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ROBERT M. NORRIS

New Zealand Oceanographic Institute
Memoir No. 26.

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FOREWORD

THE Chatham Rise, extending from Banks Peninsula to the Chatham Islands, is one of a number of large ocean highs that form the New Zealand Plateau.

There has been an increasing geological interest in the Chatham Rise area in the last decade: not only are aspects of its morphology unique in the New Zealand area but it forms a still enigmatic link between the continental rocks of the South Island and the similar rocks of Chatham Islands.

The surface sediment samples that have accrued in the course of recent sampling operations, together with others available from the Chatham Islands 1954 Expedition, have supplemented those especially obtained for the present study.

Preliminary editing has been carried out by Mrs P. M. Cullen. The material has been finally edited for publication by Miss G. L. Smith, Information Service, D.S.I.R.

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

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1. (In pocket) Bathymetric chart of the Chatham Rise showing locations of stations and concentration of calcareous materials (brown shades) and glauconite concentration (dark-green contours) in the sediments.

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SEDIMENTS OF CHATHAM RISE

by

ROBERT M. NORRIS*

Fulbright Research Scholar,
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ABSTRACT

The Chatham Rise is a broad, elongate submarine ridge extending about 500 miles east of South Island, New Zealand. It includes three banks, two of which may have been Pleistocene islands.

Little is known of the structure or bedrock composition of the Rise except at the Chatham Islands near its eastern extremity where schists similar to those of Otago occur and are overlain by Cretaceous to Oligocene and Pleistocene to Recent sedimentary and volcanic rocks. Mernoo Bank near the western end of the Rise is probably developed on Permo-Jurassic greywacke. Greywacke, plutonic igneous rocks and fine-grained sedimentary rocks occur as scattered ice and tree-rafted erratics on all parts of the Rise.

Sediments of the Rise include shell gravels on Mernoo and Veryan Banks and concentrated greensands on Reserve Bank. Foraminiferal oozes cover most of the rest of the area shallower than about 500 m, and silty and clayey sediments, including abundant faecal pellets, blanket the deeper slopes into the adjacent basins. Sediments near the Chatham Islands and Banks Peninsula are mostly land-derived and differ mineralogically from the balance of Rise sediment.

Volcanic glass, believed derived from the Taupo rhyolitic eruptions of North Island on the basis of the associated suite of minerals, is widely disseminated throughout the sediments, being present even in depth as shown by ash horizons in the cores. Most of this glass was wind transported from its source.

Glauconite comprises up to about 80 per cent of some samples and occurs mainly as discrete sand-size grains. It is believed to be forming at the present time in sheltered, slightly reducing environments where illite clays occur and iron compounds are made available by bacterial destruction of organic colloids. Similarity of recent glauconitic sediments on Chatham Rise and Tertiary calcareous greensands of New Zealand provides a strong basis for reconstructing the Tertiary paleogeography of parts of New Zealand.

Phosphatised Miocene foraminiferal oozes in nodular form are widely distributed on the surface of the Rise suggesting a continuously marine environment since Miocene time at least, in which organic carbonates have been dissolved about as fast as they were deposited.

Sediments, rocks exposed in the Chatham Islands, and what is known of the bedrock structure of the Rise suggest a schist undermass outlined structurally about the beginning of the Tertiary and persisting in more or less the same form to the present time with occasional volcanic activity at the eastern and western ends.

Phosphate nodules, glauconite, and the calcareous organic components of the sediment may be of future economic value to New Zealand as a substitute for phosphates and potash presently imported to maintain the fertility of grazing lands.

INTRODUCTION AND PREVIOUS STUDIES

The Chatham Rise is a broad submarine ridge about 500 miles long, extending eastward from Banks Peninsula on the east coast of the South Island, New Zealand, to a short distance beyond the Chatham Islands (chart 1). The portion of the Rise shoaler than 1000 m covers an area of approximately 60,000 square miles, roughly equal to the land area of the South Island. Below the 1000-m isobath, the sea floor descends rather abruptly into Hikurangi Trench to the north and more gradually and less evenly into the Bounty Trough to the south (fig. 1).

The sediments studied for the present report are from the collections of the New Zealand Oceanographic Institute, and include samples taken during several different oceanographic cruises. A few of the earlier samples were collected during the course of other marine work, but the bulk of the material studied was obtained specifically for the present investigation and includes a line of cores taken during a cruise on MV *Viti* together with a series of dredges and some additional cores taken by the author from MV *Taranui*. A total of 11 cores and 52 dredge and grab samples have been examined. Although this comprises by far the most extensive and detailed picture of Chatham Rise sediments thus far assembled, the density of sampling is still very low, averaging only about one station for

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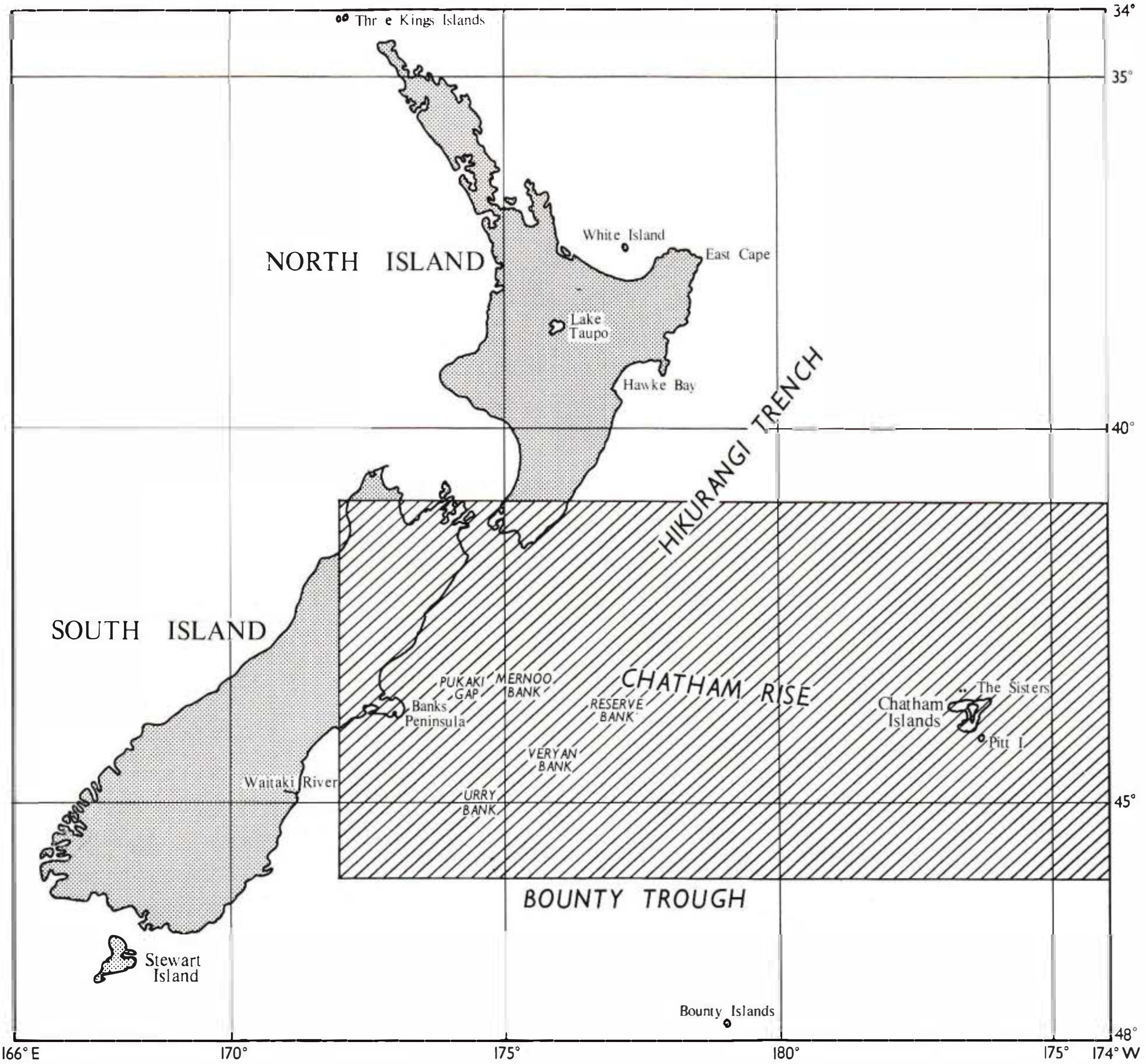

Fig. 1: Locality chart.

1000 square miles. Moreover, the stations are unevenly distributed, so it is clear that this report can present only a picture painted in broadest outlines. Detailed sediment distribution maps must await additional sampling.

Very little published material is available concerning the Chatham Rise, although a number of papers have dealt with the Chatham Islands at the eastern end of the Rise and several with Banks Peninsula at the western end. Reed and Hornibrook (1952) published an excellent detailed study of a single cone dredge sample obtained by RRS *Discovery II* in 1950; this station is numbered Z 269 in this report and its location is shown on chart 1. Fleming and Reed (1951) investigated the topography and sediments of Mernoo Bank near the western end of the Rise. Knox (1957) has considered briefly the nature of the Chatham Rise, particularly the portion near the Chatham Islands. Cullen (1962) has reported a glacial erratic pebble from the area and D. J. Cullen and H. M. Pantin (in preparation) dealt with the petrography of rock samples dredged from various parts of the Chatham Rise.

TOPOGRAPHY AND STRUCTURE

TOPOGRAPHY

On the basis of present information, the Chatham Rise may be divided into three topographic units. The easternmost of these includes the Chatham Island group, the only land area on the Rise. To the west of the 250-m isobath surrounding the islands lies the second unit, the central portion. This section has a generally undulating, more or less featureless crest about 50 miles wide between the limiting 500-m isobaths, with probably no more than 100 m of relief. The western portion, beginning at about 177° 30′ E and extending to the Pukaki Gap off Banks Peninsula, includes three banks.

Mernoo Bank is the largest and shoalest of these features and minimum depths are as little as 51 m in two places (Fleming and Reed, 1951, p. 19). These authors report valley-like channels, ridges standing above the general level of the Bank, and the cliff-like nature of the south-eastern margin, all of which are taken to be indicative of a period of subaerial erosion. Such a suggestion seems probable in view of the depths involved as well as because of evidence of recent submergence of subaerial features on Banks Peninsula (Speight, 1943). This is consistent with the generally held view that sea level stood about 100 m below present sea level during the final Pleistocene glacial advance about 17,000–35,000 years ago (Fairbridge, 1961).

Veryan Bank, first charted by the HMS *Veryan Bay* in 1950, rises to within about 145 m of the sea surface from a prominent narrow-necked topographic salient extending southward from the Chatham Rise just to the east of the 176° E meridian.

The third bank in the western portion of the Rise is Reserve Bank, a more or less circular feature of low relief lying just east of the 177° E meridian. The minimum depth of Reserve Bank so far charted is 230 m. This bank was first noted in 1962 by D. C. Krause and A. G. York, New Zealand Oceanographic Institute, in the course of preparing the forthcoming edition of the Bounty 1 : 1,000,000 bathymetric sheet.*

The Chatham Rise is bounded on the west by Pukaki Gap, a broad saddle with sill depth of about 572 m, separating the Rise proper from the bulge in the South Island shelf off Banks Peninsula. The Pukaki Gap is dissected on the north by branches of the Pegasus Canyon which leads downward into the southern end of the Hikurangi Trench.

Urry Bank, named for W. D. Urry, who first reported it in 1949 and referred to it as 64-fathom Bank (Urry, 1949), is shown on the most recent published edition of the South Island bathymetric chart, but subsequent attempts to revisit the bank have been unsuccessful. It seems probable that if the bank exists at all, it is pinnacle-like and of very small area. Its reported location is indicated on chart 1.

STRUCTURE

The convex upper surface of the Chatham Rise as well as the gently sloping flanks suggest a broad anticlinal structure, as does the undulating surface along the length of the Rise. However, no direct information is available on bedrock attitude from any part of the Rise except at the Chatham Islands The northern portion of Chatham Island is composed of complexly folded schists with a steep dip and an east–west strike, whereas the remainder of the island consists of gently dipping beds of Paleocene and younger age. Middle Cretaceous (Albian to Turonian) sedimentary rocks occur at Waihere Bay, Pitt Island, and Boreham (1959) has described macrofossils of Middle Cretaceous age, probably not younger than Cenomanian, from the tuff on the east side of Pitt Island. There is an unsubstantiated report of early Mesozoic(?) greywacke from The Sisters. The steeply inclined schists are judged to be Paleozoic by most investigators and have evidently undergone considerable pre-Rise diastrophism, for their structure is not clearly related to the present form of the Chatham Rise. Chatham Rise thus appears to be post-Paleozoic and is probably post-Mesozoic; low dips in the Cretaceous and Tertiary deposits of the Chatham Islands are consistent with a Tertiary or Quaternary origin for the structure. In such a case, dips across the crest of an anticlinal arch could easily be low and the Chatham Islands lie in such a structural position. Even the North Chatham Slope facing the Hikurangi Trench, the steepest slope associated with the Chatham Rise, is inclined only at about 250 ft to a mile, or $3\frac{1}{2}$ degrees.

On the other hand, the lithology of the Tertiary and Quaternary sedimentary materials exposed on the islands and found on the Rise make a middle Tertiary to Quaternary age improbable for the development of the Rise. Greensands, including a horizon with abundant phosphatic nodules of Paleocene age, occurring at Tioriori on Chatham Island (W. A. Watters, pers. comm.) suggest a depositional environment not very different from that prevailing today over much of the Chatham Rise. However, a second group of Eocene rocks in the Chatham Islands is Arnold in age (middle to upper Eocene) and includes loose bryozoan limestone and hard orbitoidal limestone associated in

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*Reserve Bank and other new names for features on the Chatham Rise – Pegasus Canyon, North Chatham Slope – are those proposed by Krause (in press).

many places with basic tuffs (W. A. Watters, pers. comm.). If all the Chatham Rise shoaler than 500 m were elevated above sea level, it would be found to be covered with unconsolidated and partly consolidated sediments approximately the equivalents of the Tertiary sedimentary rocks of the Chatham Islands. Cores show that limy greensands on the Rise are at least several feet thick, and the presence of phosphatised masses of Miocene foraminiferal ooze on the surface of Chatham Rise (Reed and Hornibrook, 1952, p. 186) indicates slow deposition and long-continued marine conditions. Sediments on the slopes of the Rise differ, being predominantly greenish-grey foraminiferal silts and silty clays, and unless they can be shown to overlie shallow water deposits of the type now accumulating on the crest of the Rise, it seems likely that they have been accumulating in place since at least early Miocene time. It is suggested, therefore, that the present structural form of the Chatham Rise dates back to early Tertiary time, and that aside from the minor uplift necessary to produce the Chatham Islands at the eastern end, little structural change has occurred since.

The crustal structure beneath the Chatham Rise is not yet known. However, the probability of a schist and greywacke undermass suggests that the block is continental in common with New Zealand to the west, despite the fact that the average relative height of the Chatham Rise block is much less than the South Island, a block of comparable size. Evison (1960) notes the present anomalous average elevation of the main islands of New Zealand compared to large continental structures elsewhere, and points out that, in equilibrium, a plastic body of the size of New Zealand would lie far below sea level. If Evison's views are correct, it seems an additional reason for supposing that the Chatham Rise block is now and has been in approximate crustal equilibrium since early Tertiary time.

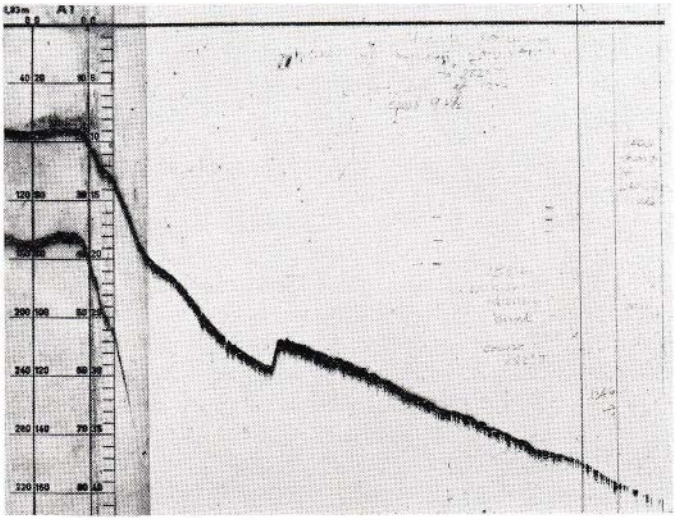

Fig. 2: Photograph of echogram showing fault scarp at western end of Chatham Rise: a record made on MV *Taranui.* Scale: 0–320 fathoms (0–585 m).

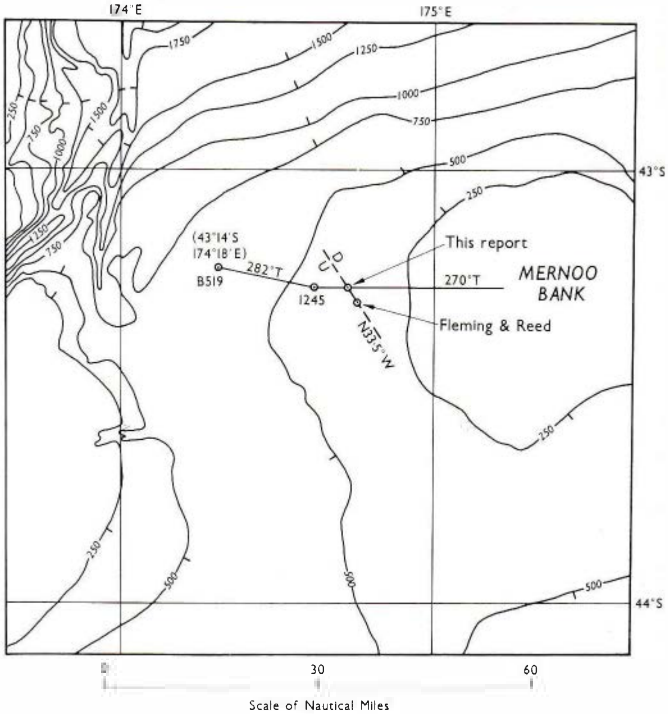

Fig. 3: Location of the two crossings of the fault scarp.

A small structural feature, presumably a fault scarp of recent date, has been described by Fleming and Reed (1951, p. 21) from the west side of Mernoo Bank. The gentle continuous westward slope from Mernoo Bank into Pukaki Gap is interrupted by an abrupt east-facing scarp about 37 m (120 ft) high. Fig. 2 shows a portion of an echo sounding trace made aboard the MV *Taranui* in February 1962 in which the same feature was crossed, but at a slightly different place. The *Taranui* record gives a height of 26 m (84 ft). Fig. 3 shows the relative positions of these two crossings, which yield an approximate strike of N 33° W. The plotted positions, however, which were determined by celestial navigation, cannot be said to be fixed more accurately than about ±2 miles, and since the positions are only 2½ miles apart, the strike direction could be in error as much as 90°! There is no doubt that the feature is real and the sharpness of the upper edge is indicative of very recent geologic origin. So far as is known, there is no record of seismic activity in the area with which a fault might be correlated. The seismological station in Wellington has, however, recorded several shallow focus earthquakes along the North Chatham Slope to the east (F. F. Evison, pers. comm.).

BEDROCK GEOLOGY

Virtually nothing is known of bedrock geology on the Chatham Rise except of course, at the Chatham Islands and from one probable exposure of greywacke at Mernoo Bank (Cullen and Pantin, unpublished work). The Mernoo Bank sample (C 595), obtained by orange peel grab consists of several freshly broken specimens of well indurated fine-grained grey sandstone, lithologically very similar to the late Paleozoic-early Mesozoic greywackes exposed on both the North and South Islands of New Zealand. The specimens give every indication of having been freshly detached during sampling and are associated with large quantities of subangular to rounded pebbles of similar lithology. The smaller pebbles could easily have been produced more or less *in situ* by beach erosion during one of the Pleistocene low sea levels when Mernoo Bank was an island.

It is possible that schists comprise the core of the Rise and are overlain by early Mesozoic greywackes, at least in the western part of the Rise, although the unconfirmed report of greywacke from the island known as The Sisters north of Chatham Island may indicate a more extensive greywacke cover, as does the presence of greywacke pebbles in the Middle Cretaceous conglomerate of Pitt Island (W. A. Watters, pers. comm.).

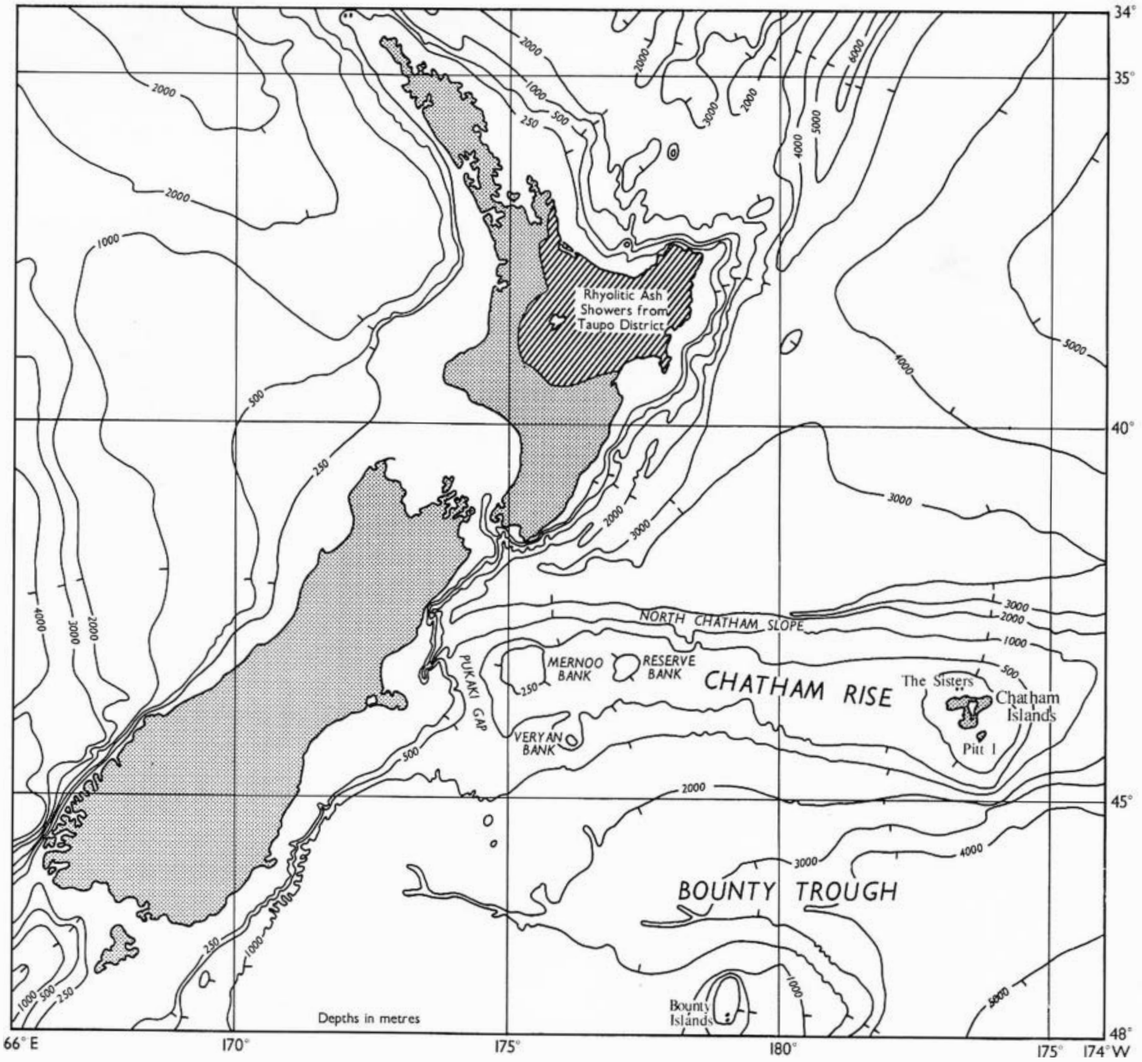

Fig. 4: Area covered by Taupo and related ash showers on bathymetric diagram of Chatham Rise.

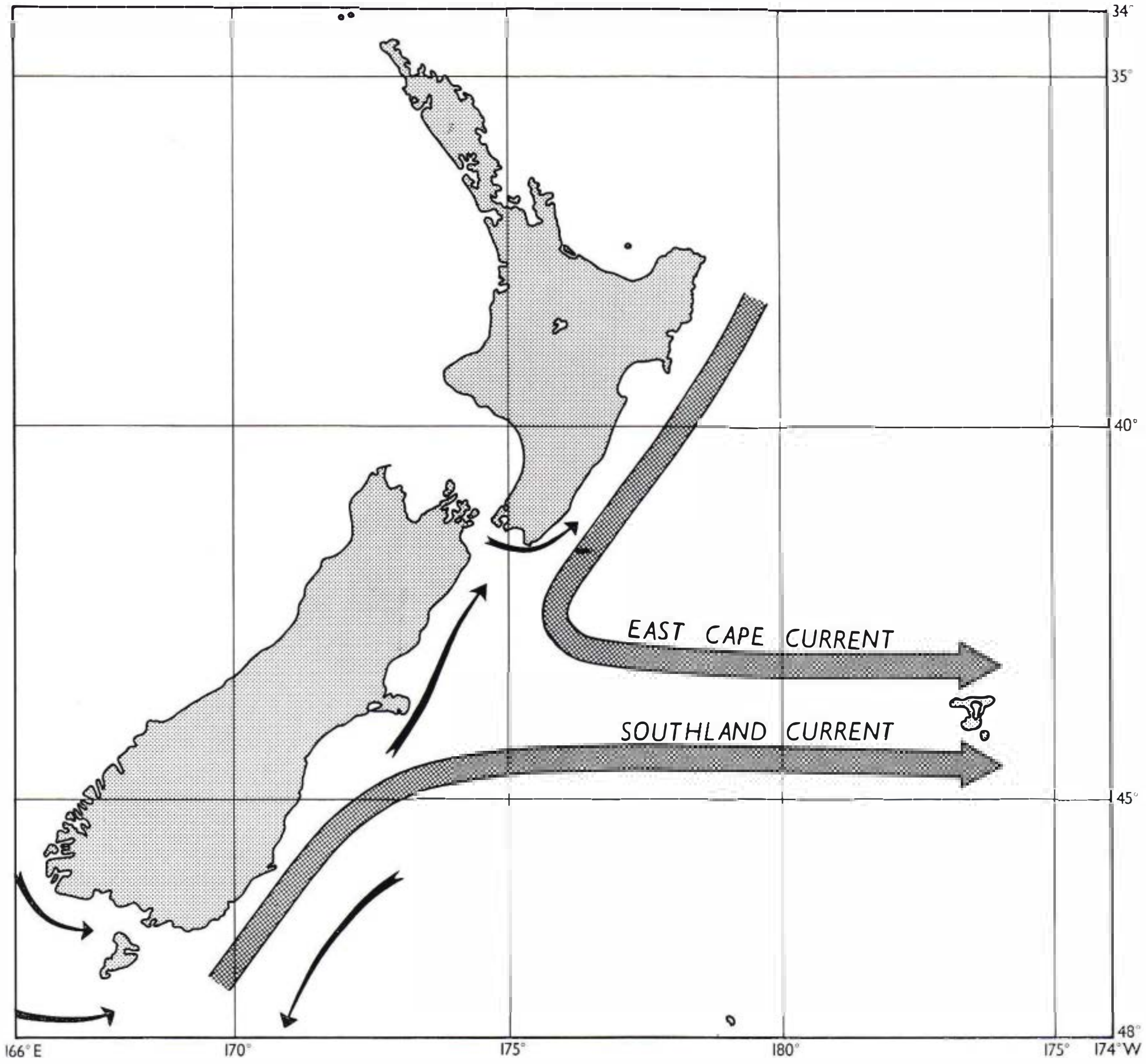

Fig. 5: East Cape and Southland currents.

Many of the dredge samples used in this study contained derived rock fragments ranging in size from pebbles down to large sand grains, these being accompanied by unconsolidated sediments, authigenic phosphorite nodules, or aggregated coralline bryozoans in various proportions. Most of the pebbles and large rock grains are greywacke, but there are a few examples of granite, granite gneiss, diorite gneiss, and, near the Chatham Islands, schist and vesicular volcanic rocks (andesite, limburgite, and basalt). Cullen (1962) has described a probable glacial erratic, a striated subangular pebble of fine-grained unfossiliferous red sandstone, lithologically unlike any rocks known from the main islands of New Zealand or the Chatham Islands. He points out that the Chatham Rise lies near the northern limit for drifting berg ice from the Antarctic and suggests that the pebble may have come from there. The granitic rocks and many of the greywacke pebbles may have been rafted by berg ice or by the roots of floating trees. Floods in some of the larger South Island rivers such as the Rakaia and Waimakariri could easily have transported large trees with a load of greywacke in their roots. Once delivered to the sea, north- and then east-flowing currents similar to those postulated by Burling (1961, chart 1), could have carried them over the Chatham Rise (fig. 4 and 5).

If these pebbles were not exotic, but were eroded from bedrock of the Chatham Rise, the associated finer grades of sediment should also include the characteristic mineral assemblages of the rocks in question. This is not the case, for, as will be shown, the mineral grains in the sediment are authigenic or largely derived from rhyolitic ash, except near Banks Peninsula and the Chatham Islands where local land sources are important.

THE SEDIMENTS

INTRODUCTION

Unconsolidated deposits and calcareous organic aggregates form a nearly complete blanket over the Chatham Rise. The main components of these sediments may be grouped into five categories. Firstly, there are rock fragments, which are believed to have been rafted in by ice or floating trees except near Banks Peninsula, Mernoo Bank, and the Chatham Islands. In the second category are the authigenic minerals including glauconite, phosphorite, and gypsum. Thirdly, there are the organically produced materials, mainly Foraminifera and shell fragments of molluscs, echinoderms, and bryozoa, but including also a small amount of coccolithophores and siliceous materials from diatoms, radiolaria, and sponges. The fourth category consists of faecal pellets and slime-cemented silty aggregates and trails. It is extremely difficult to estimate the amount of sediment represented in these last materials because silt and clay forming the aggregates tend to separate into their component grains during processing of the sample. The fifth category contains the monomineralic grains in the finer size grades. Most of the grains retained by the 0·066 mm sieve are derived from North Island volcanic sources except near land. Monomineralic grains are also abundant in the fraction passing through the 0·066 mm sieve, again mostly derived from North Island volcanic sources. The finest fractions doubtless include also air-borne materials from very distant sources plus a range of clay minerals.

Pie diagrams (fig. 6) illustrate the relative abundance of the various components of sand size and smaller at some selected stations on the Chatham Rise. It will be seen that glauconite, prominent in many samples, tends to be most

Fig. 7: Photograph of sediment from station B 515.

Fig. 8: Photograph of phosphorite nodules from station Z 1036.

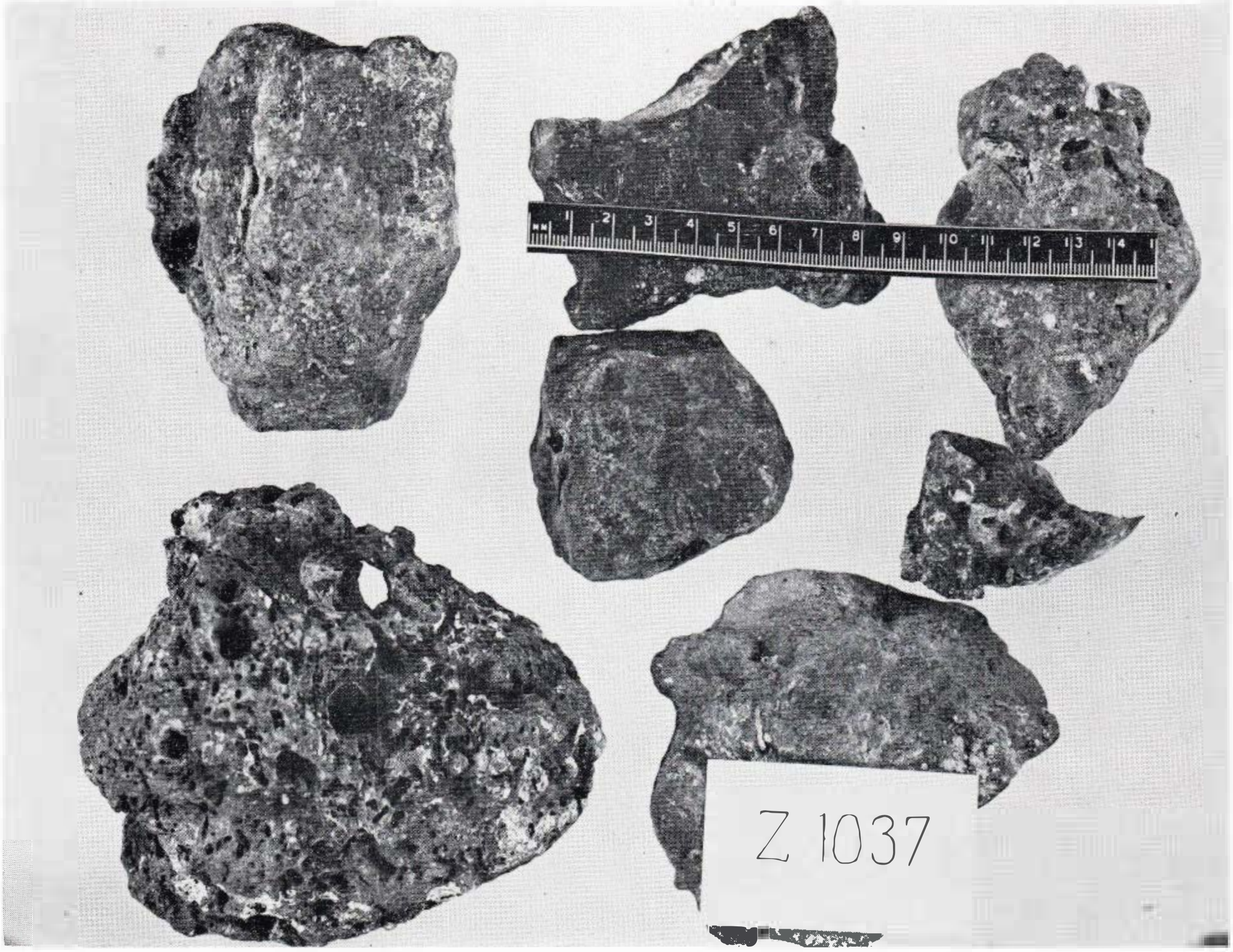

Fig. 9: Photograph of phosphorite nodules from station Z 1037.

abundant near the middle part of the Rise, whereas calcareous materials, almost entirely of organic origin, are most concentrated on Mernoo and Veryan Banks and east of the Chatham Islands. Their distribution patterns are shown by means of contours on chart 1. These and other sediment distribution patterns represent broad generalisations of the available data, but even with the sparse coverage now available, it is apparent that deposits near the Chatham Islands are variable and patchy, and include ordinary mineral grain sands, shell gravels, foraminiferal oozes, and glauconitic sediments.

The Mernoo and Veryan Banks are capped with very coarse shell gravels containing a considerable number of greywacke pebbles (fig. 7). If Urry Bank proves to be a real feature, it is probable that it, too, will be capped with this type of deposit. Reserve Bank, however, being deeper and of less prominent relief than Mernoo and Veryan Banks, is the locus of the most highly glauconitic deposits known from the Chatham Rise area.

Although few samples were obtained from the area, it is probable that Pukaki Gap is floored mostly with the same fine-grained greenish-grey silty mud prevalent on the North Chatham Slope and in the Hikurangi Trench.

Most of the balance of the Chatham Rise between depths of about 150–300 m and 500 m is blanketed by a prevailing sandy or silty sediment containing abundant Foraminifera, usually pelagic species, and locally abundant glauconite. The shell gravels which are so prominent on bank tops tend to give way to foraminiferal sediments below 150–300 m. Also present on the Rise are scattered concentrations of phosphorite nodules up to 10–15 cm across, and the derived rock fragments described in the previous section. Fig. 8 and 9 illustrate some of the phosphorite nodules from the Chatham Rise and a group of these at station Z 269 have been described in detail by Reed and Hornibrook (1952). A very large number of phosphorite nodules have been collected at stations C 602, C 605, C 607, C 608, Z 288, Z 1036, and Z 1037 (fig. 10). Abundant greywacke pebbles have been obtained from C 601 on Veryan Bank and C 595 on Mernoo Bank. Rock fragments and phosphorite nodules probably are even more abundant on the Rise than present sampling would indicate because many of the samples were collected with gear incapable of obtaining large rocks.

The sand fractions of the Chatham Rise samples were broken down by sieving into the various subdivisions making up the sand grade (fig. 6), but the fine fractions (less than 0·066 mm in diameter) from Chatham Rise samples were not further analysed for size distribution, although microscopic inspection suggests that most of the material in the fine fractions was of silt size (more than about 0·004 mm). The relatively low amount of clay-size material probably indicates that the upper part of the Chatham Rise receives rather little transported sediment of any kind except that rafted in or delivered by the wind. Furthermore, tidal and perhaps other currents at depth very likely create sufficient turbulence across the crest of the Rise to keep most of the meagre amount of fine material in suspension and prevent its deposition there.

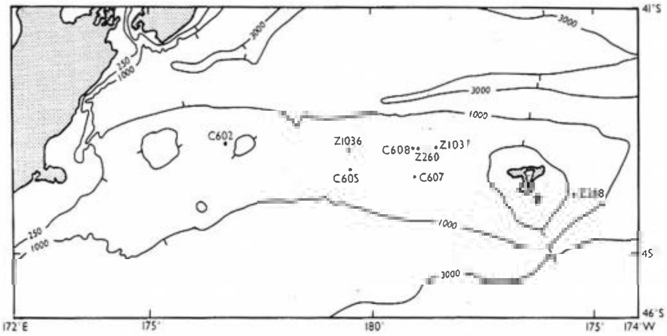

Fig. 10: Generalised bathymetry of Chatham Rise and locations of phosphorite stations.

DERIVED MINERALS

Beyond the direct influence of local land-masses, most of the rock-derived sand grains are minerals and glass fragments forming an assemblage characteristic of the Quaternary rhyolitic ash showers erupted from the Taupo area in the centre of North Island (fig. 4). As a rule, less than 10 per cent of rock-derived grains required sources other than the ash showers. Such exceptions as do occur are mostly confined to the areas near land.

Plagioclase feldspar, mainly oligoclase and andesine, is by far the most abundant mineral species in this group. Rhyolitic glass is abundant and rock-forming minerals present in most samples include augite, hypersthene, hornblende, and quartz.

VOLCANIC GLASS

Distribution

Glass fragments are present in virtually all the samples examined for this report, including samples from various points below the surface in cores. Occurrences of this sort are illustrated in the diagrammatic sketches of the cores. (fig. 11). The amount of glass present in the surface samples varies widely and unsystematically (table 1).

TABLE 1—GLASS PERCENTAGES AND NUMBERS OF SAMPLES

Glass in sample exclusive of material less than 0·066 mm in diameter (%)	*Number of samples*
10 and over	8
5·0–9·9	3
1·0–4·9	12
Present to 0·9	23
Not observed	10

Description

Ross (1928, p. 146) recognised three main forms of glass fragments in ash deposits, each of which is present among the Chatham Rise grains, plus intermediate types. These are:

(1) Curved fragments of glass, evidently parts of bubble walls.
(2) Nearly flat glass plates derived from walls of flattened vesicles.
(3) Fibrous or pumiceous fragments with elongate parallel vesicles.

Glass fragments with completely enclosed vesicles are very uncommon, and aside from the lack of these, the range of types is similar to what A. Ewart (pers. comm.) has found in the Taupo ash deposits of North Island.

All the glass fragments from the Rise are fairly angular, but nevertheless show very slight signs of abrasion just sufficient to round off the tips of the sharper points (fig. 12). They also show a slight frosting or pitting on all exposed surfaces, even inside deep vesicles which must have been protected from any abrasive contact with other grains at the time of eruption and during transport to the site of deposition.

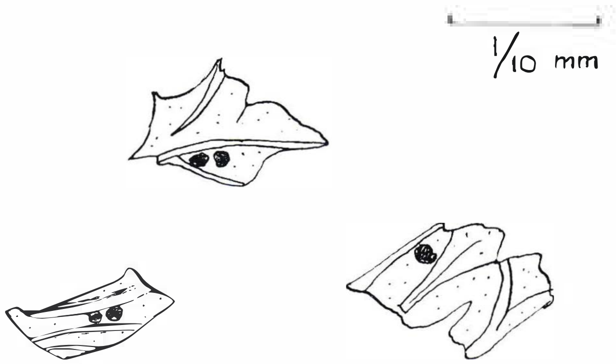

Fig. 12: Line drawing of glass fragments.

Glass fragments in the Chatham Rise sediments are most abundant in the size fraction 0·125–0·066 mm. This is due, probably, to the distance of transport from the source, which would bring about a sorting according to size plus the influence of bottom currents over the Rise which would tend to sweep away the finest glass fragments and allow the coarser ones to settle to the bottom.

Petrographically, the glass fragments are clear, very pale pinkish in colour, and a little over half the grains show inclusions which give the grains a dirty appearance; the inclusions are probably crystallites and other stages of the beginning of devitrification. Vesicles are numerous and vary in shape from elongate parallel types to nearly spherical forms. Practically all vesicles are open to the outside and commonly contain black bead-like grains of glauconite or pale buff silty material, identical with the bulk of the enclosing sediment at many stations.

The refractive index of the glass varies from 1·498 to 1·504 with most grains about 1·500. About 1 per cent of the glass grains are pale to medium brown in colour, but otherwise similar to the pale pink grains.

Origin of the Glass Fragments

Glass in the surface samples, as well as those from depth, is almost certainly traceable to the Taupo eruptions culminating in about 250 A.D. (Baumgart and Healy, 1956, p. 124). Reed and Hornibrook (1952, p. 179) recognised similar materials from the *Discovery* station (Z 269), and Macpherson and Hughson (1943) have reported rhyolitic ash from the Chatham Island peat, in some cases in layers 6–8 in. thick and 12–15 in. below the surface. These authors, likewise, suggest that the source of ash was in the Taupo district of North Island. The ash, therefore, may give a measure of the rate of peat accumulation on Chatham Island and of the rate of sedimentation on the Chatham Rise when more cores are available.

Factors Governing the Distribution of Ash

The variation in quantity of ash at different stations on the Rise may be attributed to several factors probably operating simultaneously. Firstly, topographic irregularities on the sea bottom would have encouraged somewhat increased deposition in hollows and depressions, where some protection from bottom currents would be afforded. Secondly, initial distribution on the sea floor, however uniform, is likely to be altered by benthic organisms that stir the sediment, construct burrows into which the ash can pour, or move ash from slightly protected zones to other places where currents are more effective. Thirdly, rates of non-volcanic sedimentation vary from place to place on the Chatham Rise; near land, terrigenous deposits tend to be delivered to the sea floor at such a rate as to dilute or bury the ash and reduce its percentage abundance in the samples. Sediments collected near the Chatham Islands and Banks Peninsula account for most of the 10 samples in which no ash at all was observed. The other samples in which ash percentages are low are from the higher parts of the Rise, namely Mernoo and Veryan Banks, where rapid accumulation of shelly gravels has diluted and to some extent perhaps buried the ash. In addition, tidal currents across the saddles and lower parts of the crest of the Rise have no doubt served to reduce the absolute amount of deposition.

The relatively poor development of discrete ash layers in the sediments of the Rise, as compared with the Chatham Island peats, is evidently due to the activities of marine benthic organisms, which must tend to destroy layering.

The contrast in the concentration of ash in Chatham Island peats and on the surface of the Chatham Rise is probably due mostly to the low effective specific gravity of the pumiceous grains in the ash, which would permit wide dispersal at sea through floating, whereas no such process would operate on land. Moreover, if the bulk of the ash now present in Chatham Rise surficial sediments was derived from the Taupo eruptions culminating in about 250 A.D., what may have been originally a more or less uniform layer has, in the ensuing 1700 years, been shifted about and generally mixed with the upper 2 to 3 cm of the Chatham Rise sediments.

Occurrence of ash pockets and crude layers at depth in cores has been mentioned previously (see fig. 11). Because ash beds have long been recognised as useful time lines in sediments and sedimentary rocks, there is need to examine the possibility of correlating ash zones in different cores with each other and with different eruptive periods established on land. It is clear from an examination of fig. 11 that correlation of zones between nearby cores is most uncertain because of variations in thickness and form of the zones as well as because of the differing depths at which the zones occur. Variations in rate of sedimentation from one core station to another plus the activity of benthic animals are likely to have been important causes of the effects observed.

There is a puzzling contrast between ash beds of regular thickness and wide areal distribution found in marine Tertiary rocks of New Zealand, California, and elsewhere, and the imperfect and irregular ash layers found in the cores from the Chatham Rise and many other areas of

Recent sedimentation. It may be that the ash layers on the Chatham Rise area are of less original thickness than typical marine Tertiary ash layers and consequently more readily mixed with the associated sediments than was the case for older ash deposits, or perhaps the benthic population is greater in Recent than in Tertiary sediments.

Correlation of Chatham Rise ash layers with land sequences cannot be accomplished at present by means of mineralogical affinities. The differences so far found between various members of the Taupo ash sequence are small or negligible, making a distinction on compositional grounds difficult and uncertain.

Additional coring on a closely spaced grid, especially on the slopes of the Chatham Rise, in Pukaki Gap and in the Hikurangi Trench – all areas receiving fine-grained sediments – may provide a useful basis for correlation of ash beds, now out of the question with only 11 widely spaced cores.

Transportation of Volcanic Ash from its Source to Chatham Rise

The glass gives no evidence of having been subjected to the wear and tear of either stream transport or wave abrasion in the surf. The uniform angularity of the glass fragments, even those of sand-size, provides evidence that they were derived directly from a large ash shower eruption and delivered to the area of deposition mostly by wind transport. J. Healy (pers. comm.) suggests that the observed slight abrasion of grains can be accounted for by wear as large numbers of ash fragments moved up the throat of the vent during eruption. As far as the pitting of the glass is concerned, it seems possible that corrosive volcanic gases, fluorine or hydrofluoric acid, could easily have produced this effect. A. Ewart (pers. comm.) suggests, on the other hand, that the pitting may be due to weathering or to the coalescence of very tiny vesicles. It cannot, in any case, have been produced by abrasion during transport.

Because much of the eruptive material from the Taupo district is pumiceous and of low density, a large part of the ash falling into the sea would float and be carried long distances by surface currents before becoming waterlogged and sinking or being cast up on beaches.

Burling (1961, pp. 51–52) in his discussion of oceanic currents off the east coast of New Zealand, shows that the north-flowing Southland Current and the south-flowing East Cape Current tend to merge in the vicinity of Mernoo Bank at the western end of the Chatham Rise. The combined current flows eastward above and more or less parallel to the Rise. Consequently, pumiceous material falling into the sea off the eastern side of North Island south of East Cape would tend to be swept over the Chatham Rise during the first few weeks after an eruption. Contributions of volcanic glass by this means to Chatham Rise sediments, however, are likely to have been small because nearly all the buoyant grains and pebbles would tend to be carried far to the east of the Chathams before sinking and the non-buoyant grains would probably fail to reach the Chatham Rise at all. It is thus considered here that direct transport by wind provides a more likely alternative. Additional supporting evidence for direct wind transport of most Chatham Rise ash comes from the fact that glass fragments with completely enclosed vesicles are almost totally lacking in the sediments, although they are common in the land deposited ash beds of North Island, demonstrating that nearly all glass present in Chatham Rise deposits was incapable of floating any appreciable distance.

Moreover, if the East Cape Current had transported any appreciable volume of ash from Taupo showers, the sandy beaches of the Chatham Islands should have appreciable numbers of pumice pebbles, in common with the sandy beaches of North Island where such pebbles are a common feature. As far as the writer is aware, there are no reports of pumice pebbles from Chatham Islands beaches.

The possibility that the Chatham Rise glass fragments were derived from reworking of tuffaceous rocks and the ash beds in Chatham Island peats must be considered. Both sources seem ruled out since the glass fragments (as mentioned previously) show no evidence of abrasion by wave action. Further, the tuffaceous rocks of the Chatham Islands are too basic in composition to be confused with rhyolitic glass of the Taupo showers (W. A. Watters, pers. comm.).

If winds are capable of bringing ash from the Taupo area, there is a possibility that wind-blown materials from the central volcanic plateau of North Island may have been added to the sediments of Chatham Rise. Again, lack of abrasion of grains makes an origin by deflation improbable, and the composition of Chatham Rise sediments is too much related to the mineralogy of Taupo ash to admit the possibility of significant contributions of such a heterogeneous nature as would be provided by the surface of central North Island.

FELDSPAR GROUP

Among the rock-forming minerals present in Chatham Rise sediments, plagioclase feldspar is by far the most abundant. It typically occurs as fresh, sharply angular, water-clear cleavage fragments and euhedra, mostly confined to size grades less than 0·125 mm. Many euhedral crystals are attached to the glass matrix in which they were originally formed. Refractive index ($\alpha = 1{\cdot}538$ to $1{\cdot}555$) and other optical characteristics show a range in composition from about An_{20} to An_{55}, oligoclase to labradorite. Most grains are andesine, An_{35} to An_{45}.

Zoned crystals are present in most samples and occasionally a particular crystal shows a very large number of zones. The plagioclase phenocrysts that occur in the Taupo ash showers are zoned in a very similar manner (A. Ewart, pers. comm.).

Orthoclase is present as an occasional grain recognisable by its low refractive index. It is not, however, reported as a separate mineral species in the mineral grain counts given in the Appendix. It is estimated that orthoclase accounts for not over 2 per cent of the feldspar grains.

The composition, physical characteristics, and the intimate association with glass fragments show that essentially all the feldspar grains, except those in samples near shore, were derived almost certainly directly from the Taupo volcanic eruptions. Feldspar grains in nearshore samples have a wider range in refractive index, colour, and degree of abrasion.

ACCESSORY MINERALS

Disregarding for the moment the authigenic and organic constituents of Chatham Rise sediments, the mineralogy of the remaining materials shows a strong similarity to the suite of minerals identified by A. Ewart in his study of the Taupo ash showers (pers. comm.). Included in the Taupo suite are hypersthene, augite and magnetite as common accessory minerals, and apatite, zircon, rutile, quartz, and fayalite as minor accessories. Some peculiar differences occur between the Taupo suite and the Chatham Rise suite, which are considered in the following section.

Magnetite

According to A. Ewart (pers. comm.) this mineral is a persistent and ubiquitous accessory in the Taupo ash deposits, but fewer than a dozen grains were observed in the Chatham Rise samples studied. No process of selective sorting seems adequate to explain this effect, nor does weathering seem a likely explanation because magnetite is at least as stable as augite and hypersthene, both of which are common. Ash found in the peats of Chatham Island have been examined by Hutton (in Macpherson and Hughson, 1943, p. 38) and magnetite is not listed among the accessory minerals, which in other respects are similar to those of the Taupo ash and the Chatham Rise sediments. Most of the samples examined in the present study contain an appreciable number of opaque, flaky, red-brown grains of limonite. This limonite, of course, may have been produced by the alteration of magnetite. However, the glass fragments of the Taupo ash showers examined by A. Ewart (pers. comm.) contain phenocrysts of magnetite as tiny perfect octahedra. No magnetite in this form was seen in the glass fragments from Chatham Rise. For these reasons, it seems unreasonable to assert that the magnetite delivered to the Chatham Rise with other volcanic products was entirely altered to limonite. H. M. Pantin (pers. comm.) has suggested that in each Taupo eruption magnetite was concentrated near the base of the magma chamber owing to its high specific gravity, and that the higher parts of the eruptive cloud, with little or no magnetite, were distributed more widely into Hawke Bay and to the Chatham Rise area, while the lower, more magnetite-rich materials were deposited nearer the source. In addition, of course, the lack of magnetite may indicate an entirely different source than the Taupo area, but no vents of the requisite type are known from any other place in New Zealand.

Hypersthene

In about three-quarters of the samples, hypersthene is present, often as blunt-ended euhedral crystals occasionally attached to volcanic glass. The optic sign is negative, the 2V about 65°, and the pleochroism greenish-brown to yellow. These characteristics indicate a $MgSiO_3/FeSiO_3$ ratio of about 65/35 in general agreement with the nature of hypersthenes described from the Taupo showers by A. Ewart (pers. comm.) and those described by Hutton (in Macpherson and Hughson, 1943, p. 38) from the ash beds in Chatham Island peats.

Augite

Like hypersthene, augite occurs in about three-quarters of the samples, although generally less abundantly than hypersthene. It is usually present as irregular bottle-glass green grains showing poor cleavage. Occasional bluish and brownish-green grains occur. Generally the 2V is about 60°, and $Z \wedge c$ 45°. A few grains of titaniferous augite were observed with the characteristic mauve colour and violet to yellow pleochroism; these are probably from a non-volcanic source as this mineral is not an accessory in the Taupo ash deposits of North Island.

Hornblende

Two-thirds of the samples contain hornblende, usually the brown variety, but occasionally olive-green and bluish-green types. For most grains the extinction angle is between 15° and 17°, but is occasionally as low as 12°. A few grains of basaltic hornblende with straight extinction occur, but no other intermediate types. Winchell (1933, p. 252) states that lower extinction angles may be produced by partial oxidation of the iron through heating, and that basaltic hornblende may be produced from ordinary hornblende by heating to about 800° C under oxidising conditions, which suggests a volcanic source.

These hornblende varieties do not so clearly point to a rhyolitic ash source as some other minerals. A. Ewart (pers. comm.) points out that oxidised hornblende is fairly common in one or two of the Taupo ash showers and is a very minor constituent of the others, and W. A. Watters (pers. comm.) reports that brown to dark-brown hornblende is found in some of the limburgites of Chatham Island, but, in the absence of associated minerals indicating other parent rocks such as schists or limburgites, it would seem unwise to postulate additional sources for hornblendes except in samples close to land.

Quartz

Quartz is found in virtually all samples, but much subordinate in quantity to plagioclase. In general, two types of quartz grains are present. Most abundant are subangular to subround grains containing "dirty" inclusions and occasionally possessing a ferric hydroxide surface stain. About a third of these grains show undulose extinction and are probably derived from metamorphic rocks. The rounding of the grains suggests stream or beach abrasion. Owing to the depth of the Chatham Rise, it seems probable that most of these grains are allochthonous, perhaps being derived from river beds and beaches of South Island and transported by wind or rafted by floating trees. Some of the grains may have been brought in by berg ice from the Antarctic, a mechanism previously mentioned in connection with the derived rock fragments.

The second form of quartz present is angular, water-clear chips very similar in appearance to the oligoclase and andesine from volcanic sources. Refractive index is of little use in distinguishing these minerals, and in making the mineral counts it was necessary to use a subtle colour difference which could not always be recognised with certainty. (Most feldspars had a faint bluish tint and the quartz a faint yellowish tint under white light passed through a blue filter.) Optic figure checks showed that among the water-clear mineral grains, no more than 5 per cent were quartz. A. Ewart's study of the Taupo ash showers showed an even lower percentage (pers. comm.).

Hutton (in Macpherson and Hughson, 1943, p. 38) does not give the relative amounts of water-clear quartz and feldspar. Because the separation of the two minerals which are so similar in appearance is extremely tedious, Hutton may have relied upon some such subjective method as has been used in the present report. It is believed that the abundance of quartz suggested by Hutton may be too high.

Other Minerals

A number of other minerals occur as minor accessories. Of these, the following are reported by A. Ewart (pers. comm.) from the Taupo ash deposits: zircon, fayalite, apatite, and rutile. Other minerals indicative of metamorphic sources such as the Chatham Islands and Otago schists are chlorite group minerals, zoisite, clino-zoisite, colourless garnet, muscovite, and epidote. Diaspore and diopside, neither of which is reported from the aforementioned schists, are present. None of these minerals, except those of the chlorite group and zircon, are represented by as much as 10 grains in all the counts taken together.

Brown biotite occurs in only 11 samples, and only as a minor constituent in these. The rarity of this mineral as well as the small number of other mineral grains characteristic of the Chatham Island schist shows that any schist outcrops on the Chatham Rise, if they occur at all, must be of very small size. Reed and Hornibrook (1952, p. 177), on the basis of angularity of grains, suggest the occurrence of a schist outcrop at *Discovery* station 2733 (Z 269 in this report). The depth of this sample is given as 275–310 m. Until more substantial evidence of subaerial erosion of such deeply submerged portions of the Rise is forthcoming, it appears probable that schist pebbles, both angular and rounded, are more probably rafted materials derived from Chatham Island or Otago or, possibly, from some even more distant source.

It is clear that the most prominent and persistent mineral assemblage present in the Recent sediments of the Rise is that indicative of a rhyolitic source, almost certainly the Taupo ash showers from central North Island. That there has been a contribution from other sources, especially the Chatham Islands schist and the Permo-Jurassic greywackes is not doubted. The stations near the Chatham Islands and Banks Peninsula are rich in quartz and poor in glass and associated rhyolitic material.

AUTHIGENIC MINERALS

GLAUCONITE

Distribution

Glauconite is widely distributed in the sediments of the Chatham Rise and in some places comprises more than half the total material, especially in the vicinity of Reserve Bank (chart I). This is an unusually high concentration to judge from the statement made by Emery (1960, p. 212) that glauconite rarely comprises more than about 20 per cent of a sediment. The present study shows that the Chatham Rise glauconite is generally more abundant at depths less than 500 m, but no systematic increase with decreasing depth can be detected; little or no glauconite occurs on the shallowest parts of the Rise, nor on Mernoo and Veryan Banks.

Vertical distribution of glauconite within the sediment blanket, as illustrated by the cores, suggests that as a rule the percentage of glauconite declines with depth of burial, especially in the sediments of the North Chatham Slope and the Hikurangi Trench. Stations on the Rise vary in this regard. B 444 and B 446 show little variation from top to bottom, but B 445B shows a decrease in abundance with depth. Although one must be circumspect in generalising on the basis of such limited evidence, it appears likely that present conditions on the Chatham Rise and adjacent areas are more favourable for glauconite formation than was the case in the recent past when the lower parts of the cores were deposited. Glauconite is a stable mineral under marine conditions and an alteration with time or moderate depth of burial is exceedingly unlikely.

Areal variations in abundance of glauconite in surficial samples are shown on chart I and for some selected stations on the Rise, in the pie diagrams (fig. 6). These illustrations show that a concentration of glauconite occurs near Reserve Bank, a topographic feature too deep to accumulate large quantities of mollusc shells, but sufficiently isolated to be protected for the most part from terrigenous contributions. Similarly, east of Chatham Island, not far from the Forty Fours, a secondary, but much less pronounced glauconite concentration occurs. Occasional anomalous values are found which are not readily explained in the light of present information. For example, 36·2 per cent of the material less than 2·0 mm size grade at station C 605 is glauconite, whereas at station Z 996, apparently very close by, the glauconite percentage is only 0·8. The cause of this is unknown but may be due to the patchy distribution of sediment as suggested by the pie diagrams (fig. 6), or to errors in station location which may exaggerate the importance of this anomaly.

Form of Glauconite

Glauconite occurs in four different forms on the Chatham Rise; commonest are small grains averaging about 0·6 mm in diameter with rounded form and shiny surface, usually black or very dark green. The appearance of these grains is similar to that of small phosphorite pellets called "sporbo" by Galliher (1931), and found in some California Miocene shales. Grains of this sort are found among the silt particles comprising faecal pellets, among silty aggregates which occasionally form the matrix sediment at Chatham Rise stations, and as tiny round grains without associated silt, inside vesicles in the glass fragments. Some grains included in this category may actually belong to one of the following groups, but their small size makes determination of origin difficult.

The second form in which glauconite occurs is as internal casts of Foraminifera. These casts often faithfully reflect the shape of the enclosing organism. Occasionally, corroded and broken bits of foraminiferal test may be found still attached to the glauconite. Because many glauconite grains show what appears to be expansion cracks on their surfaces and because foraminiferal tests enclosing glauconite grains are often corroded, it is likely that expansion from the inside and corrosion from the outside acting together eventually release the glauconite grains.

Many glauconite grains which began as internal casts of Foraminifera eventually break up into segments, each having a flattened surface where it was in contact with the neighbouring grain or with an internal chamber wall in the test. Such grains can usually be easily recognised as parts of casts because they superficially resemble chestnuts that have been released from the shell, each kernel showing the impress of the adjacent kernel. Glauconite grains of this type average about 0·10 mm in diameter.

According to Emery (1960, p. 213) most glauconite formed in this way is associated with species possessing relatively large apertures such as *Cassidulina*. However, in Chatham Rise sediments, a number of grains, generally small, were found in the tests of such genera as *Globigerina*, which have apertures about half as large as *Cassidulina*. Many fresh uncorroded Foraminifera from the Chatham Rise are found to contain glauconite grains which can often be seen just inside the aperture.

The third manner of occurrence of glauconite grains is as replacements of faecal pellets. Unaltered faecal pellets characteristic of the Chatham Rise are composed of fine well-sorted silt, with an ellipsoidal form and a length varying from about 0·1 to 2·0 mm. Many glauconite grains of appropriate size and roughly ellipsoidal shape, and which bear no clear resemblance to Foraminifera species, are placed in this category. No good examples of partial alteration of faecal pellets to glauconite were observed and it is probable that alteration, when it occurs, proceeds rapidly. Silt-size glauconite grains that occur in many faecal pellets could as easily represent grains of diverse origin passed through the gut of the pellet-producing animal, as they might the beginning stages of alteration to glauconite.

The fourth way in which glauconite is forming on the Chatham Rise is described by Cullen (1962), who has found a thin coating of the mineral on pebbles of various types. Although it is probable that the pebbles studied by Cullen were not deeply buried, it seems likely that they were nestled among other rocks or sediment in such a way as to provide the relatively sheltered environment believed necessary for glauconite formation. Similarly, some of the phosphorite pebbles from the Chatham Rise are found to show irregular surficial coatings of glauconite, especially in the pits and hollows on the surface.

Origin of Glauconite on Chatham Rise

The occurrences of glauconite on Chatham Rise seem all to have at least one thing in common – the glauconite is forming in an environment which, in a broad sense, is affected by tidal and other currents, is oxidising, and in most respects is typical of the open sea. But, because the grains are nestled between the silt grains, enclosed in faecal pellets or sequestered inside pumice vesicles or otherwise protected, all appear to require a microenvironment that is neither as oxidising as in the open sea, nor as reducing as in stagnant basins. Thus an intermediate range of E_h (oxidation – reduction potential) seems necessary.

Cloud (1955, p. 490), in summarising current views regarding the formation of glauconite, states that slightly reducing conditions, probably provided by protected microenvironments, organic materials in the surrounding sediment, and sediment of high iron content are necessary for the development of glauconite.

With the exception of iron-rich sediments, these and the other requirements enumerated by Cloud seem to be present on the Chatham Rise. The parent material providing the silica and potassium necessary is very probably illite clay, which has an appropriate structure, glauconite being a member of the illite group (Grim, 1953, p. 68). Because clay-size grains rarely comprise more than 10 per cent of the sediment in stations on the Chatham Rise, it is likely that much of the illite deposited is converted into glauconite. Other sources of silica and potash are present, such as orthoclase and the micas, but these are quite rare and no cases of alteration of these minerals to glauconite have been observed.

Glauconite contains both ferric and ferrous iron, suggesting that the mineral cannot form under strongly oxidising or reducing conditions, but at some intermediate E_h. This conclusion is supported by the sedimentary environment and mode of occurrence of the Chatham Rise glauconite.

The source of the required iron is not certainly known in so far as the Chatham Rise glauconite is concerned. Iron-bearing minerals, mainly hypersthene, augite, and limonite are present in nearly every sample, but no evidence of alteration of any of these to glauconite was observed. It appears doubtful that any of these minerals provide the necessary iron. It has been suggested that the lack of magnetite mentioned earlier may indicate that most magnetite grains have been converted into glauconite. Although this may be the case in some instances, the irregular distribution of glauconite, the nearly complete absence of magnetite grains either as individuals or enclosed by glass, and the lack of magnetite crystals with a coating of glauconite make magnetite a most unlikely source for most of the iron required. Biotite and other micas have been observed grading into glauconite in other parts of the world, but these micaceous minerals are quite rare in Chatham Rise sediments and cannot possibly provide the iron or other necessary elements.

Glauconite is associated with faecal pellets and silty fillings and Foraminifera and glass vesicles, and may therefore be derived in part from these materials. The colour of the silty material and the glass, however, indicate a very low iron content for each. H. M. Pantin (pers. comm.), as a result of his work on sediments from other New Zealand waters, has suggested that under conditions in which most autochthonous organic matter is swept away by currents, bacteria living in the bottom sediments may be forced to depend upon vagrant organic colloids and small particles of organic matter carried by the sea water. Colloidal ferric hydroxide and ferric phosphate are associated with some of these organic colloids and particles (Cooper, 1948, pp. 300–1), and these iron compounds would be released as the organic fractions were ingested by the bacteria. Bacterial activity would also be capable of producing the slightly reducing environment necessary for glauconite to form. One important source of organic material with which the iron compounds are associated may be phytoplankton. Harvey (1937) and Hedley (1960) have shown that colloidal ferric hydroxide or ferric phosphate can be absorbed by certain diatoms and Foraminifera.

Summarising, glauconite on the Chatham Rise seems to be forming in an area of very slow sedimentation, in numerous microenvironments which are shielded from the oxidising conditions in the sea water just above the bottom. The E_h of the microenvironment is slightly reducing and maintained by bacterial destruction of organic colloids. The main parent materials for glauconite are believed to be illite clays and waste products, mostly iron, released by bacterial attack on organic colloids. Iron-bearing derived minerals present do not appear to participate in the formation of glauconite.

The virtual absence of glauconite on Mernoo and Veryan Banks is probably due in part to the relatively rapid accumulation there of calcareous debris derived from molluscs, echinoderms and bryozoans, which serves to mask or bury the accumulating glauconite. Moreover, in areas receiving such coarse sediment, the interstitial sea water may be more readily and frequently exchanged, inhibiting the development of the semiprotected environments that appear to be necessary for glauconite formation.

The occurrence of glauconite in Eocene rocks on the Chatham Islands indicates that the process of glauconitisation has been more or less continuous on the Chatham Rise area since then, although at the present time no other evidence has been obtained to demonstrate that any of the greensands on the surface of the Rise or in the cores are older than Recent.

PHOSPHORITE

Distribution

Phosphorite, unlike glauconite, occurs mostly as nodules in coarse fractions of the deposits, and, because many of the sampling devices used to obtain the materials used in this study are more or less inefficient for collecting large masses of rock, the actual distribution of phosphorite is very imperfectly known and probably much more extensive than at present realised.

Fig. 10 shows locations of stations from which phosphorite nodules have been obtained. This distribution suggests that phosphorite is most abundant between the Chatham Islands and Reserve Bank, although, owing to limitations of sampling equipment and generally sparse coverage of the area, phosphorite may have a much more general distribution. A programme of bottom photography coupled with more extensive use of large-mouthed dredges would be especially instructive in this regard.

Phosphorite also occurs in the sand-size materials from Chatham Rise, occasionally as discrete grains, but most often as a thin, blackish pellicle on glauconite grains. Laboratory washing or treatment with dilute hydrochloric acid both readily removed the pellicle. An analysis of a glauconite sand concentrate from the top of core B 446 was provided through the courtesy of Dr I. K. Walker, Chemistry Division, D.S.I.R., Lower Hutt, and is given in table 2.

TABLE 2—CHEMICAL ANALYSIS OF A GLAUCONITE SAND CONCENTRATE FROM TOP OF CORE B 446

	Per Cent
SiO_2	48·5
Al_2O_3	9·2
Fe_2O_3	16·7
FeO	1·8
MgO	4·4
CaO	1·0
Na_2O	0·15
K_2O	7·9
TiO_2	0·05
P_2O_5	0·70
MnO	0·00
$H_2O + 110°$	6·3
$H_2O - 110°$	2·7
CO_2	$< 0·1$

Nature of the Phosphorite Nodules

All the phosphorite nodules thus far recovered from the Chatham Rise are examples of phosphatised foraminiferal ooze, which, judging from the external appearance of some nodules and the internal structures illustrated in the cross-section shown in fig. 13, was slightly indurated before phosphatisation began, permitting borings and worm tubes to be clearly preserved without collapsing. Two types of nodules occur. Most abundant are irregular slabby masses up to about 10 cm across, with a dull black crust enclosing buff to pale-brown phosphatised calcareous material. Locally, the blackish crust has a greenish cast, especially around indentations in the surface. The blackish crust is believed to be mainly glauconite. The second type, represented by a single nodule from station Z 1036 (fig. 8), is slightly different from the usual type, having a glossy, mottled brown and black surface and formed from what was obviously a mollusc-bored chunk of slightly indurated foraminiferal ooze. Fig. 13 shows one of the nodules from Station Z 1037 in cross-section and filled worm or mollusc burrows can be seen easily. The shiny brown crust coats the inside of the mollusc borings as well as the exposed outer surfaces. This variety of phosphorite bears a very close resemblance to phosphorite obtained from banks off the coast of southern California and described by

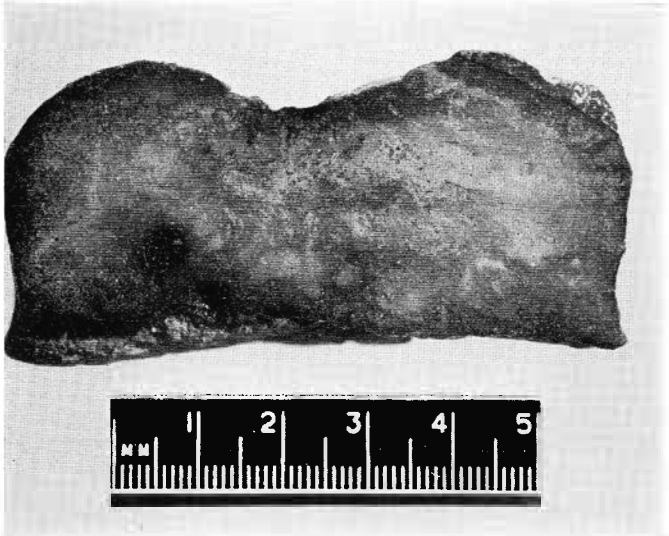

Fig. 13: Photograph of a cross-section of a phosphorite nodule from station Z 1037.

Dietz, Emery, and Shepard (1942). In other respects, however, this nodule is like the more characteristic Chatham Rise type previously described.

Reed and Hornibrook (1952) first reported the presence of Miocene Foraminifera in the Chatham Rise phosphorite. Their material came from the *Discovery* station labelled Z 269 in the present report. Other phosphorite nodules from stations Z 1036 and Z 1037 have been sectioned and also were found to contain Miocene Foraminifera. It is probable that most, if not all the phosphorite on the Chatham Rise was produced by phosphatisation of Miocene foraminiferal oozes. The absence of Foraminifera older than Recent in the sediment associated with the phosphorite led Reed and Hornibrook (1952) to propose that following phosphatisation of the Miocene sediments, uplift of the sea floor accompanied by slow erosion terminated deposition and removed unconsolidated sediment, leaving only the phosphorite nodules behind.

Post-Miocene erosion vigorous enough to sweep away all the finer sediments, yet so delicately adjusted as to leave unrolled and uneroded phosphorite nodules averaging only 1·5 cm in diameter is difficult to visualise. The smooth surface, the fairly common encrusting bryozoans, and the subangular to subrounded shape of the Chatham Rise nodules suggest little if any abrasion subsequent to their formation. Moreover, the crust on the nodules was almost uniform in thickness in all cases examined; in exposed portions, in pits, and as linings in borings. Abrasion would tend to remove the crust from the exposed parts of nodules, and, even if the crust was being reformed under present conditions, it should be thicker in protected places if the nodule was abraded at some earlier time in its history.

The thin coating of phosphorite on some glauconite grains is an indication that deposition of phosphorite is in progress at the present time. The apparent absence of phosphorite with an age between Miocene and Recent may indicate that conditions since the Miocene have fluctuated between an environment favouring solution or non-formation of phosphorite and one favouring its precipitation, thus permitting the development of thin pellicles of phosphorite on modern glauconite grains, while, at the same time, discouraging the development of new nodules. Additional samples from the Rise may, of course, yield phosphorite nodules containing Pliocene and younger organisms.

Unfortunately, very little is at present known about the chemistry of the sea water in the Chatham Rise region. Measurements of oxygen and carbon dioxide concentrations, E_h and pH of the bottom waters and the interstitial water in the sediments and concentrations of phosphate and organic colloids are all needed to assess the accuracy of the inferences drawn from the sediments themselves. For example, the oxygen minimum in the sea usually occurs between 500 and 700 m (the surface of the Chatham Rise is largely within this zone), but it is not known whether or not the oxygen concentration is the same in waters over the Rise as in the open ocean. The importance of this information in understanding the origin of phosphorite nodules may be appreciated in view of Emery's comment (1960, p. 106) that the concentration of phosphorus in the form of phosphate is more or less inversely related to dissolved oxygen in the sea water off southern California, and that of Clark and Turner (1955), who found experimentally that the rate of precipitation of phosphate increases with temperature when the concentrations are low, and that phosphate tends to be adsorbed on the surfaces of calcium carbonate crystals.

Gypsum

Very small amounts of gypsum have been detected in the cementing material of the silty aggregates. The gypsum doubtless plays a role in the formation of the aggregates, but a less important one than the organic slime previously mentioned (see p. 15). Pantin (1964) has found gypsum cement in silt aggregates from Milford Sound, New Zealand. This gypsum is attributed by him to bacterial oxidation of sulphides produced during the decay of organic materials in the bottom sediments. Some gypsum in sediment samples that have dried in air may be due to post-sampling oxidation of original sulphide concentrations.

CHATHAM RISE SEDIMENTS AND THE TERTIARY GREENSANDS OF NEW ZEALAND

Glauconite and associated phosphorite occur in several Tertiary calcarenites in various parts of New Zealand. Examples include the Duntroonian Kokoamu Greensand and the Waitakian to Otaian Gee Greensand of the Waitaki district of South Island, described by Gage (1957, pp. 48, 55). He mentions that the Kokoamu Greensand rests on a mollusc-bored and corroded limestone. Although the nature of the bedrock on which Chatham Rise greensands rest is necessarily imperfectly known, the deposits are closely associated with mollusc-bored phosphorite nodules and occasional fragments of slightly indurated foraminiferal ooze, also bored. The associated shell fragments are, moreover, often corroded (fig. 8). This suggests that the depth and rate of deposition of the Tertiary greensands were roughly similar to those of the present day on Chatham Rise. Another calcareous greensand of similar type and age has been described by Macpherson (1948) from near Paraparaumu, North Island. Glauconite occurs in these and other New Zealand greensands as discrete sand-size grains generally set in a calcareous matrix. There are striking resemblances between such rocks and the sediments from the Chatham Rise (fig. 14, 15, and 16).

N. de B. Hornibrook (pers. comm.) has pointed out that in several areas, the Tertiary calcareous greensands are poorer in planktonic Foraminifera species than is generally the case in the Chatham Rise glauconitic sediments, although in at least a few cases the planktonic-benthonic ratio in Tertiary greensands is consistent with the prevalent ratio in Rise sediments.

Accordingly, the present geologic and oceanographic setting of the Chatham Rise is a useful analogue to keep in mind when one is reconstructing early and middle Tertiary ecology and paleogeography of the New Zealand region. Conditions of temperature, chemical environment, depth, organic activity, and the degree of isolation from sources of terrigenous sedimentation similar to those found in the central part of the Chatham Rise must have, to a

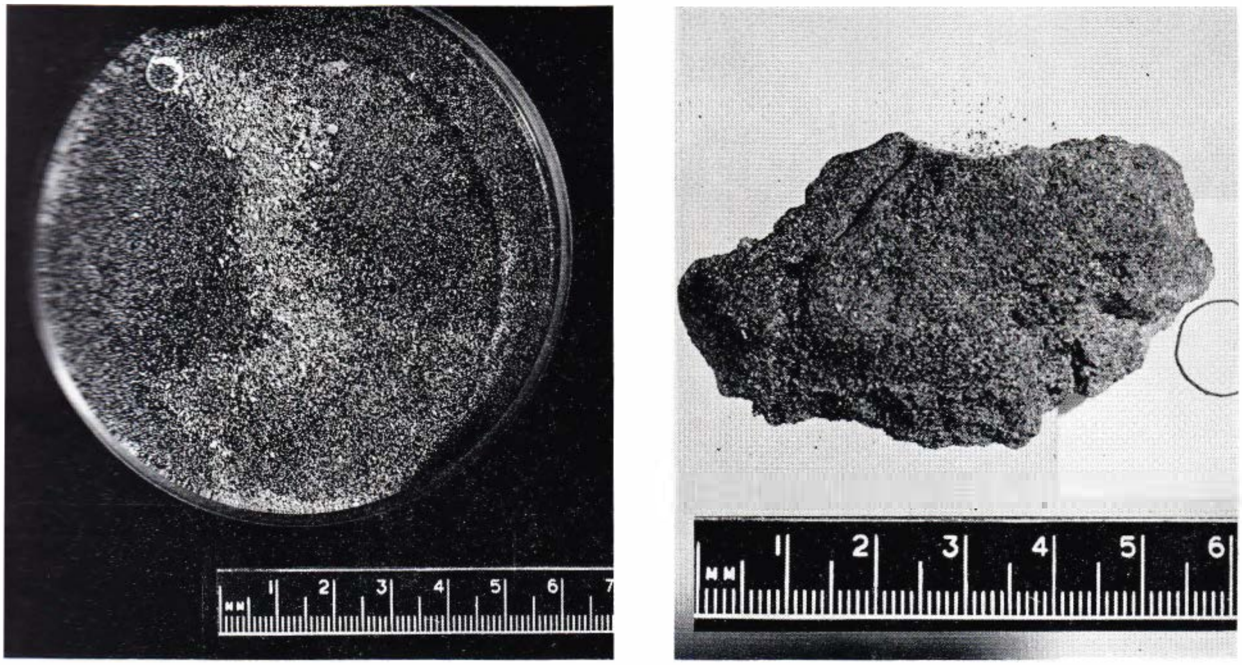

Fig. 14: Photographs of glauconite from stations Z 994 and C 602.

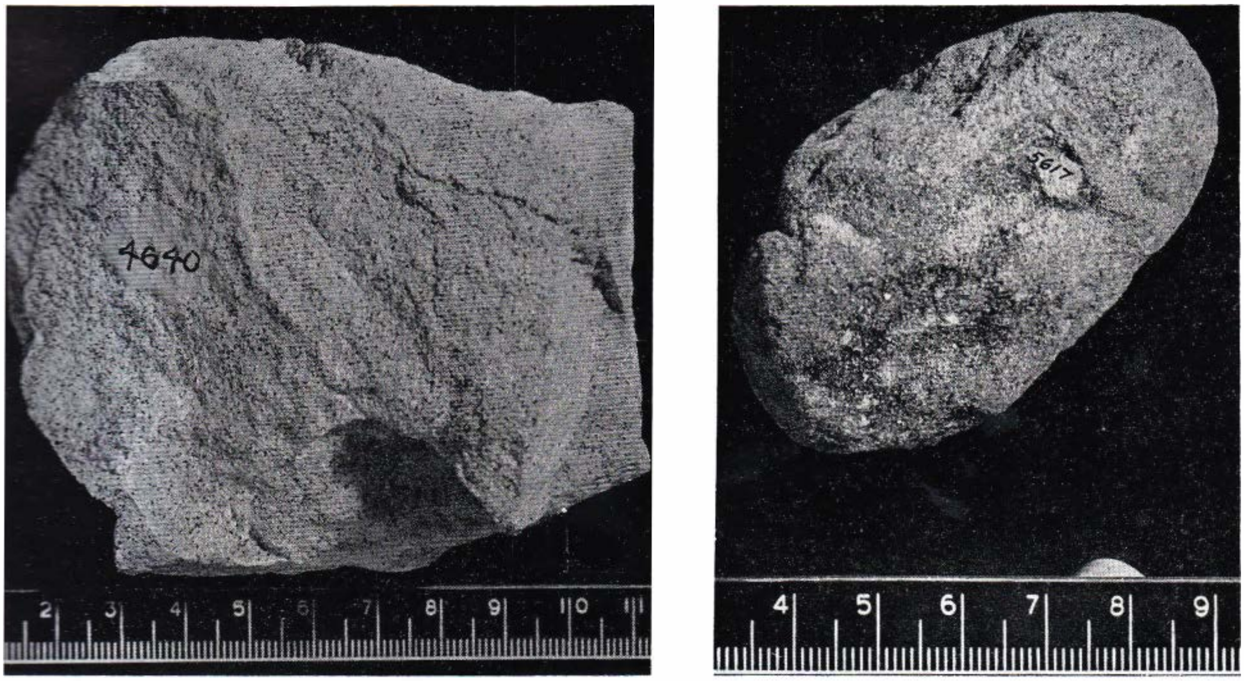

Fig. 15: Photographs of Tertiary greensands from South Island, NZGS 4640 and NZGS 5617. Scale is in cm.

Fig. 16: Photograph of greensand core from station B 446.

very large extent, prevailed during deposition of the richly glauconitic Tertiary deposits now found in various parts of New Zealand.

ORGANIC COMPONENTS

The organic components of Chatham Rise sediments are dominated by organisms with calcareous shells—by molluscs at depths less than about 150 m and by Foraminifera at greater depths. In the muddy sediments found along the edge of the Rise, on the slopes, and in the Hikurangi Trench, faecal pellets probably produced by sediment-eating worms comprise a substantial portion of the sediment. Other less abundant organic materials include calcareous bryozoa, brachiopods, echinoderms, coccolithophorids, and ostracods. Siliceous diatoms, radiolarians, and sponges are widely distributed in the area, but nowhere are especially abundant.

A few fish teeth and some rounded cetacean (?) bones have been found in Chatham Rise sediments.

SHELL GRAVELS

The shell gravels are composed primarily of pelecypod shells and shell fragments with smaller but still significant amounts of debris derived from gastropods, bryozoans, and echinoderms. These shelly deposits are best developed on the tops of Mernoo and Veryan Banks, encouraged by the shallow, somewhat warmer waters there and by the freedom from inundations of land-derived sediment. Reserve Bank, near the centre of Chatham Rise (chart 1) is evidently rather too deep for vigorous growth of the larger lime-secreting organisms, as shell material occurs there only in subordinate amounts. Associated with shelly deposits on Mernoo and Veryan Banks are rounded greywacke pebbles and at least in the case of Mernoo Bank, some outcrops of greywacke bedrock. A sample believed typical of the two banks is from station B 515 and is illustrated in fig. 7.

Although stations around the Chatham Rise indicate a generally patchy distribution of sediment types, most of the stations within a mile or two of the islands are dominated by land-derived rock and mineral grains; these give way outwards to shell gravels which, at about 150 m depth, yield in turn to finer-grained foraminiferal oozes and muds. Shell gravels tend to approach shore somewhat more closely where the island is small or where surface drainage brings little material into the sea. Station Z 287 is a shell gravel, but located quite close in to South East Island and The Pyramid in the Chatham group.

Occasional mollusc shells are present in samples from all parts of the Chatham Rise and even from the deeper waters to the north and south, but there is a marked decrease in abundance below about 150 m everywhere in the area investigated. In a study of the sea floor sediments near San Nicolas Island, California (Norris, 1951), the writer found a similar distribution of shell gravel, patchy in detail, but generally covering a shallow rocky floor a short distance offshore outward to a depth of about 150 m where shell gravels gave way to foraminiferal muds.

Shell fragments comprising these Chatham Rise gravels show a moderate to a considerable amount of abrasion; corners and projections are commonly ground off and surface ornamentation is blurred. Because the shell material includes few, if any extinct forms, and shell chips showing fresh evidence of abrasion are common, some modern agency seems capable of agitating the shell gravel enough to produce the observed wear and tear, but not enough to carry it away from the site of deposition. Ordinary storm waves theoretically do not have appreciable energy below depths of about 30 m, which, if true, makes it necessary to call on some such mechanism as tidal currents for the required agitation.

The larger shell fragments often show marked solution or corrosion effects. Surfaces are roughened by solution, which presumably begins to attack as soon as abrasion has removed the chitinous coating. Waters in the Chatham Rise area are presumably sufficiently cold to be slightly undersaturated as far as calcium carbonate is concerned, encouraging solution which eventually destroys shelly material lying exposed on the sea floor. Parenthetically, sea water seems saturated with calcium carbonate only in shallow places within the tropics.

If, since Miocene time, relatively cool waters undersaturated with respect to calcium carbonate have prevailed over the Chatham Rise, limy organisms would probably be dissolved about as fast as deposited, leaving only the modern representatives at any given instant in geological history. This sort of a process may explain why Miocene foraminiferal oozes remained for a sufficient time to be converted into phosphorite (a period of warm water) and why Pliocene and Pleistocene molluscs and Foraminifera are absent (a period of cool to cold water encouraging solution of calcium carbonate). A history of this sort, assuming near-continuous marine conditions and slow terrigenous and authigenic deposition, would leave phosphorite nodules near the surface, concentrate the insoluble components of the sediment, such as glauconite and volcanic glass, and allow continuous replacement of calcareous materials, essentially the situation that prevails at present.

A. Edwards, New Zealand Geological Survey (pers. comm.), has reported late Eocene to early Miocene coccoliths and discoasters mixed with Recent coccolithophores and Foraminifera, at station C 605, near the centre of the Rise. This report, if confirmed by other samples, may require the presence of outcrops of incompletely indurated Upper Eocene to Lower Miocene chalks on the Chatham Rise, the nearest equivalent of which are bryozoan Te One and Te Whanga limestones of the Chatham Islands (W. A. Watters, pers. comm.). It seems unlikely that coccolithophorids and discoasters were derived from sources either in the Chatham Islands or on the South Island, both of which are more than 150 miles from station C 605.

FORAMINIFERAL SEDIMENTS

Foraminifera are present in every sample collected from the Chatham Rise, but are relatively rare in stations on the tops of the Mernoo and Veryan Banks, and generally uncommon in samples taken close to land as well. These areas are all sites of relatively more rapid deposition and greater turbulence than is characteristic for the Rise as a whole. Foraminifera tend to be dispersed through a correspondingly larger volume of material and may be selectively winnowed out by stronger water motion as well.

Much of the calcareous sediment present on the Chatham Rise is properly considered a foraminiferal or globigerina ooze, on the basis that sediments containing 30 per cent or more of foraminiferal tests are so defined (Sverdrup, Johnson, and Fleming, 1946, p. 972). Chart 1 shows the distribution of calcium carbonate in Chatham Rise sediments and areas covered with globigerina ooze generally correspond to those with less than 75 per cent and more than 25 per cent of calcium carbonate. There are three calcium carbonate highs—areas having more than 90 per cent of calcium carbonate—Mernoo and Veryan Banks and a shallow area to the east of the Chathams. A value of more than 90 per cent is shown for station A 307 on the North Chatham Slope. This particular sample is a nearly pure globigerina ooze suggesting that some of the deeper unsampled areas surrounding the Chatham Rise may be covered with foraminiferal oozes.

S. Kustanowich, formerly of the New Zealand Oceanographic Institute, has kindly examined the foraminiferal faunas from several Chatham Rise stations and reports that, in every case, including faunas from as much as 200 cm below the surface in cores, there is no suggestion of anything other than a Recent age, nor any marked indication of a temperature regime different from that presently prevailing. He points out, however, that some tentative generalisations may be made. For example, assuming a constant rate of deposition of planktonic Foraminifera over the entire region east of the South Island, an increase in benthonic species is apparent from the Hikurangi Trench upward to the crest of the Chatham Rise. Further, on the basis of the limited number of stations examined, the planktonic species suggest the occurrence of slightly warmer water in two areas, one above the North Chatham Slope near longitude 177° 30′ W and another east of the Chatham Islands group. In neither case does present knowledge of the physical oceanography provide more than a hint of substantiating evidence, although the east-flowing current over the Chatham Rise (Burling, 1961, p. 51), may, on being deflected or divided by the islands, produce a slightly warmer pocket of water on the lee side.

FAECAL PELLETS

Ellipsoidal faecal pellets from about 0·1 to 2·0 mm long, composed of evenly sorted silt grains cemented mainly with organic material, are common features of the finer-textured sediments in the Chatham Rise area. The nature of the organic cement is not known, but it is probably a mucus or slime produced in the guts of the worms that excreted the pellets. The cement is weak and the pellets can be broken readily when they are wet. Because of this characteristic, pellets disintegrate or fracture easily during the washing and sieving involved in mechanical analysis.

Irregular grains, which although they have no obvious ellipsoidal shape, are probably fragments of large faecal pellets in many cases. The latter, however, are not easily distinguished, although sorting in the identifiable faecal pellets tends to be slightly better than in the silty aggregates, presumably because the worm ingesting the sediment is more selective than the processes which govern the transport and deposition of the sediment on the Rise. Moreover, no evidence of gypsum cement was found in any of the pellets, although a little was found in the silty aggregates of irregular form. It is at present impossible to give any reliable estimate of the quantitative importance of the pellets in the silty and clayey deposits of the Chatham Rise. In several samples, however, nearly half the material between 0·5 and 2·0 mm in diameter was found to be faecal pellets, and as much as 30 per cent was common in fine-grained fractions.

Some of the larger pellets contain shiny, rounded, blackish-green glauconite grains of the same size grade as the majority of the pellet grains. Typically, such glauconite grains are internal casts of small Foraminifera and are scattered more or less randomly through the pellets. It is clear that the glauconite grains passed through the intestinal tract of the pellet-producing worm without much change, except, perhaps, to dissolve off the foraminiferal test which originally enclosed the grain.

Although a number of glauconite grains have external shapes which are suggestive of a development from faecal pellets, no examples were found in which there was clear evidence of alteration from faecal pellet to glauconite grain. All the glauconite found in pellets was in the form of discrete grains similar to the larger grains discussed earlier in every respect save that of size. The answer may be found in the as yet incompletely known history of faecal pellets in the coarser sediments at the surface of the Chatham Rise. Glauconite seems to form most rapidly in such an environment and faecal pellets, which are less numerous in this type of setting, may therefore be more readily converted into glauconite. This suggestion must be regarded as speculation until further evidence is obtained.

SILT AND CLAY FRACTIONS

Most of the sediment from the Chatham Rise of less than 0·066 mm particle diameter, appears to lie within the silt range (0·066–0·004 mm) rather than in the finer clay-size grade. No mechanical analyses were made to separate these two grades because the procedure tends to destroy virtually all the faecal pellets, and because the results that would have been achieved were not believed important enough to warrant the expenditure of time. Nevertheless, rough visual estimates under the microscope indicate that no less than two-thirds of the material was composed of mineral fragments and glass chips very similar to those in the 0·066–0·125 mm grade, on which the grain counts were made (see appendix 2). Feldspar cleavage fragments dominate the non-calcareous portion of the silt fraction in most samples.

Calcareous material present in the finer grades consists mostly of broken chips of foraminiferal tests with minor amounts of complete foraminiferal tests and broken fragments of calcareous material from other sources. Stations in areas of shell gravel yield virtually no material of silt size at all.

Glauconite grains, rounded, shiny and blackish-green, are present in the silt size grade in some samples, especially those collected near Reserve Bank. Because of the frequent association of glauconite and Foraminifera, most glauconite is found in the coarser fractions in which Foraminifera are also the most common. Although frequently present among silt size grains, in no case was glauconite found to be as abundant as in the corresponding coarser material from a given station.

The pie diagrams and histograms (fig. 6) show the relative importance of the silt-and-clay fractions at 18 selected stations. Despite the patchy nature of sediment distribution on the Chatham Rise, it is clear that samples with high percentages of silt and clay tend to be located along the margins of the Rise and on the adjacent slopes. Most of the area, including Mernoo, Veryan, and Reserve Banks and the areas east of the Chatham Islands, averages less than 10 per cent silt and clay per sample. Percentages are slightly higher on the Rise between Chatham Islands and Reserve Bank, although still less than 20 per cent. Even in these areas of low percentages of silt and clay, foraminiferal tests and pumice vesicles are commonly found to be filled with silt. This may mean that in some places silt and clay are kept in suspension by currents except where they have been trapped in pumice vesicles and Foraminifera tests, or it may suggest that the sampling equipment used permitted finer materials to be washed out of the samples during the time they were being raised from the sea floor.

Most of the silty material in the samples possesses a weak patchy coherence such as it would if it were held together by a feeble cementing agent. This caused it to break down completely during mechanical analysis, with the production of relict silty aggregates. The presence of gypsum was alluded to earlier and no doubt contributes in some instances to this effect, but it is not abundant and most silty aggregates appear to owe their coherence to mucus or organic slime, which is weakened by soaking in water. Samples were washed gently in distilled water to remove the easily soluble salts. They were then soaked overnight in distilled water, which was poured off, and evaporated. In most cases, a small colourless, gelatinous residue was left, occasionally associated with tiny gypsum crystals.

Judging by the cores, nearly all the silt-clay fractions are thoroughly worked over by burrowing worms, which can be expected to leave small amounts of mucus or slime on the walls of their burrows as well as in the sediment passed through their digestive system. In the course of time, this slime would become a ubiquitous, if not abundant constituent of the sediment. Where clay is abundant in the sediment, it can be expected to contribute to the cementing effect as well.

GEOLOGIC HISTORY

So little is at present known about the bedrock of the Chatham Rise that any attempt to reconstruct the history of the area must be done with considerable caution. Because there is good reason to believe the Chatham Rise to be a block of continental crust in approximate equilibrium (see discussion in "Structure") since Miocene time at least, it is probable that since the Rise was first developed as a distinct crustal structure, it has, for the most part, been a marine environment.

PRE-MIOCENE HISTORY

Although schists of the Chatham Islands and adjacent sea floor and the greywackes of Mernoo Bank are as yet undated, it is probable that they are correlative with similar rocks of the South Island and that they indicate marine conditions, probably geosynclinal, for the Chatham Rise area from late Paleozoic to middle Mesozoic time.

Lignitic coal measures of Senonian age are exposed on the Chatham Islands (W. A. Watters, pers. comm.) and indicate that a portion of the area, at least, was above sea level toward the end of the Cretaceous period.

Tuffaceous rocks and limestones of Eocene age, exposed on the Chathams, indicate subsidence and shallow marine conditions accompanied by some explosive volcanic activity centred, possibly, south of Chatham Island (W. A. Watters, pers. comm.).

No deposits from early Oligocene to late Miocene age are known either from the Chatham Islands or from the Chatham Rise. It is possible that all or part of the area was above sea level at this time, but the elevation, if any, must have been small because the early Tertiary sediments of the Chatham Islands are neither destroyed by erosion nor markedly tilted from their original horizontal position.

MIOCENE

Sometime during the early Miocene, marine conditions again prevailed permitting deposition of foraminiferal ooze under conditions not greatly different from those found at present. Hornibrook (in Reed and Hornibrook, 1952, p. 185) states that the relative proportions of cold, temperate, and warm foraminiferal species of Miocene age (from the phosphorite nodules) is much in accord with what would be expected in the latitude of the Chatham Rise.

During Miocene or perhaps early Pliocene time, phosphatisation of foraminiferal oozes took place on the Chatham Rise producing the irregular masses of phosphorite. Toward the end of Miocene time, volcanic activity was resumed on the Chathams with the explosive eruption of tuffs (W. A. Watters, pers. comm.).

PLIOCENE

No record of Pliocene deposits has yet been found on the Chatham Rise, but it is probable that marine conditions characteristic of the Miocene persisted throughout the epoch. The presence of discrete masses of Miocene phosphorite on the surface of the Rise is incompatible with any post-Miocene period of erosion. The absence of Pliocene Foraminifera and larger calcareous organisms can be explained as a result of solution (see p. 26–7).

Pitt Group rocks, found only on Pitt Island in the Chathams, include probable Waitotaran (middle-upper Pliocene) bryozoan shallow water limestones and basic tuffs (W. A. Watters, pers. comm.). Although recent sediments on most of the Chatham Rise are not rich in bryozoa, stony bryozoa are present, probably in abundance on some of the banks (see p. 26) and suggest that present conditions on the banks are not unlike those prevailing at the time and place the Pitt Group was deposited.

Preservation of limy sediments on the Chatham Islands and their simultaneous destruction on the Rise may be due to burial by a protective mantle of volcanic material on and near the Chathams as compared with the absence of such a mantle over much of the Chatham Rise. Very little locally derived tuffaceous material or flows of lava seem to be present on the Chatham Rise except close to the islands suggesting that neither of these materials were deposited there. Moreover, the tuffs in question are basic in composition and had they been deposited in association with the Miocene foraminiferal ooze (now phosphorite), they should be easily distinguished from the Recent rhyolitic glass found in most Rise samples.

PLEISTOCENE

No deposits or organisms positively identified as Pleistocene have as yet been recovered from the Chatham Rise, although it should be remembered that many living species of Foraminifera and Mollusca have ranges which extend at least as far back as Pleistocene.

Shallow marine conditions alternating with low land, in the form of islands, seem to have prevailed during the Pleistocene. Rounded greywacke pebbles at Mernoo Bank and possibly elsewhere indicate shoreline erosion of the highest parts of the Rise during the low sea levels associated with the glacial stages. It is probable that during these low sea levels, one or more islands existed along the Chatham Rise, perhaps providing a broken land bridge adequate for the introduction, from mainland New Zealand, of the living and fossil flightless birds known from the Chathams. The present unbroken stretch of water makes additional introductions of flightless birds from either North or South Island most improbable.

According to W. A. Watters (pers. comm.) the Chatham Islands achieved roughly their present form by the opening of the Quaternary and have since been modified mainly by shoreline erosion and deposition.

RECENT

Recent sedimentation on the Chatham Rise has continued the earlier pattern without notable change except for the addition of substantial amounts of rhyolitic glass derived from the violently explosive eruptions in the Taupo area on North Island, which culminated about 250 A.D.

TECTONISM AND VULCANISM

Despite the fact that the Chatham Islands have been more persistently a land area than other parts of the Rise, the entire block seems to have been remarkably stable during the whole of the Tertiary and Quaternary periods with only minor amounts of folding or vertical movement. Late Tertiary volcanic activity is known from the Chatham Islands, particularly in the south-eastern portion and Miocene and Quaternary volcanic activity occurred at Banks Peninsula at the western extremity of the Rise (Grindley, Harrington, and Wood, 1959, p. 51) and additional volcanic centres along the axis of the Rise may thus eventually be disclosed, although present information provides no hint of them.

ECONOMIC CONSIDERATIONS

New Zealand's dependence upon agricultural exports and the need to maintain soil fertility by the addition of lime, phosphate, and potash (N.Z. Soil Bureau, 1954) makes the sediments of Chatham Rise of some interest, because they include materials that would supply some or all of these needs plus, very probably, a range of trace elements useful to the soils as well.

A. J. Metson (pers. comm.), New Zealand Soil Bureau, has kindly tested some glauconite sand from station B 446 for rate of potash release by means of successive extractions with boiling nitric acid (Metson, Arbuckle, and Saunders, 1956; Metson, 1960); after a sufficient number of extractions, a given sample reaches a nearly constant rate of release which is called the K_c value.

He has found that New Zealand soils give K_c values from zero to about 0·8 m-equiv.% (milliequivalents/100g of soil) with the borderline between potash-deficient soils and potash-sufficient soils about 0·3 m-equiv.%. Soils with high K_c values usually contain appreciable amounts of clays of the illite group.

In making rough comparisons with glauconites exposed on land, with potassium-bearing minerals and with soils, Chatham Rise glauconites show a much greater initial release of potash and about twice the value for K_c found in other samples tested. These comparisons are set forth in detail in table 3.

In nature, the initial as well as the sustained rate of release of potash available for plant growth would be a slow process depending upon the rate of weathering. Both the fine grinding and the rather drastic nitric acid treatment used in Metson's work hastened the process. Fine grinding would make Chatham Rise glauconite a better source of agricultural potash, but would of course greatly increase its cost.

TABLE 3—RELEASE RATES OF POTASSIUM FROM VARIOUS GREENSANDS AND SOILS

Nature of Sample	Size fraction	Total K (m-equiv. %)*	Exchangeable K (m-equiv. %)	Ratio sample: acid	K extracted by boiling for 15–20 min. with N-HNO_3 (first extract) (m-equiv. %)	K dissolved in subsequent extracts (m-equiv. %)			K_c (m-equiv. %)
Glauconite (Chatham Is., from ocean floor)	Fine sand (as received)	138	0·67	1: 100	47·2	3·7	3·5	3·1	3·44
				1 : 12·5					
	< 300 mesh (prepared by grinding)			1 : 100	68·6				
				1 : 12·5		10·3	8·6	7·9	8·9
Greensand (Waipara, north Canterbury	< 2 mm (contained fine material	74		1 : 100	6·5				
				1 : 12·5		1·9	1·3	1·8	1·83
	300 mesh (prepared by grinding)			1 : 100	17·8				
				1 : 12·5			4·1	4·0	4·05
Greensand (Waipaoa R., Taradale, Gisborne)	< 2 mm (contained fine material)	91	0·29	1 : 12·5		1·4	1·1	1·0	1·17
Skeletal soil from greensand (Waikanae, Wellington)	< 2 mm (contained fine material)			1 : 12·5	2·8	1·9	1·4	1·5	1·60
Biotite†	Fine sand		15·7	1 : 1000	160	9·5	0·05	0·0	
	Silt		29·2	1 : 1000	155	3·2	0·0	0·0	
Vermiculite†	Coarse sand		8·1	1 : 100	45·6	9·2	1·15	0·5	
	Coarse sand		10·7	1 : 1000	55·8	4·2	0·0	0·0	
Muscovite†	Coarse sand		0·4	1 : 125	2·0	0·8	0·45	0·45	0·50
	Fine sand		1·7	1 : 250	8·8	4·9	3·3	3·0	3·2
Orthoclase†	Fine sand		0·20	1 : 100	0·34	0·39	0·39		
	Fine sand		0·43	1 : 100	0·66	0·69	0·67	0·64	0·67
Fertile soil (illitic) (Lincoln, Canterbury)	< 2 mm (contained fine material)	56	0·49	1 : 12·5	2·0	0·88	0·85	0·77	0·78

Table prepared by A. J. Metson, 1961 (N.Z. Soil Bureau).

*Milliequivalents/100g of soil. †Values from Haylock (1956).

More phosphate fertiliser is used in New Zealand than any other type, and this at present is obtained mainly from Nauru and the phosphate islands of the Gilbert and Ellice group, which of course have finite resources. Moreover, Australia depends upon the same sources so it is obvious that adequate supplies closer at hand would benefit New Zealand.

Chatham Rise sediments contain phosphate as discrete nodules composed mostly of the minerals fluorapatite ($3Ca_3P_2O_8 \cdot CaF_2$) and collophane [$3Ca_3P_2O_8 \cdot Ca(CO_3, F_2 SO_4, O) \cdot nH_2O$], and as coatings on glauconite grains. An analysis by the Chemistry Division, Lower Hutt (table 2), shows that the phosphate coatings on glauconite average about 0·7 per cent of the total material, too low to be of any commercial consequence at present. The nodules, however, average a little more than 21 per cent of phosphorous pentoxide (Reed and Hornibrook, 1952, p. 181). Some nodules found on Chatham Island and possibly derived from lower Tertiary deposits were found to contain as much as 27·2 per cent of phosphorous pentoxide (W. A. Watters, pers. comm.).

Phosphate nodules have been recovered from the stations shown in fig. 10 and it is probable that additional detailed sampling will disclose many more localities from which phosphorite may be obtained. The chances are good that future work will demonstrate widespread occurrence of phosphorite nodules on the Chatham Rise, but it is too early at the present time to make any estimates of tonnages available.

The third important constituent in sediments of the Rise is calcium carbonate present as shells, tests and fragments of a wide range of organisms. This material has the advantage of being largely in sandy or gravelly form, which would facilitate its collection, the removal of sea water, handling and ultimate use. Because of the abundance and greater convenience of limestones, marls and marbles on land, calcareous sediments from the Chatham Rise are unlikely ever to have much value in their own right. However, were they to be produced as a by-product of phosphate and potash exploitation, it might be worth while to utilise them rather than attempt to separate them from glauconite and phosphorite. Emery (1960, p. 319) reports on an experiment in which about 10 kg of sediment from one of the basins off southern California produced favourable results (after the salts were leached out) when applied as a fertiliser to grass. It would seem worth while to collect several large samples of sediment from the Chatham Rise for the purpose of running some field trials on New Zealand grasses and perhaps other crops.

The technological problems of recovery of sediment from the Chatham Rise, assuming a demonstration of their agricultural value, should not be especially serious. Some American firms are currently investigating the feasibility of recovering manganese nodules from the deep sea floor off California (Mero, 1959).

A detailed survey of Chatham Rise is not only very desirable scientifically, but would appear to be the first step required for any programme of exploitation of the resources there.

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REFERENCES

Baumgart, I. L.; Healy, J. 1956: Recent Volcanicity at Taupo, New Zealand. *Proc. 8th Pac. Sci. Congr. 2* : 113–25.

Boreham, A. U. E. 1959: Cretaceous Fossils from the Chatham Islands. *Trans. roy. Soc. N.Z. 86* : 119–25.

Burling, R. W. 1961: Hydrology of Circumpolar Waters South of New Zealand. *N.Z. Dep. sci. industr. Res. Bull. 143*: 66 pp.

Clark, J. S.; Turner, R. C. 1955: Reactions between Solid $CaCO_3$ and Orthphosphate Solutions. *Canad. chem. J. 33* : 665–71.

Cloud, P. E., jun. 1955: Physical Limits of Glauconite Formation. *Bull. Amer. Ass. Petrol. Geol. 39* : 484–92.

Cooper, L. H. N. 1948: The Distribution of Iron in the Waters of the Western English Channel. *J. Mar. biol. Ass. U.K. 27* : 279.

Cullen, D. J. 1962: The Significance of a Glacial Erratic from the Chatham Rise, East of New Zealand. *N.Z. J. Geol. Geophys. 5* : 309–13.

Dietz, R. S.; Emery, K. O.; Shepard, F. P. 1942: Phosphorite Deposits on the Sea Floor off Southern California. *Bull. geol. Soc. Amer. 53* : 815–48.

Emery, K. O. 1960: "The Sea off Southern California." John Wiley and Sons, New York.

Evison, F. F. 1960: On the Growth of Continents by Plastic Flow under Gravity. *Geophys. J. 3* : 155–90.

Fairbridge, R. W. 1961: Eustatic Changes in Sea Level. *Physics and Chemistry of the Earth. 4* : 99–185. Pergamon Press, New York.

Fleming, C. A.; Reed, J. J. 1951: Mernoo Bank, East of Canterbury, New Zealand. *N.Z. J. Sci. Tech. B. 32 (6)* : 17–30.

Gage, M. 1957: The Geology of the Waitaki Subdivision, *N.Z. geol. Surv. Bull. n.s. 55.*

Galliher, E. W. 1931: Collophane from Miocene Brown Shales of California. *Bull. Amer. Ass. Petrol. Geol. 15* : 257–69.

Grim, R. E. 1953: "Clay Mineralogy." John Wiley and Sons, New York.

Grindley, G. W.; Harrington, H. J.; Wood, B. L. 1959: The Geological Map of New Zealand. *N.Z. geol. Surv. Bull. n.s. 66.*

Harvey, H. W. 1937: The Supply of Iron to Diatoms. *J. Mar. biol. Ass. U.K. 22* : 205.

Haylock, O. S. 1956: A Fractionation of Acid-Soluble Non-exchangeable Potassium in some New Zealand Soils into Available and Non-available Forms. Ph.D. Thesis, University of New Zealand. Copy on file at Massey University.

Hedley, R. H. 1960: The Iron-Containing Shell of *Gromia oviformis* (Rhizopoda). *Quart. J. micr. Sci. 101, 3* : 279–94.

Knox, G. A. 1957: General Account of the Chatham Islands 1954 expedition. *N.Z. Dep. sci. industr. Res. Bull. 122* : 37 pp.

Krause, D. C. in press: Structure of Bounty Trough, *N.Z. Dep. sci. industr. Res. Bull.*

Macpherson, E. O. 1948: The Otaihanga Faulted Outlier and Notes on the Greensand Deposit. *N.Z. J. Sci. Tech. B.30 (2)* : 70–83.

Macpherson, E. O.; Hughson, W. G. 1943: Wax from Chatham Island Peat. *N.Z. J. Sci. Tech. B. 25 (1)* : 1–44.

Mero, J. L. 1959; "The Mining and Processing of Deep-Sea Manganese Nodules." Institute of Marine Resources, University of California, Berkeley.

Metson, A. J. 1960: Some Factors Affecting the Potassium Status of New Zealand Soils. *Potash Rev. 4/24* : 1–10.

Metson, A. J.; Arbuckle, R. H.; Saunders, Mary L. 1956: The Potassium-Supplying Power of New Zealand Soils as Determined by a Modified Normal Nitric Acid Method. *Proc. 6th int. Congr. Soil Sci. (Paris) B* : 619–27.

Norris, R. M. 1951: Marine Geology of the San Nicolas Island Region, California. Unpublished Doctoral Dissertation, Scripps Institution of Oceanography, University of California, La Jolla.

N.Z. Soil Bureau 1954: General Survey of the Soils of North Island, New Zealand. *N.Z. Soil Bur. Bull. n.s. 5.*

Pantin, H. M. 1964: *In* Studies of a Southern Fiord. Ed. by Skerman. T. M. *N.Z. Dep. sci. industr. Res. Bull. 157.*

Reed, J. J.; Hornibrook, N. de B. 1952: Sediments from the Chatham Rise. *N.Z. J. Sci. Tech. B. 34 (3)* : 173–88.

Ross, C. S. 1928: Altered Paleozoic Volcanic Materials and their Recognition. *Bull. Amer. Ass. Petrol. Geol. 12* : 143–64.

Speight, R. 1943: The Geology of Banks Peninsula. *Trans. roy. Soc. N.Z. 73* : 13–26.

Sverdrup, H. U.; Johnson, M. W.; Fleming, R. H. 1946: "The Oceans." Prentice-Hall, New York.

Urry, W. D. 1949: Radioactivity of Ocean Sediments: VI. Concentrations of the Radio-elements in Marine Sediments of the Southern Hemisphere. *Amer. J. Sci. 247* : 257–75.

Winchell, A. N. 1933: "Elements of Optical Mineralogy," 3rd ed. John Wiley and Sons, New York.

APPENDIX 1 — STATION LIST

N.Z.O.I. STATIONS

No.	Date	Lat. S	Long.	Depth (m)	Sampling gear*	Cruise
A 307	20/7/56	42° 55′	177° 26′W	640	D.G.	Cruise III 56, *Tui*
A 309	28/7/56	44° 17′	174° 52′ E	545	D.G.	Cruise IV 56, *Tui*
B 441	15/5/61	41° 25′	176° 45′ E	2960	P.C.	Chathams II 61, *Viti*
B 442	16/5/61	42° 28·7′	176° 44·5′ E	2000	P.C.	Chathams II 61, *Viti*
B 443	16/5/61	42° 37′	176° 42′ E	1180	P.C.	Chathams II 61, *Viti*
B 444	16/5/61	42° 51′	176° 39′ E	585	P.C.	Chathams II 61, *Viti*
B 445a	17/5/61	43° 02′	177° 00′ E	372	P.C.	Chathams II 61, *Viti*
B 445b	17/5/61	43° 02′				
B 446	17/5/61	43° 31′	176° 59′ E	250	P.C.	Chathams II 61, *Viti*
B 447	18/5/61	42° 15·8′	176° 57′ E	2750	P.C.	Chathams II 61, *Viti*
B 448	19/5/61	41° 31′	176° 30′ E	2000	P.C.	Chathams II 61, *Viti*
B 449	19/5/61	41° 22′	176° 21′ E	1195	P.C.	Chathams II 61, *Viti*
B 515	5/2/62	43° 27′	175° 03′ E	146	D.C.	Magnet I 62, *Taranui*
B 517	11/2/62	43° 05′	175° 20′ E	2853	D.C.	^{14}C Jan 62, *Taranui*
B 518	11/2/62	43° 12′	175° 20′ E	132	D.C.	^{14}C Jan 62, *Taranui*
B 519	12/2/62	43° 15′	174° 17′ E		P.C.	^{14}C Jan 62, *Taranui*
C 593	8/11/60	43° 30′	178° 00′ E	351	G.H.O.M. + corer	Carbon III 1960, *Viti* ^{14}C Cruise III Nov 60, *Viti*
C 594	9/11/60	43° 17′	176° 00′ E	300	G.H.O.M. + corer	^{14}C Cruise III Nov 60, *Viti*
C 595	10/11/60	43° 23′	175° 17′ E	70, 80, 95	G.H.O.M.	^{14}C Cruise III Nov 60, *Viti*
C 599	23/4/61	44° 54′	174° 30′ E	845	D.C.	Chathams Cruise Apr–May 61, *Viti*
C 601	24/4/61	44° 18′	176° 13′ E	140	D.D. and G.H.O.M.	Chathams Cruise Apr–May 61, *Viti*
C 602	24/4/61	43° 13·2′	176° 40·3′ E	285	D.D. and G.H.O.M.	Chathams Cruise Apr–May 61, *Viti*
C 603	25/4/61	42° 31′	176° 41·9′ E	1530	D.D.	Chathams Cruise Apr–May 61, *Viti*
C 605	26/4/61	43° 40′	179° 30′ E	440–460	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 606	26/4/61	44° 15·2′	179° 35·4′ E	990–1000	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 607	27/4/61	43° 48′	179° 00′ W	420–430	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 608	27/4/61	43° 19′	179° 00′ W	450–465	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 609	27/4/61	43° 03′	178° 58′ W	570–580	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 617	30/4/61	43° 58·4′	175° 22·9′ W	300–286	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 618	30/4/61	43° 52′	175° 20′ W	625–690	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 619	2/5/61	43° 52′	174° 48′ W	780–805	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 620	2/5/61	43° 40′	174° 47′ W	740–755	D.D. + P.D.	Chathams Cruise Apr–May 61, *Viti*
C 621	6/5/61	43° 56·4′	176° 33·3′ W	13	G.H.O.M.	Chathams Cruise Apr–May 61, *Viti*
C 623	7/5/61	44° 25·5′	175° 16′ W	400–702	D.D. and Dp.S	Chathams Cruise Apr–May 61, *Viti*

OTHER COLLECTIONS

Registration No.						
Z 191	1952	43° 57′	173° 57′ E	220	Worzel Sampler	Lachlan Station 225/52
Z 269	4/11/50	43° 48′	178° 58′ W	287	D.C.	Sta. 2733 RRS *Discovery II*
Z 270	31/1/54	43° 55·5′	177° 08′ W	172	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 272	21/1/54	43° 56′	176° 18·5′ W	55	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 273	7/2/54	43° 34′	176° 02′ W	284	O.T., D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 274	7/2/54	43° 35′	176° 03·5′ W	220–229	D.L., O.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 275	31/1/54	43° 56·7′	176° 33·3′ W	13	D.A.	Chatham Islands 1954 Expedition MV *Alert*
Z 276	29/1/54	43° 36·2′	176° 48·5′ W	70	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 277	28/1/54	43° 42′	176° 22′ W	27	D.L., O.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 278	28/1/54	43° 39′	176° 34·5′ W	37	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 279	30/1/54	43° 57′	176° 47′ W	91	D.L., O.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 280	7/2/54	43° 44′	176° 15·5′ W	6	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 281	31/1/54	43° 56·5′	176° 37′ W	40	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 282	10/2/54	44° 04′	178° 04′ W	475	D.L., B.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 283	27/1/54	44° 01·2′	176° 21·7′ W	7–11	D.L., O.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 284	3/2/54	44° 32′	176° 50′ W	283	D.L., O.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 285	3/2/54	44° 35·5′	176° 04′ W	603	O.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 286	2/2/54	44° 17·2′	176° 18·7′ W	79	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 287	2/2/54	44° 21·5′	176° 13′ W	55	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 288	1/2/54	44° 04′	175° 23·5′ W	238	D.L., O.T., D.S.	Chatham Islands 1954 Expedition MV *Alert*
Z 993	11/2/54	43° 40′	177° 59′ E	585	D.L., B.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 994	11/2/54	43° 38′	177° 19′ E	530	D.L., B.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 996	24/1/54	43° 40′	179° 28′ E	402	D.L., B.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 1012	23/1/54	43° 14′	176° 11′ W	366	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 1013	23/1/54	43° 10·15′	175° 29′ E	75	D.L.	Chatham Islands 1954 Expedition MV *Alert*
Z 1014	12/2/54	43° 36′	175° 31′ E	375	B.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 1015	23/1/54	43° 03·5′	175° 18·5′ E	183	D.L., D.N.	Chatham Islands 1954 Expedition MV *Alert*
Z 1016	23/1/54	43° 08′	175° 25′ E	112	D.N., O.T.	Chatham Islands 1954 Expedition MV *Alert*
Z 1036	2/61	43° 20′	179° 31′ E	421	D.Ch.	*Argo* Scripps Inst. Feb 61
Z 1037	2/61	43° 15′	178° 30′ W	402	D.Ch.	*Argo* Scripps Inst. Feb 61

*The following abbreviations are used: B.T., beam trawl; D.A., anchor dredge; D.C., cone dredge; D.Ch., chain dredge; D.D., Devonport dredge; D.G., Dietz grab; D.L., large dredge, 3 ft x 1 ft; P.D., pipe dredge; D.S., salpapattern dredge; Dp.S., downpipe sampler; O.T., otter trawl; P.C., piston corer.

APPENDIX 2 — INORGANIC MINERALS*

	A 307	A 309	B 441 A	B 441 B	B 441 C	B 442 A	B 442 B	B 442 C	B 443 A	B 443 B	B 444 A	B 444 B	B 444 C	B 445 AA	B 445 AB	B 445 BA	B 445 BB	B 445 BC	B 445 BD	B 446 A	B 446 B	B 446 C	4 447 A	B 447 B	B 448	B 449	B 515	B 519A	B 519 B	B 519 C	C 593	C 594	C 599	C 601	C 602	C 603	C 605
Apatite																																	R				
Augite	R		R		R	R	R	R	U	R	R		R	U		U		U	R		U	U	U	R	R	M	U				R	R	R	U	U	R	R
Basaltic hornblende																																					
Biotite			R					R											R	R							U	R		R	R						
Chlorite group		R	M		R																				R	R	M	M		U	R		M				
Clinozoisite																													R								
Diaspore																																					
Epidote																													R				R				
Feldspar group	C	A	C	M	C	M	C	M	M	M	M	M	M	M	M	M	M	M	U	M	M	M	M	U	M	M	A	A	A	A	M	M	A	M	M	C	M
Garnet	R																				R											R			R		
Glass	U	M	M	A	C	M	M	A	A	A	A	A	A	M	U	C	M	C	U	U	R		M	A	M	C		M	M		M	M	R	M	M	A	C
Glauconite	C			U	U	M	M				M	M	U	A	C	A	A	A	R	A	A	A	U	U	R			M	M		A	A	M	C	A	U	C
Hornblende	U		R	U	R	R	R	R	R	U		R	R			R	U	U		R	R			R	R	U		R		R		U	U		R	R	U
Hypersthene		R	R	R	R		R		R	R		U	U	U	U	R	U	R	R	R	R	R	R	R		M				R	R	R			R	U	R
Monazite																																					
Muscovite																			R																		
Olivine group																																					
Opaques	U		M	U	M	M	M		M	U		U		R		R	R	R		U		U	M	R	M	M		R	R	R			R	M			
Quartz	U	M	M	R	M	U	M	U	U	U	U	R				U	M	U	U	R	U	U			M	M	M	M	M	U	R	U	M	M	R	U	U
Rutile																																					
Staurolite																																					
Titanaugite																																					
Titanite																																					
Topaz																																					
Tourmaline																																					
Zircon								R					R	R		R										R					R						R
Zoisite																																					

*Excluding calcite and aragonite.

C 606	C 607	C 608	C 609	C 617	C 618	C 619	C 620	C 621	C 623	Z 191	Z 270	Z 272	Z 273	Z 274	Z 275	Z 276	Z 277	Z 278	Z 279	Z 280	Z 281	Z 282	Z 283	Z 284	Z 285	Z 286	Z 287	Z 288	Z 993	Z 994	Z 996	Z 1012	Z 1013	Z 1014	Z 1015	Z 1016	
																																					Apatite
R	R	U	R	U	U	R	M	U				M	R		M	U	U	U	U	M	M		M	U	U	R	U	U					M	R	U	R	Augite
																										R										R	Basaltic hornblende
												U		U							U						R										Biotite
R														M		U			U	U					U				R								Chlorite group
												U		U	U						U																Clinozoisite
																																					Diaspore
															U								U		R												Epidote
M	M	M	M	M	M	M	M	A	C	M	A	C	C	C	A	A	A	A	A	A	C	M	M	A	C	A	M	A	M	M	M	M	C	M	C	M	Feldspar group
																	U						U					R									Garnet
M	A	A	A	M	U	A	A		M		U		C	M		U				U		A		M	C	M	U	R	A	U	A	U	U	R	M	M	Glass
A	C	M	M	M	A	M	M		M	R	U		M	M		U		U						M	U	U	U	M	U	A	M	A	M	A	C	M	Glauconite
	U				U				U			U		U		U	U			U		U		U	R	R		R	R		R	U		R	R		Hornblende
U	R	R	R	U		R		U					R	U		U			U	U	U	U				U	R	R		U	U		U	R	U	R	Hypersthene
														U																							Monazite
																						R															Muscovite
												U						R							R		U										Olivine group
	R	U		M	U	R		U	C	U		M	U	U	M		U	U	U	U	M	U	C		M	M	A	U					M		U	R	Opaques
U	R	R	R	R		U	R	M	U	M	A	M	U	M	C	C	C	M	M	M	M		M		U	M	U	M			R	M	M	M	M	M	Quartz
				R						R																											Rutile
								U																													Staurolite
																U							R														Titanaugite
																							R														Titanite
										R		R		R																							Topaz
	R																													U							Tourmaline
						R						U			U	U							U											R			Zircon
								U							U											R		R									Zoisite

KEY: A, Abundant (>50%); C, common (25–50%); M, moderately common (5–25%); U, uncommon (1–5%); R, rare (<1%); no symbol, absen

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[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. Yaldwin. (*Published May 1960*)	*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. (*Published May 1960*)	*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. (*Published May 1960*)	*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. Edmonds. (*Published May 1960*)	*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	In press	Bathymetry of the New Zealand Region. By J. W. Brodie	*N.Z. Dep. sci. industr. Res. Bull. 161.*
12	In press	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. (*Published September 1961*)	*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 pre-	Marine Geology of Cook Strait. By J. W. Brodie	*N.Z. Dep. sci. industr. Res. Bull.*
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17	In press	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. (*Published September 1961*)	*N.Z. Dep. sci. industr. Res. Bull. 142.*
19	1962	The Fauna of the Ross Sea. Part 2. Scleractinian Corals. By Donald F. Squires. (*Published November 1962*)	*N.Z. Dep. sci. industr. Res. Bull. 147.*
20	1963	*Flabellum rubrum* (Quoy and Gaimard). By Donald F. Squires. (*Published December 1963*)	*N.Z. Dep. sci. industr. Res. Bull. 154.*
21	1963	The Fauna of the Ross Sea. Part 3. Asteroidea. By Helen E. Shearburn Clark. (*Published December 1963*)	*N.Z. Dep. sci. industr. Res. Bull. 151.*
22	1964	The Marine Fauna of New Zealand: Crustacea Brachyura. By E. W. Bennett. (*Published April 1964*)	*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. (*Published December 1963*)	*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	In press	A Foraminiferal Fauna from the Western Continental Shelf, North Island, New Zealand. By R. H. Hedley, C. M. Hurdle, and I. D. J. Burdett.	*N.Z. Dep. sci. industr. Res. Bull.*

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COMPOSITION AND SIZE DISTRIBUTION OF SOME CHATHAM RISE SEDIMENTS

LEGEND

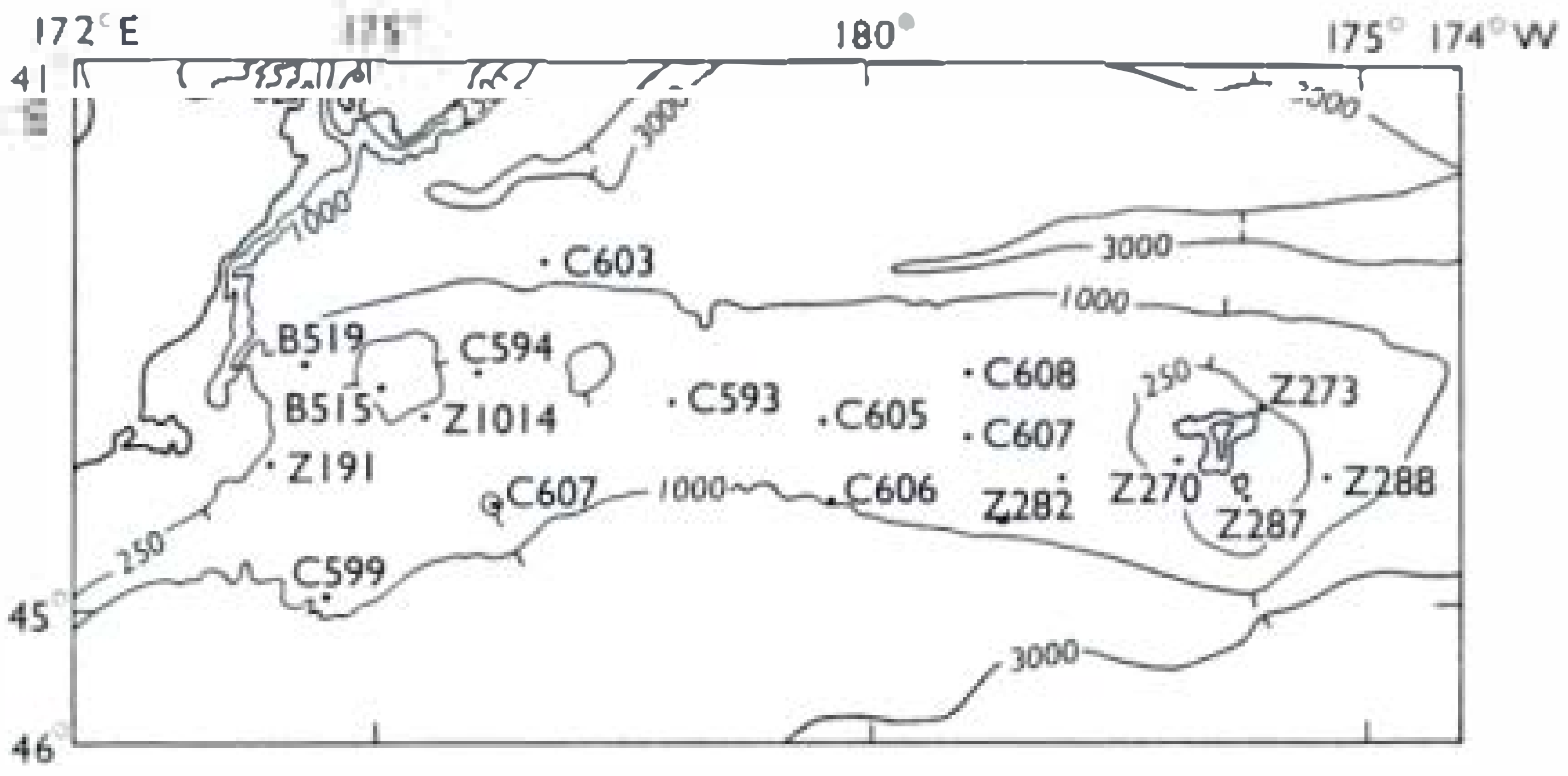
⬜ CALCAREOUS MATERIALS

🟧 VOLCANIC GLASS

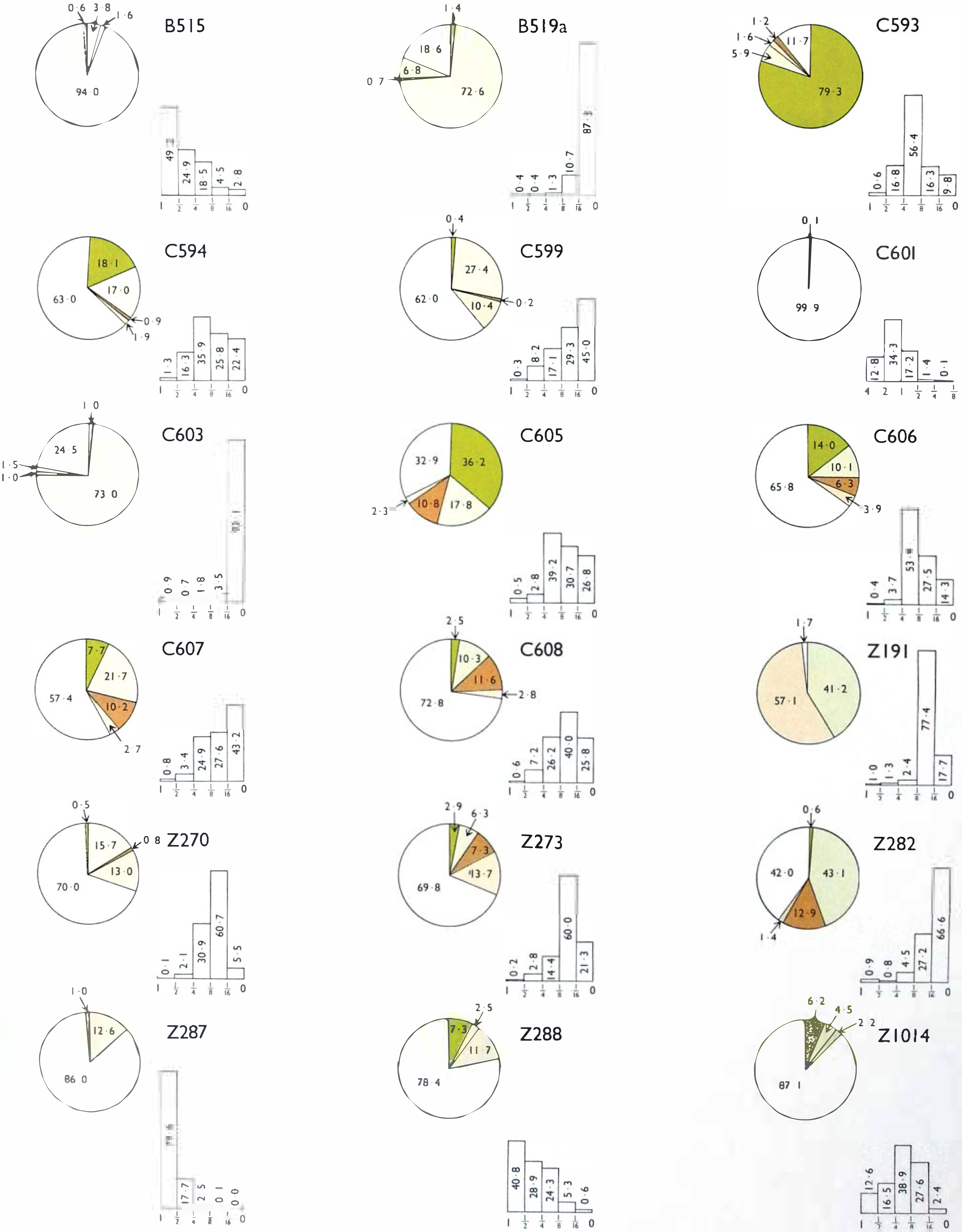
⬜ ROCK & ROCK-FORMING MINERALS

🟩 GLAUCONITE

⬜ SILT & CLAY



Histograms expressed in percentages Size grades in mm.



DESCRIPTIONS OF CORES

TO ACCOMPANY N.Z. OCEANOGRAPHIC
INSTITUTE MEMOIR NO. 26

CHATHAM RISE SEDIMENTS

SCALE 1 : 2,191,400 AT LAT. 0°

NOT TO BE USED FOR NAVIGATIONAL PURPOSES
MISCELLANEOUS SERIES NO. 6

Drawn by B. W. Creed

R. E. Owen, Government Printer, Wellington, N.Z.

C. T. T. Webb, Chief Cartographer

Bathymetry adapted from N.Z. Oceanographic Institute Charts, Oceanic Series 1 : 1,000,000 Bathymetry, Bounty, Coastal Series 1 : 200,000 Bathymetry, Turnagain 1962; and General Bathymetric Chart of the Oceans, Sheet A II, 3rd edition. Bathymetry compiled by J. G. Gibb. Depths are in metres.

Percentage $CaCO_3$ by weight in total sediment

0
25
50
75
90
100

References

Glauconite :

Approximate percentage by weight in total sediment

Isobaths (Depths in metres)

Down-slope direction

NEW ZEALAND OCEANOGRAPHIC INSTITUTE
WELLINGTON

Published by the Department of Scientific & Industrial Research, 1963

Sediment distribution patterns by R. M. Norris; analyses by Dominion Laboratory, D.S.I.R.
This chart is not to be used for navigational purposes.
Refer to this chart as N.Z. Oceanographic Institute Chart, Miscellaneous Series No. 6, Chatham Rise Sediments, 1963.