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BULLETIN 177

HYDROLOGY OF THE SOUTHERN HIKURANGI TRENCH REGION

by

D. M. GARNER

New Zealand Oceanographic Institute, Department of Scientific
and Industrial Research, Wellington

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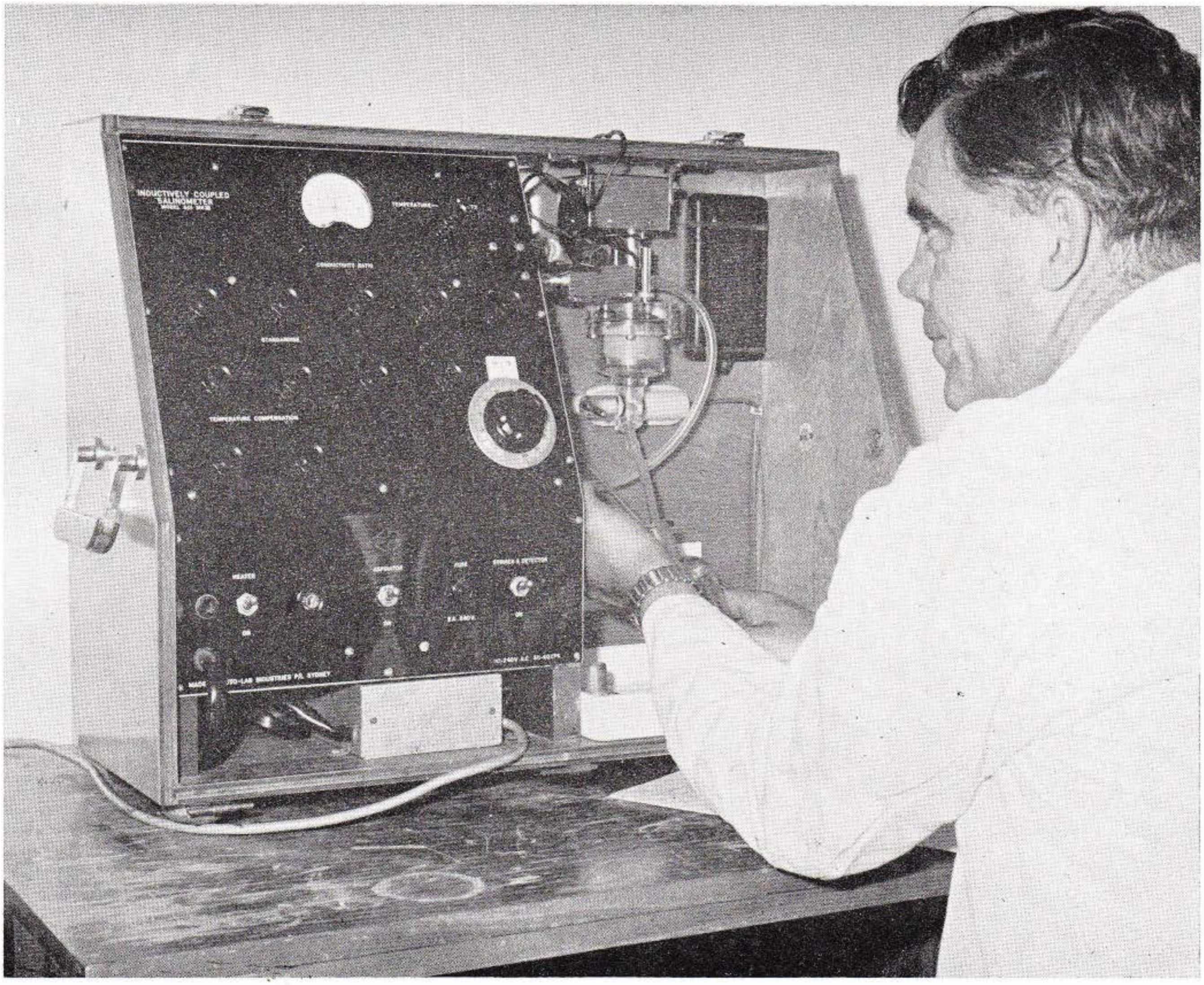

N. M. Ridgway determines the salinity of water samples using the Auto-Lab inductively coupled salinometer.
Photo: J. Whalen

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FOREWORD

DURING the last few years our knowledge of the hydrological environment around New Zealand has been considerably increased both in near-shore and off-shore areas. Up to the present, studies in the off-shore area have been of a reconnaissance nature.

This memoir reports the results of a detailed study of the hydrological circumstances in a region off the east coast that lies across and north of the Subtropical Convergence. As well as defining the circumstances here, the study forms a basis for future comparative work in other significant regions near New Zealand.

The memoir was prepared for publication by Mrs P. M. Cullen.

J. W. BRODIE, Director,
New Zealand Oceanographic Institute.

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HYDROLOGY OF THE SOUTHERN HIKURANGI TRENCH REGION

by D. M. GARNER

New Zealand Oceanographic Institute, Department of Scientific and Industrial Research, Wellington

ABSTRACT

The distribution of temperature and salinity in oceanic waters over the southern Hikurangi Trench to the east of North Island, New Zealand, was surveyed in February 1963.

The results of this survey are tabulated, charted, and discussed in terms of interaction between the East Cape Current, the Subtropical Convergence and the Antarctic Intermediate Current. The effect of the hydrological environment on sound propagation in the survey area is described.

INTRODUCTION

In the summer of 1963 the distribution of temperature and salinity was surveyed in oceanic waters lying over the southern end of the Hikurangi Trench and the northern flank of the Chatham Rise. The area studied extended eastwards from the North Island coast to longitude 176°W between latitudes 39° 30′S and 44° 30′S. The positions of stations at which measurements were made are shown relative to the main bathymetric features of this region in fig. 1.

The survey was conducted from the m.v. *Taranui* operating under charter to the New Zealand

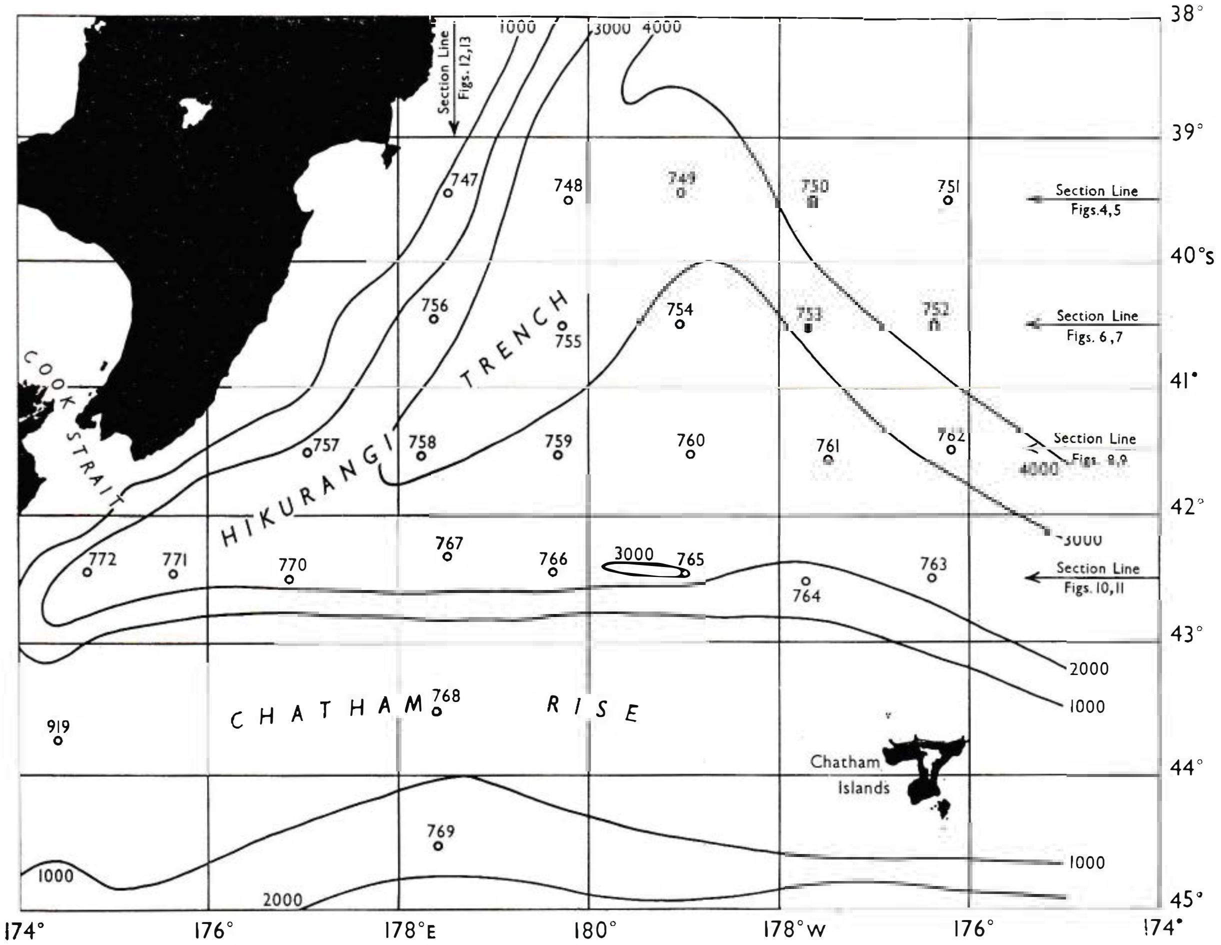

Fig. 1. The survey area showing Station positions, the general bathymetry, in metres, of the southern Hikurangi Trench and Chatham Rise; also key to vertical sections.
(Note: Nos. from N.Z.O.I. Station Register B except for 919 from Register A.)

Oceanographic Institute. Stations were worked on an approximately 60-mile grid from a 2½ km wire. At each station temperatures and depths were measured, and water samples collected, by means of a series of 22 Knudsen reversing bottles carrying Negretti and Zambra protected and unprotected reversing thermometers. In addition a bathythermograph sounding to a maximum depth of 275 m was made at most stations. At each point of the water column sampled, temperature and depth were computed from the thermometric data by use of the procedure described by Eger (1962). Salinities of water samples were determined on shore with an inductively coupled salinometer (Brown and Hamon, 1961) relative to I.A.P.O. Standard Sea Water.

Stations were worked between 18 February and 3 March 1963. This would be soon after the period of maximum surface temperature in the seasonal cycle. A great variety of weather conditions was encountered, including two periods of gale-force winds. The circumstances of each station are given in table 1. In general, the water depth was beyond the range of the ship's echo sounder, so no bathymetric data can be included in this table.

TABLE 1—STATION CIRCUMSTANCES

Air (screen) temperature and wind properties were estimated at bridge level.

Station No.	N.Z. Date/Time start	N.Z. Date/Time finish	Air Temp. (°c)	Wind Direction	Wind Speed	Latitude (south)	Longitude
	1963 (Feb/March)			(°T)	(kts)		
B 747	18/1800	18/1840	22·2	210	15	39°29·5′	178°29·5′E
B 748	19/0300	19/0530	21·7	170	13	39 31	179 46 E
B 749	19/1300	19/1620	21·1	160	13	39 28	179 01 W
B 750	19/2238	20/0137	18·3	360	9	39 30	177 36 W
B 751	20/0835	20/1048	21·1	350	10	39 30	176 09 W
B 752	20/1700	20/1945	22·2	350	13	40 31	176 22 W
B 753	21/0200	21/0647	18·9	340	18	40 32	177 41 W
B 754	21/1345	21/1705	20·0	010	36	40 30	179 02 W
B 755	22/0630	22/0915	20·6	330	17	40 30	179 39 E
B 756	22/1638	22/1858	20·6	280	5	40 28	178 20 E
B 757	23/0715	23/1010	17·8	190	14	41 30	177 00 E
B 758	23/1845	23/2030	17·2	220	9	41 32	178 13 E
B 759	24/0630	24/1015	17·8	330	9	41 32	179 42 E
B 760	24/1720	24/1915	20·0	350	12	41 32	178 57 W
B 761	25/0225	25/0600	18·9	360	24	41 33	177 27 W
B 762	25/1330	25/1540	19·4	360	36	41 30	176 10 W
B 763	25/2240	26/0200	18·9	320	35	42 30	176 22 W
B 764	26/1510	26/1800	21·1	240	11	42 32	177 43 W
B 765	27/0305	27/0515	18·3	310	18	42 28	179 00 W
B 766	27/1545	27/1735	18·9	310	18	42 28	179 36 E
B 767	28/0315	28/0915	17·8	260	8	42 20	178 28 E
B 768	28/2305	1/0010	13·9	220	12	43 30	178 20 E
B 769	1/0745	1/1010	13·9	270	9	44 30	178 20 E
B 770	2/0230	2/0605	17·8	350	20	42 29	176 50 E
B 771	2/1305	2/1510	18·3	330	35	42 25	175 35 E
B 772	3/0000	3/0310	15·6	180	24	42 24	174 40 E
	(Feb. 1964)						
A 919	8/1252	8/1457		020	18	43 35	174 15 E

PREVIOUS WORK

Relatively few deep hydrological stations have been worked previously in the area covered by this survey. The most recently published hydrological investigation in the southern Hikurangi Trench area is that of Sdubbundhit and Gilmour (1964). This work provides a convenient lead to other relevant publications, and describes how surface waters to the east of the southern North Island coast are thought to be dominated by the south-flowing, warm East Cape Current.

The existence of this current has been inferred mainly from the presence off this coast of a broad tongue of warm surface water. This warm tongue of Subtropical Water has been shown to meet the colder Subantarctic Water to the east of South Island in the general region of the Chatham Rise. The resulting zone of relatively large horizontal temperature gradient at the surface has been called the Subtropical Convergence.

The behaviour of the East Cape Current immediately to the north of the Subtropical Convergence, where the south-going movement must be turned to a general east-going flow, was one feature of the circulation studied by the present survey. Also examined were the properties of the Antarctic Intermediate Water in the submarine embayment between the northern flank of the Chatham Rise and the North Island slope. The Antarctic Intermediate Water has its properties determined at the surface in the Southern Ocean and spreads northwards and eastwards throughout southern hemisphere oceans, to form a layer of minimum salinity in depths of 800–1,000 m. The distribution of salinity in this layer to the north of the Chatham Rise was examined by this survey for indications of the presence of an eddy of the Antarctic Intermediate Current in the "lee" of this ridge.

Both these features, the eastwards deflection of the East Cape Current and a secondary circulation of the Antarctic Intermediate Current, were mentioned by Sdubbundhit and Gilmour. It will be shown that there is indeed a close dynamic link between these two branches of the oceanic circulation over the southern Hikurangi Trench.

PRESENTATION OF DATA

The basic numerical depth/temperature/salinity data are tabulated for each station in Appendix 1, together with derived values of density, sound velocity, and cumulative dynamic height anomalies. These derived quantities were computed from formulae described by La Fond (1951, p. 14) for density and dynamic height, and by Wilson (1960) for sound velocity. The mean vertical sounding velocity was calculated by numerical integration of the sound velocity - depth relationship. Tracings of bathythermograph records are reproduced in Appendix 2. From this basic reference material charts of property distributions on various surfaces though the block of ocean surveyed are reproduced to illustrate points raised in the following discussion.

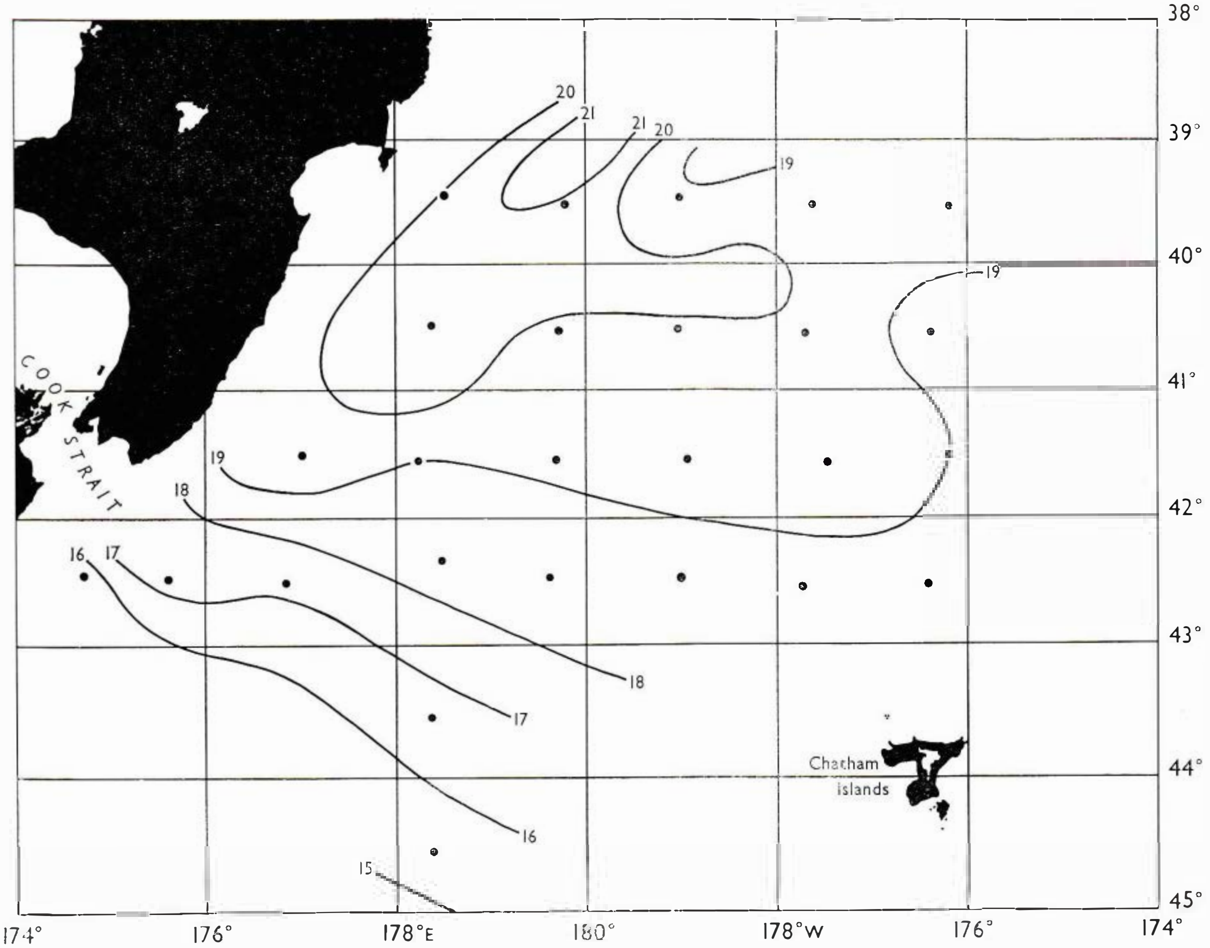

Fig. 2. Isotherms (°c) at the free surface.

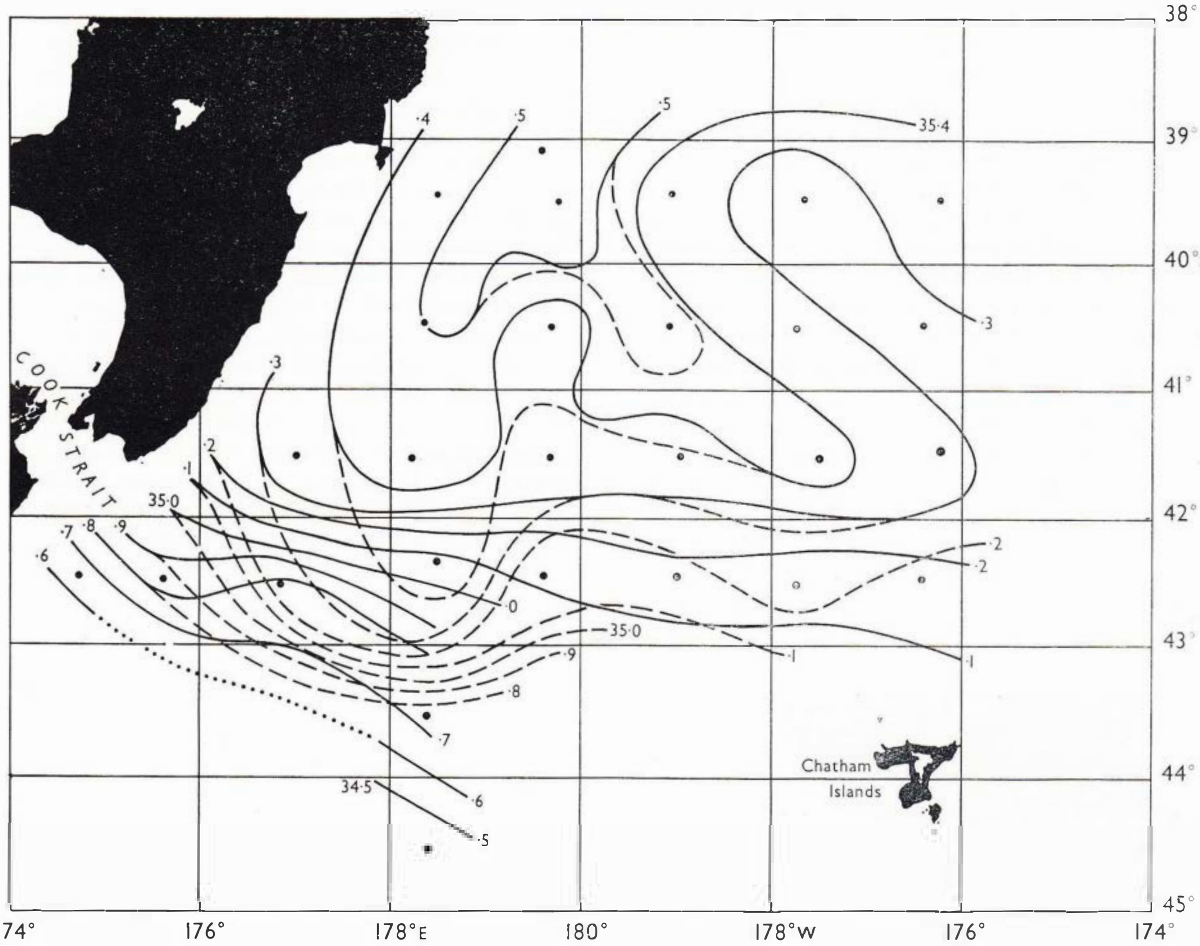

Fig. 3. Full lines are isohalines ($^{0}/_{00}$) at the free surface. Where broken lines diverge from full lines, a subsurface salinity maximum in the salinity-depth relationship was observed, and the broken lines represent isohalines on this surface of maximum salinity.

DISCUSSION

SURFACE TEMPERATURE AND SALINITY

The distribution of temperature and salinity (fig. 2, 3) divides the surface waters of the survey area into two distinct regions. In the north, surface water warmer than 19°C and of salinity greater than $35{\cdot}3^{0}/_{00}$ covers an area where horizontal gradients of these properties are relatively small. The warm, highly saline tongue of the East Cape Current lies over the western slope of the Hikurangi Trench. In the south, over the northern slope of the Chatham Rise, is a region of relatively steep horizontal gradients of temperature and salinity. These gradients may well be locally steeper than shown in the figures since observations were confined to station positions. This southern region is associated with the Subtropical Convergence marking the boundary zone between Subtropical and Subantarctic Waters. The surface isotherms and isohalines have almost the same configuration. Surface temperature ($T^{\circ}C$) and salinity ($S^{0}/_{00}$) over the survey area are closely represented by the linear relation:

$$S = 0{\cdot}21T + 31{\cdot}22$$

VERTICAL WEST – EAST CROSS-SECTIONS OF:

Temperature (^{0}c)

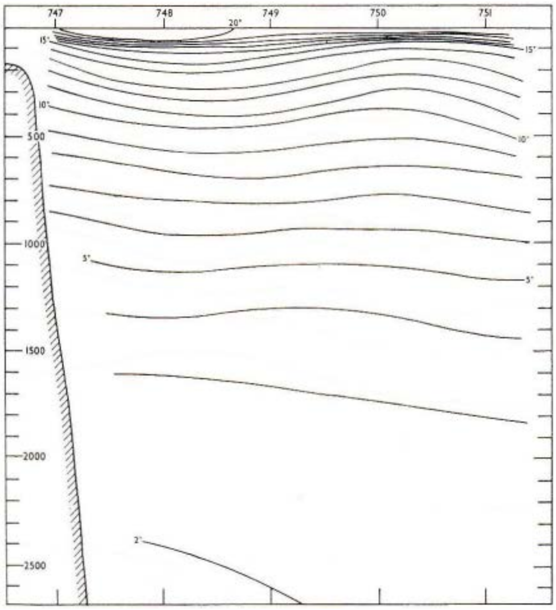

Fig. 4. Stations B 747 to B 751

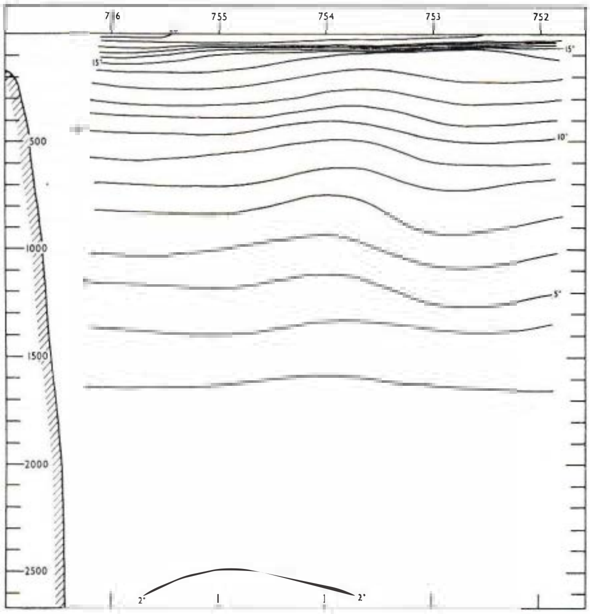

Fig. 6. Stations B 756 to B 752

Salinity ($^{0}/_{00}$)

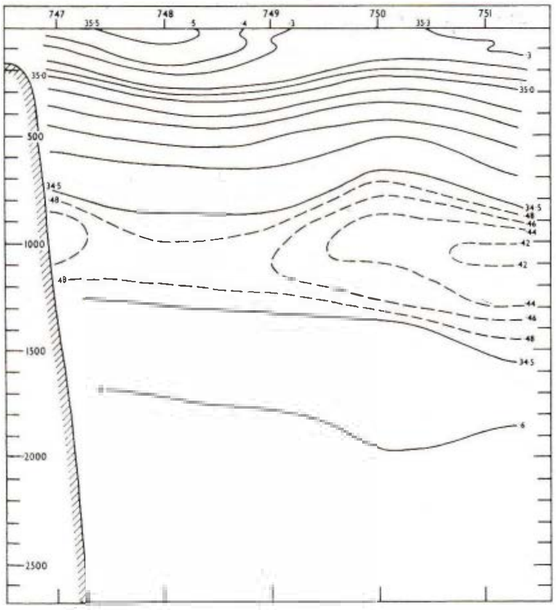

Fig. 5. Stations B 747 to B 751

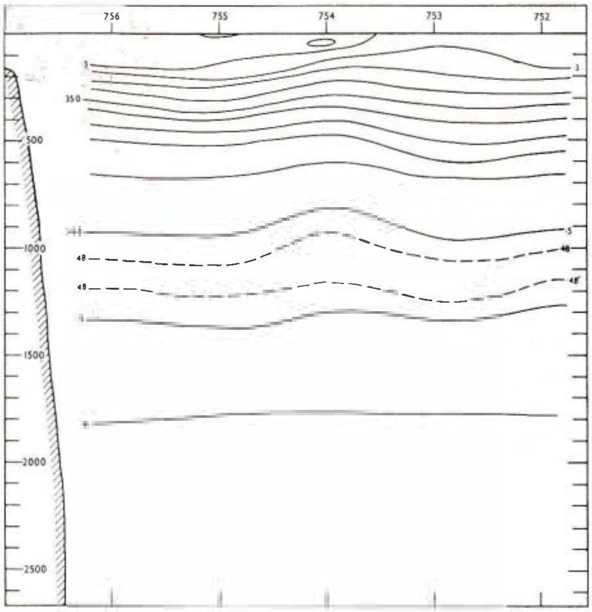

Fig. 7. Stations B 756 to B 752

Location: See Fig. 1. Depth in metres. Shaded area represents North Island shelf. The contour interval has been reduced in all salinity sections (broken lines) in the vicinity of the 1,000 m level to show details of salinity structure of the Antarctic Intermediate Waters.

VERTICAL WEST – EAST CROSS-SECTIONS OF:

Temperature (^{0}c)

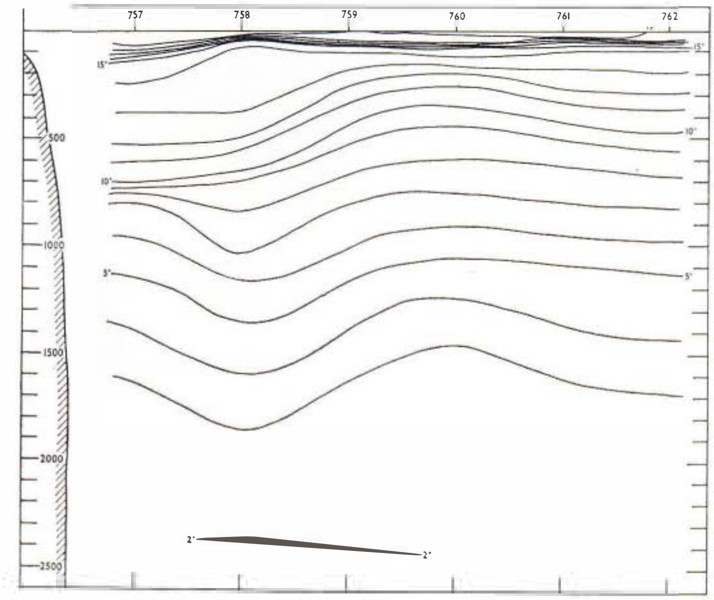

Fig. 8. Stations B 757 to B 762

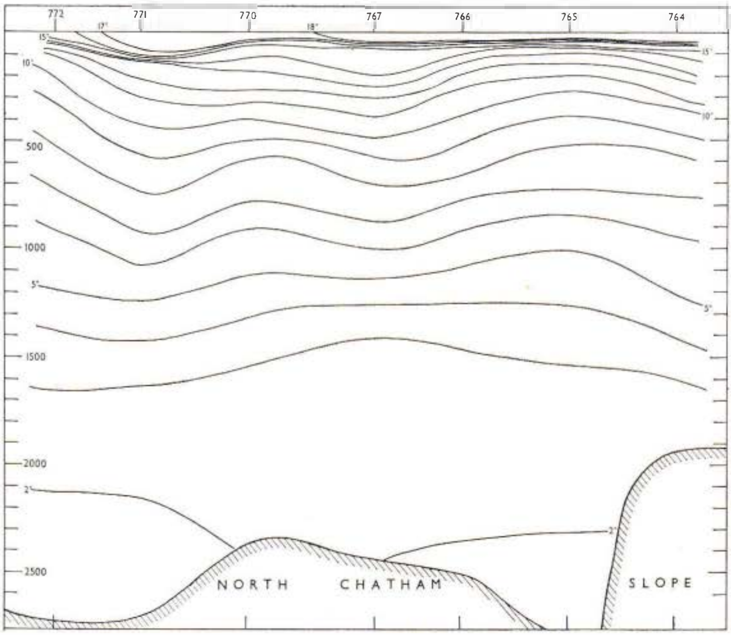

Fig. 10. Stations B 772 to B 764 along the North Chatham Rise.

Salinity ($^0/_{00}$)

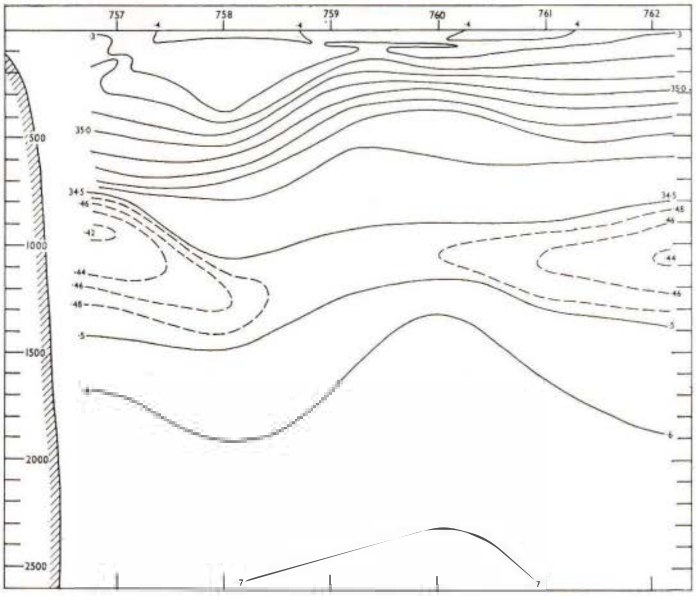

Fig. 9. Stations B 757 to B 762

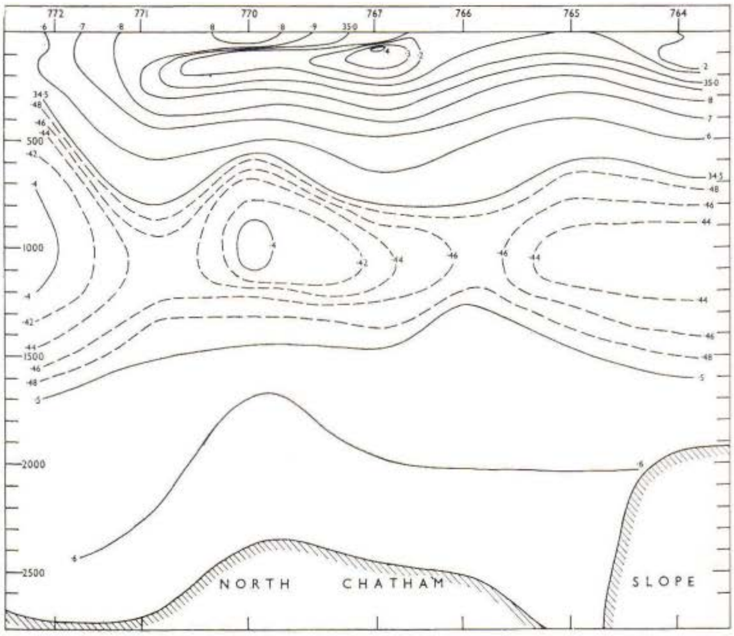

Fig. 11. Stations B 772 to B 764 along the Chatham Slope.

Location: See Fig. 1. Depth in metres. Shaded area represents North Island shelf. The contour interval has been reduced in all salinity sections (broken lines) in the vicinity of the 1,000 m level to show details of salinity structure of the Antarctic Intermediate Waters.

VERTICAL NORTH – SOUTH CROSS-SECTIONS

Temperature (°c)

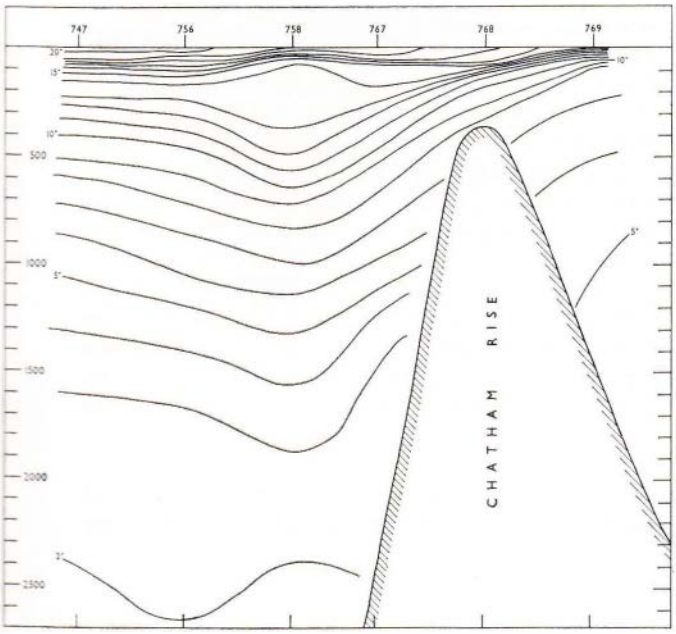

Fig. 12. Stations B 747 to B 769 along the Chatham Rise.

Salinity (°/₀₀)

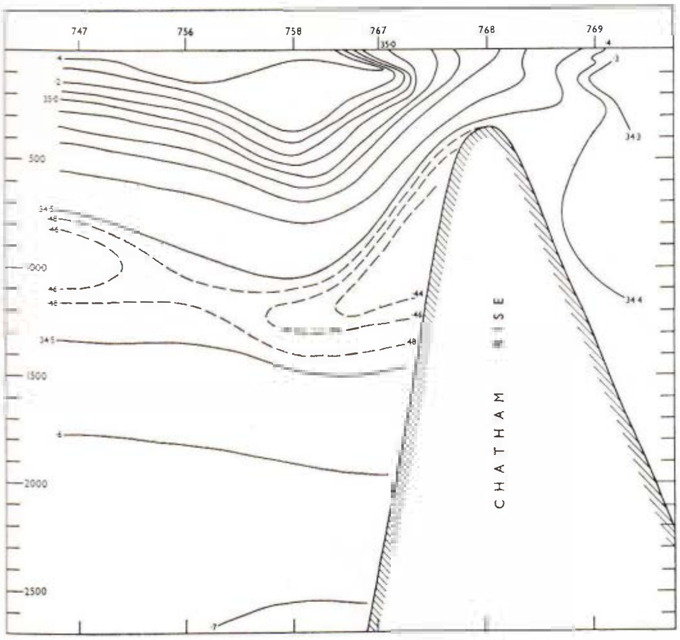

Fig. 13. Stations B 747 to B 769 along the Chatham Rise.

Location: See Fig. 1. Depth in metres. Shaded area represents North Island shelf. The contour interval has been reduced in all salinity sections (broken lines) in the vicinity of the 1,000 m level to show details of salinity structure of the Antarctic Intermediate Waters.

THERMOCLINE AND UPPER MIXED LAYER

Through the vertical mixing of water by waves and turbulent wind-drift, the wind characteristically stirs near-surface waters to form an "upper mixed layer" in which temperature and salinity vary but little with depth. Beneath this mixed layer is the great mass of oceanic water whose temperature normally decreases slowly with depth. Between these two masses of water lies the "thermocline layer". This is a region of relatively large vertical temperature gradient which forms a transition region between the upper mixed layer and the water beneath. These three layers are well illustrated in simple form by the bathythermograph trace for Station B 758. (App. 2.) Remaining traces show the variations which appear on this general theme at other stations.

Because of the locally large vertical temperature gradient, the thermocline layer has relatively great hydrostatic stability, and inhibits turbulent exchange of water vertically. The top of the thermocline layer thus effectively represents a lower limit to the direct action of local weather on the properties of water beneath the surface. Variations in mixed layer thickness will be controlled externally by the recent weather history and internally by mutual adjustment of the density and velocity fields. During the period chosen for this survey it is likely that the temperature of the upper mixed layer was near its seasonal maximum, and the layer thickness near its seasonal minimum.

Layer thickness may be conveniently defined in terms of the depths of intersection of extrapolations of the linear temperature-depth relations representative of each of the three layers. On this basis, the upper mixed layer over the survey area had an average thickness of some 35 m, varying from about 25 m to about 45 m. The thickness of the thermocline layer varied from some 10 m to 50 m with an average of about 25 m.

Small secondary thermoclines were apparent in the mixed layer of the eastern central survey region where also the layer thickness was generally greatest. Temperature inversions, or reversals of the normal decrease of temperature with depth, were features of bathythermograph soundings at Station B 749 in the centre of the northernmost line of stations, and at the group of Stations B 767, B 770, B 772, and A 919 in the south-west of the survey area. As this southern group lies in the region of the Subtropical Convergence, these inversions probably represent an interfingering of waters from both north and south of this boundary zone.

The temperature contrast across the thermocline layer was greatest at Station B 769, on the southern flank of the Chatham Rise, where the mixed waters of the convergence zone lie over the cold Subantarctic Water of the Bounty Trough.

The salinity structure of the upper mixed layer and of the underlying thermocline layer was not resolved by the reversing-bottle sampling in detail comparable with that provided for the temperature structure by the bathythermograph. Salinity generally decreased with depth in the upper part of the water column, with little variation in the mixed layer. However, reversals of this trend are evident at several stations. The horizontal salinity plot of fig. 3 and the vertical sections of figs. 11 and 13 show that these reversals are due mainly to a penetration of Subtropical Water further southwards under the thermocline than was achieved in the upper mixed layer. This resulted in a pronounced maximum in the salinity-depth curve at a depth of about 80 m. This maximum is probably associated with the barrier to vertical exchange formed by the thermocline layer and may thus be expected to follow the seasonal variations in depth of this layer.

ANTARCTIC INTERMEDIATE WATER

The outstanding feature of the hydrological structure of deeper waters is a salinity minimum at a depth of about 1 km marking the core of the Antarctic Intermediate Water. The survey area appears to have included an eddy movement in this water mass. Over an extensive region in the centre of the survey area the salinity in this core layer was relatively high, a maximum of 34·49$^{0}/_{00}$ being reached at Station B 759 (fig. 14) compared with values around 34·40$^{0}/_{00}$ found in the north-east, south-east, and south-west parts of the area. A depression in the topography of the core layer was also evident, the salinity minimum being found at a depth of over 1·2 km at Station B 758 rising to depths of less than 1 km at the outer stations (fig. 15). These patterns suggest the presence of an anticyclonic eddy of the Antarctic Intermediate Current north of the Chatham Rise, frictionally driven by the main stream of this current which may be expected to flow generally northwards east of the Chatham Islands. On this view, the depression

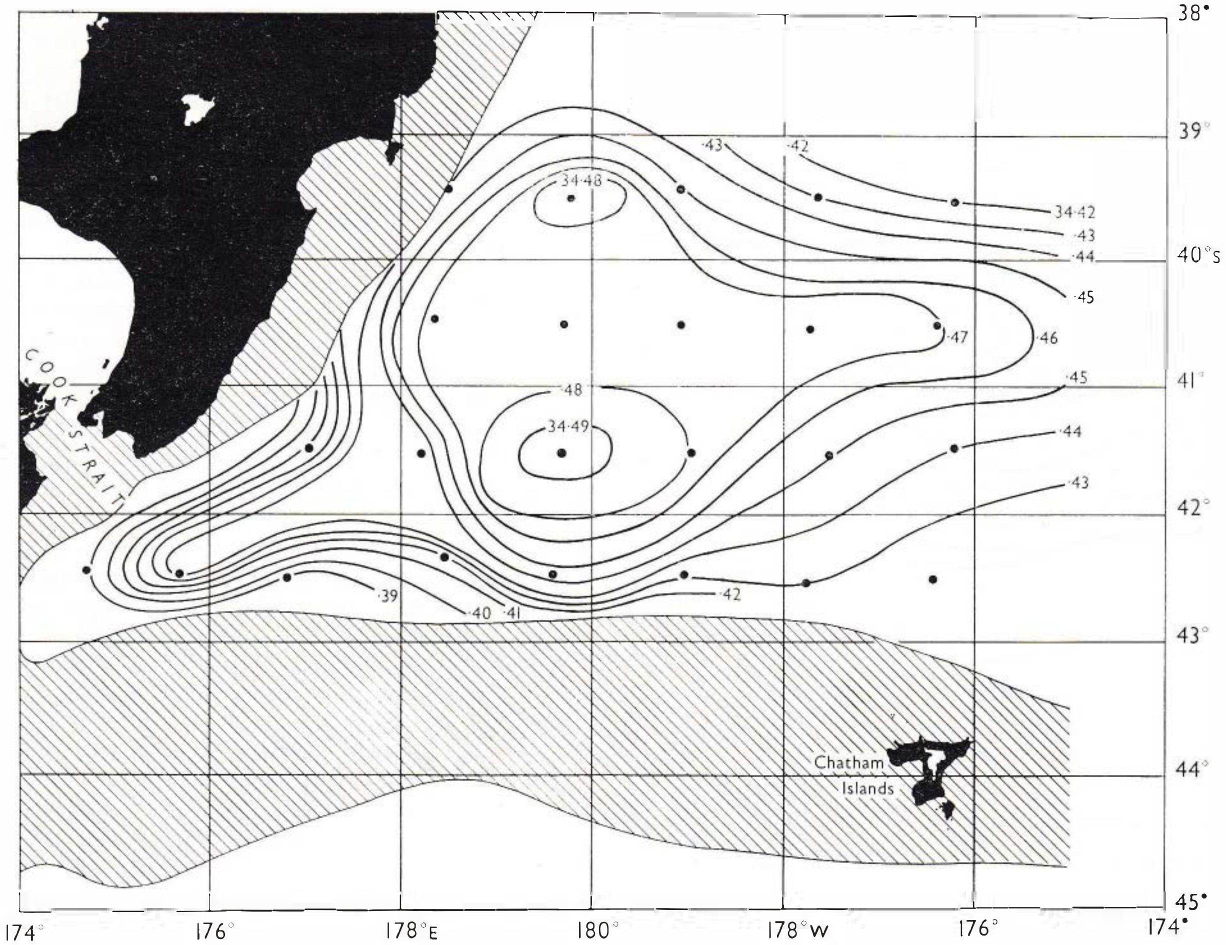

Fig. 14. Isohalines ($^{0}/_{00}$) on the surface of minimum salinity characteristic of the core of the Antarctic Intermediate Water. Water of depth less than 1000 m is shown shaded.

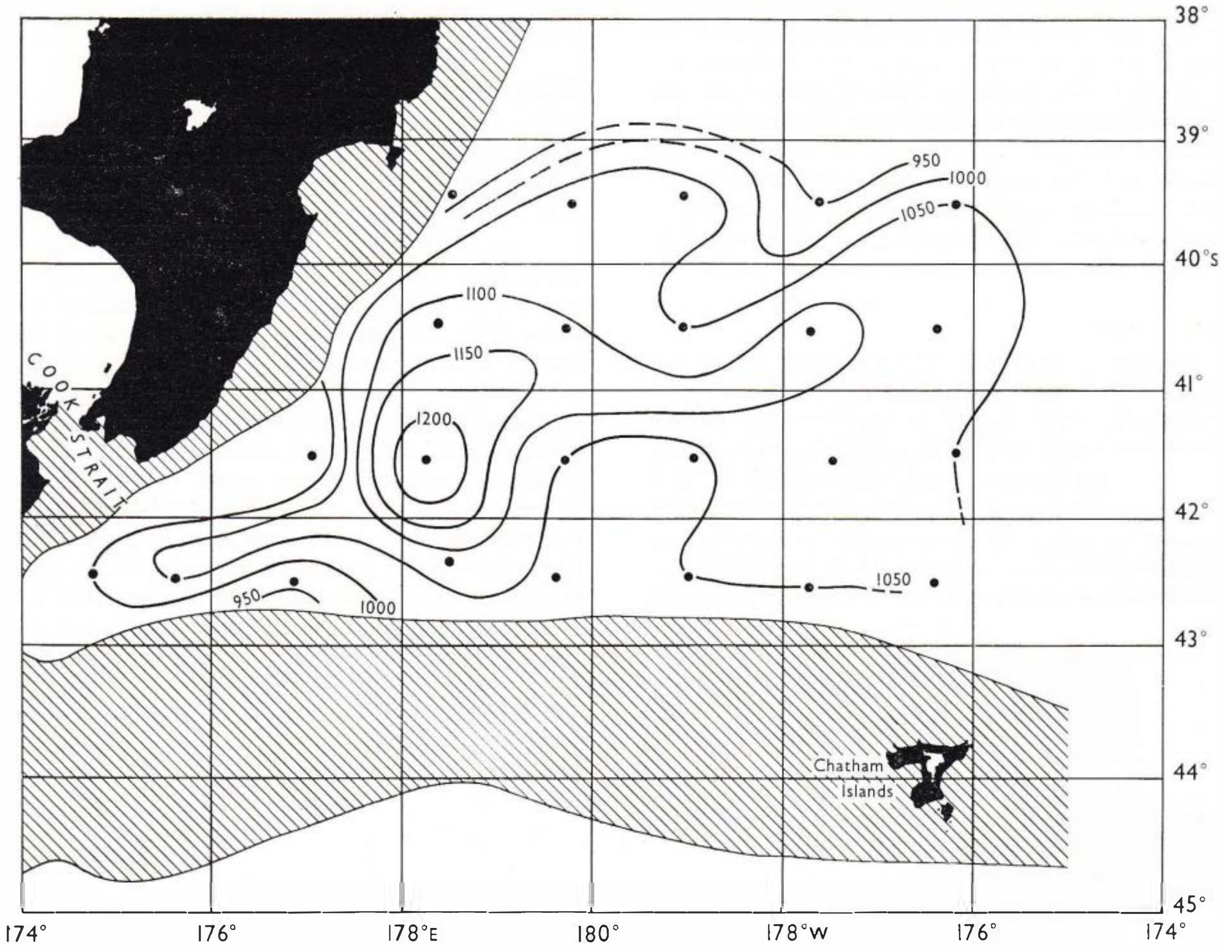

Fig. 15. Isobaths (m) of the surface of minimum salinity described for figure 14.

of the Intermediate core layer would be the result of a tendency towards mutual geostrophic adjustment between the circulation and the density (or pressure) field. An estimate of the geopotential topography of the 100 bar pressure surface relative to the 200 bar surface, derived from the distribution of density, does indeed show an anticyclonic eddy in the geostrophic circulation at a depth of about 1 km over the head of the Hikurangi Trench, centred around Station B 758.

The Antarctic Intermediate core is sandwiched between water of higher salinity both above, in the form of Subtropical Surface Water, and below, in the form of the Pacific Deep Water. The higher salinity of the central region may thus be attributed to a relatively long residence-time of water in this eddy movement which permits a greater amount of vertical mixing to occur. The density of the higher salinity water tends to be greater than that of the lower salinity water in the core layer by about 0·05 units of σ_t. At a constant temperature of about 5°C an increase in salinity of 0·1 $^{0}/_{00}$ gives rise to an increase of about 0·15 units of σ_t. The source of high salinity "contamination" in the eddy region would thus appear to be predominantly from the overlying lighter water rather than from the underlying colder Deep Water.

Antarctic Intermediate Water presumably enters the survey area mainly from a north-flowing stream east of the Chatham Islands. The lowest salinity in the Intermediate core was found, however, in the head of the Hikurangi Trench (at Stations B 770 and B 772). If the situation revealed by the survey represents an approximately steady state, the prevailing pressure gradient would not permit this relatively low salinity water to flow westwards along the northern slope of the Chatham Rise. A southwestward path along the North Island slope is unlikely because of the relatively high salinity in the Intermediate core at Station B 747. The possibility that Antarctic Intermediate Water of low salinity may be drawn into the Hikurangi Trench from the

Bounty Trough through the Pukaki Gap may be worth some exploration. This Gap cuts across the western end of the Chatham Rise between the Mernoo Bank and the shelf east of Banks Peninsula with a saddle depth of some 570 m. A station (A 919) worked in a depth of 530 m in the vicinity of this saddle during the summer following this survey did not extend to a sufficiently great depth to resolve this question, but indicates that water of Intermediate character could exist over this saddle.

DEEP WATER

Neither observations of the present survey nor those of previous expeditions have extended to a sufficiently great depth to discover the salinity maximum which marks the core of the Pacific Deep Water. In the Bounty Trough, south of the Chatham Rise, previous expeditions have found the deep salinity maximum to lie at depths between 2½ and 3 km with values between 34·75 and 34·78 ‰ Water with similar properties is probably present in the Hikurangi Trench, but this remains to be explored.

GEOSTROPHIC CIRCULATION

For a density-stratified ocean in which the pressure is everywhere in hydrostatic equilibrium, the "geostrophic" circulation is that steady-state, unaccelerated, frictionless movement which would be maintained by the pressure-gradient forces associated with the density distribution. Experience shows that large-scale features of the ocean circulation of surface and intermediate-depth waters are usually approximated closely by this geostrophic mode. Derived from the distribution of density measured at the survey stations, streamlines of the geostrophic circulation at the sea surface, relative to an undetermined motion at the 1 km level, are reproduced in fig. 16. Compared with that of major current systems, the structure revealed is dynamically rather weak. An extensive anticyclonic eddy is defined at all levels, however, centred over the

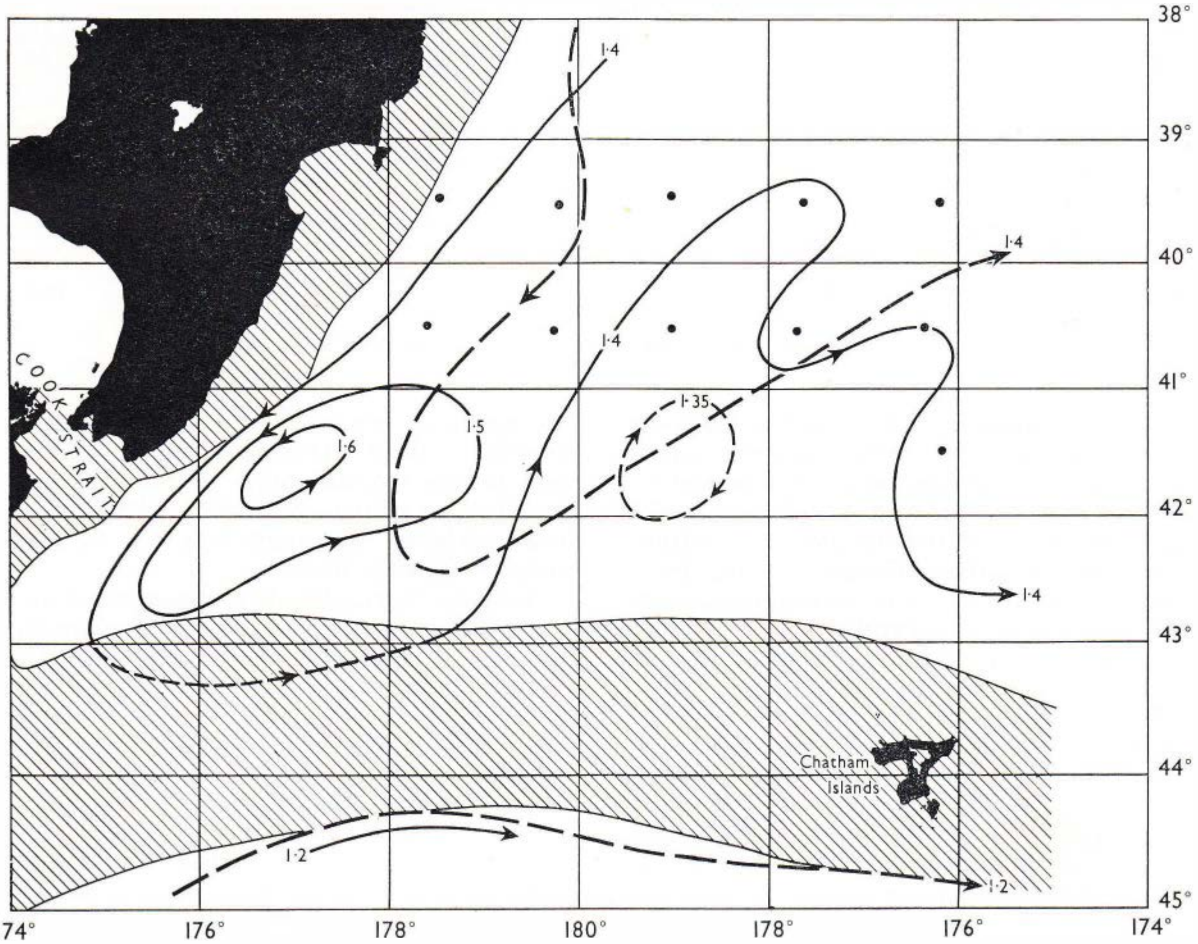

Fig. 16. Anomaly of the geopotential thickness of the 0–1000 decibar layer in dynamic metres. Contours are also streamlines of the relative surface geostrophic circulation. Water of depth less than 1,000 m is shaded. The heavy broken contours are from Reid (1961).

Hikurangi Trench east from Cape Palliser. Probably frictional coupling, between the East Cape Current system at the surface and the topographically induced eddy of the Antarctic Intermediate Current at depth, is sufficiently great to maintain the elevation in the dynamic topography associated with this eddy motion as a semi-permanent feature of the entire water column over the southern Hikurangi Trench.

North-west of the Chatham Islands, and to the east of this anticyclonic eddy, is a weakly developed depression in the surface topography. Again, this feature is evident throughout the entire water column. The dynamic topography of all isobaric surfaces relative to the 200 bar level have essentially the same configuration as is shown in fig. 16. Little variation of current direction with depth thus seems to occur in this region. The circulations of surface Subtropical Water and of Antarctic Intermediate Water seem to be closely linked, probably through vertical frictional coupling and topographic control. The particular reference level of 1,000 decibars was chosen for reproduction partly to show, for comparison, contours estimated by Reid (1961). Reid published a map showing the anomaly of geopotential distance between the zero and 1,000 decibar surfaces over the entire Pacific Ocean, based on a compilation of expedition stations. While it is unfair to compare a very small section of this map with the results of a detailed survey of a restricted area, the agreement between the general structure of the two patterns is striking, and lends support to the view derived from previous work (Garner, 1962) that the dynamic structure of New Zealand waters is rather stable, and that the gross detail of the hydrological regime may be constructed from the superposition of observations made in different years.

SOUND VELOCITY

Values of sound velocity listed in Appendix 1 were derived from Wilson's (1960) formula. This formula gives values at the surface that are greater by about 2·8 m/sec than those computed from Kuwahara's formulae used, for example, as the basis of tables in La Fond (1951) and Matthews (1939). A misprint in Wilson's formula appears in Vigoureux and Hersey (1962, p. 478) where the co-efficient of *pts* in the correction term for simultaneous variation of temperature, salinity, and pressure is written as 209×10^{-6} instead of $2{\cdot}09 \times 10^{-6}$. This error caused difficulty during the present study and is recorded here for reference.

A study of the variation of sound velocity in New Zealand waters has two applications in the present context – the structure of the SOFAR channel and the correction of deep echo soundings.

(a) *The SOFAR channel.* Except in polar seas, and neglecting local complications that may arise in the upper mixed layer, the velocity of sound decreases with depth in upper water layers under the dominant influence of the vertical temperature gradient. In deeper water, velocity increases with depth as the effect of increasing pressure becomes the controlling factor. The resultant velocity minimum causes refraction effects that can channel suitably propagated sound rays into paths that avoid energy-consuming reflections at the ocean surface and bottom. Sound travelling along such paths may therefore be detected over great distances. This SOFAR channel (for example, see Officer, 1958, p. 100) is of interest in questions of underwater sound-ranging and detection of submarine geophysical disturbances.

The scale of geographical variation in the oceanic sound velocity pattern is such that the Hikurangi survey area was not sufficiently extensive to show much of interest. However, the results presented here will form a nucleus around which further studies may be built, based on the accumulation of hydrological work of past expeditions (e.g., Garner, 1962) and on future systematic surveys such as that reported here.

In the Hikurangi survey area, the sound-velocity minimum was located in a depth of some 1,400 m, placing it below the salinity minimum of the

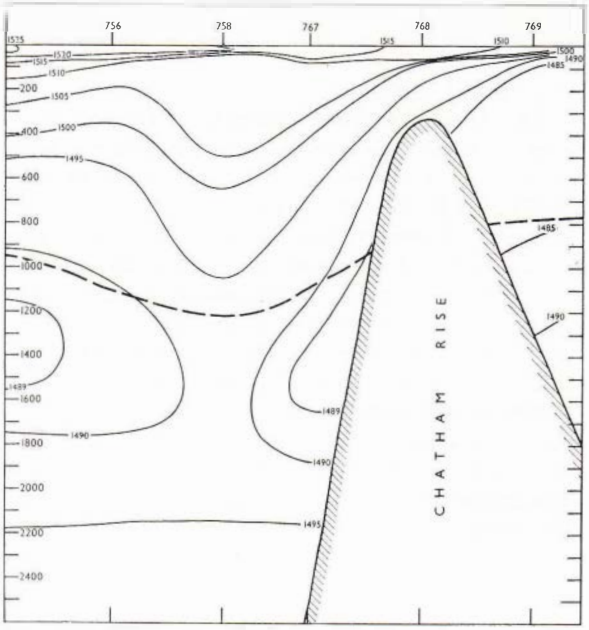

Fig. 17. Contours of equal sound velocity (m/sec) in a vertical section along a north-south line across the Chatham Rise between Stations B 748 and B 769. The heavy broken line shows the axis of the salinity minimum of the Antarctic Intermediate core. Depth scale is in metres.

Antarctic Intermediate core. Fig. 17 shows the variation of sound velocity along a vertical cross-section of the survey area, meridionally oriented across the Chatham Rise. This may be compared with the similarly placed temperature and salinity sections shown in figs. 12 and 13. An anticyclonic eddy to the north of the Chatham Rise was the major dynamical feature of the survey area. This feature has the effect, through its relatively warm core, of decreasing the intensity of the velocity minimum at the sound-channel axis (Station B 758). Variations of this kind, if sufficiently extensive, could allow for leakage of sound energy from the channel. A major change in the vertical temperature structure of water on each side of the Chatham Rise has a correspondingly great effect on the depth and intensity of the velocity minimum. Propagation along the sound channel through the Subtropical Convergence zone in deep water should thus make an interesting study, as would the shadowing effect of topographic features, such as the Chatham Rise, which extend above the sound channel axis.

(b) *Vertical Mean Sounding Velocity*. Values of this quantity, tabulated in Appendix 1, represent the integral mean sound velocity between the sea surface and each sampling depth. This was obtained from the depth and velocity data by application of the trapezoidal rule.

TABLE 2—MEAN VERTICAL SOUNDING VELOCITIES

Station B 748			B 758		B 769	
A	B	C	B	C	B	C
200	1516	1530	1509	1504	1490	1489
400	1510	1514	1508	1499	1487	1487
600	1505	1504	1505	1496	1485	1486
800	1502	1499	1505	1493	1485	1486
1000	1499	1496	1503	1492	1485	1486
1200	1498	1494	1502	1491	1486	1485
1400	1497	1493	1500	1490		
1600	1496	1492	1499	1490		
1800	1495	1491	1499	1490		
2000	1495	1491	1498	1489		
2200	1495	1492	1498	1490		
2400	1495	1492				
2600	1496	1492				

column A – depth in metres
column B – MVSV in m/sec from survey data
column C – MVSV in m/sec from Matthews (1939, p. 16)

The Admiralty issued tables of corrections to be applied to the records from echo-sounding machines calibrated for a constant sound velocity (Matthews, 1939). With the accumulation of an increased coverage of temperature and salinity observations in the area, it becomes of interest to discover whether amendment or refinement of these tables is indicated for local use. A comparison between Matthews' corrections for the area, and corrections calculated from the survey data reported here, will permit a preliminary discussion of this question. Table 2 shows the mean vertical sounding velocity as a function of depth for three stations along the meridional section shown in fig. 17. Also shown are the corresponding relations on which were based Matthews' corrections for the location of these stations. For the southernmost station of the series, B 769 in Subantarctic Water, the agreement between survey and Matthews values is very close, although the measured data do not extend to any great depth. For typical Subtropical stations to the north of the Chatham Rise, values of mean vertical sounding velocity at depths below about 800 m tend to be around 3 m/sec higher than the corresponding Matthews tabulations. The difference between sound-velocity figures computed here and

TABLE 3

Corrections in metres to be added to an echo sounder set for a velocity of 1500 m/sec:
(a) from survey data for Station B 748;
(b) from Matthews (1939, p, 16).

Depth (m)	(a)	(b)
200	+2	+4
400	+3	+4
600	+2	+2
800	+1	−1
1000	0	−3
1200	−2	−5
1400	−3	−7
1600	−5	−9
1800	−6	−11
2000	−7	−12
2200	−8	−12
2400	−8	−13
2600	−9	−14

those derived from Kuwahara's formula will account for most of this difference. Table 3 lists, for the representative Station B 748, the sounding corrections to be applied to records from a machine calibrated for a velocity of 1,500 m/sec. Also listed are the corrections tabulated by Matthews (1939, p.16, area 41) for the appropriate area. The extent to which the differences between the two sets of corrections are significant, compared with other sounding errors, gives some basis for an evaluation of the desirability of making a revision of Matthews' tables. This comparison must be extended over a greater geographical area before this question may be more confidently answered.

SUMMARY

The results of a survey of the temperature and salinity structure of waters to a depth of $2\frac{1}{2}$ km over the southern Hikurangi Trench east of the North Island of New Zealand are tabulated. In upper layers, the water in the northern part of the area is mainly Subtropical in character, entering the area with the East Cape Current, which flows southwards along the slope of the North Island shelf. In the southern part of the area, over the northern flank of the Chatham Rise, steeper horizontal gradients of temperature and salinity mark the Subtropical Convergence region, a zone of mixing between the Subtropical Water surveyed and the Subantarctic Water adjacent to the south.

Streamlines of the relative surface geostrophic circulation show that the eastward deflection of the East Cape Current to the north of the Subtropical Convergence region is complicated by the formation of extensive eddy motions. A large anticyclonic eddy to the east of Cape Palliser appears to be associated with a secondary circulation of the Antarctic Intermediate Water to the north of the Chatham Rise. Residence time of water in this eddy is sufficient for the salinity of the core of this layer to be appreciably raised, probably mainly by vertical exchange with overlying waters.

The configuration of the SOFAR channel, marked by a sound-velocity minimum lying at a depth of about 1,400 m, is described, and a comparison made between echo-sounding velocity corrections derived from the measured temperature and salinity distributions on the one hand, and from Admiralty Tables on the other.

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APPENDIX 1

Under station numbers below are listed measured depths, temperatures, and salinities. These are followed by derived values of density, dynamic height anomaly, and sound velocity. The meaning of the table headings is as follows:

D	is the sampling depth in metres.
T	is the sample temperature in °c × 100.
S	is the sample salinity in $^{\circ}/_{00}$ × 100.
σ_t	is the density reduced to surface pressure isothermally.
σ_{stp}	is the *in situ* density. The "σ" value is derived from the specific gravity, ρ, from the relation $\sigma = [(\rho - 1) \times 10^5]$
$\Sigma\Delta D$	is the anomaly of the geopotential distance from the sea surface to the sample depth in dynamic metres × 100.
C	is the *in situ* sound velocity in m sec^{-1} × 10.
C_m	is the integral mean sound velocity between the sea surface and the sample depth in m sec^{-1} × 10.
K	is the correction (m × 10) to be applied to an echo sounding reading of D on a machine calibrated for a velocity of 1,500 m sec^{-1}.

For further information see the text under "Presentation of Data". Difficulty with matching the data from several overlapping casts, also thermometer malfunction, led to the discarding of data from Station B 763. For station circumstances see table 1.

D	T	S	σ_t	σ_{stp}	$\Sigma \Delta D$	C	Cm	K
B 747								
0	2004	3544	2511	2511	0	15228	15228	0
11	2004	3543	2510	2515	3	15230	15229	2
28	1882	3540	2539	2551	8	15198	15220	4
44	1644	3535	2593	2613	12	15130	15199	6
63	1507	3532	2622	2650	15	15090	15172	7
99	1406	3528	2641	2685	22	15063	15138	9
134	1330	3522	2652	2712	27	15043	15116	10
167	1271	3512	2656	2731	32	15028	15100	11
234	1160	3498	2667	2772	42	14999	15075	12
304	1063	3486	2674	2812	52	14977	15055	11
442	922	3470	2687	2887	70	14944	15025	8
545	831	3461	2694	2942	83	14926	15008	3
616	772	3456	2699	2980	92	14915	14998	1-
684	732	3453	2702	3015	100	14910	14990	5-
753	688	3450	2706	3051	108	14904	14982	9-
820	630	3447	2712	3088	115	14892	14975	14-
890	578	3445	2717	3125	122	14882	14968	19-
959	535	3445	2722	3163	129	14876	14962	4-
B 748								
0	2098	3553	2492	2492	0	15254	15254	0
24	2098	3555	2494	2504	7	15259	15257	4
48	2038	3555	2510	2531	14	15246	15255	8
73	1782	3549	2571	2603	21	15177	15240	12
98	1614	3547	2609	2653	26	15131	15218	14
147	1514	3542	2628	2694	35	15107	15185	18
197	1400	3530	2644	2732	44	15078	15162	21
246	1330	3521	2651	2761	52	15061	15143	23
344	1150	3497	2668	2823	67	15013	15113	26
492	935	3472	2686	2909	87	14958	15075	25
639	806	3459	2696	2987	106	14932	15045	19
787	709	3452	2705	3064	123	14918	15022	12
886	642	3449	2712	3117	134	14908	15010	6
984	584	3448	2718	3170	144	14901	15000	0
1083	528	3448	2725	3223	154	14895	14990	7-
1182	477	3448	2731	3275	163	14890	14982	14-
1280	428	3450	2738	3328	172	14887	14975	21-
1378	389	3452	2744	3379	180	14887	14969	29-
1477	359	3453	2748	3429	187	14891	14963	36-
1969	249	3463	2766	3674	218	14928	14950	66-
2462	197	3468	2774	3907	243	14990	14952	79-
B 749								
0	1912	3535	2528	2528	0	15201	15201	0
24	1911	3534	2527	2538	7	15205	15203	3
48	1852	3525	2535	2556	13	15191	15200	6
97	1517	3530	2618	2661	24	15099	15172	11
195	1332	3528	2656	2743	41	15055	15124	16
243	1248	3520	2667	2776	48	15033	15108	18
340	1113	3497	2675	2828	62	15000	15082	19
500	947	3470	2683	2909	83	14963	15050	17
632	825	3460	2694	2982	100	14938	15029	12
778	724	3452	2703	3058	118	14922	15011	6
874	646	3449	2711	3111	129	14907	15000	0
972	580	3447	2718	3164	139	14897	14990	6-
1069	518	3446	2725	3216	148	14888	14981	13-
1166	466	3447	2732	3268	157	14883	14973	21-

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
1263	410	3449	2739	3322	165	14876	14966	28-
1360	370	3451	2745	3373	173	14876	14960	37-
1554	317	3455	2753	3471	187	14886	14950	52-
1943	250	3465	2767	3664	210	14925	14941	76-
2428	211	3468	2773	3889	235	14990	14944	90-
B 750								
0	1955	3527	2510	2510	0	15212	15212	0
22	1914	3527	2521	2531	6	15205	15209	3
45	1721	3526	2568	2588	12	15152	15193	6
67	1464	3522	2624	2654	17	15076	15167	7
90	1409	3524	2637	2677	21	15062	15142	9
135	1316	3522	2655	2715	28	15039	15112	10
180	1240	3512	2662	2743	35	15019	15091	11
200	1217	3507	2663	2753	38	15014	15084	11
315	1070	3482	2671	2813	54	14979	15052	11
450	933	3465	2681	2885	73	14949	15025	8
585	830	3453	2688	2954	90	14931	15006	2
720	740	3448	2697	3026	107	14918	14991	5-
810	678	3445	2704	3074	118	14909	14982	10-
900	620	3443	2710	3122	128	14900	14974	15-
990	564	3443	2717	3171	138	14893	14967	22-
1080	510	3444	2724	3221	146	14886	14961	28-
1170	465	3445	2730	3269	155	14883	14955	35-
1260	421	3448	2737	3318	163	14880	14950	42-
1350	391	3450	2742	3365	170	14883	14945	49-
1800	280	3459	2760	3590	201	14912	14933	80-
2250	223	3465	2769	3806	226	14965	14934	99-
B 751								
0	1951	3536	2518	2518	0	15212	15212	0
23	1932	3536	2523	2533	6	15211	15212	3
46	1823	3535	2550	2570	12	15183	15204	6
69	1527	3524	2612	2642	18	15096	15183	8
92	1442	3530	2635	2676	22	15074	15158	10
137	1385	3529	2646	2707	29	15063	15129	12
184	1327	3518	2650	2732	37	15050	15110	14
229	1278	3509	2652	2755	44	15040	15097	15
320	1176	3494	2661	2805	58	15018	15078	17
459	1018	3473	2673	2880	78	14983	15054	17
595	887	3461	2685	2955	97	14955	15035	14
732	773	3453	2697	3030	114	14934	15018	9
823	703	3448	2703	3079	125	14921	15008	4
914	641	3444	2708	3126	136	14911	14999	1-
1007	585	3442	2713	3175	146	14904	14990	6-
1099	533	3442	2720	3224	155	14898	14983	12-
1287	453	3444	2731	3323	173	14897	14971	25-
1380	422	3447	2736	3372	181	14900	14966	32-
1474	383	3449	2742	3421	189	14900	14962	38-
1854	290	3460	2760	3614	216	14926	14952	60-
2338	228	3465	2769	3844	243	14982	14952	75-
B 752								
0	1862	3529	2536	2536	0	15186	15186	0
16	1862	3535	2540	2547	4	15190	15188	2
32	1860	3528	2535	2550	8	15191	15189	4
51	1589	3528	2601	2623	13	15113	15175	6
71	1467	3523	2624	2656	17	15078	15153	7

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
102	1402	3535	2647	2693	22	15063	15128	9
142	1366	3533	2653	2717	28	15058	15109	10
182	1333	3521	2651	2732	34	15052	15097	12
247	1252	3512	2660	2771	45	15034	15083	14
359	1113	3493	2672	2833	61	15002	15063	15
463	1012	3481	2680	2890	75	14982	15047	14
573	912	3468	2687	2947	90	14962	15033	12
717	796	3456	2695	3022	108	14940	15016	8
790	740	3453	2701	3062	117	14931	15009	5
860	700	3451	2705	3098	125	14926	15002	1
932	643	3449	2712	3138	133	14916	14996	3-
1003	603	3448	2716	3175	141	14911	14990	7-
1077	561	3447	2720	3214	148	14907	14985	11-
1440	393	3453	2744	3407	181	14899	14964	35-
1783	278	3460	2761	3584	204	14909	14952	57-
B 753								
0	1982	3534	2509	2509	0	15221	15221	0
8	1982	3534	2509	2512	2	15222	15221	1
25	1880	3533	2534	2545	7	15196	15213	4
35	1652	3532	2589	2605	9	15130	15199	5
52	1462	3530	2630	2654	13	15074	15167	6
80	1354	3526	2650	2686	17	15043	15129	7
115	1326	3526	2656	2707	23	15039	15102	8
135	1322	3524	2655	2716	26	15041	15093	8
200	1300	3519	2656	2745	36	15044	15077	10
290	1204	3505	2664	2794	49	15024	15063	12
380	1112	3493	2672	2843	62	15006	15052	13
470	1020	3482	2680	2892	75	14986	15041	13
530	971	3476	2683	2923	83	14978	15034	12
585	922	3470	2687	2952	90	14968	15029	11
645	872	3464	2690	2983	98	14958	15023	10
705	830	3458	2692	3012	106	14952	15017	8
765	788	3455	2696	3044	113	14945	15011	6
822	751	3453	2700	3074	120	14940	15007	4
882	721	3451	2702	3105	127	14938	15002	1
1176	540	3447	2723	3262	159	14915	14983	13-
1457	383	3454	2746	3417	184	14898	14968	31-
B 754								
0	1991	3542	2512	2512	0	15224	15224	0
45	1844	3553	2559	2578	12	15191	15208	6
85	1422	3532	2641	2678	20	15067	15171	10
122	1361	3528	2650	2705	26	15052	15137	11
169	1296	3518	2656	2732	33	15037	15111	13
233	1217	3508	2664	2768	43	15020	15089	14
293	1120	3498	2674	2806	51	14995	15072	14
373	1023	3486	2682	2851	62	14972	15053	13
524	881	3463	2688	2926	82	14942	15025	9
680	747	3453	2700	3011	101	14915	15003	1
834	642	3449	2712	3094	118	14899	14985	8-
1003	556	3447	2721	3182	136	14892	14970	20-
1081	515	3447	2726	3223	143	14889	14964	26-
1157	478	3448	2731	3263	150	14886	14959	31-
1233	441	3449	2736	3304	157	14884	14955	37-
1312	401	3451	2742	3347	163	14881	14950	43-
1390	371	3453	2746	3388	169	14882	14947	49-
1470	339	3455	2751	3430	175	14882	14943	56-

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
1636	298	3458	2757	3513	186	14892	14937	68-
1978	241	3464	2767	3680	206	14926	14933	89-
2410	205	3469	2774	3883	227	14985	14937	102-
B 755								
0	1992	3535	2507	2507	0	15224	15224	0
13	1992	3541	2511	2517	4	15226	15225	2
39	1992	3545	2514	2532	11	15231	15228	6
55	1705	3544	2586	2610	15	15151	15217	8
73	1528	3544	2627	2659	19	15100	15194	9
117	1457	3541	2640	2692	26	15084	15156	12
159	1401	3535	2647	2718	33	15072	15135	14
203	1346	3530	2655	2746	40	15061	15120	16
287	1233	3512	2664	2792	53	15035	15099	19
420	1064	3483	2673	2862	72	14994	15072	20
600	887	3464	2688	2960	97	14957	15043	17
662	821	3460	2695	2996	105	14941	15034	15
786	746	3456	2703	3061	119	14933	15019	10
878	685	3452	2708	3109	130	14924	15009	6
972	626	3449	2714	3159	140	14916	15001	1
1069	562	3448	2721	3211	150	14906	14993	5-
1164	506	3447	2727	3262	159	14899	14985	11-
1263	448	3449	2735	3316	168	14892	14978	18-
1364	402	3450	2741	3369	177	14890	14972	26-
1913	249	3463	2766	3649	214	14919	14952	61-
2413	202	3468	2774	3884	239	14984	14952	77-
B 756								
0	2022	3550	2510	2510	0	15234	15234	0
23	1989	3546	2516	2526	7	15228	15231	4
47	1875	3544	2544	2565	13	15199	15222	7
95	1471	3542	2638	2680	23	15085	15182	12
143	1404	3541	2651	2715	31	15071	15147	14
190	1328	3525	2655	2740	38	15052	15126	16
285	1205	3506	2664	2792	53	15024	15097	18
380	1078	3487	2673	2845	66	14993	15075	19
523	928	3469	2685	2922	86	14960	15048	17
665	812	3460	2696	2999	104	14939	15027	12
760	751	3456	2702	3049	115	14930	15015	8
854	690	3452	2708	3098	126	14922	15005	3
949	626	3449	2714	3148	136	14912	14996	2-
1043	565	3448	2721	3199	146	14903	14988	8-
1233	449	3449	2735	3303	164	14887	14974	21-
1327	408	3450	2740	3352	171	14886	14968	28-
1804	271	3460	2761	3594	205	14909	14949	61-
2287	215	3467	2772	3825	231	14968	14947	81-
B 757								
0	1942	3536	2521	2521	0	15210	15210	0
21	1942	3532	2518	2527	6	15213	15211	3
43	1942	3531	2517	2536	12	15216	15213	6
65	1920	3535	2526	2554	18	15214	15214	9
87	1833	3536	2548	2587	24	15193	15211	12
128	1527	3520	2608	2665	33	15106	15191	16
172	1449	3524	2629	2705	42	15089	15167	19
215	1428	3522	2632	2727	49	15089	15152	22
302	1362	3520	2644	2779	64	15081	15132	27
432	1252	3505	2655	2848	86	15064	15114	33
558	1158	3491	2662	2912	106	15051	15101	38

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
689	1004	3472	2675	2985	125	15015	15088	41
775	731	3449	2699	3053	137	14924	15075	39
861	668	3444	2704	3098	147	14913	15060	34
947	603	3442	2711	3145	156	14901	15046	29
1032	561	3442	2716	3190	165	14899	15034	23
1118	510	3443	2723	3237	174	14892	15023	17
1204	454	3446	2732	3286	182	14884	15013	11
1290	418	3448	2738	3332	189	14884	15005	4
1720	257	3461	2763	3559	219	14889	14975	28-
B 758								
0	1904	3545	2537	2537	0	15200	15200	0
20	1903	3546	2538	2547	5	15203	15202	3
54	1415	3539	2647	2672	12	15060	15158	6
89	1394	3538	2651	2691	18	15059	15119	7
130	1387	3537	2652	2710	24	15063	15101	9
168	1387	3537	2652	2727	30	15069	15093	10
210	1387	3536	2651	2745	37	15076	15089	12
252	1387	3536	2651	2763	44	15083	15087	15
337	1315	3534	2664	2815	57	15073	15085	19
470	1263	3516	2661	2871	77	15075	15082	26
604	1035	3481	2676	2949	97	15014	15074	30
740	874	3464	2690	3025	116	14975	15059	29
830	809	3458	2695	3072	127	14964	15049	27
920	761	3455	2700	3118	138	14960	15041	25
1007	716	3453	2705	3163	149	14957	15034	23
1095	649	3449	2711	3211	159	14945	15027	20
1184	582	3446	2717	3259	168	14933	15020	16
1273	534	3446	2723	3306	177	14928	15014	12
1363	497	3447	2728	3353	186	14928	15008	8
1817	305	3458	2757	3594	222	14926	14988	14-
2273	223	3466	2770	3817	249	14969	14980	30-
B 759								
0	1921	3538	2528	2528	0	15204	15204	0
19	1921	3535	2525	2534	5	15207	15206	3
41	1859	3534	2540	2558	11	15193	15203	6
63	1550	3524	2606	2634	16	15103	15183	8
86	1425	3538	2645	2683	20	15068	15157	9
133	1365	3531	2652	2711	28	15056	15124	11
205	1273	3514	2657	2749	39	15035	15096	13
303	1117	3491	2669	2806	53	14994	15070	14
450	952	3471	2683	2887	73	14957	15039	12
599	839	3460	2692	2965	93	14938	15016	6
748	756	3455	2701	3042	111	14930	15000	0
847	690	3452	2708	3095	122	14921	14991	5-
946	633	3449	2713	3146	133	14914	14983	10-
1045	575	3449	2720	3199	143	14907	14977	16-
1144	515	3449	2728	3253	153	14900	14970	23-
1243	461	3450	2734	3306	162	14894	14964	30-
1343	406	3452	2742	3361	170	14888	14959	37-
1442	365	3454	2748	3413	178	14888	14954	44-
1938	244	3466	2769	3663	209	14921	14941	76-
2434	195	3470	2776	3896	233	14985	14944	91-
B 760								
0	1983	3537	2511	2511	0	15221	15221	0
11	1983	3537	2511	2516	3	15223	15222	2
33	1953	3539	2520	2535	9	15219	15221	5

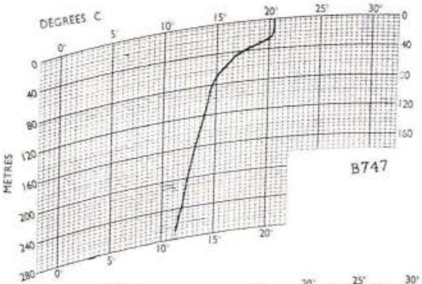
D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
54	1853	3539	2546	2569	15	15194	15215	8
76	1509	3526	2617	2651	20	15092	15195	10
111	1414	3534	2644	2693	26	15068	15158	12
151	1336	3527	2655	2722	32	15049	15132	13
224	1183	3505	2668	2769	43	15006	15098	15
334	1018	3479	2678	2829	58	14963	15061	13
446	900	3466	2687	2890	73	14936	15033	10
556	824	3461	2695	2948	87	14925	15013	5
668	753	3456	2702	3007	100	14916	14997	1-
742	708	3453	2706	3045	109	14910	14989	6-
817	650	3451	2712	3086	117	14900	14981	10-
889	606	3450	2717	3125	124	14894	14974	15-
962	555	3449	2723	3165	132	14886	14968	21-
1038	510	3448	2727	3205	139	14880	14962	27-
1100	474	3449	2732	3239	144	14875	14957	32-
1185	439	3451	2738	3284	152	14875	14951	39-
1554	303	3461	2759	3478	178	14881	14934	69-
1908	231	3468	2771	3653	197	14911	14927	93-
B 761								
0	1989	3542	2513	2513	0	15224	15224	0
9	1989	3541	2512	2516	3	15225	15224	1
29	1935	3541	2526	2539	8	15213	15221	4
43	1606	3536	2603	2622	11	15118	15203	6
60	1510	3536	2625	2651	15	15091	15175	7
88	1414	3530	2641	2680	20	15064	15144	8
120	1363	3525	2648	2701	25	15052	15121	10
148	1337	3521	2650	2716	29	15048	15108	11
202	1276	3515	2658	2748	38	15036	15090	12
298	1152	3500	2670	2804	52	15007	15068	13
360	1062	3490	2678	2841	60	14984	15055	13
472	948	3475	2686	2900	75	14960	15036	11
529	890	3469	2691	2931	82	14947	15027	9
589	846	3463	2693	2961	90	14939	15018	7
647	794	3458	2697	2992	97	14928	15011	5
702	760	3455	2700	3020	103	14924	15004	2
763	718	3452	2704	3052	111	14918	14997	1-
1211	475	3447	2731	3288	157	14894	14963	29-
1296	438	3450	2737	3334	164	14893	14959	35-
1727	288	3461	2761	3558	195	14904	14944	65-
2157	234	3465	2769	3762	219	14954	14941	85-
B 762								
0	1893	3534	2532	2532	0	15196	15196	0
31	1884	3530	2531	2545	8	15198	15197	4
69	1565	3521	2601	2631	17	15108	15173	8
102	1386	3521	2640	2685	23	15056	15143	10
140	1326	3519	2651	2713	30	15043	15118	11
173	1302	3516	2653	2731	35	15040	15103	12
212	1267	3513	2658	2753	41	15034	15091	13
244	1226	3506	2660	2770	46	15024	15083	13
314	1144	3496	2668	2810	56	15006	15068	14
423	1011	3478	2678	2869	71	14975	15048	14
528	902	3466	2687	2927	85	14951	15031	11
635	831	3458	2692	2981	99	14941	15017	7
706	781	3454	2696	3018	108	14933	15009	4
777	734	3451	2701	3055	116	14926	15001	1
845	681	3448	2706	3092	124	14916	14995	3-
918	639	3446	2710	3130	132	14911	14988	7-

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
991	592	3445	2715	3169	140	14905	14982	12-
1063	543	3444	2720	3208	147	14897	14977	16-
1132	508	3445	2725	3245	154	14894	14972	21-
1483	351	3452	2748	3432	184	14888	14953	47-
1872	260	3460	2762	3626	209	14916	14942	72-
B 764								
0	1868	3516	2524	2524	0	15187	15187	0
18	1868	3525	2531	2539	5	15191	15189	2
23	1868	3514	2523	2533	6	15190	15189	3
45	1831	3516	2534	2553	12	15183	15188	6
63	1528	3523	2611	2639	16	15096	15174	7
90	1454	3521	2625	2665	21	15076	15148	9
157	1313	3523	2656	2727	33	15042	15110	11
235	1191	3503	2665	2770	44	15011	15082	13
289	1105	3484	2666	2796	52	14987	15066	13
377	996	3473	2677	2847	64	14961	15045	11
466	903	3464	2685	2897	76	14940	15027	8
533	843	3457	2689	2932	85	14928	15015	5
625	792	3452	2693	2978	96	14923	15002	1
730	727	3448	2699	3033	109	14915	14990	5-
819	672	3446	2705	3080	120	14908	14982	10-
907	628	3444	2710	3125	129	14905	14974	16-
1062	544	3443	2719	3207	146	14897	14964	26-
1350	410	3445	2736	3358	172	14890	14949	46-
1792	274	3454	2756	3584	205	14908	14936	76-
B 765								
0	1857	3519	2529	2529	0	15184	15184	0
9	1857	3508	2521	2525	2	15184	15184	1
33	1841	3509	2526	2540	9	15183	15184	4
57	1531	3504	2595	2621	15	15093	15165	6
80	1375	3504	2629	2665	19	15047	15138	7
128	1201	3496	2657	2715	27	14996	15094	8
174	1139	3487	2662	2741	34	14981	15066	8
217	1079	3479	2667	2765	40	14965	15048	7
305	988	3468	2674	2812	52	14946	15021	4
439	895	3459	2683	2882	71	14932	14996	1-
450	880	3458	2684	2889	72	14928	14994	2-
509	829	3453	2688	2920	80	14918	14986	5-
570	790	3451	2692	2952	87	14913	14979	8-
634	746	3448	2697	2986	95	14907	14972	12-
682	718	3448	2701	3012	101	14904	14967	15-
700	710	3447	2701	3021	103	14903	14965	16-
760	687	3447	2704	3052	110	14904	14961	20-
773	677	3446	2705	3058	111	14902	14960	21-
1080	579	3443	2715	3210	145	14914	14945	40-
B 766								
0	1878	3516	2522	2522	0	15189	15189	0
20	1877	3513	2520	2529	6	15192	15191	3
42	1865	3512	2522	2541	12	15192	15192	5
63	1583	3513	2590	2618	17	15112	15178	7
82	1462	3511	2616	2652	21	15076	15159	9
126	1331	3507	2640	2697	28	15040	15124	10
170	1229	3503	2657	2734	35	15013	15099	11
212	1159	3495	2665	2760	42	14995	15080	11
298	1059	3480	2671	2806	54	14972	15052	10
428	947	3469	2682	2876	72	14951	15024	7

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
605	808	3455	2693	2969	94	14926	14999	0
769	700	3450	2705	3056	114	14911	14982	9-
853	650	3448	2710	3100	123	14905	14975	14-
939	597	3447	2716	3146	132	14898	14968	20-
1025	538	3447	2723	3194	141	14889	14962	26-
1110	492	3447	2729	3239	149	14884	14956	32-
1195	435	3448	2736	3287	157	14875	14951	39-
1280	388	3450	2742	3333	163	14870	14946	46-
1708	268	3457	2759	3549	193	14892	14929	80-
2128	217	3462	2768	3749	217	14941	14927	104-
B 767								
0	1843	3507	2524	2524	0	15178	15178	0
2	1843	3507	2524	2525	1	15179	15179	0
30	1818	3507	2530	2543	8	15176	15177	4
51	1784	3506	2538	2560	14	15169	15176	6
70	1599	3543	2610	2641	18	15121	15167	8
102	1477	3537	2633	2678	24	15088	15148	10
140	1428	3536	2642	2705	30	15078	15130	12
213	1351	3526	2651	2746	42	15064	15110	16
238	1321	3517	2650	2756	46	15057	15105	17
348	1161	3493	2663	2819	63	15017	15083	19
450	1023	3478	2676	2879	78	14984	15064	19
555	922	3467	2684	2936	92	14963	15047	17
625	863	3463	2691	2975	101	14952	15037	15
684	817	3457	2693	3004	109	14943	15029	13
765	759	3452	2698	3046	119	14934	15020	10
833	728	3448	2699	3079	127	14932	15013	7
900	690	3446	2703	3114	135	14928	15007	4
971	641	3444	2708	3152	143	14921	15001	0
1035	587	3443	2714	3188	150	14910	14995	3-
1383	400	3448	2739	3377	183	14892	14971	26-
1730	272	3457	2759	3558	208	14897	14956	51-
B 768								
0	1705	3472	2531	2531	0	15134	15134	0
17	1705	3471	2530	2537	5	15136	15135	2
39	1690	3471	2533	2551	10	15135	15135	4
60	1614	3472	2552	2579	16	15116	15132	5
83	1536	3468	2566	2603	21	15095	15125	7
128	1107	3466	2652	2710	30	14959	15090	8
174	1021	3464	2665	2744	37	14936	15052	6
222	950	3458	2673	2774	44	14917	15025	4
269	910	3454	2676	2799	50	14909	15006	1
317	869	3449	2679	2823	57	14901	14990	2-
B 769								
0	1553	3449	2548	2548	0	15084	15084	0
24	1474	3439	2558	2568	6	15062	15073	1
47	1268	3440	2601	2622	11	14998	15052	2
69	952	3434	2654	2685	15	14889	15017	1
113	767	3426	2676	2728	21	14826	14955	3-
158	755	3428	2680	2752	27	14829	14919	9-
225	722	3443	2696	2799	35	14829	14892	16-
314	687	3441	2699	2844	45	14830	14874	26-
449	629	3438	2705	2911	60	14829	14861	42-
537	595	3436	2707	2955	70	14830	14856	52-
626	561	3436	2712	3000	79	14831	14852	62-
804	523	3434	2715	3085	97	14844	14849	81-

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
893	509	3436	2718	3130	106	14854	14849	90-
982	502	3438	2720	3173	115	14866	14850	98-
1072	500	3442	2724	3217	124	14880	14852	106-
B 770								
0	1724	3479	2531	2531	0	15140	15140	0
17	1724	3476	2529	2537	5	15143	15141	2
41	1723	3476	2529	2548	11	15146	15143	4
64	1455	3485	2597	2626	17	15068	15130	6
83	1445	3524	2629	2666	20	15073	15117	6
130	1372	3515	2638	2696	28	15056	15098	8
167	1314	3511	2647	2722	34	15042	15087	10
218	1250	3503	2653	2751	42	15028	15075	11
308	1103	3483	2666	2805	56	14989	15055	11
439	935	3462	2678	2878	75	14948	15029	9
620	794	3447	2689	2971	98	14923	15002	1
702	740	3443	2693	3014	109	14915	14992	4-
792	689	3440	2698	3060	120	14909	14983	9-
879	627	3438	2705	3108	130	14899	14975	15-
966	575	3438	2712	3155	140	14893	14968	21-
1057	538	3439	2717	3202	149	14893	14962	27-
1142	482	3442	2726	3251	158	14885	14956	33-
1230	435	3446	2734	3301	165	14881	14951	40-
1319	400	3448	2739	3348	173	14881	14946	47-
1760	267	3462	2763	3576	203	14901	14932	79-
2201	224	3465	2769	3783	227	14957	14932	100-
B 771								
0	1718	3488	2540	2540	0	15139	15139	0
45	1718	3486	2538	2558	12	15147	15143	4
67	1715	3487	2540	2569	17	15149	15145	6
90	1697	3486	2543	2583	23	15148	15146	9
135	1293	3488	2633	2694	33	15027	15126	11
180	1230	3493	2650	2730	41	15014	15100	12
225	1188	3493	2658	2759	48	15007	15082	12
316	1098	3488	2670	2813	61	14990	15058	12
452	992	3469	2674	2879	80	14971	15034	10
588	901	3460	2682	2949	99	14959	15018	7
724	818	3454	2691	3020	117	14950	15006	3
815	775	3449	2693	3064	128	14948	15000	0
906	717	3447	2700	3113	140	14940	14994	3-
996	648	3445	2708	3163	150	14928	14989	7-
1087	600	3445	2714	3211	160	14924	14984	12-
1178	557	3446	2720	3260	170	14922	14979	17-
1268	488	3446	2728	3311	179	14909	14974	22-
1359	441	3448	2735	3360	187	14905	14970	27-
1821	269	3459	2761	3601	220	14911	14954	56-
2264	192	3460	2768	3812	245	14953	14950	76-
B 772								
0	1557	3462	2557	2557	0	15087	15087	0
15	1557	3462	2557	2564	4	15089	15088	1
35	1475	3462	2575	2591	8	15067	15082	2
55	1277	3461	2616	2640	12	15005	15066	2
75	1205	3461	2630	2663	16	14984	15047	2
109	1085	3462	2653	2702	22	14948	15021	2
144	1060	3467	2661	2726	27	14945	15003	0
179	1025	3465	2666	2747	32	14938	14991	1-
250	960	3460	2673	2786	42	14925	14974	4-

D	T	S	σ_t	σ_{stp}	$\Sigma\Delta D$	C	C_m	K
358	891	3452	2678	2841	57	14917	14958	10-
463	830	3446	2683	2894	71	14910	14948	16-
572	777	3443	2688	2949	85	14908	14941	23-
639	741	3442	2693	2985	93	14905	14937	27-
712	700	3441	2698	3023	102	14901	14933	32-
779	666	3441	2702	3059	110	14898	14931	36-
850	626	3441	2707	3097	118	14894	14928	41-
921	598	3440	2710	3133	126	14895	14925	46-
991	563	3440	2715	3170	133	14892	14923	51-
1062	533	3440	2718	3206	141	14892	14921	56-
1463	369	3445	2740	3415	177	14892	14913	85-
1765	262	3452	2756	3572	199	14898	14910	106-
A 919								
0	1542	3465	2563	2563	0	15083	15083	0
12	1530	3473	2572	2577	3	15082	15082	1
25	1269	3467	2622	2633	5	14998	15060	1
38	1070	3474	2665	2682	8	14932	15028	1
52	1070	3471	2662	2686	10	14934	15002	0
76	1052	3473	2667	2701	13	14932	14980	1-
103	1059	3479	2670	2717	17	14940	14969	2-
128	1056	3480	2672	2730	20	14943	14963	3-
175	1014	3473	2674	2753	26	14935	14957	5-
250	913	3461	2681	2795	36	14908	14946	9-
328	847	3456	2688	2837	46	14896	14936	14-
399	766	3448	2694	2876	55	14876	14927	19-



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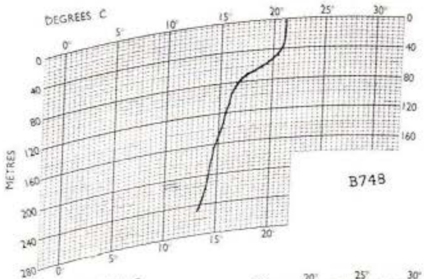

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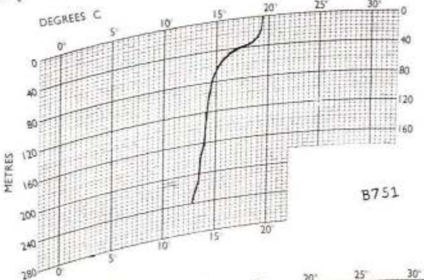

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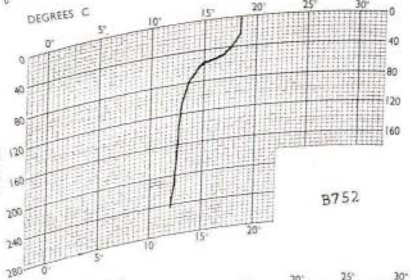

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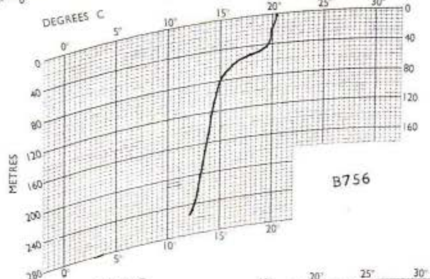

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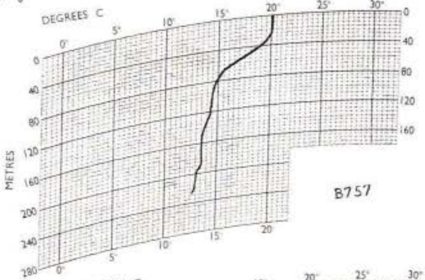

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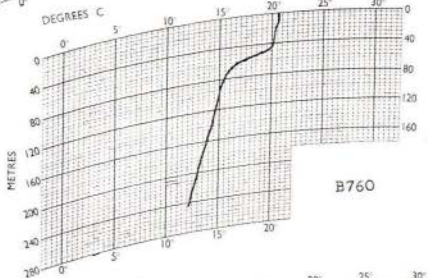

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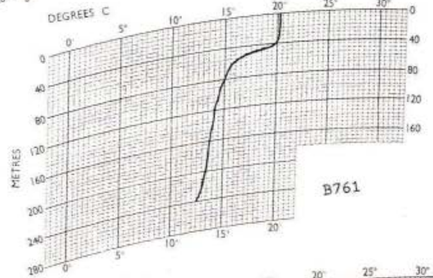

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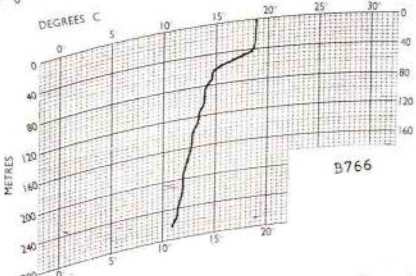

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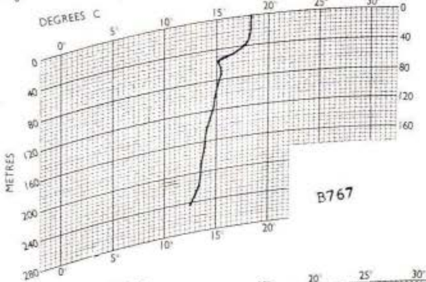

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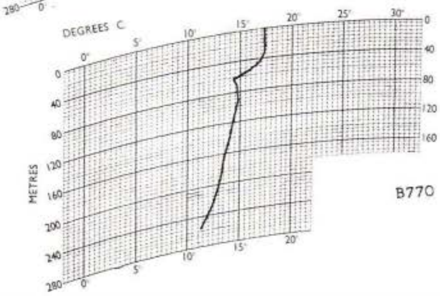

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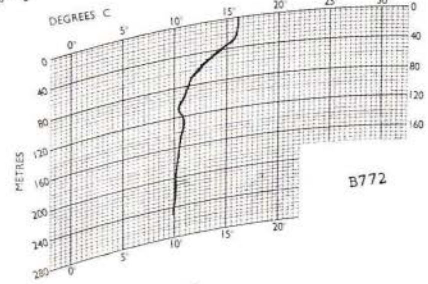

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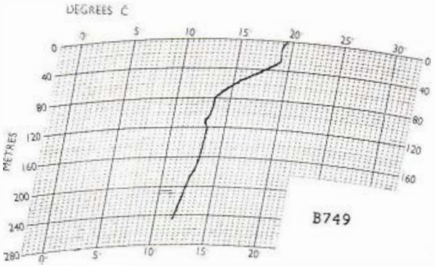

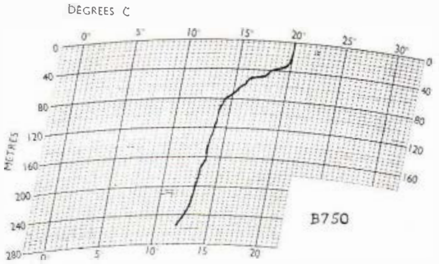

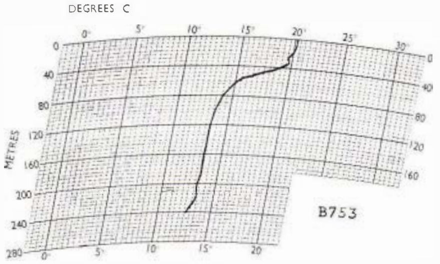

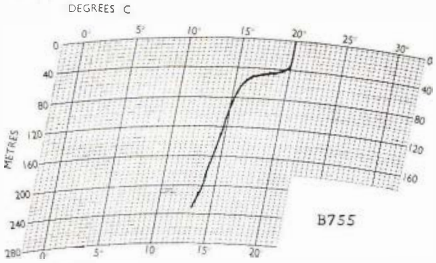

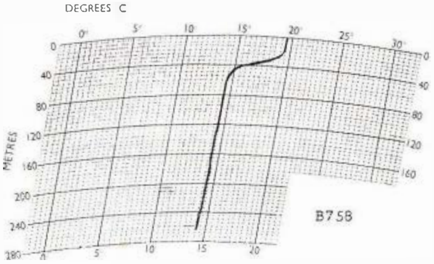

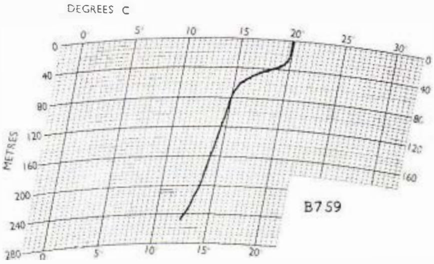

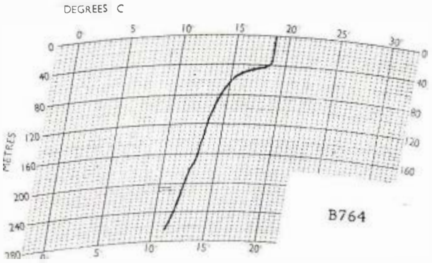

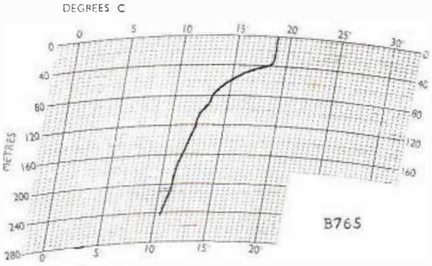

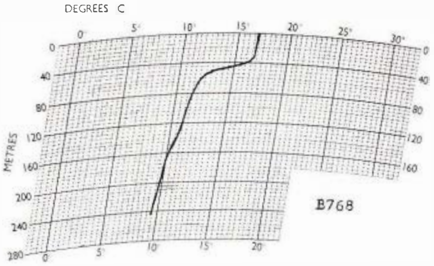

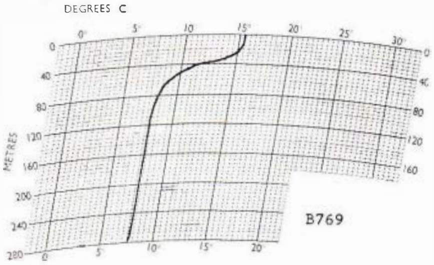

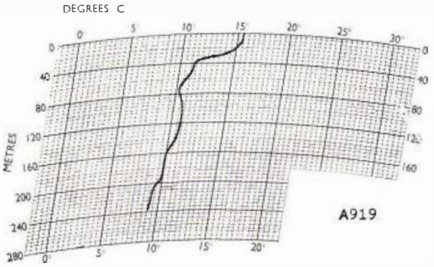

APPENDIX 2

Reproduced above are tracings of bathythermograph records from those stations at which weather permitted soundings to be made. For station circumstances see table 1.

MEMOIRS OF THE NEW ZEALAND OCEANOGRAPHIC INSTITUTE

Memoir No.	Date	Title
[1]	1955	Bibliography of New Zealand Oceanography, 1949–1953. By N.Z. Oceanographic Committee, *N.Z. Dep. sci. industr. Res. geophys. Mem. 4.*
[2]	1957	General Account of the Chatham Islands 1954 Expedition. By G. A. Knox. *N.Z. Dep. sci. industr. Res Bull. 122.*
3	1959	Contributions to Marine Microbiology. Compiled by T. M. Skerman. *N.Z. Dep. sci. industr. Res. Inf. Ser. 22.*
4	1960	Biological Results of the Chatham Islands 1954 Expedition. Part 1. Decapoda Brachyura, by R. K. Dell; Cumacea, by N. S. Jones; Decapoda Natantia, by J. C. Yaldwyn. *N.Z. Dep. sci. industr. Res. Bull. 139(1).*
5	1960	Biological Results of the Chatham Islands 1954 Expedition. Part 2. Archibenthal and Littoral Echinoderms. By H. Barraclough Fell. *N.Z. Dep. sci. industr. Res. Bull. 139(2).*
6	1960	Biological Results of the Chatham Islands 1954 Expedition. Part 3. Polychaeta Errantia. By G. A. Knox. *N.Z. Dep. sci. industr. Res. Bull. 139(3).*
7	1960	Biological Results of the Chatham Islands 1954 Expedition. Part 4. Marine Mollusca, by R. K. Dell; Sipunculoidea, by S. J. Edwards. *N.Z. Dep. sci. industr. Res. Bull. 139(4).*
8	1961	Hydrology of New Zealand Coastal Waters, 1955. By D. M. Garner. *N.Z. Dep. sci. industr. Res. Bull. 138.*
9	1962	Analysis of Hydrological Observations in the New Zealand Region 1874–1955. By D. M. Garner. *N.Z. Dep. sci. industr. Res. Bull. 144.*
10	1961	Hydrology of Circumpolar Waters South of New Zealand. By R. W. Burling. *N.Z. Dep. sci. industr. Res. Bull. 143.*
11	1964	Bathymetry of the New Zealand Region. By J. W. Brodie. *N.Z. Dep. sci. industr. Res. Bull. 161.*
12	1965	Hydrology of New Zealand Offshore Waters. By D. M. Garner and N. M. Ridgway. *N.Z. Dep. sci. industr. Res. Bull. 162.*
13	1961	Biological Results of the Chatham Islands 1954 Expedition. Part 5. Porifera: Demospongiae, by Patricia R. Bergquist; Porifera: Keratosa, by Patricia R. Bergquist; Crustacea Isopoda: Bopyridae, by R. B. Pike; Crustacea Isopoda: Serolidae, by D. E. Hurley; Hydroida, by Patricia M. Ralph. *N.Z. Dep. sci. industr. Res. Bull. 139(5).*
14	1963	Submarine Morphology East of the North Island, New Zealand. By H. M. Pantin. *N.Z. Dep. sci. industr. Res. Bull. 149.*
15	In prep.	Marine Geology of Cook Strait. By J. W. Brodie. *N.Z. Dep. sci. industr. Res. Bull.*
16	1963	Bibliography of New Zealand Marine Zoology 1769–1899. By Dorothy Freed. *N.Z. Dep. sci. industr. Res. Bull. 148.*
17	1965	Studies of a Southern Fiord. By T. M. Skerman (Ed.) *N.Z. Dep. sci. industr. Res. Bull. 157.*
18	1961	The Fauna of the Ross Sea. Part 1. Ophiuroidea. By H. Barraclough Fell. *N.Z. Dep. sci. industr. Res. Bull. 142.*
19	1962	The Fauna of the Ross Sea. Part 2. Scleractinian Corals. By Donald F. Squires. *N.Z. Dep. sci. industr. Res. Bull. 147.*
20	1963	Flabellum rubrum (Quoy and Gaimard). By Donald F. Squires. *N.Z. Dep. sci. industr. Res. Bull. 154.*
21	1963	The Fauna of the Ross Sea. Part 3. Asteroidea. By Helen E. Shearburn Clark. *N.Z. Dep. sci. industr. Res. Bull. 151.*
22	1964	The Marine Fauna of New Zealand: Crustacea Brachyura. By E. W. Bennett. *N.Z. Dep. sci. industr. Res. Bull. 153.*
23	1963	The Marine Fauna of New Zealand: Crustaceans of the Order Cumacea. By N. S. Jones. *N.Z. Dep. sci. industr. Res. Bull. 152.*
24	1964	Bibliography of the Oceanography of the Tasman and Coral Seas 1860-1960. By Betty N. Krebs. *N.Z. Dep. sci. industr. Res. Bull. 156.*
25	1965	A Foraminiferal Fauna from the Western Continental Shelf, North Island, New Zealand. By R. H. Hedley, C. M. Hurdle, and L. D. J. Burdett. *N.Z. Dep. sci. industr. Res. Bull. 163.*
26	1964	Sediments of the Chatham Rise. By Robert M. Norris. *N.Z. Dep. sci. industr. Res. Bull. 159.*
27	1965	The Fauna of the Ross Sea. Part 4. Mysidacea, by Olive S. Tattersall; Sipunculoidea, by S. J. Edmonds. *N.Z. Dep. sci. industr. Res. Bull. 167.*
28	1966	Sedimentation in Hawke Bay. By H. M Pantin. *N.Z. Dep. sci. industr. Res. Bull. 171.*
29	1964	Biological Results of the Chatham Islands 1954 Expedition. Part 6. Scleractinia. By D. F. Squires. *N.Z. Dep. sci. industr. Res. Bull. 139(6).*
30	1966	Geology and Geomagnetism of the Bounty Region east of the South Island, New Zealand. By Dale C. Krause. *N.Z. Dep. sci. industr. Res. Bull. 170.*

MEMOIRS OF THE NEW ZEALAND OCEANOGRAPHIC INSTITUTE—*continued*

Memoir No.	*Date*	*Title*
31	In prep.	Contribution to the Natural History of Manihiki Atoll, Cook Islands. Ed. C. A. McCann. *N.Z. Dep. sci. industr. Res. Bull.*
32	In press	The Fauna of the Ross Sea. Part 5: General Accounts, Station Lists, and Benthic Ecology. By John S. Bullivant and John H. Dearborn. *N.Z. Dep. sci. industr. Res. Bull. 176.*
33	In press	The Submarine Geology of Foveaux Strait. By D. J. Cullen. *N.Z. Dep. sci. industr. Res. Bull.*
34	In prep.	Benthic Ecology of Foveaux Strait. By E. W. Dawson. *N.Z. Dep. sci. industr. Res. Bull.*
35	1966	The Marine Fauna of New Zealand: Spider Crabs. Family Majidae, (Crustacea Brachyura). By D. J. Griffin. *N.Z. Dep. sci. industr. Res. Bull. 172.*
36	1966	Water Masses and Fronts in the Southern Ocean South of New Zealand. By Th. J. Houtman. *N.Z. Dep. sci industr. Res. Bull. 174.*
37	In press	The Marine Fauna of New Zealand: Porifera, Demospongiae. Part I. Tetractinomorpha and Lithistida. By Patricia M. Bergquist. *N.Z. Dep. sci. industr. Res. Bull.*
38	In press	The Marine Fauna of New Zealand: Intertidal Foraminifera of the Corallina officinalis zone. By R. H. Hedley, C. M. Hurdle, and I. D. J. Burdett. *N.Z. Dep. sci. industr. Res. Bull.*

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