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Norwegian Sea Deep Water overflow across the Wyville-Thomson Ridge during 1987-88

D. J. Ellett

Dunstaffnage Marine Laboratory, P.O.Box 3, Oban, Argyll, Scotland

Abstract

As part of the ICES NANSEN investigations of Atlantic - Norwegian Sea exchange, current meters were deployed to the west of the Wyville-Thomson Ridge between September 1987 and June 1988. CTD surveys of the area and of Faroe Bank were also made in these two months. A rather steady westward flow was found throughout the period at the lowest levels and a variable eastward flow at 275m depth, but mid-water currents changed from weak easterlies in autumn and early winter, to episodes of strong westerlies in late winter and spring.

Introduction

Overflow of Norwegian Sea Deep Water (NSDW) across the Wyville-Thomson Ridge was first documented in 1972 (Ellett and Roberts, 1973), and short-term current measurements were made during the ICES Overflow '73 Expedition by J. Crease in a narrow gulley west of the ridge. When combined with CTD data for a day (28 August 1973) when the mean current velocity was about 10% higher than the 25-day mean, the results gave a total westward flow of 1.2 Sv below a reference level of about 350 m depth, of which the NSDW component was 0.33 Sv (Ellett and Edwards, 1978). Subsequently, long-term current measurements were made some 75 km downstream from the ridge-crest by J. Gould during 1978-83, and at the lowest point of the ridge crest and upon the southeastern part of the ridge during 1982-83 by H.D.Dooley. Some results from these deployments are given by Dickson et al (1986). The Overflow '73 surveys had confirmed that overflow was not confined to the lowest part of the ridge-crest, but takes place along all the northwestern half of the ridge and Dooley's observations showed that short-term flows of water from intermediate levels of the Norwegian Sea occurred at approximately 30-day intervals at the southeastern end of the ridge. The fate of the latter overflow is unknown; it is not apparent upon water-bottle sections taken by the Aberdeen Laboratory immediately to the south of this position during 1927-52 (Tait, 1957), and in view of its intermittent nature it will not be considered here. Overflow northwestwards from the lowest point of the ridge-crest in about 7° 45'W, however, is trapped by topography and descends into the Rockall Channel by a narrow channel between Faroe Bank and the northern end of the Ymir Ridge

(Figure 1). Because of this constriction of the flow, it was apparent that long-term monitoring of the Wyville-Thomson overflow could be carried out more readily in this vicinity than in upstream or downstream areas, and a programme of current measurements and CTD sections was executed between September 1987 and November 1988.

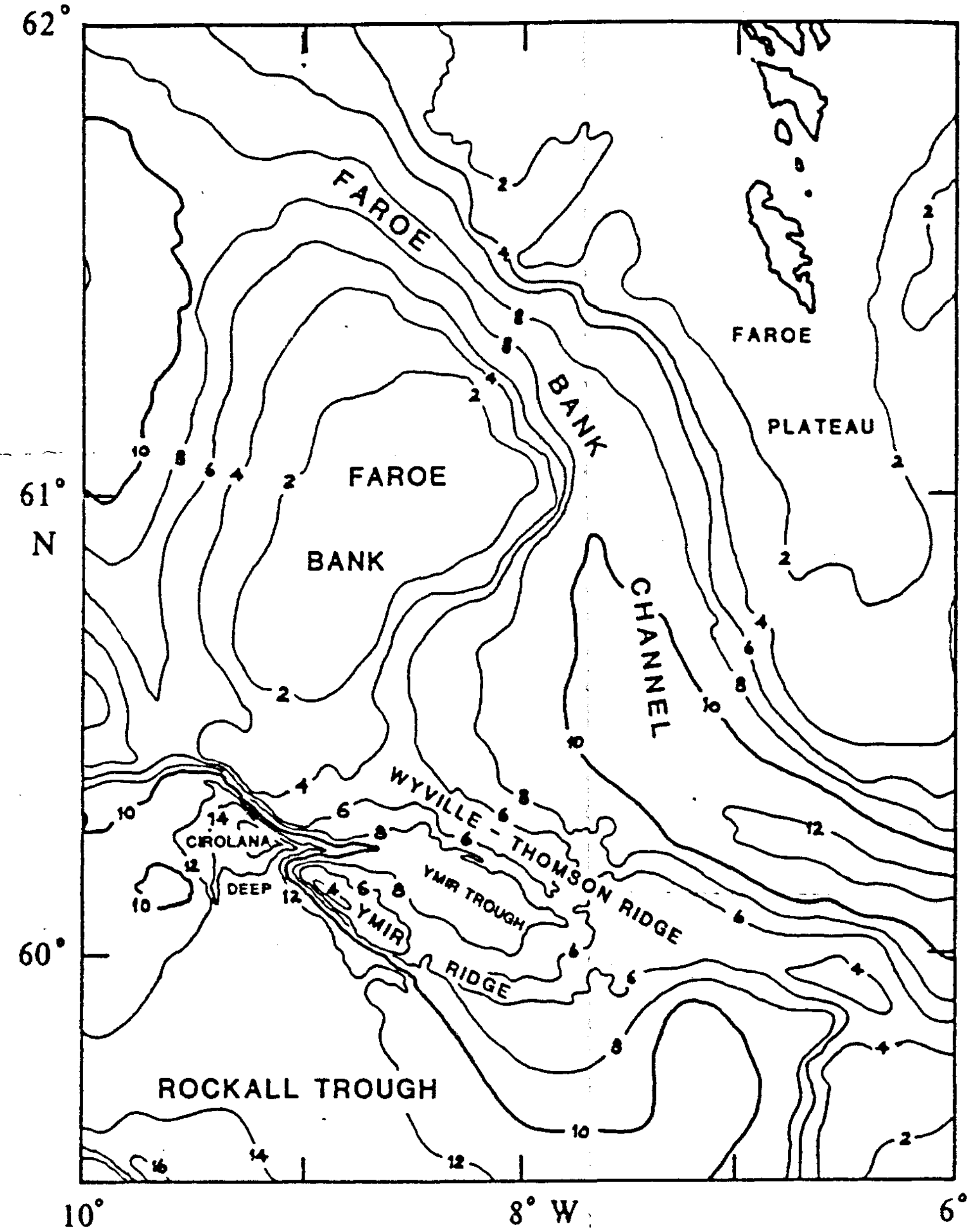

Figure 1. General topography of the area. Isobaths in hectometers.

Current Meter Observations

Two current meter mooring sites were selected with regard to detailed sounding surveys made over a decade (Ellett, 1988). Earlier work, borne out by subsequent CTD surveys of the area, showed that the core of the overflow water was centred upon the lower southern slopes of Faroe Bank, extending upwards from the gulley between the bank and the Ymir Ridge. The sites, N1 and N2, were repectively in the centre of the gulley in soundings of 1115 m and upon the slope in 710 m (Figure 2), and both were deployed on 6 September 1987. From this first

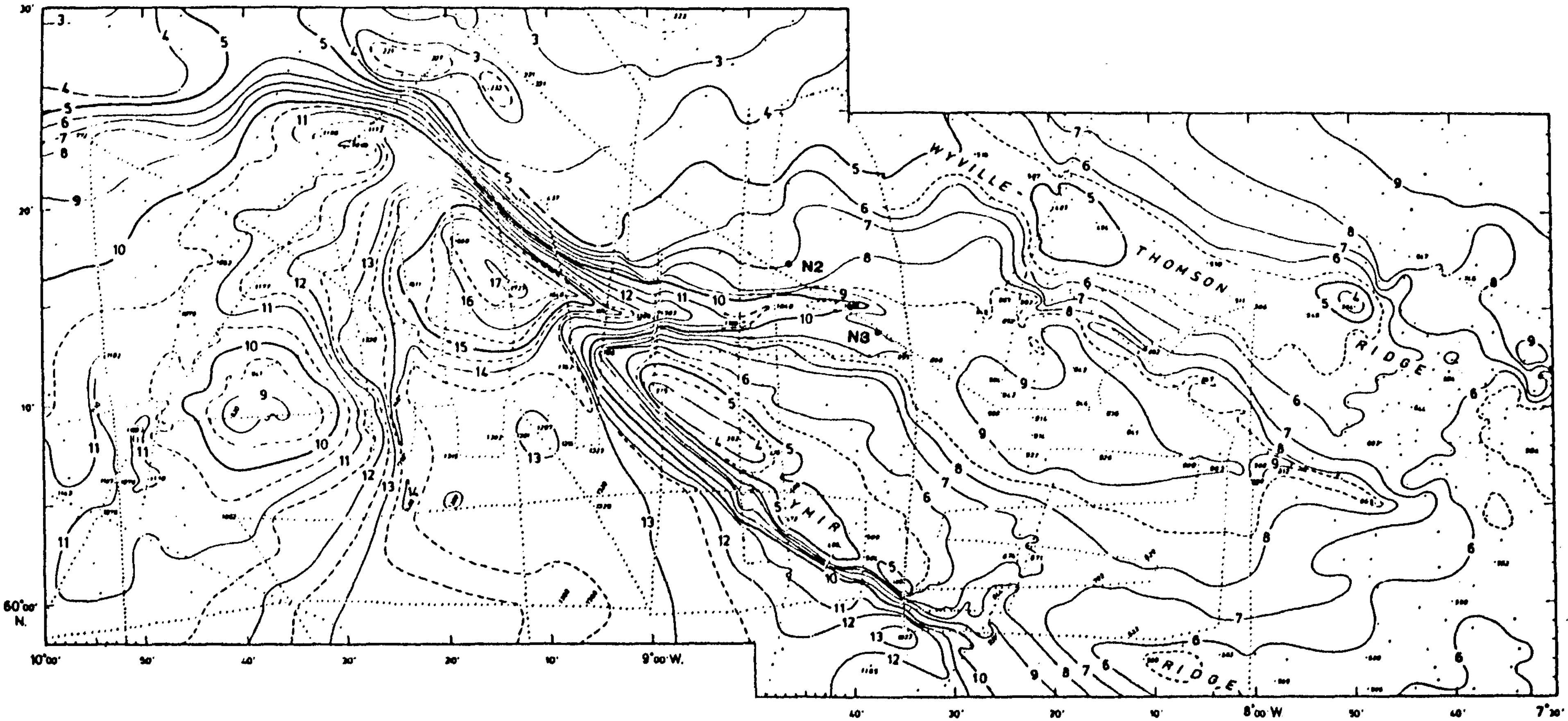

Figure 2. Current meter mooring positions and bottom topography (Ellett, 1988) to the west of the Wyville-Thomson Ridge. Isobaths labelled in hectometers.

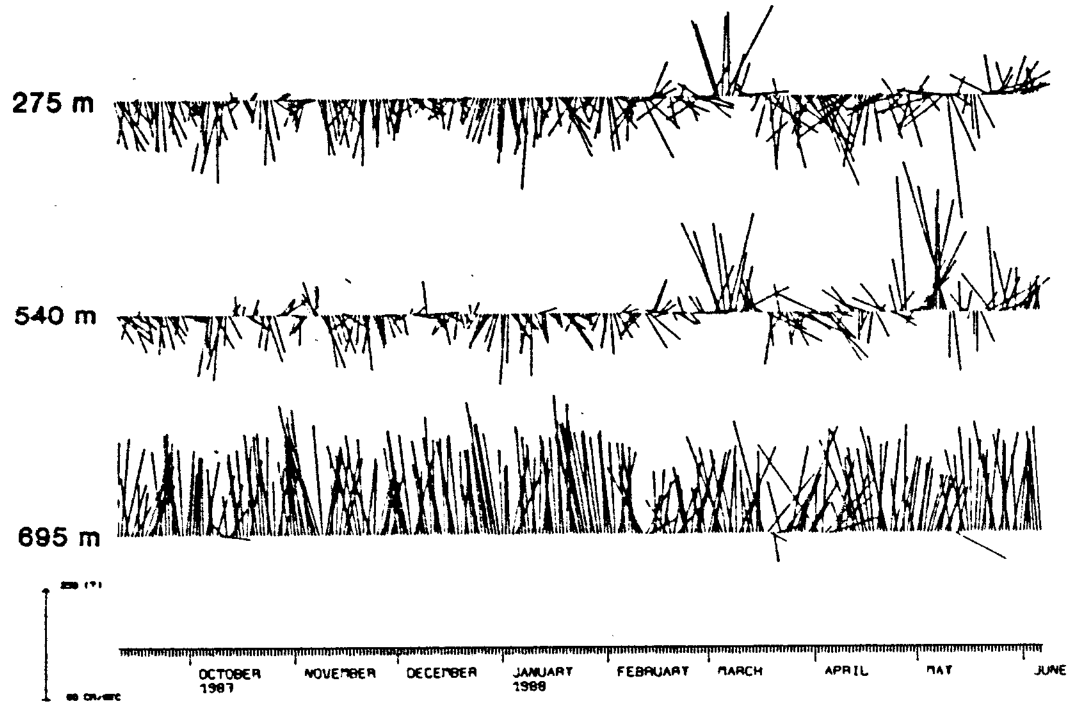

Figure 3. Daily current vectors at mooring N2, September 1987 - June 1988. (The arrow, bottom left, points towards 258°T and represents 60 cm/sec)

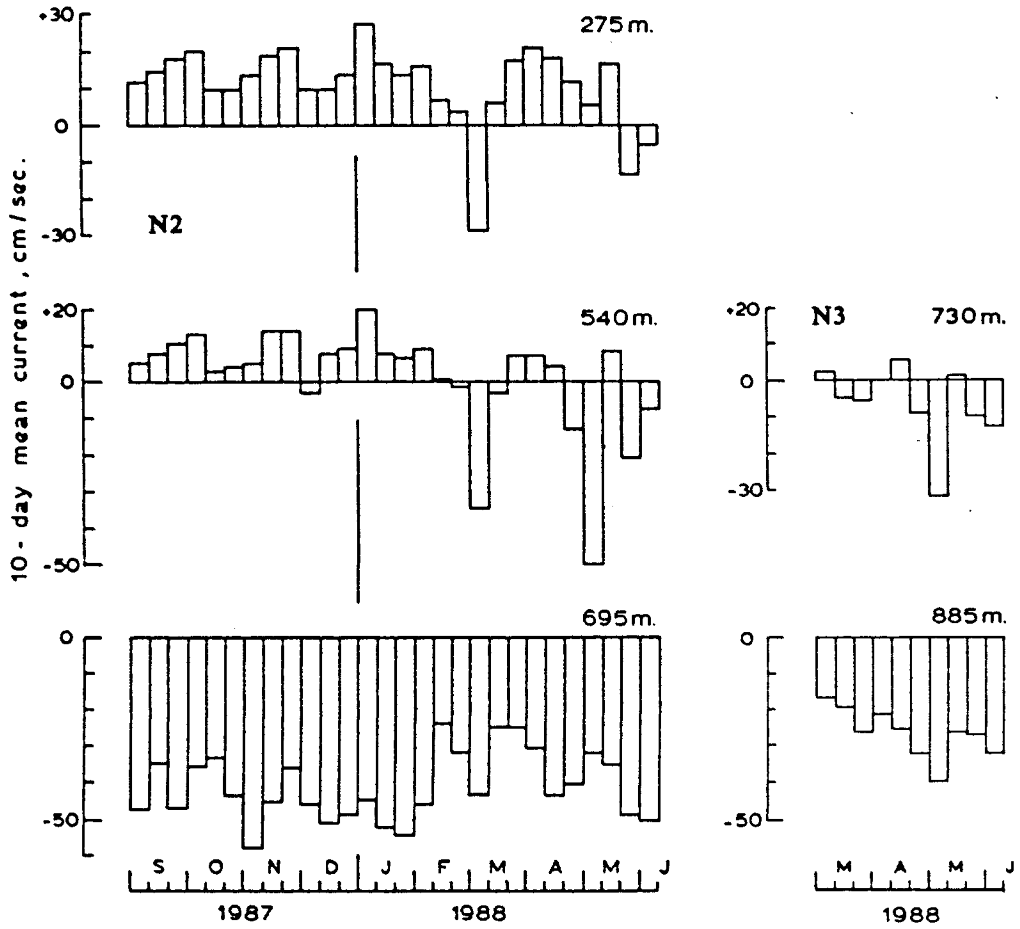

Figure 4. 10-day mean easterly (+ve) current components at N2 and N3.

deployment 177 days' records were obtained from N2, but N1 failed to surface on command, releasing itself later only to be broken up in a gale. It was suspected that the strong currents in the gulley had delayed release by leaning the mooring out of the vertical, so the replacement mooring, N3, was laid in 900 m depth at the head of the gulley where currents might be expected to be less. 100 days' records were obtained from each of the five current meters of this deployment. A further deployment at these two sites was unsucessful due to fishing activity, a single meter and release being returned from N2 by a trawler a few weeks after deployment.

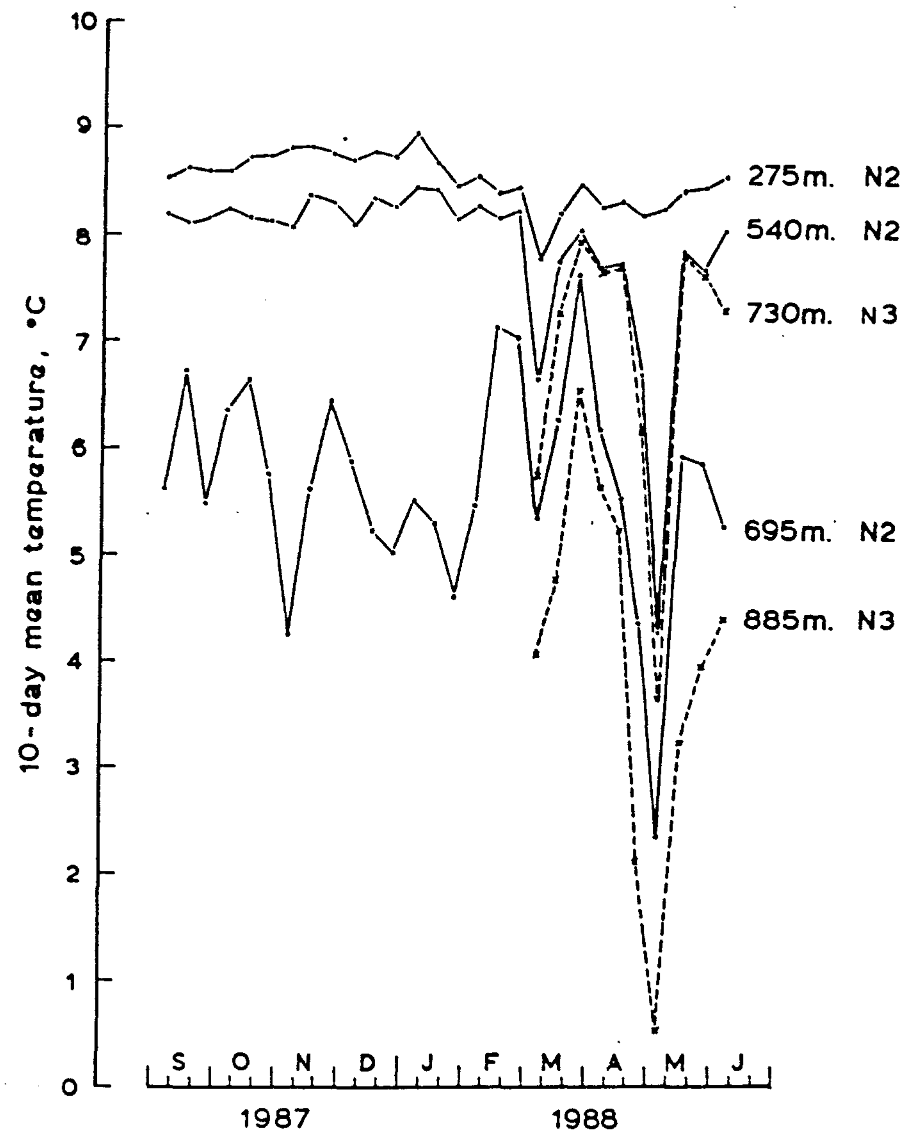

Figure 5. 10-day mean temperatures at the current meters.

Results

Figure 3 shows daily mean vectors at N2 in soundings of 710 m for September 1987 to June 1988. The vectors are resolved relative to the trend of the 700 m isobath at the position, 258°T (+ve). They show strong westerly flow immediately above the bottom on all but four days of the 9 months' record, mostly easterly flow in mid-water until March, when west to southwest periods occurred, and more persistently eastward flow in the upper water column, although with two periods of westerly currents in March and May-June. The data have been smoothed in Figure 4 which shows 10-day means of the easterly components. This emphasises

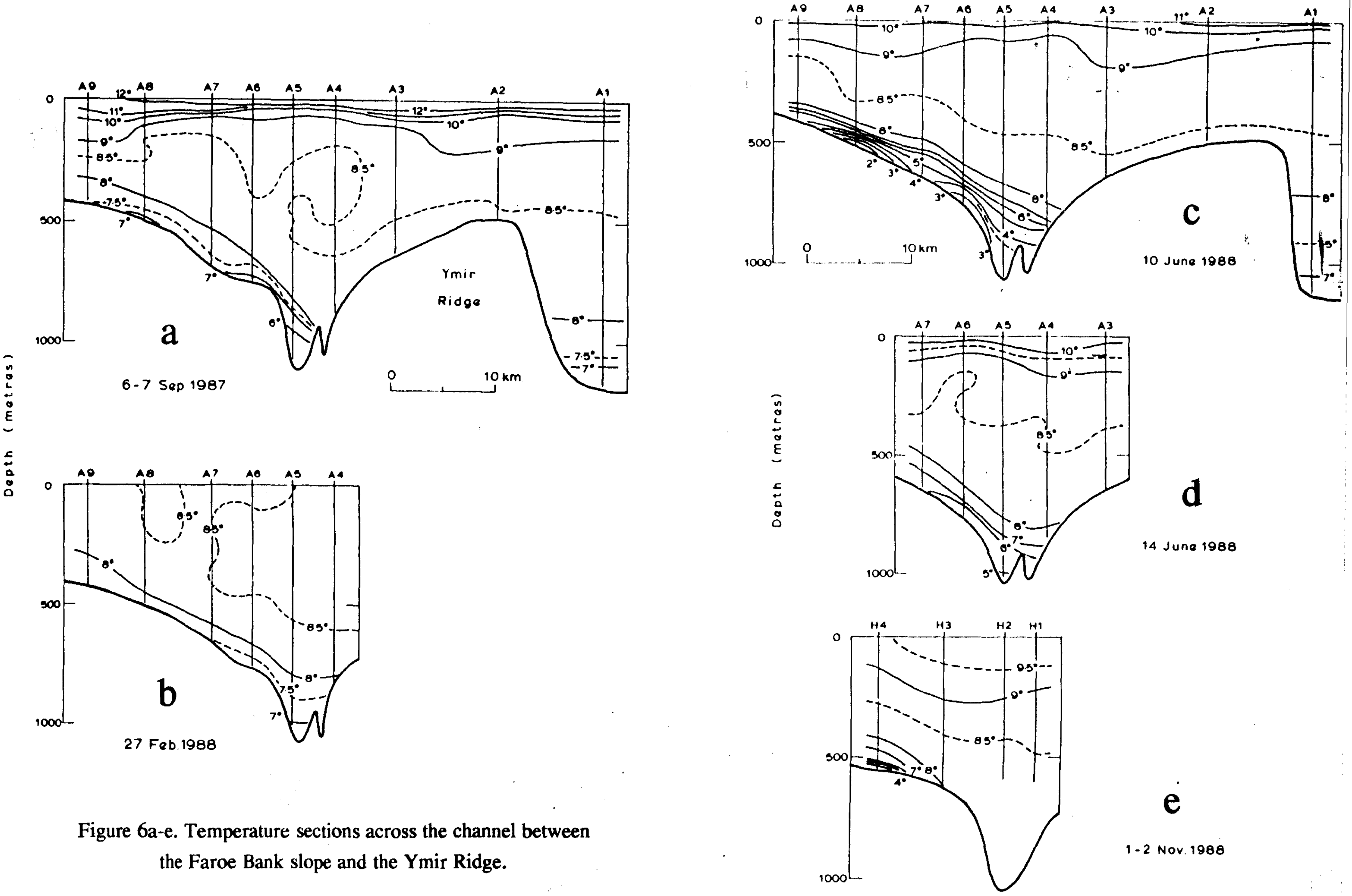

Figure 6a-e. Temperature sections across the channel between the Faroe Bank slope and the Ymir Ridge.

the anomalous mid-water westerly flow during March to June, and shows that bottom currents on the whole were somewhat less at this time than in earlier months. Figure 4 also shows that the available records from N3 in the centre of the western exit from the Ymir Trough have very similar features to N2 records from the slope of Faroe Bank, although with generally lower current speeds. A high degree of coherence is particularly apparent in the 10-day mean temperatures of Figure 5, where closely similar variations occurred at the mid-water and bottom levels of both moorings. It had been anticipated that the two principal sources of coldest overflow, the col in the Wyville-Thomson Ridge crest in 7° 35'W and the northern sector of the crest, might produce differing signals at the two mooring sites, but upon the 10-day time scale both seem equally affected by events from either source.

CTD profiles upon a north-south section through the position of mooring N2 are shown in Figure 6a-e, and show the way in which water with a Norwegian Sea Deep water (NSDW) content blankets the lower Faroe Bank slopes. Short-term variations in the mode of overflow are evident; In September 1987 and March 1988 lowest temperatures were found at the bottom of the gulley running from the Ymir Trough to the Cirolana Deep, but on 10 June 1988 the lowest values were in depths of 500 m on the bank slope, with a second cold core of slightly higher temperature below at 700 m. The position of the upper core was not sampled four days later, but the lower had disappeared at this time. Cold water was at about 540 m upon the slope in early November 1988, but sampling on this cruise (upon a chartered ship) was limited to 600 m depth. This random CTD sampling shows considerable short-term variability, possibly connected with alternative routes for overflow across the Wyville-Thomson Ridge, as mentioned above, but detailed CTD surveys of the area in September 1987 and June 1988 proved insufficiently synoptic to trace these cores back to the ridge crest.

An estimate of the total mean volume of overflow

Despite this short-term variability, the good correlations of currents and temperature on the 10-day time scale make it not unreasonable to attempt estimation of the volume of NSDW entering the Rockall Trough, using the mean east-west velocities and mean temperatures at the current meters over the deployment periods. Figure 7 shows these values and the approximate profiles they suggest for the two N2 records and the single N3 deployment. Since the flow at both positions was predominantly east-west, a zero level separating the overflow and the Atlantic inflow to the Norwegian Sea above it can be estimated for N2 and extrapolated with a degree of confidence for N3. For the 100 days for which data are available for both sites the mean westward bottom currents were 37 and 27 cm/sec for N2 and N3 respectively. At both moorings the mean thickness of the westerly flow was about 250 m, and the difference in latitude, projecting both onto a common north-south section was 7.2 km. These values, since we are neglecting overflow to north and south of the moorings, give us a minimum estimate of westward transport from the Ymir Trough of 0.3 Sv for the 100-day period 2 March - 10 June 1988, and is composed of water with a temperature (from both mean profiles) below 8°C. This is much below the estimate of 1.2 Sv total westward flow made from short-term measurements during Overflow '73, and which was regarded as near-maximal by Ellett and Edwards (1978), who suggested a minimal transport of 70% of this value (i.e., 0.8 Sv) for the period 11 August - 4 September 1973. The CTD data suggest

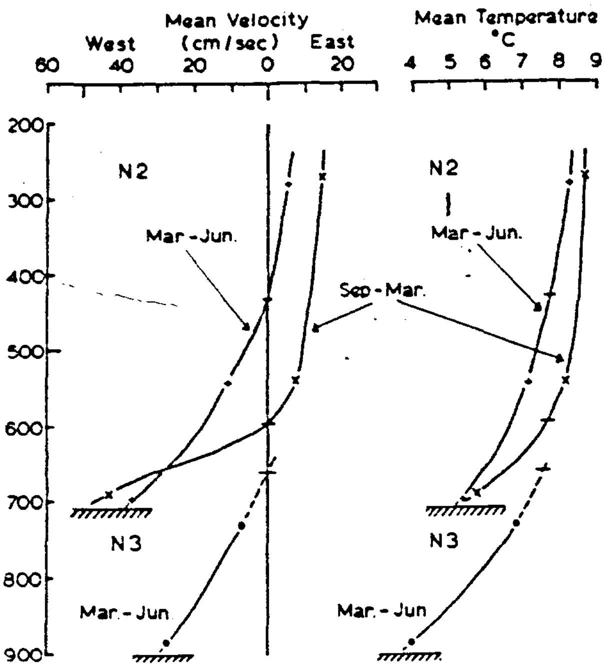

Figure 7. Mean E-W velocity components and temperatures from the current meter deployments.

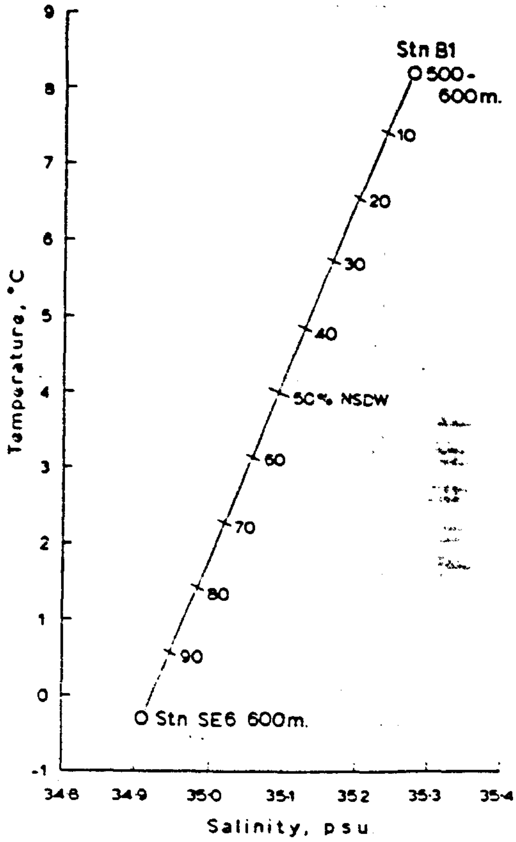

Figure 8. Temperature - salinity mixing diagram for the overflow, June 1988.

that differences of this order are unlikely to have arisen from neglected overflow to north and south of the moorings, and must reflect the random nature of short-term determinations. The September to March N2 velocity and temperature profiles of Figure 7 appear to indicate a lesser mean transport value for the autumn-winter period, but this is an unsafe assumption without data from the lower current meter position.

Estimating the NSDW content

The mean temperatures from the lower current meters indicate a relatively low content of NSDW. The June 1988 CTD data allow us to establish a mixing line between the Atlantic water at crest-depth (500-600 m) approaching the Wyville-Thomson Ridge from the southwest and water at similar depth in the Norwegian Sea to the north of the ridge. These values are 8.25°C, 35.255 psu and -0.30°C, 34.910 psu respectively (Figure 8). Mean temperatures for the overflow were 5.4°C (bottom) to 7.8°C (zero velocity level) at N2 and 4.0° to 7.6°C at N3 (Figure 7), giving an approximate overall mean of 6.2°C. From Figure 8, this implies a NSDW admixture of 6-8% at the zero velocity level and 33-50% at the bottom, with an overall value of 25%.

Discussion

These figures emphasise the importance of entrainment and mixing in the Wyville-Thomson overflow, and suggest that it may often be composed of mixed water from intermediate depths north of the ridge rather than of pure NSDW.

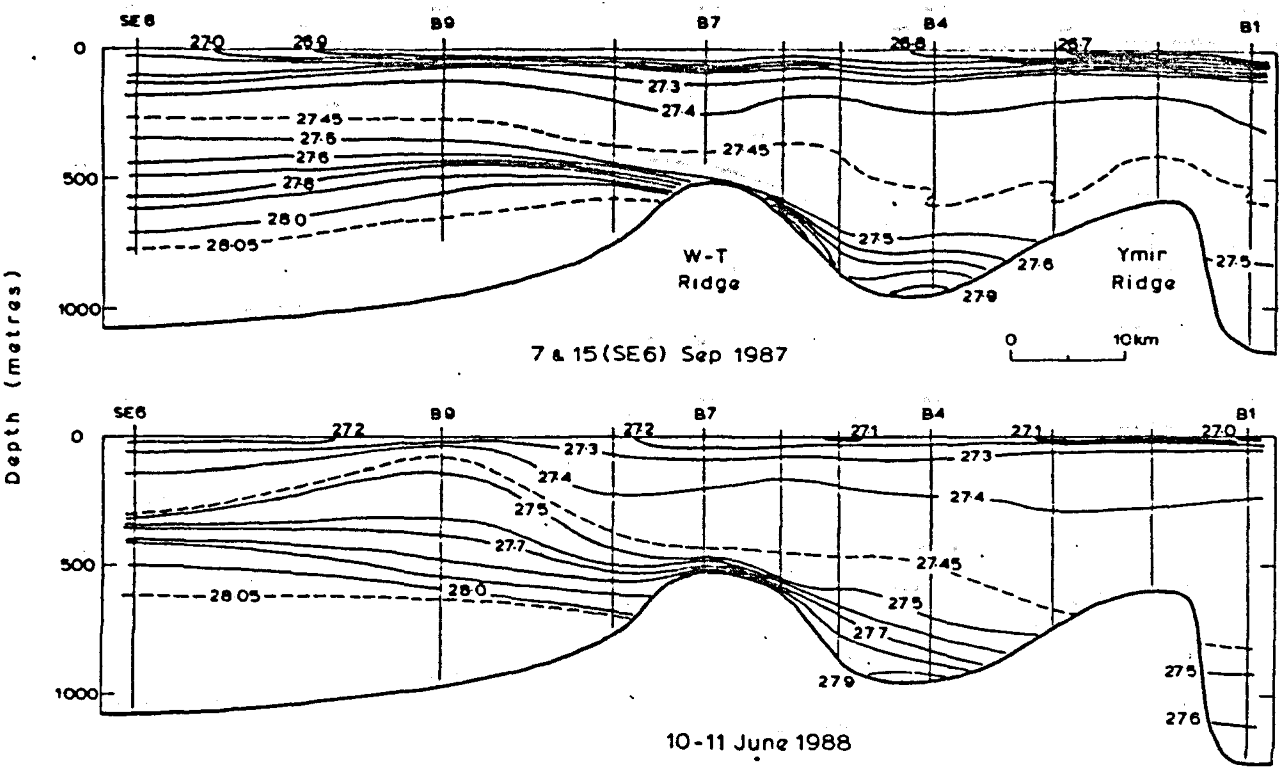

Figure 9. Density (σ_t) sections northeast-southwest across the ridges.

Density sections across the ridge from the September 1987 and June 1988 cruises are given in Figure 9, where large horizontal increases in density at 400-500 m levels north of the ridge can be seen. Regular or irregular movements such as tidal cycles, spring/neaps cycles or internal waves may allow some of this water to reach the south side of the ridge crest. A general relaxation of the predominating winter southwesterly wind forcing in spring, by allowing some of this intermediate mixed water to cross the ridge, may account for the outbreaks of westerly flow seen at this season in the mid-water current records.

A related point concerns the irregular appearance of low temperature water at relatively shallow depths upon the southern Faroe Bank slope, as at station A8 in Figure 6c. As noted earlier, short-term variability made it impossible to trace this water back to the ridge crest, though it is probable that it came from the junction of the ridge and Faroe Bank. Its shallow depth is anomalous in comparison with all the nearest Norwegian Sea stations, and Figure 10 shows that shallower cold water was found only in the middle of the entrance to the Faroe Bank Channel. In December 1988 a satellite-tracked drogue confirmed the existence of a cyclonic gyre in this area (Hansen et al, 1991), which connects well with the doming of the isopycnals in the sections of Figure 9. Displacement of this gyre may be the mechanism which brings shallow cold water to the northwestern ridge crest.

The discrepancies between the long-term estimate of volume transport westwards from the ridge during March-June 1988 (0.3 Sv below 8°C) and Ellett and Edwards' (1978) estimates of a near-maximal value of 1.2 Sv total and 0.33 Sv NSDW have been mentioned above. Two other short-term determinations have been made by Saunders (1990), of 0.35 Sv on 1 June 1987 and 0.3 Sv on 21 May 1988,

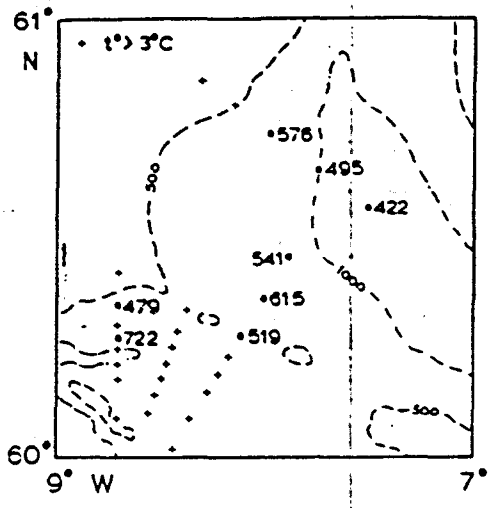

Figure 10. Depth (m) of the 3°C surface, 10-14 June 1988.
(+ indicates stations with no water below 3°C.)

which though of similar magnitude to the long-term value, differ completely in composition. Saunders' estimates are for water of temperature below 3°C, whereas only one 10-day period at N2 (1-10 May 1988) and two at N3 (21 April - 10 May 1988) had mean temperatures of this order (see Figure 5). Calculations from the current meter data for 1-10 May 1988, the coldest period and shortly before Saunders' second determination, give a mean total transport westwards of 0.61 Sv, of which 0.08 Sv was water of temperature less than 3°C. For 21 May an estimate of 0.44 Sv is obtained, with mean temperatures for the day at the current meters not falling below 5.95°C, and the highest of the daily estimates for the next few days, that for 24 May, is 0.60 Sv, with west-going currents extending through most of the water column on the Faroe Bank slope and daily mean temperatures not below 3.35°C. The central site of Saunders' observations is some 50 km from the current meter positions, apparently giving sufficient distance for mixing processes to smooth out the extreme characteristics of the NSDW, although continuity of the volume of water descending into the Rockall Trough, and at times an increase in volume from entrainment, seem likely from these estimates. Thus Saunders' determinations and the current meter estimates are not incompatible, but the former may represent an upper value for overflow of 3°C water across the Wyville-Thomson Ridge, whereas the March-June mean of 0.3 Sv provides a general estimate of cold, intermediate and entrained water descending into the Rockall Trough at this season.

The study demonstrates the value of an extended period of observations of this overflow. The short-term data of Ellett and Edwards (1978) and Saunders (1990) appear to have been taken at times of high NSDW overflow and, in the former case, high entrainment. Such episodes are obviously not infrequent, and other brief and more extreme Wyville-Thomson overflow events are suggested by data from the JASIN surveys (Zenk, 1980) and especially by the dense water encountered upon one of four repeated sections across Rosemary Bank in 1965 by Elder (1970), but comparison with the relatively long-term mean currents presented here puts these into context.

Conclusions

1) Current measurements made about 50 km west of the Wyville-Thomson Ridge for 9 months at one site and 3 months at a second show a relatively steady westward flow at the lowest levels, a general eastward flow interrupted and sometimes reversed in spring in mid-water, and a variable easterly flow at the upper level.

2) For the 100 days in March-June 1988 when data for two moorings are available the westward flow descending into Rockall Trough was estimated to have a minimum mean value of 0.3 Sv, with a 25% content of NSDW.

3) Although dense water may cross the ridge at a number of points, currents upon the south slope of Faroe Bank and those in the westward-leading trough are coherent upon a 10-day time scale.

4) The movements in relation to wind forcing of a cyclonic gyre at the southern entrance to the Faroe Bank Channel to the northeast of the ridge may be an important factor upon the seasonal and short-term variability and the composition of the overflow.

Acknowledgements

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