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PHYSICAL OCEANOGRAPHY OF THE WATERS OVER THE CHATHAM RISE

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D S I R

Publications in this series result from specific enquiries for information. They record and comment on relevant available data.

Recent interest in the mineral deposits on the Chatham Rise has highlighted the need for scientific information about the Chatham Rise to be summarised and made generally available. The present contribution was compiled in response to that need.

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PHYSICAL OCEANOGRAPHY OF THE WATERS OVER THE CHATHAM RISE

R.A. Heath

INTRODUCTION

Recent renewed interest in the economic mineral deposits on the Chatham Rise, located east of New Zealand, has led to a growing interest in scientific, economic, and environmental aspects of the Rise and the surrounding ocean. Such is the relief and length of the Chatham Rise that it strongly controls the water movements in the area and, as a result, significantly influences physical, biological, and sedimentological processes. The present summary of existing published information of the physical oceanography of the waters near the Rise is intended as a base for future studies in the area. It complements similar summaries being prepared of the biology and geology.

GENERAL MORPHOLOGY OF THE CHATHAM RISE

The Chatham Rise is the ridge-like eastern part of the New Zealand Plateau which extends from approximately 100 km east of Banks Peninsula, eastwards for 1450 km (Fig. 1). At its western end, the Chatham Rise is separated from the New Zealand continental shelf by the 580-metre-deep Mernoo Saddle. From this saddle to 730 km east to the Chatham Islands the mean depth of the Chatham Rise is about 200–400 m with about 3000 m of relief on both the northern and southern flanks. The slope on the northern flank into the Hikurangi Trough is, however, steeper than that into the Bounty Trough on the southern flank. From the Chatham Islands the depth of the Chatham Rise increases as it extends a further 750 km east-north-eastwards to about 42°S, 168°W, where the depth is around 2000 m. Its eastern end is separated by a gap from the north-west to south-east-trending Louisville Ridge. About 400 km eastwards from the Chatham Islands the Chatham Rise is cut by the narrow Broughton Gap (42°40'S, 171°40'W, Wanoa and Lewis, 1972), which is 30 km wide with about 750 m of relief (Cullen 1969).

CIRCULATION

Mean Circulation

In the open ocean the mean circulation is usually evaluated using the geostrophic method where the speed-dependent Coriolis Acceleration is equated with the horizontal pressure-gradient. The horizontal pressure-gradient (in practice the dynamic height between isobaric surfaces is evaluated) is calculated from the temperature- and salinity-dependent density field. Through the late 1960s and early 1970s, physical oceanographic research priority in the New Zealand region was observation of the temperature and salinity fields, initially from a series of block surveys encompassing New Zealand and then in complex circulation areas as revealed from the block surveys. Of relevance to the circulation near the Chatham Rise, in these surveys, are the publications of Garner (1967, 1969), Heath (1968, 1972a, b, 1973b, 1975a, 1976a), and Ridgway (1975) which build on the pioneering studies, in the area, of Deacon (1937, 1945), Fleming (1950), Garner (1953, 1955, 1959, 1961, 1962), Brodie (1960), Sdubbundhit and Gilmour (1964) and Garner and Ridway (1965).

New Zealand lies athwart what, without the presence of the extensive submarine platform, would be a general eastwards-directed zonal flow. This flow is effectively split by New Zealand (Fig. 2) with the subsequent flow being strongly controlled along areas of large topographic relief. Conservation of vorticity requires that mean currents have a strong tendency to flow along isobaths with some deviation to account for changes in latitude. Comparison of lines of constant planetary vorticity (Fig. 3; Bye *et al.* 1979) and mean geostrophic circulation (Fig. 4) demonstrate clearly the strong topographic control of the Chatham Rise. The mean flow tends to parallel, and be intensified over, the Chatham Rise but the flow variability there is probably closely linked to the flow variability along the entire east coast. This variability is complicated by the presence of the Mernoo Saddle, at the western end of the Chatham Rise, which allows interaction between the alongshore flows from both the north and the south.

To the north of New Zealand, flow out of the Tasman Sea gives rise to the East Auckland Current (Fig. 2) which flows south-eastwards along the east coast of North Island, between North Cape and East Cape (Barker and Kibblewhite 1965). Near East Cape the main flow of the East Auckland Current turns north (i.e., that part north of approximately 37°S) while the rest turns in a clockwise direction around East Cape, giving rise to the southwards-flowing East Cape Current. This current adjusts the temperature and salinity distribution such that a warm, saline tongue extends southwards from East Cape.

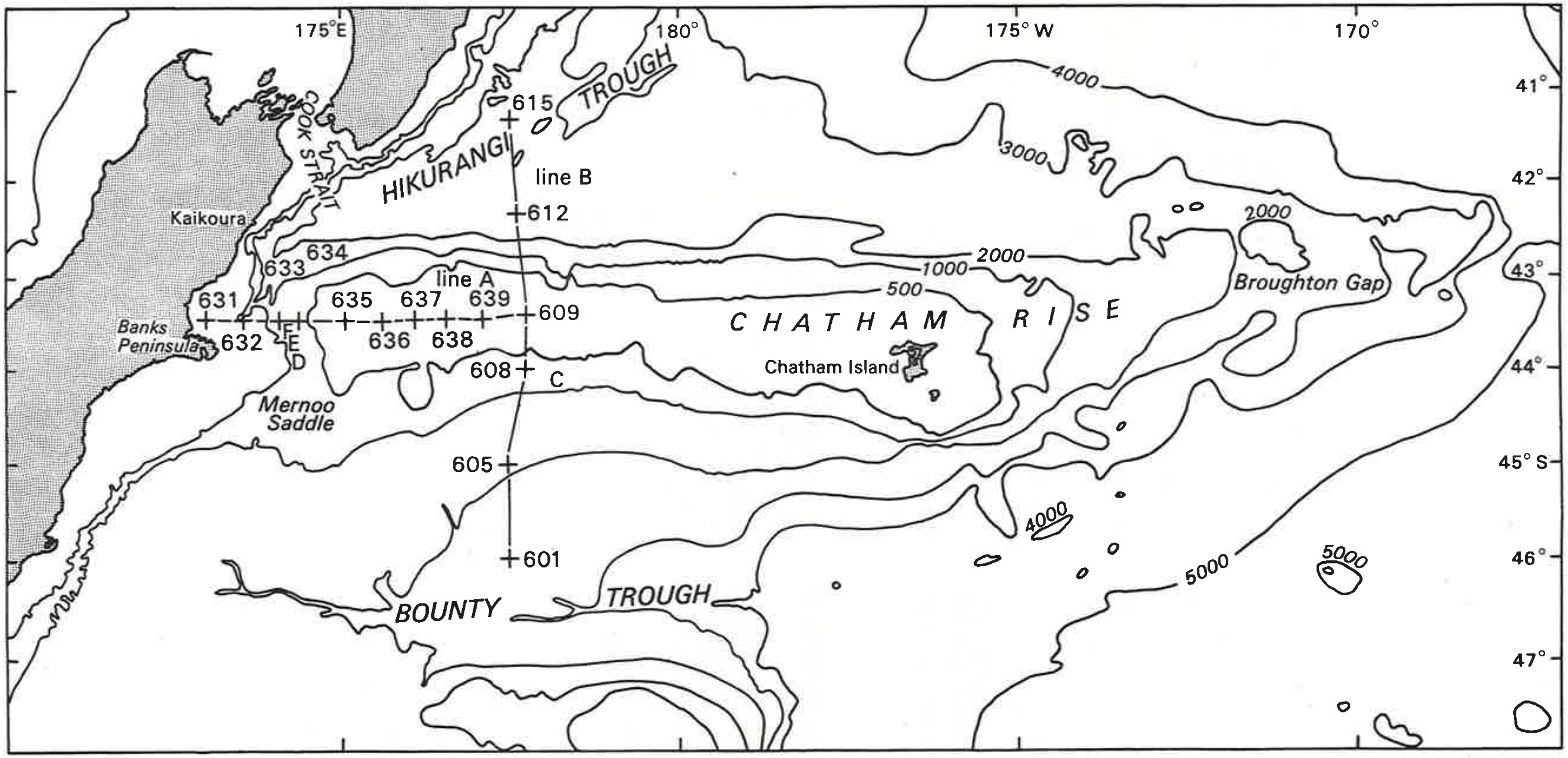

Fig. 1. Bathymetry (m) off the east coast of New Zealand (from Carter 1980). Locations of the lines of stations across the Mernoo Saddle (line A, see Fig. 6) and the Chatham Rise (line B, see Fig. 8b) and the location of the current drogue observations (C to F) referred to in the text are shown.

Water of mainly subtropical origin flows eastwards through Foveaux Strait, across the Snares Shelf and through the Snares Depression south of New Zealand, then north-eastwards on the continental shelf and slope of the east coast of South Island (Brodie 1960; Garner 1961; Houtman 1965; Jillett 1969; Heath 1975b, 1981a). Subantarctic Water (cf. p.7) also flows north-eastwards on the continental slope of the east coast of South Island. The combined flow of both water types on the shelf and slope constitutes the Southland Current (Jillett 1969; Heath 1972b, 1975b, 1981a). South of the Mernoo Saddle the Southland Current is identified at the surface by its warm, Subtropical Water component on the continental shelf which contrasts with its cooler, less saline coastal water inshore and with the Subantarctic Water component offshore (Fig. 5; Jillett 1969). Subantarctic Water is brought closer to the surface as it flows through the Mernoo Saddle (Heath 1972a, b) and consequently alters the surface characteristics north of the saddle by which the Southland Current can most easily be recognised. Thus, north of the Mernoo Saddle, the Southland Current is identified at the surface by its cool, low-salinity Subantarctic Water which contrasts with its more saline water inshore and warmer, more saline water derived (Fig. 6) mainly from the East Cape Current offshore (Heath 1972b).

The Southland Current has been observed to branch near Kaikoura with one component meandering towards the east and the other continuing northwards on the continental shelf and slope (Heath 1972b). This northwards-extending component diverges seawards north of Kaikoura with most of the water sweeping across the southern end of Cook Strait but with some water entering Cook Strait around Cape Campbell (Fig. 2). The relative strength of these two flows, the one sweeping across the southern end of Cook Strait and the other entering Cook Strait, probably depends on the amount of water derived from the East Cape Current, which is present over the Cook Strait Canyon (Heath 1971).

Warm, saline Subtropical Water in the D'Urville Current sweeps into Cook Strait from the north-west (Brodie 1960; Heath 1969). This current is derived from the Westland Current flowing northwards along the west coast of South Island. The water of the Southland Current in Cook Strait mixes both with water from the D'Urville Current flowing in from the north, and with water over the Cook Strait Canyon from the East Cape Current. Mixed water derived from all three currents travels eastwards across Cook Strait and around Cape Palliser to meet the water of the Southland Current that has diverged seawards between Kaikoura and Cook Strait (Heath 1972b, 1975a). The Southland Current turns eastwards and back southwards south of Hawke Bay (usually near Cape Turnagain) combining with the East Cape Current (Heath 1975a). The combined Southland and East Cape Current water, after flowing south to about the latitude of Cape Palliser, turns east then north to form the outer arm of the East Cape Current System and the water sweeping along the northern flank of the Chatham Rise (Sdubbundhit and Gilmour 1964; Garner 1967; Heath 1968, 1972b, 1975a).

The south-western flank of the Chatham Rise is bathed by eastwards-moving water which has flowed along the continental slope of the east coast of South Island south of the Mernoo Saddle but has swept towards the east rather than rising through the saddle (Heath 1972b, 1975b). The south-eastern flank of the Chatham Rise is also bathed by water which enters the Bounty Trough (Fig. 1) via the Pukaki Saddle (Figs 2, 4, 5) and circulates clockwise around the eastern side of the Bounty Trough (Ridgway 1975).

The Chatham Rise limits the meridional flow immediately east of New Zealand. Where the depth of the Chatham Rise increases, however, east of the Chatham Islands, the constraining influence decreases and the eastwards flow may also have either a northwards or southwards component (Ridgway 1975; Heath 1981a). Horizontal distributions of surface (Fig. 5) and near-surface water properties have a tongue-like form east of the Chatham Islands with the tongue protruding towards the south. This tongue may result from eddies translating into the area from north of the Chatham Rise rather than result just from a time-averaged mean circulation pattern.

Variability in the Circulation

Although the mean circulation, as described above, is controlled by the large topographic relief, accumulated evidence indicates that there is considerable temporal variability in the east coast circulation and, hence (because these are the source waters for the Chatham Rise), on the Chatham Rise.

Where the East Cape Current turns north a large anticyclonic eddy is formed. This eddy is evidently a permanent feature since it is evident in all data collected in this region (Sdubbundhit and Gilmour 1964; Garner 1967; Heath 1968, 1972b, 1973b, 1975a) and contains higher-salinity Antarctic Intermediate Water (raised 0.1‰ above the surrounding water (Garner 1967)). Eddies in this region are frequently evident in measurements of temperature by aerial radiometer (Ridgway 1970) and satellite as areas of warmer water. Recent analysis of new data and reanalysis of existing data suggest that eddies are also located over shallow bathymetric features off the east coast of New Zealand (Bradford *et al.* in press).

Small eddies, which are probably periodically shed off from the "permanent" eddy, are guided by the bottom topography either towards Kaikoura (Fig. 1; Heath 1975a), where they raise the temperature and salinity above the seasonal mean (Garner 1953; Houtman 1965;

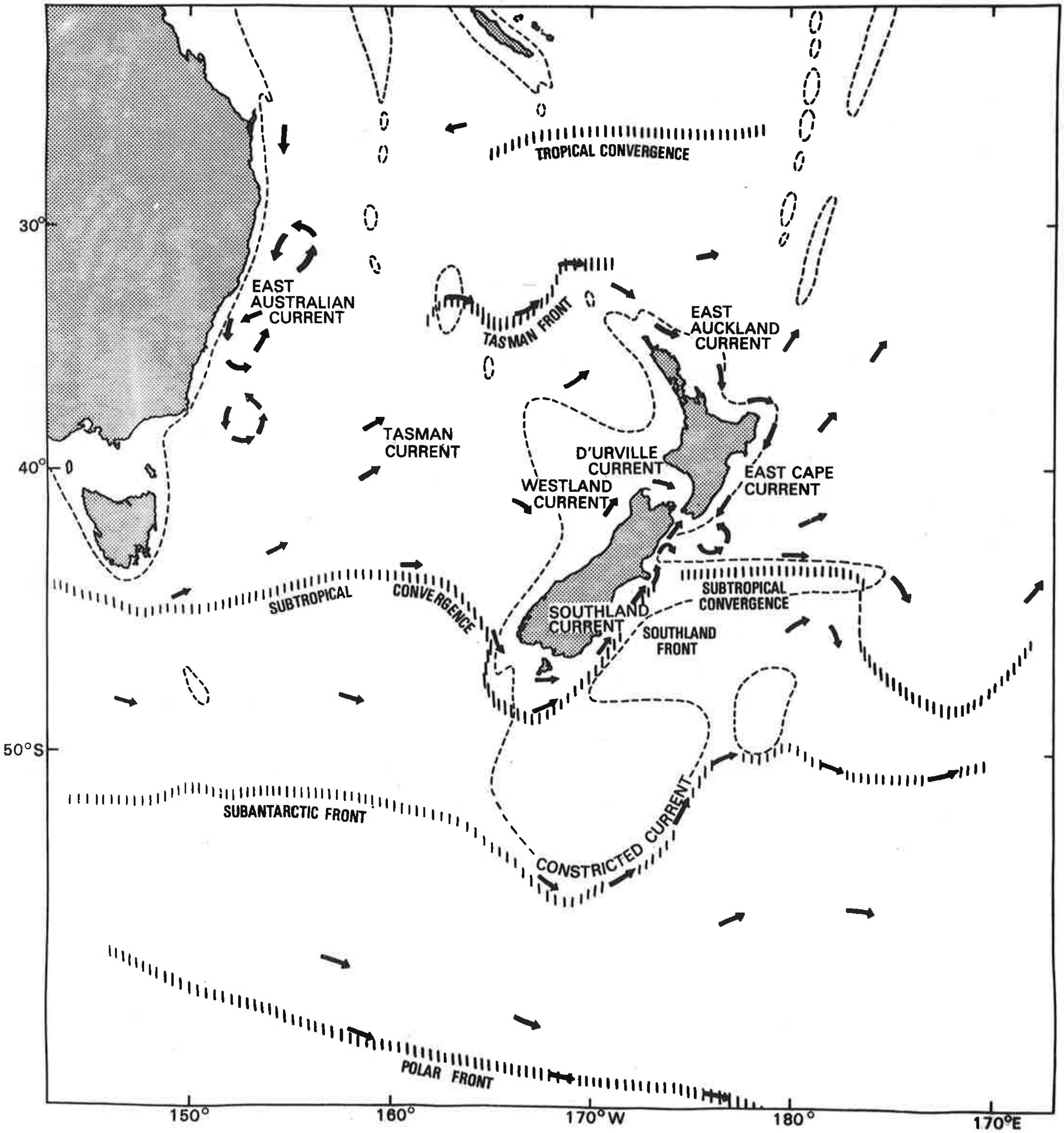

Fig. 2. Schematic diagram of the oceanic circulation in the south-western Pacific (after Heath 1980, fig. 1). The dashed line corresponds to the smoothed 1000 m isobath.

Bradford 1972), or towards the Mernoo Saddle (Heath 1975a). The temporal variability is further complicated by the variable strength of the Southland Current. Current observations from the continental shelf east of Banks Peninsula have demonstrated large variability which appears to be correlated with atmospheric conditions (Heath 1976a). Indirect evidence for the variation in the strength of the Southland Current is provided by observed lowering of the sea-surface temperatures recorded from the inter-island ferries in passage between Lyttelton and Wellington (Fig. 1), and from Kaikoura. Analysis of the temperature record from Kaikoura for the period during and following the particularly strong southerly storm of 9-10 April 1968 clearly indicated that part of the decrease in water temperature was caused by advection of cold water from the south in the Southland Current (Heath 1970).

The flow on the Chatham Rise must strongly depend on the interaction of the East Cape and Southland Currents, local atmospheric forcing and, specifically, on the presence or otherwise, and location of, a small eddy shed off from the permanent eddy located in the Hikurangi Trough (which itself probably depends on circumstances well removed from the immediate area). For example, it appears possible that a small eddy could be guided towards the Mernoo Saddle and there strongly influence the flow through the saddle and therefore the eastwards flow on the Chatham Rise.

Recently a team of scientists from Auckland University, State University of New York at Stony Brook, and the New Zealand Oceanographic Institute have taken sets of oceanographic observations in, and south-east of, Cook Strait which include the first sets of nutrient, plankton, and primary production data from the area (Bowman 1979). These observations demonstrate a region of high biological productivity extending as a plume south-eastwards from Cook Strait. Although final analysis is not complete (the plume could be due to tidal mixing in Cook Strait, coastal upwelling, or interaction between the eddies from the East Cape and Southland Currents turning offshore between Kaikoura and Cape Campbell) these observations provide further insight into the variability in the area and clearly indicate that, despite considerable research to date, a concentrated effort is needed to enable the variability to be better understood.

Direct Measurements of Currents

The only presently published direct current measurements from the Chatham Rise itself are two current-drogue observations made over a tidal cycle at 43°56'S, 178°E on the southern flank of the Chatham Rise (Fig. 1; Heath 1976a). Over the one tidal cycle of observations the mean speed for both the drogue at 25 m depth and the one at 150 m depth was $0.15\ \mathrm{m\ s^{-1}}$ at 315°T superimposed on a peak tidal flow of $0.3\ \mathrm{m\ s^{-1}}$. These observations alone give an idea only of the typical (but not the long-term time-averaged) speed to be expected. They are, however, of the same order as the mean speeds of $0.2\ \mathrm{m\ s^{-1}}$ (towards the east) computed with a numerical model (Bye *et al.* 1979).

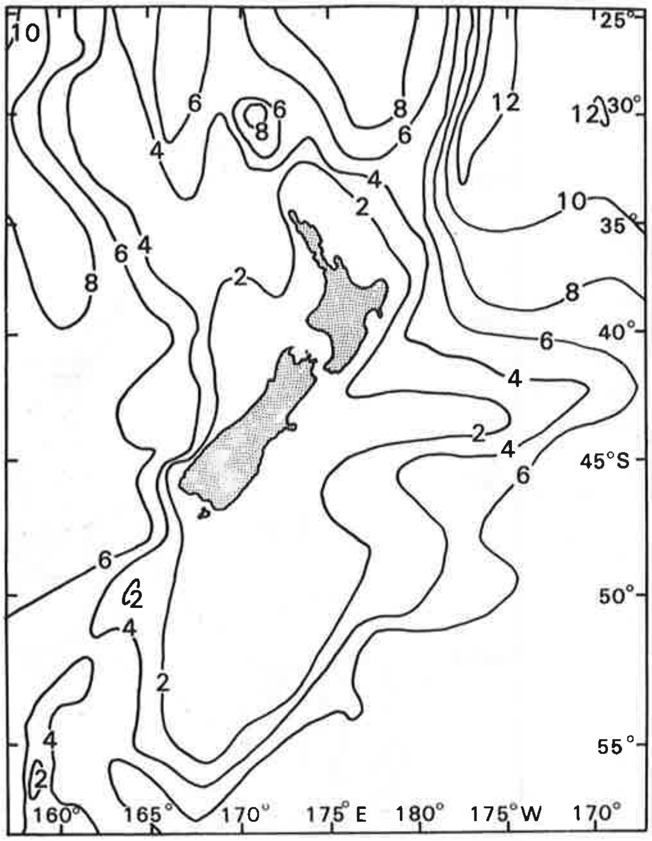

Fig. 3. Contours (km) of H cosec θ (H the depth; θ the latitude) (after Bye *et al.*, fig. 5).

Current drogue observations from the western side of the Mernoo Saddle in the Southland Current have given mean flows of $0.08\ \mathrm{m\ s^{-1}}$ at 25°T (drogue at 300 m depth over a 10-hour period on 22 April 1971 at 43°26'S, 173°49.6'E, Heath 1973b) and $0.09\ \mathrm{m\ s^{-1}}$ at 1°T (drogue at 100 m depth over a period of nine tidal cycles starting on 16 January 1975 at 44°00.1'S, 174°09.3'E) - drogue observation locations are shown in Fig. 1. These mean flows are superimposed on considerably faster tidal flows (see p. 12). Detailed analysis of observations from within the Mernoo Saddle and comparison with theoretical models of flows in straits give an estimate for the volume transport in the Mernoo Saddle of $1.7 \times 10^6\ \mathrm{m^3 s^{-1}}$ with typical speeds of $0.05-0.1\ \mathrm{m\ s^{-1}}$ (Heath 1976a).

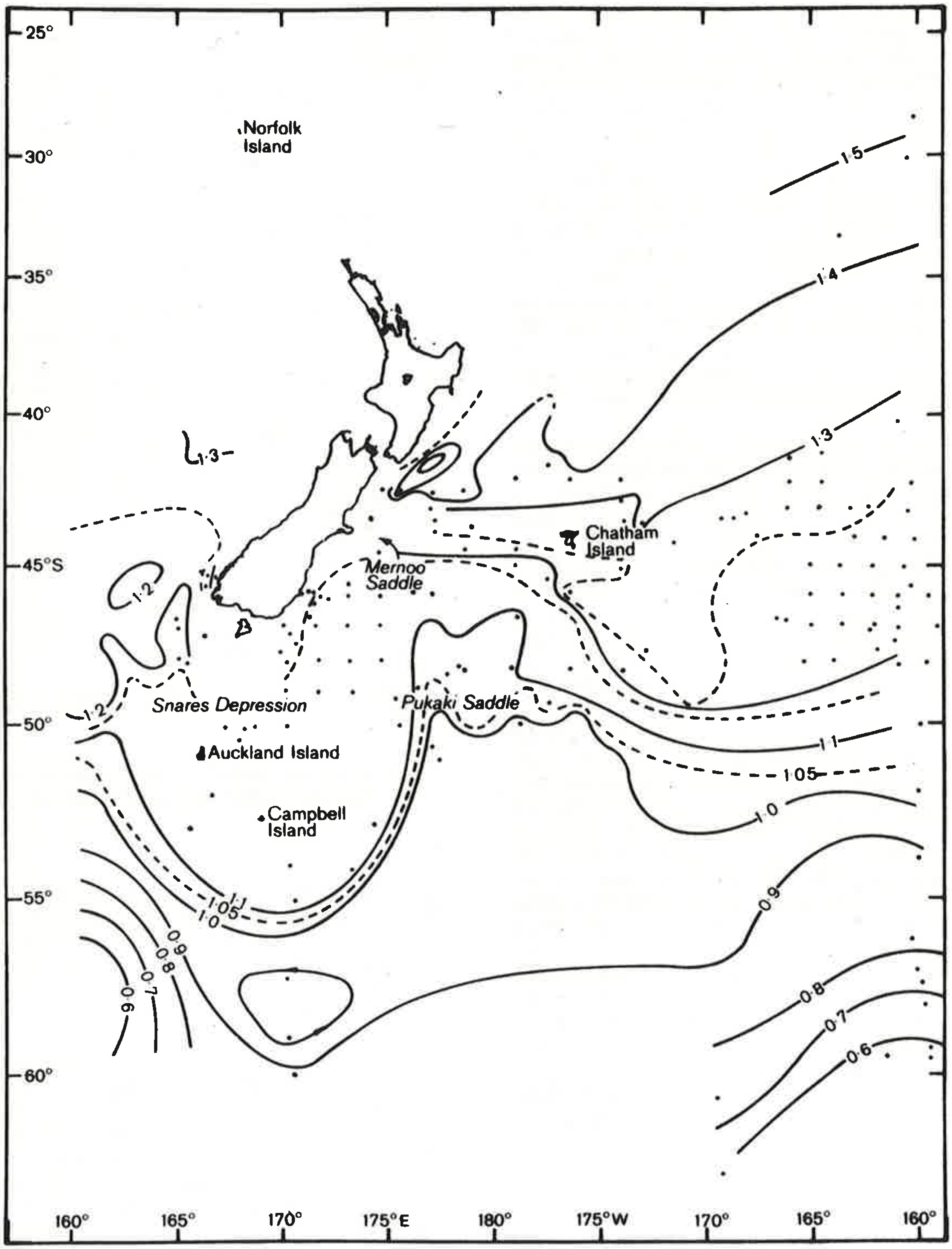

Fig. 4. Contours (dyn. m) of the geopotential topography of the sea surface relative to 1000 dbars around southern New Zealand (after Heath 1981a, fig. 5).

WATER PROPERTIES AND THEIR DISTRIBUTION

Temperature and Salinity

In the ocean surrounding New Zealand there are five main water masses each of which has distinctive temperature/salinity (T/S) characteristics. These are (Fig. 7) :

(1, 2) surface and near-surface Subtropical and Subantarctic Waters, the Subtropical Water being warm and saline and the Subantarctic Water cooler and less saline.

Increasing in depth, the other three water masses are :

(3) Antarctic Intermediate Water which is characterised by a minimum in salinity of 34.3 - 34.4‰ with its core at about 800–1200 m depth.

(4) Pacific Deep Water which is characterised by a salinity maximum of about 34.72‰ with its core at a depth of about 3500 m.

(5) Bottom Water which is located below the Pacific Deep Water with lower temperatures and salinities.

The boundary between Subtropical and Subantarctic Water is the Subtropical Convergence which is characterised by strong horizontal gradients of water properties. In the open ocean this convergence undergoes large irregular north-south excursions in position with a range of as much as 6° of latitude (Deacon 1937). East of New Zealand, however, the Chatham Rise acts as a partial barrier to meridional flow and the Subtropical Convergence is bound to the shallow section of the Chatham Rise between the Mernoo Saddle and the Chatham Islands (Fig. 5; Garner 1957; Heath 1975a, 1976b). From the western end of the Chatham Rise the Subtropical Convergence extends towards Kaikoura (Figs 1, 2), forming the seawards arm of the horizontal salinity and temperature tongue of the return flow from Kaikoura of water from the Southland and East Cape Currents. The inner arm of the tongue is the Southland Front (Heath 1972a). It should be emphasised again that this is the mean pattern and that the temporal variability is very pronounced.

East of the Chatham Islands the restraining influence of the Rise decreases as the depth of the Rise increases and the Subtropical Convergence projects as a horizontal tongue towards the south (Fig. 2).

Limited available observations suggest that the Subtropical Convergence over the Chatham Rise may be located further south in winter than in summer (Heath 1975a). One possible explanation for this has been offered in terms of the seasonal variation of the vertical structure of the currents in this region. In summer the vertical shear of the currents is nearly uniform to a depth of at least 1000 m, whereas in winter the vertical shear is larger in the subsurface layers (depth greater than 300 m). The vertical stress component will therefore be less in winter than in summer allowing the Subtropical Convergence to move further south (Heath 1975a).

Deacon (1945) found that from the Subtropical Convergence in the open ocean a high-salinity subsurface tongue can extend as far south as the Antarctic Convergence (a distance of about 1400 km). This subsurface layer is found at depths between 100 and 300 m in the Atlantic Ocean and western side of the Indian Ocean and at somewhat greater depths in the Pacific Ocean (Deacon 1945). The southwards projection of this tongue is also limited by the Chatham Rise. The horizontal scale (L) of the tongue (as defined by the salinity anomaly created by the tongue (Heath 1976b), $s = s_0 \exp(-y/L)$, y positive towards the south), as evident from existing hydrographic data, is 100–200 km south of the shallower section of the Chatham Rise (177°00'E, 179°00'E), increasing to 350 km east of the Chatham Islands (174°00'W, Ridgway 1975), but is 3000 km in the open coast west of New Zealand (163°50'E). This meridional-restricting influence of the Chatham Rise has important consequences for the formation of Subantarctic Mode Water over the Campbell Plateau south of the Chatham Rise (McCartney 1977; Heath 1981a). The weak thermal structure over the Campbell Plateau, brought about by reduction of the southwards extension of warm Subtropical Water by the Chatham Rise (Fig. 5) and enhanced mixing over the shallow depths of the Plateau, probably leads to increased production of Subantarctic Mode Water and would explain the relatively large zonal decrease in temperature of the Subantarctic Mode Water in its passage past New Zealand compared with that at other longitudes (McCartney 1977; Heath 1981a).

The Subantarctic Mode Water found in the south-eastern Pacific Ocean and Scotia Sea is identical in characteristics to the Antarctic Intermediate Water in the south Pacific Ocean indicating that the Antarctic Intermediate Water is renewed north of the Polar Front (rather than south of the front which is the classical belief) (McCartney 1977). By limiting the southwards passage of water over itself the Chatham Rise plays a role in determining the characteristics of the Subantarctic Mode Water formed in the New Zealand sector (Heath 1981a).

Meridional components of water movement at the Subtropical Convergence are small and are likely to be highly time-dependent. In the circumstances, long-term current observations are needed to allow the advective and diffusive transport components to be defined; the strong time-dependent component (with time scales of several tens of days), then, is interpreted as diffusion. The classical view is shown in Fig. 8a. In the light of recent knowledge of the influence of eddies on the distribution of water properties, some of the arrows shown would represent diffusive rather than the clas-

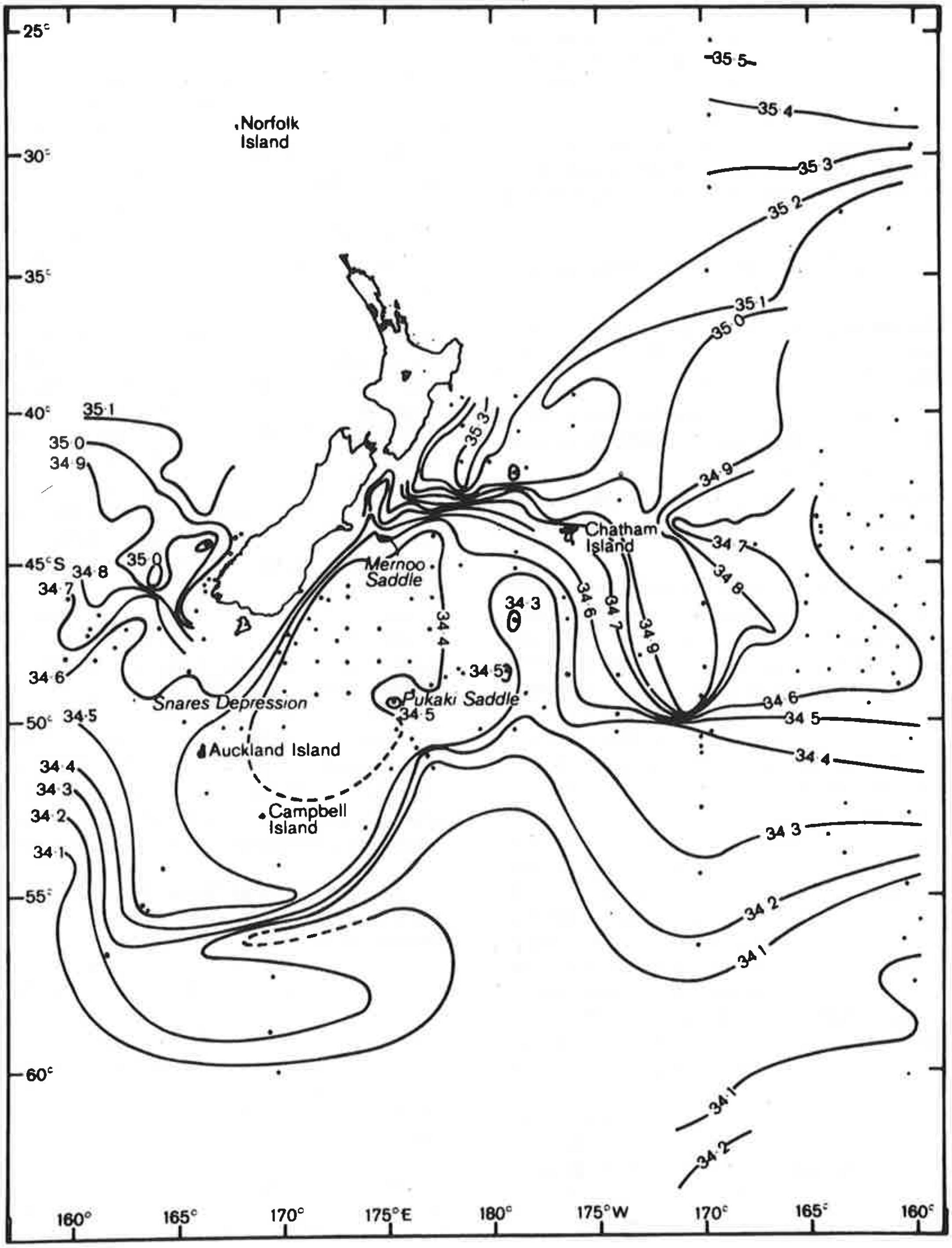

Fig. 5. Contours of the salinity (‰) at 200 m around southern New Zealand (after Heath 1981a, fig. 4).

sical advective transports. Current observations are not available, over the Chatham Rise, to allow direct definition of the diffusive and advective transports. Estimates have, therefore, been made by fitting the observations with simple diffusive-advective models (Heath 1976b). These models are based on a smoothed salinity-anomaly field (the anomaly defined by the difference between the observed T/S relationship and a specified linear relationship; this allows the salinity field associated with the Subtropical Convergence to be studied separately without having to consider the overall dynamics associated with a T/S relationship which changes with position). The meridional circulation emerging from the model study at the Subtropical Convergence over the Chatham Rise is shown in Fig. 8B. North of the Subtropical Convergence the nett flow in the mixed layer is towards the north at 1-2 cm s^{-1} (due largely to the direct wind transport) and the salinity balance is between horizontal diffusion towards the south and northwards advection. Immediately below the mixed layer the meridional flow is towards the south (at less than 0.5 cm s^{-1}). This meridional flow gives rise to an upwards flow at the Subtropical Convergence (with vertical speeds of the order of 10^{-3} those of the meridional flow). In the tongue of saline water extending southwards from the Subtropical Convergence the horizontal salinity-balance is between horizontal diffusion and weak northwards advection while the vertical scale in the tongue (200-400 m) is determined by the current shear in the horizontal flow and by vertical diffusion (Heath 1976b).

Antarctic Intermediate Water lies below the depth of the section of the Chatham Rise, located west of the Chatham Islands, the minimum salinity core being located at about 1000-1200 m depth north of the Rise and 700-900 m depth south of the Rise (Garner 1967; Heath 1972a). The Antarctic Intermediate Water north of the Rise in the head of the Hikurangi Trough is partially replenished by low-salinity water upwelling through the Mernoo Saddle. East of the Chatham Islands the increasing depth of the Chatham Rise does not present a direct obstacle to Antarctic Intermediate Water although the flow is constrained by the bottom topography.

Pacific Deep Water, which is located below the Antarctic Intermediate Water and has its core at about 4000 m depth, flows northwards on the western side of the Pacific Ocean as a deep western boundary current. At these depths the south-western margin of the Pacific Ocean is formed by the Subantarctic Slope, located south-east of New Zealand, and the Kermadec-Tonga Trench system located north-east of New Zealand. Sections of temperature and salinity extending north-eastwards from the Chatham Rise, collected from *Eltanin* in September 1969, indicate that the passage of the Pacific Deep Water across the Chatham Rise is intensified in the Broughton Gap (Fig. 1).

Nutrients

Near-surface nutrients exhibit rapid changes in concentrations across the Subtropical Convergence. For example, in summer, reactive phosphorus at the surface increases from 0.2 to 0.5 μg at ℓ^{-1} from north to south across the Chatham Rise (Bradford and Roberts 1978). These nutrients also highlight areas of upwelling in the Mernoo Saddle and over the Mernoo Bank (on the Chatham Rise adjacent to the Mernoo Saddle) by exhibiting greater concentrations than those in the surrounding water.

Climatic Influence of the Subtropical Convergence

The presence of the Subtropical Convergence, and its associated temperature contrast, influences the local meteorological conditions by frequently inducing low cloud formation as the air is cooled by the sea (Heath 1973a) and has been shown to be a preferred site for atmospheric vortex development (NOAA 1979, fig. 3.1).

TIDES

Predominant amongst the tidal constituents near the Chatham Rise is the principal lunar semi-diurnal constituent (M_2) with a period of 12.42 hours. At the Chatham Islands the amplitude of this constituent is 0.29 m compared to 0.08 m for the next largest fundamental constituent, N_2. At Lyttelton, near the western end of the Chatham Rise, the amplitudes are 0.88 and 0.20 m respectively. The tides are unusual in that the constituent which has the next-to-largest forcing potential, the principal solar semi-diurnal constituent (S_2), is very small (0.01 m and 0.05 m at the Chatham Islands and Lyttelton respectively). This is a consequence of the nature of the overall New Zealand tide.

The New Zealand tidal regime is notable in that the semi-diurnal tidal constituents exhibit the full 0-360° range of phases - this means there is always a high tide occurring somewhere on the New Zealand coast. This phase distribution is a consequence of the nature of the tidal wave on the coast. The tide exists primarily as a trapped progressive wave (mainly the fundamental parabolic shelf Kelvin Wave (Bye and Heath 1975)). The amplitude of this wave decreases away from the coast and, as a result, the M_2 tide at the Chatham Islands has an amplitude only 33% of that on the coast at Lyttelton. In contrast to the M_2 tide, the S_2 tide on the west coast of New Zealand has a standing-wave component which is larger than the progressive-wave component. (Differences in amount of standing- to progressive-wave energies on the west coast are a consequence of differences in the relative strengths of the tidal energy incident on New Zealand from different directions. Energy from the north-east of New Zealand

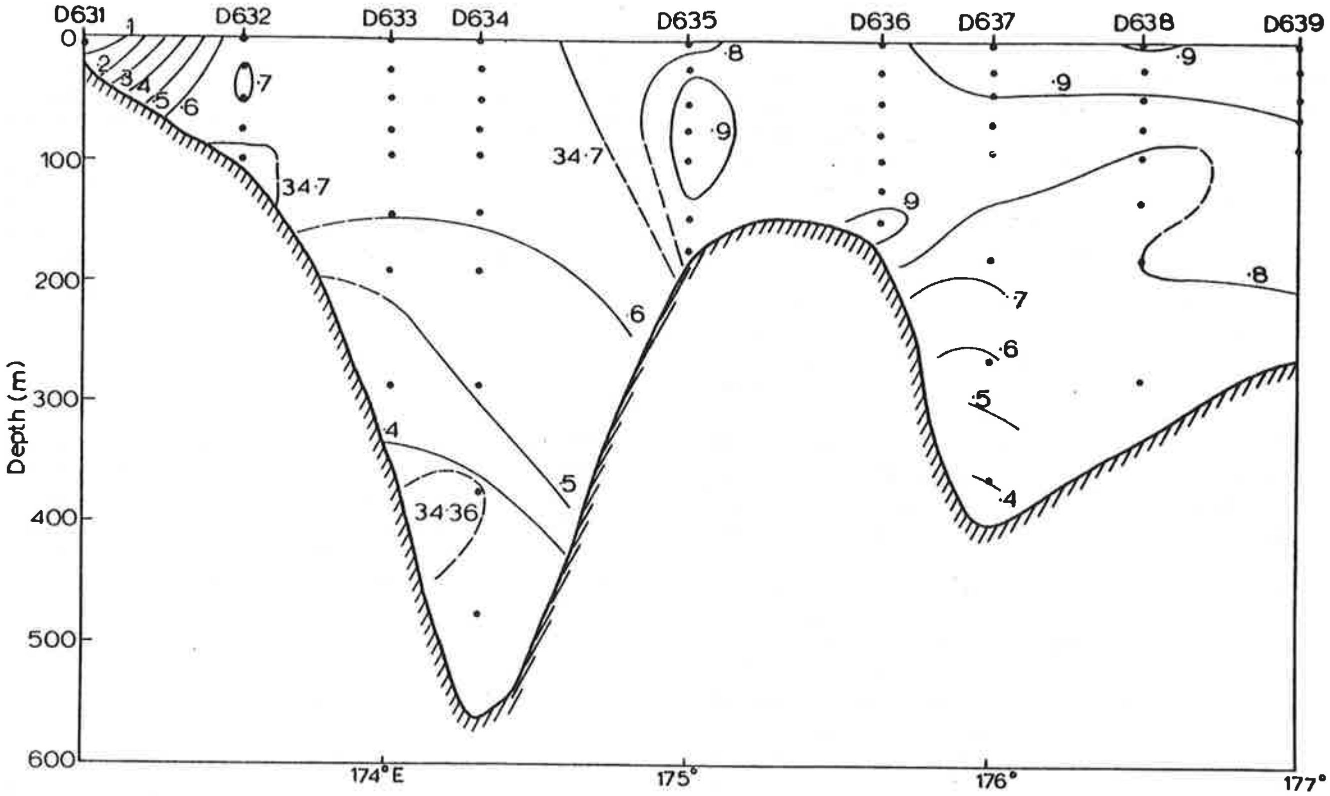

Fig. 6. Zonal profile of salinity extending from the east coast of South Island, New Zealand, at latitude 43°30'S in September–October 1967 (after Heath 1972b, fig. 7, from the N.Z. Journal of Marine and Freshwater Research). The position of the line of stations is shown in Fig. 1 (line A).

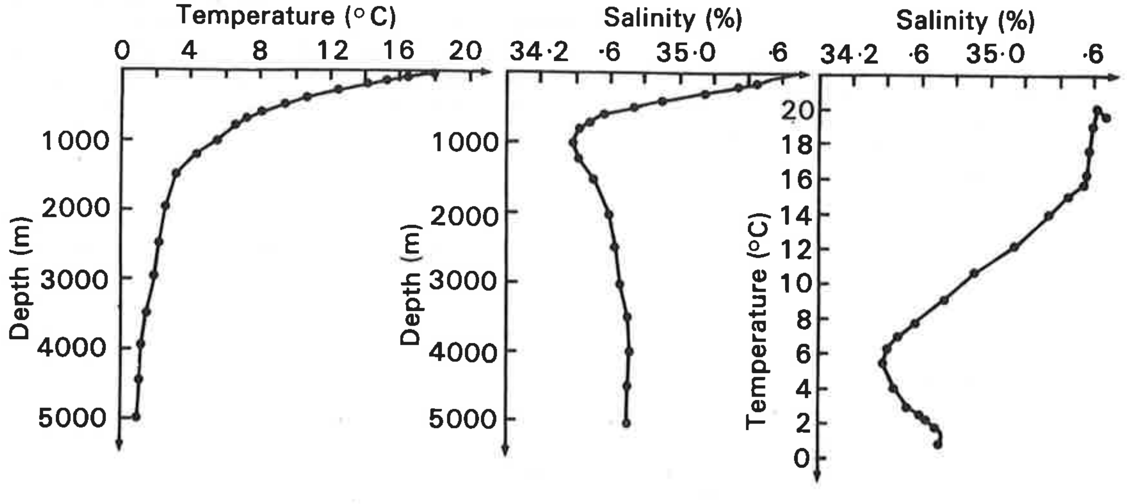

Fig. 7. Plots of temperature (°C) and salinity (‰) against depth (m), and salinity against temperature, from a standard hydrological station occupied by the Danish Oceanographic Vessel *Dana* in December 1928 north-east of New Zealand positioned at latitude 31°35'S, longitude 176°25'W (after Heath 1973c, fig. 1).

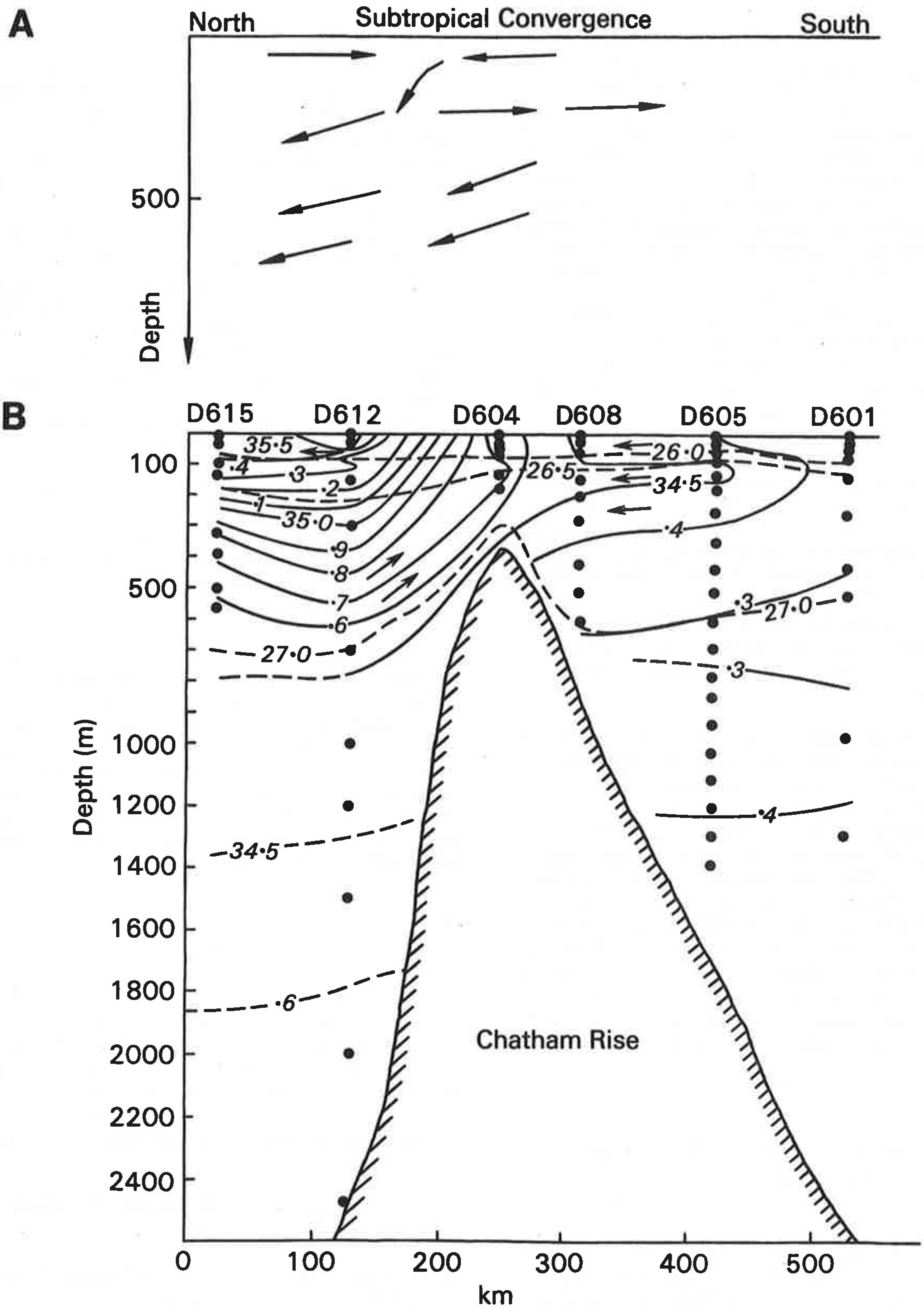

Fig. 8A. Schematic representation of the classical open-ocean meridional circulation near the Subtropical Convergence (after Gordon 1967, fig. 3). (Contours are of salinity (‰)).

8B. Schematic representation of the meridional circulation near the Subtropical Convergence over the Chatham Rise as deduced from simple diffusive-advective model studies (Heath 1976b). Contours are of salinity at longitude 177°40'E (after Heath 1976b, fig. 2). The position of the line of stations is shown in Fig. 1 (line B).

gives rise to trapped progressive-wave components which move anti-clockwise around the coast, whereas incident tidal energy from the north-west gives rise to standing-wave components on the west coast. The difference in the incident directions results initially from spatial differences in the tidal distribution of the semi-diurnal constituents in the Pacific Ocean north of New Zealand (Heath 1981b, c)). Only the trapped progressive-tidal-wave energy manages to travel around southern New Zealand and on to the east coast. Wave energy incident from the north-west, which gives rise to the standing wave on the west coast, travels across the Campbell Plateau but is not transmitted on to the east coast (Heath 1981c). The Chatham Rise is in the shadow of New Zealand with respect to tidal energy incident from the north-west and consequently has small S_2-tidal amplitudes.

Contours of equal phase of the semi-diurnal tide lie approximately parallel to the Rise and therefore will not be appreciably refracted. Tidal flow amplitudes are larger (0.44 m s^{-1}) in the Mernoo Saddle (Heath 1973a) at the western end of the Chatham Rise than on the adjacent continental shelf, or on the Chatham Rise itself (0.13 m s^{-1} at 44°S, 178°E, Fig. 1; Heath 1976a), indicating that the tidal flow is to some extent diverted through the Saddle. The same type of effect could be expected at the eastern end of the Chatham Rise.

Contours of the observed phase of the two largest diurnal tidal constituents, the lunar declinational constituents K_1 and O_1, exhibit amphidromes* immediately north of the Chatham Rise (Heath 1977). Current observations presently being analysed by the author, from the Campbell Plateau 750 km south of the Chatham Rise, show that there are stronger diurnal than semi-diurnal tidal-flow signals. These can be attributed to either tidal excitation of a continental shelf wave or to the proximity of the diurnal amphidrome. A similar situation of relatively large diurnal tidal flow on the Chatham Rise might therefore not be unexpected. (Current measurements on the Chatham Rise would allow further elaboration of the alternative explanation.)

INFLUENCE OF THE CHATHAM RISE ON LONG WAVES

A recent analysis of sea-surface oscillations on the east coast of New Zealand indicates that the Chatham Rise may play a role in trapping long waves. In several east coast New Zealand harbours sea-surface oscillations are sometimes observed with periods of about 2.5 hours. These oscillations have been regarded as a response to edge waves on the continental shelf and slope generated by atmospheric forcing and occasionally by tsunamis (Heath 1976c, 1979a). Numerical calculation of the modal structure of edge waves on the New Zealand east coast continental shelf and slope and on the Chatham Rise indicate that the observed 2.5-hour oscillation could be produced by a three-quarter wavelength standing edge wave along the Chatham Rise, which acts as an aerial. This suggestion is consistent with the observation that the largest 2.5-hour oscillational response is observed at Lyttelton, for Lyttelton is situated at the antinode (the 2.5-hour period is also close to Lyttelton's Helmholtz mode response of about 2.2 hours). Further, the selective harbour response of 2.5 hours to the 1960 Chilean tsunami rather than the quarter-wavelength harbour resonance of 1.6 hours, as recorded in response to the 1964 Alaskan tsunami, agrees with stronger generation of an edge wave by the Chilean tsunami, which would travel more nearly parallel to the Chatham Rise than would the Alaskan tsunami. (Heath in press).

Observations to test this suggestion would consist of bottom tide-gauge records from on the Chatham Rise – the current speeds associated with these edge waves correspond generally with standard current-meter resolutional ability. Indeed, it seems highly likely that direct current and sea-surface elevational observations would provide very interesting records which would allow study of the theoretically possible trapped long waves, specifically for energy incident from the south (Heath 1979b).

SUMMARY

The Chatham Rise, extending some 1450 km approximately perpendicular to the New Zealand coast, is a unique feature. On *a priori* grounds it is likely to present many interesting environmental consequences. Research to date has revealed several of these. In terms of the physical oceanography they are briefly :

1. Its strong control in guiding the mean oceanic flow eastwards.

2. Its association with the Subtropical Convergence which is remarkable in its lack of latitudinal change according to season. (This fixed positioning of the convergence over the Chatham Rise has interesting biological, geological, and climatic implications.)

3. Upwelling of water through the Mernoo Saddle and the northwards flow of Pacific Deep Water through

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* A region where the amplitude of the tidal constituent is small, around which the phase changes through the complete range of 0–360°.

the Broughton Gap and around the eastern end of the Chatham Rise.

4. Its influence on long-wave propagation both at tidal and other frequencies and, in particular, the possibility of edge-wave entrapment.

Obviously, recent observations have provided more questions than answers. Such is the strong topographic control of the Chatham Rise that the mean circulation, temperature and salinity fields that have been presented are probably fair representations of reality. What is needed now in terms of the physical oceanography is concentrated research into the temporal variability around this mean.

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REFERENCES

BARKER, P.H.; KIBBLEWHITE, A.C. 1965: Physical oceanographic data from the *Tui* cruise, 1962. *N.Z. Jl Sci. 8(4)* : 604–34.

BOWMAN, M.J. 1979: Late winter oceanographic conditions of the shelf seas of central New Zealand. The University of Auckland Maui Development Environmental Study Phase II Report 79–6. 24 p.

BRADFORD, J.M. 1972: Systematics and ecology of New Zealand central east coast plankton sampled at Kaikoura. *Mem. N.Z. oceanogr. Inst. 54.* 87 p.

BRADFORD, J.M.; ROBERTS, P.E. 1978: Distribution of reactive phosphorus and plankton in relation to upwelling and surface circulation around New Zealand. *N.Z. Jl mar. Freshwat. Res. 12(1)* : 1–15.

BRADFORD, J.M.; HEATH, R.A.; CHANG, F.H.; HAY, C.H. (in press): The effect of warm-core eddies on oceanic productivity off north-eastern New Zealand. *Deep Sea Res.*

BRODIE, J.W. 1960: Coastal surface currents around New Zealand. *N.Z. Jl Geol. Geophys. 3(2)* : 235–52.

BYE, J.A.T.; HEATH, R.A. 1975: The New Zealand semi-diurnal tide. *J. mar. Res. 33(3)* : 423–42.

BYE, J.A.T.; HEATH, R.A.; SAG, T.W. 1979: A numerical model of the oceanic circulation around New Zealand. *J. phys. Oceanogr. 9(5)* : 892–99.

CARTER, L. 1980: New Zealand Region Bathymetry (2nd edition) 1:6,000,000. *N.Z. oceanogr. Inst. Chart, Misc. Ser. 15.*

CULLEN, D.J. 1969: Chatham Bathymetry. *N.Z. oceanogr. Inst. Chart, Oceanic Ser. 1:1,000,000.*

DEACON, G.E.R. 1937: Hydrology of the Southern Ocean. *'Discovery' Rep. 15* : 1–126.

DEACON, G.E.R. 1945: Water circulation and surface boundaries in the ocean. *Q. Jl R. met. Soc. 71* : 11–25.

FLEMING, C.A. 1950: Some South Pacific sea-bird logs. *The Emu 49(3)* : 169–88.

GARNER, D.M. 1953: Physical characteristics of inshore surface waters between Cook Strait and Banks Peninsula, New Zealand. *N.Z. Jl Sci. Technol. Sect. B 35(3)* : 239–46.

GARNER, D.M. 1954: Sea surface temperature in the south-west Pacific Ocean, from 1949 to 1952. *N.Z. Jl Sci. Technol. Sect. B 36(3)* : 285–303.

GARNER, D.M. 1955: Some hydrological features of the tropical south-west Pacific Ocean. *N.Z. Jl Sci. Technol. Sect. B 37(1)* : 39–46.

GARNER, D.M. 1957: Hydrology of Chatham Rise. Pp 18–27 *in* Knox, G.A. "General Account of the Chatham Islands 1954 Expedition". *Mem. N.Z. oceanogr. Inst. 2.* (*Bull. N.Z. Dep. scient. ind. Res. 122.*). 37 p.

GARNER, D.M. 1959: The Subtropical Convergence in New Zealand surface waters. *N.Z. Jl Geol. Geophys. 2(2)* : 315–37.

GARNER, D.M. 1961: Hydrology of New Zealand coastal waters, 1955. *Mem. N.Z. oceanogr. Inst. 8.* (*Bull. N.Z. Dep. scient. ind. Res. 138.*). 85 p.

GARNER, D.M. 1962: Analysis of hydrological observations in the New Zealand region, 1874–1955. *Mem. N.Z. oceanogr. Inst. 9.* (*Bull. N.Z. Dep. scient. ind. Res. 144.*). 45 p.

GARNER, D.M. 1967: Hydrology of the southern Hikurangi Trench region. *Mem. N.Z. oceanogr. Inst. 39.* (*Bull. N.Z. Dep. scient. ind. Res. 177.*). 33 p.

GARNER, D.M. 1969: The geopotential topography of the ocean surface around New Zealand. *N.Z. Jl mar. Freshwat. Res. 3(2)* : 309–19.

GARNER, D.M.; RIDGWAY, N.M. 1965: Hydrology of New Zealand offshore waters. *Mem. N.Z. oceanogr. Inst. 12.* (*Bull. N.Z. Dep. scient. ind. Res. 162.*). 62 p.

GILMOUR, A.E.; COLE, A.G. 1979: The Subtropical Convergence east of New Zealand. *N.Z. Jl mar. Freshwat. Res. 13(4)* : 553–57.

GORDON, A.L. 1967: Structure of Antarctic Waters between 20°W and 170°W. *Antarctic Map Folio Ser. 6* : 10 p., 14 pls.

HEATH, R.A. 1968: Geostrophic currents derived from oceanic density measurements north and south of the Subtropical Convergence east of New Zealand. *N.Z. Jl mar. Freshwat. Res. 2(4)* : 659–77.

HEATH, R.A. 1969: Drift card observations of currents in the central New Zealand region. *N.Z. Jl mar. Freshwat. Res. 3(1)* : 3–12.

HEATH, R.A. 1970: An occurrence of low water temperatures on the north Canterbury coast. *N.Z. Jl mar. Freshwat. Res. 4(2)* : 223–26.

HEATH, R.A. 1971: Hydrology and circulation in central and southern Cook Strait, New Zealand. *N.Z. Jl mar. Freshwat. Res. 5(1)* : 178–99.

HEATH, R.A. 1972a: Choice of reference surface for geostrophic currents around New Zealand. *N.Z. Jl mar. Freshwat. Res. 6(1 & 2)* : 148–77.

HEATH, R.A. 1972b: The Southland Current. *N.Z. Jl mar. Freshwat. Res. 6(4)* : 497–533.

HEATH, R.A. 1973a: Low cloud boundaries coincident with oceanic convergences. *N.Z. Jl mar. Freshwat. Res. 7(3)* : 209–16.

HEATH, R.A. 1973b: Direct measurements of coastal currents around southern New Zealand. *N.Z. Jl mar. Freshwat. Res. 7(4)* : 331–67.

HEATH, R.A. 1973c: Present knowledge of the oceanic circulation and hydrology around New Zealand – 1971. *Tuatara 20(3)* : 125–40.

HEATH, R.A. 1975a: Oceanic circulation off the east coast of New Zealand. *Mem. N.Z. oceanogr. Inst. 55* : 80 p.

HEATH, R.A. 1975b: Oceanic circulation and hydrology off the southern half of South Island, New Zealand. *Mem. N.Z. oceanogr. Inst. 72* : 36 p.

HEATH, R.A. 1976a: Oceanic circulation in the head of the Hikurangi Trench, east coast, New Zealand. *N.Z. Jl mar. Freshwat. Res. 10(4)* : 651–74.

HEATH, R.A. 1976b: Models of the diffusive-advective balance at the Subtropical Convergence. *Deep Sea Res. 23* : 1153–64.

HEATH, R.A. 1976c: The response of several New Zealand harbours to the 1960 Chilean tsunami. *In* "Tsunami Research Symposium 1974". *Bull. R. Soc. N.Z. 15* : 71–82.

HEATH, R.A. 1977: Phase distribution of tidal constituents around New Zealand. *N.Z. Jl mar. Freshwat. Res. 11(2)* : 383–92.

HEATH, R.A. 1979a: Edge waves on the New Zealand east coast. *Mar. Geod. 2(4)* : 337–50.

HEATH, R.A. 1979b: Transmission of tidal energy over a plateau. *Dt. hydrogr. Z. 32(6)* : 289–96.

HEATH, R.A. 1980: Descriptive oceanography in the south-western Pacific. *In* "Proceedings of the Fourth CSK Symposium, Tokyo, 1979" : 290–96.

HEATH, R.A. 1981a: Oceanic fronts around southern New Zealand. *Deep Sea Res. 28A(6)* : 547–60.

HEATH, R.A. 1981b: Estimates of the resonant period and Q in the semi-diurnal tidal band in the north Atlantic and Pacific Oceans. *Deep Sea Res. 28A(5)* : 481–93.

HEATH, R.A. 1981c: Variations of the semi-diurnal tidal admittance near New Zealand. *Deep Sea Res. 28A(8)* : 847–58.

HEATH, R.A. (in press): Generation of 2- to 3-hour oscillations on the east coast of South Island, New Zealand. *N.Z. Jl mar. Freshwat. Res.*

HOUTMAN, Th.J. 1965: Winter hydrological conditions of coastal waters south of Kaikoura Peninsula. *N.Z. Jl Geol. Geophys. 8(5)* : 807–19.

JILLETT, J.B. 1969: Seasonal hydrology of waters off the Otago Peninsula, southeastern New Zealand. *N.Z. Jl mar. Freshwat. Res. 3* : 349–75.

McCARTNEY, M.S. 1977: Subantarctic Mode Water. *In* "A Voyage of Discovery". *Deep Sea Res. 24* (*suppl.*) : 103–19.

NOAA, 1979: Ocean heat transport and storage – a program plan for investigating the ocean's role in climate variability. U.S. Department of Commerce, National Oceanic and Atmospheric Administration Environmental Research Laboratories. 47 p.

RIDGWAY, N.M. 1970: Aerial radiometry of sea surface temperatures on the east coast, North Island, New Zealand. *N.Z. Jl mar. Freshwat. Res. 4(4)* : 474-78.

RIDGWAY, N.M. 1975: Hydrology of the Bounty Islands region. *Mem. N.Z. oceanogr. Inst. 75* : 27 p.

SDUBBUNDHIT CHA ERB; GILMOUR, A.E. 1964: Geostrophic currents derived from oceanic density over the Hikurangi Trench. *N.Z. Jl Geol. Geophys. 7(2)* : 271-78.

WANOA, R.J.; LEWIS, K.B. 1972: Gazetteer of sea-floor features in the New Zealand region. *NZOI Rec. 1(5)* : 67-106.

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