Characteristics of Water in the South China Sea, Area III: Western Philippines

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ABSTRACT

The characteristics of water in the South China Sea from latitude 11° N to 20°N and longitude 117°E to 121°E during 18 April to 8 May 1998 have been studied using Integrated CTD instruments onboard MV. SEAFDEC. It was found that there are six watermasses in the study area and there is upwelling off coast of northern Luzon Island at from the surface down to 200-meters. The water properties are influenced both by northeast and southwest monsoon winds as the duration of survey are during the transitional period, also by outflow from shore. The strong thermocline, halocline and pycnocline are present all over the area.

Introduction

This study is a part of the Interdepartmental Collaborative Research Program in the South China Sea area continuously carried out since 1995. The main objective is to collect and analyze the information necessary for management through collaboration among Southeast Asian Fisheries Development countries and other organizations concerned.

The survey was conducted by MV. SEAFDEC between 18 April and 8 May 1998 using 31 stations off the coast of the Philippines (Figure 1). The study area covers from latitude 11° N to 20° N and longitude 117° E to 121° E, which is about 272,000 square kilometers. The maximum depth reaching to about 5000 m. (Figure 2). The area covers the deep area of the South China Sea (SCS).

The Philippines separates the South China Sea from the Pacific Ocean with a steep continental slope and practically no continental shelf. The sea is connected to the Pacific Ocean by the Luzon Strait, the deepest and widest part having a sill depth of about 2,000 m. There are two narrow, shallow passages to the north and south of Palawan Island connecting the South China Sea to the Sulu Sea.

There are several studies indicating that the major circulation and variability of the water properties field in the South China Sea is driven by the monsoon winds (Shaw and Chao (1994), Nasir *et al.* (1997), Uu and Brankart (1997) and *etc*.). In the SCS, the wind prior to September is dominated by the southeast monsoon. The northeast monsoon begins to appear north of 20° N in September while south of that latitude, the southwest monsoon still prevails. The northeast monsoon is expanding southward against and decreasing the southwest monsoon in October. In December the northeast monsoon reaches its maximum strength and covers the entire SCS in December. The end of the northeast monsoon is in April. The southwest monsoon first appears in the central parts of the South China Sea in May and expands over the entire basin during July and August.

Another circulation pattern is the Kuroshio intrusion through the Luzon Strait below 100

m. and Pacific intrusion at depths between 1,500 and 2,000 m. This circulation pattern is significant only along the northern areas of the SCS and coincides with the appearance of the northeast monsoon (Uu and Brankart 1997)

This survey period is in the transition between northeast and southwest monsoon. At that time the survey the northern part was influenced by the northeast monsoon while the southern part was dominated by the southwest monsoon.

D.V. Uu and J. -M. Brankart, 1997 indicated watermasses in SCS from the analysis of a three – dimensional thermohaline structure where there are two types of water. The first permanent and the second seasonal. There are four permanent masses, two masses in the upper mixed layer: Open Sea Water (OSW) and the continental shelf waters (CSW). The third is exhibits maximum salinity water (MSW) and the fourth is deep water (DW). The seasonal masses exist only during some parts of the season. There are two seasonal watermasses in the SCS. The first is the water of the northern part of the open sea during winter (Northern open sea during winter, NOSW). The second is a water mass from the Pacific Ocean (POW).

The particular objective of this project is to find the characteristics of the water in the study area during the survey period and to provide principal data to other researchers in the collaborative survey-working group.

Methods

Hydrographic data were collected using the onboard Falmouth Integrated CTD instrument with conductivity, temperature, pressures, dissolved oxygen, fluorescence and pH sensors. (In this paper the fluorescence and pH data was excluded) According to the manufacturer's specification, the instrument has an accuracy of ±0.003 mmhn. , ± 0.003 c, ± 0.03% and ± 100 ppm. for conductivity, temperature, pressure and dissolved oxygen respectively. The CTD was equipped with twelve 2.5 liter bottles for *in situ* water sampling. Dissolved oxygen in the water samples was determined by a modification of the Winkler procedure (Parsons, Maita and Lalli, 1984) for the calibration of dissolved oxygen data. The oxygen calibration procedures are given in the catalogue of oceanographic data, area III: off the West Coast of the Philippines. Calibration of conductivity, temperature and pressure sensors were not performed due to the lack of a suitable precision calibration instrument. The CTD unit was last sent for calibration and deck testing by the manufacturer in April 1997.

Because of the length of the armored sea cable, the maximum depth for CTD casting was limited to a depth of about 1500 meters. The efficiency of the oxygen sensor is limited for shallow water, the lowest dissolved oxygen data collecting depth was not reached nor the depth for temperature and salinity.

Raw counts of each variable were calculated and raw data were averaged at every 1 dbar interval using the FSI post acquisition data analysis software.

Because sea conditions vary such that the start point for measurement is problematic, the start point was taken as being 10 meters.

Results and discussions

Temperature distribution

The sea surface temperature of the area is increases from 28.0° c in the higher latitudes to 30.9 °c at the lower latitudes. The exceptions are at the station off the northern coast of Luzon

Island near stations. 5, 7 and 10 and the station near the passage between the South China Sea and Sulu Sea, these stations show a lower temperature than other stations in the survey pattern at the same latitude (Figure 3). At 500 m., the temperature gradient decreases from the surface down while the pattern of temperature distribution remains the same (Figure 4). The distribution of temperature at 1000 m. is homogeneous all over the area. (Figure 5). The characteristics of the temperature at 10, 500,1000 and 1500 are 28.45-30.4 °c, 8.1-8.6 °c, 4.3-4.45 °c and 2.8-2.9 °c respectively (Figure 6,7 and 8). The strongly defined thermocline, which is a character of equatorial water, is present at between 30-150 m depth. At the shallow stations, the thermocline is still present but shallower and narrower than the deeper areas.

Salinity distribution

The interval of sea surface salinity in the study area is 33.7-34.6 p.s.u. Salinity distributions at the northern part near station 5,7 and 10 are higher than in adjacent areas where it was found to be about 0.1-0.2 p.s.u. The highest surface salinity area was found near the passage between the South China Sea and Sulu Sea. The lowest was located near the shore off the middle of Luzon island and in the vicinity of station 27, 29 and 30, which may be the influence of less saline water from Manila bay and Palawan Island. (Figure 3,10 and 11). Small salinity gradients were found at 500 m. and 1000 m. depth (Figure 4 and 5). The halocline zone that is present between 20-150 m., and which resembles the thermocline zone being at similar depths. There is an exception in the area, which has the highest sea surface salinity at the upper layers and a shallow halocline. The intrusion from Sulu Sea may have an influence on this area.

There is a maximum salinity layer between about 100-200 meter depth, which is a characteristic of the equatorial regions (Figure 6,7,8,9,10 and11). Salinity profiles (Rojana-anawat *et.al, 1998*) show that the upper limit of the halocline zone is below the mixing zone and the lower limit is at the highest salinity depth. The sea at 10, 500, 1000 and 1500 are dominated by water at 33.8-34.2 p.s.u. , 34.4-34.5 p.s.u. , 34.6-34.7 p.s.u. and 34.6 p.s.u. respectively.

Density distribution

The distribution of sea surface density can be described roughly by starting that the value of sigma theta ($\sigma\theta$) and are in the range of 20.6-21.7 kg/m^3. As the density depends upon by temperature and salinity, the highest density areas were found at the surface near stations 5,7 and 10 and around stations 23 and 24 and had a lower temperature and higher salinity than the nearby waters (Figure 3). Density distribution at 500 m. and 1000 m. are shown in figures 4 and 5, respectively. The pycnocline was also found at all stations at similar depth to the thermocline and halocline. The characteristics of sigma theta at 10, 500, 1,000 and 1,500m.depth are 20.8-21.6 kg/m^3, 26.7-26.8 kg/m^3, 27.4 kg/m^3 and 27.6 kg/m^3 respectively. Vertical cross sections of sigma theta are shown in Figures 6,7,8,9,10 and 11.

Oxygen distribution

Lower concentrations of dissolved oxygen were found at the surface in the northern part of the area while at the southern part it was found to be a little higher (Figure 3). The high oxygen concentrations were present in the upper layers from the surface down to about 100 m. The occurrence of oxyclines are at about 80-120 meter from (Figures 6,7,8,9,10 and 11). Lower oxygen concentrations at the upper layer of water was found between station 5,7 and 10 (Figure 6).

Watermasses

The characteristics of the watermasses are identified following the study of D.V. Uu and J.M. Brakart (1997) and the watermasses of the Pacific Ocean (Pickard and Emery, 1990). The upper mixed layer of the area during the survey period, open sea watermass, (OSW) occupied about 85% of the surface area and at about 0-30 m. depth (Figures 3,6,7 and 8). The open sea watermass was characterized by salinity between 33.5 –34 p.s.u. , and temperatures between 27-30 °c.

The depths between 50-100 m. are dominated by the mixed water between the northern open sea during winter (NOSW) and the Pacific Ocean water (POW). This coincides with the study of D.V. Uu and J. -M. (1997) that postulates that at the end of the winter monsoon of northeastern part of the SCS, the surface occupied by NOSW decreases with the decrease of the northeast monsoon and mixes with the POW until the summer monsoon. This was confirmed during this survey. NOSW was characterized by temperatures of less than 25 °c to about 23 °c and salinity variations from 34.0 to 34.5 p.s.u. , while temperature and salinity of the POW are about 25-27 °c and 34.0-35.0 kg/m^3 respectively. In the areas of stations 2 and 3, which are at the passage between the SCS and the Pacific Ocean, these are dominated by NOSW indicated by high salinity.

The maximum salinity water (MSW) which was indicated by temperature between 15-17 c and salinity from 34.5 – 35.0 p.s.u., at about 100-200 m. depth.
Beneath the MSW to about 1000 m. is the location of the mixing water between North Pacific Intermediate Water and Pacific Equatorial Water with temperatures of about 5-13 °c, salinity from 34-35 p.s.u. The T-S diagram of station no.2 (Figures 12 and 13) shows the difference from the others by having the lowest minimum salinity (34.42 p.s.u.) at about 500 m. this means that this area is dominated by the North Pacific Intermediate water, which is evident from the salinity minimum.

The last watermass is the deepwater (DW) with temperatures varying from 2-5 °c, and salinity between 34-35 p.s.u. at depths below 1000 m.

Table 1. Characteristics of the water masses.

Watermass	Salinity (p.s.u.)	Temperature (°c)	Depth (m)
Open sea water (OSW)	33.5-34.0	27-30	0-30
Northern open sea during winter (NOSW)	34.0-34.5	23-25	50-100
Pacific Ocean water (POW)	34.0-35.0	25-27	50-100
Maximum salinity water (MSW)	34.5-35.0	15-17	100-200
Mixing of north Pacific intermediate water and Pacific equatorial water			34.0-35.0
5-13	200-1000		
Deep sea water (DW)	34.0-35.0	2-5	<1000

*The table was modified from the study of D.V. Uu and J.M. Brankart 1997

Upwelling

The occurrence of cooler and more saline water at the surface between stations 5,7 and 10 (Figure 3) indicate that this area is influenced by upwelling, which generally is the reason for the high biological productivity. This was emphasized by the vertical distribution of water properties shown in figure 4, which has an influence on the area from the surface down to about 200 meters. It is in agreement with the study of P. –T. Shaw and S. –Y. Chao (1994) that there is upwelling at the eastern boundary of the South China Sea while downwelling is present off the coast of Vietnam during the northeast monsoon period.

Conclusion

1. There was an occurrence of upwelling at the northern part of the area during the survey period, which may be an influence of the northern monsoon wind.
2. The strong thermocline halocline and pycnocline, narrow mixing layer and the maximum salinity layer at about 100-200 meter depth are the dominant characteristics of the waters in the area.
3. The properties of the water during the survey period influenced by the transition between the northeast monsoon and southwest monsoon wind and outflow from the shore.
4. There is unusual water with lower temperatures, higher salinities and concentration of dissolved oxygen and with a narrower halocline at the station near the passage between the South China Sea and the Sulu Sea. This water may be influenced by the Sulu Sea waters.
5. Six watermasses were found during the survey period.

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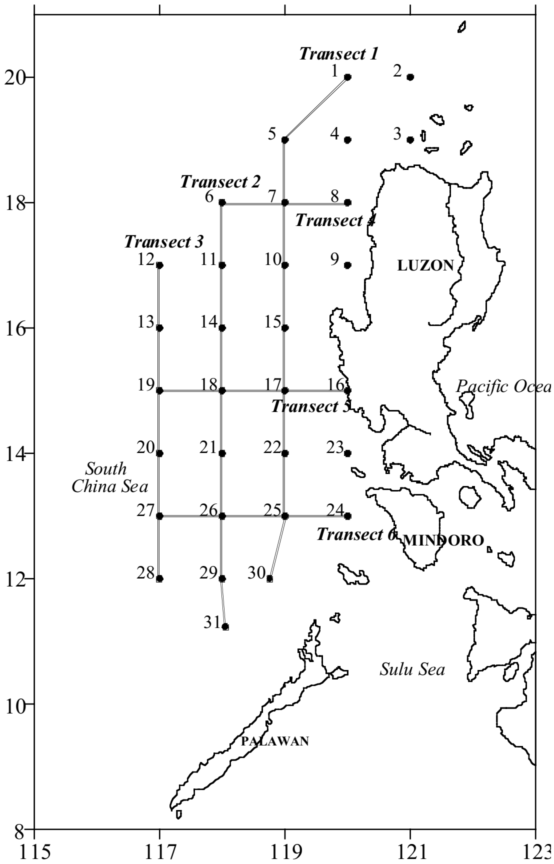

Fig. 1. All sampling station and six selected transects.

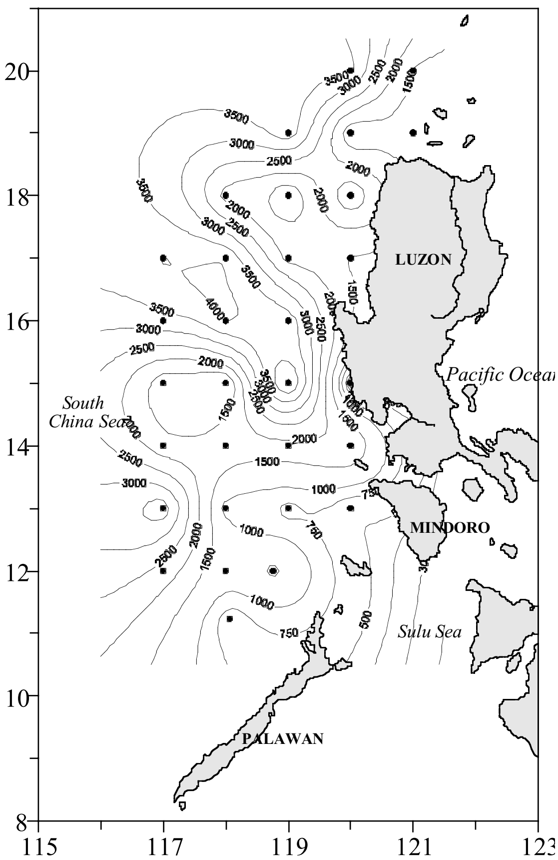

Fig. 2. Depth contour (m) of the study area.

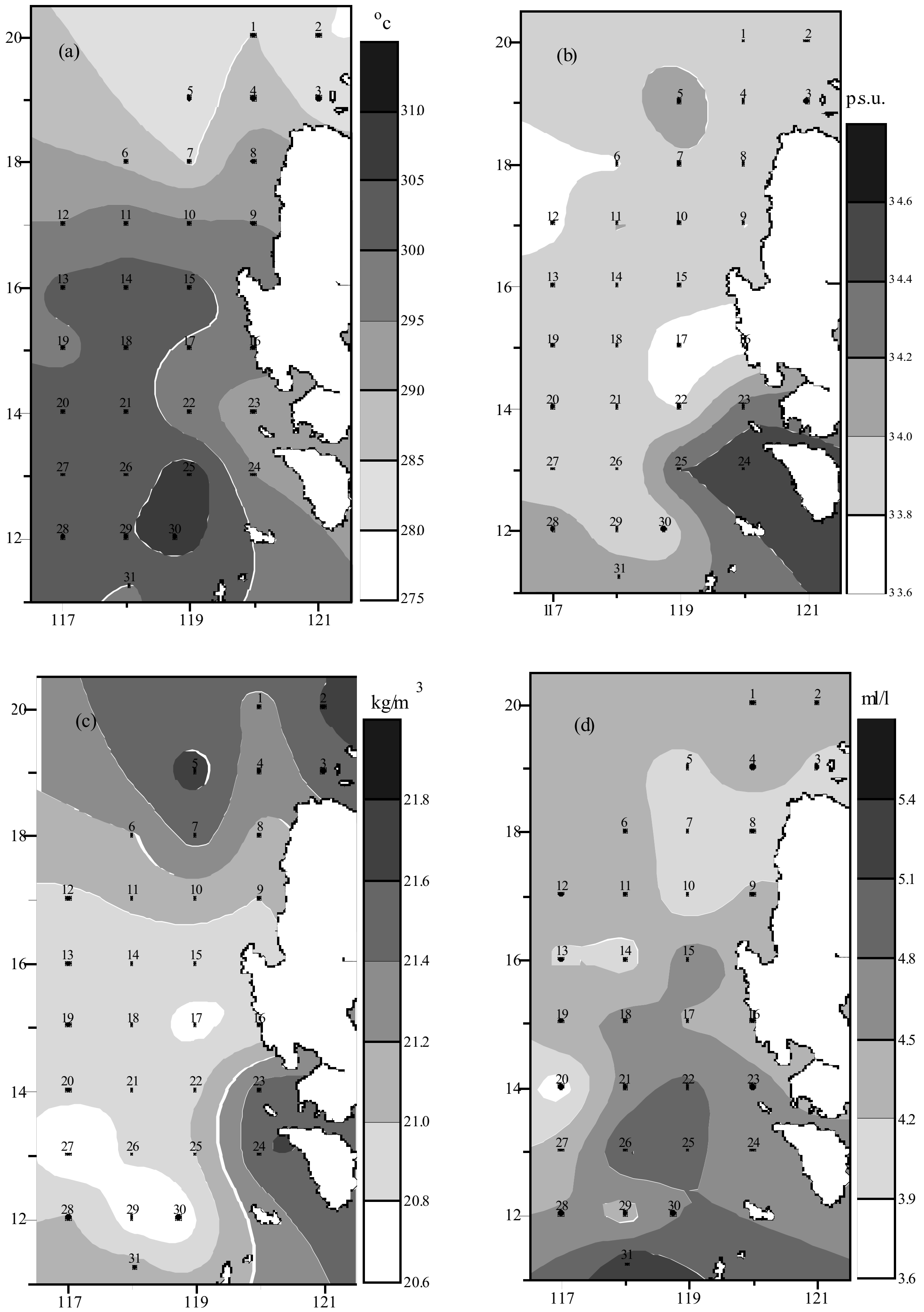

Fig. 3. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m³) and dissolve oxygen (ml/l) at surface (10 m.).

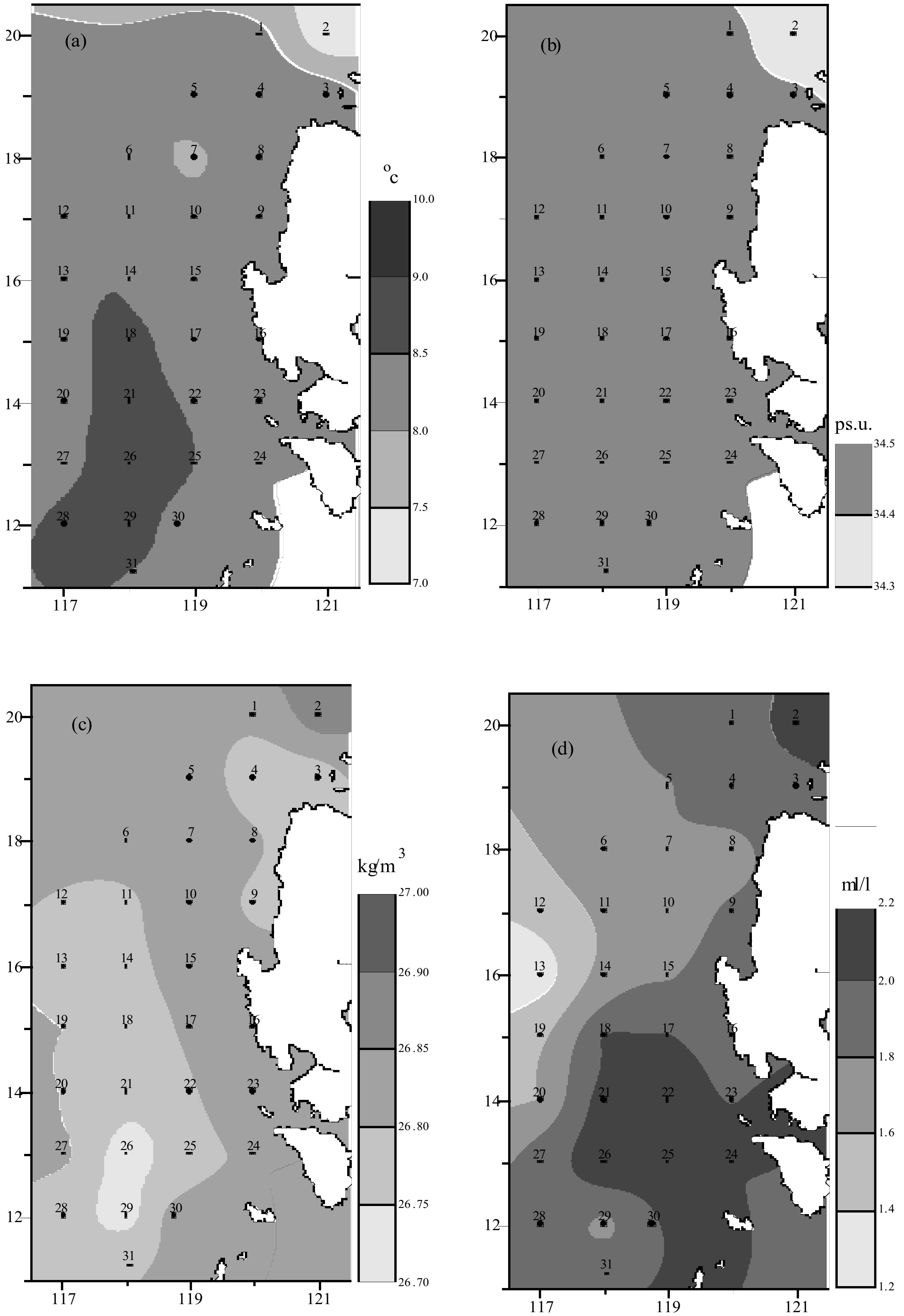

Fig. 4. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m³) and dissolve oxygen (ml/l) at 500m.

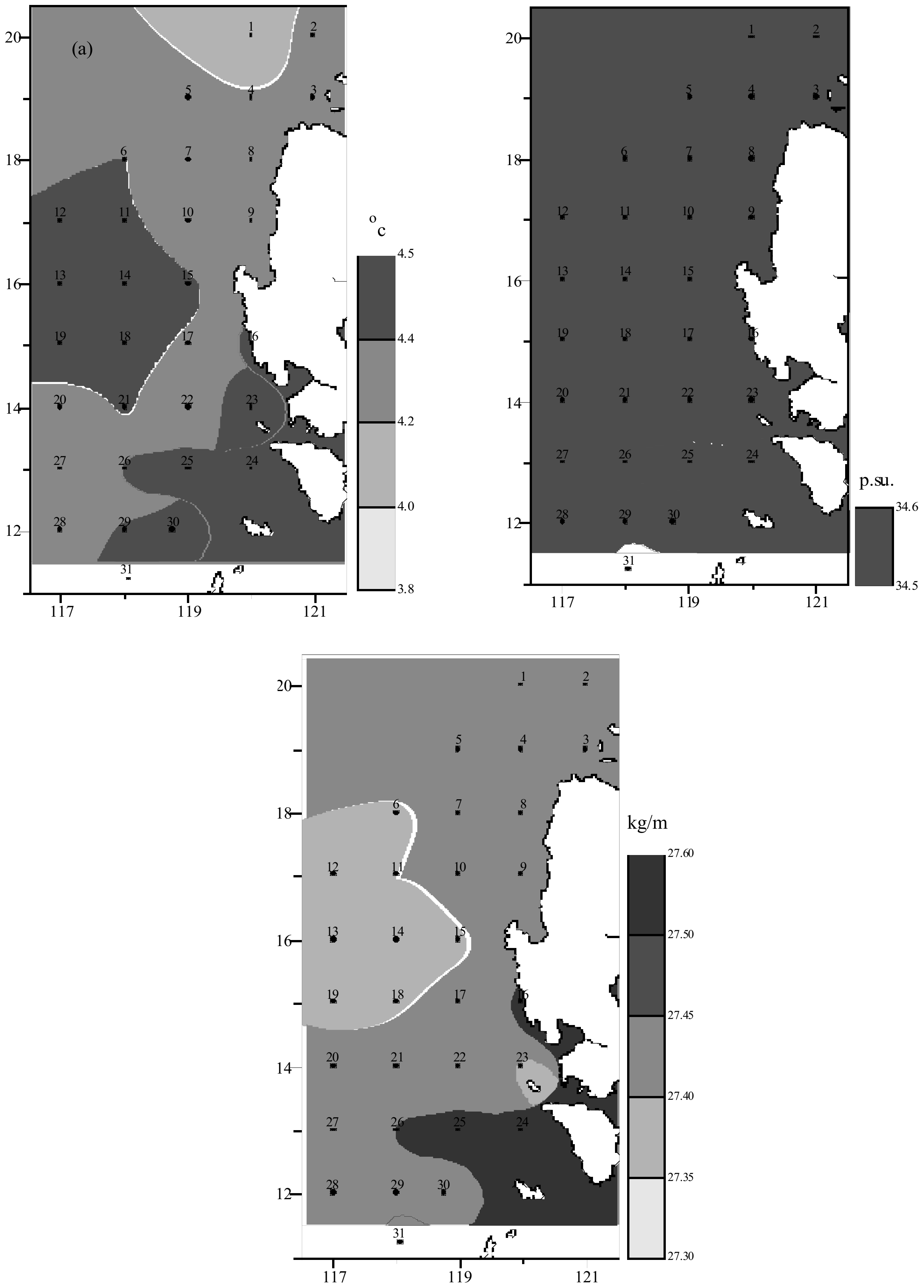

Fig. 5. Distribution of temperature (°c), salinity (p.s.u.) and density (kg/m^3) at 1000 m.

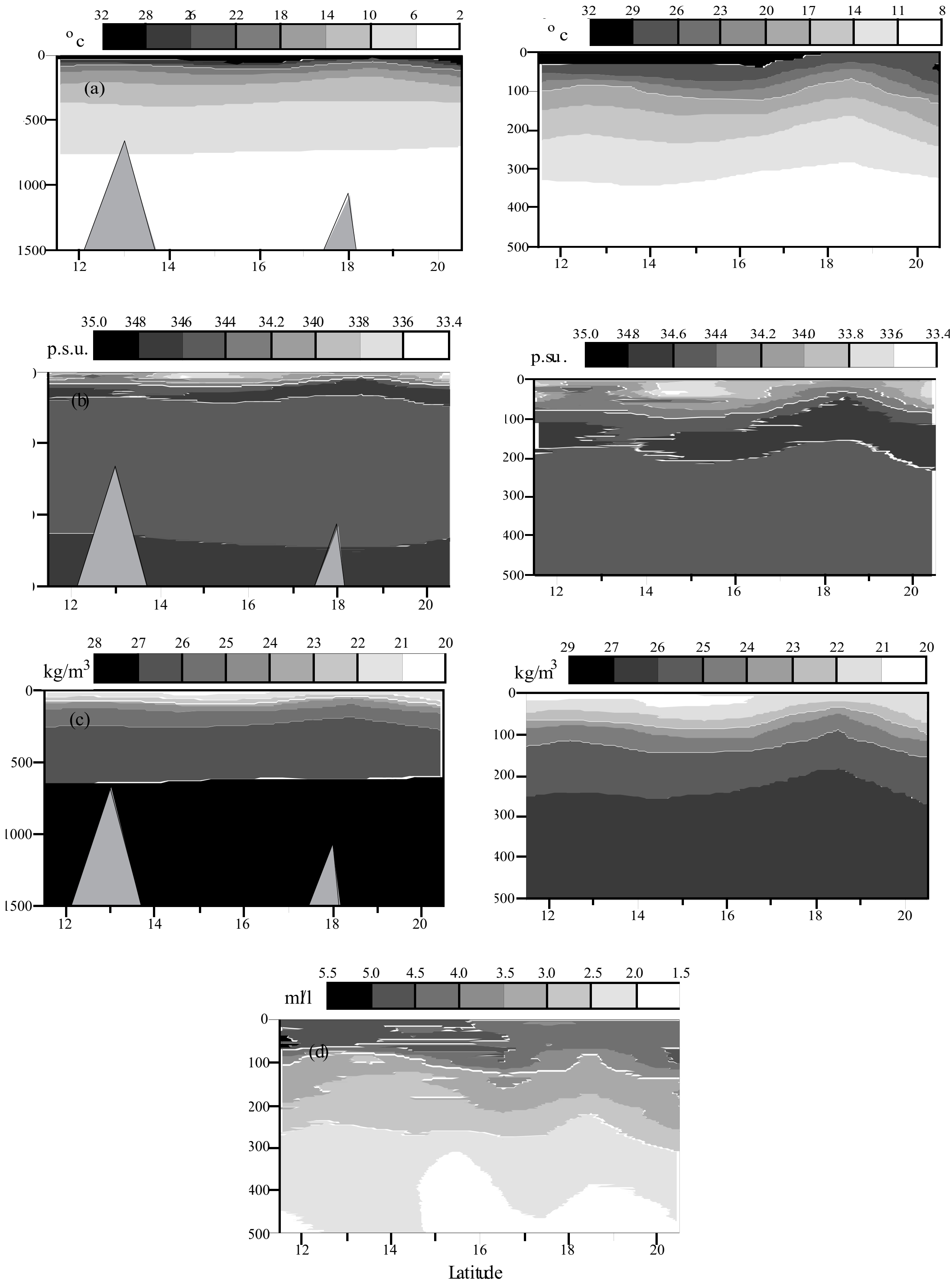

Fig. 6. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m³) and dissolve oxygen (ml/l) from sea surface to 500 m. and 1500 m. along transect 1.

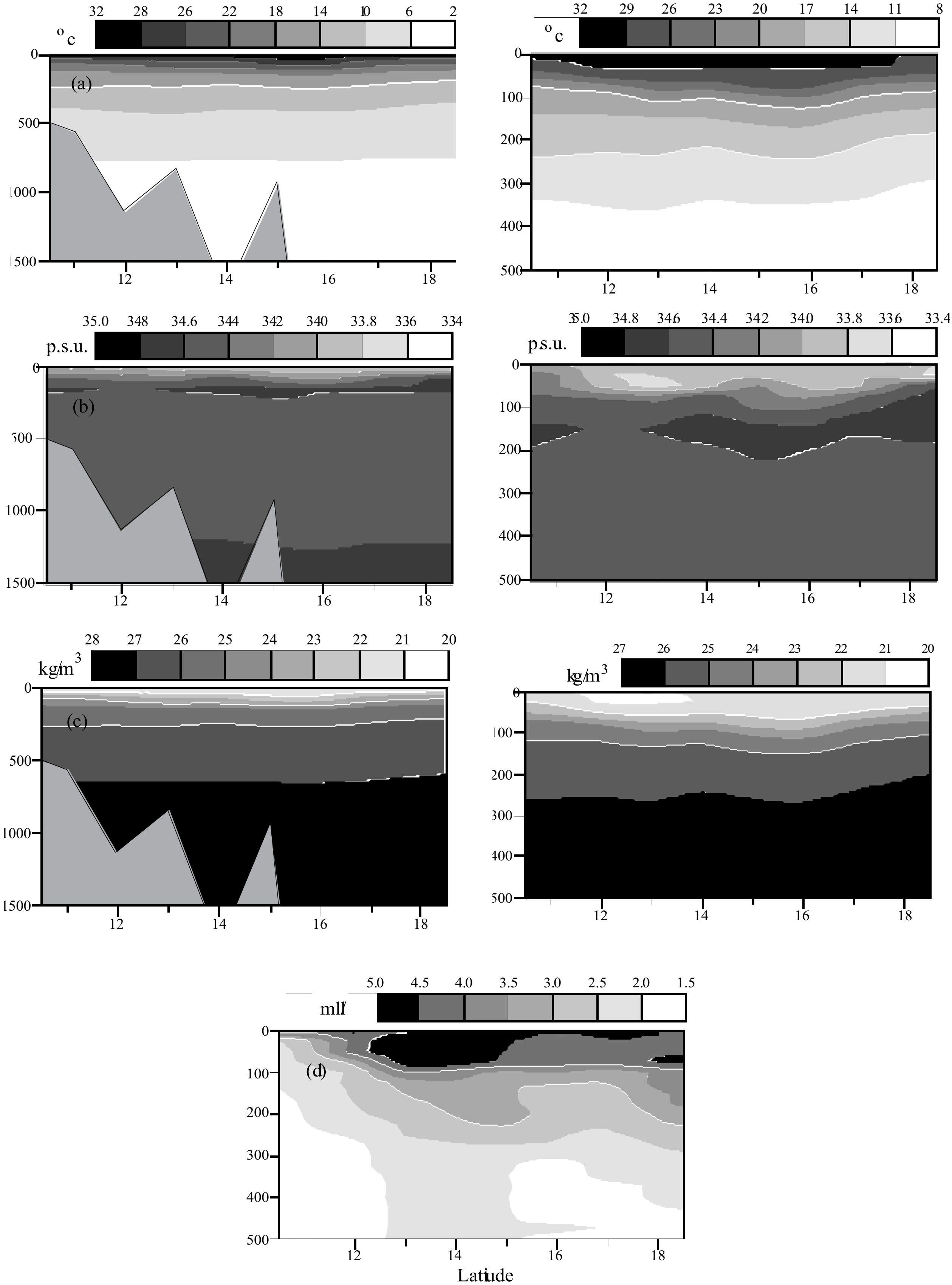

Fig. 7. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m^3) and dissolve oxygen (ml/l) from sea surface to 500 m. and 1500 m. along transect 2.

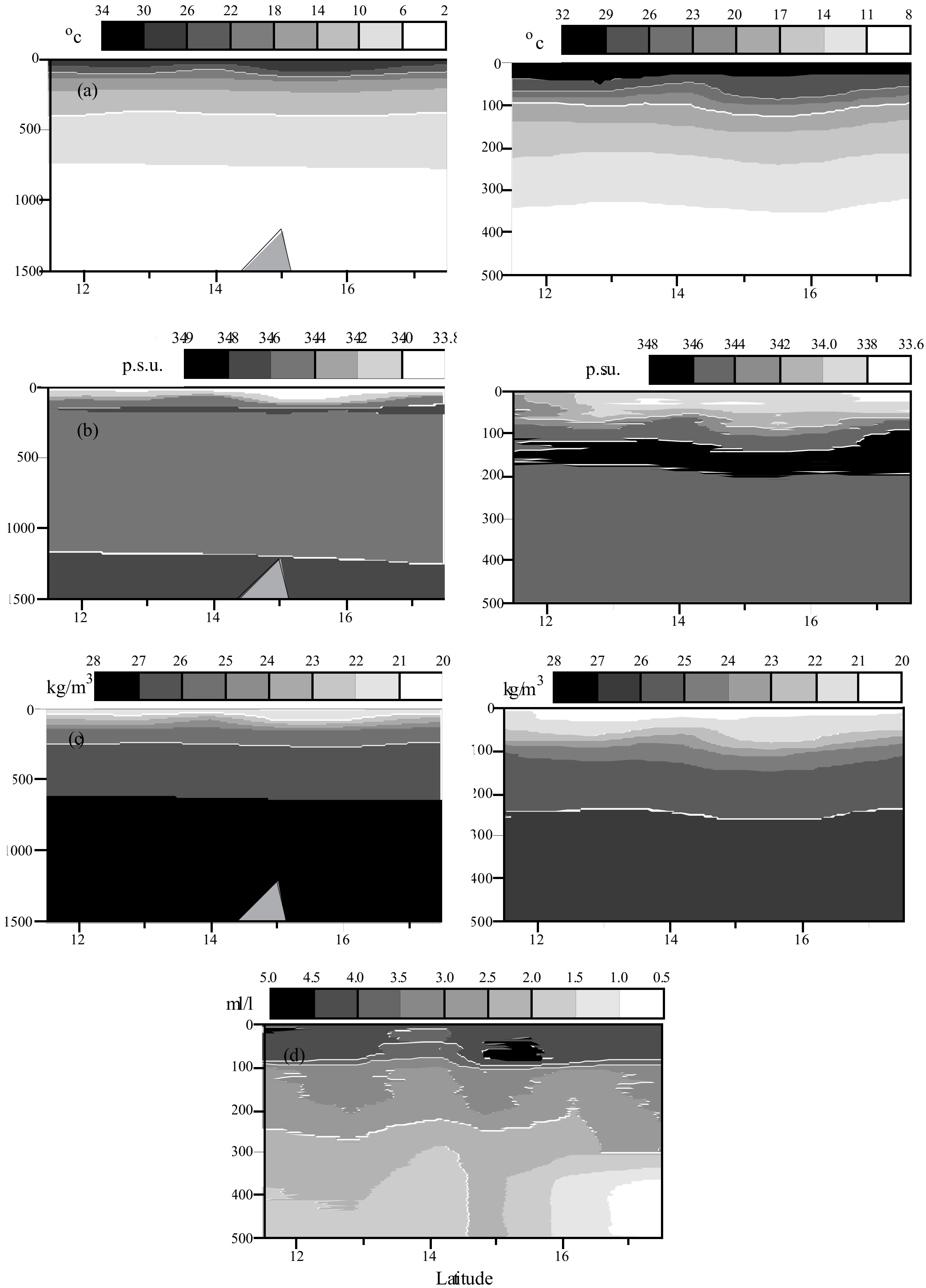

Fig. 8. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m^3) and dissolve oxygen (ml/l) from sea surface to 500 m. and 1500 m. along transect 3.

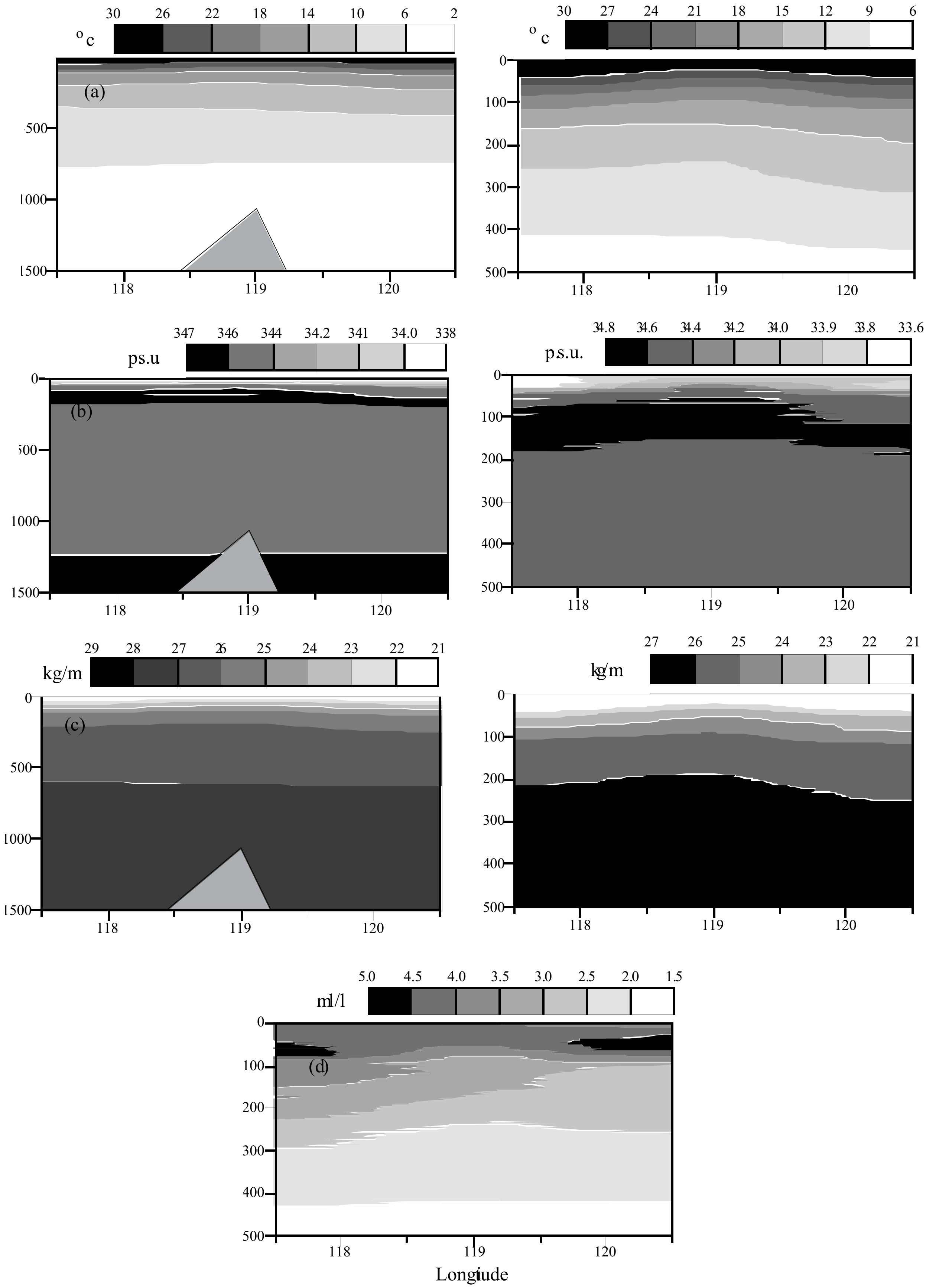

Fig. 9. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m^3) and dissolve oxygen (ml/l) from sea surface to 500 m. and 1500 m. along transect 4.

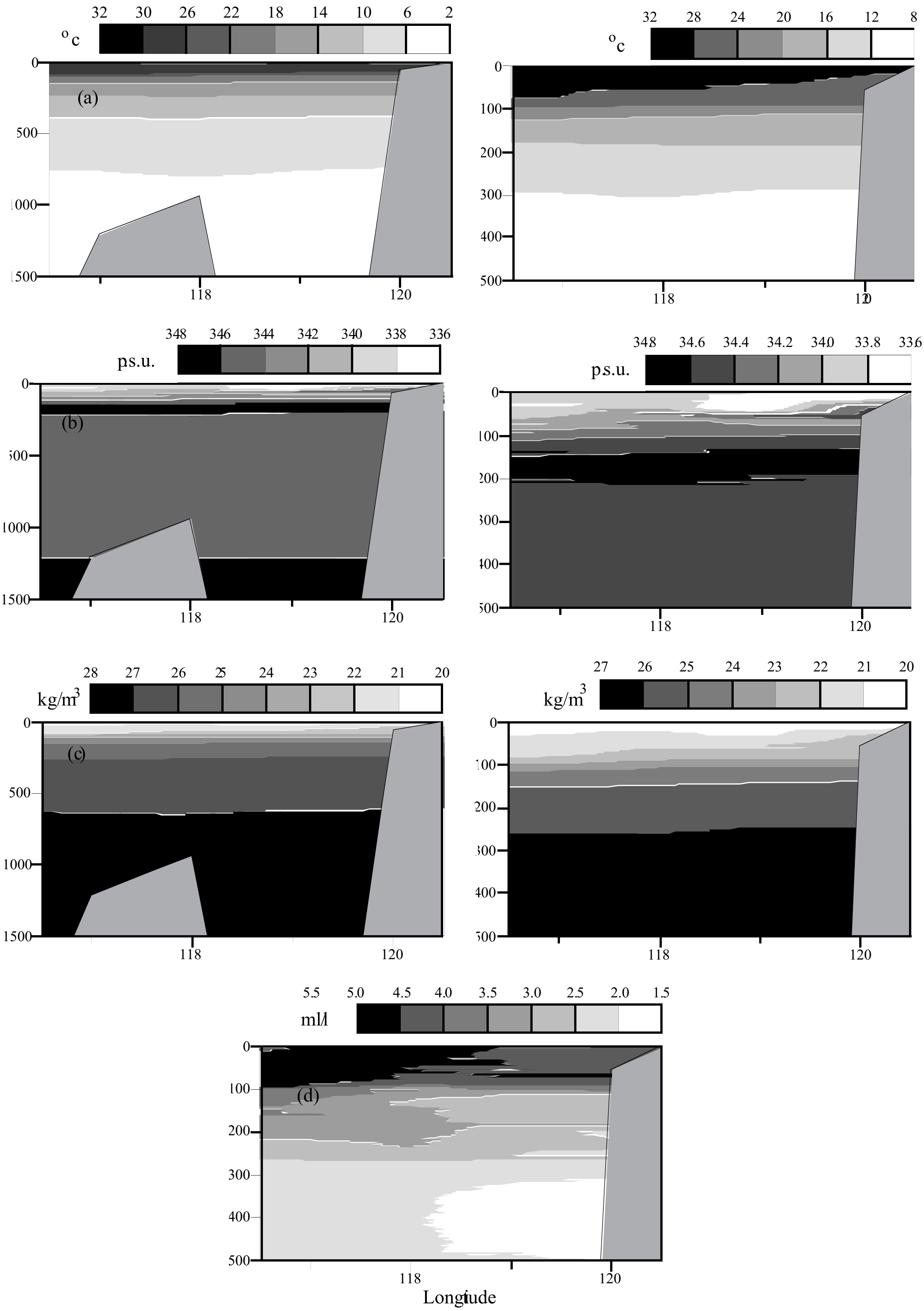

Fig. 10. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m^3) and dissolve oxygen (ml/l) from sea surface to 500 m. and 1500 m. along transect 5.

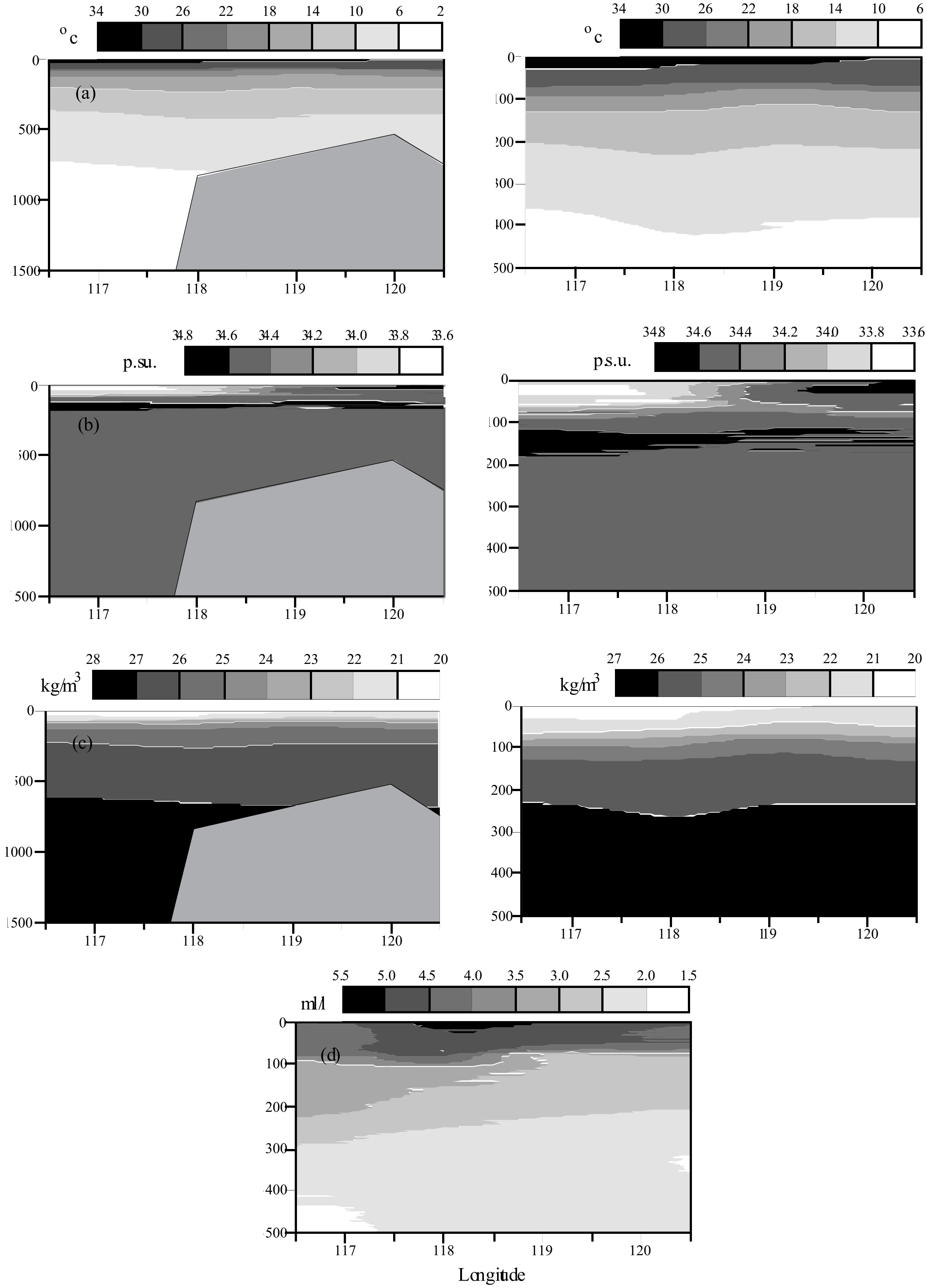

Fig. 11. Distribution of temperature (°c), salinity (p.s.u.), density (kg/m³) and dissolve oxygen (ml/l) from sea surface to 500 m. and 1500 m. along transect 6.

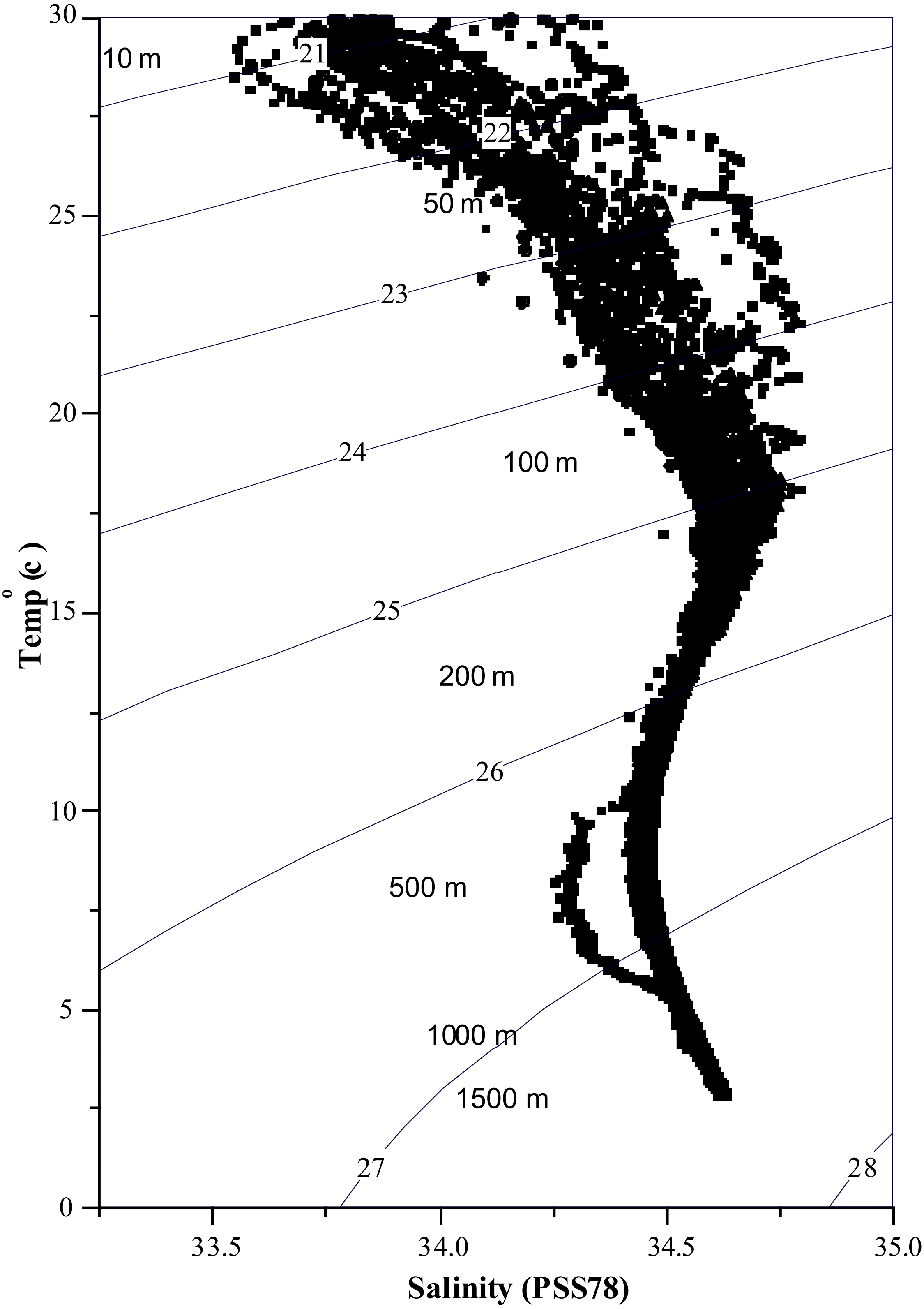

Fig. 12. T-S scatter plot of all the station deeper than 500 m.

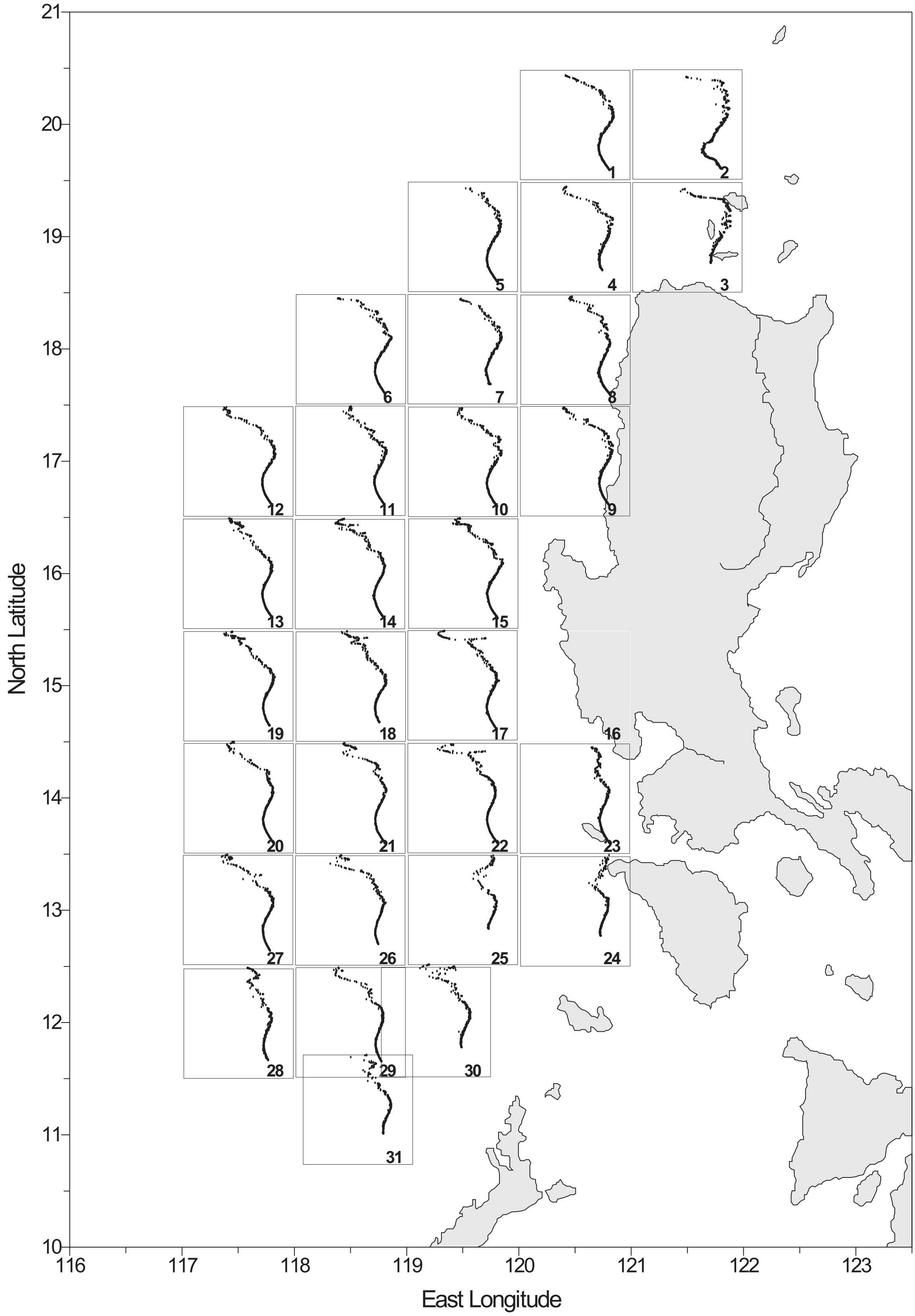

Fig. 13. T-S diagram for the station deeper than 500 m.