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Hydrology and hydrochemistry of the surface water layer near the sea-ice edge in the Scotia Sea (December 1988 – January 1989)

ABSTRACT: Four water masses were distinguished in the upper water layer between Elephant Island and the South Orkneys. Measurements of temperature, salinity, concentrations of dissolved oxygen and silicates were used for the analysis of the hydrological situation and to recognise the origin of water masses. For additional information, nitrates and chlorophyll concentrations were used. Drake Passage and Bransfield Strait waters occupied the western part of the investigated area, from surface to 150 m depth. Below, the Circumpolar Warm Deep Waters (CWDW) were found. The region east of 53.5°W was occupied by winter Weddell Sea water. Above this, a 45 m thin layer of summer modification of Weddell Sea Surface Water was found between 49°W and the South Orkneys. The highest chlorophyll *a* concentrations were found in this modified water.

Key words: Antarctica, hydrology, hydrochemistry, sea-ice zone.

Introduction

The structure of water masses in the region, where our research was conducted, is complex. Several masses are encountered in the vicinity of Elephant Island. Antarctic Surface Waters flowing through the southern part of the Drake Passage are modified on the shelf of the South Shetlands (Clowes 1934, Anonymus 1983). Waters flowing through the Bransfield Strait also undergo transformation in this strait, either by mixing with Weddell Sea waters or, in the result of processes taking place on the shelf of the Antarctic Peninsula (Clowes 1934, Gordon and Nowlin 1978, Tokarczyk 1987). In the vicinity of Elephant I, these two water masses, already partially modified, meet Weddell Sea surface water, which flows from the south-west. However, mixing of these waters is restricted by the Scotia Arc, which forms an effective barrier (Wüst 1926, Deacon 1937). Waters which meet over this submarine ridge form a relatively narrow, 10–100 km wide, zone called the Weddell-Scotia Confluence (WSC) (Gordon 1967, Patterson and Sievers 1980). This is the zone of relatively homogenous water between Circumpolar Warm Deep Water (CWDW) on one side, and Warm Deep Water of the Weddell Sea on the other and stretches from the region of the South Shetlands, through Elephant Island and the South Orkneys up to the South Sandwiches (Gordon, Georgi and Taylor 1977, Patterson and Sievers 1980). Latest data (Gordon and Huber 1984) suggest that some of its characteristics extend eastward to the Greenwich Meridian. The fronts marking the northern and southern edges of WSC have been called the Scotia Front, and Weddell Front respectively (Gordon, Georgi and Taylor 1977). Between Elephant I and the South Orkney Islands the boundaries of this zone are marked by a thin, homogenous water column, in which water temperature remains constant at depths from several hundred meters to several kilometers (Stein 1981, Anonymus 1983, Gordon 1988). However, in the upper water layer, from surface to a few hundred meters depth, this pattern is not visible (Sievers and Nowlin 1988). Formation of this homogenous column seems to be associated with intensive thermohaline convention, which takes place in the region in the periods of pack ice melting and formation (Deacon and Moorey 1975, Deacon and Foster 1977). In summer this homogenity is supported by the processes of vertical mixing caused by lateral friction between flowing water masses and the submarine ridge (Patterson and Sievers 1980). The sea ice edge extending along this front displays irregular patterns responsive to mesoscale activity (Carsey *et al.* 1986, Comiso and Sullivan 1986).

The aim of this study was to determine the structure and origin of water masses encountered in the upper 200 m layer, and thus to give the hydrological basis for interpretation of oceanobiological data collected on this region at the same time.

Materials and methods

In the period between December 29. 1988 and January 13. 1989 41 oceanographics stations located within 40 miles zone of the ice edge between Elephant I. and South Orkneys Is. were occupied (Fig.1). The geographical coordinates of the stations and other details of the r/v „Profesor Siedlecki" cruise are given in the expedition report (Rakusa-Suszczewski 1991). Measurements of salinity, temperature and dissolved oxygen from the surface to 1000 m depth were taken with Neil-Brown probe. The probe was calibrated with certified reversal thermometers GOHLA-KIEL (FRG), and the Plessey Model 6230N Laboratory Salinometer. The dissolved oxygen sensor was calibrated using the modified Winkler method (Carritt and Carpenter 1966).

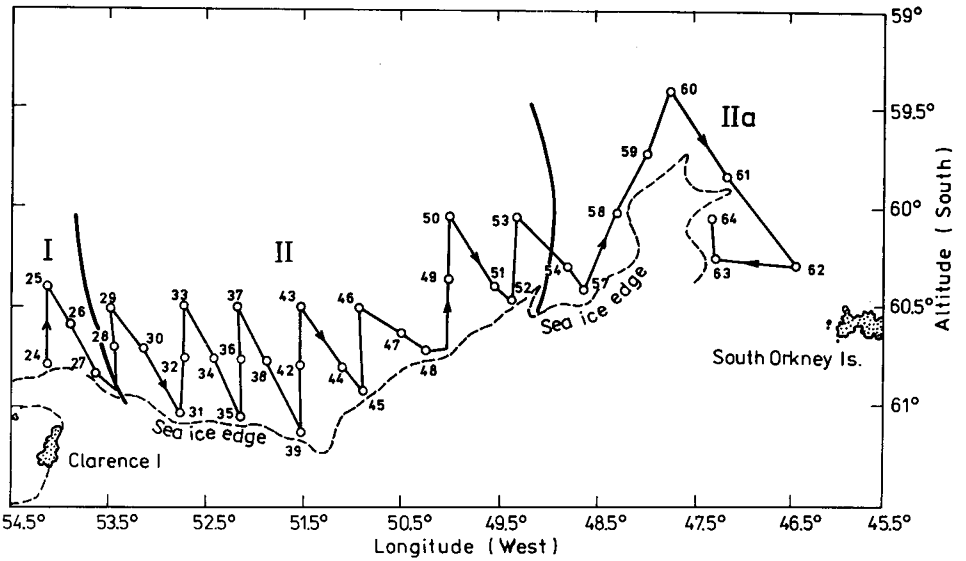

Fig. 1. Location of oceanographic stations during r/v „Profesor Siedlecki" cruise (Dec. 29 1988 — Jan. 9 1989) and surface distribution of water masses.
Description of water types see Fig. 2.

The water samples were collected at depths of 0, 10, 20, 30,40, 50, 75, 100, and 150 m with 5 liters Hydrobios bottles. The nutrients were analysed immediately using a Technicon autoanalyser; nitrates according to reduction method on a Cd–Cu column as modified by Mourino and Fraga (1985), silicates following the method of Hansen and Grasshoff (1983). Chlorophyll *a* content was measured as continuous fluorimetric records (Turner Design 1000 R) and additional spectrophotometric determinations were conducted at the oceanographics stations (Lipski 1991).

Results and discussion

The analyses indicated the presence of 4 water types in the research area (Figs. 1 and 2). The western part of the research area, between 54.5°W and 53.5°W was occupied by surface waters of the Bellingshausen Sea origin, flowing through the Drake Passage and the Bransfield Strait (type I, Figs. 1 and 2). These waters, extending from the surface to about 150 m depth had relatively high temperatures 0.4°C to 0.8°C (Fig. 3) and very low content of silicates 36 to 64 mmol/m^3 (Figs. 8 and 9). Both these parameters indicate, that these waters

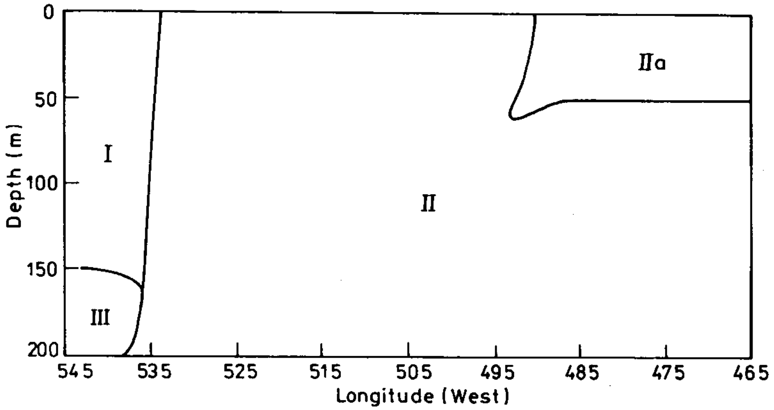

Fig. 2. Vertical distribution of water masses.
type I — Antarctic Surface Water of Bellinghausen Sea origin; type II — Weddell Sea Surface Water of winter modification; type IIa — Weddell Sea Surface Water of summer modification; type III — Circumpolar Warm Deep Water (CWDW)

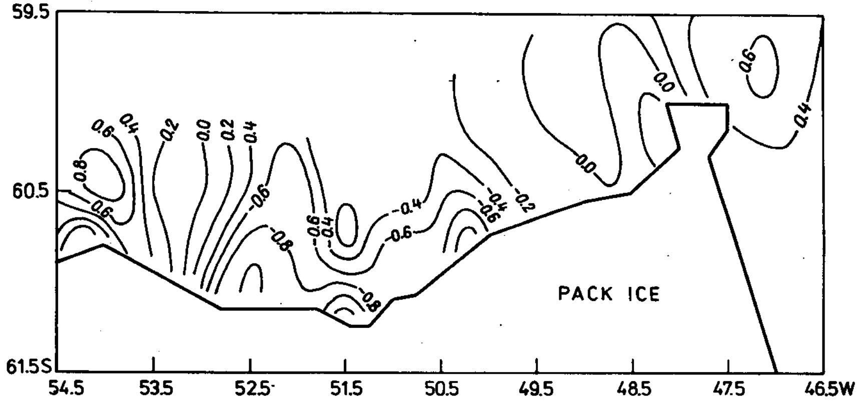

Fig. 3. Surface water temperature (°C) on the investigated area

flow along the shelf of the South Shetlands, through the southernmost part of the Drake Passage and the Bransfield Strait. This conclusion can be drawn, because waters which flow through the central part of the Drake Passage usually have higher surface temperature (> 1°C), and lower surface content of silicates (<20 mmol/m^3) (Kharitonov 1976, Salamanca and Acuña 1982; Szpiganowicz, Tokarczyk and Wojewódzki 1985, Tokarczyk 1987). Below these waters, from the depth of about 150–200 m Circumpolar Warm Deep Water (type III, Fig. 2) with a temperature of about 1.8°C (Fig. 4), and salinity 34.60 (Fig. 6) were found. In these waters dissolved oxygen content was very low (4.6 cm^3/dm^3) and the concentration of nitrates was very high (38 mmol/m^3). The eastern

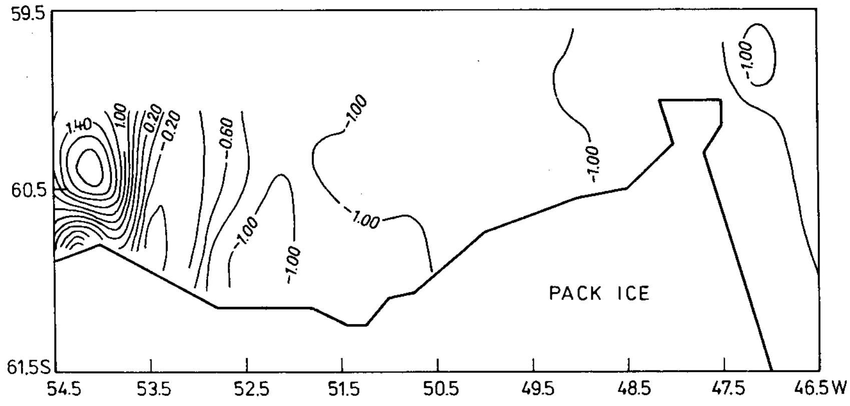

Fig. 4. Horizontal distribution of temperature (°C) at 200 m depth

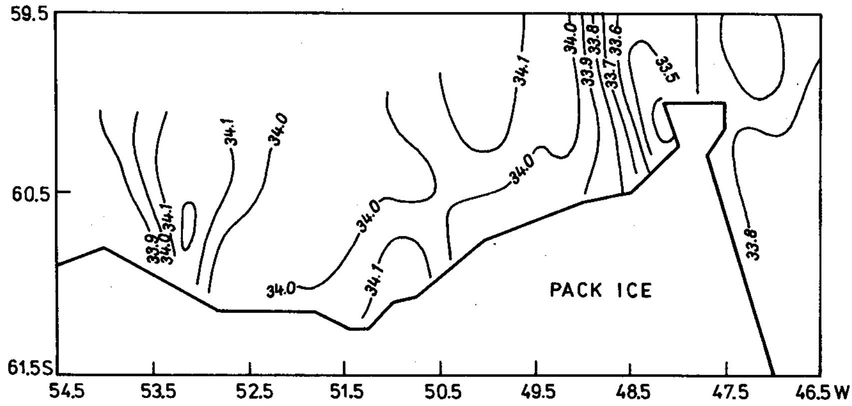

Fig. 5. Surface water salinity on the investigated area

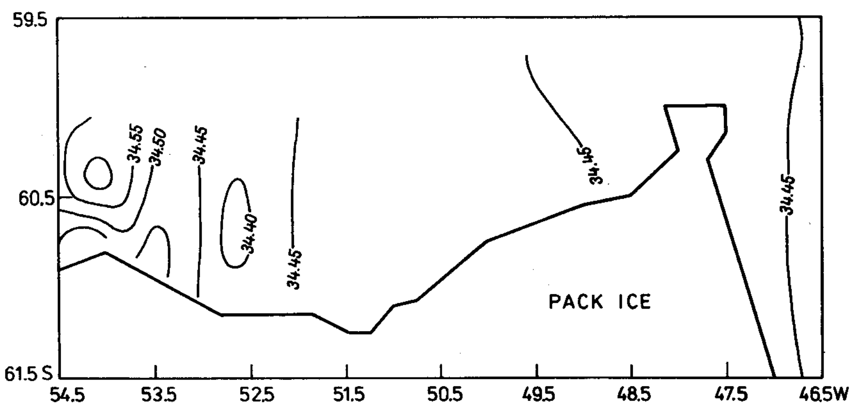

Fig. 6. Horizontal distribution of salinity at 200 depth

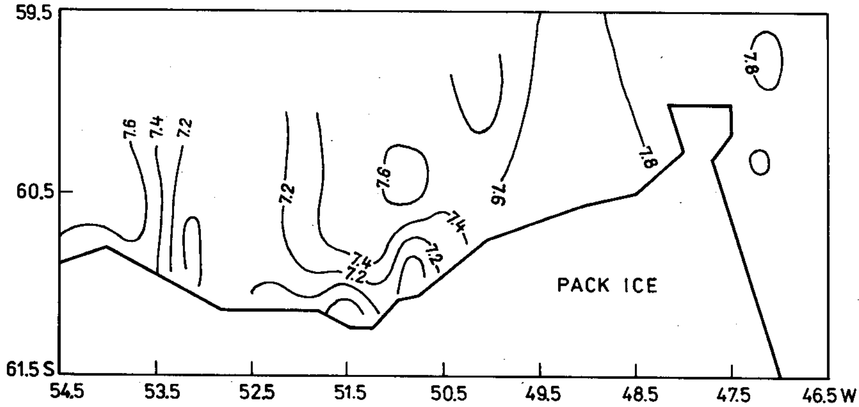

Fig. 7. Distribution of dissolved oxygen in the surface water (cm^3/dm^3)

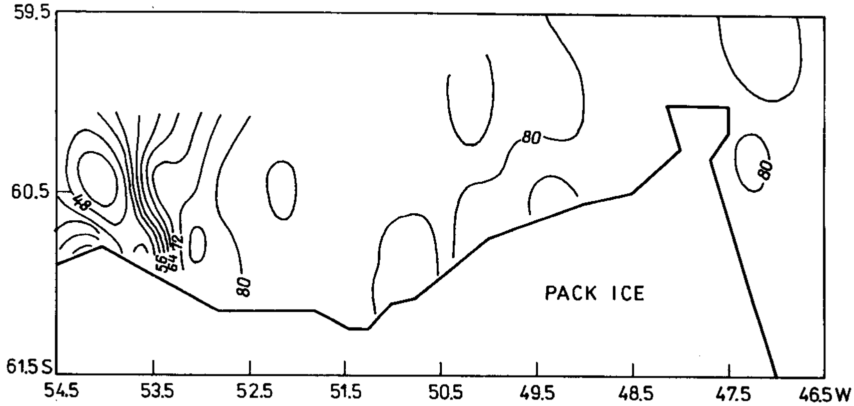

Fig. 8. Distribution of silicate contents in the surface water ($mmol/m^3$)

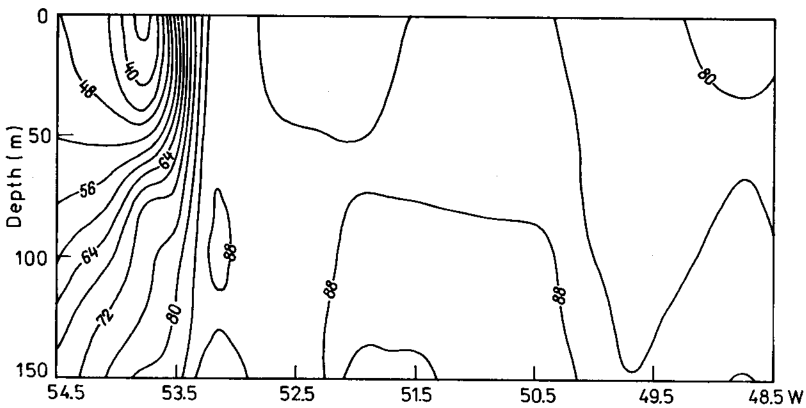

Fig. 9. Vertical distribution of silicates to the depth 150 m ($mmol/m^3$)

boundary of these two water masses shows the positions of the Scotia Front, which in this region is directed from south to north along 53.5°W. This is in a very good agreement with earlier data (Anonymus 1983). Using the silicate distribution seems to be most convenient to determine the position of this front. The concentration changed from 32 to 80 mmol/m^3, i.e. from the values typical for the waters flowing through the Drake Passage to those typical for the Weddell Sea (Arzhanova 1974, Kharitonov 1976, Szpiganowicz, Tokarczyk and Wojewódzki 1985). Horizontal and vertical sections of silicates distribution (Figs. 8 and 9) showed very sharp gradients that precisely confirm the conclusions which can be drawn from temperature and salinity distributions. The possibility of using the gradient of silicates for determining the position of WSC has been indicated by Bogdanov *et al.* (1969), Arzhanova (1974), and confirmed later by Smith and Nelson (1986).

The central and eastern parts of the study region, east of 53.5°W were occupied by surface waters of the Weddell Sea origin (type II and IIa, Figs. 1

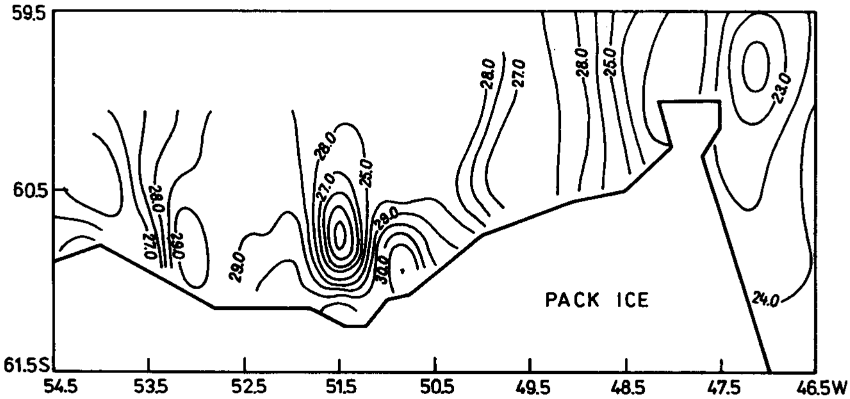

Fig. 10. Distribution of nitrate contents in the surface waters (mmol/m^3)

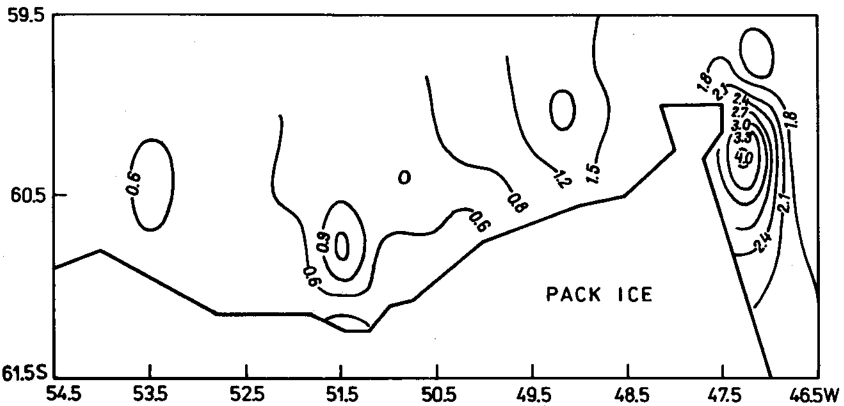

Fig. 11. Distribution of chlorophyll *a* values in surface waters (mg/m^3)

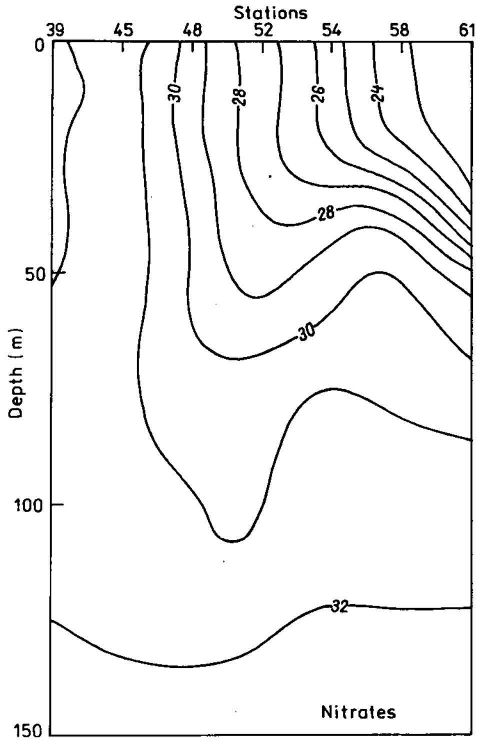

Fig. 12. Vertical distribution of nitrates to the depth 150 m (mmol/m^3)

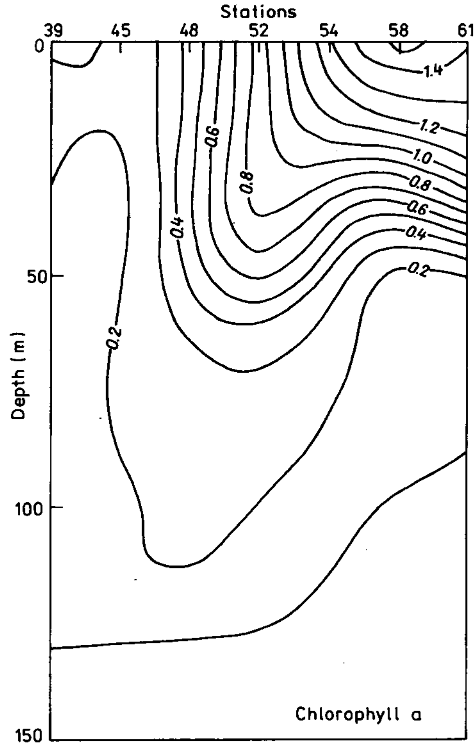

Fig. 13. Vertical distribution of chlorophyll *a* to the depth 150 m (mg/m^3)

and 2). This relatively homogenous and cold winter water (temp. from –0.2° to –1.0°C, Figs. 3 and 4), of high salinity (34.0 to 34.5, Figs. 5 and 6) had dissolved oxygen content ranging from 7.2 cm^3/dm^3 at surface (Fig. 7) to 6.4 cm^3/dm^3 at the depth of 200m. The content of silicates was high and fluctuated close to 80 mmol/m^3 (Figs. 8 and 9). These parameters showed clearly that this was the water of the Weddell Sea origin.

In the eastern part of the study region, between 49°W and the South Orkney Is. a thin layer (about 45 m) was encountered of distinctly warmer (from 0° up to 0.6°C, Fig. 3), and less saline (33.4 – 33.8, Fig. 5) surface waters of summer modification (type IIa). Below a depth of about 45 m, temperature and salinity equalled to the values typical for cold waters of the central part of the study region. The content of silicates was high (> 80 mmol/m^3), proving that this water was of the Weddell Sea origin. Probably the observed layer was a fragment of a larger lens of modified water, which could be formed as a result of local heating and ice melting. The occurrence of such lenses of low salinity waters was observed in other marginal ice zones (Alexander and Niebauer 1981, Smith and Nelson 1985, Smith *et al.* 1985) and has been attributed to ice melting. These lenses were frequently associated with phytoplankton biomass maxima and local decrease in nutrient (especially nitrate) concentrations (Nelson and Smith 1986). As it was shown by Nelson *et al.* (1987) such decrease results from uptake by phytoplankton rather than from dilution by meltwater. During our investigations this was confirmed by local near surface chlorophyll maximum (>4.0 mg/m^3, Fig. 11) and decrease of nitrate content observed in water layer of type IIa (Fig. 10). Relatively high chlorophyll *a* value showed that a phytoplankton bloom had taken place and was probably still developing. In water layer of type IIa, low density of meltwater enhanced the vertical stability of the water column, restricting vertical movement and preventing phytoplankton dissipation by physical processes. However, some of these processes were visible. On vertical sections along stations 39, 45, 48, 52, 58 and 61 the distribution of nitrates (Fig. 12), and chlorophyll (Fig. 13) showed a characteristic downwelling pattern. Waters present near the lower boundary of modified surface water (type IIa) were carried downwards into water of type II to about 100–120m depth, 50.5°W. A density front at the boundary between these two water masses which was visible in the salinity distribution (Fig. 5), was also influenced by this local downwelling. More detailed analysis of its structure reveals, that it consisted of two parts. The eastern branch, with higher salinity gradient, delimited less saline water. In the western one, observed between stations 45 and 48, the gradient was less pronounced, but it extended deeper.

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Streszczenie

Na badanym obszarze, 40-milowej strefie przylegającej do skraju dryfującego paku lodowego rozciągającego się pomiędzy wyspą Elephant i Południowymi Orkadami, w powierzchniowej warstwie do głębokości 200 m wyróżniono 4 masy wodne (Rys. 1, 2). Od wyspy Elephant do 53.5° w warstwie do 150 m występowała zmodyfikowana woda pochodząca z morza Bellinghausena (typ I). Poniżej tej warstwy znaleziono wokółantarktyczną ciepłą wodę głębinową (CWDW, typ III). Na wschód od 53.5° na całym badanym przez nas obszarze, aż do Płd. Orkadów występowały wody pochodzące z morza Weddella. Większość tego akwenu zajmowana była przez zimne i stosunkowo jednorodne wody powierzchniowe o zimowej modyfikacji. Od 49°W do Płd. Orkadów w cienkiej warstwie powierzchniowej do głębokości 45 m znaleziono wody cieplejsze i mniej zasolone. Wysoka zawartość krzemianów w tych wodach (Rys. 8 i 9) pozwala na rozpoznanie tych wód jako letniej modyfikacji powierzchniowych wód morza Weddella (typ IIa).

Rozmieszczenie wartości temperatury, zasolenia, zawartości O_2, krzemianów, azotanów oraz chlorofilu *a* na badanym obszarze przedstawiają rysunki od 3 do 13. Zakwit fitoplanktonu (ze stężeniami chlorofilu 4.0 mg/m^3) zaobserwowany był w wodach typu IIa, które z rozpoznanych przez nas mas wodnych, posiadają największą stabilność kolumny wodnej.