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HYDROLOGICAL FEATURES OF A WARM CORE EDDY AND THEIR BIOLOGICAL IMPLICATIONS

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HYDROLOGICAL FEATURES OF A WARM CORE EDDY AND THEIR BIOLOGICAL IMPLICATIONS

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Abstract

The distributions of salinity, temperature, dissolved oxygen, nitrate and silicate are described for an anticyclonic mesoscale warm core eddy located in the Tasman Sea. Vertical discontinuities in the hydrological properties show that both intrusive and extrusive advection occurred on the coastal side of the eddy. The concentration of macro-nutrients decreased towards the centre of the eddy, particularly at the depth of the central core. These smaller nutrient concentrations imply that the biomass and productivity of this eddy are less than those of the surrounding ocean, but the more homogeneous and persistent character of the eddy suggests that the eddy may provide an ideal habitat for larger planktonic animals with prolonged life cycles, such as some coelenterates.

INTRODUCTION

Warm core mesoscale eddies have been found to be a common feature of the oceanic circulation off the south east coast of Australia, and their formation has been described by Nilsson *et al.* (1977). These warm eddies have been found by their surface temperature characteristics as described by Andrews and Scully-Power (1976), Hynd (1969), and Rochford (1977), and more recently by satellite-tracked buoys as described by Cresswell (1976), and Cresswell and Wood (1977). It has been proposed by Scully-Power (1973) that these eddies form further north on the N.S.W. coast then migrate slowly southwards, but later evidence presented by Nilsson *et al.* (1977) shows that the eddies reform and persist in certain areas, and that these positions may be linked to the bottom topography.

The physical structure of these eddies has been described from bathythermograph data by Andrews and Scully-Power (1976), and Nilsson *et al.* (1977), and from XBT, hydrological and satellite-tracked buoy data by Nilsson and Cresswell (personal communication). The concentrations of the macro-nutrients and the biomass in these warm core eddies of the N.S.W. coast have not been reported previously, but it was assumed the nutrient concentrations and the biomass were less than the surrounding ocean, as has been suggested for warm core eddies in the N.W. Atlantic Ocean (Oceanographic Study of Warm Core Gulf Stream Rings 1977).

The present paper describes the distribution of salinity, temperature, dissolved oxygen, nitrate and silicate within a warm core eddy which was centered about 250 km ESE of Eden, on the south N.S.W. coast. This particular eddy was reported a year earlier in April 1977 by Cresswell and Nilsson (1977), and had persisted in the same region, although the central mixed core had been covered by a cap of warmer water, similar to an eddy described by Nilsson *et al.* (1977).

METHODS

The data were collected during a cruise of the R.V. *Sprightly* in the Tasman Sea, between 9 and 11 February 1978, at the positions shown in Fig. 1. The location of the warm core anticyclonic eddy was found, using expendable bathythermographs, before the sampling on the eddy section was commenced. The water samples were collected using Nansen reversing water samplers, and temperatures were measured using reversing thermometers attached to these samplers. Salinity and concentrations of dissolved oxygen, nitrate and reactive silicate were determined by the methods described by Major *et al.* (1972).

RESULTS

The variation of temperature with depth across the eddy section (Fig. 2) shows the central zone of downwelled warmer water with an isothermal core of 16°C water between 250 and 350 m depth.

The salinity varies across the eddy section as shown in Fig. 3. The eddy has an isohaline core at 200 and 350 m depth, with a salinity of 35.5°/$_{oo}$. The salinity structure is not quite the same as the temperature structure and there is a salinity maximum at 100 m depth and a layer of slightly higher salinity water extending from 475 m at Stn 174 to 275 m at Stn 178. The deflection of the contours near the eddy core shows that there is some vertical movement, with slight downwelling at Stn 169 and slight upwelling at Stn 163.

The density varies across the eddy section as shown by the sigma-*t* values in Fig. 4. The density structure is similar to that for temperature which shows a central region of downwelled less dense water and a core of isopycnal water with a sigma-*t* of 26.1.

The dissolved oxygen varies across the eddy section as shown by the percent saturation values in Fig. 5. The percent saturation in the eddy is greater than that in the surrounding ocean, and it increases to a value of almost 90% at the centre of the core. This section also shows layering of the vertical structure on the coastal side of the eddy, with a layer of lower oxygen water extending from 200 and 250 m at Stn 178 to 400 m at Stn 174.

The concentration of nitrate across the eddy (Fig. 6) shows a similar structure to that shown by the salinity, with a layer of richer nitrate water extending from 250 m at Stn 178 to 400 and 450 m at Stn 174. The contours near the core of the eddy also indicate some vertical transport of nitrate, with slight downwelling at Stn 169 and upwelling at Stn 163. The surface waters of the eddy are poorer in nitrate in the central region than at the edges.

The concentration of silicate across the eddy (Fig. 7) shows a similar pattern to those for salinity and nitrate, with a layer of richer silicate water extending from 250 m at Stn 178 to 400 and 450 m at Stn 174. The surface waters and the core of the eddy are much poorer in silicate than the edges of the eddy, and the core water from 200 to 350 m at Stn 169 has an almost uniform silicate concentration of about 2.0 mmol m^{-3}.

DISCUSSION

Physical Structure

The physical structure of this anticyclonic warm core eddy appears to be similar to that described by Nilsson *et al.* (1977), with a subsurface mixed core of downwelled surface water covered by a cap of warmer water of more recent origin. This eddy also has a deep root of less dense water extending below the 500 m depth, but it is not known how far this root extends towards the bottom, which is 4800 m deep in this locality. The distribution of salinity and nitrate in the central zone of the eddy shows that there is some vertical movement which may cause horizontal differences in the flux into the surface waters of the eddy. The distribution of salinity, dissolved oxygen, nitrate and silicate all show that there are vertical discontinuities in the structure on the coastal side of the eddy at Stns 178 and 174, with layers of water which appear to have moved along the isopycnal surfaces. The layering and movement of warm water into a cold core eddy near the Gulf Stream has been observed by Lambert (1974), who suggested that the entrainment and radial advection of the warm water into the eddy would cause it to lose energy and spin down. Similarly, the loss of water from the core region as a layer along the isopycnal surfaces to the surrounding ocean could also cause loss of energy and spin down.

The layers on the coastal side of the eddy are shown also by the relationships of temperature to salinity for each station on the section (Fig. 8). The layer of water at 275 m on Stn 178 has an identical salinity and temperature to that at 475 m on Stn 174, and the greater salinity at these points indicates that this water has originated from the core of the eddy, which has a greater salinity than the surrounding ocean. The water at 100 m at Stn 178 also appears to be a layer of water which has originated from about 200 m in the core of the eddy. Similarly, the salinity-temperature data from Stn 163 show water which has originated from the core, but these layers do not appear to extend to the south east side of the eddy and may be remnants of layers which formed on the coastal side of the eddy before rotation to this position.

Salinity-temperature anomalies similar to those reported here have been described in the Tasman Sea by Boland (1971) and were attributed to intrusions of more saline water from Bass Strait into the Tasman Sea. However it is possible that some of the anomalies observed by Boland may have been due to the presence of eddies, since the clearest example of an anomaly similar to those at Stns 163, 174 and 178 was at a position located on the edge of an eddy area which was found later by Cresswell and Wood (1977) at 33°09'S, 155°32'E.

The salinity-temperature relationships show that, although the greater temperature of the eddy and the central isothermal core are the most noticeable features of this eddy, the salinity measurements are the mose useful in determining the structure of the eddy. For example, the layers originating from the eddy core at Stn 178 would appear as layers of isothermal water on bathythermograph records, but salinity measurements would show increases of salinity in these layers which would indicate their origin more clearly. The salinity also can be used as a guide to the concentrations of dissolved oxygen, nitrate and, to a lesser extent, the silicate as shown by the similarity of Figs 3, 5, 6 and 7.

Chemical Structure

The concentration of dissolved oxygen in the water is often used as an indicator and a measure of biological activity or, in conjunction with the macro-nutrients, as an indicator of water origin, as described by Redfield (1942), who used the Apparent Oxygen Utilization (AOU) as a measure of the amounts of biological material oxidised, and the nutrients regenerated from this material.

The variation of AOU across the eddy section (Fig. 9) shows that the AOU values within the eddy are less than those in the surrounding ocean, particularly below the core. This AOU structure indicates that the central core of downwelled and trapped surface water had produced a much smaller quantity of oxidisable detritus than the surrounding ocean and that the surface zone of the eddy still has a lower productivity than the surrounding ocean. The layering in the coastal side of the eddy is shown again by the water of greater AOU present at 200 and 250 m at Stn 178 and 400 m at Stn 174, which appears to originate from outside the eddy.

Since the rates of uptake and regeneration of the macro-nutrients by phytoplankton and other micro-organisms in the ocean are different, a comparison of any two macro-nutrients over an area or period of time will indicate abnormal rates of uptake or release at any particular place or time. The relationship of silicate to nitrate in the eddy section indicates that there are no aberrant points, as shown in Fig. 10.

The relationship of the macro-nutrients to AOU should also follow a smooth curve unless abnormal processes take place. The relationship of nitrate to AOU in the eddy section does not show a smooth curve, particularly at the intermediate AOU values where there is a large scatter, as shown in Fig. 11. However the data from the two stations on the edge of the eddy show the expected smooth relationship of nitrate to AOU, while the data from the core of the eddy appear to be abnormal. Since the silicate-nitrate relationship indicated no abnormal biological activity, the most likely explanation of these data is that they are the result of mixing of high nitrate-AOU water originating from deeper water outside the eddy, with low nitrate-AOU water originating from near the surface. Amongst the abnormal points are two from 275 and 300 m at Stn 178, which indicates that this water has come from within the eddy, and amongst the normal group are two almost identical points from 400 m at Stn 174 and 250 m at Stn 178, which indicates that this water has come from outside the eddy. There is also one abnormal point below the curve from 75 m at Stn 163, which can be interpreted as greater than normal nitrate uptake at this point without a corresponding increase in oxygen due to photosynthesis of phytoplankton. This interpretation is consistent with the suspected upwelling in the core at this station described above, and that this sample was collected after nightfall.

The relationship of silicate to AOU (Fig. 12) also shows similar anomalies to that of the nitrate-AOU relationship indicating a mixed central core and a layer of water leaving the eddy at Stn 178 at the same depth as indicated by the nitrate-AOU relationship above. There are some data points below the curve in Fig. 12 from depths of about 100 to 250 m, indicating uptake of silicate without a corresponding production of oxygen. These anomalies may indicate the existence of a small but dominant diatom population in the oligophotic zone where the nutrient concentrations are greater, as suggested by Parsons *et al.* (1978).

Biological Structure

Although no direct measurements of biomass and productivity were made during this study of the eddy, the small concentrations of nitrate and silicate in the centre of the eddy and the small values of AOU below the core show that the biomass and productivity in the eddy must be much smaller than that of the surrounding ocean. This small biomass should be accompanied by deeper light penetration and a dominance of small flagellates towards the centre of the eddy surface zone, as suggested by Parsons *et al.* (1978). The vertical movement of water within the eddy may also produce small areas of increased productivity, but these are not likely to be more productive than the ocean surrounding the eddy. The silicate-AOU relationship shows that there may be a small dominant diatom population in the oligophotic zone of the eddy, but this feature could also be common to other regions of the surrounding ocean.

The animal population of the eddy may also be quite different to that of the surrounding ocean. Regardless of the productivity of an eddy, the physical structure with its stable position, temperature, salinity and associated micro-organisms can provide a unique environment for animals which need a stable environment for breeding and development to an adult stage. The eventual spin down and dispersion of a warm eddy may thus release these animals into the colder waters and result in a swarm of animals of apparently tropical or other origin. One example of an animal which may breed and develop in warm eddies is the well known Portuguese Man-of-war, or bluebottle (*Physalia physalis*), which appears in swarms on N.S.W. beaches at irregular and unexplained intervals, as described by Southcott (1967).

ACKNOWLEDGEMENTS

I would like to express my gratitude to G.R. Cresswell of CSIRO and C.S. Nilsson of RANRL who collected the hydrological data and encouraged me to prepare this report. These data were collected as a part of the study of the birth and evolution of anticyclonic eddies in the Tasman Sea, which is in preparation for publication by Nilsson and Cresswell.

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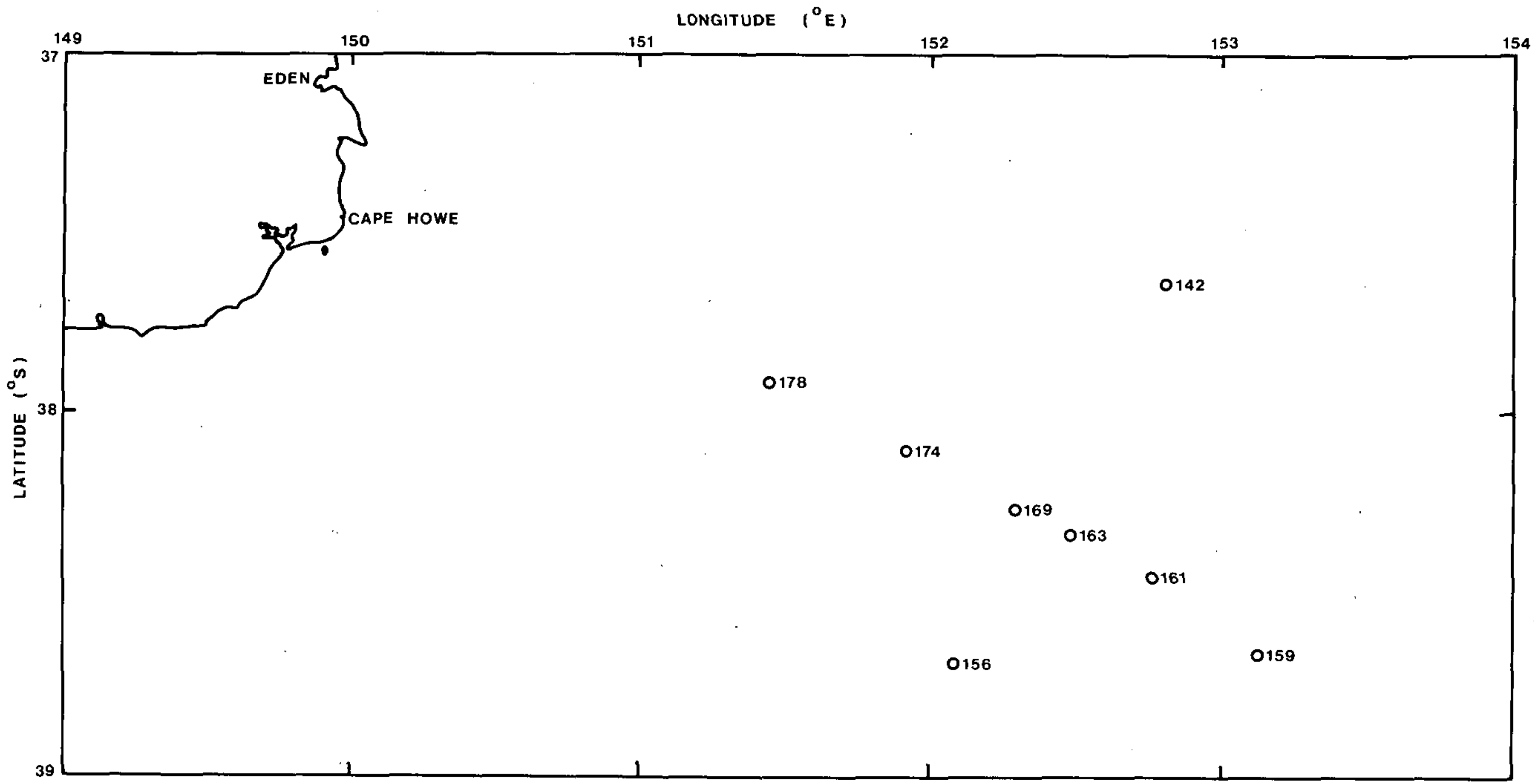

Fig. 1. Hydrological station positions occupied in the region of a warm core eddy in the Tasman Sea, February 1978.

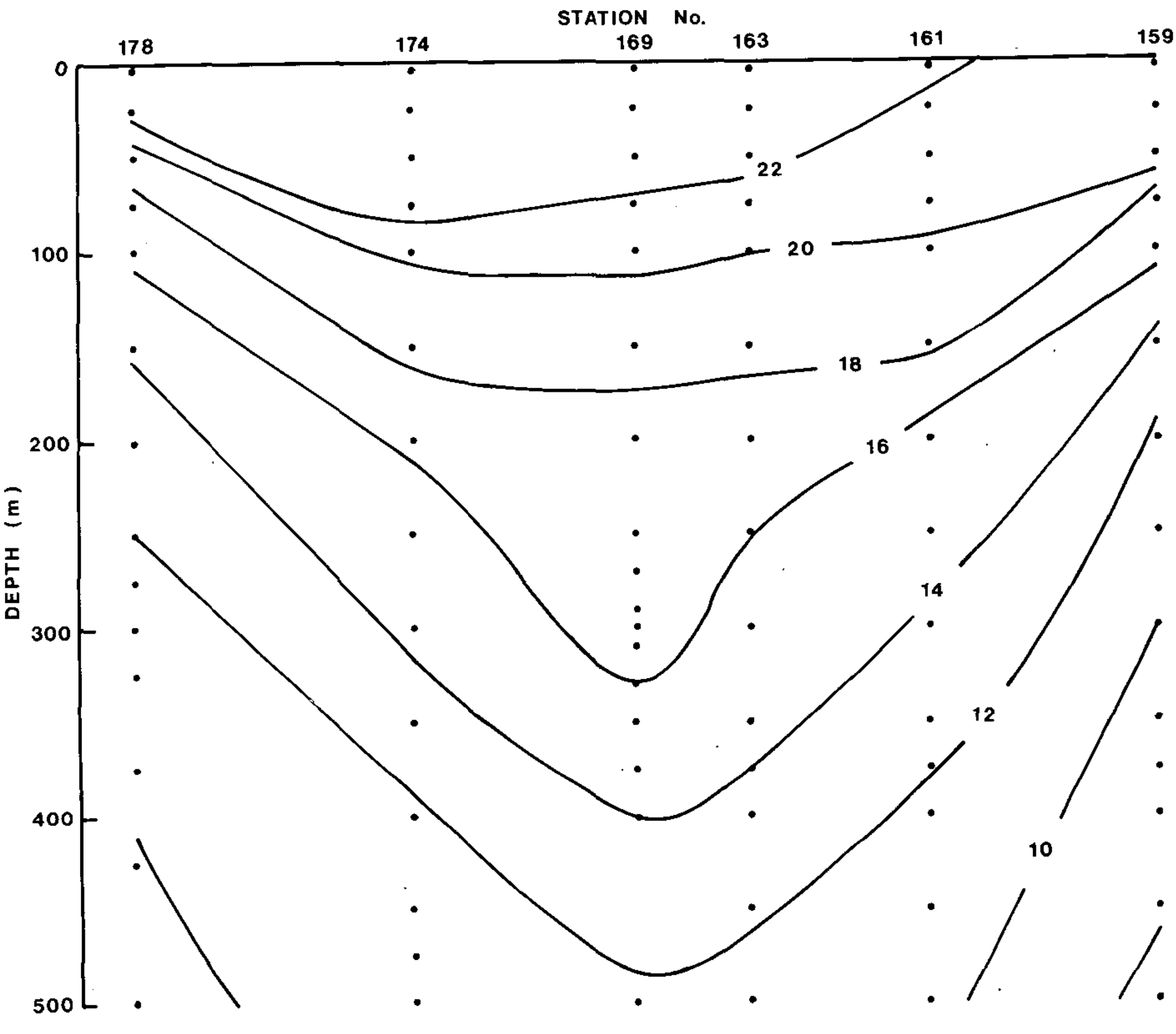

Fig. 2. The variation of temperature (°C) across the warm core eddy.

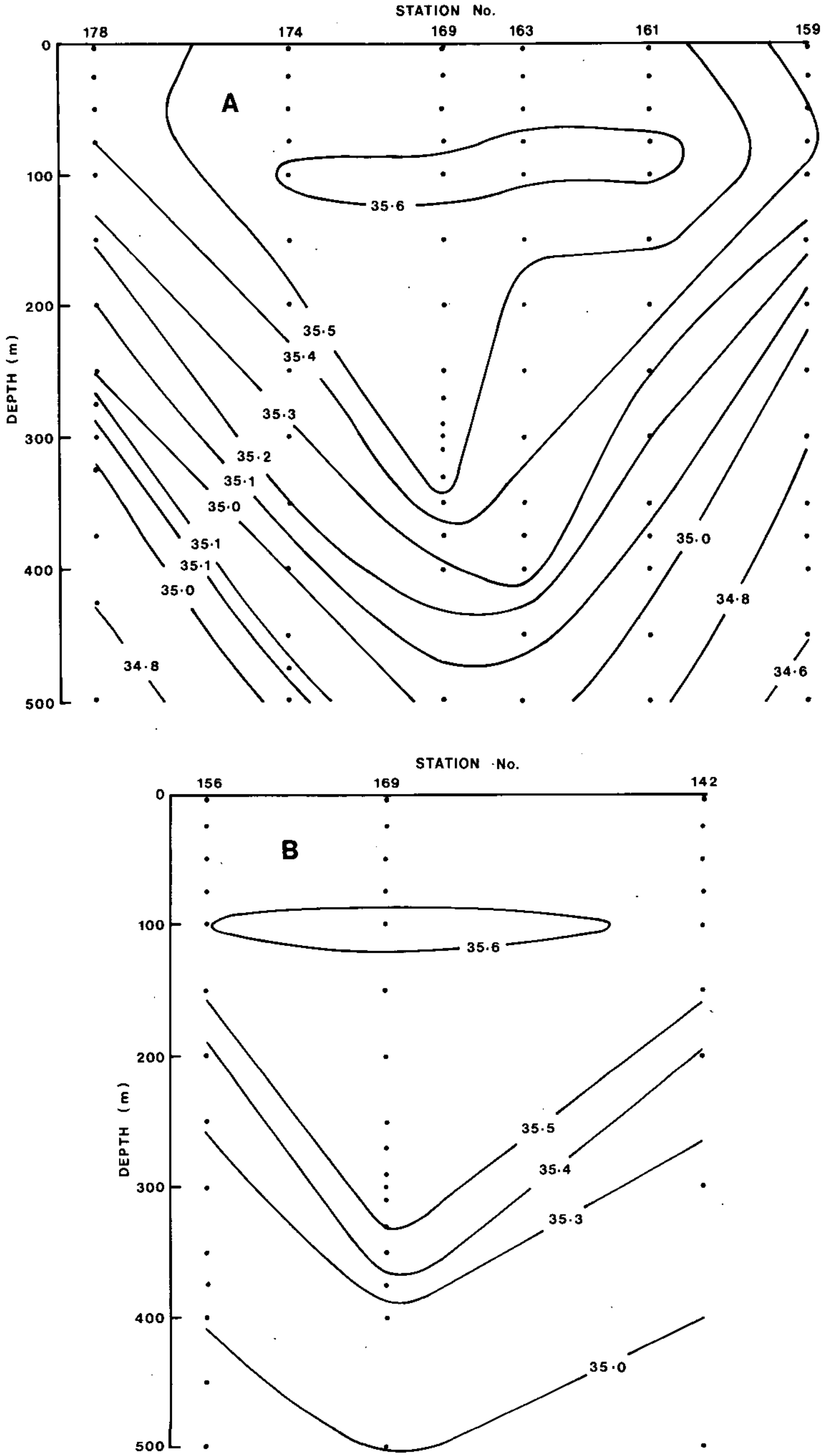

Fig. 3. (a & b) The variation of salinity (°/₀₀) across the warm core eddy, in two directions.

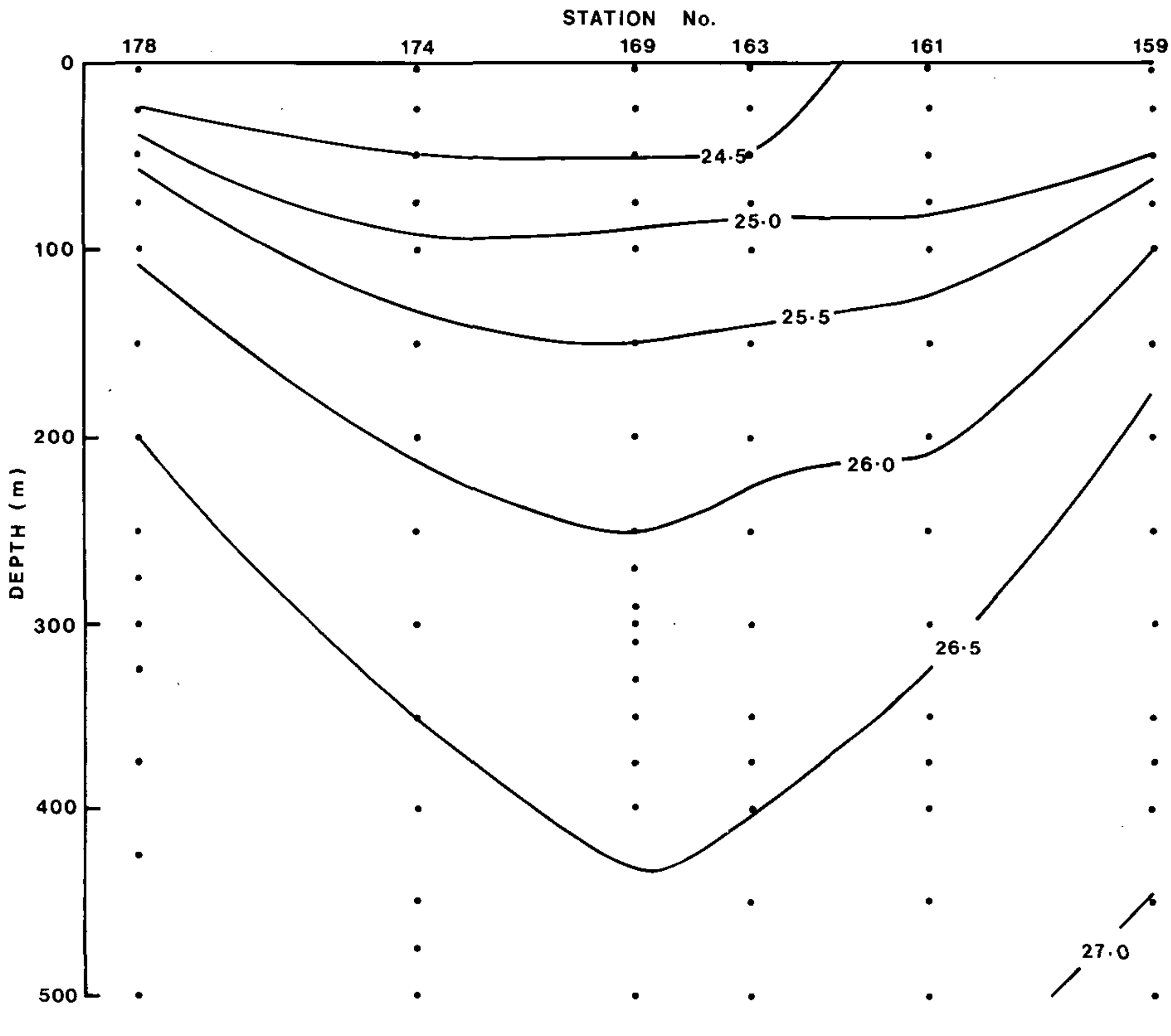

Fig. 4. The variation of density (σ-t) across the warm core eddy.

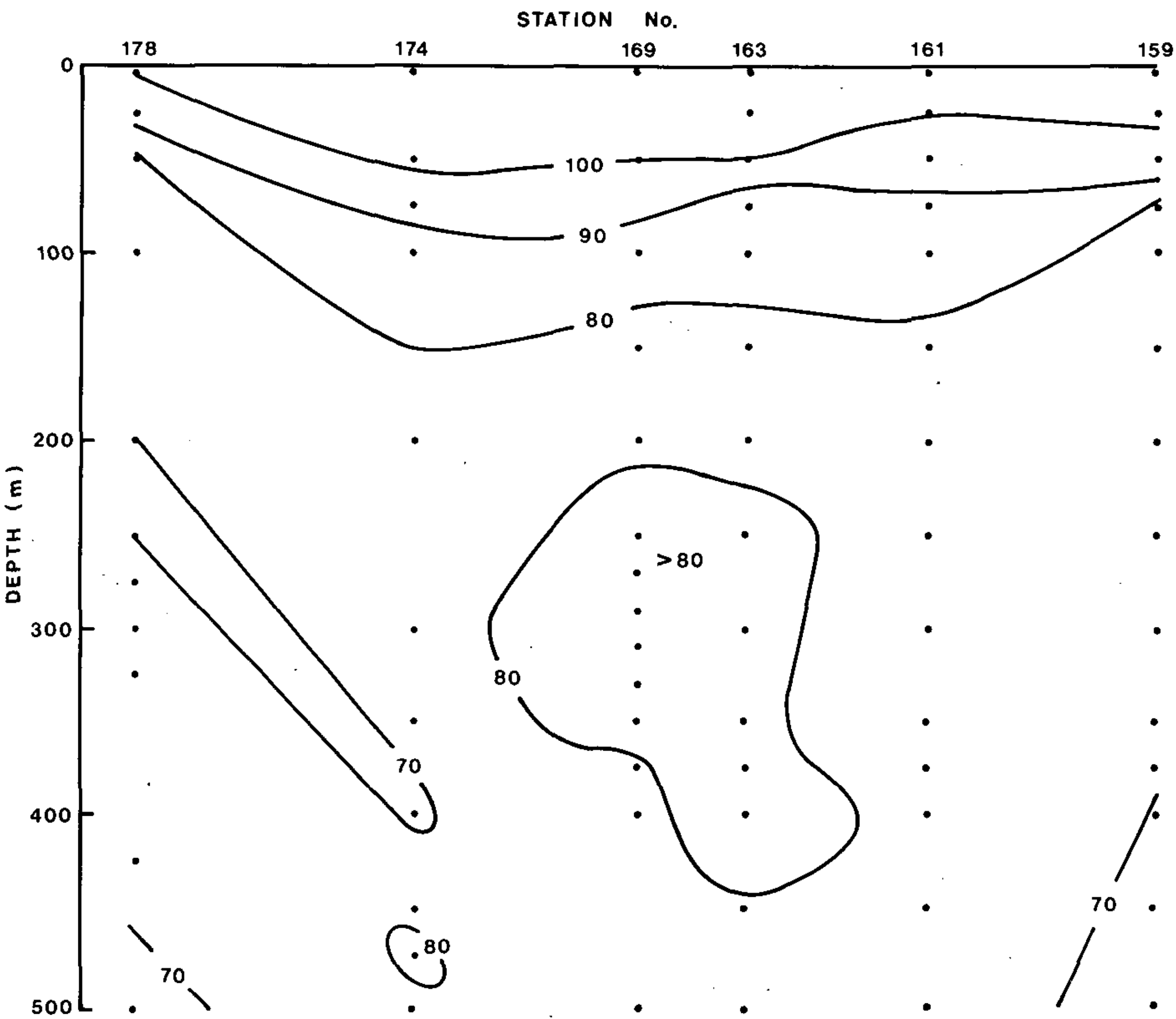

Fig. 5. The variation of dissolved oxygen (% saturation) across the warm core eddy.

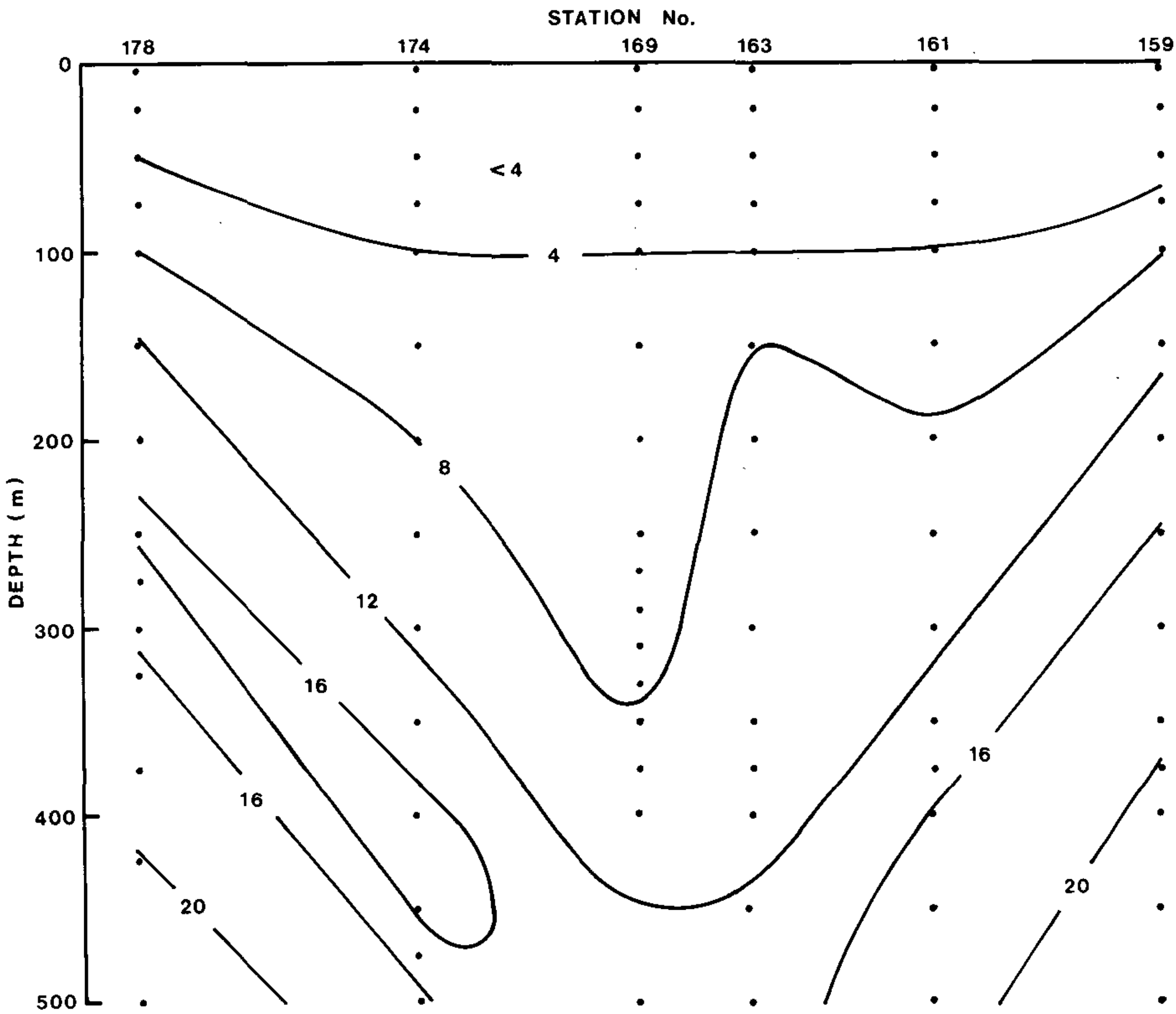

Fig. 6. The variation of nitrate (mmol m^{-3}) across the warm core eddy.

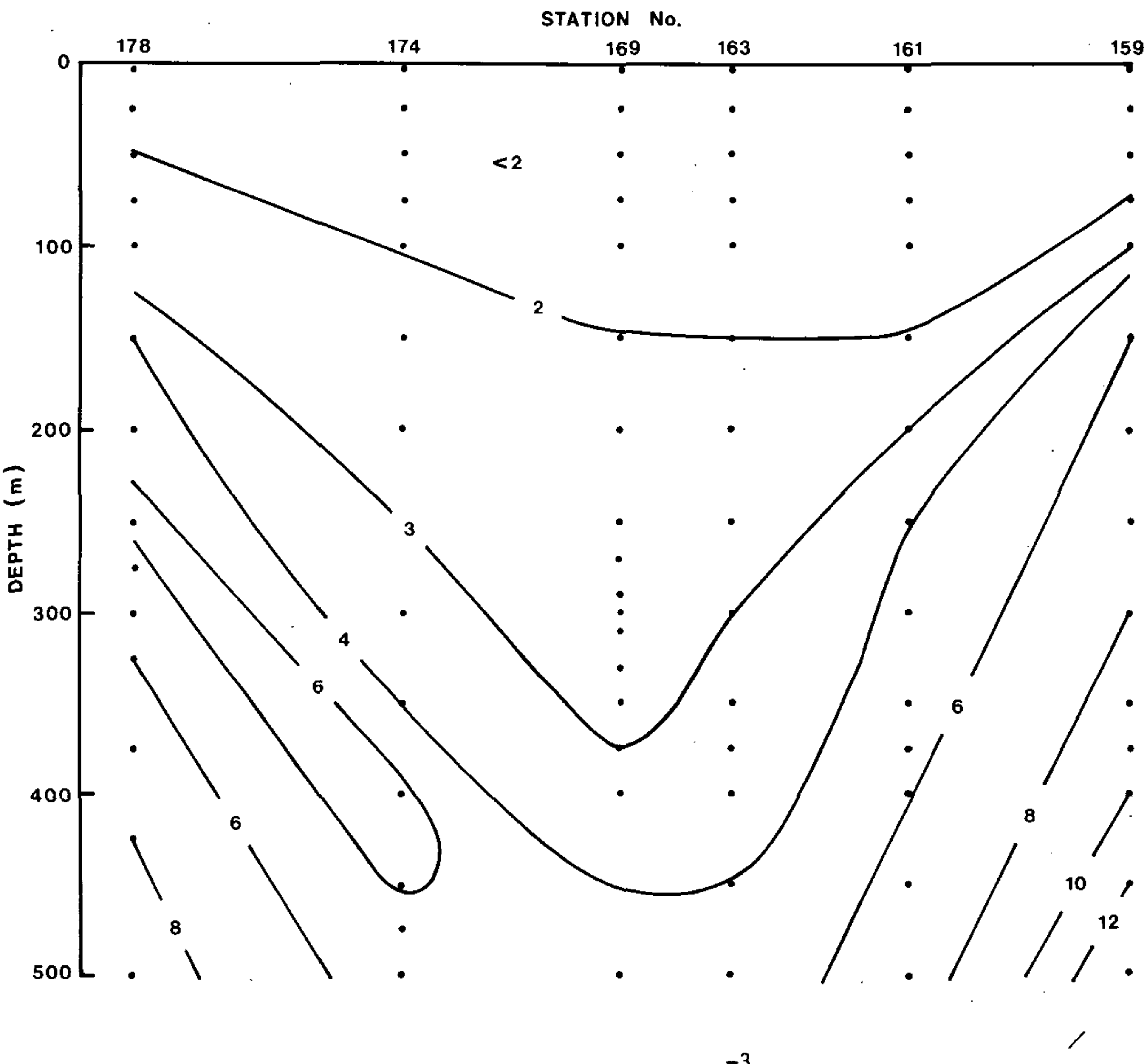

Fig. 7. The variation of reactive silicate (mmol m^{-3}) across the warm core eddy.

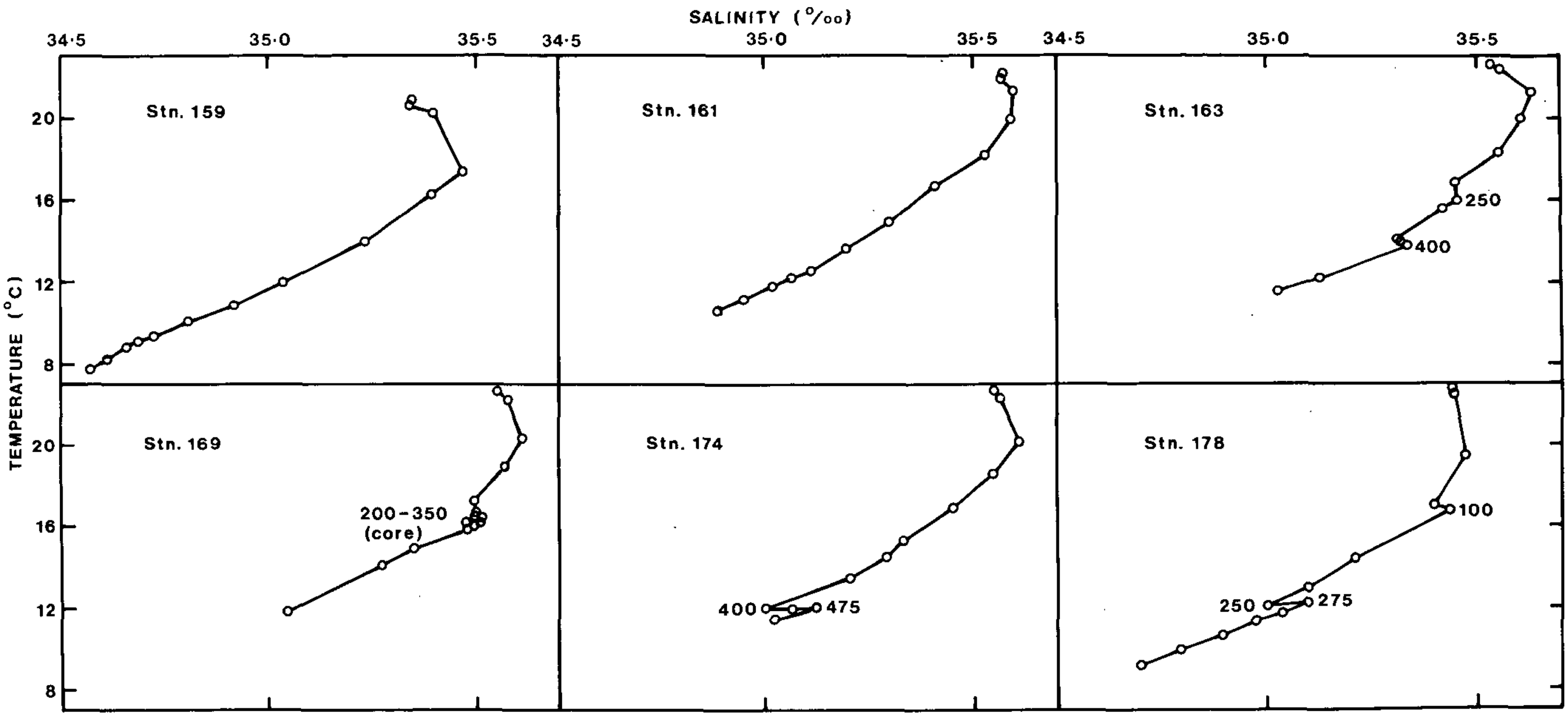

Fig. 8. Salinity-temperature relationships at the eddy stations. The depths (m) of the discontinuities are shown.

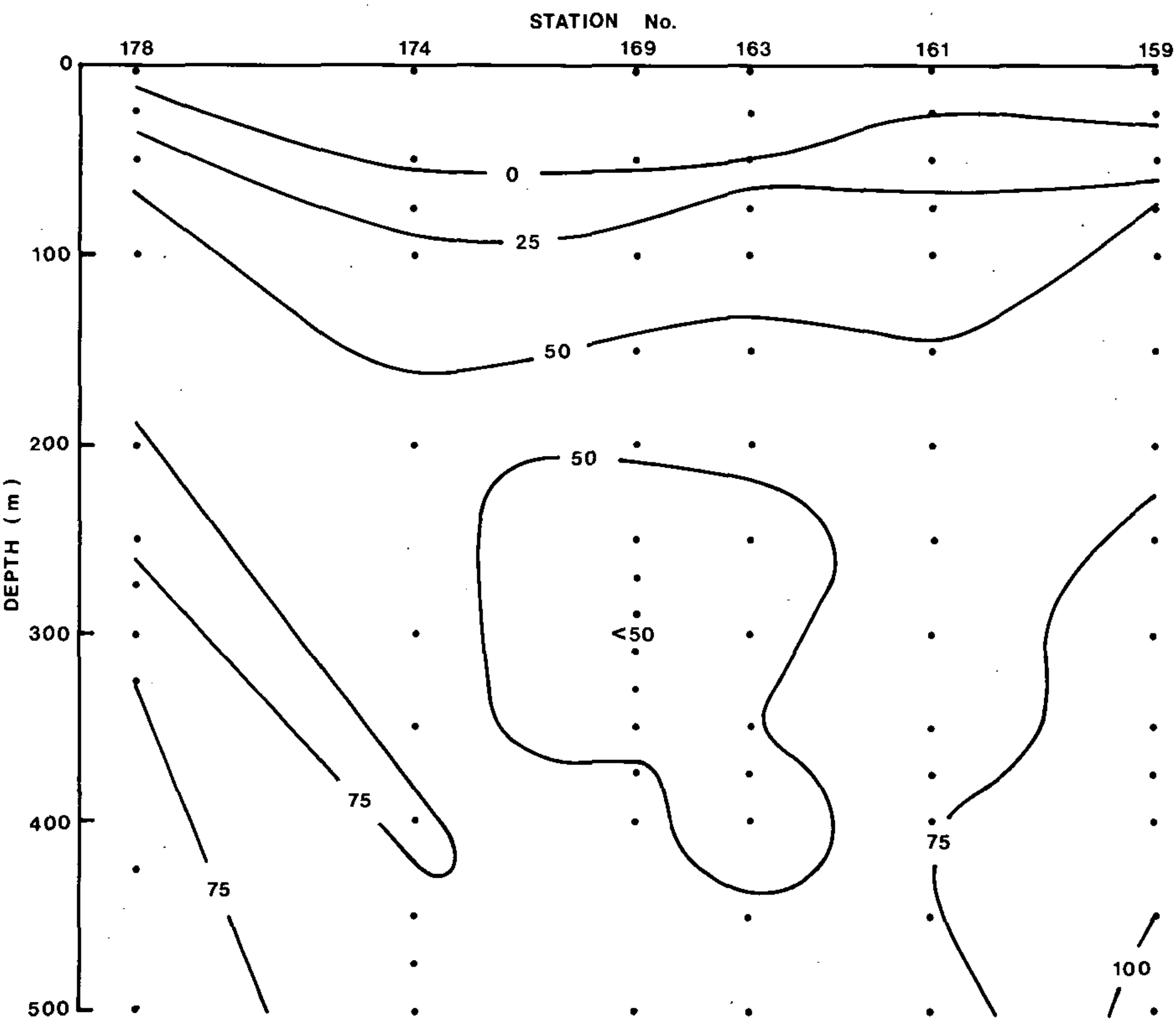

Fig. 9. The variation of apparent oxygen utilization, or AOU (mmol m^{-3}) across the warm core eddy.

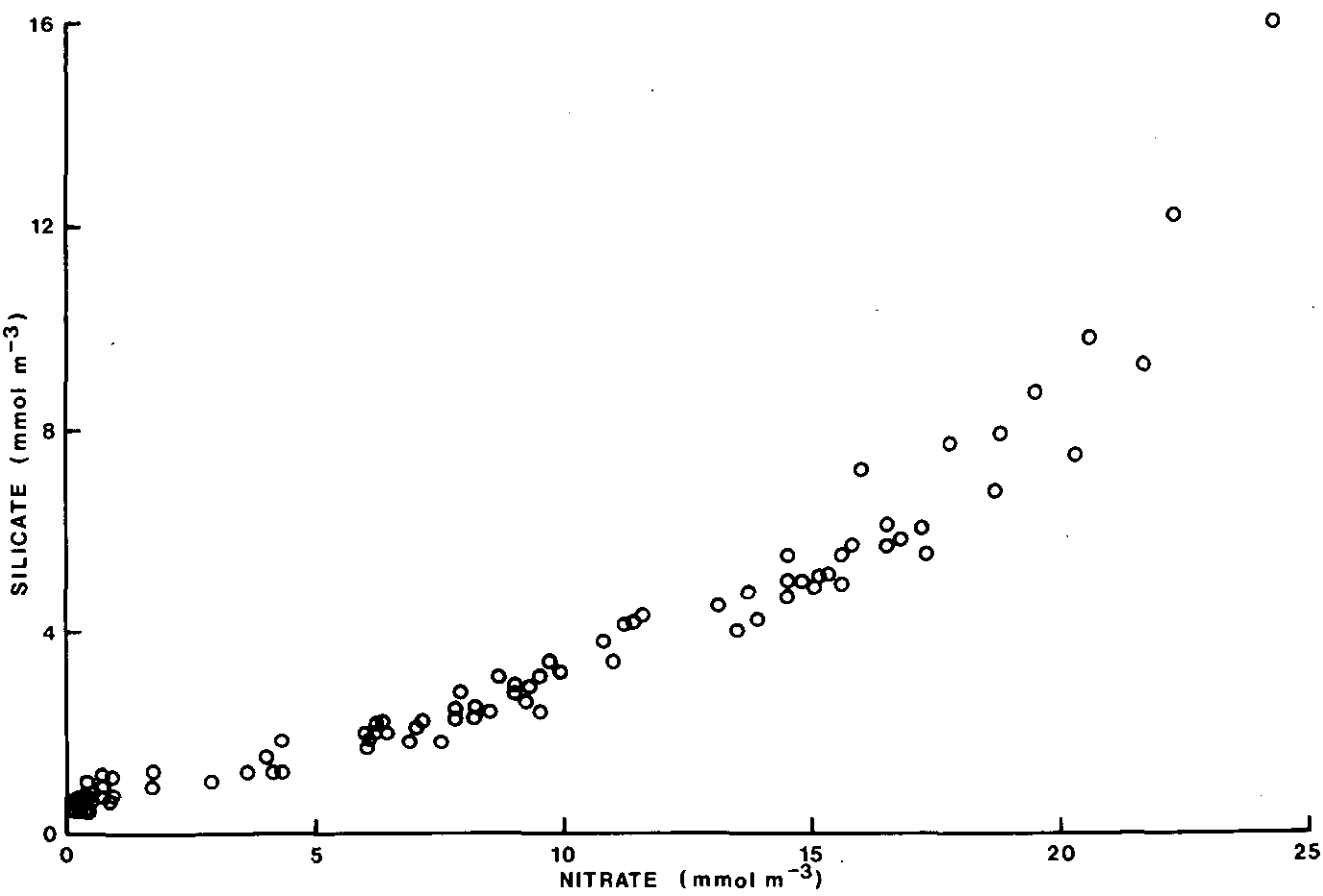

Fig. 10. The relationship of reactive silicate to nitrate at the eddy stations.

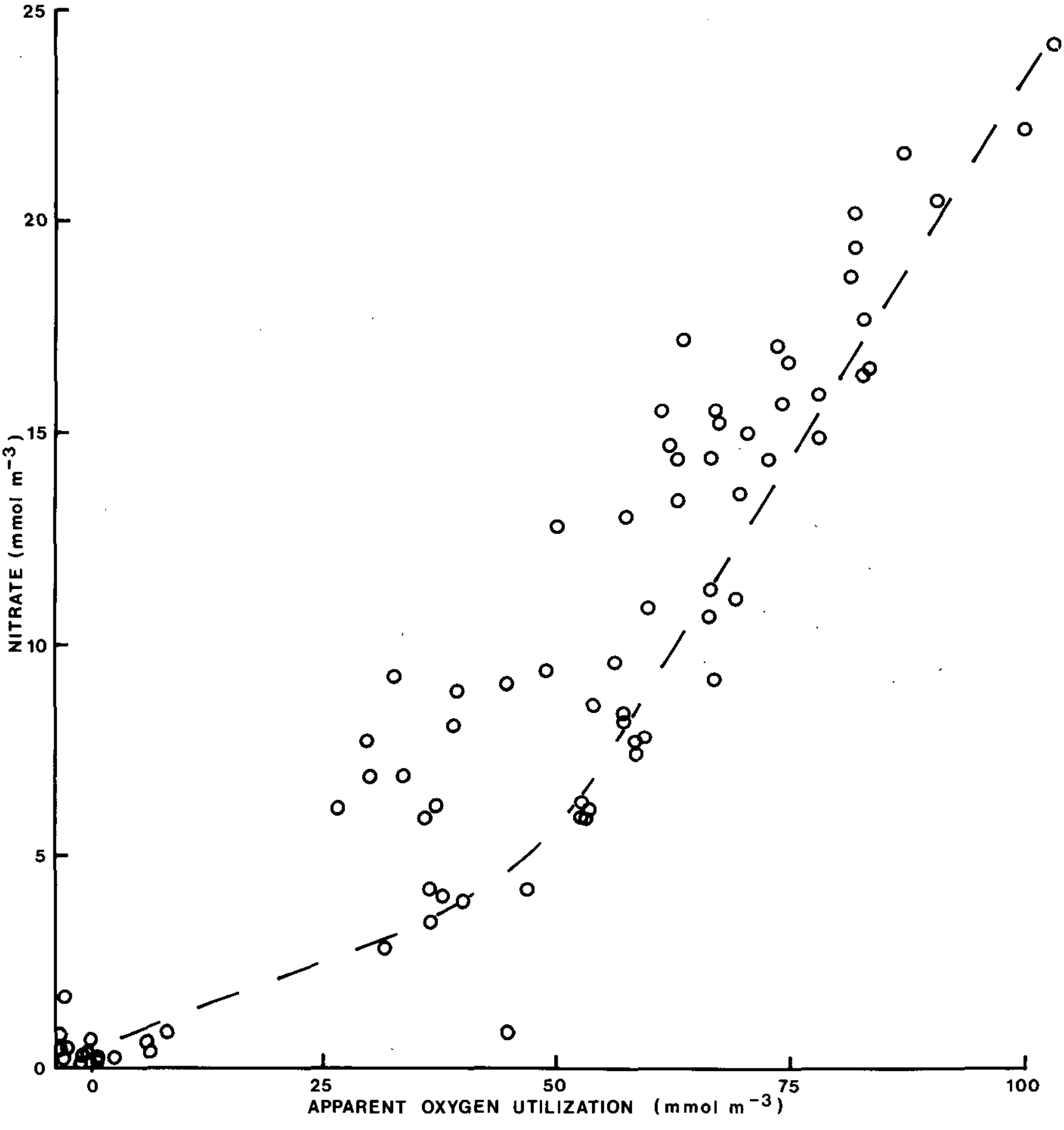

Fig. 11. The relationship of nitrate to apparent oxygen utilization, or AOU, at the eddy stations. The values for the outer eddy stations Nos. 178 and 159, lie close to the dashed curve.

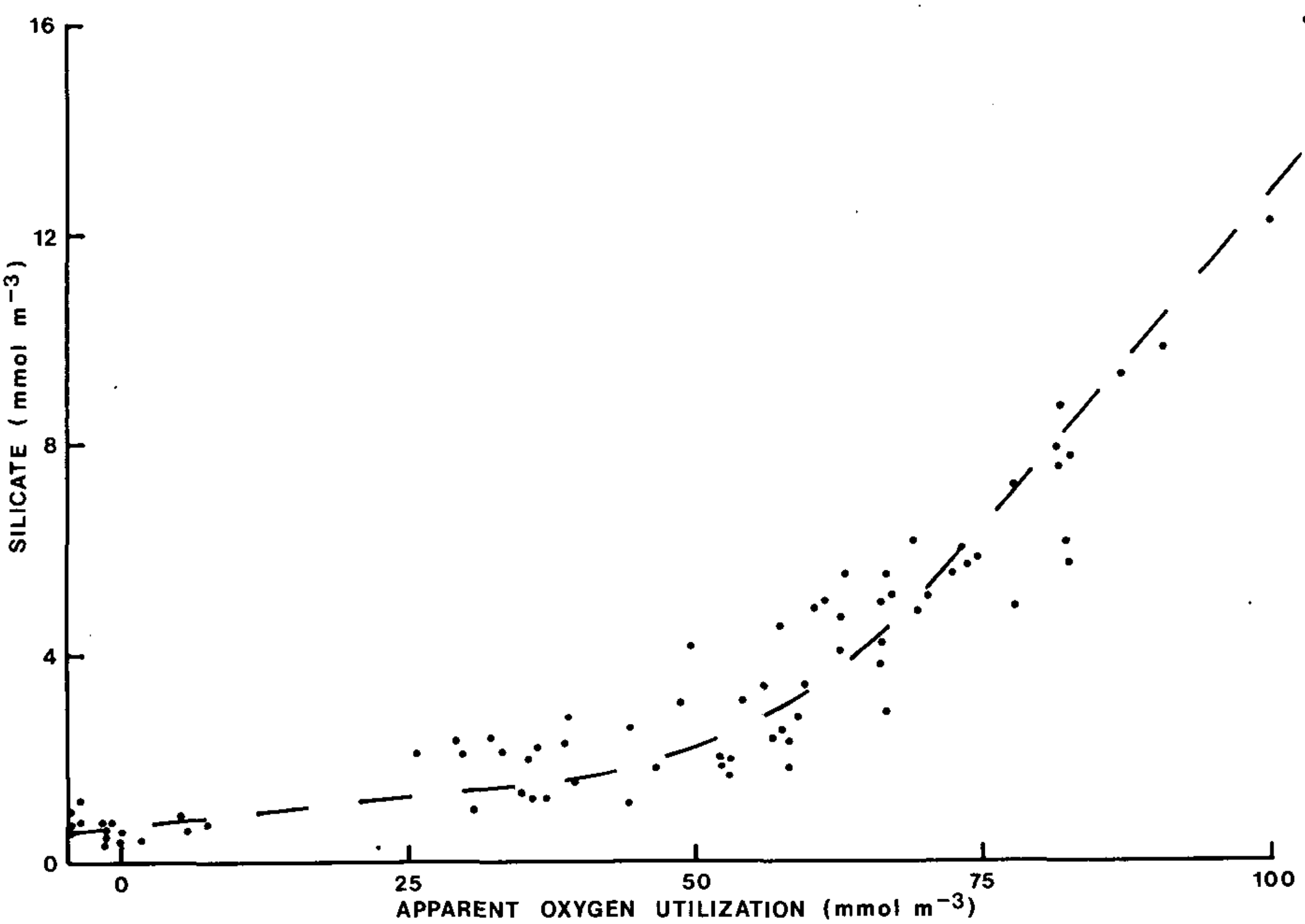

Fig. 12. The relationship of reactive silicate to apparent oxygen utilization, or AOU, at the eddy stations. The values for the outer eddy stations, Nos. 178 and 159, lie close to the dashed curve.