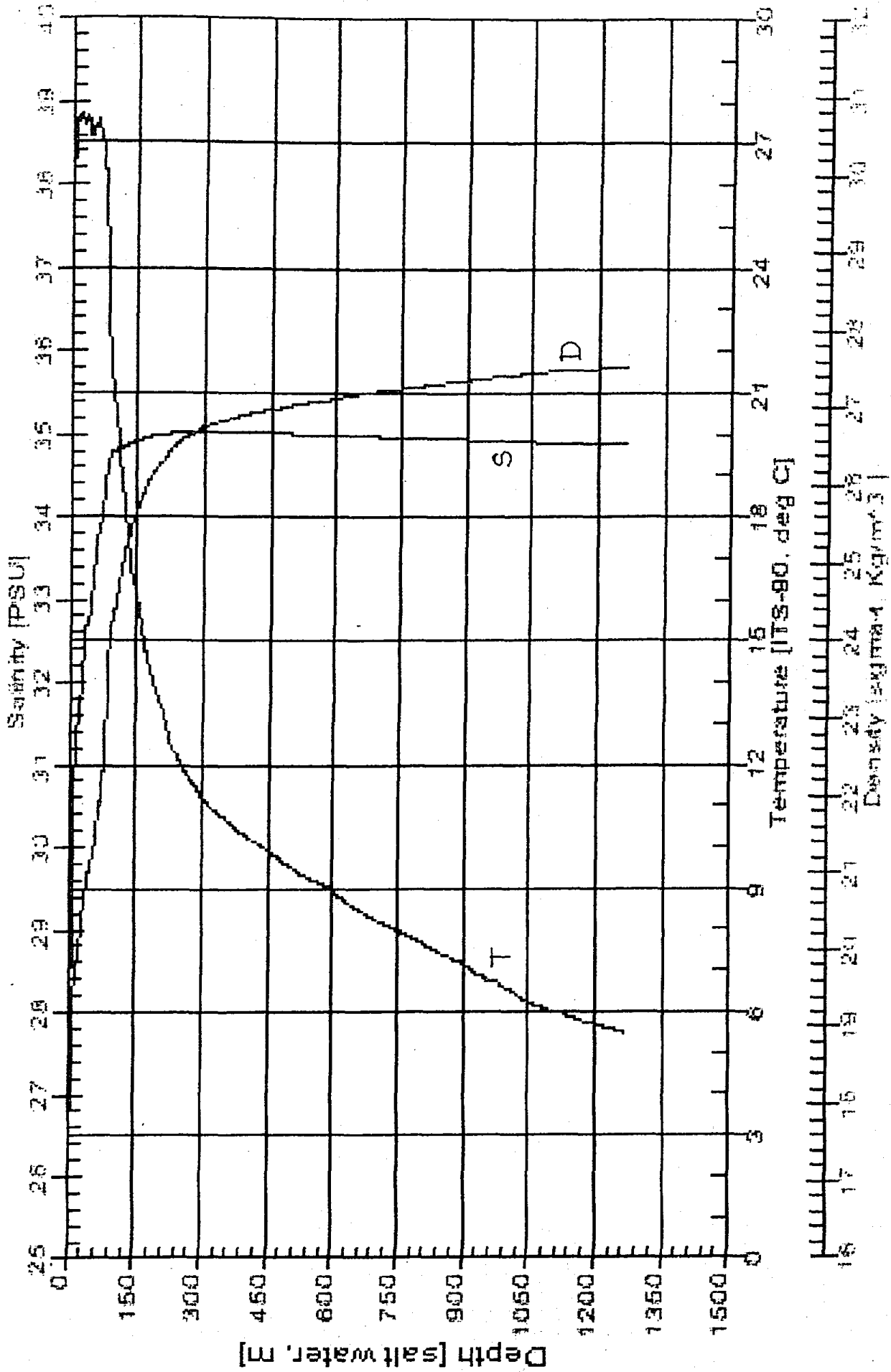


Fig-2

# AASGH4, Ref03

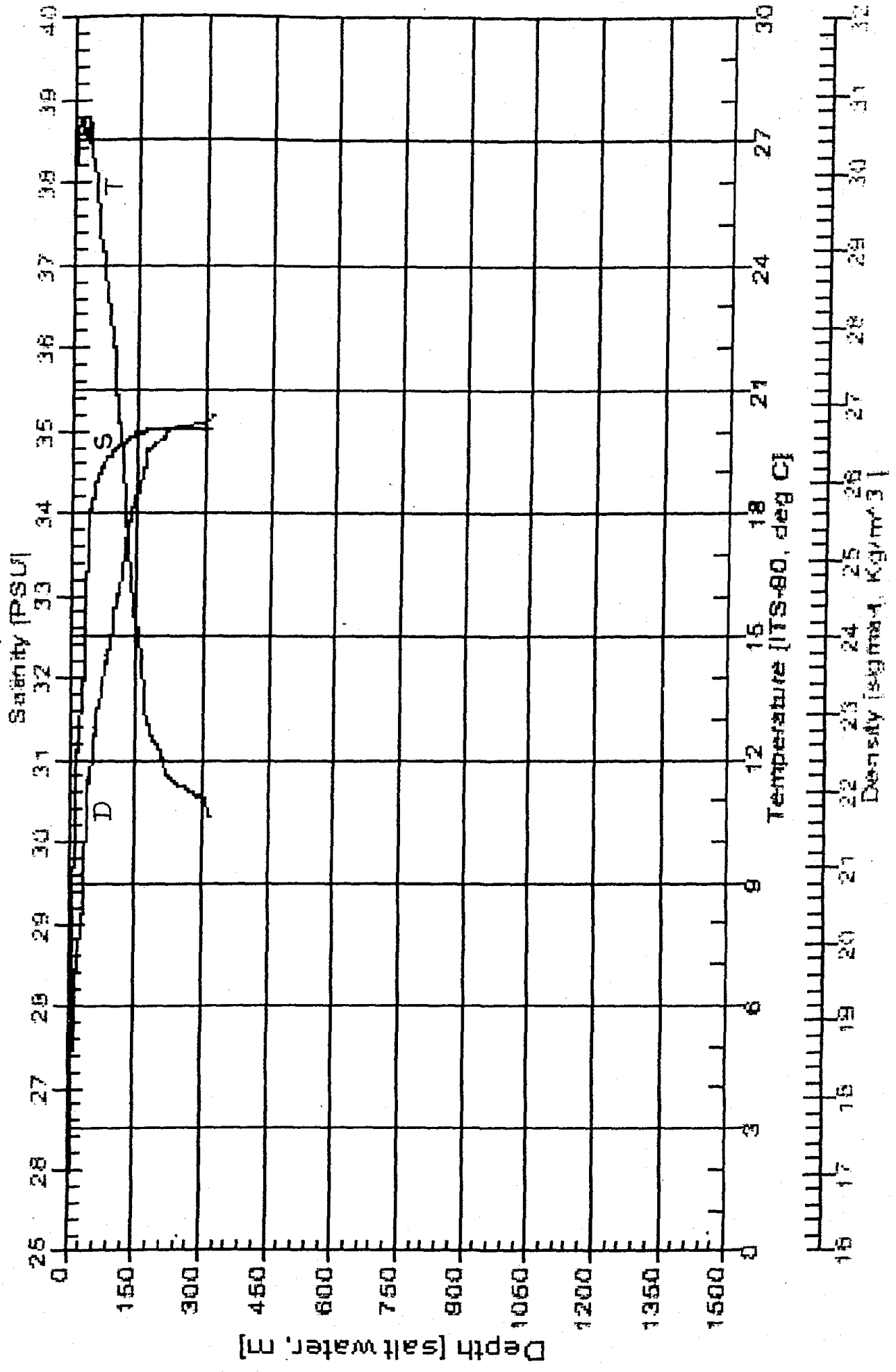
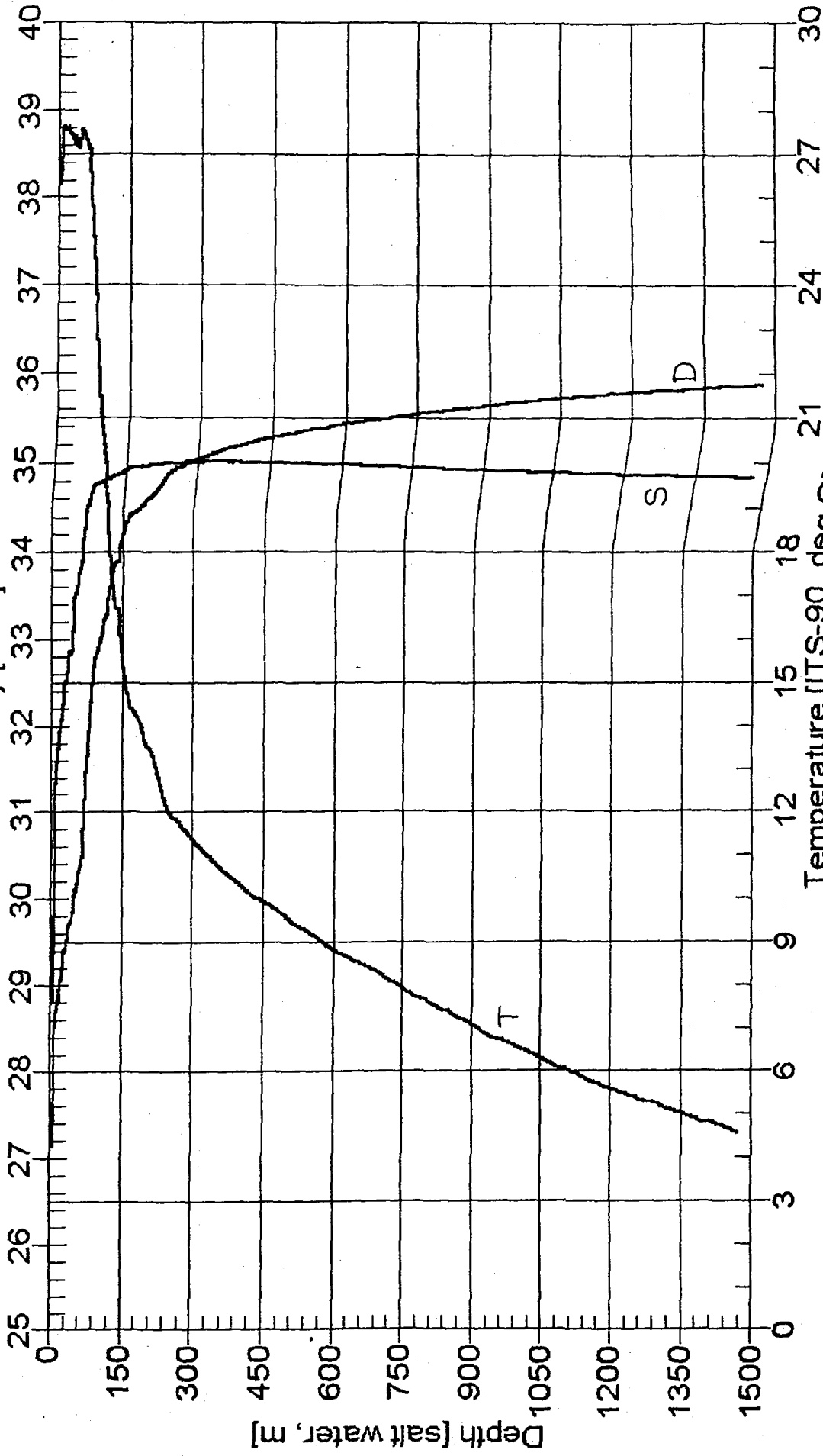


Fig-3

# AASGH4, stat04

Salinity [PSU]



Temperature [ITS-90, deg C]

Density [sigma-t, Kg/m³]

FIG. 4



# AASGH4, stat24

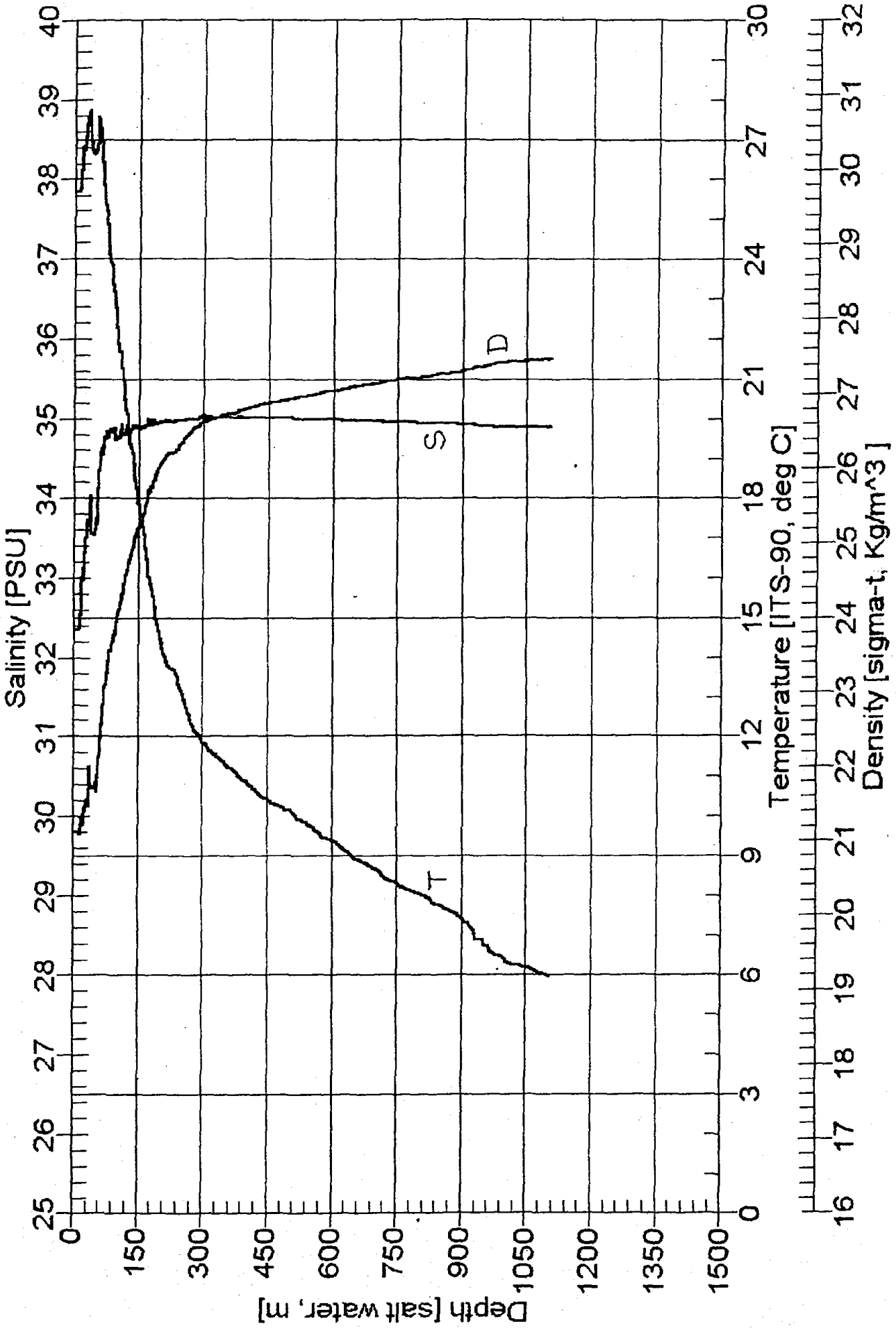


FIG - 5

# AASGH4, stat33

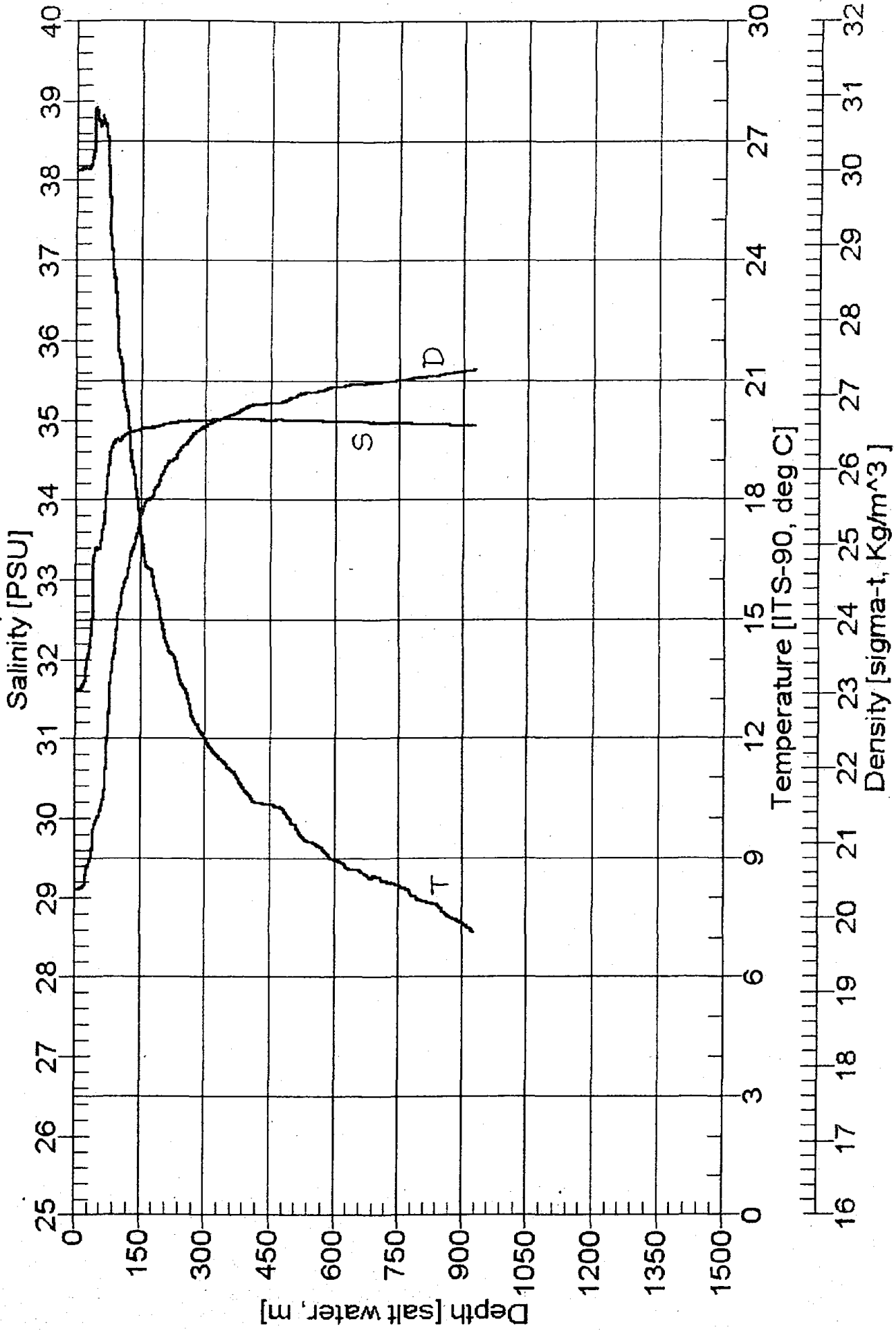
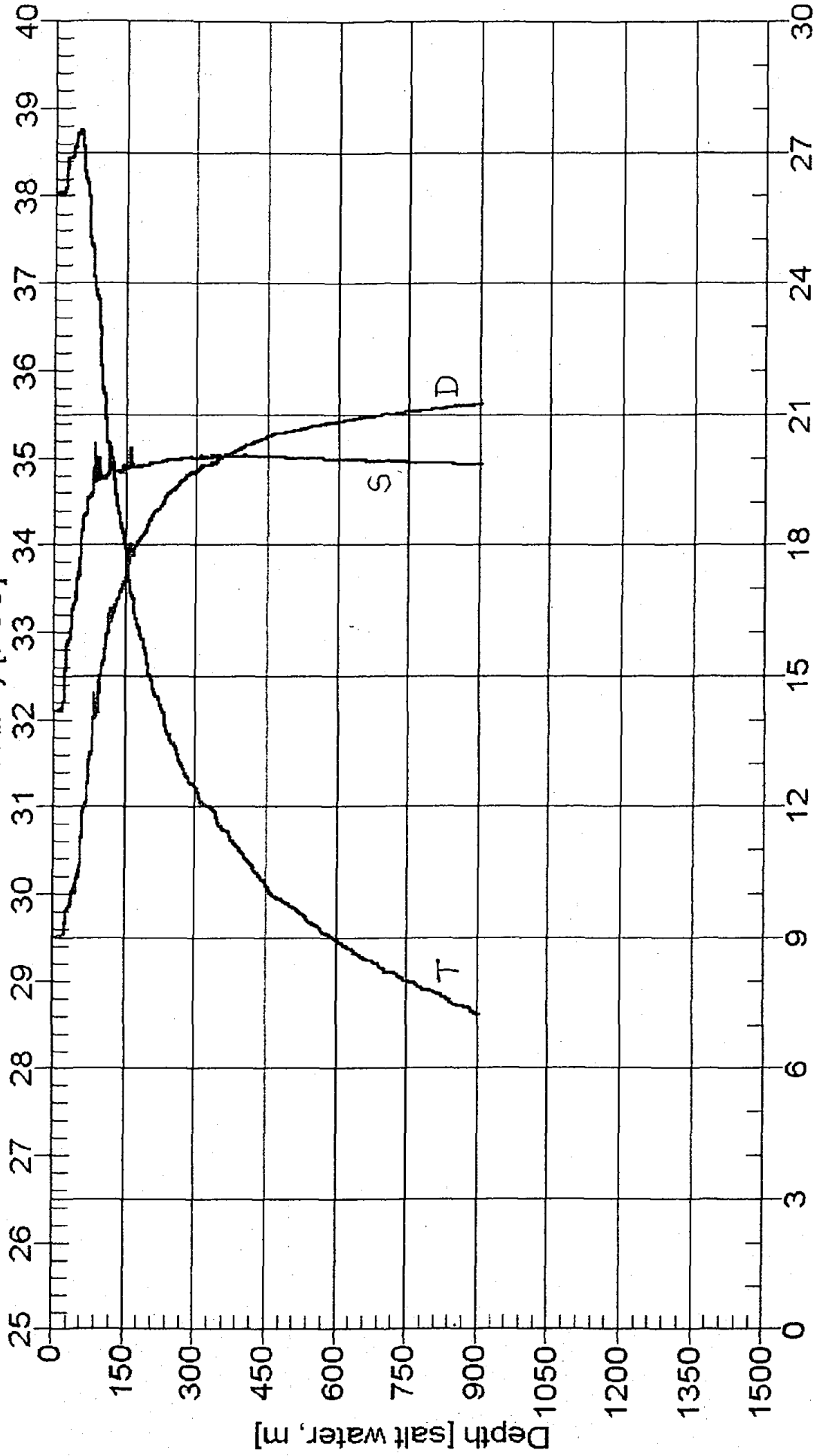


FIG. 6

# AASGH4, stat43

Salinity [PSU]



Temperature [ITS-90, deg C]

Density [sigma-t, Kg/m³]

FIG. 7

# AASGH4, stat49

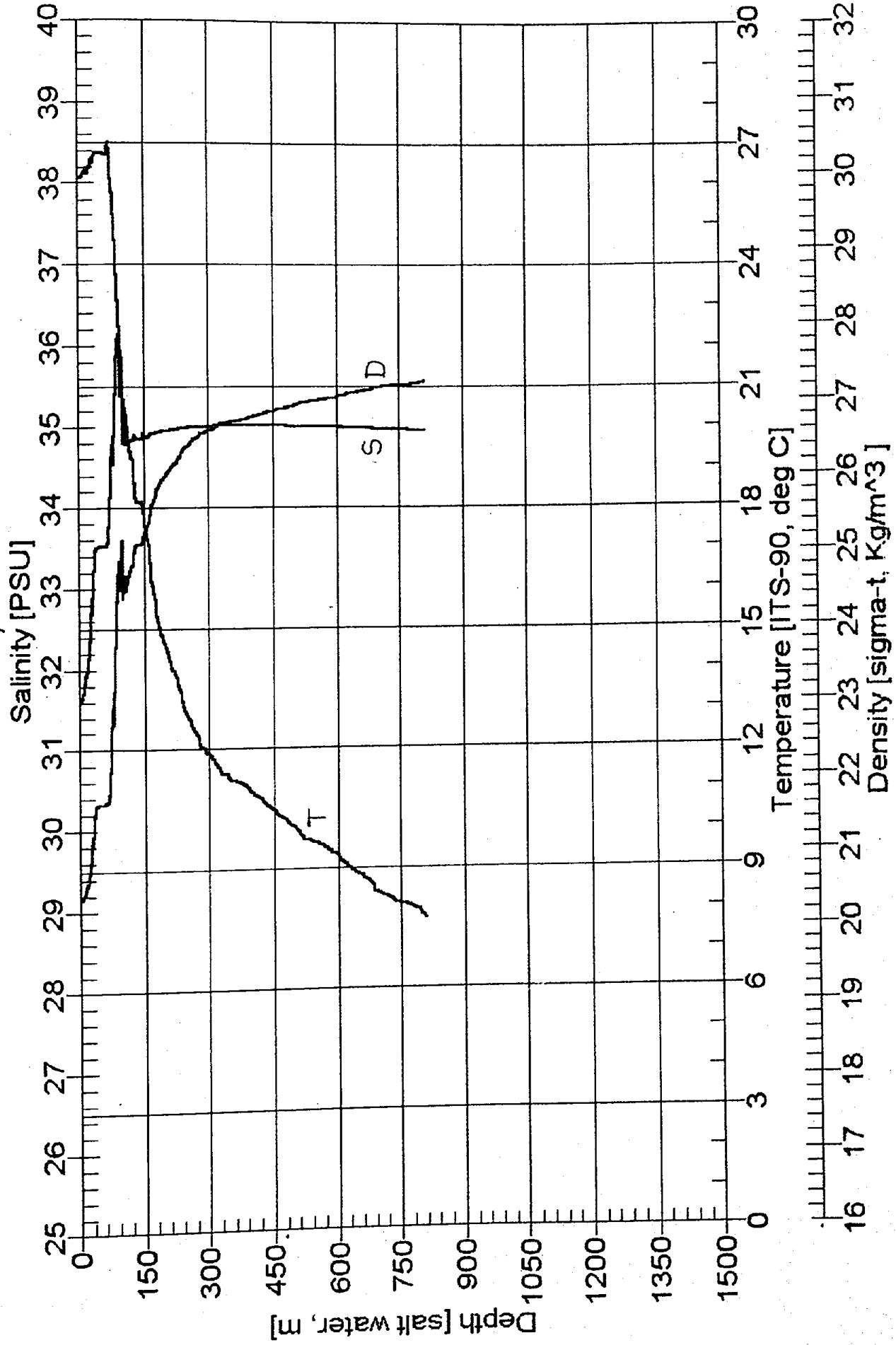


FIG. 8

# AASGH4, stat60

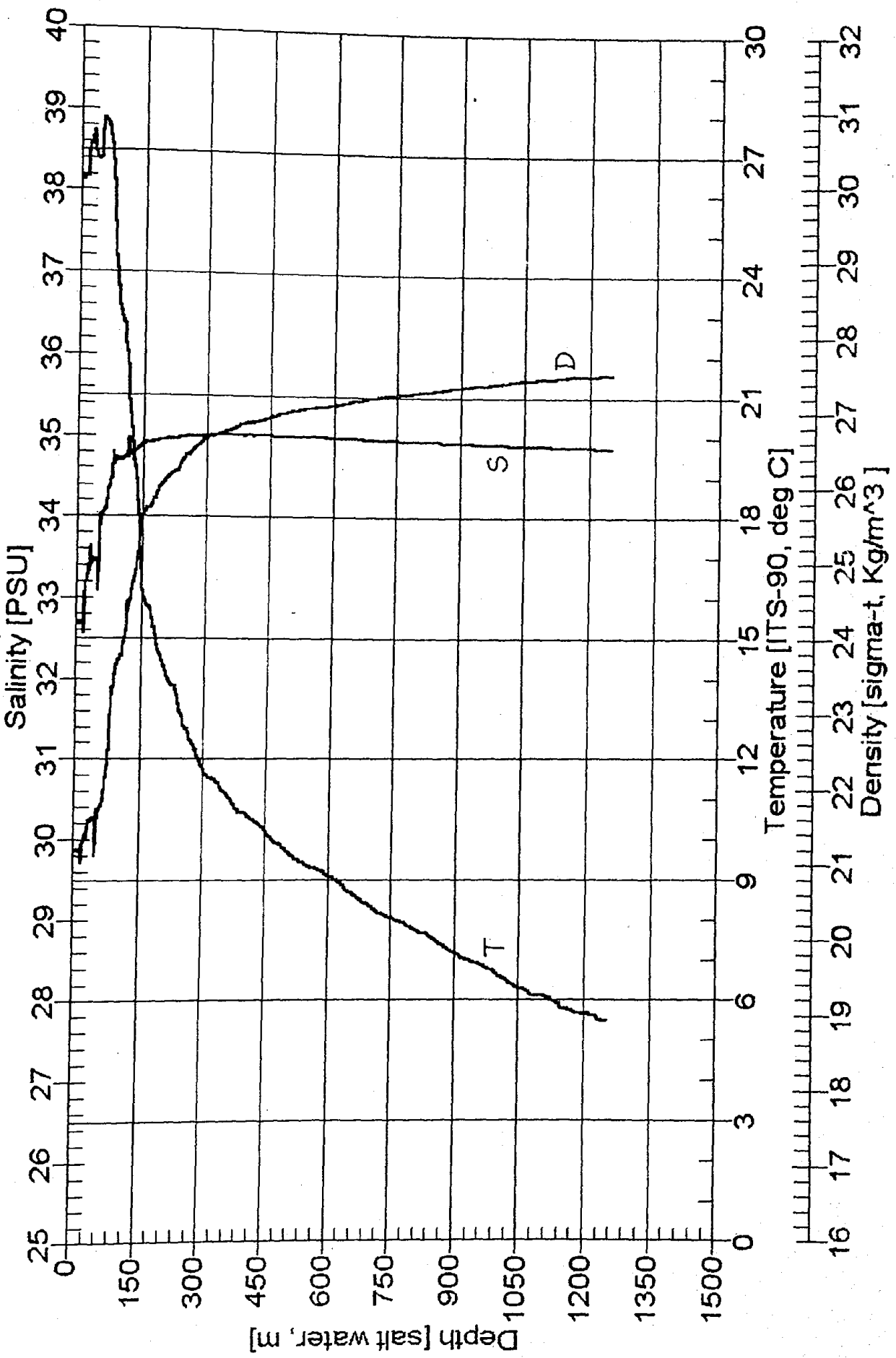


FIG. 9

# AASGH4, stat65

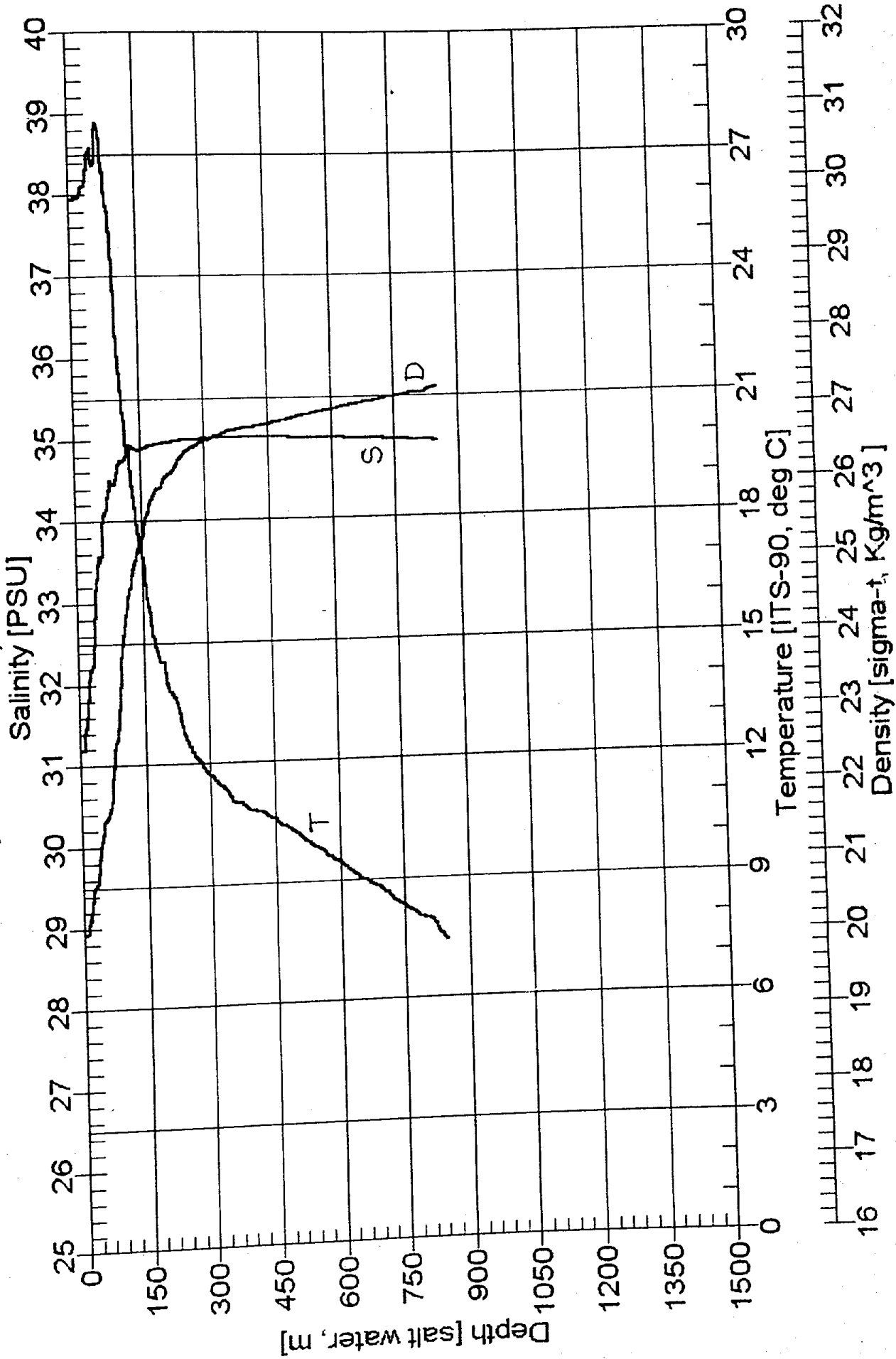


FIG. 10

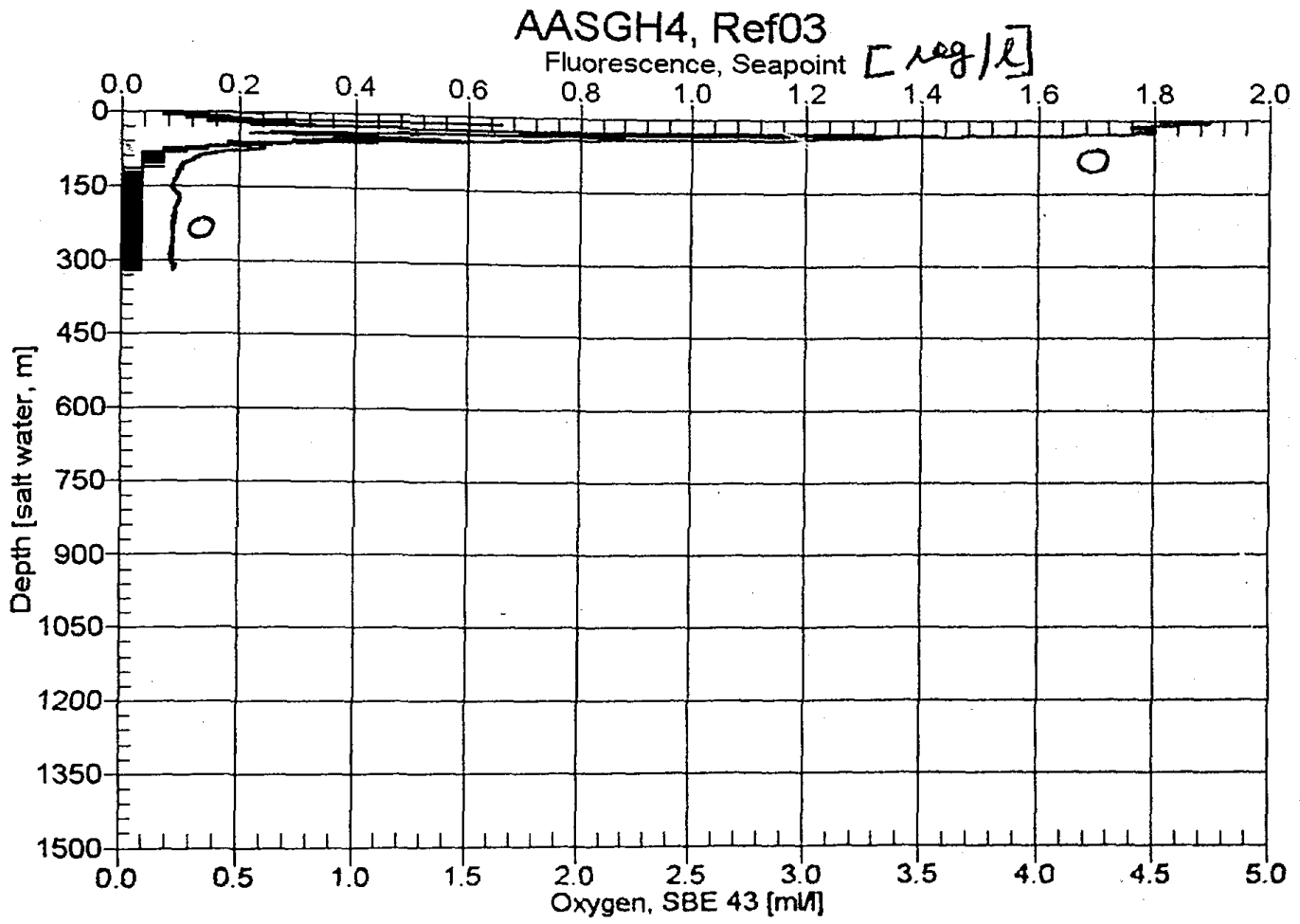


FIG. 11

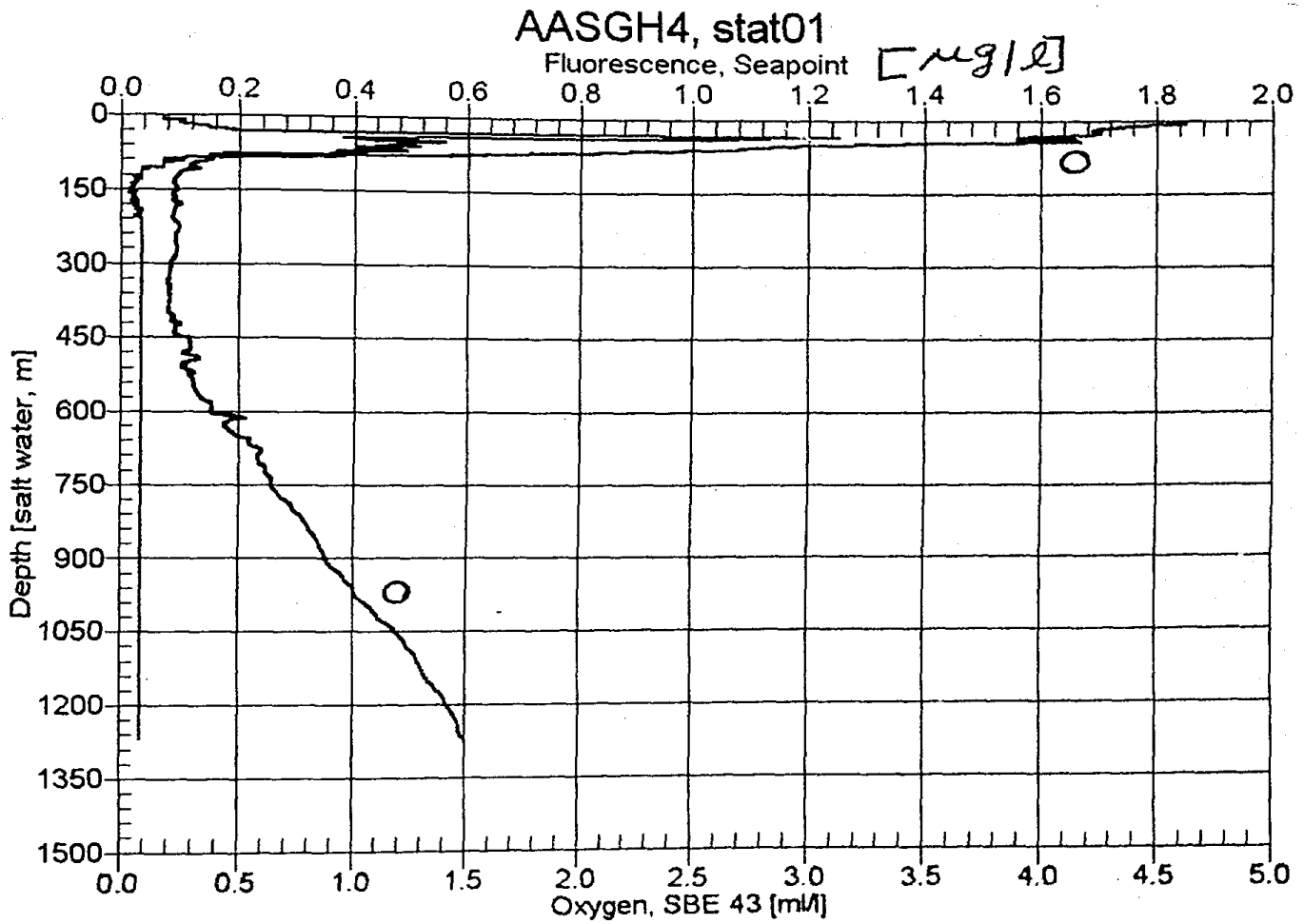


FIG. 12



AASGH4, stat04

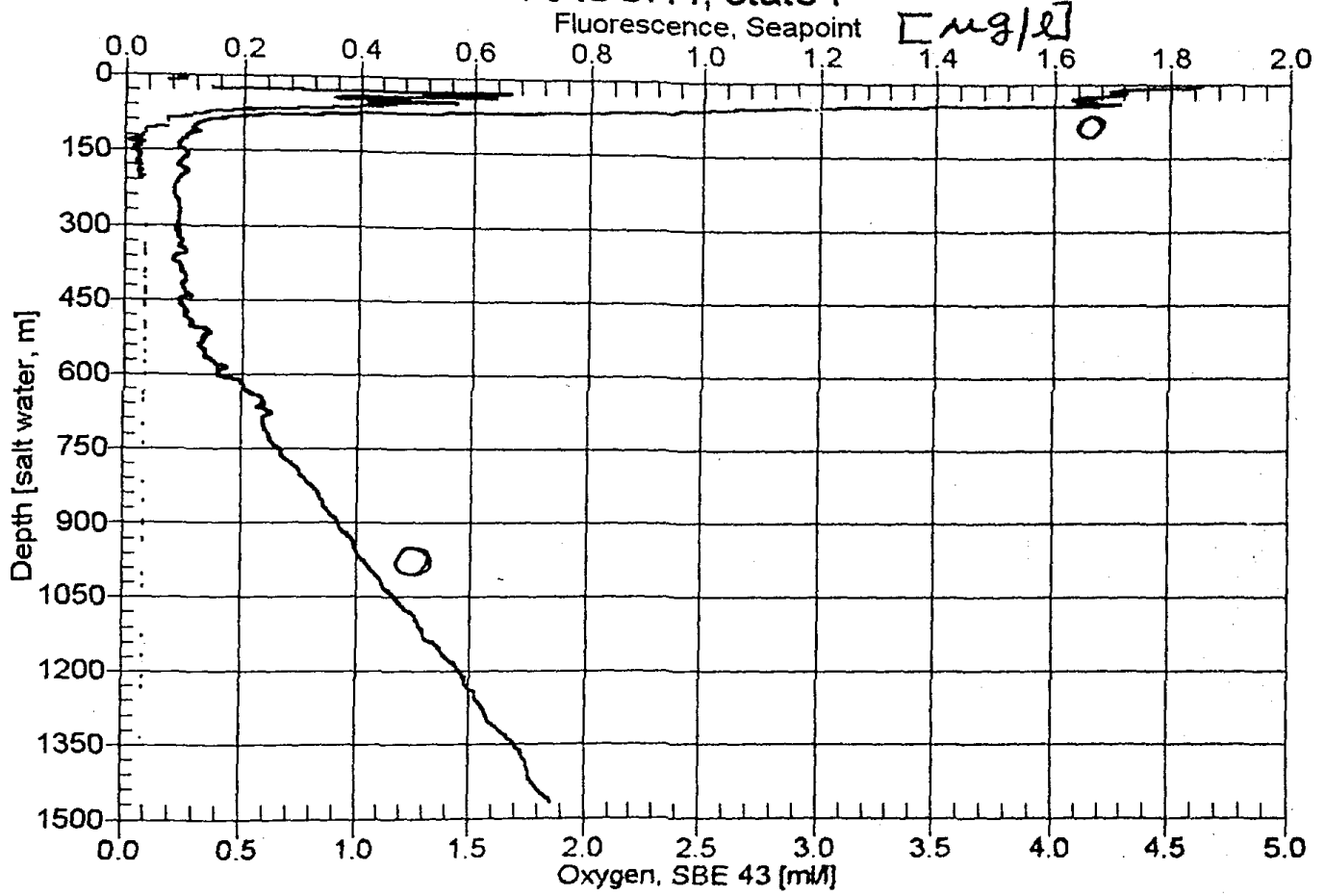


FIG. 13

AASGH4, stat24

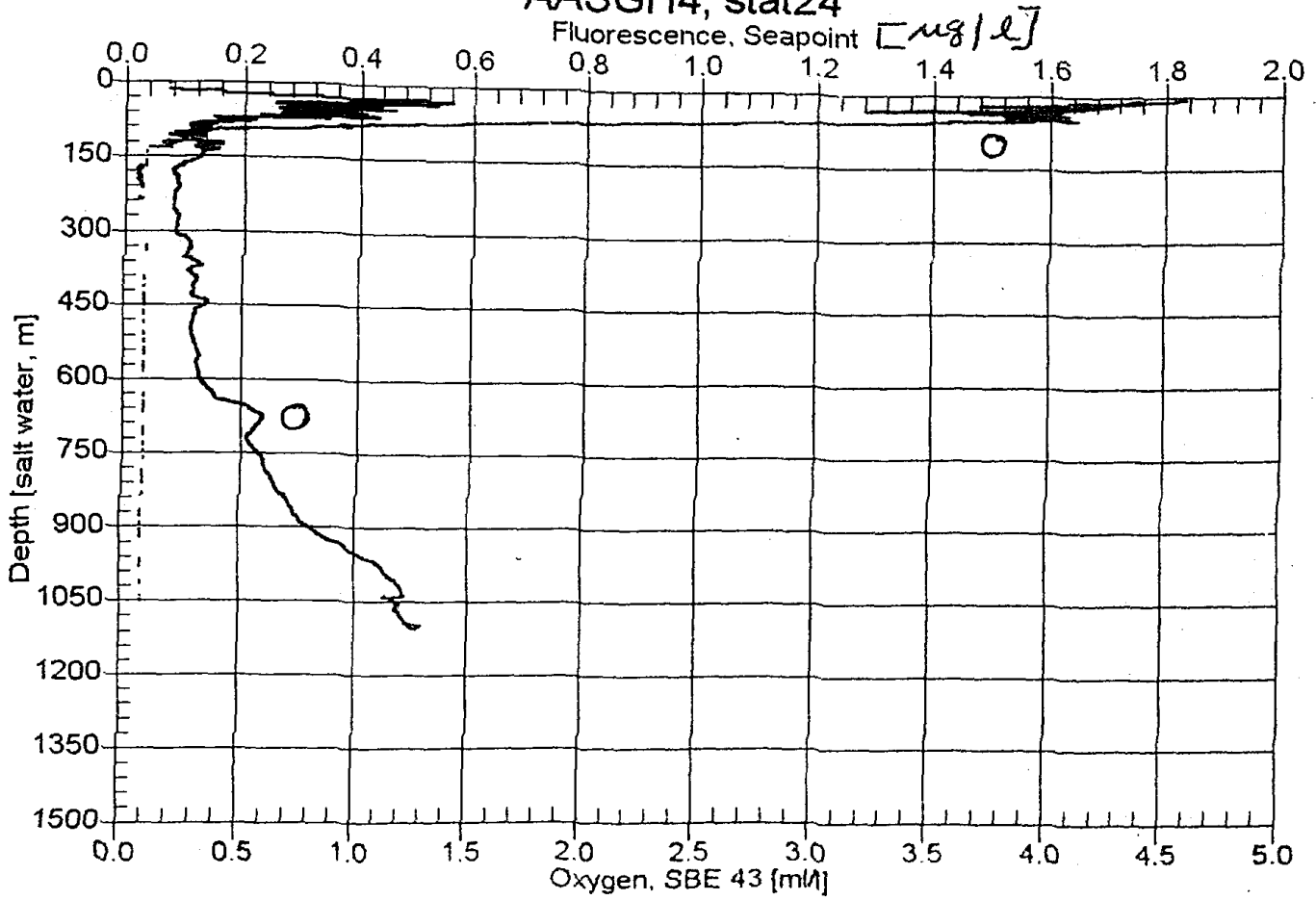


FIG. 14

AASGH4, stat33

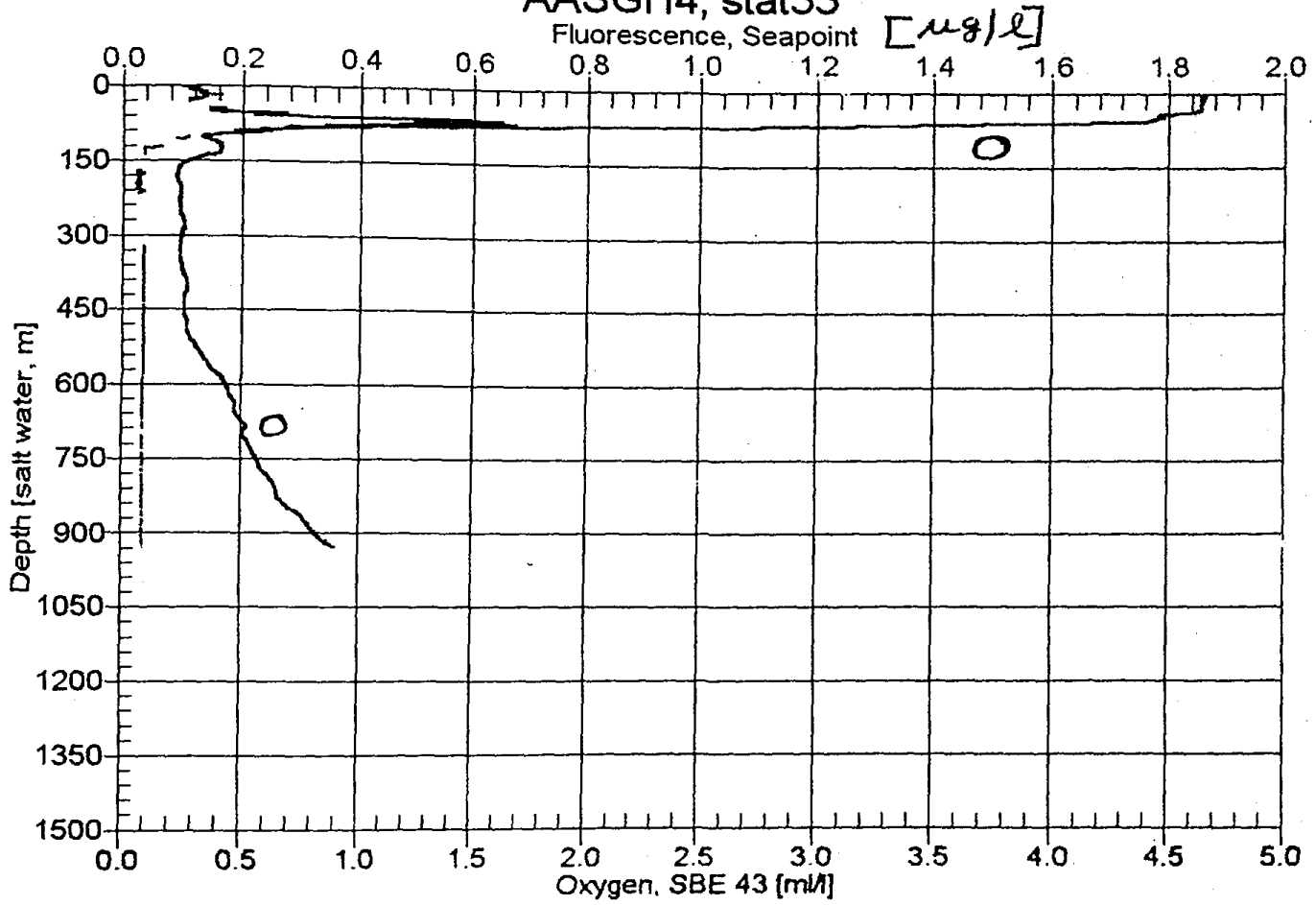


FIG. 15

AASGH4, stat43

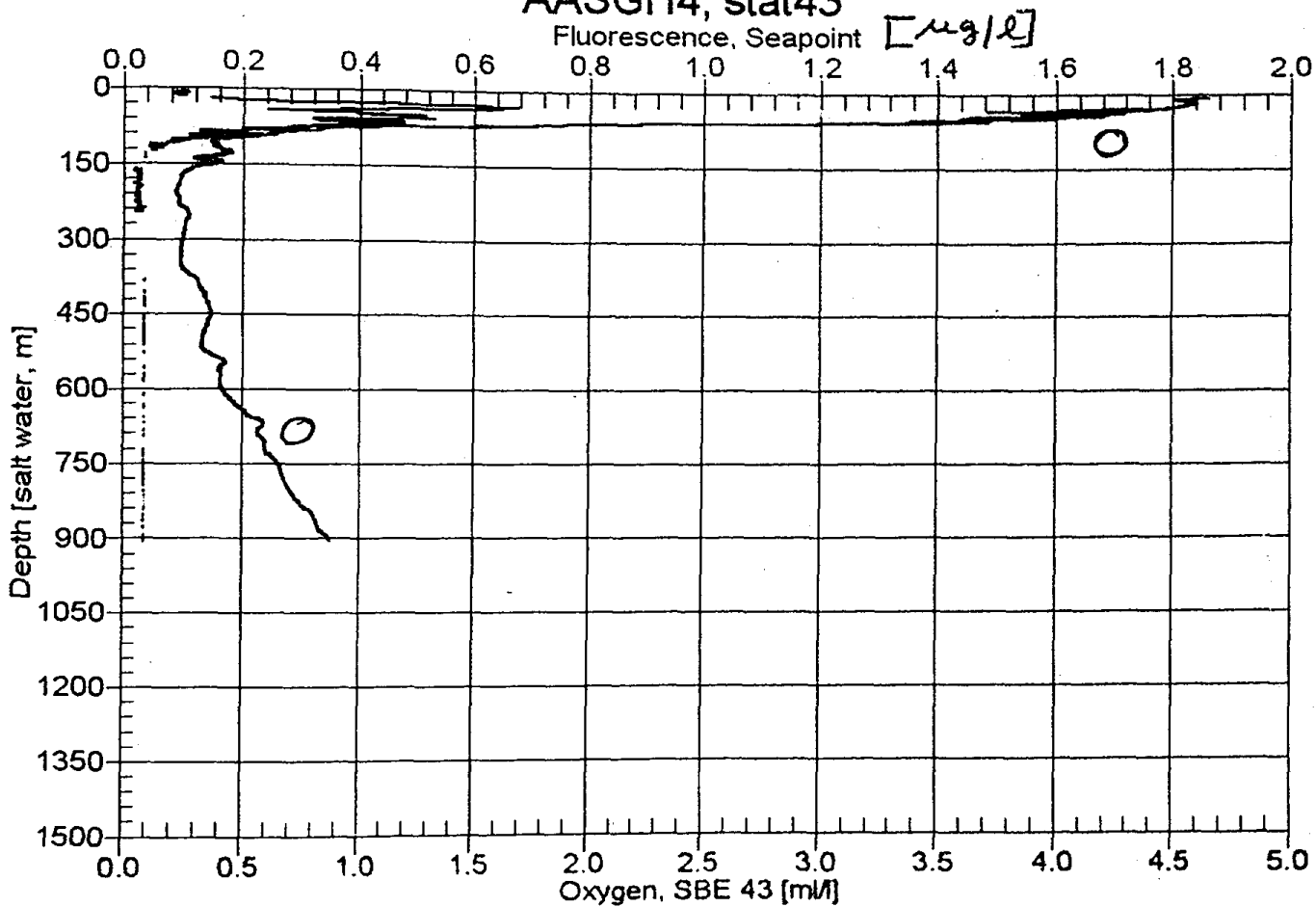


FIG-16

AASGH4, stat49

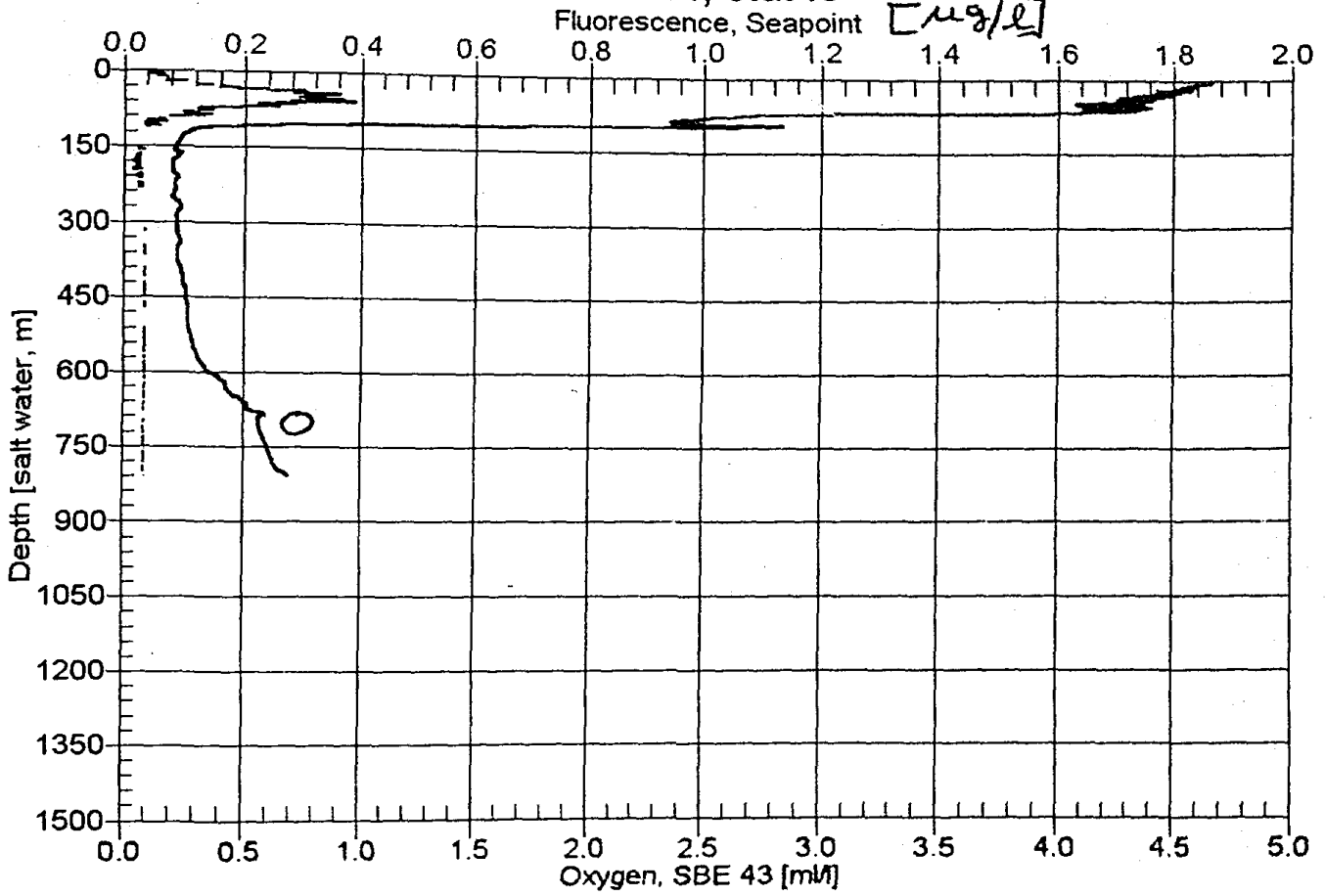


FIG. 17

AASGH4, stat60

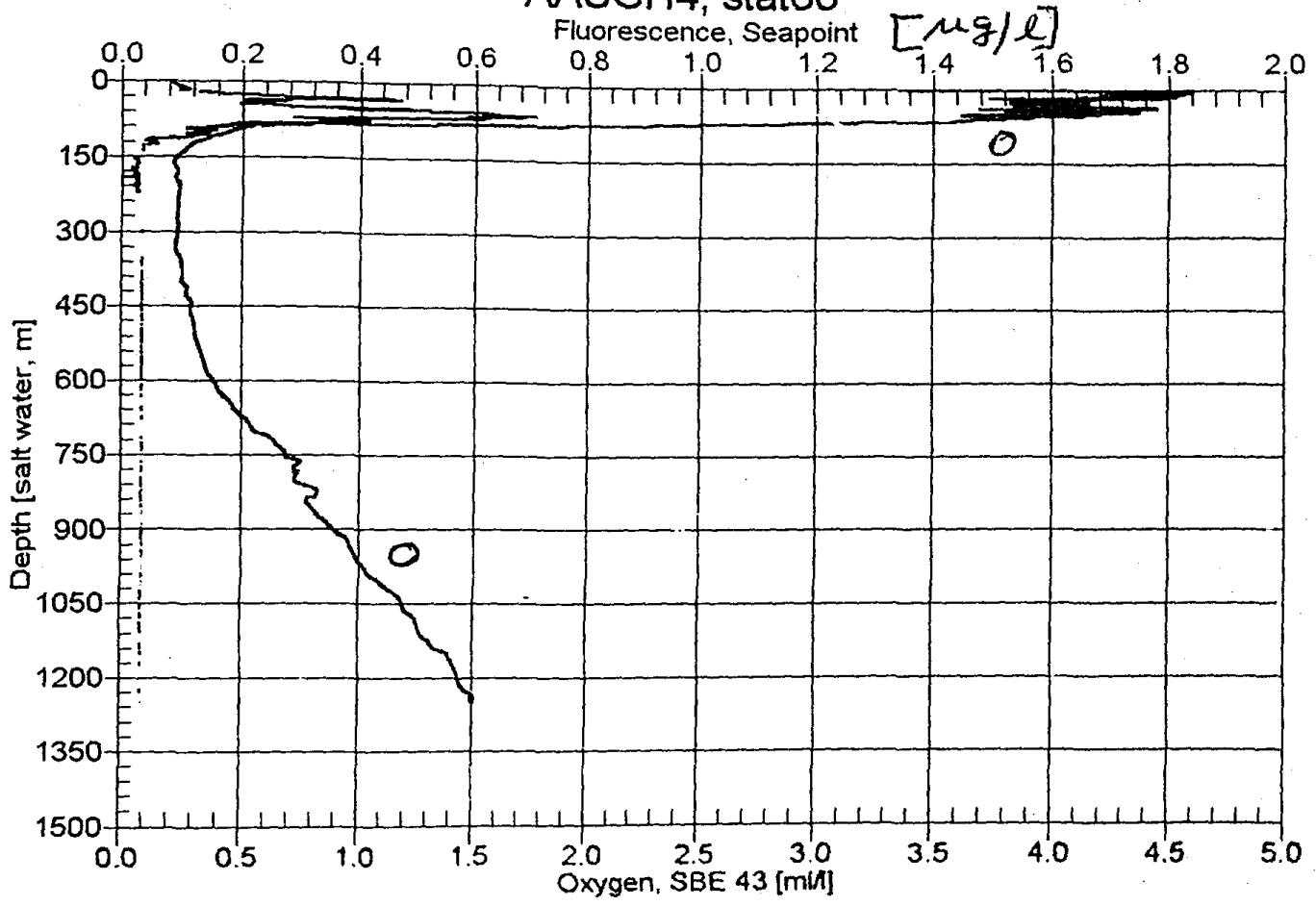


FIG. 18

AASGH4, stat65

Fluorescence, Seapoint

[ $\mu\text{g/l}$ ]

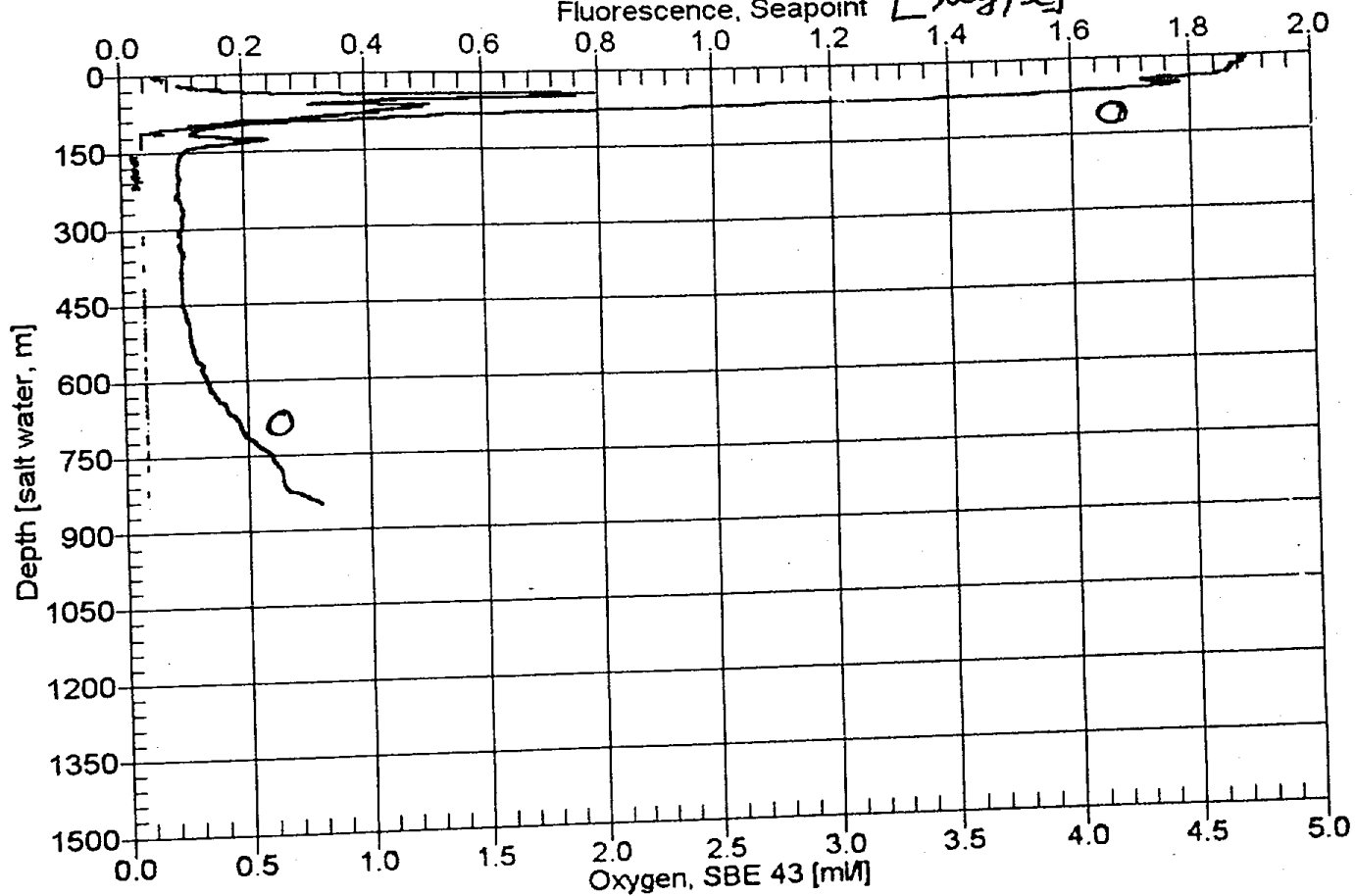
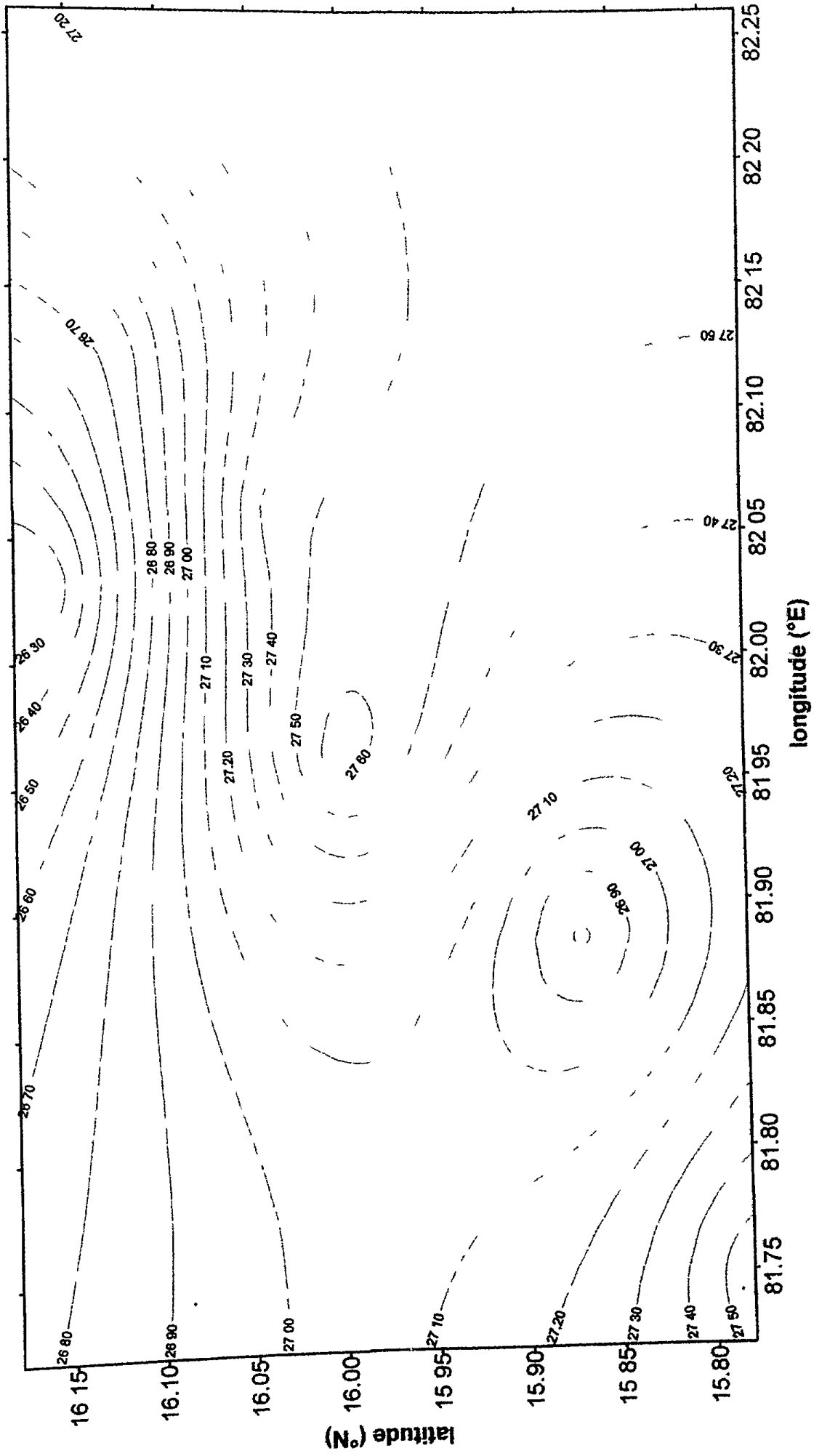


FIG. 19

**AASGH4**  
**(Temperature contour at 50m depth)**



**FIG.20**



AASGH~~2~~H  
(Temperature Contour at 100m depth)

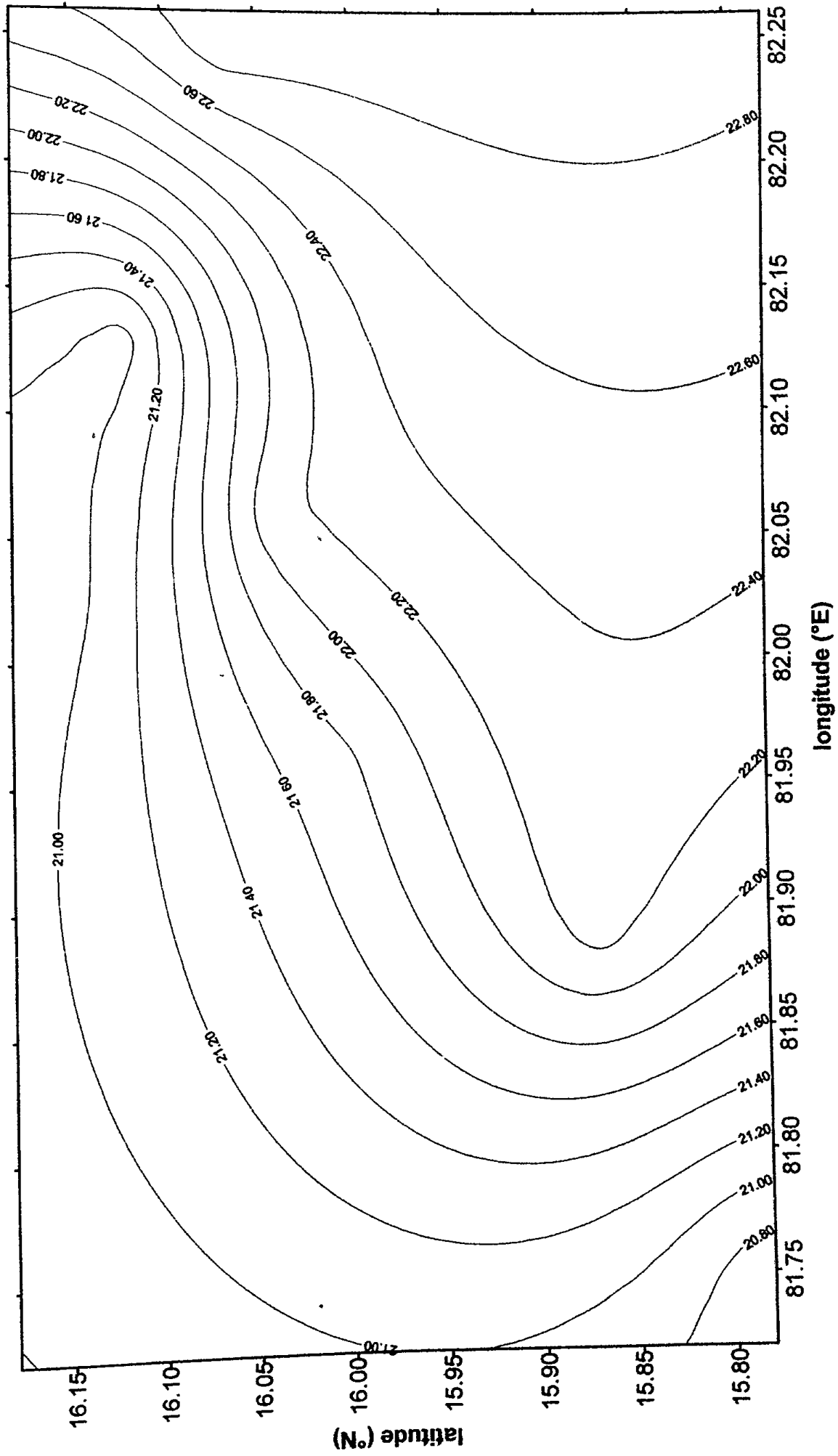
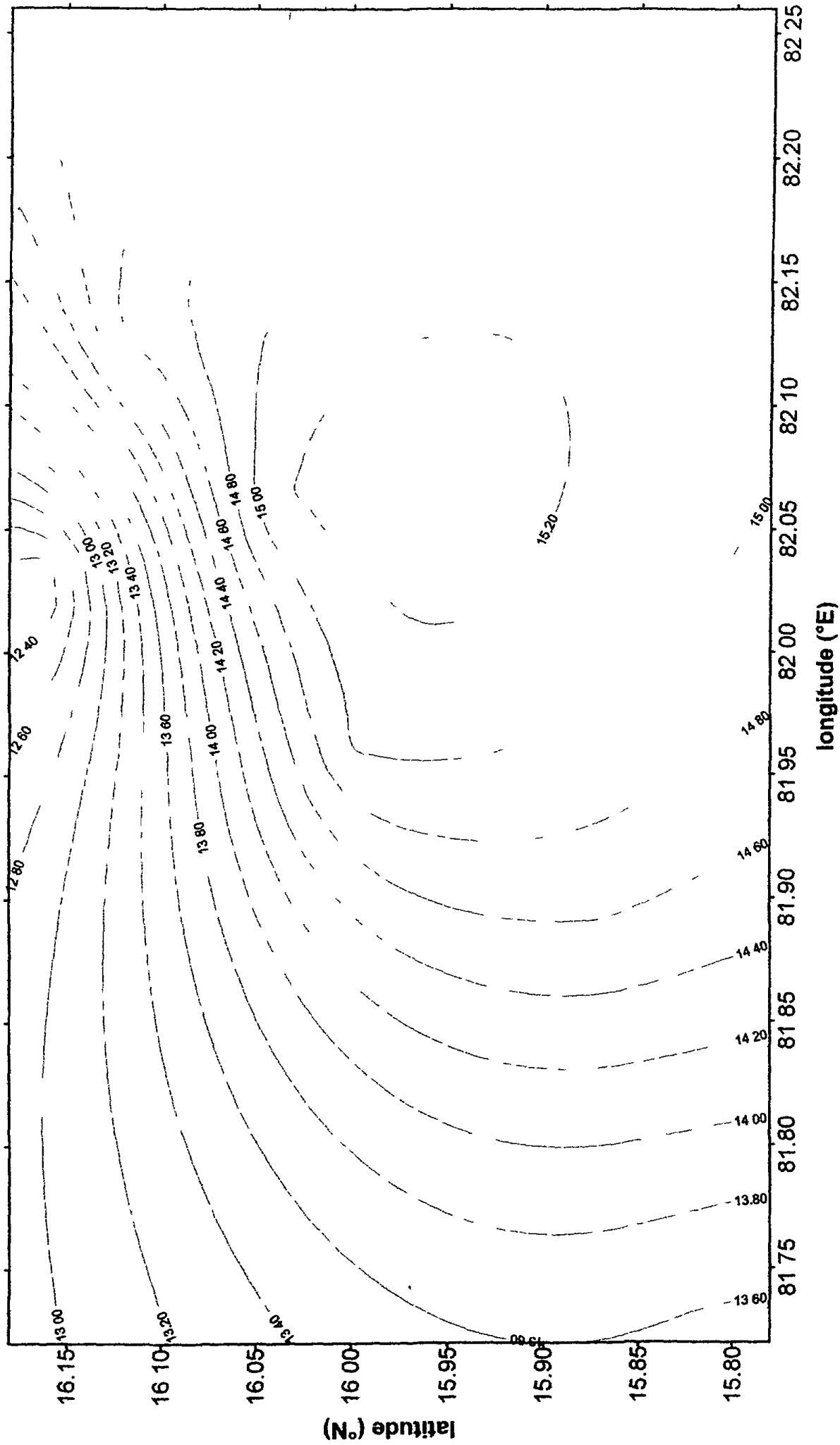


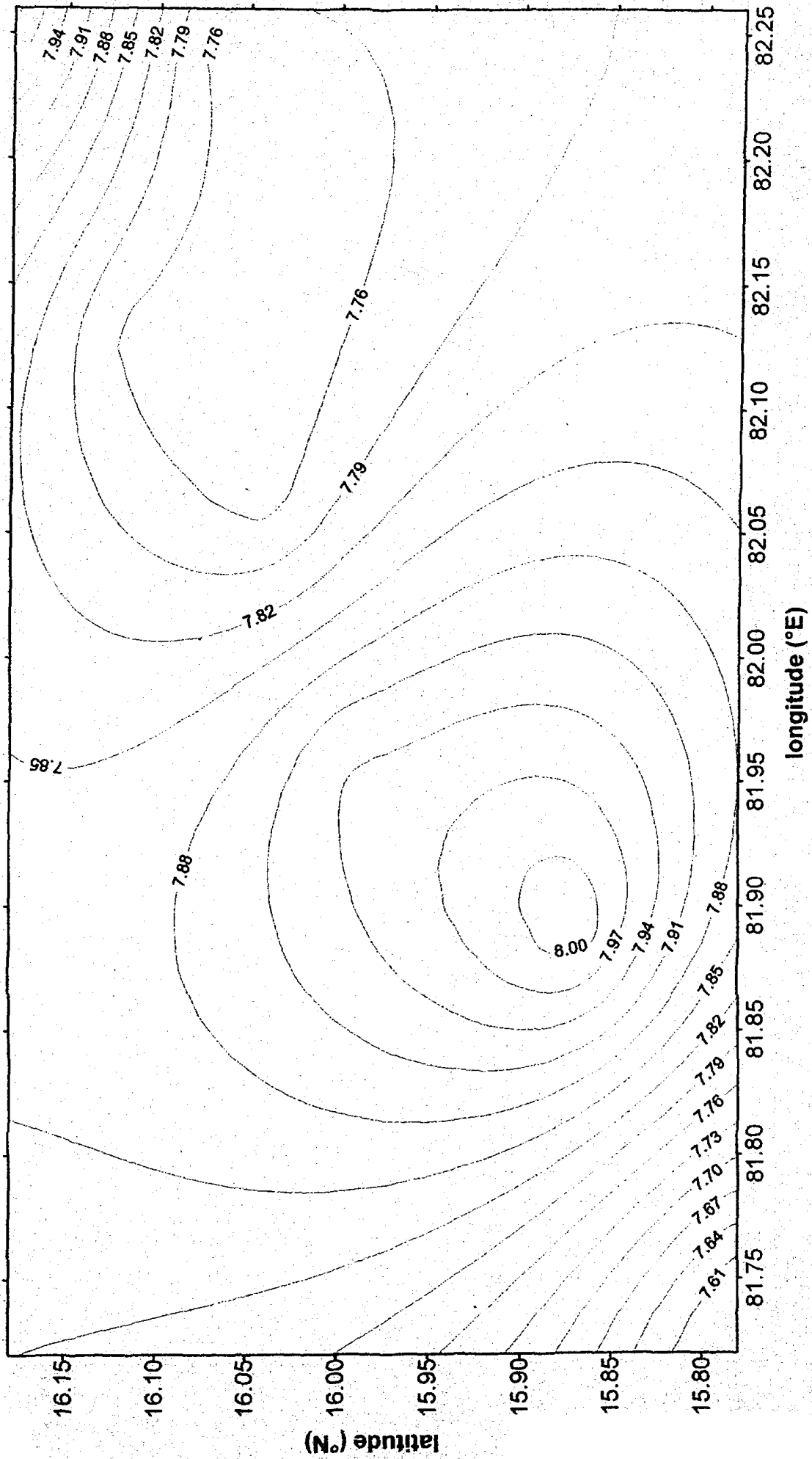
FIG.21

**AASGH4**  
**(Temperature contour at 200m depth)**



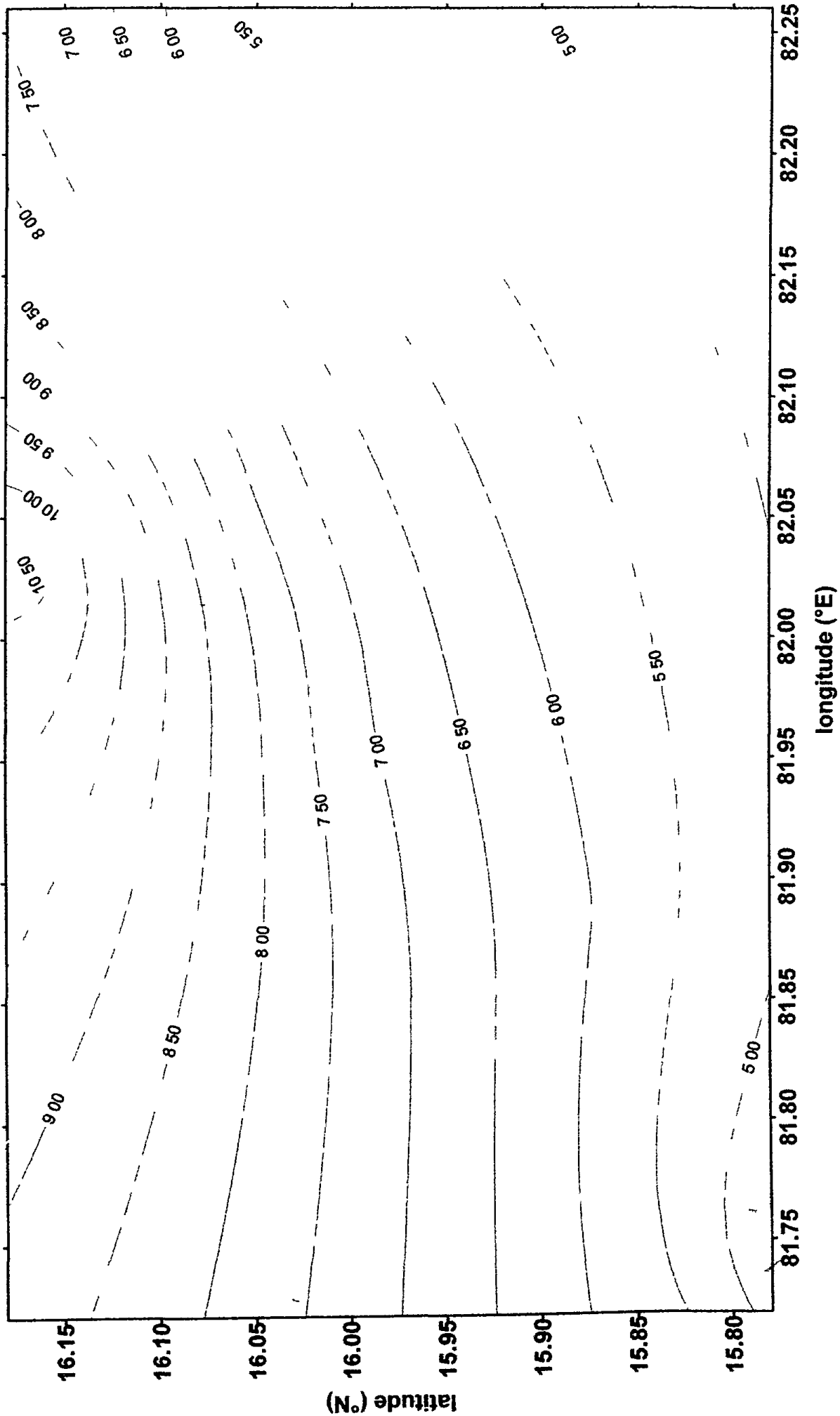
**FIG.22**

**AASGH4**  
**(Temperature contour at 811m depth)**



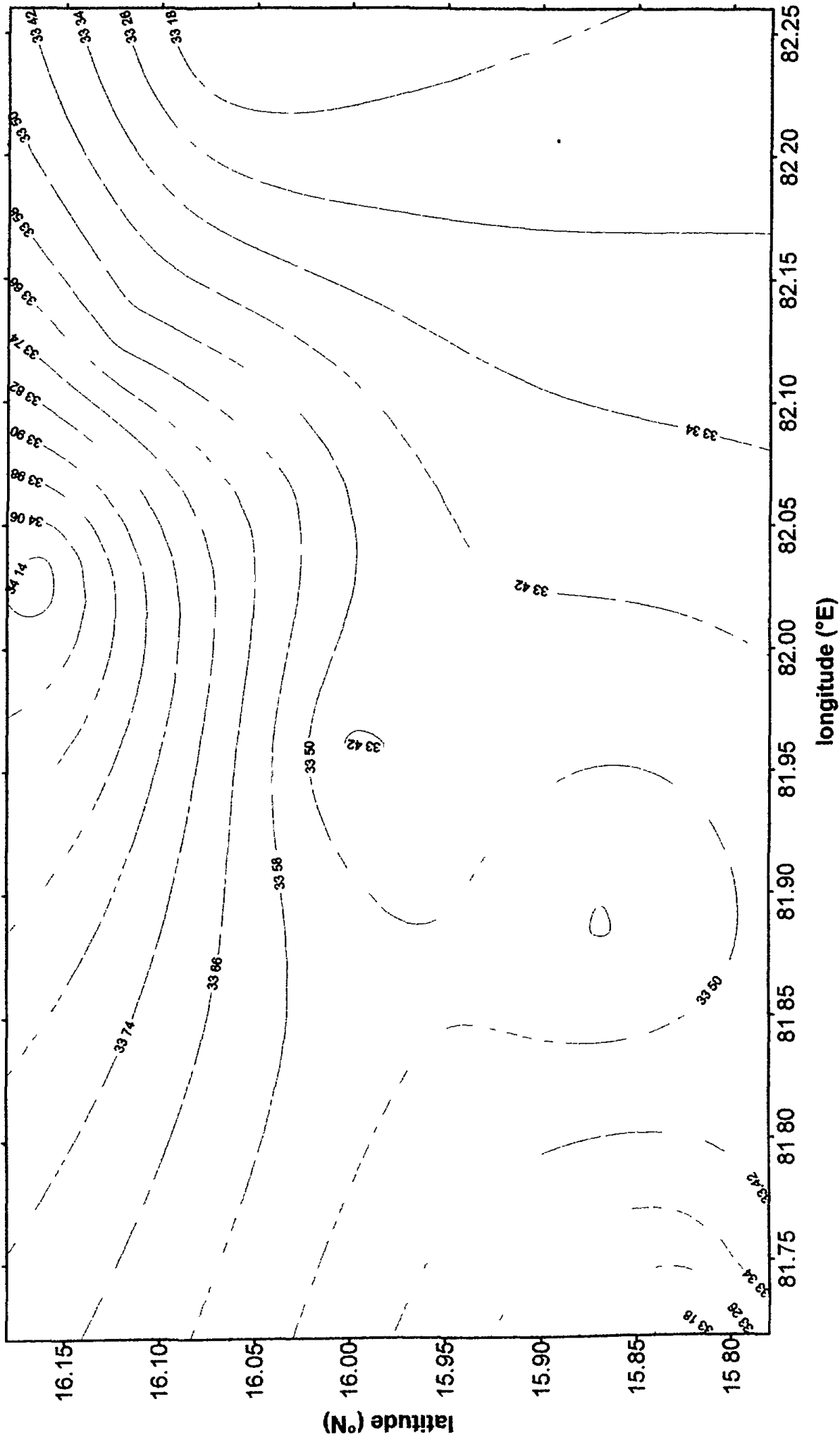
**FIG. 23**

**AASGH4  
(Temperature contour at seabed)**



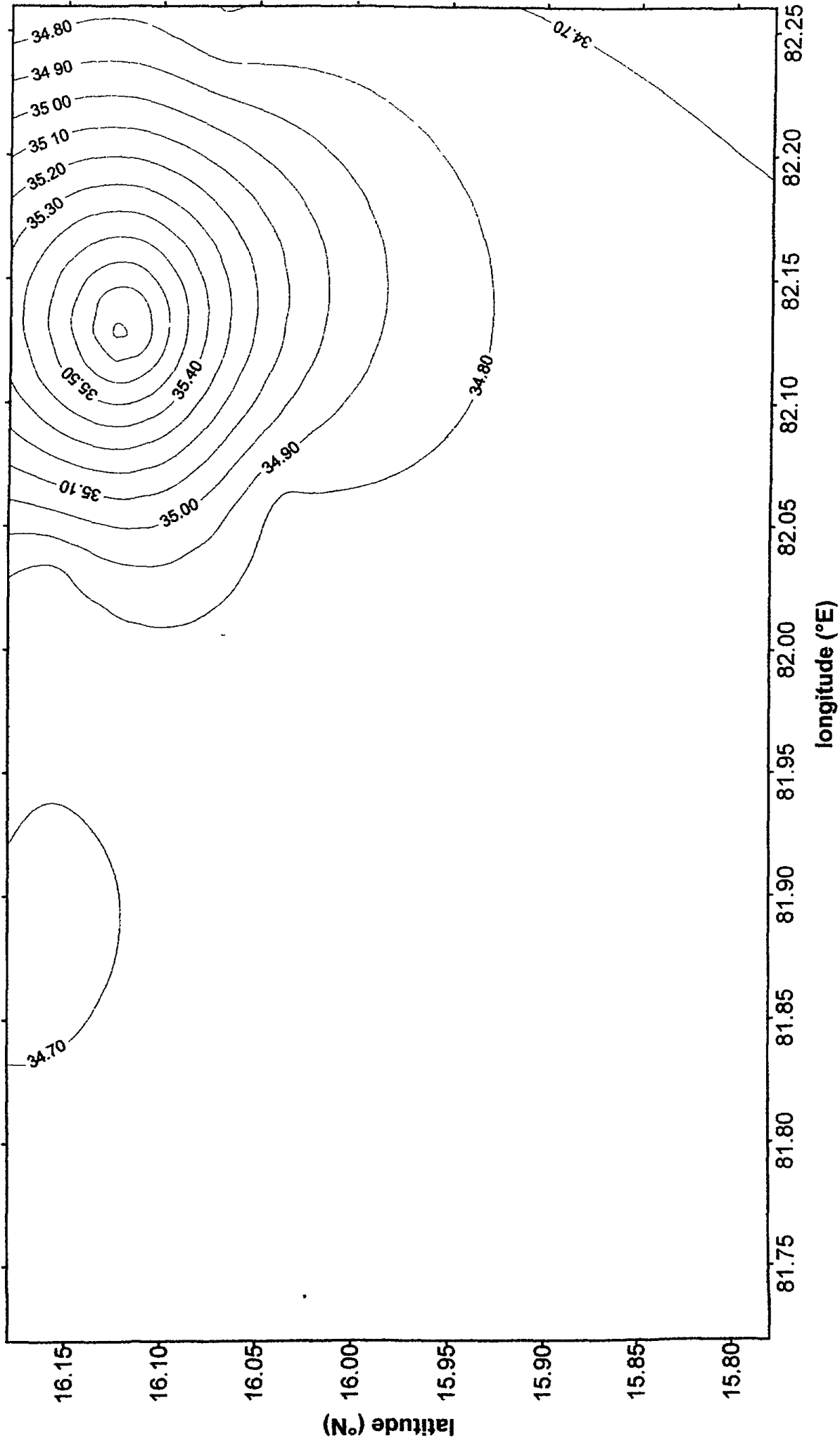
**FIG.24**

**AASGH4**  
**(Salinity contour at 50m depth)**



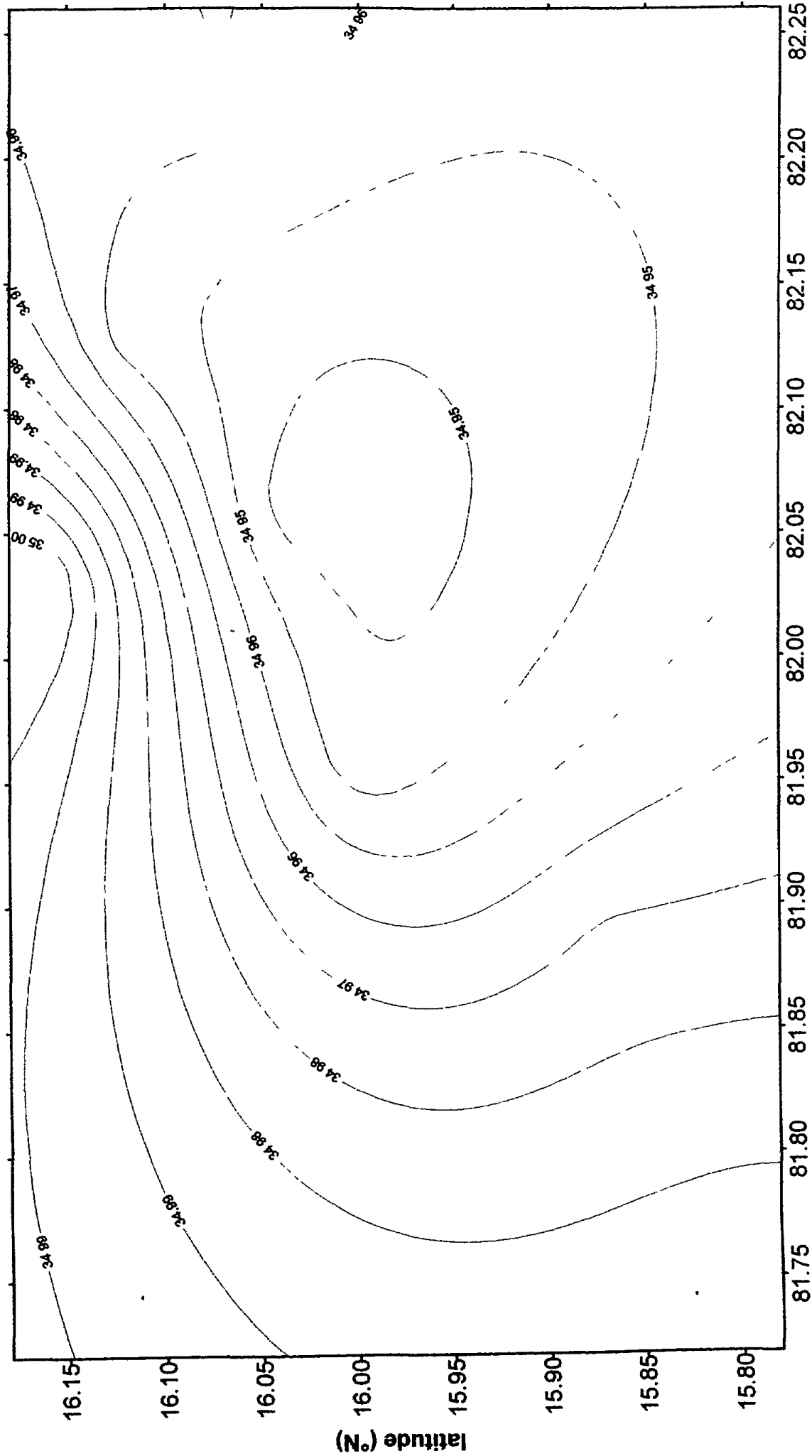
**FIG. 25**

**AASGH4**  
**(Salinity contour at 100m depth)**



**FIG. 26**

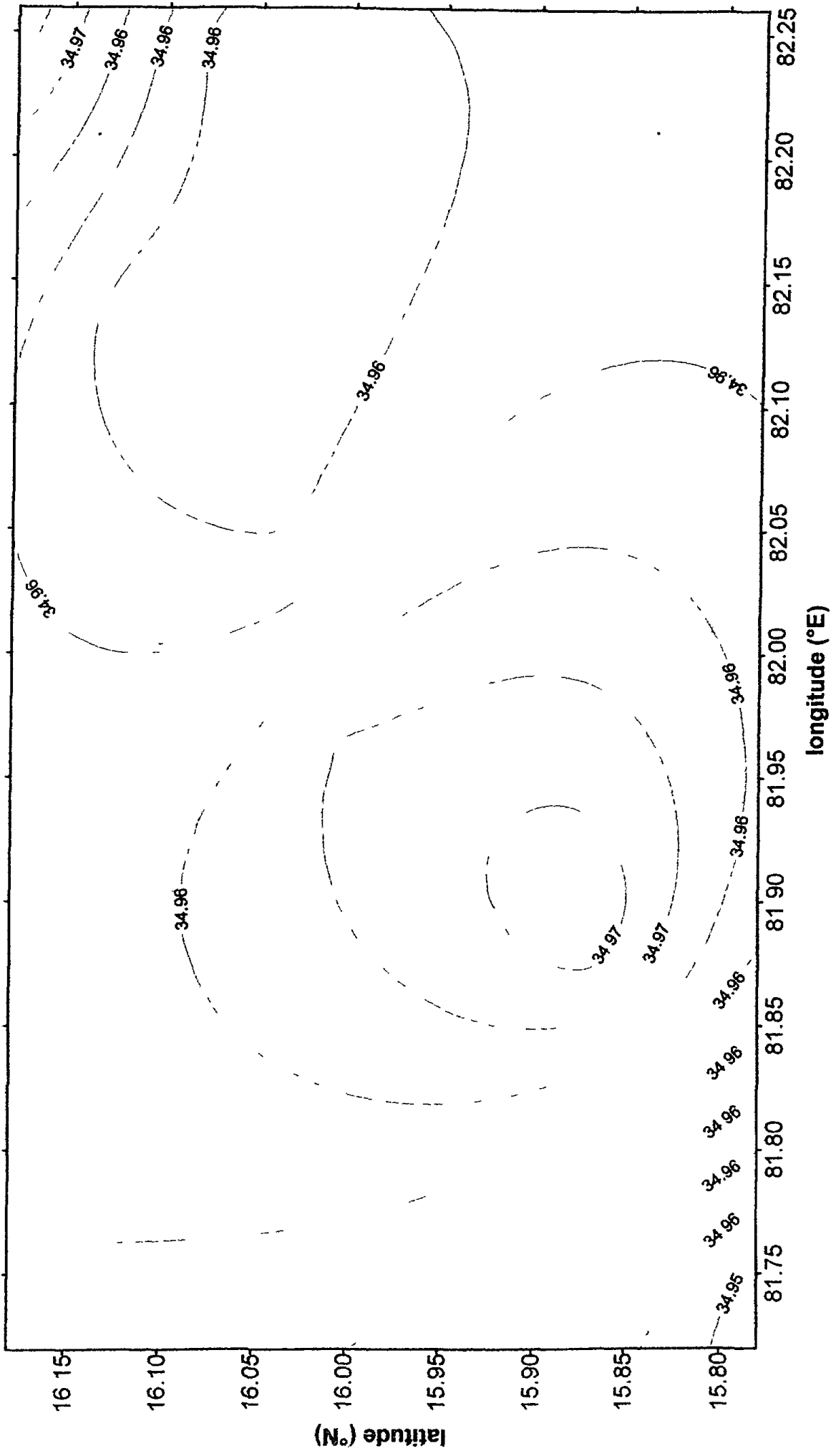
**AASGH4**  
**(Salinity Contour at 200m depth)**



longitude (°E)

**FIG.27**

**AASGH4**  
**(Salinity contour at 811m depth)**

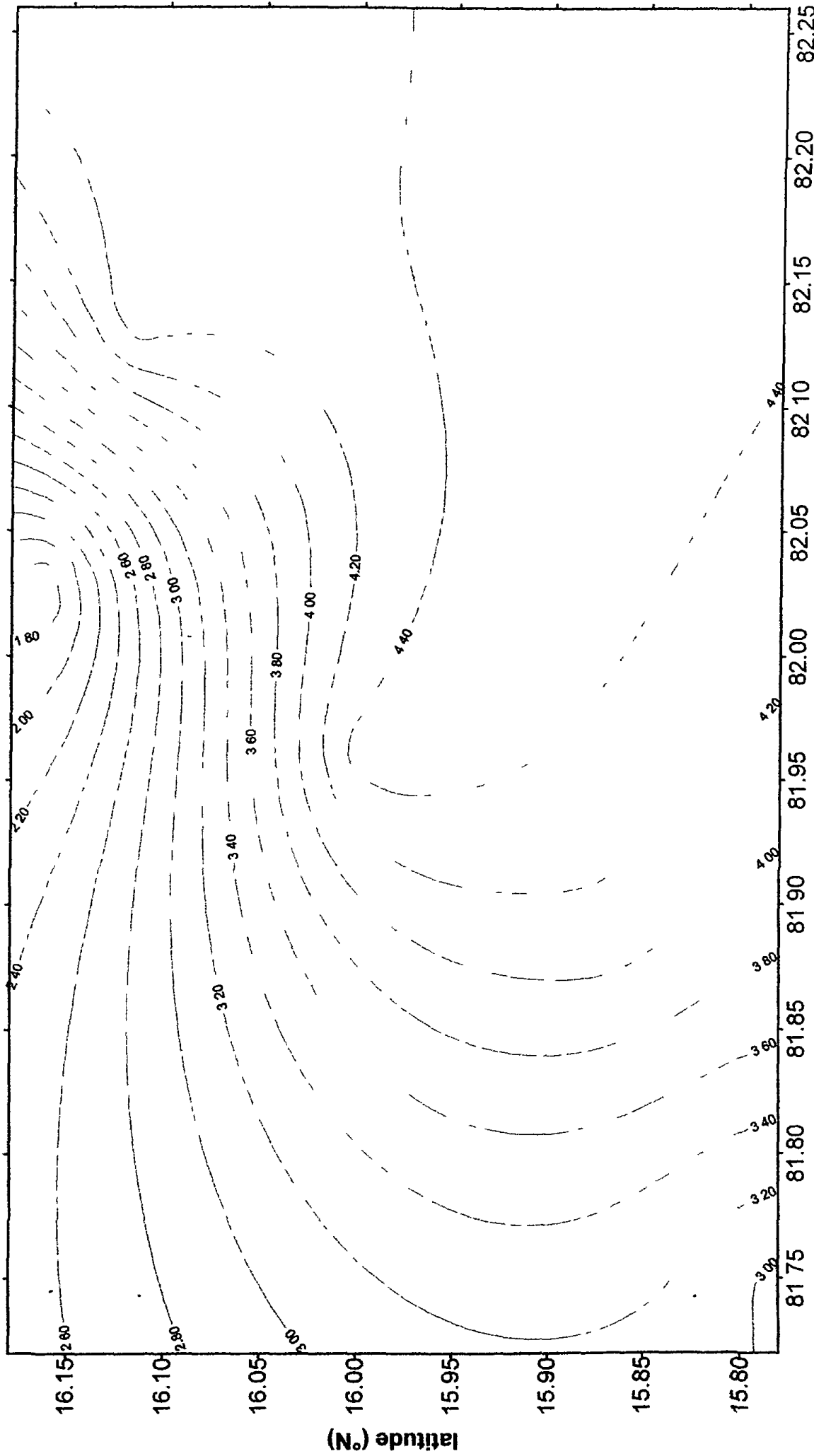


**FIG. 28**





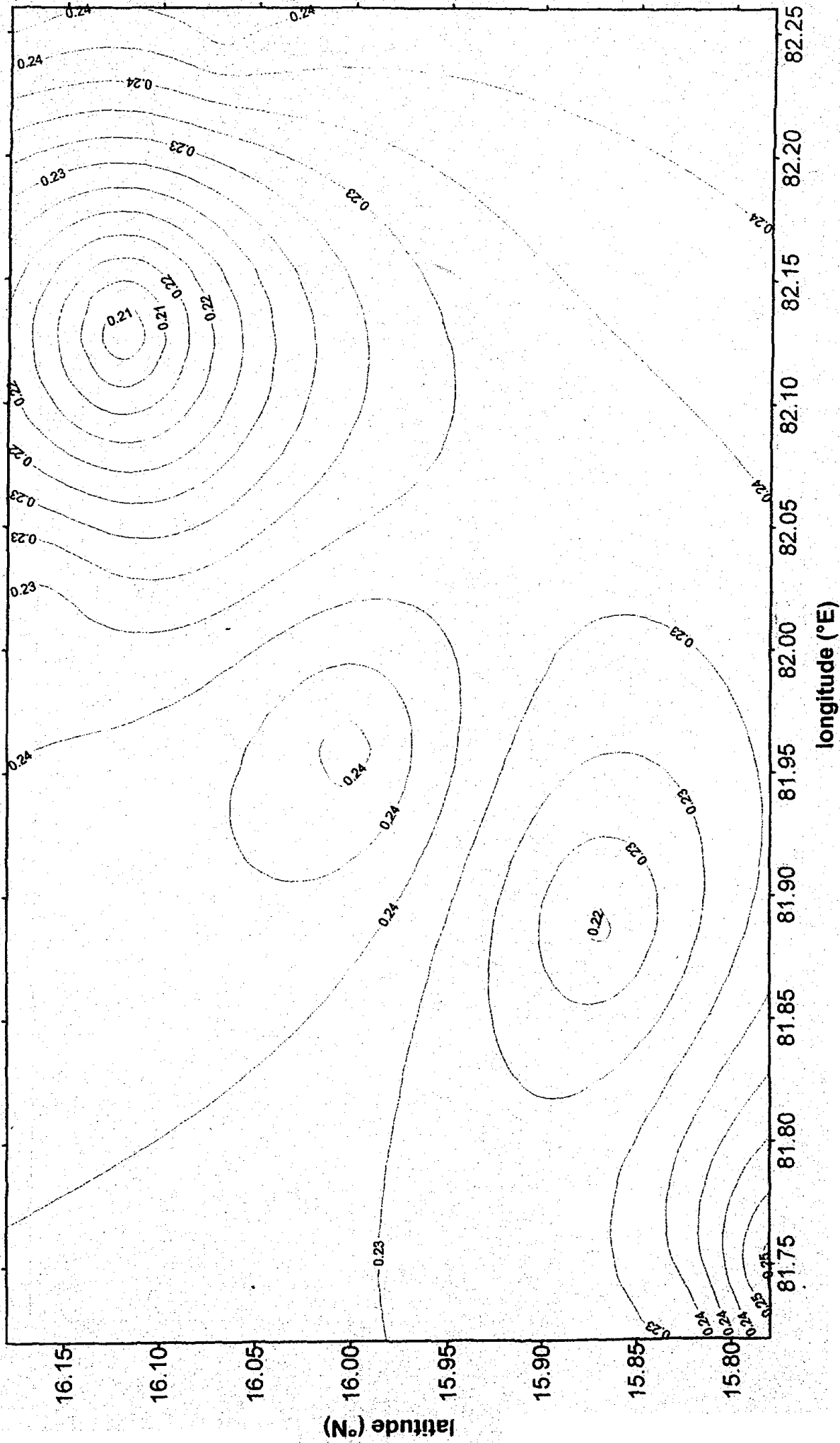
**AASGH4**  
**(Dissolved Oxygen contour at 50m depth)**



longitude (°E)

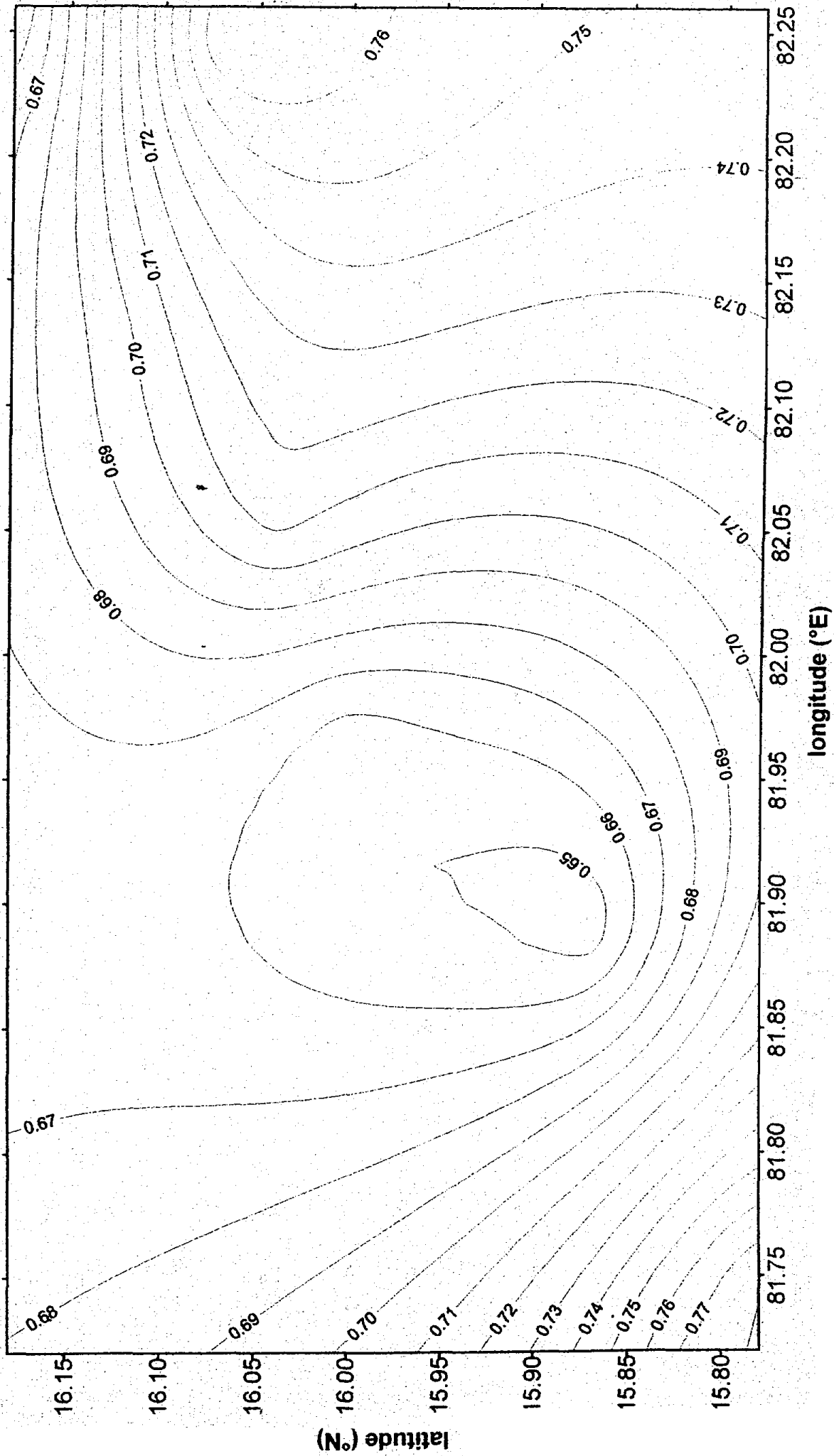
**FIG. 30**

**AASGH4**  
**(Dissolved Oxygen contour at 200m depth)**



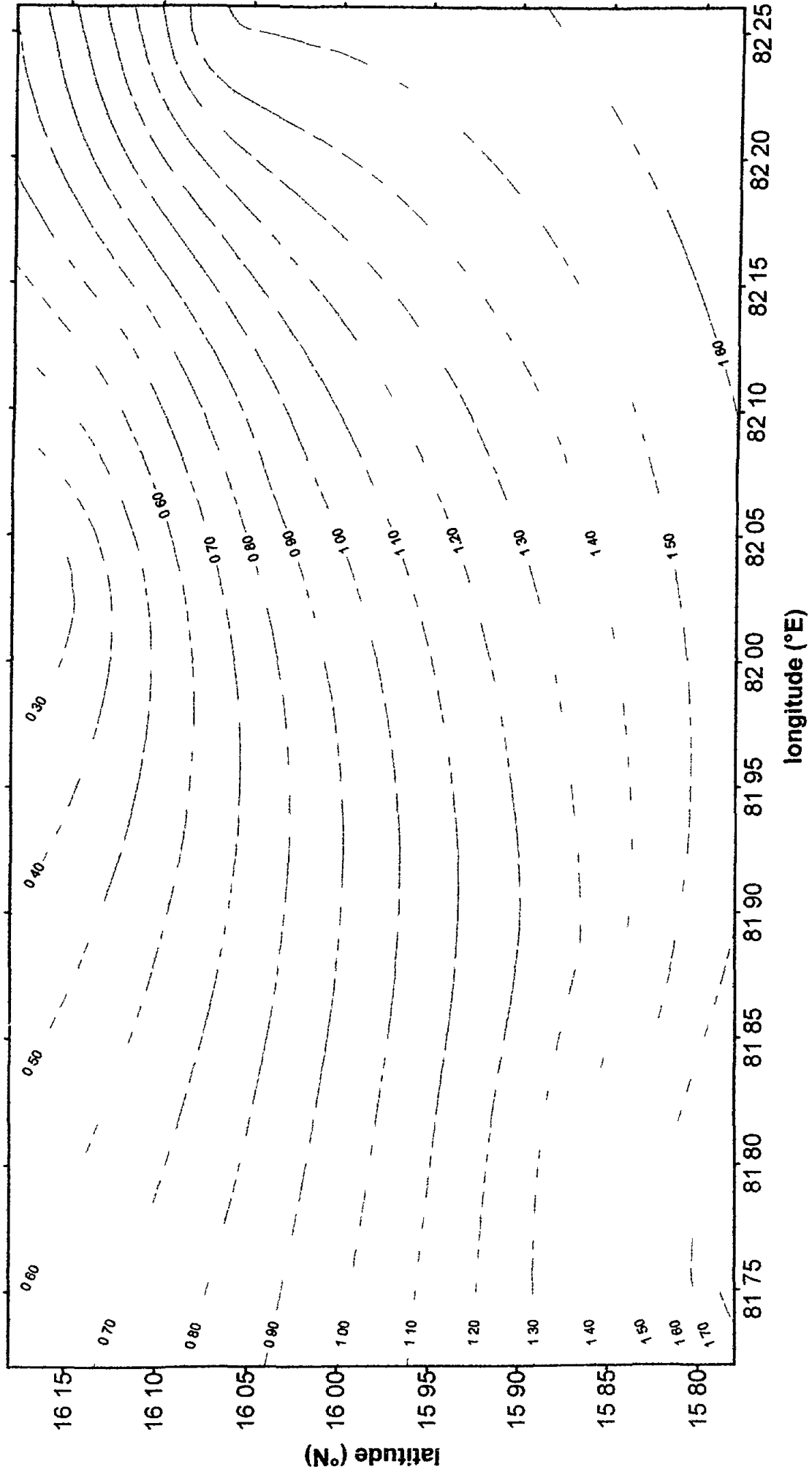
**FIG. 31**

**AASGH4**  
**(Dissolved Oxygen contour at 811m depth)**



**FIG. 32**

**AASGH4**  
**(Dissolved Oxygen contour at seabed)**



**FIG. 33**

