The hydrology of waters close to Gough Island

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Water samples were collected from 32 stations close to Gough Island. Temperature and salinity values indicate that the waters sampled were essentially sub-Antarctic in character. Distribution of the major elements of the water column were relatively uniform both horizontally and vertically. This would suggest that considerable mixing of surface waters was taking place probably as a result of prevailing weather conditions in the region. Chlorophyll a *(0,00 – 0,49 mg/m³), phosphate (0,81 – 2,77 µg-at/l), nitrate (3,47 – 14,62 µg-at/l) and silicate (3,07 – 6,98 µg-at/l) ranges were low but still directly comparable with available data for the area. However, indications are that water properties may be influenced both by variations in the position of the subtropical convergence and by possible topographical effects of the island itself.*

Watermonsters is versamel by 32 stasies om Gough-eiland. Temperature en soutgehaltes dui aan dat hierdie waters hoofsaaklik sub-Antarkties van aard was. Beide die horisontale en vertikale verspreiding van belangrike elemente in die watermassa was relatief uniform. Dit sou voorgee dat aansienlike vermenging van water naby die oppervlakte plaasgevind het, moontlik as gevolg van heersende weerstoestande oor die gebied. Waardes van chlorofiel a *(0,00 – 0,49 mg/m³), fosfaat (0,81 – 2,77 µg-at/l), nitraat (3,47 – 14,62 µg-at/l) en silikaat (3,07 – 6,98 µg-at/l) was laag maar tog direk vergelykbaar met beskikbare data vir die gebied. Aanduidings bestaan egter dat watertoestande beïnvloed mag word deur beide die veranderinge in die posisie van die subtropiese konvergensie asook die moontlike topografiese effek van die eiland as sulks.*

Introduction

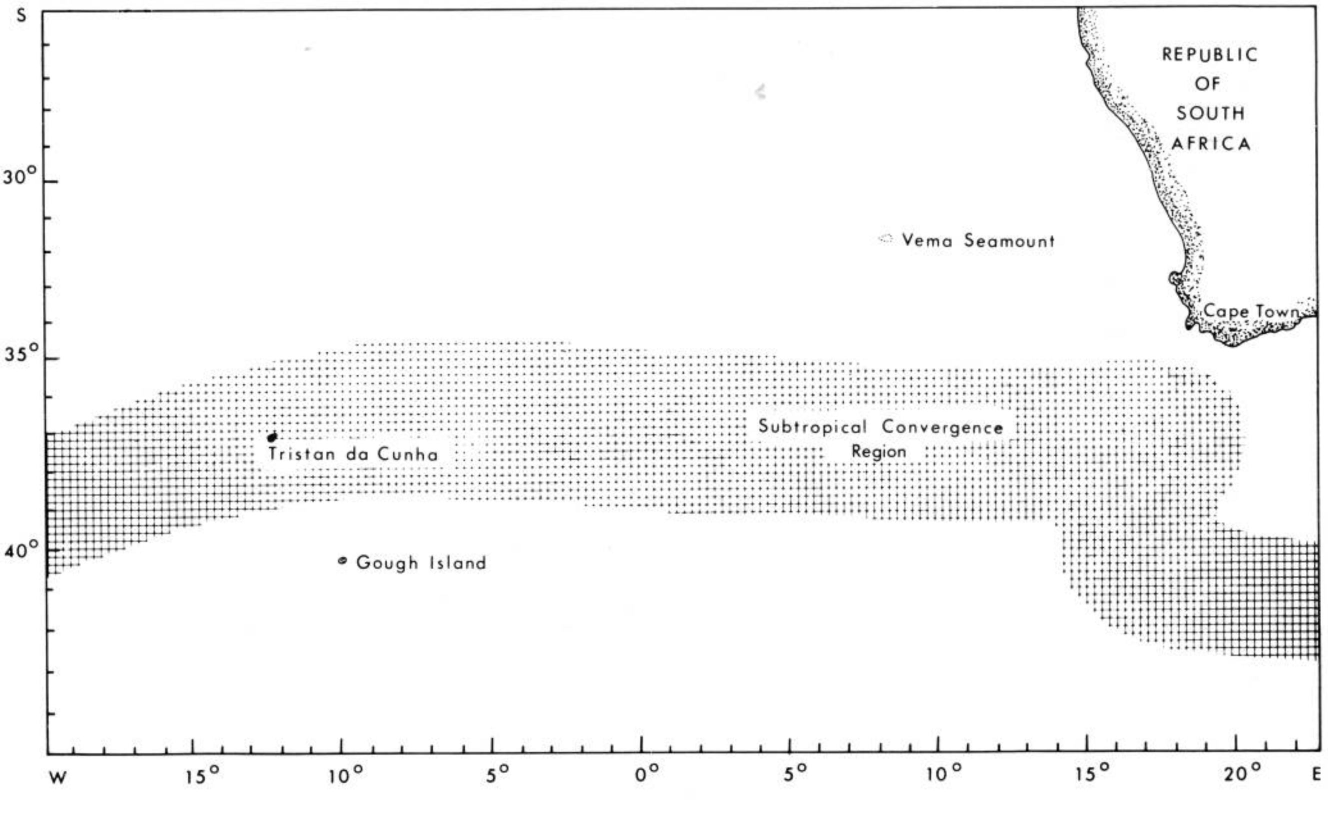
This paper presents results from a hydrological study of the nearshore waters of Gough Island (40°20′S, 09°54′W). It represents in part an overall study investigating the relationship of potential food organisms to island-based predators at selected localities in the Southern Ocean (Miller 1982a, 1982b). Gough Island is an outlying member of the Tristan da Cunha archipelago (Fig. 1) and constitutes an important breeding site for many seabird and seal species (Holdgate 1958, Anon 1979). In order to understand the biology of these animals, investigations of the distribution and abundance of marine organisms essential to their diet are required (Anon 1979). These investigations must be complemented by a full description of the physical and chemical environment of these dietary marine organisms in order to explain their distribution (El-Sayed *et al.* 1979). To date, only one hydrological survey has been undertaken in the region (Anon 1929, Henry 1975).

Materials and Methods

The survey took place during October-November 1980 and formed part of the annual Gough Island Relief Voyage of the M.V. *SA Agulhas*.

A systematic survey grid was utilised. In an attempt to maximise cover and in the absence of prior information, the

Fig. 1. The position of Gough Island relative to the subtropical convergence.



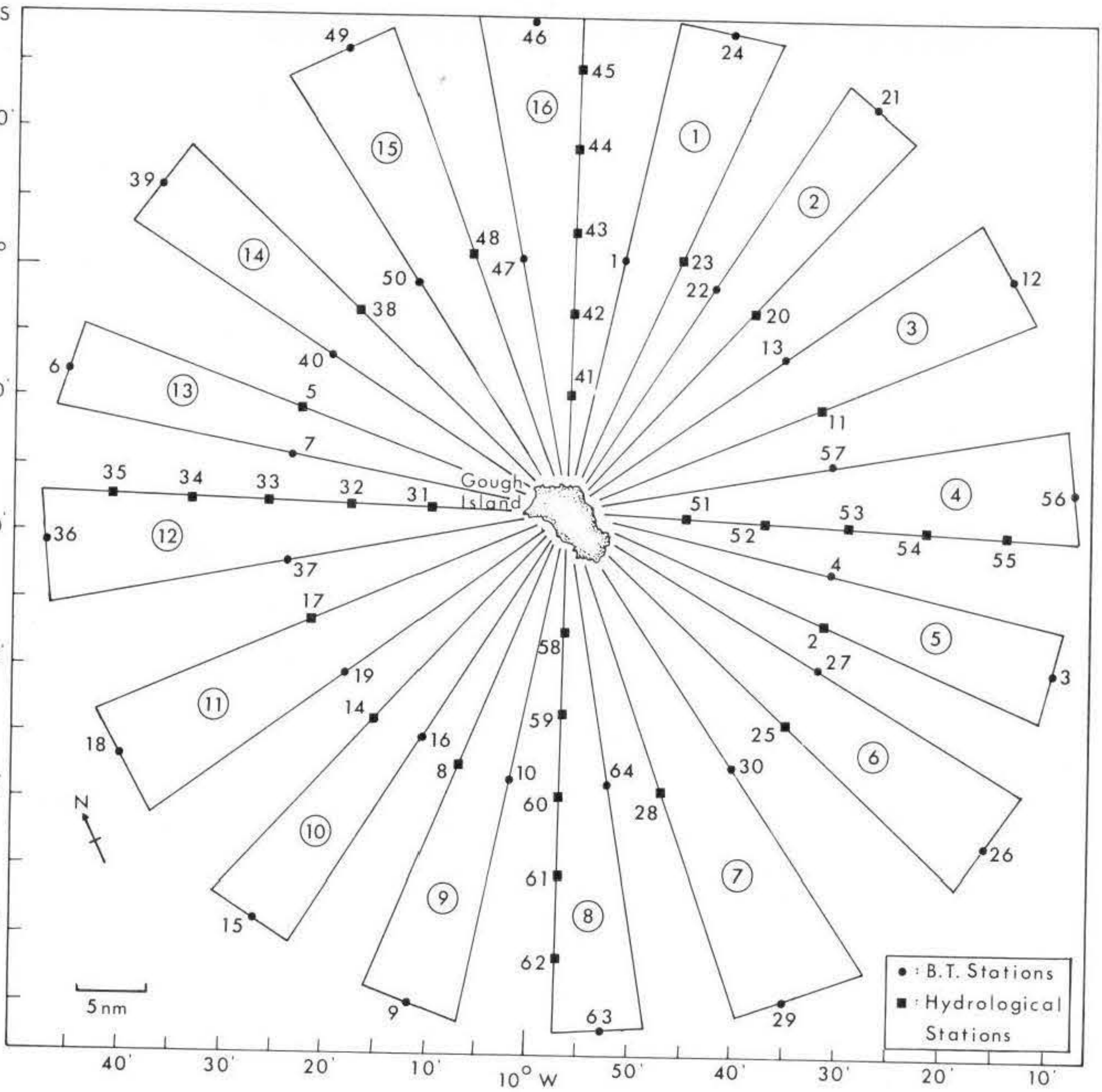


Fig. 2. Survey grid and positions of hydrological stations.

survey area was restricted to approximately 3 850 sq. nautical miles around the island (Fig. 2). This area was divided into 16 separate sectors of approximately 240 sq. miles each. A single, full hydrological station was occupied at the centre of the outgoing leg of each sector (Fig. 2). In addition, a further 16 stations were sampled, four on each leg, due north, south, east and west (Fig. 2). Vertical temperature changes were measured from the surface to 275 m depth at an additional 32 bathythermograph stations (Fig. 2). Parameters measured at each hydrological station and methods of measurement-analysis are presented in Table 1. Sampling depths were standardised to 0, 10, 25, 50, 80, 110, 150 and 200 m.

Table 1
Methods of oceanographic data collection and analyses

Parameter	Sampling method	Analysis
Temperature	CTD/Bathythermograph	—
Salinity	CTD/N.I.O. Bottles	Inductively-coupled Autolab Salinometer
Oxygen	N.I.O. Bottles	Standard Winkler Titration
Nutrients	N.I.O. Bottles	Technikon Auto-analyser (Strickland & Parsons 1968)
Chlorophyll	N.I.O. Bottles	Varian 635 Spectrophotometer (UNESCO 1966)

Results and Discussion

Temperature

Gough Island is situated in the sub-Antarctic West Wind Drift region lying between the Antarctic and subtropical convergences (Hela & Laevastu 1961).

Surface water temperatures between 10,5 – 12,4 °C were found during the present survey and a single high value of 13,4 °C was measured on the eastern perimeter of the survey grid (Fig. 3). A tongue of water warmer than 12 °C was visible to the north of the island, while the lowest temperatures were recorded in sectors 5 – 7 to the east and south-east (Fig. 3).

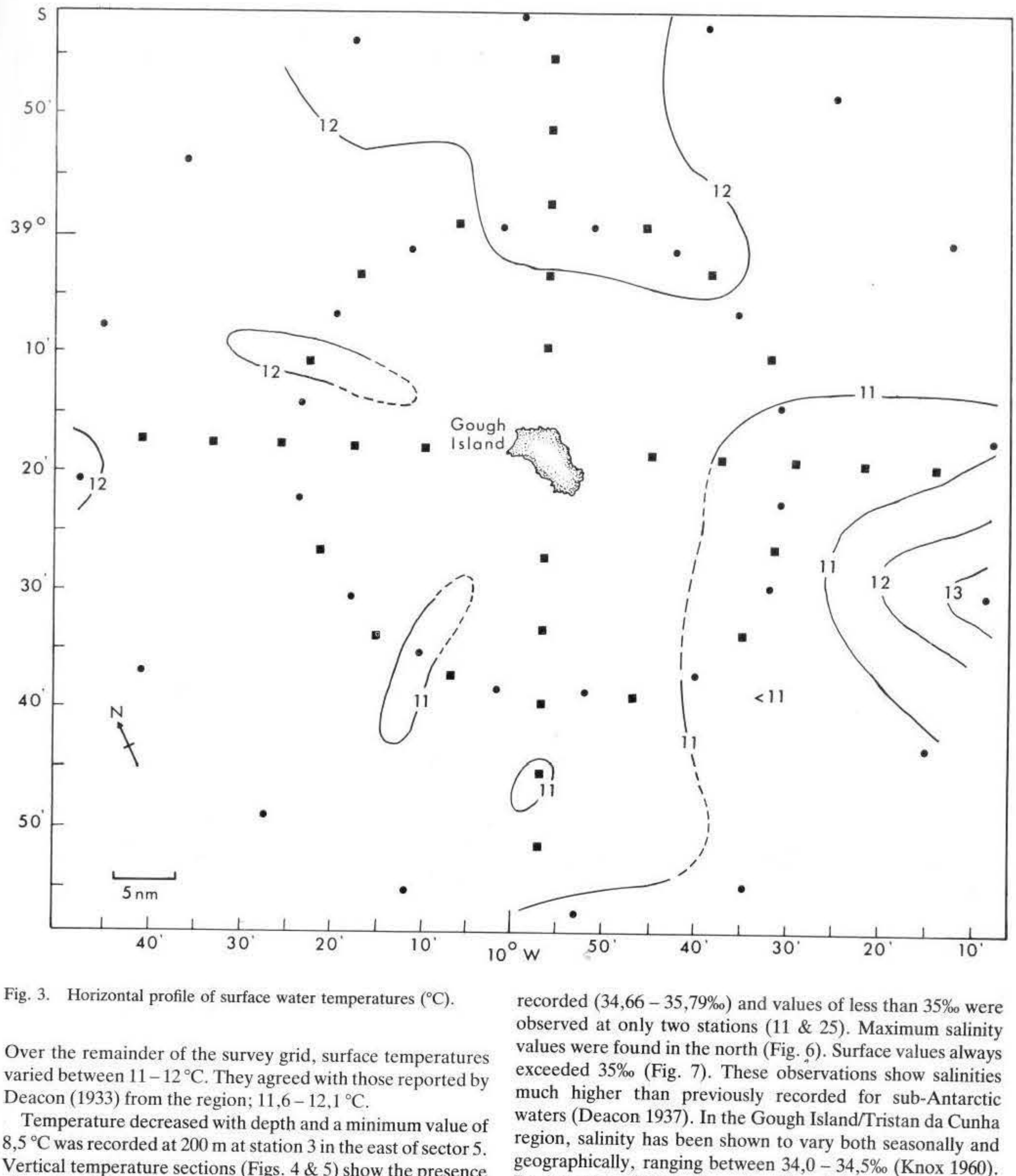


Fig. 3. Horizontal profile of surface water temperatures (°C).

Over the remainder of the survey grid, surface temperatures varied between 11 – 12 °C. They agreed with those reported by Deacon (1933) from the region; 11,6 – 12,1 °C.

Temperature decreased with depth and a minimum value of 8,5 °C was recorded at 200 m at station 3 in the east of sector 5. Vertical temperature sections (Figs. 4 & 5) show the presence of a colder body of water in the east as well as an intrusion of a subsurface temperature maximum in the north. This inversion could be attributed to an influx of warmer water from the subtropical convergence region (see below). As expected (Deacon 1962), no visible thermocline was apparent and a maximum vertical temperature gradient of 1,4 °C over a 30 m depth range was observed. Absence of a marked thermocline would be the result of vertical mixing of surface waters resulting from the almost constant rough weather conditions to which the region is subject (Knox 1960).

Salinity

During the present survey, a wide range of salinities was recorded (34,66 – 35,79‰) and values of less than 35‰ were observed at only two stations (11 & 25). Maximum salinity values were found in the north (Fig. 6). Surface values always exceeded 35‰ (Fig. 7). These observations show salinities much higher than previously recorded for sub-Antarctic waters (Deacon 1937). In the Gough Island/Tristan da Cunha region, salinity has been shown to vary both seasonally and geographically, ranging between 34,0 – 34,5‰ (Knox 1960). During the William Scoresby Expedition, salinity levels between 34,47 – 34,87‰ were recorded close to Gough (Deacon 1933). Salinity values recorded farther north, just south of the subtropical convergence, are remarkably similar (34,4 – 34,7‰) (Clowes 1950).

It is concluded that the high salinities (>35‰) of the surface waters were the result of a southward intrusion of subtropical surface water. A correlation between warm water (Fig. 4) and high salinities (Fig. 6) in the north further suggests an influence of subtropical water. Knox (1960) reports a salinity range of 34,9 – 35,5‰ for such water. However, this is inconsistent with low, sub-Antarctic water temperatures recorded elsewhere around the island. At present it must be concluded that the survey area was subject to considerable mixing, both

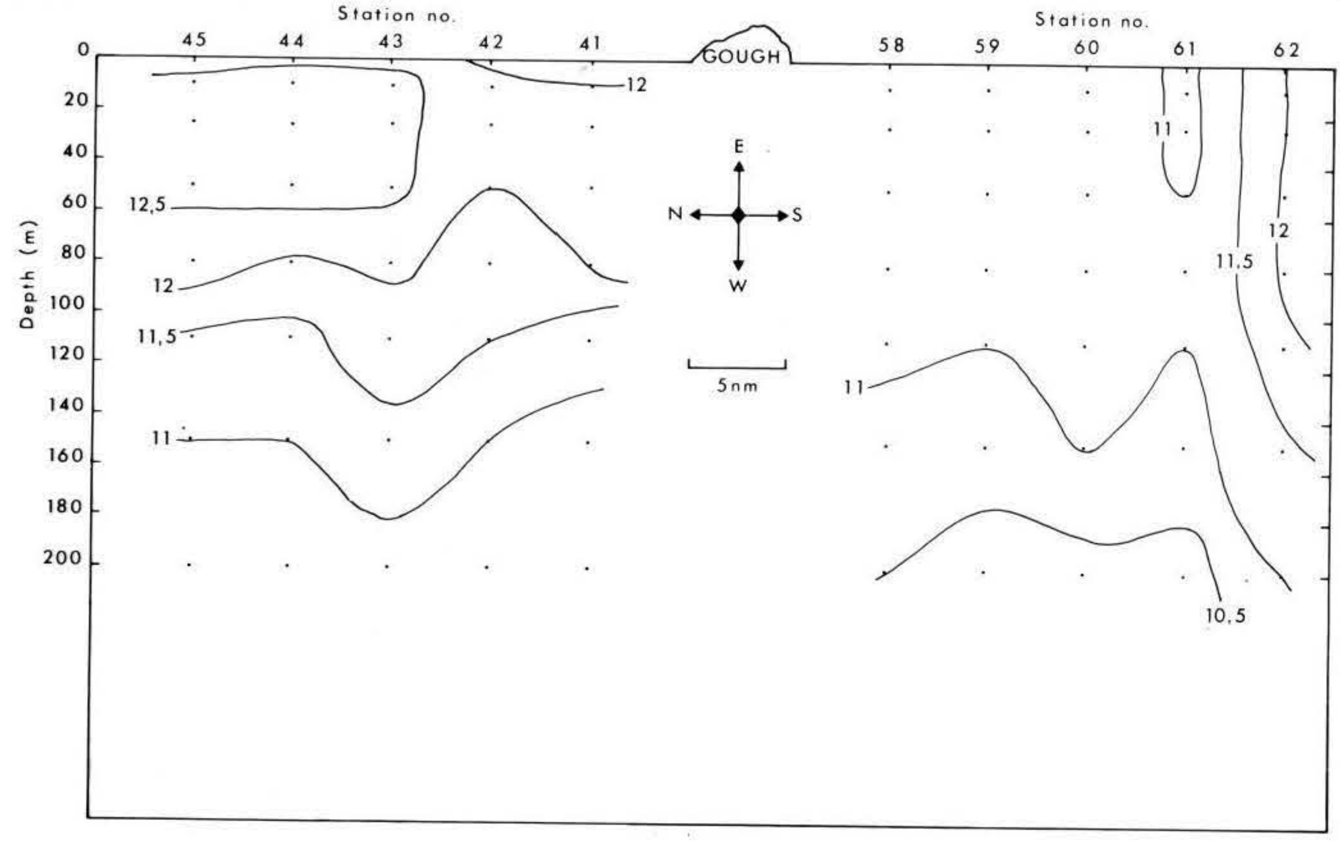


Fig. 4. Vertical temperature (°C) section, North-South survey lines.

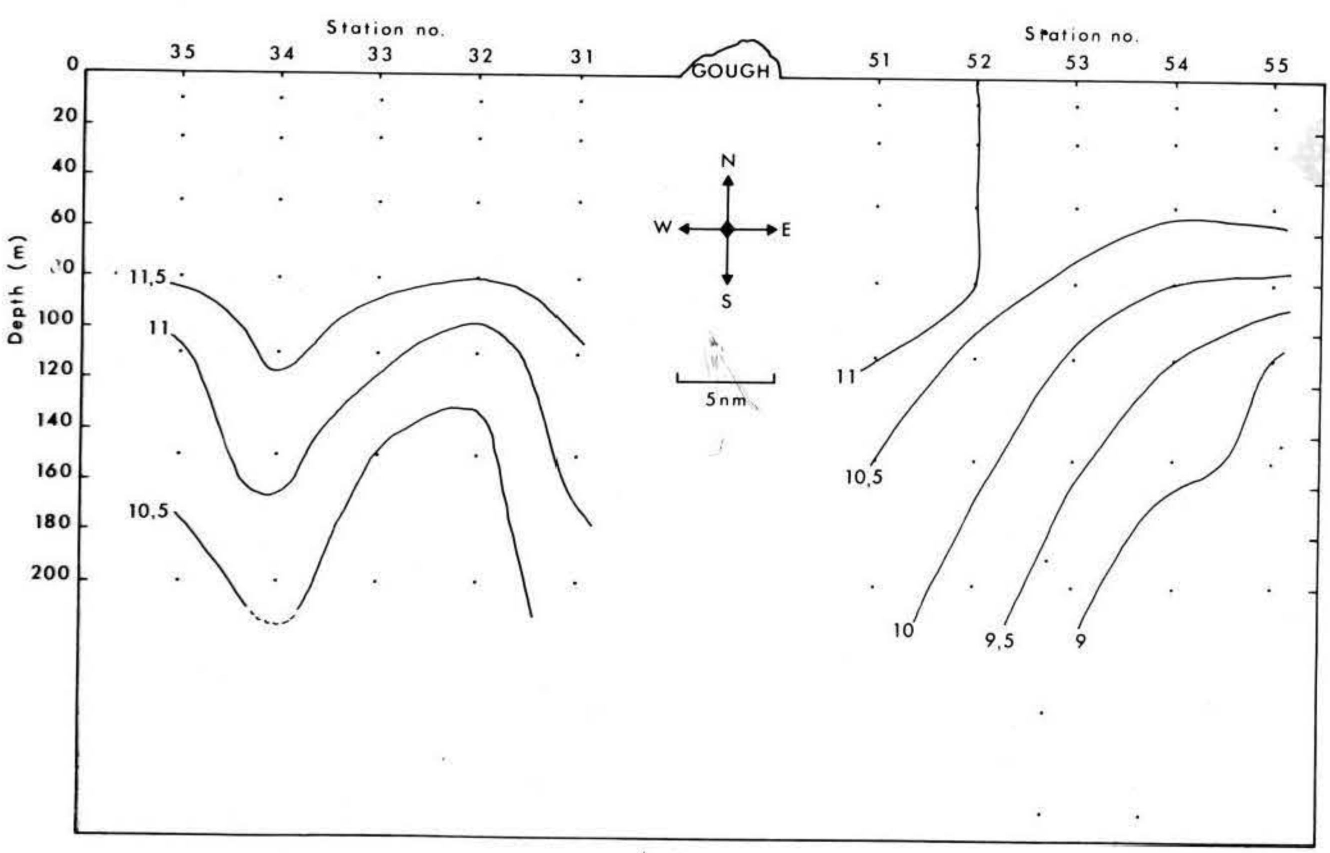


Fig. 5. Vertical temperature (°C) section, East-West survey lines.

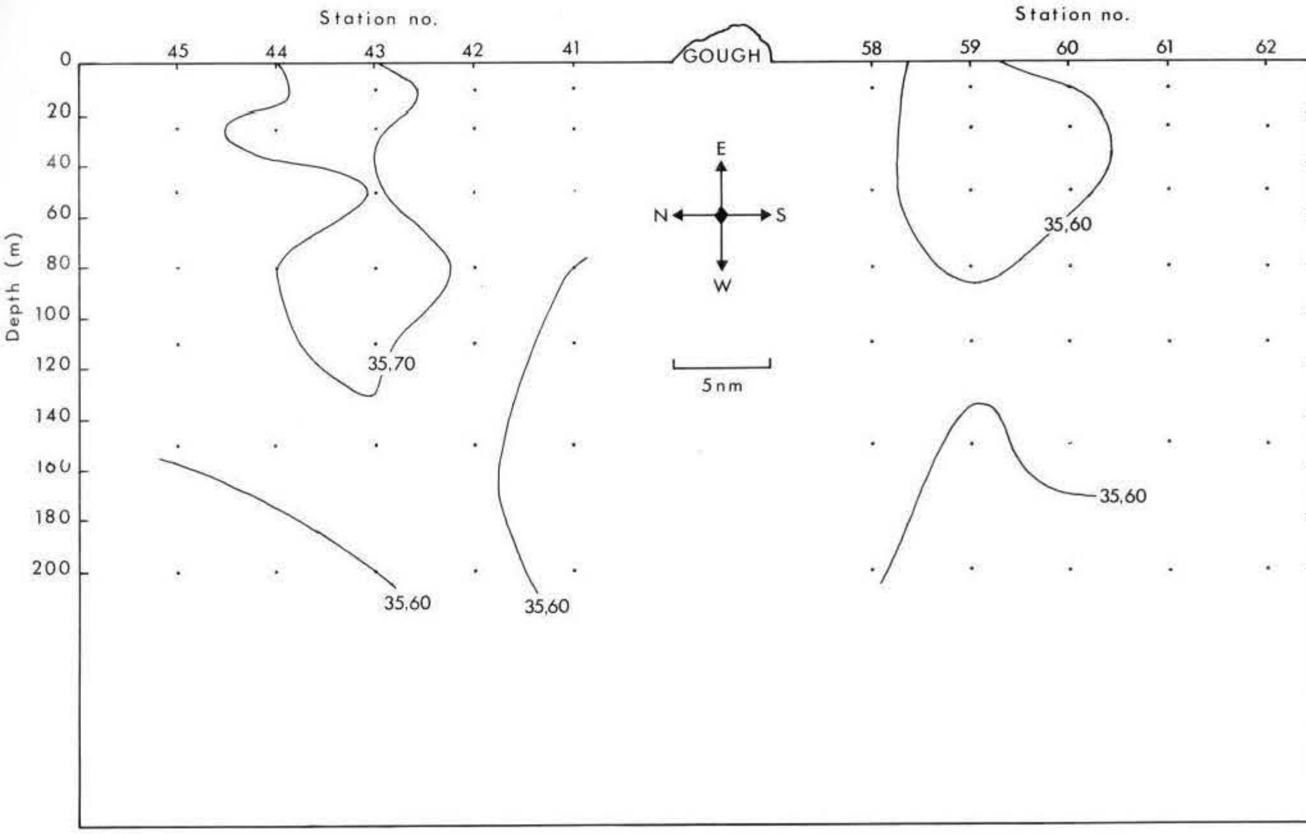


Fig. 6. Vertical salinity (‰) section, North-South survey lines.

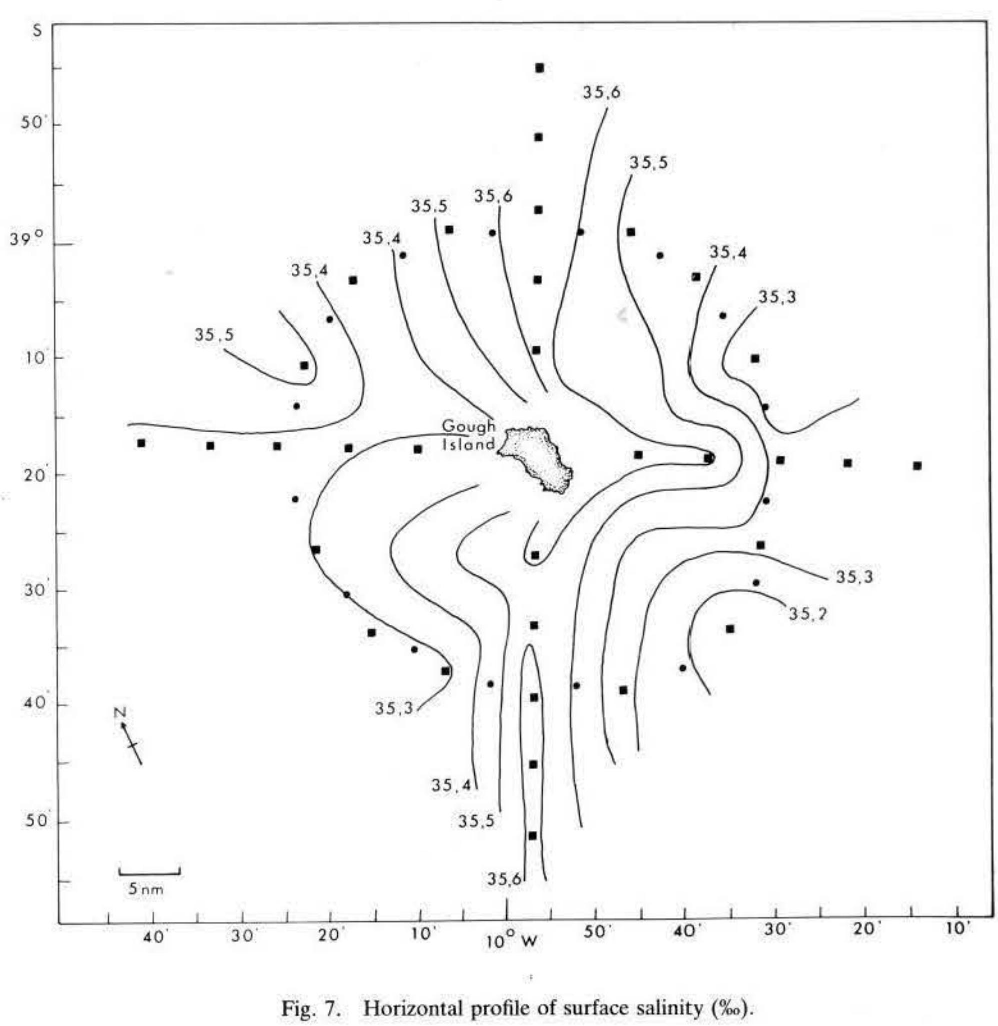


Fig. 7. Horizontal profile of surface salinity (‰).

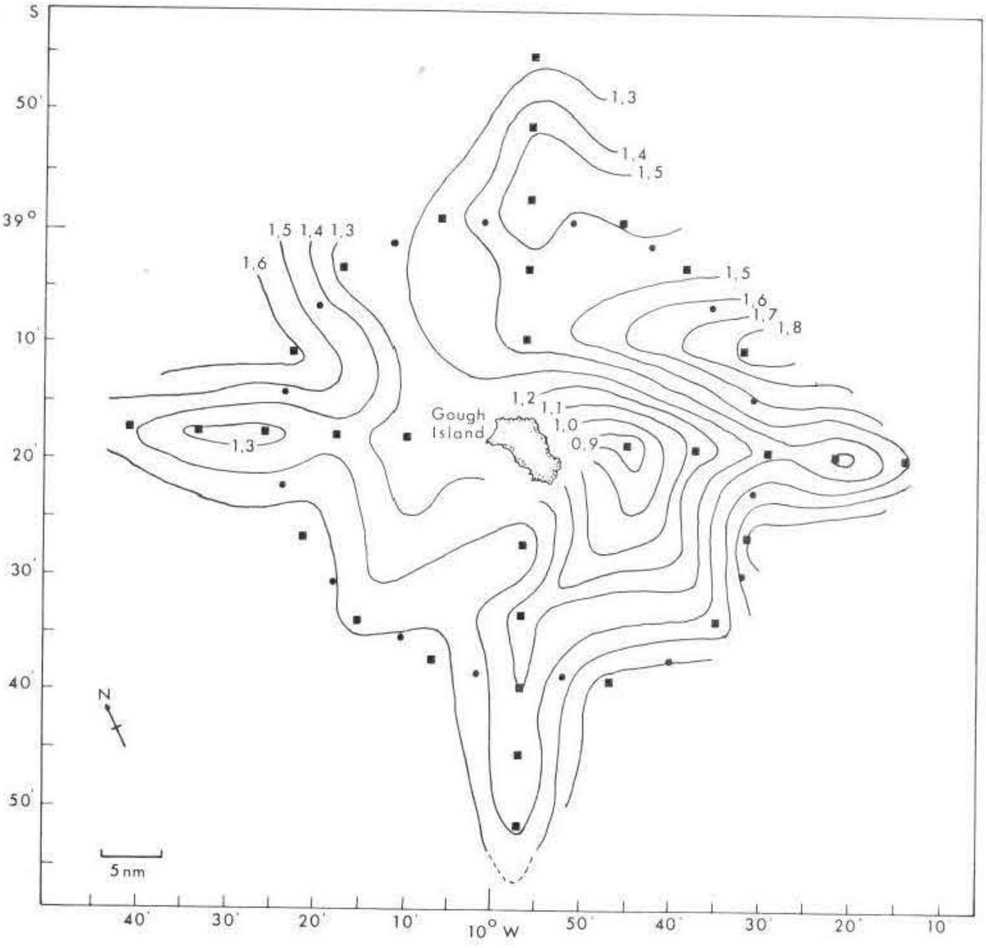


Fig. 8. Horizontal profile of surface phosphate (μg-at/*l*) values.

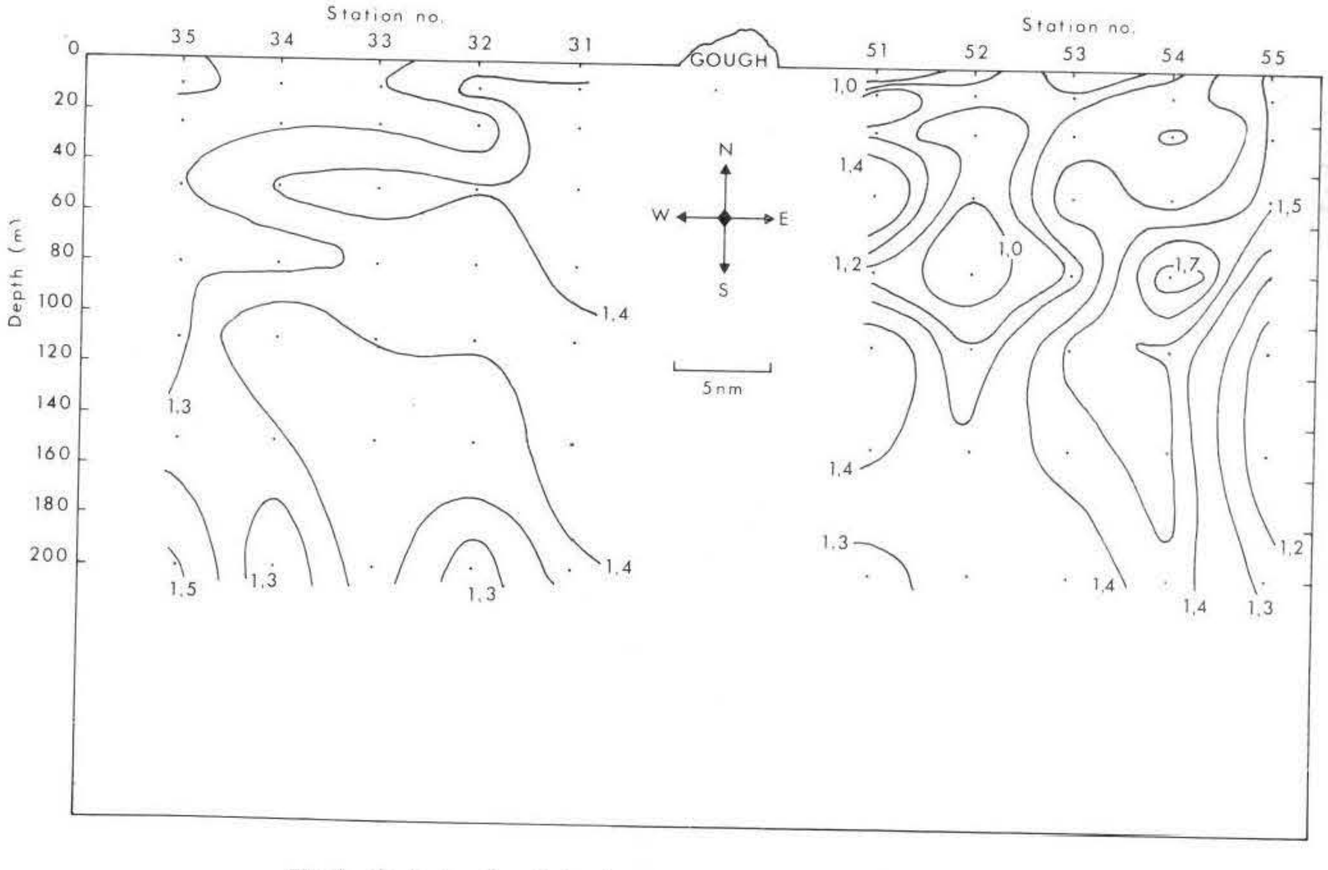


Fig. 9. Vertical section of phosphate (μg-at/*l*) values, East-West survey lines.

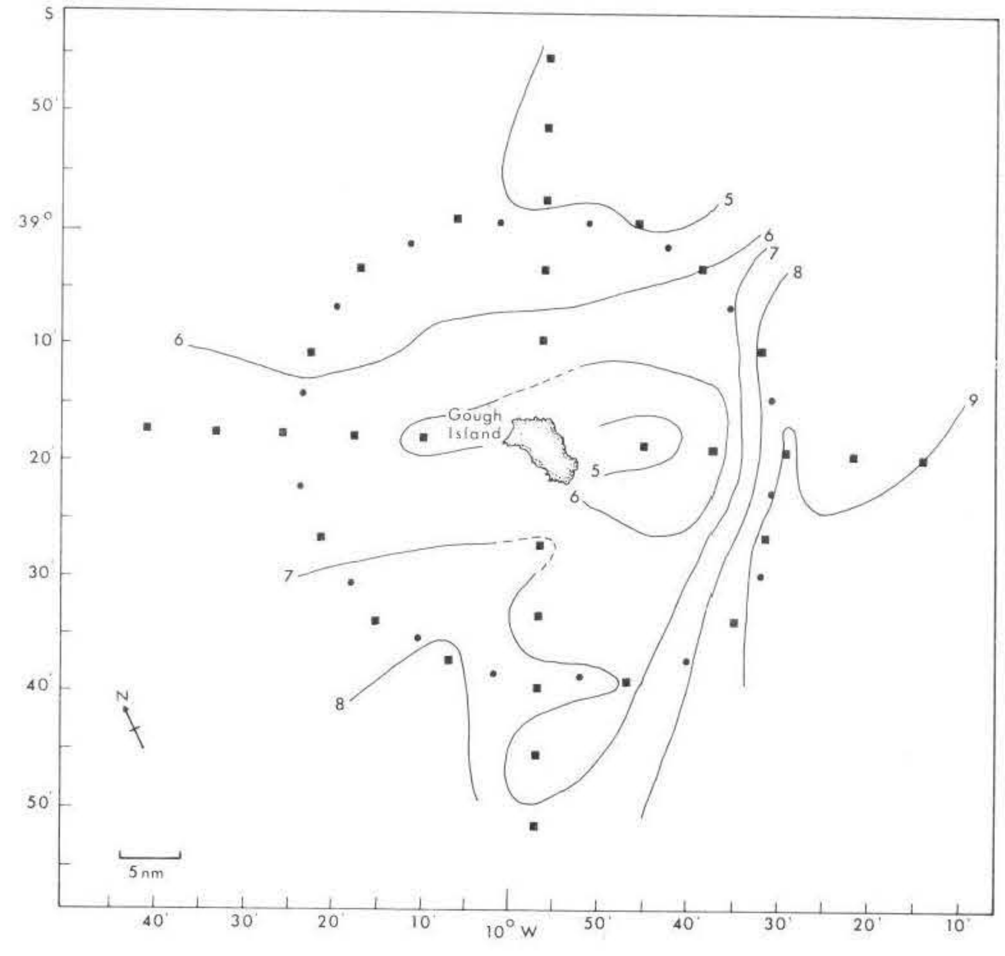


Fig. 10. Horizontal profile of surface nitrate (µg-at/l) values.

vertical and horizontal, and as a result was influenced by contrasting water types. For this reason it would exhibit rather more complex surface gradient patterns of both temperature and salinity than would normally be expected for sub-Antarctic waters, conditions similar to those found in the subtropical convergence region close to New Zealand (Garner 1959). As a result it is assumed that the proposed intrusion of subtropical water in the north could not have been affected by mixing processes, either horizontal or vertical. This would suggest that the phenomenon was transient in nature and would therefore be susceptible to both temporal and weather changes.

Temperature data indicated an upward vertical transport of cold, deep oceanic water (11 °C) in the east (stations 51 – 55) (Fig. 5). An uplift of cold water (minimum 9 °C) can be seen at stations where the 9 – 11 °C isotherm was shallower than at other locations around the island (Figs. 4 & 5). Since this phenomenon was observed at stations on the leeward side of the island, it would be reasonable to conclude a likely occurrence of upwelling (Sverdrup *et al.* 1942, Reid *et al.* 1958, Ashmole & Ashmole 1967). Although supportive evidence for vertical upwelling was apparent in the distribution of nutrient salts with depth on the eastern line (especially nitrate), the relatively high salinity values recorded obscure the origins of upward-moving water. Therefore, it is unlikely that this highly saline water could be of Antarctic origin, as would be expected if upwelling had occurred (Knox 1960). Consequently, some other explanation is necessary for the present results.

Van Dorn *et al.* (1967) have reported similar phenomena in mid-Pacific and together with Barkley (1972) and Owen (1980) show that changes in depth and degree of density stratification in the lee of islands are correlated with downstream baroclinic eddies. Our observations support this alternative to oceanic upwelling. This would account for the apparent shoaling of nutrient salts while also explaining the obvious incongruity posed by the presence of both temperate and saline water together. Combined with the effects of both horizontal and vertical mixing on water hydrology, topographical effects of the island itself must form a priority for future study.

Density distribution (Sigma-t)

Sigma-t surfaces were plotted for two levels (27,00 and 27,20) but were found to be without meaning. This result was not totally unexpected. As already demonstrated, temperature and salinity values indicate considerable vertical mixing over the depths sampled. As a result, a clear relationship between the variables would be precluded and any geostrophic pattern would be impossible to demonstrate.

Oxygen

Dissolved oxygen concentrations between 4,33 – 6,83 ml/l were recorded. This represented a much wider range than that recorded by the Scoresby Expedition close to Gough (5,23 – 5,90 ml/l) for the same depth ranges (Deacon 1933).

Present surface oxygen fluctuated between 5,16 – 6,83 ml/l representing saturation values between 84 – 108 per cent, and minimum surface concentrations were observed in the east and south-west.

Subsurface changes in oxygen concentration never exceeded 0,7 ml/l over the depth ranges sampled. Nevertheless subsurface maxima were observed at most stations, but these were not fixed at specific depths occurring over the whole range sampled (0 – 200 m). Again, this would indicate a rather even depth distribution of oxygen, thus providing further evidence for vertical mixing of surface waters (Knox 1960). Regions of significant oxygen saturation or depletion were not evident, suggesting relatively little variation in primary production around the island. Results of chlorophyll *a* analyses (see below) indicate that this in fact was true.

Reactive nutrients

1) Phosphate

Surface phosphate varied between 0,81 – 2,77 μg-at/*l* (Fig. 8) with maxima and minima being recorded in the north and east, respectively. Isoline plots indicate little variation in phosphate with depth (Fig. 9) and it must be assumed that phosphate was evenly distributed over the depth range sampled. Mean phosphate (1,43 ± 0,25 μg-at/*l*) content differed little from values obtained by other workers and thought to characterise sub-Antarctic surface waters (Deacon 1933, Clowes 1950).

2) Nitrate

Surface nitrate varied between 4,5 – 8,8 μg-at/*l* and highest values were found in the east (Fig. 10). Vertical distribution showed a gradual increase in nitrate with depth and sharp gradients were observed, particularly at 100 m on the eastern line (Fig. 11). The relatively high nitrate values observed on this line coincided with a decrease in isotherm depth, suggesting a vertical eddy effect (Fig. 5). Nitrate minima, both surface and subsurface, were found in the north and corresponded to the area of highest temperature values (Fig. 3).

The observed range and mean nitrate values (3,47 – 14,62, ± 7,84 μg-at/*l*) were similar to values (3,97 – 15,2, ± 8,28 μg-at/*l*) calculated from Scoresby Expedition results (Deacon 1933).

3) Silicate

Surface silicate varied between 3,38 – 5,75 μg-at/*l* and maximum values were recorded in the east and north (Fig. 12). For the depth range sampled, silicate varied between 3,07 – 6,98 μg-at/*l* with a mean of 4,69 μg-at/*l*. The latter is much less than mean silicate obtained for a region due south-east of Gough (27,8 μg-at/*l*) but significantly higher than a value obtained close to Tristan da Cunha (0,01 μg-at/*l*) (Clowes 1938, 1950). Silicate varied little with depth, showing only a slight increase, although maxima were observed in the east (Fig. 13).

4) Correlation of nitrate : phosphate

The relationship between nitrate and phosphate is thought to reflect both primary production and the status of the nutrient salt cycle in a particular area or region (Clowes 1938, Stefansson 1968). When nitrate/phosphate relationships were plotted little correlation was found ($r = 0,59$), indicating no significant relationship between these two nutrient salts ($P = <0,01$). The phosphate : nitrate ratio (1 : 5,47) obtained was considerably less than the classical value of 1 : 15 (Richards & Vaccaro 1956) and much lower than previous values obtained from the Tristan da Cunha-Vema Seamount region (1 : 13,47) (Henry 1975). These results suggest that the area close to Gough Island is relatively unproductive and that recycling of nutrient salts is both slow and meagre (Stefansson 1968).

Chlorophyll *a*

Surface chlorophyll *a* varied between 0 – 0,49 mg/m³ with a mean value of 0,18 mg/m³ (Fig. 14). Over all depths

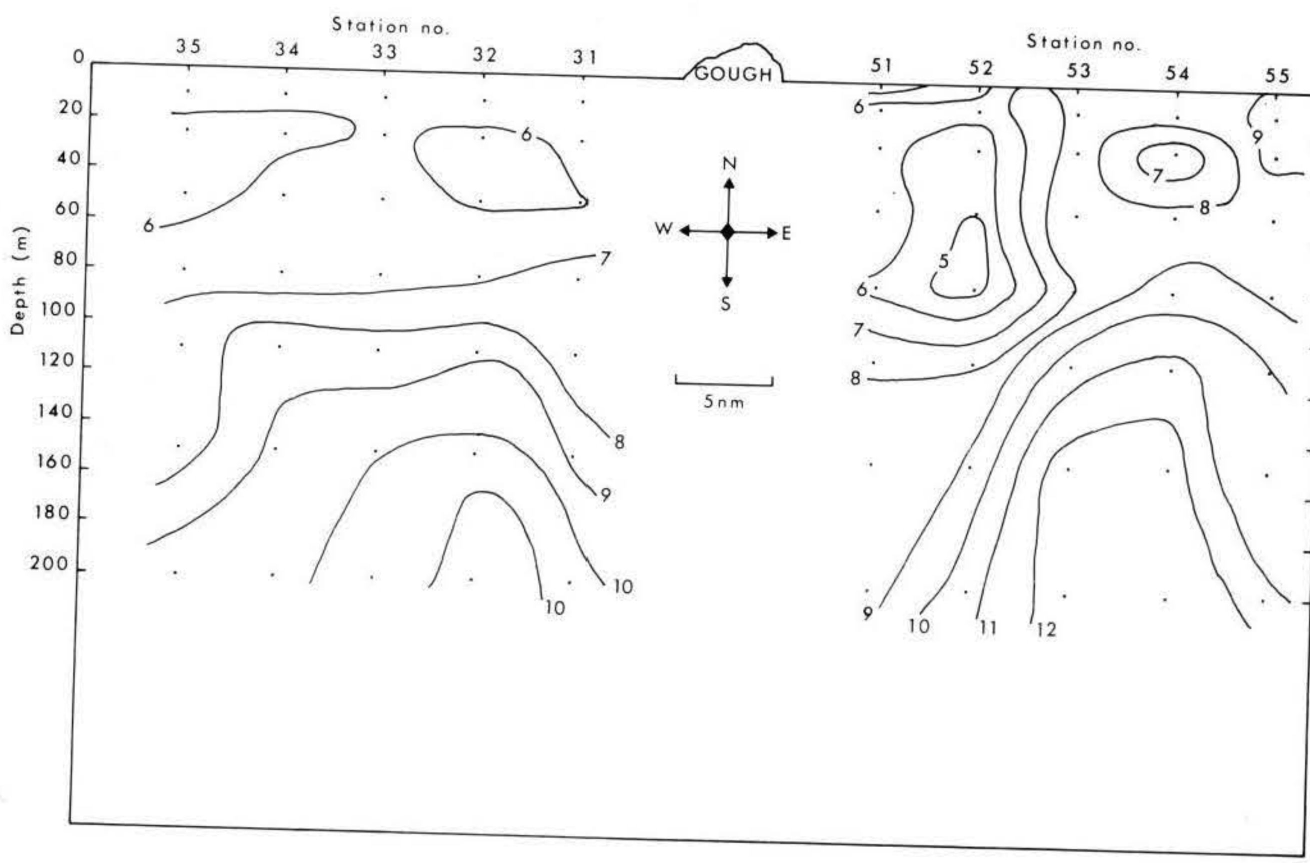


Fig. 11. Vertical section of nitrate (μg-at/*l*) values, East-West survey lines.

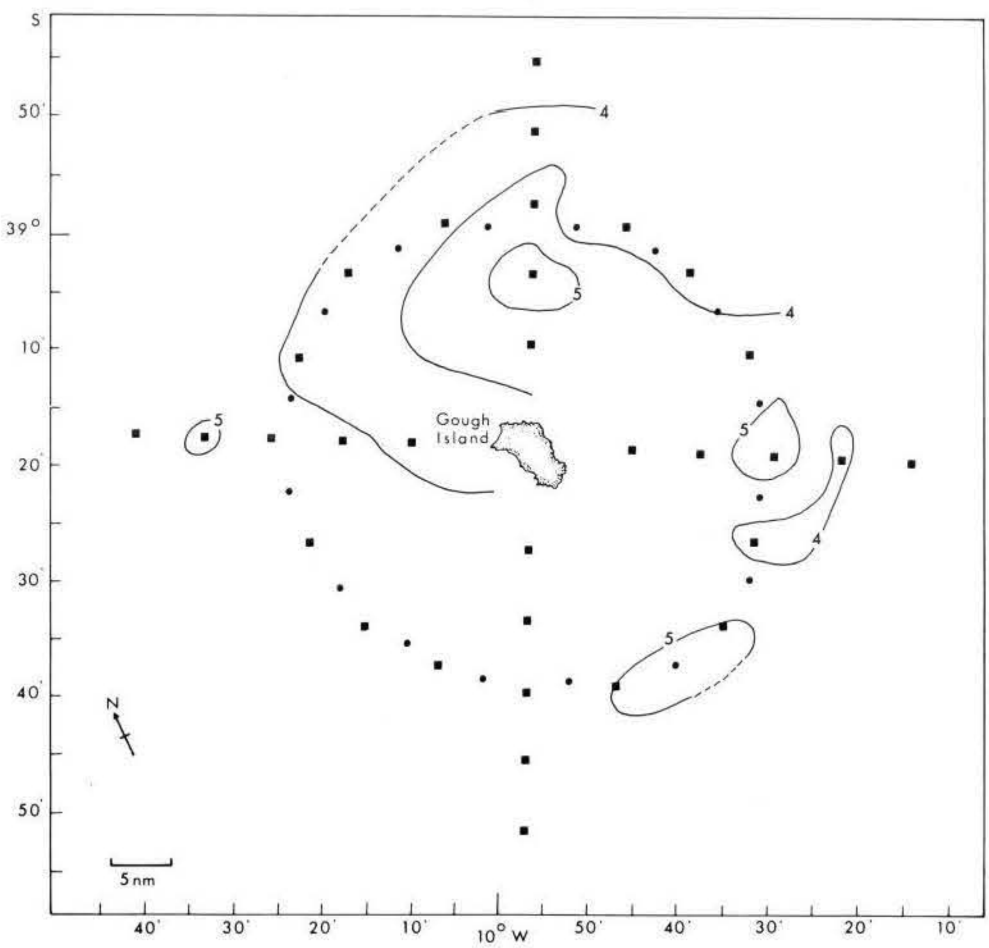


Fig. 12. Horizontal profile of surface silicate (µg-at/l) values.

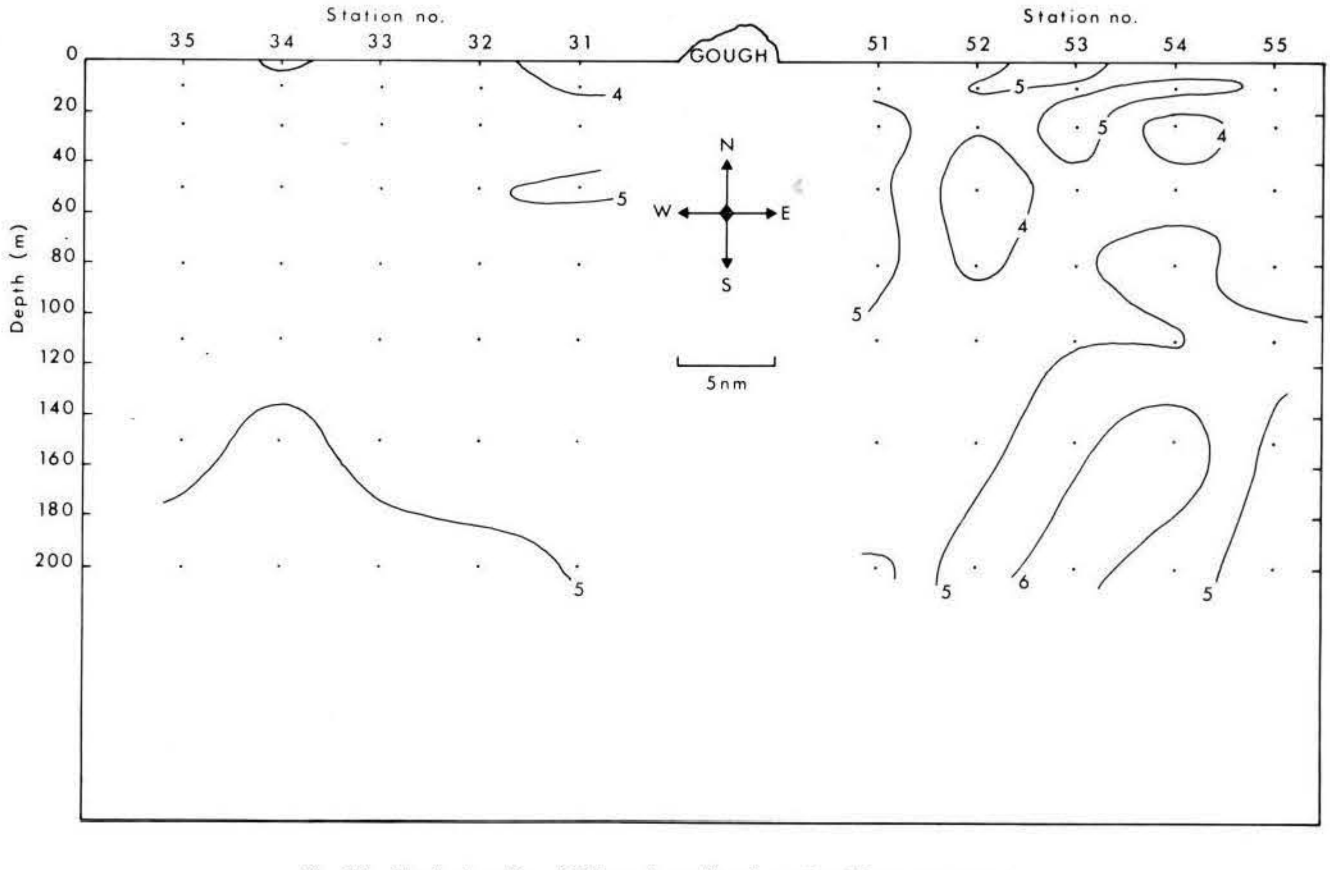


Fig. 13. Vertical section of silicate (µg-at/l) values, East-West survey lines.

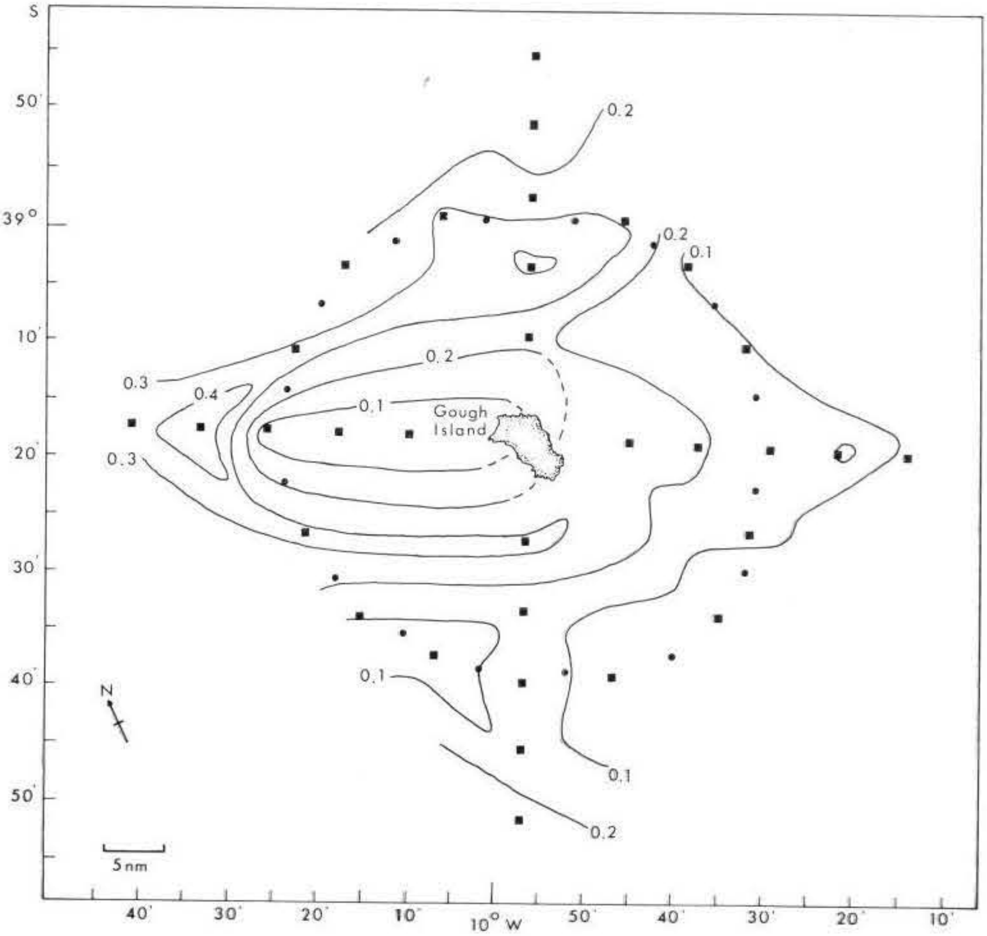


Fig. 14. Horizontal profile of surface chlorophyll *a* (mg/m³) values.

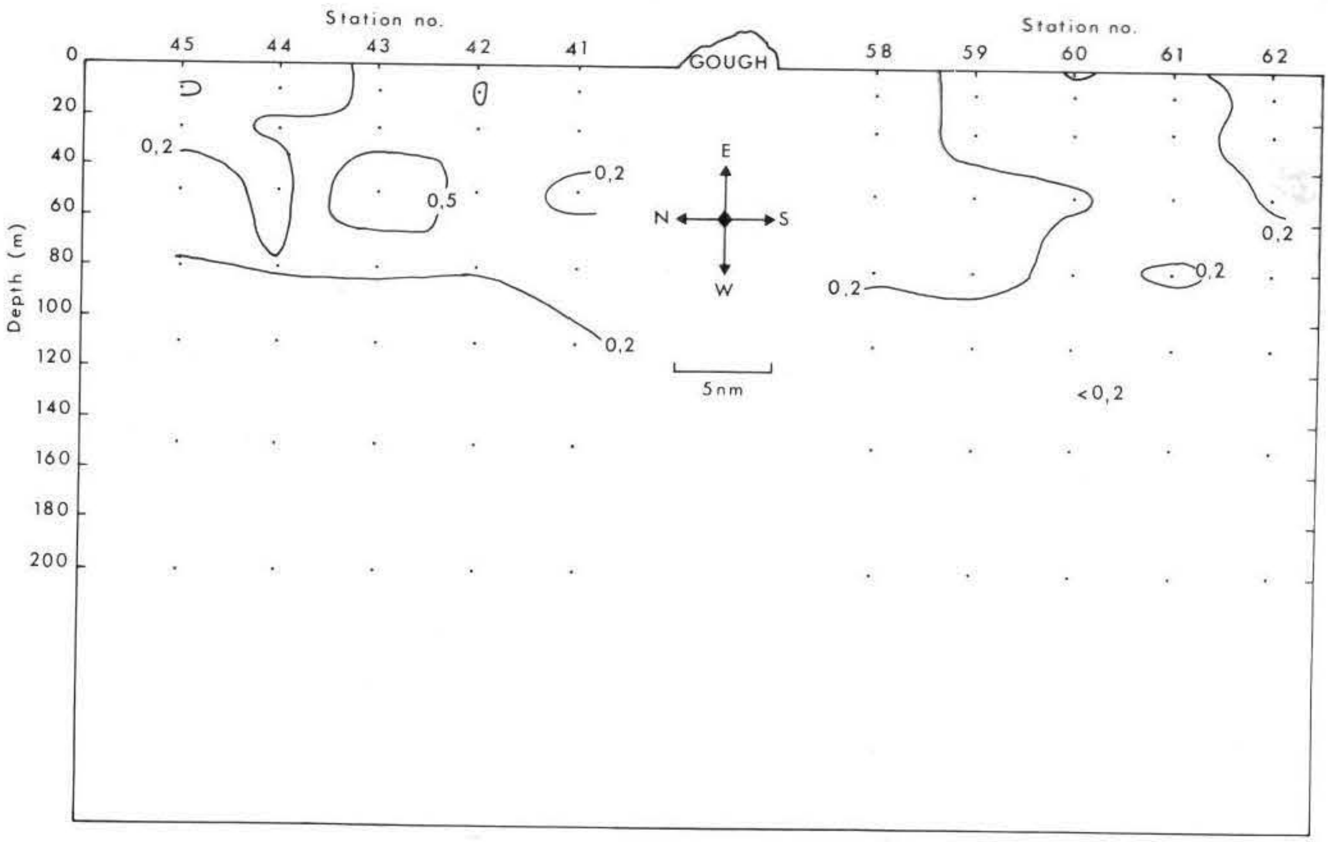


Fig. 15. Vertical section of chlorophyll *a* (mg/m³) values, North-South survey lines.

chlorophyll *a* ranged from 0 – 0,79 mg/m^3 with a mean of 0,16 mg/m^3. Maximum chlorophyll *a* values were found at stations 42, 43 and 48 to the north of the island and depths of peak chlorophyll values varied between the surface and 150 m. A single chlorophyll maximum was obtained at station 43 at a depth of 50 m (Fig. 15). In general, chlorophyll *a* was evenly distributed over the depths sampled. Values obtained were much lower than found elsewhere in the Atlantic Ocean for both sub-Antarctic and Antarctic surface waters (El-Sayed 1970).

Conclusion

The physico-chemical structure of the water column close to Gough Island was found to be directly comparable with available information for the region (Deacon 1933, Henry 1975). It would appear that waters of the region are essentially of sub-Antarctic character (Knox 1960), but there is a distinct possibility that both topography and prevailing weather conditions may influence hydrodynamics. Both relatively high salinity values and the presence of marked vertical/horizontal mixing suggest that the area may be characterised by mixed water possibly of different origins (Garner 1959, Knox 1960). Combined with cyclonic eddy formation, it is probable that a number of interrelated factors affect the hydrology of the region.

Low chlorophyll *a* and nutrient levels indicate restricted production. This observation is anomalous, as the inshore areas of Gough Island are considered to be particularly productive and have been shown to be rich in both macrophytic algae (Womersley 1954, Knox 1960, Chamberlain 1965) and higher trophic levels (Knox 1960, Penrith 1967, Heydorn 1969). It must be concluded that inshore areas are somewhat more productive than farther offshore, perhaps as a result of localised effects caused by the island itself which result in increased productivity (Burger *et al.* 1978, Van Zinderen Bakker 1978). Such effects would be greatly enhanced by vertical upwelling and by localised vertical mixing (Ashmole & Ashmole 1967). It is essential that future studies should include investigations of inshore areas, particularly as in the absence of a productive marine environment farther offshore, such areas may be implicated as an important food site for predators on the island (Miller 1982b).

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References

ANON 1929. Discovery investigations Station List 1925-1927. *Discovery Rept.* 1: 1-140.

ANON 1979. The Southern Ocean-South African co-operative research programme. *S.A. Nat. Sci. Prog. Rept.* 38: 1-23.

ASHMOLE, N.P. & ASHMOLE, M.J. 1967. Comparative ecology of seabirds of a tropical oceanic island. *Pea. Mus. Nat. Hist. Bull.* 24: 1-134.

BARKLEY, R.A. 1972. Johnston Atoll's wake. *J. Mar. Res.* 30: 201-216.

BURGER, A.E., LINDEBOOM, H.J. & WILLIAMS, A.J. 1978. The mineral and energy contributions of guano of selected species of birds of the Marion Island terrestrial ecosystem. *S. Afr. J. Antarct. Res.* 8: 59-70.

CHAMBERLAIN, Y.N. 1965. Marine algae of Gough Island. *Bull. Brit. Mus. (Nat. Hist.) Bot.* 3: 175-232.

CLOWES, A.J. 1938. Phosphate and silicate in the Southern Ocean. *Discovery Rept.* 19: 1-120.

CLOWES, A.J. 1950. An introduction to the hydrology of South African waters. *Investl Rep. Fish. mar. bio. Surv. Un. S. Afr.* 12: 29 pp.

DEACON, G.E.R. 1933. A general account of the hydrology of the South Atlantic Ocean. *Discovery Rept.* 7: 171-238.

DEACON, G.E.R. 1937. The hydrology of the Southern Ocean. *Discovery Rept.* 15: 125-152.

DEACON, G.E.R. 1962. Antarctic Oceanography: the physical environment. In: Biologie Antarctique, eds R. Carrick, M.W. Holdgate and J. Prevost. Herman, Paris. pp. 81-86.

EL-SAYED, S.Z. 1970. On the productivity of the Southern Ocean. In: Antarctic Ecology Vol 1, ed M.W. Holdgate. Academic Press, London. pp. 119-135.

EL-SAYED, S.Z., BENON, P., PASCAL, D., GRINDLEY, J.R. & MORAIL, J. 1979. Some aspects of the biology of the water column studied during the "Marion-Dufresne" Cruise 08. *CNFRA.* 44: 127-134.

GARNER, D.M. 1959. The subtropical convergence in New Zealand waters. *N.Z. J. Geol. Geophys.* 2: 315-377.

HELA, I. & LAEVASTU, T. 1961. Fisheries hydrography. Fishing News (Books), Ltd, London.

HENRY, A.E. 1975. Hydrology and nutrient salts of the South-east Atlantic and South-west Indian Oceans in 1968. *Investl Rept Div. Sea Fish.* 95: 66 pp.

HEYDORN, A.E.F. 1969. The South Atlantic rock-lobster *Jasus tristani* at Vema Seamount, Gough Island and Tristan da Cunha. *Investl Rept. Div. Sea Fish.* 73: 20 pp.

HOLDGATE, M.W. 1958. Mountains in the sea. Macmillan, London.

KNOX, G.A. 1960. Littoral ecology and biogeography of the southern oceans. *Proc. Roy. Soc. Ser. B. Biol. Sci.* 152: 577-624.

MILLER, D.G.M. 1982a. Results of a combined hydroacoustic and midwater trawling survey of the Prince Edward Island Group. *S. Afr. J. Antarct. Res., 12: 3-10.*

MILLER, D.G.M. 1982b. Results of a combined hydroacoustic and midwater trawling survey of the Gough Island region. *S. Afr. J. Antarct. Res.*, 12: 17-22.

OWEN, R.W. 1980. Eddies of the California Current system: Physical and ecological characteristics. In: The California Island, ed D. Power. *Santa Barbara Mus. Nat. Hist. (Calif.) Symp. Proc.* pp. 787-813.

PENRITH, M.J. 1967. The fishes of Tristan da Cunha, Gough Island and the Vema Seamount. *Ann. S. Afr. Mus.* 48: 523-548.

REID, J.L., RODEN, G.I. & WYLLIE, J.G. 1958. Studies of the California Current System. *California Coop. Oceanic Fish. Invest. Rep.* 1 July 1956 to 1 Jan. 1958.

RICHARDS, F.A. & VACCARO, R.F. 1956. The Cariaco Trench, an anerobic basin in the Caribbean Sea. *Deep Sea Res.* 3: 214-228.

STEFANSSON, U. 1968. Nitrate-phosphate relationships in the Irminger Sea. *J. Cons. perm. int. Explor. Mer.* 32: 188-200.

STRICKLAND, J.D.H. & PARSONS, T.R. 1968. A practical handbook of sea water analysis. *Fish. Res. Bd Canada Bull.* 167: 311 pp.

SVERDRUP, H.U., JOHNSON, M.W. & FLEMING, R.H. 1942. The oceans — their physics, chemistry and general biology. Prentice Hall Inc, New Jersey.

UNESCO, 1966. Determination of photosynthetic pigments in sea water. *Monogr. Oceanogr. Meth.* 1: 132 pp.

VAN DORN, W.G., HACKER, P.W. & LAM, R.K. 1967. Circulation round oceanic islands. *Scripps Inst. Oceanogr. Ref.* 67: 34.

VAN ZINDEREN BAKKER, E.M. 1978. Origin and general ecology of the Marion Island ecosystem. *S. Afr. J. Antarct. Res.* 8: 13-21.

WOMERSLEY, H.B.S. 1954. The species of *Macrocystis*, with special reference to those on southern Australian coasts. *Univ. Calif. Publ. Bot.* 27: 109-132.