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# Oceanographic Conditions in Fall of 1999 along the Section between the South of Kyusyu and the Yap Islands

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*Keywords* : Oceanographic observation, Western pacific ocean, CTD, XBT

**Abstract**

Oceanographic observations using the CTD, XBT and ADCP systems were conducted along a section between the south of Kyushu to the Yap Islands in the Western North Pacific on October 13-18, 1999. The surface-mixed layer higher than 29 ℃ with a thickness of 47-84 m was observed from 13° N to 25° N. The Subtropical Mode Water occupied the subsurface layer between 200 m and 400 m in the region between 21° N and 28° N. In the region south of 15° N, the isotherm depths increased towards the south from 150 m to 400 m, indicating existence of the North Equatorial Current. The current velocity was measured to be ca. 20 cm/s, nearly equal to its annual mean value, indicating that the North Equatorial Current holds its normal state in fall of 1999. The saline water higher than 34.7 psu occupied the subsurface layer between 100 m and 300 m in almost whole sections. Below the subsurface saline water, there was a halocline between 34.4 psu and 34.7 psu in the entire sections. The intermediate water less than 34.2 psu occupied the layer between 600 m and 850 m in the region between 20° N and 29° N. At some latitudes in the westward zonal current region south of 20° N, some eastward return flows were detected, i.e., at 17 °N, 18.5° N, and 19.5° N in the sea surface layer, at 18° N, 18.5° N and 19.5° N in the 50 m depth layer, and at 14.5° N ~15° N and 18° N in the 100 m depth layer.

The oceanic circulation in the western part of the Pacific including the North Equatorial Current, the North Equatorial Countercurrent, the Kuroshio and the Kuroshio Countercurrent are believed to play important roles in the global climate change through the meridional oceanic transports of heat and fresh-water. Some results of oceanographic surveys in this area have been published: those from 33° N to 3° N along 133° 40' E in July and January of 1993~1997 by Yoritaka *et al.*[1], from the south of Honshu to Pohnpei in 1994 by Higashi *et al.*[2], and from the south of Kyusyu to Palau in 1995 by Uchiyama *et al.*[3]. As the oceanic currents have large variability accompanied with the meso-scale eddies and annual signal in the wind stress, it is desired to conduct oceanographic surveys as many times as possible for monitoring the oceanic circulation in the western part of the Pacific.

From 13th October to 9th November in 1999, the Kagoshima University Research Center for the Pacific Islands, carried out interdisciplinary studies on the islands and islands zones in Oceania and its surroundings. In order to understand the basic natural environment in the islands zones in Oceania and its surroundings, it is necessary to examine the variability of oceanic conditions not only in the surrounding coastal waters but also in the wider region including the western part of the Pacific. Therefore, as a part of this research project, an oceanographic survey was conducted along the section from the south of Kyusyu to the Yap Islands on board of the T. S. Keiten Maru (G.T. 860 tons,

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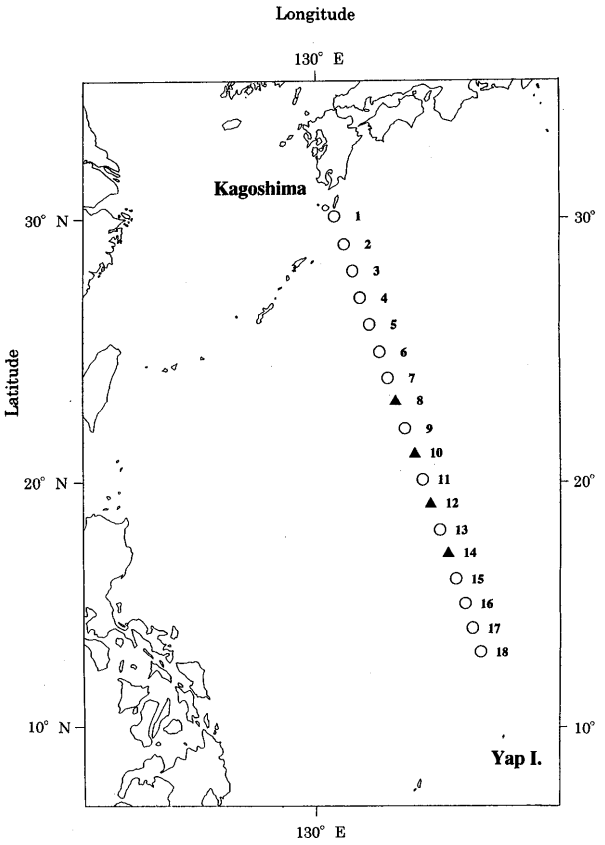


**Fig. 1** Map showing the hydrographic stations. Dark triangles: XBT, Circles: CTD

fishing training ship of Kagoshima University).

This paper presents the oceanic conditions in the western part of the Pacific when the oceanographic surveys were conducted in fall of 1999. The comparison of the conditions in 1999 with previous results will also be made.

## Oceanographic Observation

Vertical profiles of temperature and salinity were measured by a conductivity, temperature, and depth recorder system (CTD system, Neil Brown Instrument Model Mark Ⅲ with a terminal deck unit, DT 1050 WS), and those of temperature by expendable bathy-thermographs (XBT, Murayama Denki Ltd., Type Z-60-16Ⅲ). The locations of CTD and XBT stations are shown in Fig. 1. The observations were conducted from 13th to 18th October, 1999. Along the section, CTD sensor was lowered to 1000 m depth at 14 stations, and the XBT probes were launched to 900 m depth at 4 stations. These stations were selected to be every one degree latitude from 30° N, 130° - 56.1 E to 13° N, 137° - 10.0 E. The values of salinity measured by CTD were corrected by those of water samples determined by AUTOSAL 80B (IAPSO standard sea water, batch No.P555). The standard deviation of differences between corrected CTD salinity and AUTOSAL salinity was 0.003 psu for 16 pairs.

The current velocities at three layers of 5 m, 50 m and 100 m depths were measured by a ship-mounted acoustic doppler current profiler (ADCP, KAIJO DENKI, Type DCG-20B), and recorded every one minute automatically with GPS position, surface water temperature, ship's heading by Gyro compass, and ship's speed by electro-magnetic log. The 30-minute mean absolute surface current vectors were calculated subtracting the 30-minute mean ship's speed relative to water measured by ADCP from the ship's grand speed calculated from difference of ship's position during 30 minutes.

## Results and Discussion

### *Vertical section of temperature*

The vertical section of water temperature is shown in Fig. 2. The surface mixed water higher than 29° C occupied the region between Stn. 6 (25° N) and Stn. 18 (13° N), having a thickness of 47～84 m. The southward down-slope of isotherms from Stn. 1 (30° N) to Stn. 3 (28° N) corresponds to the Kuroshio. The southward up-slope of isotherms from the surface to 150 m depth showed the existence of a core of the subsurface velocity maximum. The weak southward up-slope of isotherms between Stn. 4 (27° N) to Stn. 5 (26° N) is associated with the Kuroshio Countercurrent.

In the subsurface layer, the thickness of the layer between isotherms of 20 ℃ and 12 ℃ in the regions from Stn. 3 (28° N) to Stn. 10 (21° N) was larger than other regions, which indicated the existence of the Subtropical Mode Water. In the region south of Stn. 15 (16° N), the isotherm depths increased towards the south from 150 m to 400 m, indicating the existence of the North Equatorial Current.

***Vertical section of salinity***

The salinity section is shown in Fig. 3. The less saline surface water lower than 34.2 psu occupied Stns. 1, 15, and 16. The lowest salinity value of the less saline surface water was 34.11 psu at Stn. 15. Below the surface water, the subsurface saline water higher than 34.7 psu occupied the layer between 100 m and 300 m at almost whole stations. Its highest salinity value was 35.001 psu at Stn.17. Below the subsurface saline water, the halocline between 34.7 psu and 34.4 psu was found in the entire sections. In the Kuroshio area (Stn. 1 in temperature section), a sharp down-slope of halocline was also found. The intermediate water characterized by the salinity minimum of 34.2 psu was present between Stns. 2, and 11, showing a tongue-like distribution in the layer between 600 m and 850 m with southward up-sloping. Below this intermediate water, the salinity increased downward or southward.

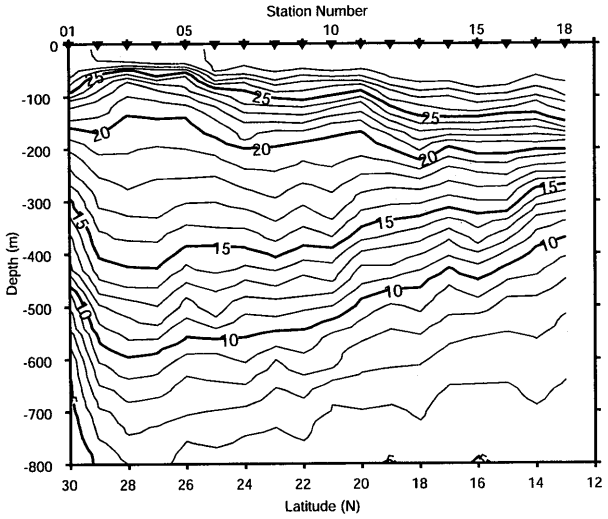


**Fig. 2** Vertical section of water temperature (℃).

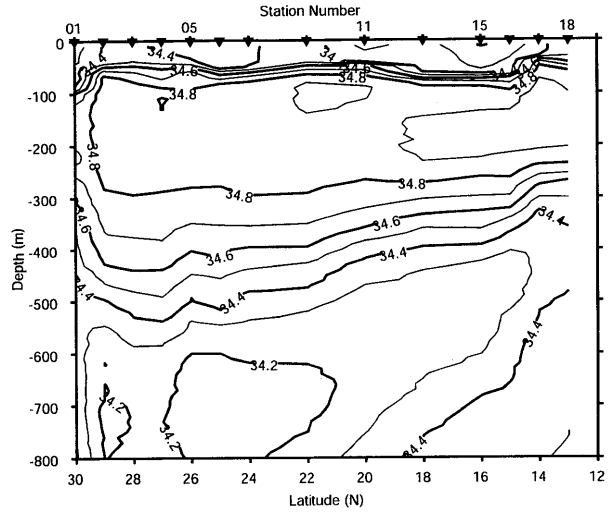


**Fig. 3** Vertical section of salinity (psu).

***Temperature-salinity relation***

The temperature-salinity relations at standard depths of 5 stations are shown in Fig. 4. The water corresponding to the maximum salinity was considered to be the Subtropical Subsurface Water. The maximum salinity value was 34.978 psu at 24.821℃ (Stn. 18) at 150 m depth. It increased southward with decreased depth. The curves gave inverted form of "S" character. The water corresponding to the minimum salinity is considered to be the North Pacific Intermediate Water. The minimum value was 34.146 psu at 6.707 ℃ (Stn. 7) in a depth of 700 m and forms well-mixed uniform water masses.

***Distribution of current velocity***

The surface currents measured by ship-mounted ADCP is shown in Fig. 5. As mentioned in the vertical sections of temperature and salinity, there exist some characteristic currents crossing the observation line. The maximum speed of current was 65 cm/s near Stn. 7 (24° N). The Kuroshio flows at Stn. 1 (30° N), and its maximum speed was 60 cm/s. The Kuroshio Countercurrent was present at ca. 27° N with the maximum speed of 30 cm/s. The North Equatorial Current appeared from 20° N to 13° N, with the maximum speed of 25 cm/s at 13° N.

Figures 6 (a), 6 (b), and 6 (c) show the eastward component of current at 5 m, 50 m, and 100 m depths, respectively. The weak westward currents in the region south of 21° N, show the North Equatorial Current. According to White *et al.*[4], the speed of long-term averaged annual mean of zonal current in the North Equatorial Current region had the maximum of 24 cm/s. According to Uchiyama *et al.*[5], the maximum current velocity was also equal to or more than 20 cm/s at 11° N. In the present observations, we obtained the maximum value of current velocity in the North Equatorial Current region to be ca. 20 cm/s, nearly equal to the annual mean. This result

indicates that the North Equatorial Current holds its normal state in fall of 1999.

In this region, some eastward current was detected at some latitude, i.e., at 17° N, 18.5° N, and 19.5° N in the sea surface layer, at 18° N, 18.5° N, and 19.5° N in the 50 m depth layer, and at 14.5° N～15° N and 18° N in the 100 m depth layer. These eastward current might indicate the existence of return flow accompanied by meso-scale eddies.

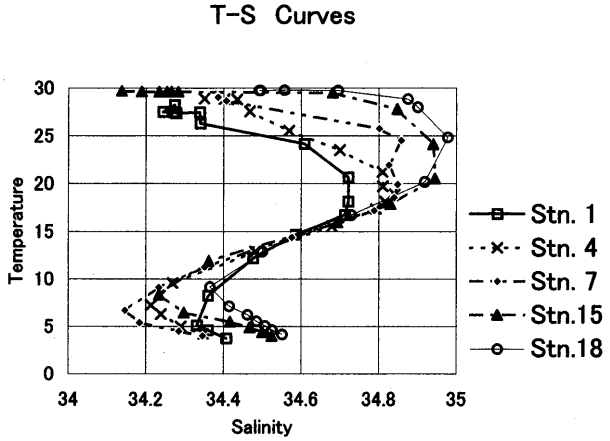


**Fig. 4** Temperature-salinity relation at Stations. 1, 4, 7, 15, and 18.

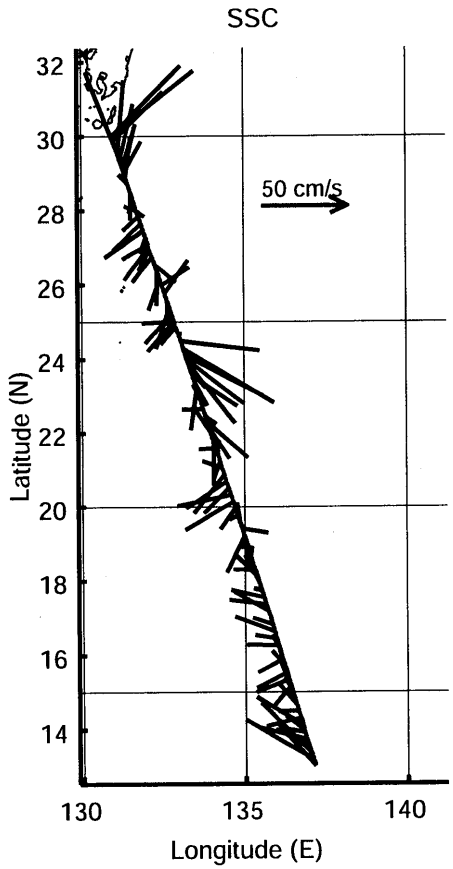


**Fig. 5** Distribution of currents at sea surface(5 m depth).

## Acknowledgements

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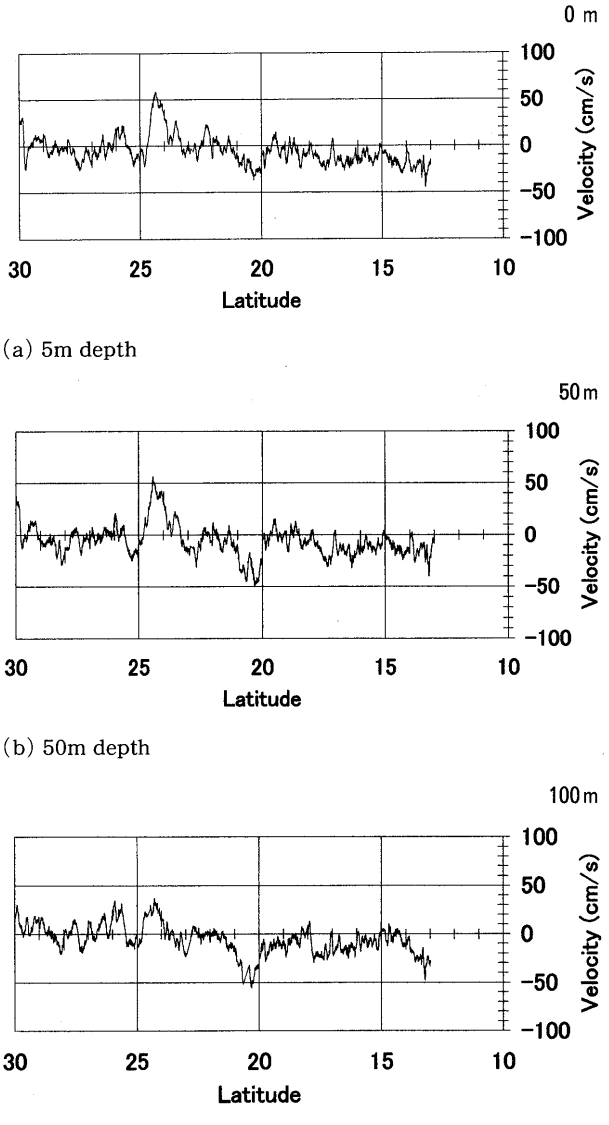


(a) 5m depth

(b) 50m depth

(c) 100m depth

**Fig. 6** The eastward component of current.

surveys. A part of this study was supported by the Kagoshima University Research Center for the Pacific Islands.

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**Appendix**

| Stn. | 1 (CTD) | | 2 (CTD) | | 3 (CTD) | | 4 (CTD) | | 5 (CTD) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Oct. 13, 1999 | | Oct. 14, 1999 | | Oct. 14, 1999 | | Oct. 14, 1999 | | Oct. 14, 1999 | |
| Time | 19:08 | | 02:14 | | 08:54 | | 15:36 | | 21:47 | |
| Lat. | 29° - 59.' 9N | | 29° - 00.' 1N | | 27° - 59.' 9N | | 26° - 59.' 8N | | 26° - 00.' 0N | |
| Long. | 130° - 56.' 1E | | 131° - 19.' 6E | | 131° - 42.' 7E | | 132° - 05.' 3E | | 132° - 29.' 3E | |
| Depth | 860 m | | 4100 m | | 2440 m | | 5398 m | | 3690 m | |
| Prs. (dbar) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) |
| 0 | 28.212 | 34.274 | 28.174 | 34.375 | 28.433 | 34.452 | 29.228 | 34.207 | 28.726 | 34.372 |
| 10 | 27.496 | 34.244 | 28.141 | 34.409 | 28.405 | 34.452 | 28.866 | 34.350 | 28.698 | 34.371 |
| 20 | 27.471 | 34.271 | 28.118 | 34.410 | 28.392 | 34.457 | 28.807 | 34.402 | 28.647 | 34.388 |
| 30 | 27.417 | 34.276 | 28.016 | 34.426 | 28.389 | 34.461 | 28.798 | 34.435 | 28.619 | 34.389 |
| 40 | 27.352 | 34.278 | 27.767 | 34.438 | 27.011 | 34.507 | 27.552 | 34.468 | 27.673 | 34.418 |
| 50 | 27.434 | 34.339 | 26.151 | 34.613 | 24.815 | 34.628 | 25.538 | 34.569 | 25.529 | 34.595 |
| 75 | 26.279 | 34.340 | 23.783 | 34.834 | 21.687 | 34.799 | 23.494 | 34.700 | 23.151 | 34.775 |
| 100 | 24.144 | 34.609 | 22.192 | 34.869 | 20.956 | 34.834 | 21.217 | 34.810 | 21.760 | 34.796 |
| 150 | 20.653 | 34.722 | 20.502 | 34.858 | 19.657 | 34.824 | 19.715 | 34.811 | 19.795 | 34.817 |
| 200 | 18.104 | 34.722 | 19.271 | 34.843 | 19.011 | 34.829 | 18.882 | 34.842 | 18.961 | 34.821 |
| 250 | 16.682 | 34.713 | 18.012 | 34.822 | 18.342 | 34.819 | 18.092 | 34.817 | 18.115 | 34.821 |
| 300 | 14.675 | 34.587 | 17.112 | 34.790 | 17.379 | 34.794 | 17.322 | 34.793 | 17.013 | 34.778 |
| 400 | 12.177 | 34.477 | 15.066 | 34.639 | 15.457 | 34.670 | 15.532 | 34.679 | 14.576 | 34.605 |
| 500 | 8.226 | 34.361 | 11.745 | 34.389 | 12.597 | 34.463 | 12.892 | 34.482 | 11.645 | 34.398 |
| 600 | 5.107 | 34.332 | 9.147 | 34.225 | 9.754 | 34.274 | 9.571 | 34.269 | 8.612 | 34.200 |
| 700 | 4.598 | 34.360 | 6.629 | 34.168 | 7.474 | 34.213 | 7.254 | 34.213 | 7.026 | 34.159 |
| 800 | 3.721 | 34.408 | 5.284 | 34.197 | 5.941 | 34.230 | 6.286 | 34.239 | 5.476 | 34.187 |
| 900 | | | 4.405 | 34.279 | 5.238 | 34.302 | 4.988 | 34.290 | 4.717 | 34.241 |
| 1000 | | | 3.860 | 34.385 | 4.166 | 34.363 | 4.224 | 34.348 | 4.112 | 34.306 |

| Stn. | 6 (CTD) | | 7 (CTD) | | 8 (XBT) | | 9 (CTD) | | 10 (XBT) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Oct. 15, 1999 | | Oct. 15, 1999 | | Oct. 15, 1999 | | Oct.15, 1999 | | Oct. 16, 1999 | |
| Time | 04:15 | | 10:23 | | 17:10 | | 22:35 | | 05:08 | |
| Lat. | 25°-00.' 0N | | 24°-00.' 0N | | 22°-56.' 9N | | 22°-00.' 1N | | 21°-00.' 0N | |
| Long. | 132°-51.' 4E | | 133°-14.' 2E | | 133°-37.' 6E | | 133°-58.' 3E | | 134°-20.' 2E | |
| Depth | 5170 m | | 4280 m | | 4610 m | | 5300 m | | 5830 m | |
| Prs. (dbar) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) |
| 0 | 29.196 | 34.342 | 29.101 | 34.385 | 29.00 | | 29.383 | 34.461 | 29.20 | |
| 10 | 29.165 | 34.344 | 29.069 | 34.384 | 29.24 | | 29.308 | 34.464 | 29.11 | |
| 20 | 29.163 | 34.344 | 29.031 | 34.386 | 29.22 | | 29.308 | 34.465 | 29.10 | |
| 30 | 29.162 | 34.344 | 29.029 | 34.386 | 29.17 | | 29.306 | 34.465 | 29.12 | |
| 40 | 29.162 | 34.344 | 29.022 | 34.386 | 29.18 | | 29.299 | 34.467 | 29.12 | |
| 50 | 29.160 | 34.343 | 28.633 | 34.407 | 29.18 | | 28.829 | 34.637 | 29.12 | |
| 75 | 25.993 | 34.730 | 25.763 | 34.802 | 27.39 | | 26.792 | 34.874 | 26.66 | |
| 100 | 23.369 | 34.877 | 24.518 | 34.858 | 25.22 | | 25.452 | 34.907 | 24.85 | |
| 150 | 20.763 | 34.870 | 21.949 | 34.827 | 21.96 | | 22.019 | 34.888 | 21.10 | |
| 200 | 19.273 | 34.867 | 19.921 | 34.849 | 19.86 | | 19.614 | 34.838 | 19.59 | |
| 250 | 17.995 | 34.820 | 18.537 | 34.840 | 18.91 | | 18.450 | 34.827 | 18.78 | |
| 300 | 16.971 | 34.783 | 17.157 | 34.789 | 17.83 | | 17.198 | 34.788 | 17.82 | |
| 400 | 14.730 | 34.613 | 14.372 | 34.576 | 15.22 | | 14.435 | 34.581 | 14.60 | |
| 500 | 12.374 | 34.424 | 11.256 | 34.351 | 11.55 | | 11.161 | 34.336 | 10.99 | |
| 600 | 8.664 | 34.200 | 9.105 | 34.233 | 8.00 | | 8.608 | 34.200 | 8.22 | |
| 700 | 6.884 | 34.152 | 6.707 | 34.146 | 6.40 | | 6.571 | 34.166 | 5.92 | |
| 800 | 5.590 | 34.181 | 5.408 | 34.184 | | | 5.514 | 34.245 | | |
| 900 | 4.701 | 34.256 | 4.518 | 34.285 | | | 4.708 | 34.324 | | |
| 1000 | 4.044 | 34.343 | 4.008 | 34.346 | | | 4.213 | 34.397 | | |

| Stn. | 11 (CTD) | | 12 (XBT) | | 13 (CTD) | | 14 (XBT) | | 15 (CTD) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Oct. 16, 1999 | | Oct. 16, 1999 | | Oct. 16, 1999 | | Oct. 17, 1999 | | Oct. 17, 1999 | |
| Time | 10:37 | | 17:02 | | 22:30 | | 04:52 | | 10:23 | |
| Lat. | 20°-00.' 0N | | 19°-00.' 0N | | 18°-00.' 0N | | 17°-00.' 0N | | 16°-00.' 1N | |
| Long. | 134°-42.' 4E | | 135°-04.' 2E | | 135°-25.' 9E | | 135°-47.' 5E | | 136°-08.' 0E | |
| Depth | 5800 m | | 5670 m | | 5070 m | | 5130 m | | 5230 m | |
| Prs. (dbar) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) |
| 0 | 29.276 | 34.166 | 29.10 | | 29.671 | 34.276 | 29.30 | | 29.684 | 34.138 |
| 10 | 29.263 | 34.266 | 29.40 | | 29.669 | 34.347 | 29.53 | | 29.613 | 34.189 |
| 20 | 29.292 | 34.303 | 29.42 | | 29.671 | 34.358 | 29.55 | | 29.591 | 34.234 |
| 30 | 29.286 | 34.307 | 29.29 | | 29.671 | 34.361 | 29.54 | | 29.587 | 34.254 |
| 40 | 29.287 | 34.350 | 29.27 | | 29.668 | 34.361 | 27.56 | | 29.583 | 34.265 |
| 50 | 28.909 | 34.632 | 29.25 | | 29.650 | 34.365 | 29.57 | | 29.589 | 34.283 |
| 75 | 26.176 | 34.868 | 28.21 | | 28.976 | 34.707 | 28.89 | | 29.484 | 34.681 |
| 100 | 24.050 | 34.907 | 26.48 | | 27.185 | 34.836 | 26.98 | | 27.790 | 34.848 |
| 150 | 20.801 | 34.859 | 22.77 | | 24.149 | 34.917 | 24.10 | | 24.114 | 34.941 |
| 200 | 19.261 | 34.844 | 20.02 | | 21.131 | 34.941 | 19.83 | | 20.520 | 34.945 |
| 250 | 17.942 | 34.817 | 17.90 | | 18.377 | 34.852 | 17.37 | | 17.815 | 34.831 |
| 300 | 16.621 | 34.758 | 16.21 | | 16.150 | 34.707 | 15.56 | | 15.941 | 34.693 |
| 400 | 12.810 | 34.447 | 12.74 | | 12.077 | 34.387 | 11.16 | | 11.891 | 34.362 |
| 500 | 9.674 | 34.260 | 8.80 | | 9.166 | 34.265 | 8.14 | | 8.340 | 34.234 |
| 600 | 7.301 | 34.213 | 7.20 | | 7.121 | 34.271 | 6.58 | | 6.451 | 34.298 |
| 700 | 5.894 | 34.263 | 5.87 | | 6.029 | 34.342 | 5.60 | | 5.497 | 34.417 |
| 800 | 5.152 | 34.343 | | | 5.471 | 34.435 | | | 4.887 | 34.468 |
| 900 | 4.674 | 34.404 | | | 4.934 | 34.481 | | | 4.403 | 34.501 |
| 1000 | 4.084 | 34.468 | | | 4.300 | 34.514 | | | 3.979 | 34.525 |

| Stn. | 16 (CTD) | | 17 (CTD) | | 18 (CTD) | |
|---|---|---|---|---|---|---|
| Date | Oct. 17, 1999 | | Oct. 17, 1999 | | Oct. 18, 1999 | |
| Time | 16:50 | | 23:38 | | 06:02 | |
| Lat. | 14°-59.' 9N | | 14°-00.' 0N | | 13°-00.' 0N | |
| Long. | 136°-28.' 5E | | 136°-49.' 0E | | 137°-10.' 0E | |
| Depth | 4980 m | | 4650 m | | 4910 m | |
| Prs. (dbar) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) | Temp.(℃) | Sal.(‰) |
| 0 | 29.821 | 34.161 | 29.711 | 34.349 | 29.736 | 34.495 |
| 10 | 29.814 | 34.234 | 29.714 | 34.357 | 29.729 | 34.494 |
| 20 | 29.672 | 34.273 | 29.721 | 34.360 | 29.730 | 34.492 |
| 30 | 29.660 | 34.293 | 29.742 | 34.399 | 29.738 | 34.496 |
| 40 | 29.656 | 34.309 | 29.833 | 34.683 | 29.766 | 34.557 |
| 50 | 29.662 | 34.323 | 29.455 | 34.806 | 29.738 | 34.695 |
| 75 | 29.122 | 34.657 | 28.332 | 34.906 | 28.810 | 34.875 |
| 100 | 27.641 | 34.822 | 26.898 | 34.937 | 27.981 | 34.901 |
| 150 | 23.900 | 34.948 | 23.584 | 34.971 | 24.821 | 34.978 |
| 200 | 20.337 | 34.930 | 20.079 | 34.924 | 20.191 | 34.919 |
| 250 | 18.028 | 34.834 | 16.670 | 34.738 | 16.693 | 34.729 |
| 300 | 15.975 | 34.690 | 13.722 | 34.502 | 12.887 | 34.501 |
| 400 | 10.809 | 34.306 | 9.721 | 34.312 | 9.167 | 34.365 |
| 500 | 7.694 | 34.257 | 7.714 | 34.385 | 7.138 | 34.415 |
| 600 | 6.456 | 34.376 | 6.664 | 34.440 | 6.230 | 34.462 |
| 700 | 5.620 | 34.431 | 5.891 | 34.482 | 5.538 | 34.486 |
| 800 | 5.004 | 34.469 | 5.291 | 34.495 | 5.042 | 34.508 |
| 900 | 4.532 | 34.503 | 4.787 | 34.518 | 4.630 | 34.526 |
| 1000 | 4.155 | 34.529 | 4.392 | 34.535 | 4.159 | 34.551 |