This paper not to be cited without prior reference to the author

International Council for the Exploration of the Sea

CM 1968/C:24
Hydrography Committee

The cold 'winter-water' of Rockall Bank

by

D. J. Ellett

Fisheries Laboratory, Lowestoft, Suffolk

Introduction

Hydrographic sections worked across Rockall Bank show a noticeable uplift of the isotherms and isohalines from their levels in the deep water to east and west of the Bank. This situation was noted first by Schmidt (1909) and by Nansen (1913), and sections published subsequently by other observers show the same features. The published material all relates to the months of April to August, but recent work by R.V. ERNEST HOLT has confirmed that the same situation can exist in the winter months. In the absence of contrary evidence we may tentatively assume that colder and rather low-salinity water occupies the Bank from January until August in every year, and may perhaps persist the whole year round. The remarkably small temperature range of published observations from comparable depths is shown by Table 1. Figures 1 and 2 show two representative temperature and salinity sections running roughly east (right-hand) to west across Rockall Bank, taken by R.V. ERNEST HOLT in July 1966 and January 1967 respectively. In these, the 9^{0} isotherm rises by amounts of from 400 to 900 metres as it passes over the Bank.

At first sight the temperature and salinity distributions seem appropriate to some form of topographic uplift, and this was the view of Knudsen (1911). However, the consistent temperature regime suggests that a steadier current system than recent observations have shown would be needed in the vicinity, and whilst we shall do well to bear these ideas in mind as possible contributory features, they do not fit the data as being the primary cause of the density distribution over the Bank. Nansen (1913) gave the first detailed observations and descriptions of conditions around Rockall and his deductions about winter conditions on the Bank fit well with the ERNEST HOLT observations.

TABLE 1 Bottom temperatures and salinities taken upon Rockall Bank

Date	Latitude N	Longitude W	Depth (m)	Temperature (°C)	Salinity (°/oo)	Source
4 July 1869	57°36'	13°41'	99	9.1		Wyville-Thomson (1874)
May 1908	57 11	14 00	150	8.6	35.23	Schmidt (1909)
8 July 1910	56 40	14 22	145	8.7	35.295	Nansen (1913)
16 June 1938	57 35	14 00	145	8.99	35.39	Bull. Hydrogr. (1944)
22 June 1951	57 40	14 13	165	8.27	35.35	Tulloch and Tait (1959)
19 August 1958	57 10	14 02	156	9.05	35.367	Fuglister (1960)
25 January 1964	57 23	13 53	145	8.82	35.265	R.V. ERNEST HOLT
17 July 1966	57 26	13 52	145	8.81	35.374	" " " "
14 January 1967	57 20	13 30	150	8.65	35.383	" " " "
19 February 1968	57 21	13 30	147	8.48	35.354	" " " "

Nansen's winter-cooling theory

Nansen considered that the water upon the crest of the Bank became colder and denser in winter than in the surrounding depths because of the more rapid overturning of the shallower water, with consequent greater heat loss to the atmosphere. This process is demonstrated clearly by our data for January 1967. Figures 2 and 3b show the very deep stirring on either side of the Bank, and the very dense water produced upon its crest. Nansen also predicted a katabatic flow of dense Bank water down the slopes of the Bank to deeper levels, in the same manner as deduced by Cooper and Vaux (1949) in their theory of cascading developed in reference to waters over the continental slope of the Celtic Sea. This is also apparent in Figure 3b, which suggests that large quantities of water with sigma-t 27.40 to 27.45 had descended from the outer edges of the Bank.

Sub-surface observations taken during January 1964 and February 1968 were confined to the eastern half of Rockall Bank, but show that the same processes were taking place during these other winters. Thus a winter-cooling origin for the cold water upon the Bank seems to be confirmed, but the question of accounting for its persistence in situ during the summer months arises. When a thermocline becomes established in spring, cascading should sooner or later denude the Bank of denser water and allow its replacement by water of the type found in the upper layers to east and west of Rockall. Nansen suggested that the presence of winter-water on the Bank at the end of the summer could be due to a cyclonic circulation around the Bank restraining the cascading process. The existence of a cold, dense mass of water surrounded by warmer, lighter water implies a cyclonic circulation of some sort, and recent cruises show evidence of this.

Observations of the circulation around the Bank

GEK cables were towed around Rockall Bank in the course of three surveys in July 1966, January 1967 and February 1968, and during the first two of these cruises sufficient serial water-bottle stations were worked for the dynamic topography around the Bank to be drawn. Figures 4a, 4b and 5 show the results obtained. The stippled areas denote the current components normal to the ship's track, and vectors obtained by steaming for ten minutes at right angles to this are shown at most stations. During the two winter cruises (Figures 4b and 5) the GEK observations do not show a clear-cut cyclonic circulation, although closer examination of Figure 5 suggests a generally cyclonic pattern around three quadrants of the Bank (with a tendency for the flow to make incursions over the shallower water), and part of an anticyclonic circulation to the north-east of Rockall. A parachute drogue at 20 metres depth was tracked for 25 hours in the vicinity of point A in Figure 5 and had a westerly residual movement at a mean speed of 16 cm sec^{-1}, in good agreement with neighbouring GEK components. A similar drogue at position B showed less than 0.5 naut. miles residual movement over 25 hours and had a tidal or inertial movement along a north-south axis. Winds were much lighter during this cruise than during that of January 1967, for which the mean wind speed was 28 knots, and this may account for the much less coherent pattern shown by the GEK components of Figure 4b. The 0-1 000 m dynamic topography for this latter survey does, however, show a generally cyclonic circulation, whilst Figure 4a shows that in July 1966 both GEK and dynamic topography agreed in denoting a cyclonic flow.

Despite this latter evidence of a well-defined summer circulation around the Bank, temperature and salinity data from this cruise show that this was not able to halt all cascading. Figure 6 is a temperature-salinity diagram for the stations of the section across Rockall Bank shown in Figures 1 and 3a. The curves fall into two groups, those from the east and those from the west of the Bank. Stations 32 and 33 on the crest of the Bank have been marked individually, and to indicate the approximate characteristics of the Bank water in the preceding winter the means of six surface observations taken over the Bank between January and March 1966 are plotted. At four of the western stations the curves bend sharply towards these winter surface values, producing an intermediate salinity maximum at stations 34, 36, 37 and 38 at depths of 150, 518, 574 and 609 metres respectively. (At station 35 no salinity observations are available below 200 m depth.) At station 33 the lowest values fall close to the surface winter values, and the curve for station 32 moves first towards those of the eastern stations and subsequently towards the station 33 bottom values.

It thus appears that in July 1966 cascading was taking place on the western slope of Rockall Bank, though it was not detected on the eastern or north-eastern slopes. Examination of the mean geostrophic velocities between pairs of stations for this cruise and those of January 1967 shows that 9.4 cm sec^{-1} was the highest velocity associated with active cascading, and that 13.8 cm sec^{-1} was the lowest velocity at the Bank shoulder when cascading appeared to be prevented, but these values must be treated with reserve, being means chiefly derived with the aid of extrapolations through the cross section of the Bank.

Discussion

Nansen's hypothesis that the cold water found upon Rockall Bank owes its origin to winter cooling agrees with our observations. His deductions about cascading in winter and the existence of a cyclonic circulation around the Bank are confirmed, but the latter does not appear to restrain all cascading in summer. However, observations made by DISCOVERY II during the IGY (Fuglister 1960) show that a good deal of winter-water remained on the Bank in mid-August 1958, which suggests that it can persist upon the crest of the Bank until at least early autumn. In order to put the problem into perspective we may make some approximate calculations.

The volume of water on Rockall Bank above the 200 m isobath is approximately 1 800 cubic km. Eighteen years of records of surface temperature and salinity taken by weather ships crossing Rockall Bank show that temperatures normally begin to rise at the surface towards the end of April, suggesting that establishment of the thermocline dates from this month. If the winter-water persists until the end of September, the rate of loss (and replacement by other water) over five months would have to be about 13 cubic km per day around a periphery of about 550 km. Taking the situation of July 1966 in order to give us maximum rates, we will say that descent is taking place over only half the periphery of the Bank, and that the cascading layer is 30 metres thick, the observations at station 34 indicating a thickness of between 20 and 50 metres. To remove all the winter-water from the Bank within five months the outward speed of the cascade under the foregoing conditions would have to be 2.2 cm sec^{-1}. Cascading could perhaps be taking place in a thinner layer, which would raise this rate, but the balance of probability seems to be that values of about 2 cm sec^{-1} are the maximal velocities which cascading can attain if some winter-water is to survive upon the Bank until the month of September. In view of the large density difference between the Bank water and its surroundings this seems a very low rate. There are two alternatives: first, that cascading takes place more rapidly and the volume of winter-water is supplemented from some other source, and second, that additional constraining forces reduce the rate of cascading to this velocity or less.

To take the first alternative, we know that over the Bank some water enters the depths of the water column immediately below the thermocline in order to replace cascaded water, but it appears unlikely that much mixing can take place to add to the quantity of potential cascade water. Water of closely similar characteristics to those of the winter-water has been shown to exist at depths of 500 to 600 metres in the Rockall Channel. This coincidence suggests an hypothesis which would be difficult to substantiate. This is that the water upon Rockall Bank could be renewed during the seasons when deep vertical mixing is not taking place by very deep upwelling from the Rockall Channel. This would supply the main compensation current for the cascading taking place on the western side of the Bank and could be aided by the interaction of the Rockall Channel current and the topography of the Bank in the manner described by Knudsen (1911). It is notable that the bottom of the Channel rises steadily from maximum depths of 3 000 m in latitude 54°N to reach depths of 1 500 m and less in latitude $59^{\circ}30'$N, just before the Channel is blocked by the Wyville-Thomson Ridge. Moreover, it is probable that there is a mean northward movement by all the water-masses present in the water column of the Rockall Channel, and this suggests that a general convergence must occur at depth in the narrower and shallower northern section of the Channel, although no consequent surface divergence has been described for this area. Possibly under such circumstances upwelling may occur on the eastern slope of Rockall Bank.

More plausibly, we may return to our second alternative and postulate that as cyclonic currents do not appear to retard cascading sufficiently to explain the persistence of winter-water until autumn, that topographic upwelling forces of the sort mentioned above are sufficient to reduce the rates of cascading to the small values deduced earlier. In these circumstances upwelling would not take place, but would just fail to balance the gravitational cascading forces.

Conclusion

The observations presented here are insufficiently detailed to resolve the question of the means by which cold water persists upon the crest of Rockall Bank for the greater part of the year. In the first place we need to know the extent of the sector of the Bank over which cascading occurs in summer and the thickness of the cascading layer. Ideally, we should like to know the speed within the cascading layer and to have accurate measurements of current velocities around the Bank. It is hoped to tackle some of these problems during future research vessel cruises.

Summary

1. Observations obtained around Rockall Bank in recent winters have confirmed the hypothesis of Nansen (1913) that the cold water found upon the Bank during the spring and summer months originates by winter cooling in the shallow water above the Bank. During January 1967 dense water formed over the Bank was observed to sink to depths of 700 and 500 metres respectively to the east and west of Rockall.

2. Circulations of a generally cyclonic character were found around Rockall Bank in January 1967 and February 1968. A more definitely cyclonic circulation existed in July 1966. In this latter month geostrophic velocities of about 14 cm sec^{-1} at 200 m depth to the east of the Bank appeared to prevent cascading of the dense water upon the crest towards the eastward, but cascading was occurring over the western slopes, where lower geostrophic velocities existed. Cascading was able to proceed in January 1967 in association with geostrophic components of up to 9.4 cm sec^{-1}.

3. Even though the surrounding circulation does not prevent all cascading, past observations show that the winter-water persists upon the Bank until August, and probably later. Rough calculations demonstrate that although the sector of the Bank from which cascading takes place may be a limited one, very low rates of cascading (probably not in excess of 2 cm sec^{-1}) are sufficient to remove winter-formed water within five months of the establishment of the thermocline. The most probable explanation is that topographical factors give rise to upward forces in the surrounding currents as suggested by Knudsen (1911), and that these almost balance the tendency of the dense winter-water to cascade.

Acknowledgements

Thanks are due to Dr. H. A. Cole, Dr. P. G. W. Jones and Mr. A. J. Lee, the Naturalists-in-charge of the three ERNEST HOLT cruises during which most of the data discussed was collected, for allowing time for the surveys, and for their kind co-operation and advice.

References

COOPER, L. H. N. and VAUX, D., 1949. Cascading over the continental slope of water from the Celtic Sea. J. mar. biol. Ass. U.K., 28: 719-50.

FUGLISTER, F. C., 1960. Atlantic Ocean Atlas of temperature and salinity profiles and data from the International Geophysical Year of 1957-1958. Woods Hole Oceanogr. Inst. Atlas Ser. 1, 209 pp.

KNUDSEN, M., 1911. Danish hydrographical investigations at the Faroe Islands in the spring of 1910. Meddr. Kommn. Havunders., Hydrogr., 2 (1), 17 pp.

NANSEN, F., 1913. The waters of the north-eastern North Atlantic. Int. Rev. Hydrobiol. Suppl. to Bd 4, 139 pp.

SCHMIDT, J., 1909. The distribution of the pelagic fry and the spawning regions of the gadoids in the North Atlantic from Iceland to Spain. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 10 (B 4), 229 pp.

TULLOCH, D. S. and TAIT, J. B., 1959. Hydrography of the North-Western Approaches to the British Isles. Mar. Res. Scot., 1959, No. 2, 32 pp.

WYVILLE-THOMSON, C., 1874. The depths of the sea. 2nd edn, London. Macmillan and Co., 527 pp.

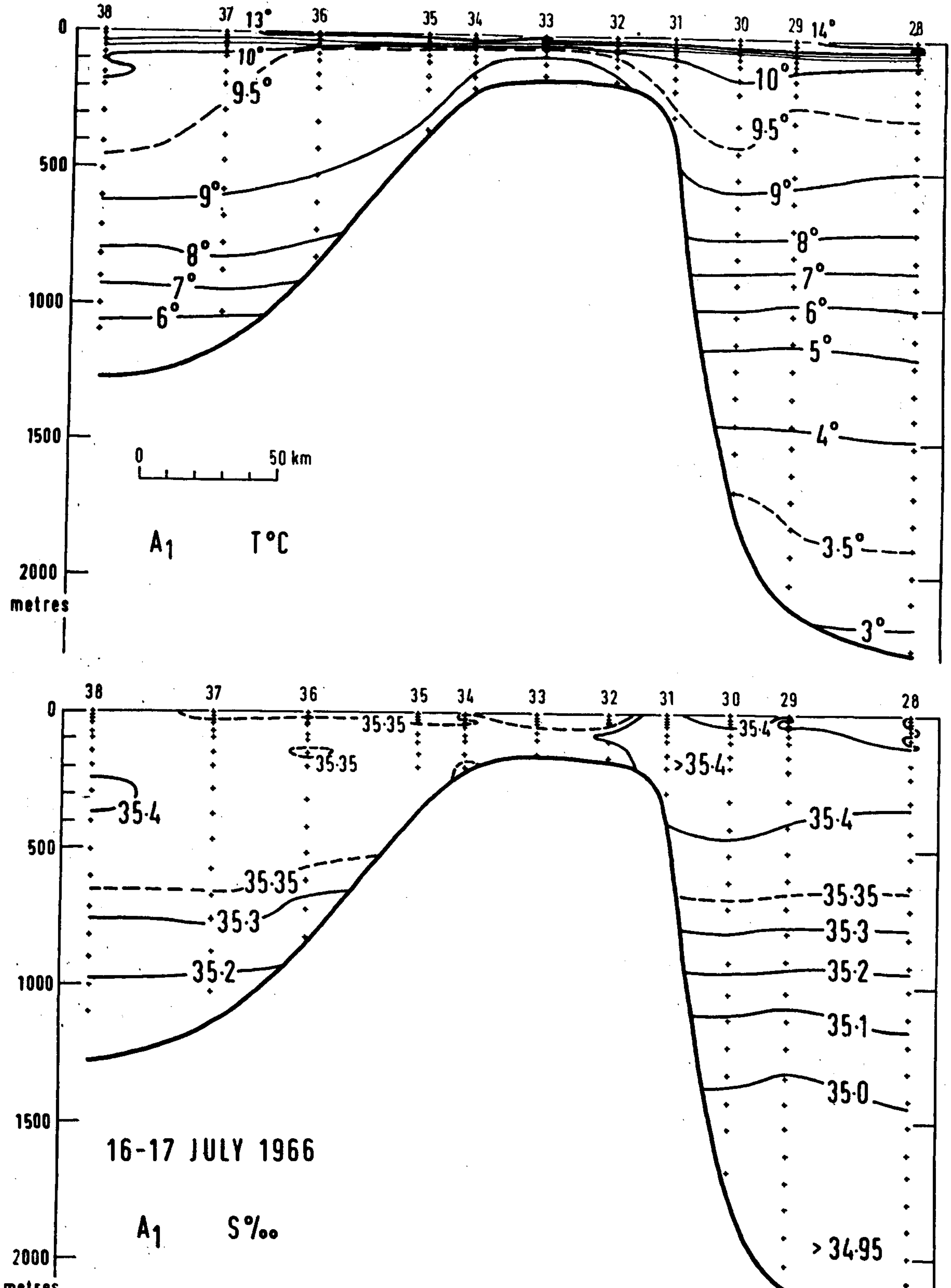


Figure 1 Temperature and salinity distributions for section across Rockall Bank, 16-17 July 1966.

X683713

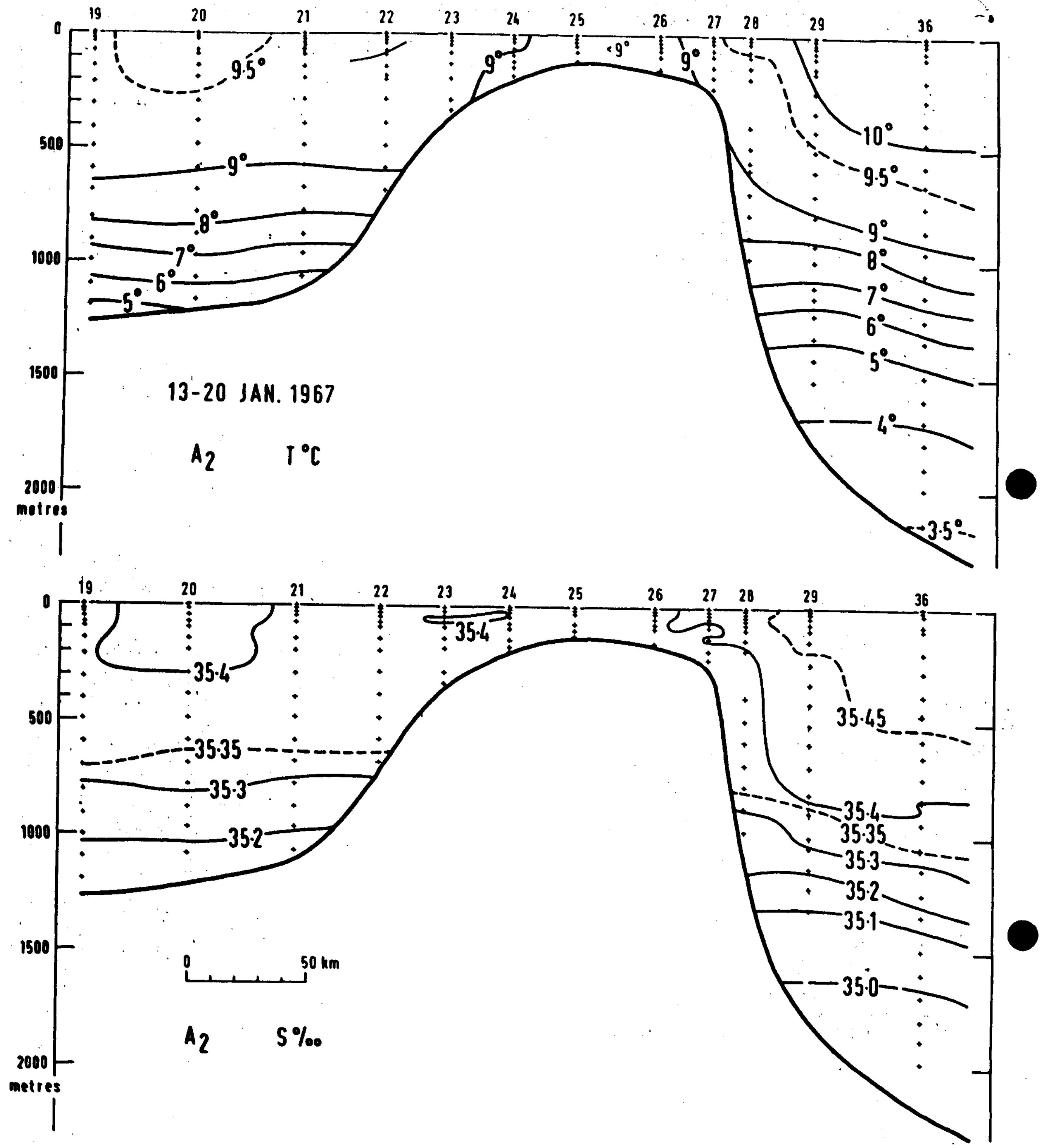
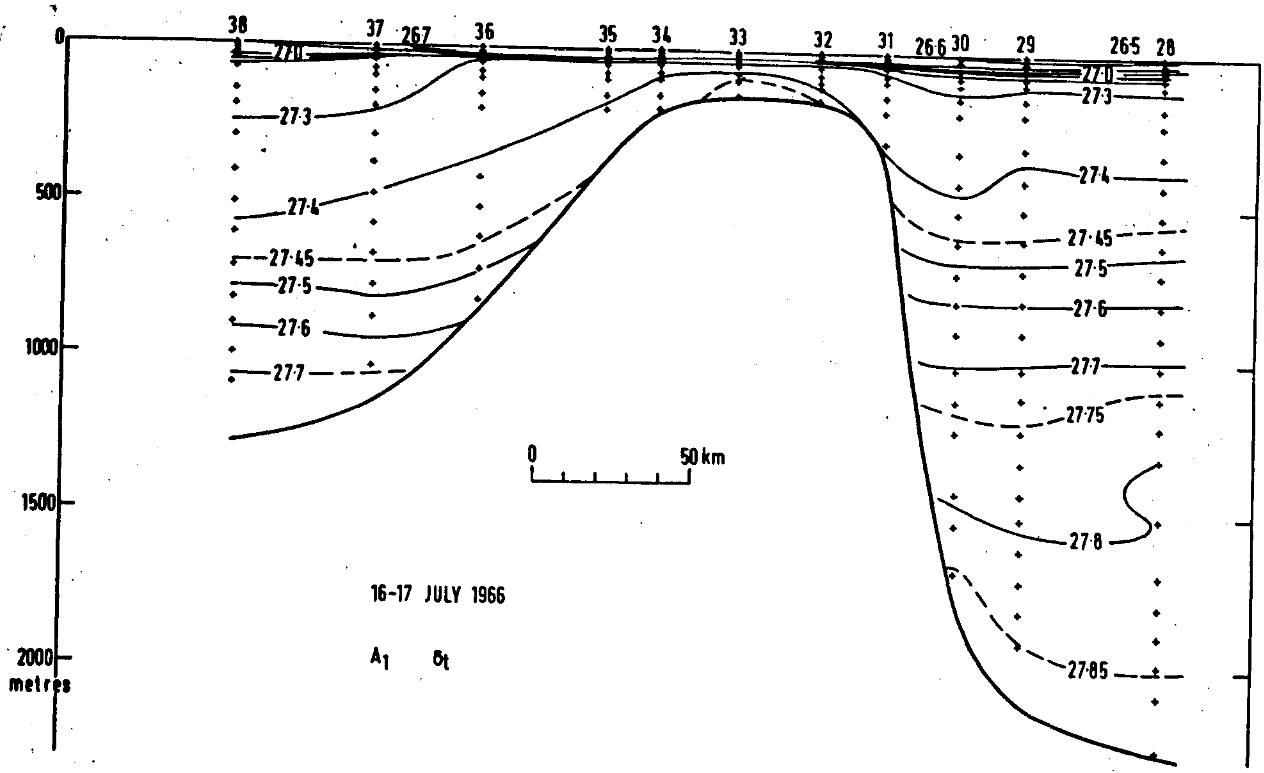


Figure 2 Temperature and salinity distributions for section across Rockall Bank, 13-20 January 1967.

X683713



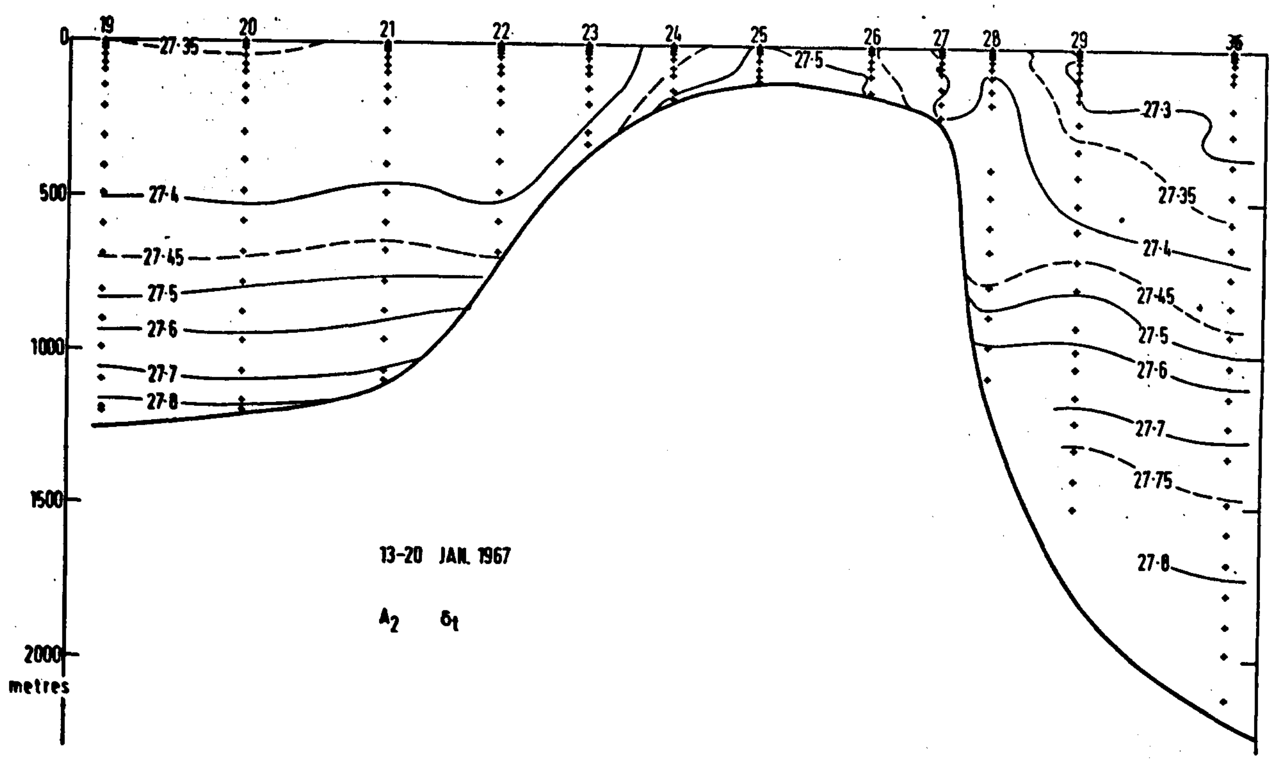
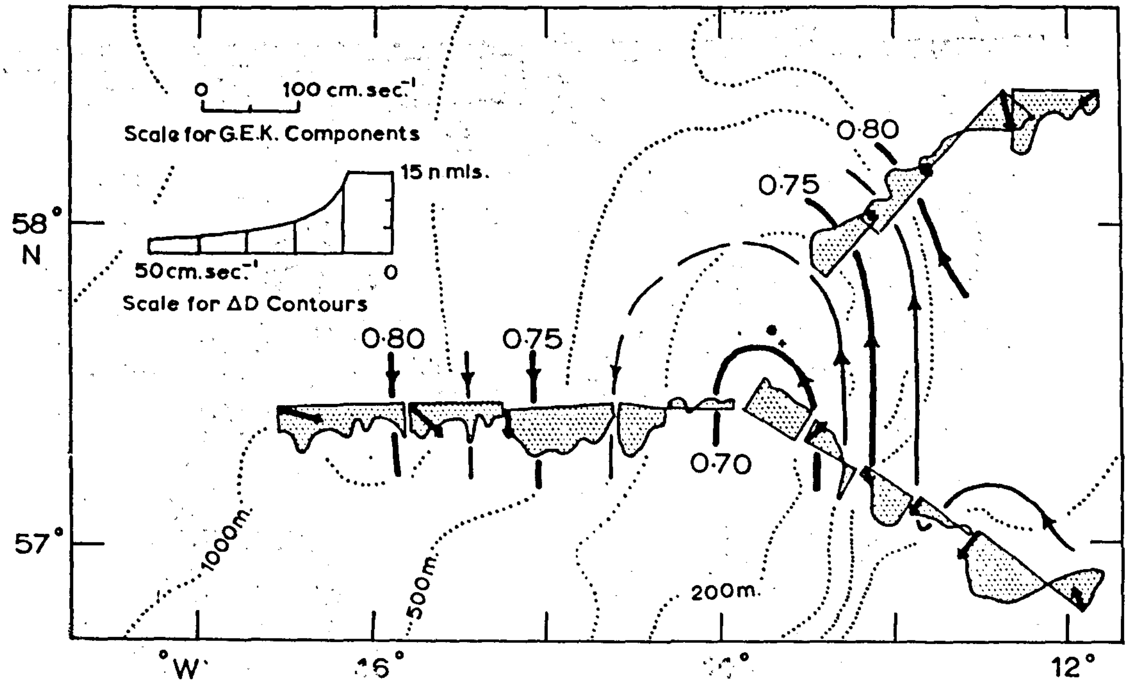


Figure 3 Sigma-t distributions for sections across Rockall Bank
a. 16-17 July 1966 b. 13-20 January 1967

X683713



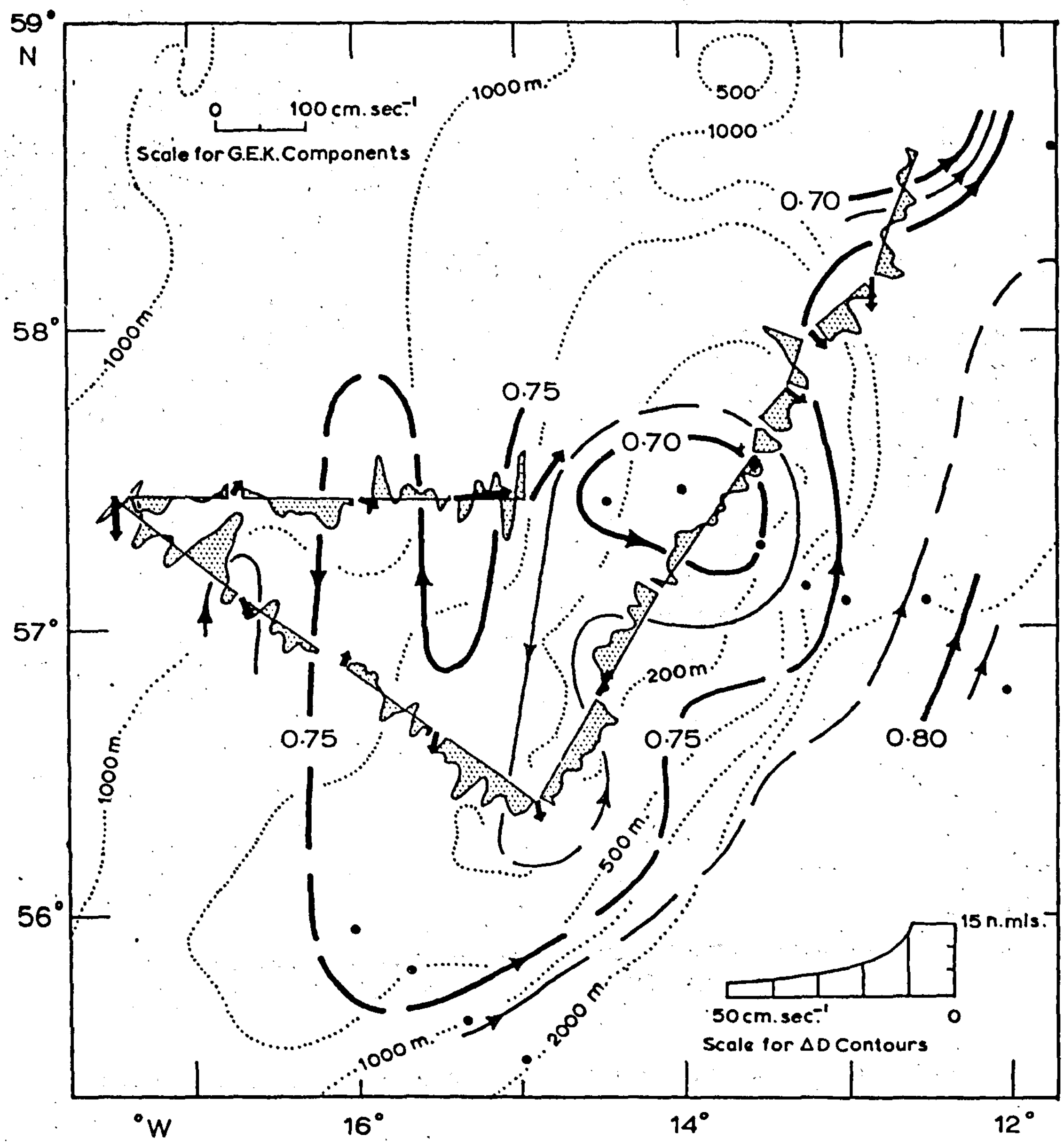


Figure 4 Contours of dynamic height anomaly (dyn. m.) 0–1000 m and surface current components and vectors by GEK
a. 16–20 July 1966 b. 9–22 January 1967

X683713

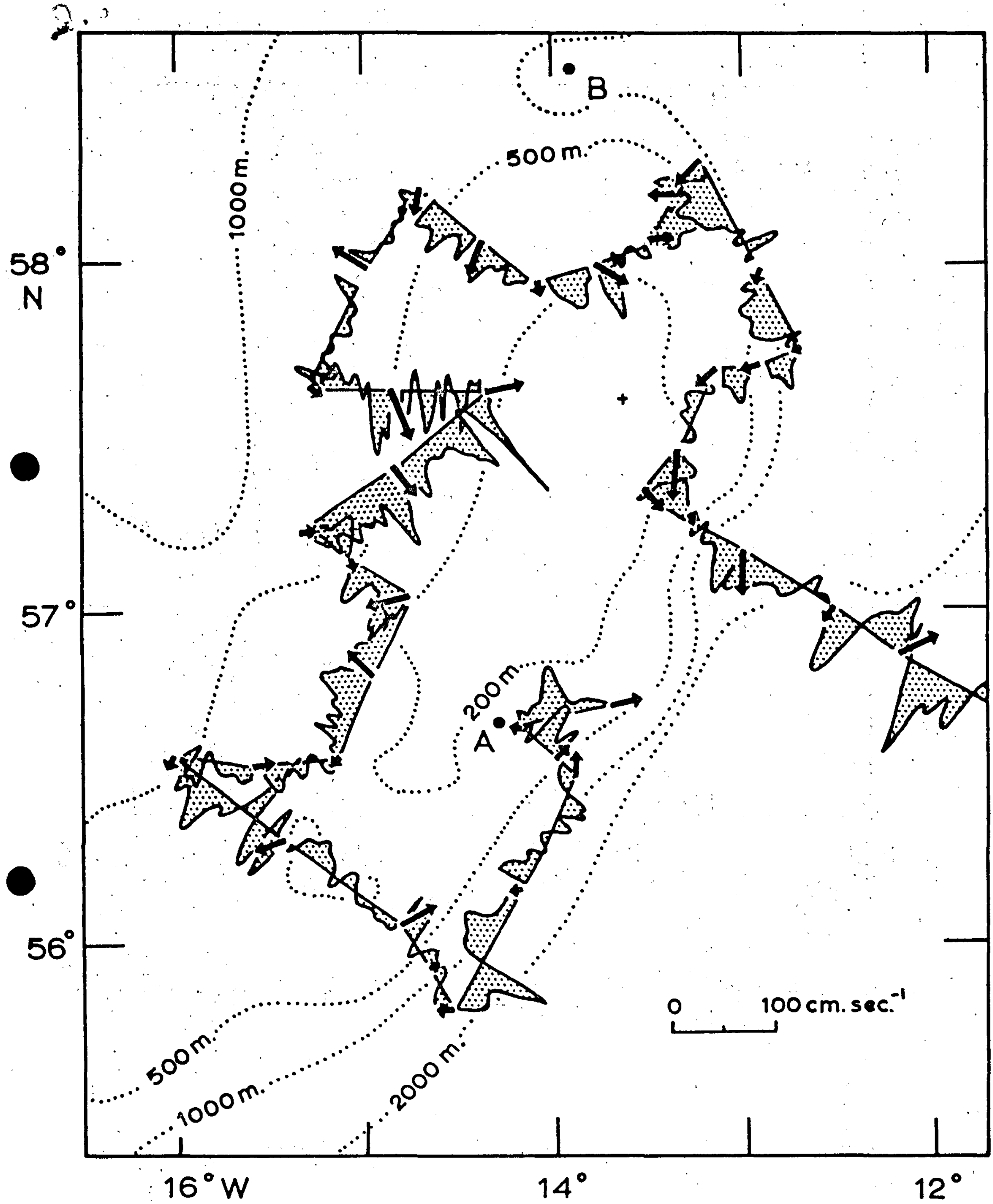


Figure 5 Surface current components and vectors by GEK, 18-22 February 1968.

X683713

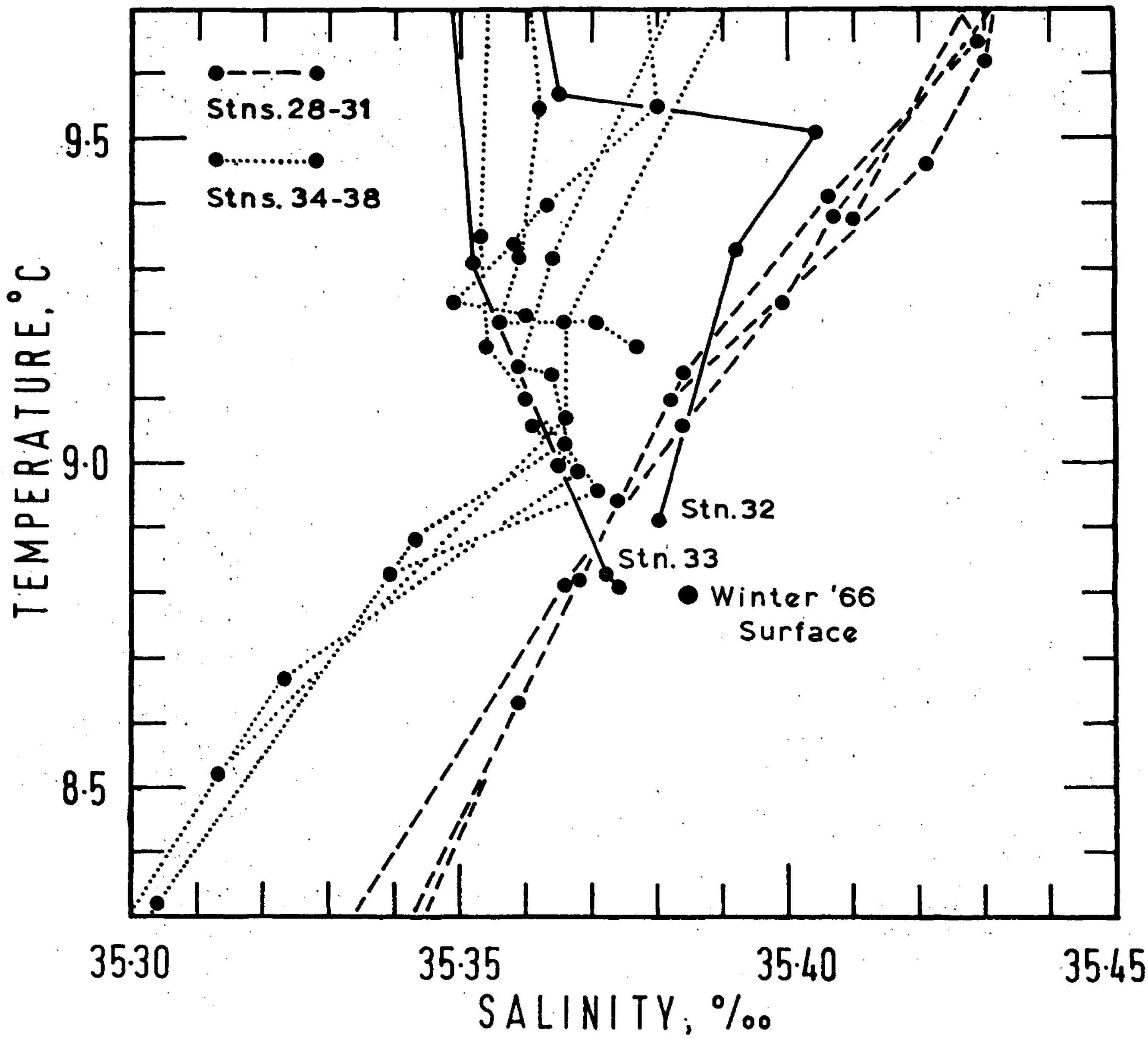


Figure 6 Temperature-salinity diagram for the stations of section A_1, 16-17 July 1966.

X683713