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GLACIOLOGICAL INVESTIGATIONS IN THE FRONTAL ZONE OF THE FILCHNER AND RONNE ICE SHELVES

by

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ABSTRACT

In the 1979-80 field season, a site survey was carried out in the southern Weddell Sea for the construction of a wintering station. The survey comprised glaciological investigations on the Filchner and Ronne ice shelves, such as ice movement, deformation, ice thickness, calving, accumulation, and snow temperature measurements which are relevant to mass-balance studies. Along with the investigations on the ice, oceanographical and bathymetrical observations were carried out along the ice front. The field data and observations lead to assumptions about the advance of the ice shelf as well as about the mass loss at the frontal zone due to calving and bottom melting. The ice-front velocity at 50°W is about 1 070 m a^{-1} and the bottom melting is estimated to be 3.2 m a^{-1} at 20 km south-west of the ice front.

INTRODUCTION

As part of the Antarctic research programme of the Federal Republic of Germany, it was planned to establish a wintering station on the continental fringe of the southern Weddell Sea. Since vast areas of this region are still unexplored, a site survey was carried out during the 1979-80 season using the Norwegian vessel Polarsirkel, together with two helicopters. The expedition operated along the coastline between 8°W and 62°W, particularly concentrating on the Filchner and Ronne ice shelves (Fig.1).

The task was to search for a suitable, crevasse-free area west of Berkner Island with access to the ice shelf from the sea. Furthermore, various glaciological parameters such as accumulation, density, and temperature distribution in the snow, and ice movement and thickness had to be investigated; these are relevant to the station construction as well as to future mass-balance studies planned in this region.

During the field season, the position and height of the ice front were surveyed between Halley and the Antarctic Peninsula. On the Ronne Ice Shelf at 77°09'S, 50°30'W, where a summer camp was established, the temperature and density distribution in the upper 10 m and the accumulation rate were determined. Ice movement and deformation were studied at the camp site and near the ice front. Ice thicknesses were obtained from radio echo-soundings on profiles parallel and perpendicular to the coastline. Water depths along the ice front were recorded continuously. Besides the glaciological investigations, oceanographical observations of salinities, temperatures, and currents were carried out along the ice shelf.

Since the area investigated is rather limited and most measurements, with the exception of Doppler positioning and accumulation rate, could be neither repeated nor extended in the following season, this presentation is confined to the discussion of a limited amount of field data. The investigations have to be regarded as a pilot study, which will be extended during the next few years to obtain comprehensive information on the mass-balance parameters in this region.

FIELD OBSERVATIONS

(a) Position of the ice front

The position of the ice front and its height were surveyed from Halley westward as far as the Antarctic Peninsula. The ice front was mapped with the aid of the ship's Doppler satellite-positioning instrument (Nautikon) together with the radar and the gyro compass. The accuracy of this method is about ±2 km. The height of the ice front was estimated by optical methods and sporadically by altimetry, using the helicopter, giving an accuracy of about ±10%*.

The 1979-80 position of the ice front is plotted in Figure 1, together with the ice front of 1957. The height of the ice front between satellite-controlled positions is given in Table I. The movement of the ice shelf in the frontal zone at 50°W was determined in 1979-80 with two Doppler satellite-positioning instruments (Magnavox). The positions were remeasured in 1980-81 with the same instruments. The ice flow is 1 050 to 1 070 m a^{-1}, with an accuracy of <10 m a^{-1}, and its direction is about 055° true (Möller and Gerdau submitted for publication**).

(b) Crevasses and calving at the ice front

Between the heavily crevassed flanks of Berkner Island and the great inlets in the west (55°W), crevasses were only found near the ice front. These crevasses were 0.3 to 0.5 m wide, following the ice front at distances of only a few metres. Steady calving was observed between the ice front and the crevasses. Since markers had been placed close to the ice front for geodetic measurements, the rela-

*The survey of the ice front and the compilation of data were carried out by the expedition members Fuchs, Gerdau, Henning, Klapdor, Möller, Reinwarth, Suhrmeyer, and the author.

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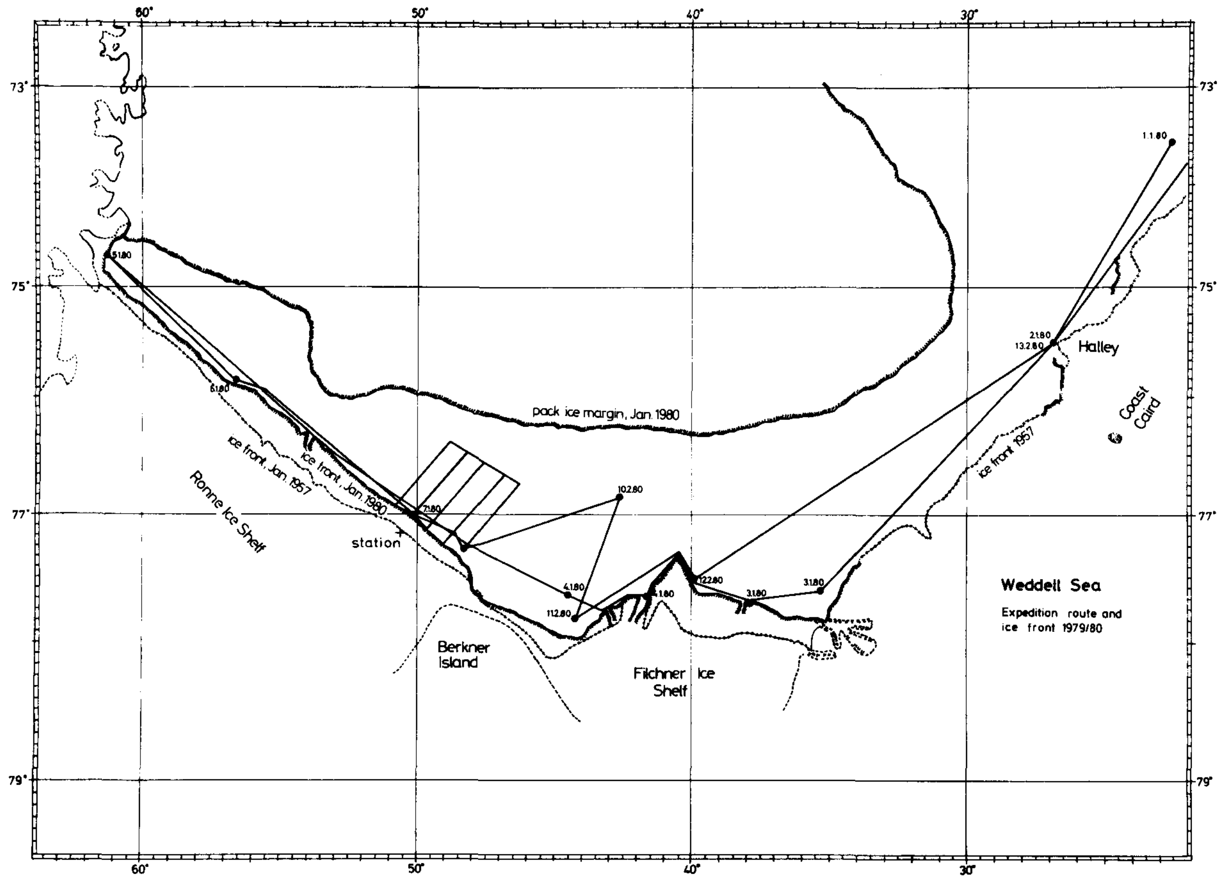

Fig.1. Route of the expedition and ice-front positions of 1957 and 1980.

TABLE I. MEAN HEIGHTS OF THE ICE FRONT/ICE WALL BETWEEN HALLEY AND THE ANTARCTIC PENINSULA, DETERMINED OPTICALLY FROM ON BOARD SHIP AND PARTLY BY HELICOPTER ALTIMETRY. THE COORDINATES WERE MEASURED BY DOPPLER SATELLITE-POSITIONING AND GIVE THE RANGE IN WHICH THE HEIGHT DETERMINATIONS WERE CARRIED OUT

Surveyed area with satellite-controlled positions	Mean height of ice front/ice wall (in m)	Remarks
25°15'W - 27°36'W 74°39'S - 76°06'S	20-45	Continuous high cliff with single inlets; Brunt Ice Shelf.
28°26'W - 36°12'W 76°08'S - 77°41'S	-	The coast is formed in this section by heavily crevassed glaciers.
36°48'W - 41°24'W 77°45'S - 77°34'S	10-20	Filchner Ice Shelf; continuous low ice front; slightly increasing from 10 to 20 m near 40°54'W.
42°09'W - 48°59'W 77°39'S - 77°10'S	(35-40) 40	Gould Bay ice wall, Berkner Island; Gould Bay was covered with fast ice; optical height determinations were only sporadically possible; the values in brackets result from helicopter survey (altimeter).
50°00'W - 55°57'W 77°00'S - 75°53'S	7-15	Ronne Ice Shelf; continuous low ice front; steep surface slope inland.
56°23'W - 61°18'W 75°53'S - 74°50'S	20-30	Ronne Ice Shelf to Antarctic Peninsula; the height of the ice front increases suddenly to 30 m at a small inlet at about 56°W; continuous high cliff.

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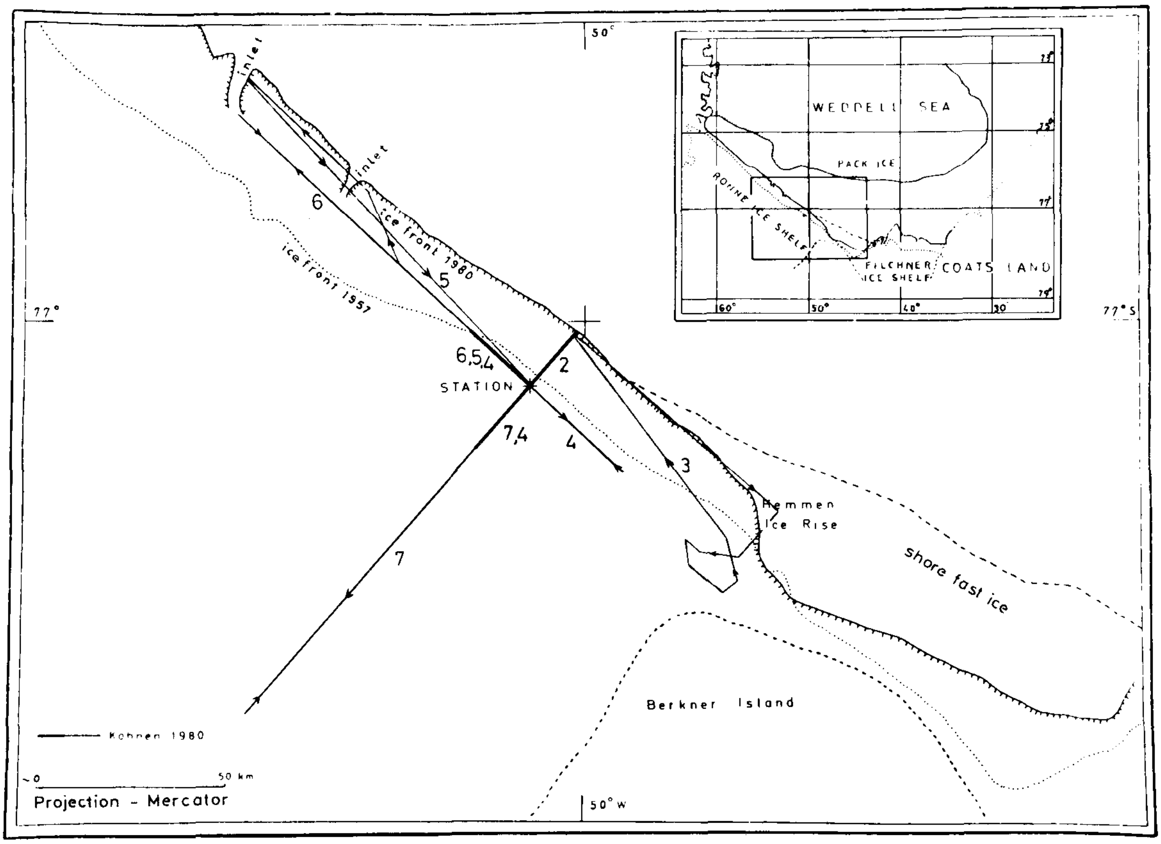

Fig.2. Flight lines of the radio echo-sounding flights.

tive retreat of the ice front within five weeks due to calving could be estimated to about 10 to 15 m. Large tabular icebergs, originating from the ice shelf in the observation area, have not been found.

In 1980-81, the same region was only inspected briefly. Calving for the year was estimated to have been about 100 m.

(c) Radio echo-soundings

Radio echo-soundings were carried out for the crevasse survey in the station area and also for ice-thickness measurements. A SPRI Mark IV system, mounted in a helicopter (Bell Jetranger), was used. The flight lines are shown in Figure 2. The maximum length was 140 km, limited by the range of the helicopter. The navigation was achieved by dead-reckoning from flight direction, ground speed, and flying time. Since no inertial navigation system was available, the error in the positioning amounts to ±5 km at the end point of the 140 km flight line. Ice thicknesses obtained on profiles perpendicular to the ice front (flight lines 2 and 7) are plotted in Figure 3. The surface topography between the ice front and the station was determined by geodetic methods (Möller and Gerdau submitted for publication). The ice-shelf elevations south-west of the station are obtained from equilibrium considerations and represent a mean buoyancy profile. Surface and bottom slopes are very steep for the first 500 m with the ice thickness increasing from about 90 to 150 m. The increase slows, reaching 230 m at the station and a maximum of 320 m at 54 km south-west of the ice front (Fig.3). A striking feature is the strong decrease in ice thickness observed south-west of 54 km, together with a considerable weakening of the bottom echo. Figure 4 shows the ice-thickness isopleths, as far as they can be deduced from our measurements.

BATHYMETRY

Routine bathymetrical measurements were carried out during the whole cruise using the ship's depth recorder (Simrad EK 12). A bathymetrical chart of the southern Weddell Sea is compiled from our data together with those of Kvinge (1968) and Admiralty Chart 5011 (Fig.5). The most prominent features are the well-known Filchner depression, the morphological high north of Berkner Island, which extends NNE to the continental slope at 74°S, and a depression west of 52°W. Figure 6 shows the bottom topography along the ice front, accentuating these three features. Apart from a single high of 350 m depth, the bottom west of Berkner Island gently slopes down from 250 m to more than 600 m, close to the Antarctic Peninsula. The depth records showed several iceberg scours (crosses in Figure 5) on the morphological high in the depth range between 300 m and less than 250 m. Many grounded icebergs originating from farther east were observed in this area during the field season. Most strikingly, however, iceberg scours were also found at depths of 400 to 500 m east of Berkner Island, which can hardly be explained in terms of recent iceberg passages. The iceberg scours were some hundred metres wide and 10 to 30 m deep.

DISCUSSION

Comparing the ice fronts of 1957 and 1979-80 of the Ronne Ice Shelf (Fig.1) yields an apparent advance of 15 to 25 km within 23 years. Extrapolating the difference between ice movement and estimated annual break-off back to 1957 would give an advance of 20 to 23 km over this period, which matches fairly well the apparent advance deduced from the two ice-front positions. One could conclude that the Filchner-Ronne system has been advancing for at least two

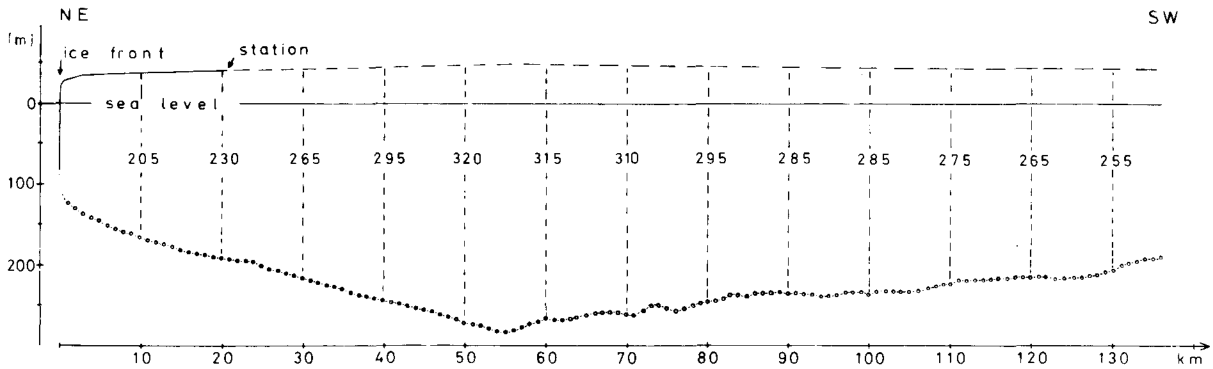

Fig.3. Ice thicknesses on a 140 km profile at 77°S, 50°W perpendicular to the ice front (see text for explanation).

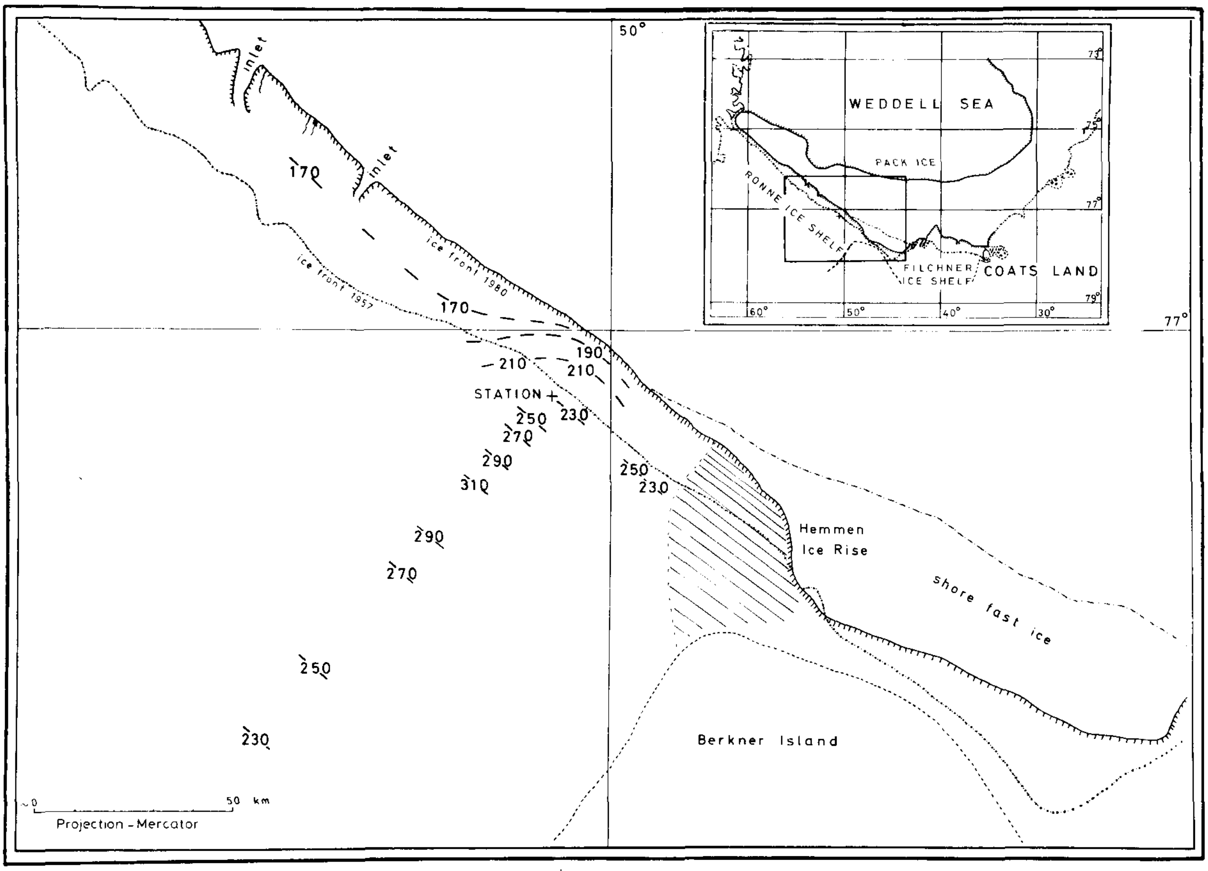

Fig.4. Ice-thickness isopleths.

decades. However, this assumption implies that there are no errors in the measurements. The satellite-controlled positions have an error of about ±2 km No satellite instruments were available in 1957, and the error in those positions is consequently much higher. The differences between the ice-wall positions of 1957 and 1980 are considerably smaller on Berkner Island, where the ice movement is slower, which lends support to the idea that the ice front advances are real. Remeasurements during the forthcoming years will show whether or not the Ronne Ice Shelf is advancing by more than 1 km a^{-1}, less 10% due to calving.

The wedge-like cross-section in the frontal part of the ice shelf at 50°W, 77°S (Fig.3) is probably caused by bottom melting. Gammelsrød and Slotsvik (submitted for publication*) have recorded strong tidal currents flowing under the ice with velocities up to 0.3 to 0.4 m s^{-1}. The inflowing water is 0.20 to 0.25°C warmer than the outflowing water. Both researchers deduce from their investigations that, besides the tidal current, there is also a general influx of water masses in this region. Strong melting increasing with depth may consequently occur at the ice front due to current components parallel to the ice front enhanced by heat advection from the warmer waters and down-welling warm water during the summer. The various mechanisms contributing to

* To be published as "Physical oceanography of the Weddell Sea. Some results from the German expedition 1979/80".

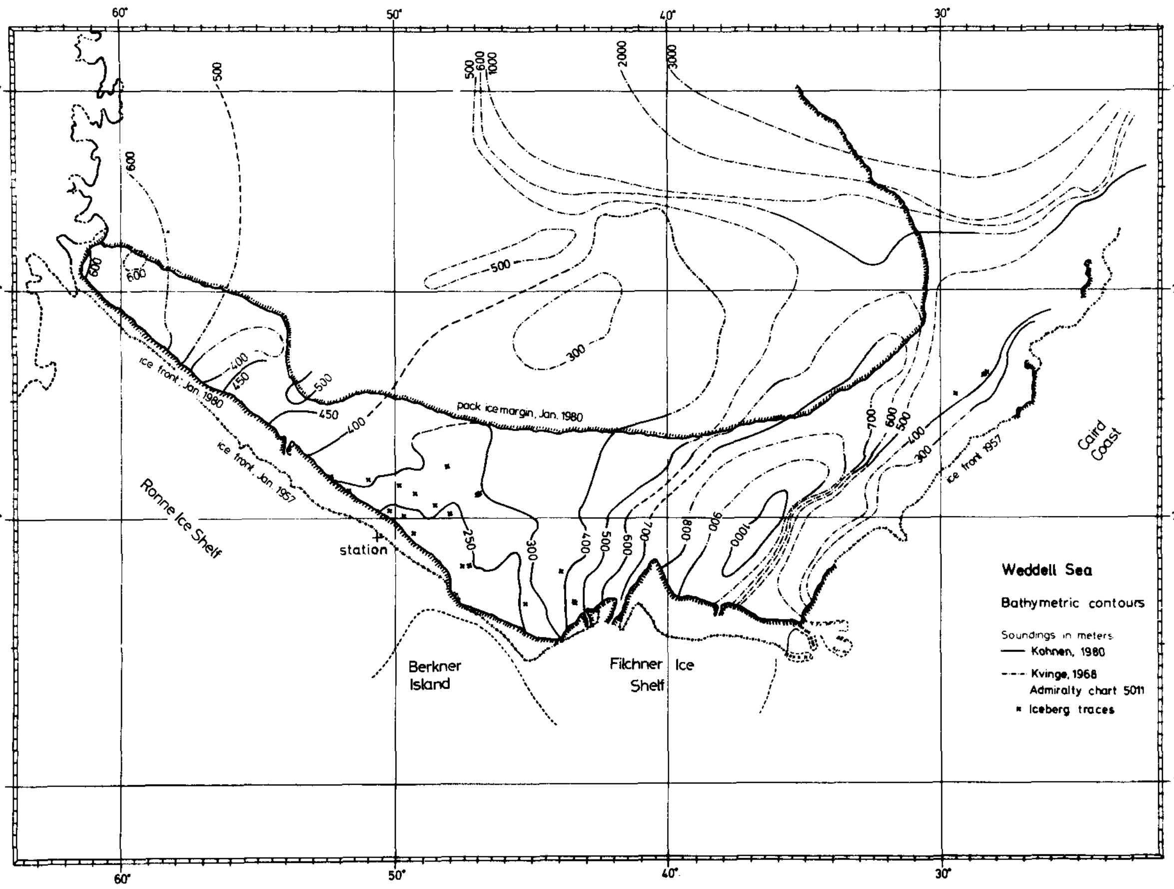

Fig.5. Bathymetrical chart of the southern Weddell Sea.

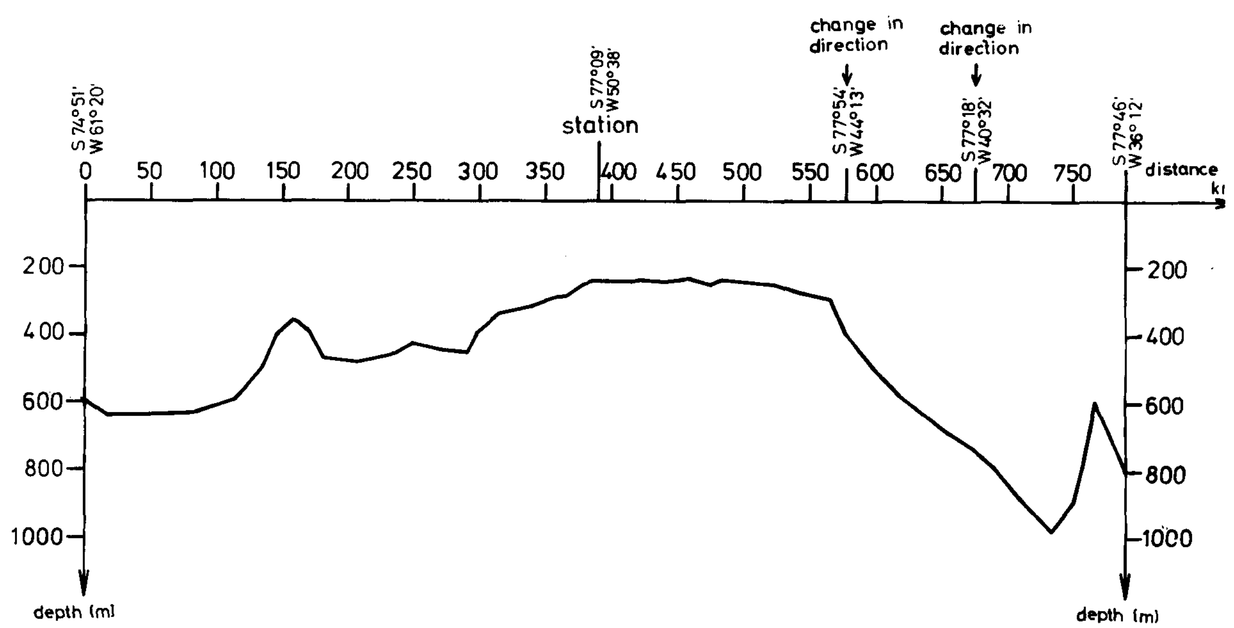

Fig.6. Water depth along the ice front.

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bottom melting have been discussed by Robin (1979) qualitatively.

Swell and wave action finally lead to calving from the thinning ice front. The combined effect of melting and calving accounts for the relative retreat of the ice front observed during January and February 1980. It is believed that a strong melt rate in conjunction with calving generally governs the mass loss along the ice front between 50°W and 56°W where a very low cliff with a steep surface slope is found (Table I).

Bottom melting may continue under the ice shelf to about 54 km inland from the ice front. This assumption is supported by indirect observations and theoretical considerations. Firstly, there is a flow of water under the ice shelf. The currents may carry shelf water from the surface to a depth of 300 m, thereby decreasing the pressure-melting point by 0.2°C, which leads to melting. This effect is enhanced by other factors (Robin 1979) but particularly by advection of warmer water (up to -1.6°C) as observed at the ice front. Secondly, radio echo-sounding showed strong bottom echoes over the first 54 km, which can be attributed to bottom melting (Neal 1979). Further south-west, where the ice thickness decreases again, very weak echoes were recorded. This fact is explained by the presence of a layer of saline ice which might freeze to the bottom in this area. The freezing may be due to the ascending cold water and the raising of its pressure-melting point. Nothing is yet known of the thinning of the ice shelf itself.

Estimating the bottom melting rate $\dot{m}$ from ice thickness H, ice thickness gradient dH/dx, horizontal velocity V_x, accumulation rate $\dot{a}$ ($\dot{a}$ = 0.2 m (Reinwarth submitted for publication*)), and vertical strain-rate using the equation

$$\dot{m} = \dot{a} - V_x \cdot dH/dx - H\dot{\varepsilon}$$

(Crary and others 1962) yields $\dot{m} \approx 3.2$ m a^{-1} at 20 km inland. The strain-rate can only be estimated to be of the order of $10^{-4} a^{-1}$, or less, because all deformations measured during the observation period in the strain pentagon were beyond the limits of the geodetic accuracy (Möller personal communication). Even if the assumed value of $\dot{\varepsilon}$ is erroneous by 100% and more, $\dot{m}$ will only be affected in the second decimal. The term, which governs the melting rate at this place, is the ice-thickness gradient times the horizontal velocity.

West of 56°W, the ice front again is 20 to 30 m high. This is also the region where colder water masses with a core temperature of -2°C (between 150 and 350 m depth; freezing point at the surface: -1.9°C) were met (Gammelsrød and Slotsvik submitted for publication). As under the Filchner Ice Shelf (Carmack and Foster 1975), currents may circulate in the south-western Weddell Sea and underneath the Ronne Ice Shelf in a clockwise pattern. Water masses, flowing out from the western Ronne Ice Shelf, may be cooled down during circulation underneath the ice shelf by heat transfer. Therefore, strong bottom melting is not expected at the ice front, which remains thicker.

The deep iceberg scours are most likely of fossil nature, witnesses of a former lower sea-level. It is interesting to note that these fossil scours were found where no great variations in coastline positions exist. No scours were observed west of the morphological high, indicating either a lack of observations or a greater advance of the ice front in earlier times.

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