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The Fauna of the Ross Sea

PART 6

Ecology and Distribution of Foraminifera

by
JAMES P. KENNETT

New Zealand Oceanographic Institute

Memoir No. 46

1968

THE FAUNA OF THE ROSS SEA

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Photograph: F. O'Leary

Ice flows in Robertson Bay, west of Cape Adare. Admiralty Range is in the distance.

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FOREWORD

Each summer season, since 1956–57, the New Zealand Oceanographic Institute has undertaken one or more research cruises in the Antarctic. Initially these were part of the International Geophysical Year programmes and their extensions, but they have been continued as part of the New Zealand Antarctic Research Programme.

The major efforts of the 1958–59 and 1959–60 seasons were devoted to an oceanographic survey of the Ross Sea. This survey yielded substantial collections of benthic animals as well as associated hydrological information, sediment samples, plankton, and fish.

Each of these expeditions was led by J. S. Bullivant. In 1958–59 he was assisted by D. G. McKnight and A. G. Macfarlane of the Institute staff, and N. A. Powell of Antarctic Division, D.S.I.R.; John Reseck, jun. (Long Beach State College, California) and Dr R. K. Dell (Dominion Museum, Wellington) were co-workers; in 1959–60, G. A. Harlen and E. C. French of Antarctic Division, D.S.I.R. assisted. Further small collections were made in 1960–61 by G. A. Harlen, A. E. Gilmour, and S. C. Watts of the Institute staff, and by C. E. Devine, D. W. Farmer, and M. R. Gregory of Antarctic Division, D.S.I.R.

The co-operation of the New Zealand Naval Board and of the commanding officer and the ship's company of HMNZS *Endeavour* is gratefully acknowledged. The Antarctic Division has materially assisted the field and laboratory work by the secondment of staff and provision of equipment.

The material reported on by Dr Kennett in the present memoir comes from the samples obtained on the two major cruises in 1958–59 and 1959–60.

The preliminary editing of the manuscript has been carried out by Dr D. E. Hurley.

Further results of examinations of the collections will be published as studies of other groups are completed.

J. W. Brodie,
Director,
N.Z. Oceanographic Institute.

CONTENTS

Ecology and Distribution of Foraminifera

James P. Kennett

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Abstract

In order to describe the foraminiferal distribution in the Ross Sea and the controlling environmental factors, 48 bottom grab and trawl samples have been analysed for their foraminiferal and sedimentary characteristics. Additional information from 60 samples of earlier workers has been included. The environmental factors studied include bathymetry, bottom temperature and salinity, median diameter of the sediment, calcium carbonate percentage, and geographic location.

Several abrupt changes in the fauna take place with increased depth and indicate boundaries to depth zones at approximately 270m, 450–550m, and 2,200m.

Two separate and greatly contrasting microfaunal types occur: calcareous, dominated by abundant and diverse calcareous Foraminifera; and arenaceous, dominated by non-calcareous, sparse Foraminifera. Most calcareous faunas are restricted to depths shallower than 550m whereas all arenaceous faunas are at depths greater than 430m. Planktonic Foraminifera, like the calcareous benthonic forms, are abundant in the calcareous faunas, but absent from or rare in the arenaceous faunas. The most obvious and important relation is that between depth and test composition. No definite relation has been found between texture of bottom sediment and test composition.

The depth distribution of the arenaceous and calcareous faunas, the distribution of planktonic Foraminifera, and the evidence of solution effects on calcareous Foraminifera in arenaceous faunas suggest the presence of a shallow calcium carbonate solution boundary in the Ross Sea at depths of approximately 500–550m. It seems that the observed solution of calcareous organisms below this depth is due to high carbon dioxide concentration and low temperatures. Calcareous and arenaceous foraminiferal faunas are associated respectively with macrofaunas having many and few calcareous forms. Solution, however, is less apparent on the macro-organisms.

INTRODUCTION

The Ross Sea lies in the Pacific sector of the Antarctic and occupies one of the two large embayments of the Antarctic continent (fig. 1). The sea, approximately 665,000 nautical square miles in area, is bounded on the west by Victoria Land and on the east by Marie Byrd Land. The southern boundary of the sea is formed by the floating margin of the Ross Ice Shelf, the seaward edge of which lies roughly at 78°S. To the north, the Ross Sea merges into the circumpolar Southern Ocean.

This paper describes the foraminiferal distribution in the Ross Sea and the environmental factors influencing this. Foraminifera have been studied from 48 bottom sediment samples (figs. 2, 3) collected within the Ross Sea by the New Zealand Oceanographic Institute during three cruises on HMNZS *Endeavour*. Samples were taken at depths ranging from 90 to 3,570 m.

The first of these cruises (January and early February 1959) involved a survey of the Ross Sea, and the second (January and February 1960) included bathymetric and oceanographic work. Both these cruises were led by Mr J. S. Bullivant. The third cruise (January and February 1961), led by Mr G. A. Harlen, was mainly hydrological and only nine additional sediment samples were obtained.

Information from samples collected during these cruises has been supplemented by that from five previous publications dealing with Foraminifera from the Ross Sea. Table 1 lists the latitude, longitude, date, depth in metres, and type of sediment sampling gear for each station.

The numerous publications dealing with Foraminifera from the Antarctic as a whole have been reviewed by McKnight (1962) and include the *Challenger* Expedition, 1873–6 (Brady, 1884); the German South Polar Expedition, 1901–3 (Wiesner, 1931); the *Scotia* Expedition, 1903–4 (Pearcey, 1914); the British Antarctic Expedition,

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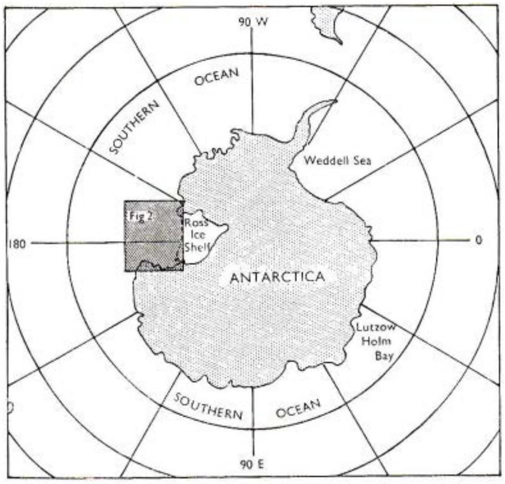
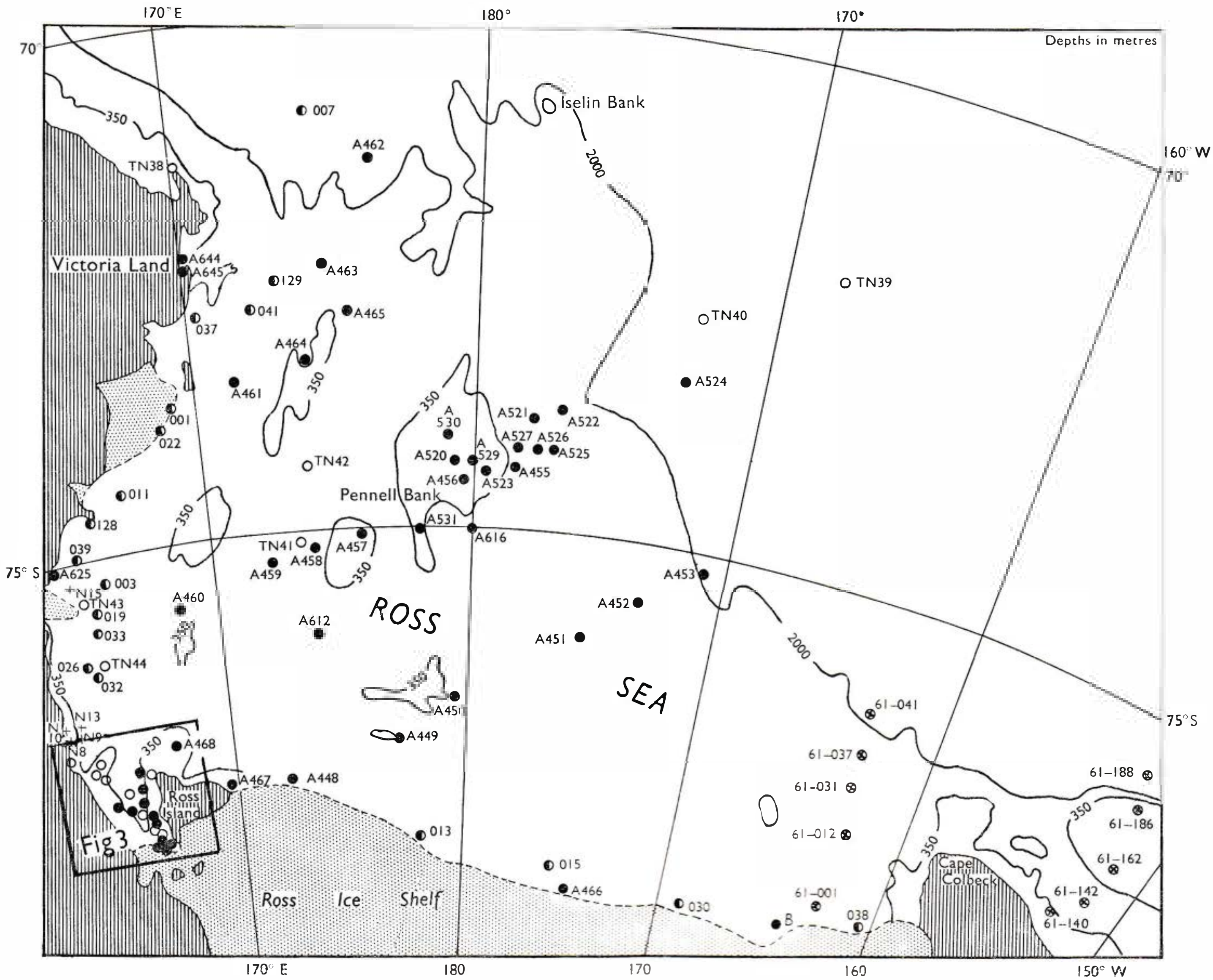


FIG. 1. Location of study area ;the Ross Sea.

FIG. 2. Microfaunal collecting stations with indications of samples. Those examined by the writer, solid circle; McKnight (1962), half solid circle; Pflum (1963), cross enclosed by open circle; Heron-Allen and Earland (1922), open circle; Chapman (1916a), cross; Warthin (1939), B.



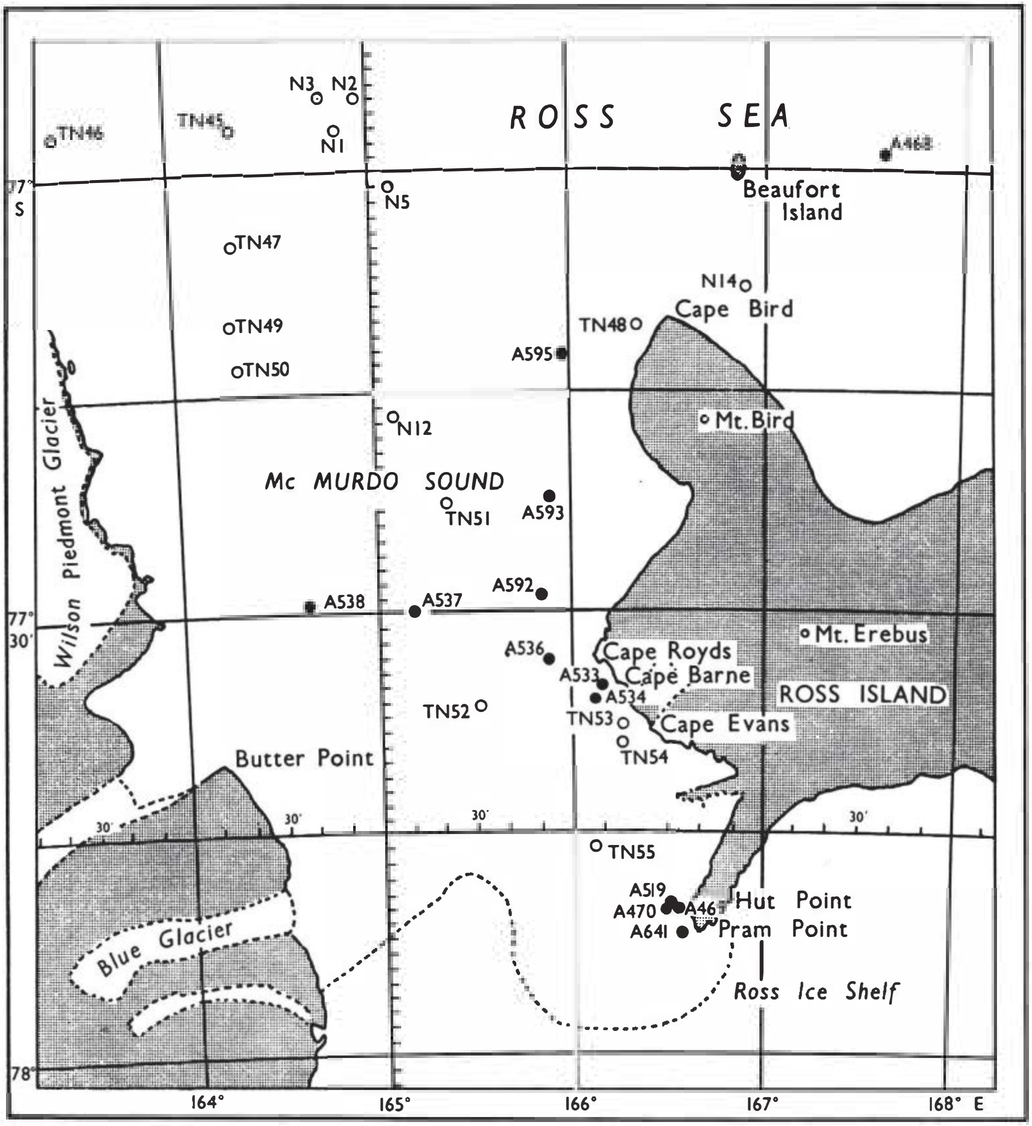


FIG. 3. Microfaunal collecting stations in the McMurdo Sound area. Samples examined by the writer are prefixed with A; by Heron-Allen and Earland (1922) with TN; and by Chapman (1916a) with N.

1907–9 (Chapman, 1916a, b); the *Terra Nova* Expedition, 1910 (Heron-Allen and Earland, 1922); *Discovery* Reports (Heron-Allen and Earland, 1932; Earland, 1933, 1934, 1936); the B.A.N.Z. Antarctic Research Expedition, 1929–31 (Parr, 1950).

Only recently have any papers been published concerning the ecology of Antarctic Foraminifera. The first of these was by Uchio (1960) who carried out a quantitative study of benthonic Foraminifera in 10 samples and recognised three depth assemblages in the Lutzow-Holm Bay area. Saidova (1961) discussed the general quantitative distribution of Foraminifera in the Indian Ocean sector of the Antarctic, especially the relation between arenaceous and calcareous benthonic faunas. McKnight (1962) and Pflum (1963) presented quantitative data on foraminiferal distribution; 19 of McKnight's samples came from the Ross Sea, and 10 of Pflum's from the eastern Ross Sea. Both recorded three foraminiferal depth assemblages. Bandy and Echols (1964) used McKnight's quantitative data to distinguish eight general depth assemblages. Most recently, Blanc-Vernet (1965) discussed the distribution of Foraminifera in nine samples from the Adelie Land coast.

TABLE 1. Station List, Ross Sea Oceanographic Survey Microfaunal Samples

N.Z.O.I. Station	Date	Locality	Lat.	Long.	Depth (metres)	Gear*
A 448	10 1 59	I mile from Ross Ice Shelf	77°27′S	172°22′E	752	GTOS, TAS
A 449	11 1 59	Ross Sea	77°05′S	177°12′E	362	GTOS, TAS
A 450	11 1 59	Ross Sea	76°42′S 76°36′S	179°44′E 179°53′E	472–318	GTHO, TAS, GTOS
A 451	12 1 59	Ross Sea	76°00′S 75°50′S	175°25′E 175°20′E	523	GTHO, TAS, GD
A 452	12 1 59	Ross Sea	75°35′S	173°18′W	1,280–1,300	GTHO, TAS
A 453	13 1 59	Ross Sea	75°09′S	171°0′W	2,195	GHO
A 455	15 1 59	Pennell Bank	74°22′S	178°35′W	322–340	GTHO, GD, DN
A 456	15 1 59	Pennell Bank	74°30′S	179°40′W	238–301	GTHO, TAS
A 457	16 1 59	Pennell Bank	75°02′S	175°50′E	315–400	GTHO, TP
A 458	16 1 59	Ross Sea	75°10′S	174°00′E	461–486	GTHO, GD, Corer, TP
A 459	16 1 59	Ross Sea	75°17′S	172°20′E	534–549	GTHO, TP, Corer
A 460	17 1 59	Ross Sea	75°38′S	168°32′E	415–430	GTHO, GD, Corer, TP
A 461	18 1 59	E of Coulman I.	73°32′S	171°22′E	578–567	GTHO, Corer, TP
A 462	20 1 59	Ross Sea	71°15′S	176°30′E	1,831–2,381	GHO, DN
A 463	21 1 59	Ross Sea	72°20′S	174°50′E	468–465	GTHO, TAS, GD, TP
A 464	22 1 59	NW Ross Sea	73°20′S	174°00′E	369–384	GTHO, DN
A 465	22 1 59	NW Ross Sea	72°55′S	175°30′E	399	GD, DC
A 466	24 1 59	Off Ross Ice Shelf	78°26′S	174°50′W	569	GTHO, TAS, Corer
A 467	26 1 59	Off Cape Crozier	77°25′S	169°28′E	88–183	DN
A 468	26 1 59	E of Beaufort I.	76°59′S	167°36′E	110	TAS
A 469	29 1 59	McMurdo Sound	77°50′S	166°33′E	64	GTHO
A 470	4 2 59	McMurdo Sound	77°50′S	166°30′E	377	GTHO
A 519	29 1 60	McMurdo Sound	77°49′50″S	166°30′45″E	479	GHO
A 520	3 2 60	Pennell Bank	74°20′S	179°30′E	201–205	GHO, DN
A 521	4 2 60	Pennell Bank	73°54′S 73°52′36″S	177°44′W 177°46′W	582–558	GHO, GTP, DD
A 522	4 2 60	Pennell Bank	73°48′S 76°50′S	176°41′W 176°54′W	1,335	GHO, GTHO, DD, GD
A 524	5 2 60	E Pennell Bank	73°20′S 73°21′S	172°48′W 172°48′W	3,566–3,577	GTHO
A 525	7 2 60	Pennell Bank	74°09′S 74°07′S	177°16′W 177°09′W	591–583	DD
A 526	7 2 60	Pennell Bank	74°07′S	177°41′W	461–465	GHO, DD
A 527	7 2 60	Pennell Bank	74°10′S	178°17′W	358–337	GHO, DD
A 528	7 2 60	Pennell Bank	74°23′S	179°26′W	274–265	DD
A 529	8 2 60	Pennell Bank	74°20′S	179°55′W	205–220	DD
A 530	8 2 60	Pennell Bank (northern slope)	74°03′30″S 74°05′S	179°21′E 179°19′E	271–267	DD
A 531	9 2 60	Ross Sea (south-west of Pennell Bank)	75°02′S 75°12′S	173°10′E 178°14′E	348	DD
A 533	16 2 60	C. Barne	77°35′S	166°10′E	84–97	DD
A 534	16 2 60	C. Barne	77°36′42″S 77°36′S	166°08′E 166°12′E	380–366	DD
A 536	17 2 60	McMurdo Sound	77°33′18″S 77°34′36″S	165°53′E 165°50′E	794–790	DD
A 537	17 2 60	McMurdo Sound	77°30′S 77°34′48″S	165°12′E 165°19′E	574–543	DD
A 538	17 2 60	McMurdo Sound	77°29′12″S 77°30′S	164°39′E 164°38′E	269–256	GD
A 592	23 1 61	McMurdo Sound	77°28′8″S	165°52′5″E	865	GD
A 593	23 1 61	McMurdo Sound	77°23′4″S	165°54′E	1,015	GD
A 595	23 1 61	McMurdo Sound	77°12′6″S	165°59′E	865	GD
A 612	2 2 61	Ross Sea	76°00′S	174°00′E	612	GD
A 616	3 2 61	S Pennell Bank	75°00′S	180°00′E	470	GD
A 625	5 2 61	Terra Nova Bay	75°0′S	163°58′7″E	520	GHO
A 641	9 2 61	S Cape Armitage	77°51′7″S	166°34′5″E	322	GHO
A 644	1 3 61	Moubray Bay	72°18′8″S	170°14′46″S	530	GHO
A 645	1 3 61	Moubray Bay	72°22′0″S	170°9′6″E	720	GHO

* The following abbreviations are used:
DN—Naturalist's dredge; DD—Devonport dredge; GD—Dietz-LaFonde grab; GHO—Hayward orange-peel grab; GTHO—Two GHO together; TP—Toothed Petersen grab; TAS—Small Agassiz trawl; DC—Cone dredge; GTOS—Two small orange-peel grabs together.

METHODS OF STUDY

Various sediment sampling devices were used during the N.Z.O.I. cruises but most foraminiferal samples were obtained by orange peel or Dietz-La Fonde grabs. The former sampler was used whenever possible because of its larger capacity, whereas the Dietz-La Fonde was mainly of subsidiary use as a bottom weight for hydrological casts. To obtain multiple grab samples, two orange peel grabs were often lowered together, suspended at either end of a 120 cm bar. In areas of rocky bottom, adequate bottom samples were obtained by the use of a Devonport dredge.

The samples collected by these grabs represent the top 15–20 cm of the sedimentary column, but the surface centimetre was not separated out for foraminiferal studies. Foraminiferal faunas were not preserved so there is no information about living assemblages.

In the laboratory, approximately 80 gm of sediment was washed through a 200 mesh (0·074 mm) sieve, dried, and examined. Depending on the total number of Foraminifera present (ranging from 65 to about 74,000) the residue in some samples was split to provide a workable representative fraction.

Approximately 500 specimens were counted with the aid of a Swift point counter. The foraminiferal tests in all residues were then concentrated by floatation, using carbon tetrachloride. The floated fraction was checked for rare species, and percentages of each species in the whole foraminiferal assemblage were calculated.

Foraminiferal investigation of the sediment included, in addition to identification of species, the estimation of (a) percentage of each species in relation to the whole foraminiferal assemblage; (b) number of arenaceous and calcareous species; (c) percentage of arenaceous and calcareous benthonics and planktonics of the total foraminiferal assemblage; (d) percentage of arenaceous and calcareous benthonics of the total benthonic fauna.

Representative samples of the sediment were also used to determine grain size distribution and calcium carbonate content. Material with a diameter greater than 2 mm was regarded as glacial erratic and excluded from the sediment study. Material in the silt and mud range (less than 0·063 mm in diameter) was analysed by the pipette method described by Krumbein and Pettijohn (1938). The size distributions of grains between 0·063 and 2 mm were determined by wet sieving. Carbonate analyses of the sediment were carried out by the acidimetric method described in Dulemba (1963).

THE ROSS SEA ENVIRONMENT

Regional Physiography and Geology

To the west of the Ross Sea, a coastal mountain range extends the length of Victoria Land which is bounded at approximately 162°E by the high ice plateau of eastern Antarctica. The greater part of Victoria Land is completely covered by glaciers with the major flow eastward from the inland ice plateau through the coastal ranges to the Ross Sea. In the coastal ranges extensive névé fields feed alpine glaciers which contribute to the main valley glaciers. In southern Victoria Land, similar east-west trunk glaciers have retreated leaving an area of approximately 4,000 square miles almost completely free of ice.

The Ross Sea is bordered on the south-east by the portion of Marie Byrd Land known as King Edward VII Peninsula. This is made up of the Alexandra and Rockefeller Mountains, two parallel and almost completely ice covered mountain chains. To the south is the Ross Ice Shelf which has an area of 540,000 sq. km., and a thickness ranging from 200 m along the ice front to as much as 1,300 m some hundreds of kilometres further south (Swithinbank and Zumberge, 1965).

The terrain of Victoria Land consists of Lower Paleozoic and older crystalline basement made up of granites, metasediments, and dykes; these are unconformably overlain to the west by nearly horizontal Upper Paleozoic Beacon Group sandstones. Ferrar Dolerite Formation sills of Upper Mesozoic age intrude both the basement and the Beacon Group.

Cenozoic volcanics, chiefly of olivine basalt, trachyte, and phonolite (Smith, 1954), occur on the west side of the Ross Sea including Mt. Erebus, one of the two known active volcanoes in Antarctica.

King Edward VII Peninsula is composed of basement rocks consisting of highly folded metasediments intruded by granites (Wade, 1945). These basement rocks are somewhat similar to those of Victoria Land.

Bottom Topography

The Ross Sea floor (fig. 4) is atypical for Antarctica in having a wide continental shelf, as in the Weddell Sea. In other parts of Antarctica the shelf is notably narrow or absent. Typical, however, is the great depth at which the shelf break occurs, which, as Brodie (1965) points out, is about 800 m in the Ross Sea and is the result of the extensive carving action by outward moving ice during the glacial maximum. The shelf area is relatively deep with depths ranging from 100–1,000 m, but averaging 550 m. Two troughs with depths greater than 900 m occur immediately north of Ross Island.

The most conspicuous feature of the Ross Sea floor topography is the relatively shallow ridge which runs north-west from Cape Colbeck to the Pennell Bank. It broadens considerably and shoals towards Pennell Bank, reaching a minimum depth of only 100 m on the top of the bank. Taylor (1930) suggested that this bank represents a vast terminal moraine formed by a grounded ice shelf during a former glacial period.

From this shallow rise near the outer shelf the surface slopes gradually inland away from the shelf edge. Thus the shallow rise forms a brim to a basin-like depression to the south and south-west. The inland slope of this basin takes the form of several fairly narrow channels deeper than 550 m which converge near the Ross Ice Shelf to form a broad, deep basin. To the west of Ross Island a narrow, deep channel extends north towards this deep basin.

Very irregular bottom topography, especially in the western portion of the Ross Sea, is regarded as being due to the shaping of the shelf by glacial action. Two major re-entrants in the slope and shelf edge occur near the eastern and western margins of the Pennell Bank and Brodie (1965) has suggested that these indicate strongly localised but large-scale glacial action.

The shelf passes outwards into the continental slope which runs approximately north-west – south-east across the northern part of the Ross Sea. The topography of the slope appears to be regular in the south-east, but in the north-west it becomes very irregular and diversified by features with strong positive and negative relief. These features include the Iselin Bank, a positive feature of volcanic origin rising from depths of 3,000 m on the ocean floor to about 350 m.

In the western Ross Sea, volcanic islands form sharp rises above the general sea floor level. The volcanoes of Ross Island, Beaufort Island, Franklin Island, and Coulman Island are roughly aligned and are probably structurally related.

In the eastern Ross Sea and Sulzberger Bay, the shelf becomes very narrow. Very irregular topography occurs in this area, especially in Sulzberger Bay, where great depressions are found in the shelf close to shore. Lepley (1964) regards this topography as being formed by strong glacial erosion and deposition of moraine.

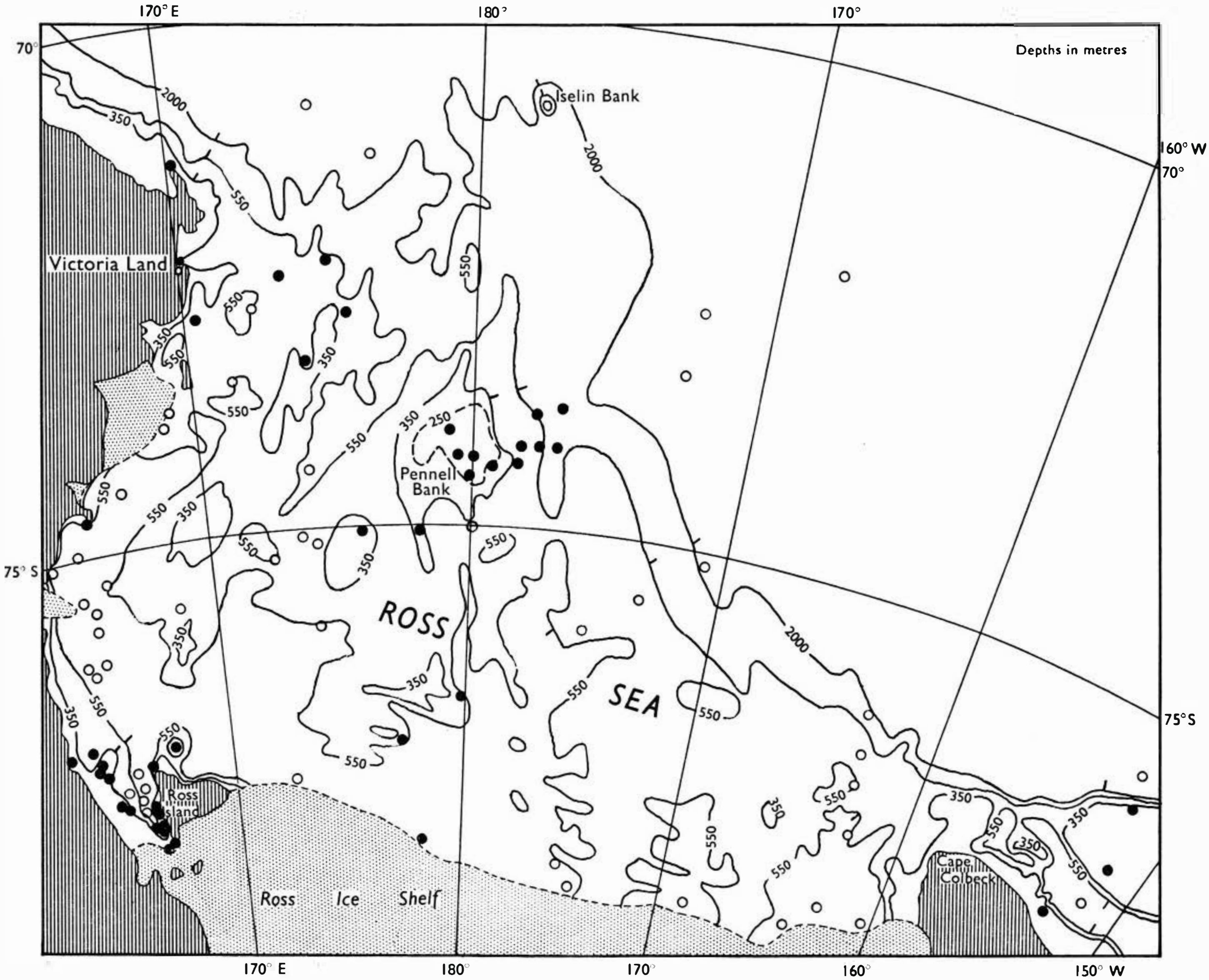


FIG. 4. Bottom topography of the Ross Sea showing the 350, 550, and 2,000 m contour intervals. Open circles indicate arenaceous foraminiferal faunas (<15% calcareous benthonics; >85% arenaceous Foraminifera); solid circles, calcareous foraminiferal faunas (>40% calcareous benthonic Foraminifera).

PHYSICAL OCEANOGRAPHY

The most recent and comprehensive study of hydrological conditions in the Ross Sea is by Newson, Francavillese, and Tierney (1965). Using detailed information from numerous traverses across the Ross Sea, these authors distinguish three general water types and two subtypes. These, in increasing order of depth, are the Upper Water, the Circumpolar Water, and the Shelf Water (Bottom Water). During the summer the Upper Water can be divided into Antarctic Surface Water (above) and Winter Water (below).

The Upper Water, extending to depths of about 400 m below the surface, is the least saline (33·50 to 34·45 ‰) and richest in oxygen (8·50 to 6·30 ml/l) and has intermediate temperatures (+1·50 to −1·90°c). It is practically homogeneous during the winter but during summer months its upper 100–200 m are warmed and their salinity reduced to form the Antarctic Surface Water (Deacon, 1937). The lower part of the Upper Water, known as the Winter Water (Mosby, 1934), is not similarly warmed and has uniform temperatures throughout the year.

Circumpolar Water is a distinct, huge water mass completely surrounding the Antarctic continent, at depths from a few hundred metres to more than 3,000 m. It is derived from the upwelling of Antarctic Deep Water near the Antarctic continent and retains the basic characteristics of Deep Water. In the Ross Sea, Circumpolar Water extends as a tongue-like wedge towards the south and south-west. It flows under the Upper Water and over the Shelf Water, forming a layer varying from 100 to 300 m thick. Circumpolar Water is the warmest (+1.50 to +0.50°c), and poorest in oxygen (4·80 to 4·30 ml/l) of the Ross Sea water types and has intermediate salinities (34·60 to 34·75 ⁰/₀₀).

The deepest water mass of the Ross Sea, the Shelf Water, is the coldest (—1·80 to —2·05°c), most saline (34·75 to 35·00 ⁰/₀₀), and densest (28·00 to 28·20σ_t) and comprises a major portion of the water column in the west and south-west regions. Little mixing takes place between the Shelf Water and the overlying warmer, less saline Circumpolar Water.

Deacon (1937) suggested that the bottom topography of the Ross Sea causes the retention of the dense Shelf Water over the shelf and that there is no cold bottom current flowing out of the Ross Sea as in the Weddell Sea. The stability of Shelf Water is clearly shown in a series of vertical cross sections (figs. 5, 6, and 7) extending from near the edge of the continental shelf south and south-westward towards the Ross Ice Shelf. The high density bottom water is the result of transfer of highly saline, dense water from the surface of the Ross Sea. The increase of salinity in the surface layer, forming water dense enough to sink, is caused by growth of sea ice (Lyman, Nutt, and Ostapoff, 1961).

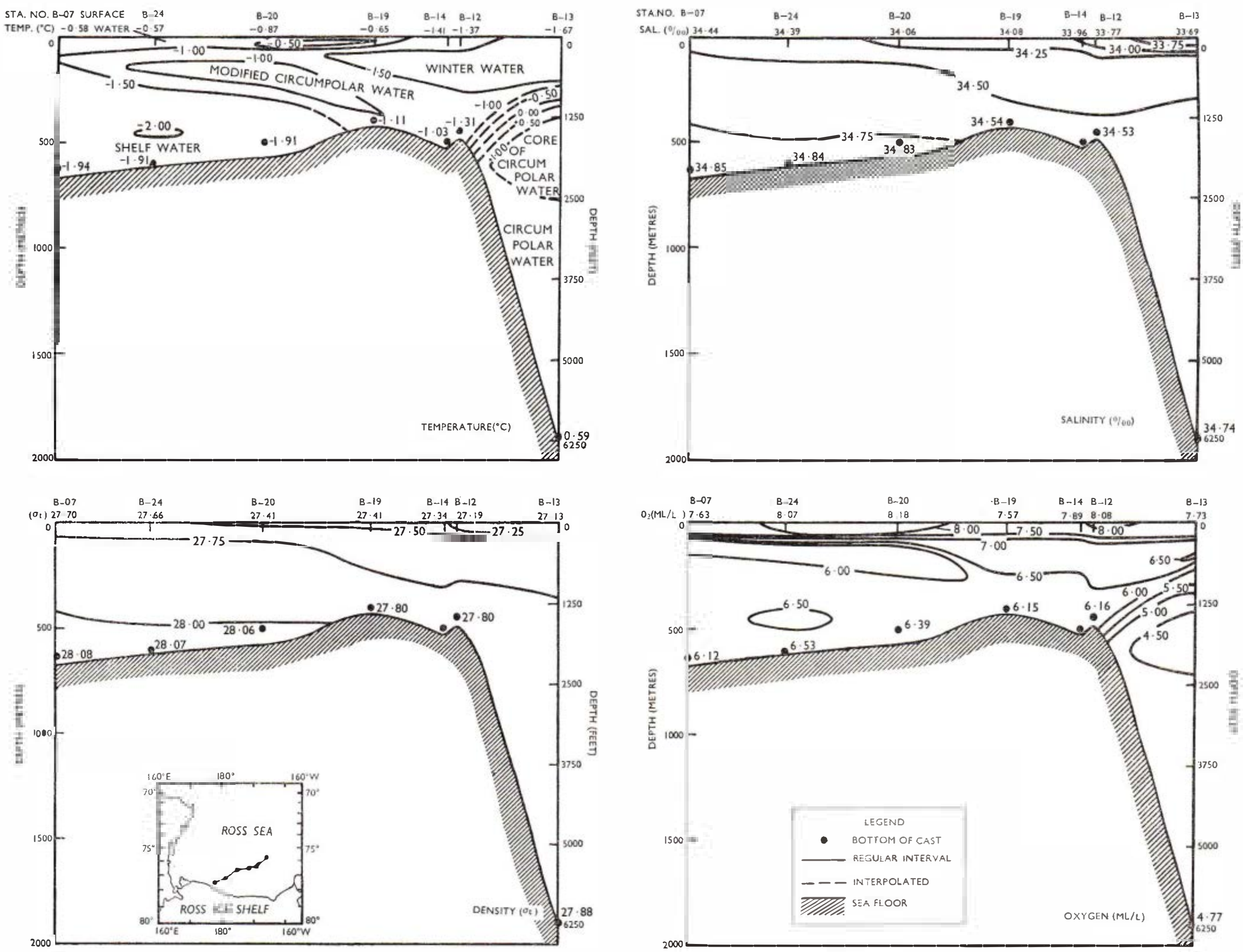


FIG. 5. Vertical cross sections of temperature, salinity, oxygen, and sigma-T (density) through stations B-07, B-24, B-20, B-19, B-14, B-12, and B-13, south-central Ross Sea. (After Newson, Francavillese and Tierney, 1965.)

The waters in which the foraminiferal samples were taken (table 2) have a temperature range of as little as 2°C (+0·4 to −2°C) and a salinity range of less than one part per thousand (34·52 to 35·08 ‰). Thus the temperatures are almost isothermal and salinities almost isohaline. The benthic faunas seem to be little affected by the small variations in temperature and salinity but may be related to the water mass types. Near-bottom temperatures and salinities from some of the stations from which foraminiferal samples were obtained are given in table 2.

Ross Sea water is entirely covered by solid ice for at least nine months of the year. During the winter months (June to September) the sea freezes over but, as spring and summer approach, southerly winds and currents break up the sea ice and push it to the north. During the summer months (December to March) a belt of ice-free water extends from the Ross Ice Shelf northwards about 100 miles to the edge of the pack. Thickness of the sea ice varies from a few centimetres to 5 m, being thickest in sheltered bays (Gunn and Warren, 1962). The ice cover affects the physical environment by reducing surface turbulence and by decreasing light penetration into the sea. Thus activities of photosynthesising organisms are limited to the short summer periods, and this in turn indirectly affects the degree of saturation of calcium carbonate in the sea water.

The direction and speeds of currents in the Ross Sea, especially in deep water, have had little study. The general surface current flows westward along the ice shelf face in a clockwise direction and then north along the coast of Victoria Land to Cape Adare (U.S. Hydrographic Office, 1956). Outside of the Ross Sea, north of Cape Adare, it joins the general circum-Antarctic surface current trend from west to east.

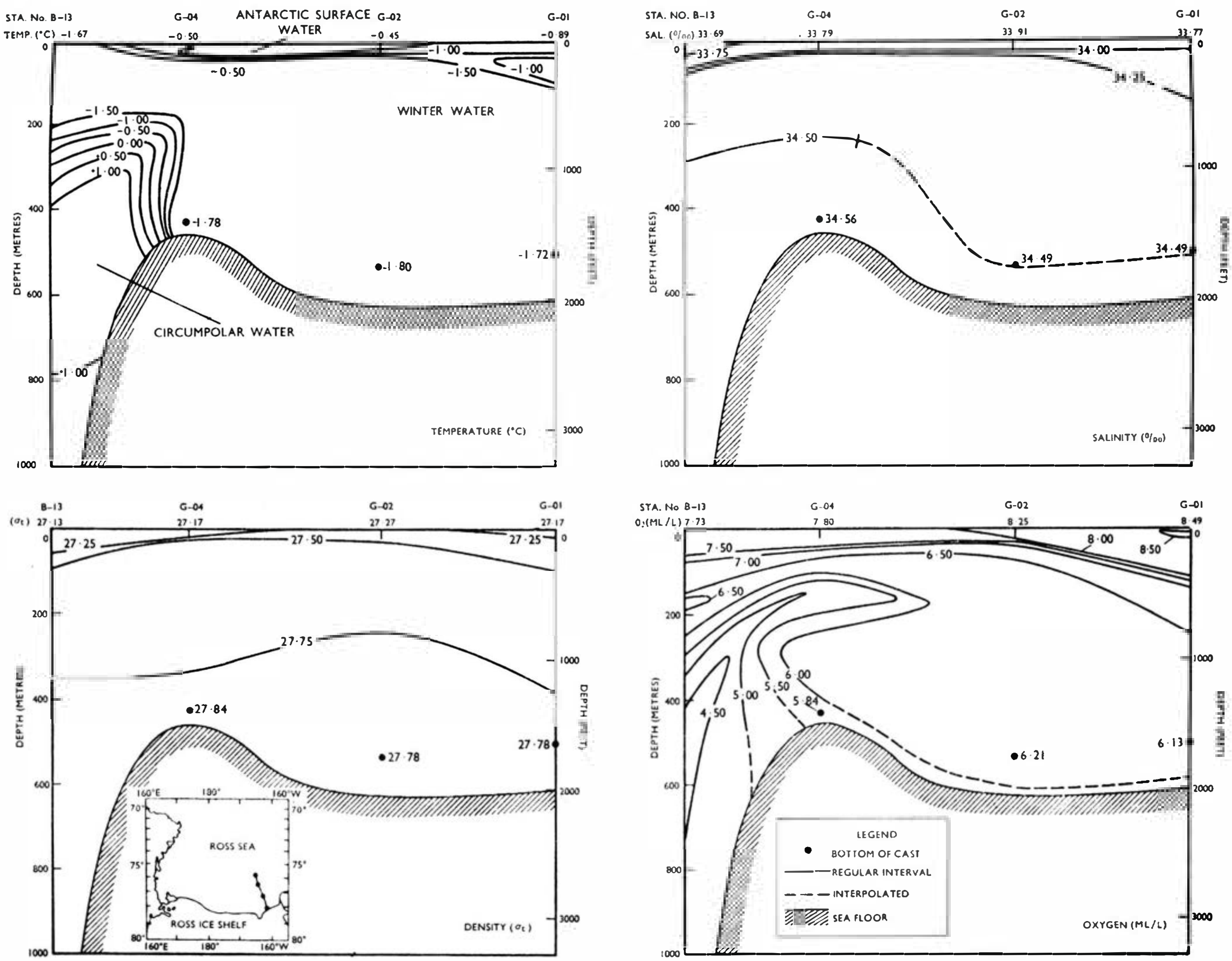


Fig. 6. Vertical cross sections of temperature, salinity, oxygen, and sigma-T (density) through stations B-13, G-04, G-02, and G-01, southeastern Ross Sea. (After Newson, Francavillese and Tierney, 1965.)

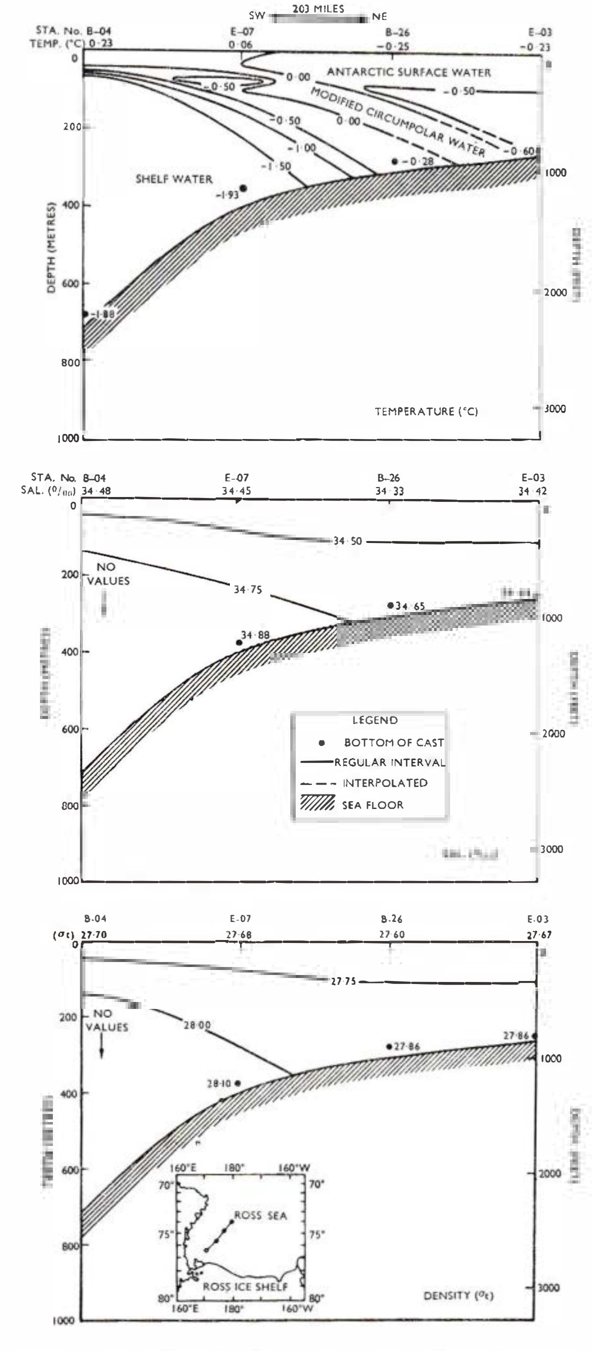


FIG. 7. Vertical cross sections of temperature, salinity, oxygen, and sigma-T (density) through stations B-04, E-07, B-26, and E-03, west-central Ross Sea. (After Newson, Francavillese and Tierney, 1965.)

SEDIMENTS

Ross Sea sediments are dominantly of terrigenous origin but have varying amounts of organic material. As shown by Hough (1956), the Antarctic continent is bordered by a deposit of glacial marine sediment grading outwards into diatom ooze. Ross Sea sediments lie

TABLE 2 Hyrological Data

Station Number	Temperature (°C)	Salinity ⁰/₀₀	Estimated Height Above Bottom (m)
A 448	−1·8	34·96	50
A 449	−1·7	34·52	130
A 450	−1·9	..	50
A 451	−1·8	..	20
A 452	+0·2	34·52	100
A 455	−1·0	34·54	20
A 456	−1·3	..	30
A 457	−0·8	..	20
A 458	−1·8	34·87	50
A 459	−1·9	35·05	30
A 460	−1·9	34·81	40
A 461	−2·0	35·08	20
A 462	+0·4	34·78	200
A 463	+0·1	34·74	30
A 464	−1·1	34·74	40
A 465	−0·5	34·76	20
A 466	−1·7	34·72	60
A 470	−2·0	..	100
A 517	−1·8	..	50
A 521	+0·0	..	20
A 522	+0·2	..	40
A 523	+0·0	..	100
A 536	−1·9	..	100
A 537	−1·8	..	50
A 538	−1·7	..	30
A 539	+0·2	..	300
A 592	−1·8	..	150
A 593	−1·7	..	200
A 595	−1·8	..	200
A 612	−1·7	..	200
A 616	−0·8	..	200

within the zone of glacial marine sediments, characterised by deposition mainly from melting ice. Immediately north of the Ross Sea the glacial marine sediments grade into diatom ooze which extends northwards to the Antarctic convergence.

For the present work, because the localities sampled were considerable distances apart, it was necessary to interpolate the sediment boundaries on the distribution map (fig. 8). No detailed discussion of sediments is given because the topic is outside the scope of this paper, but certain general conclusions can be drawn.

1. Sediments are generally poorly sorted throughout the whole area with sorting coefficients around 2·0 but ranging from 1·5 to 6·3 (table 3). Similar conclusions were drawn by Stetson and Upson (1937) and McKnight (1962). Poor sorting is due to ice rafting which is the most effective means of transportation in Antarctic waters. Sediment transported this way may be carried considerable distances out to sea before being released to the bottom. Almost all samples studied contain subangular glacial erratics of varying size. Another important feature of sediment transportation in polar regions is the freezing of shallow-water bottom sediments at the base of ice flows. If the frozen sediment adheres to the ice flows it may be carried out to sea and deposited in deeper water when the flows melt. Like turbidity currents, this mechanism plays an important part in distributing shallow-water organisms in deeper water.

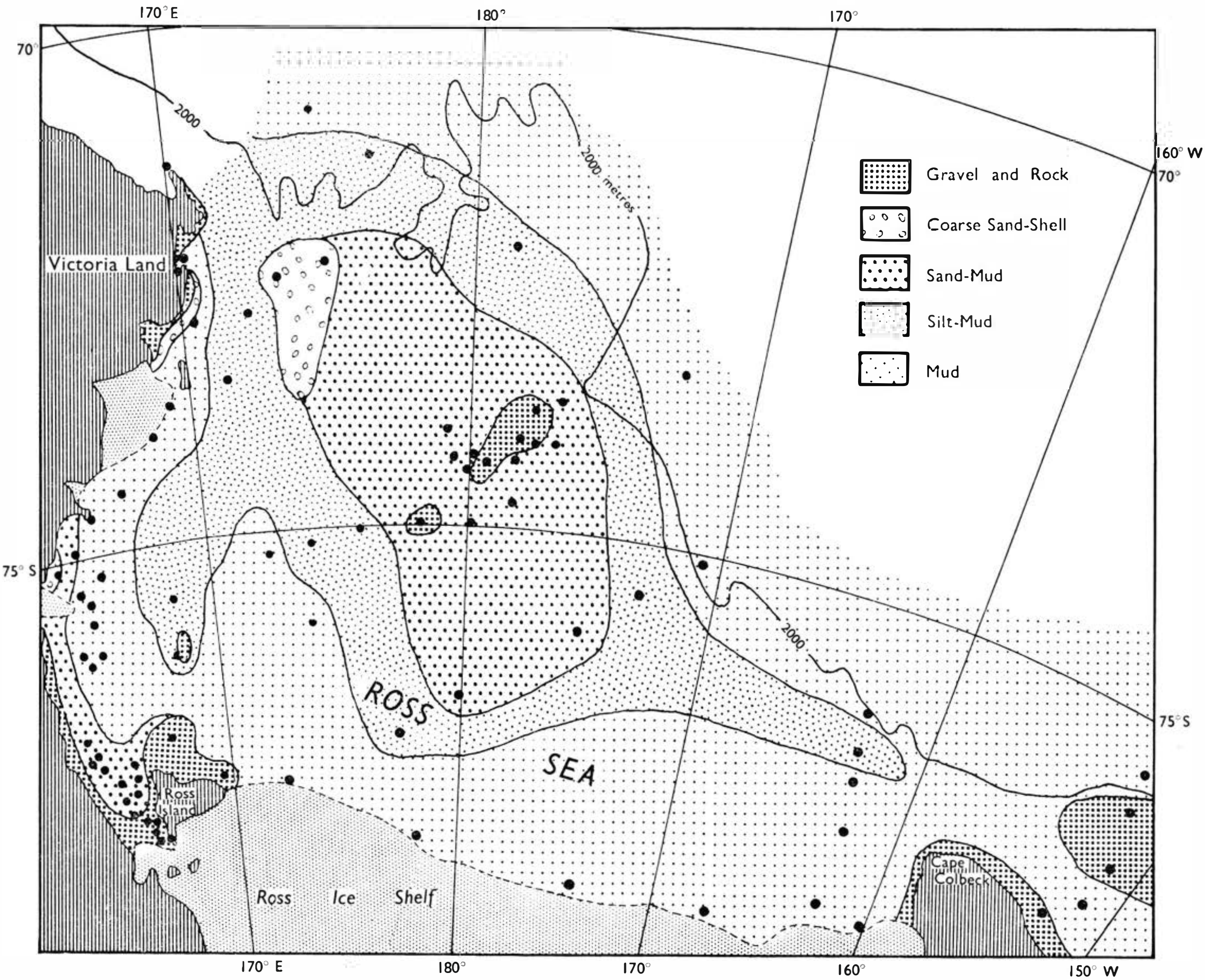


FIG. 8. Distribution of bottom sediment. Materials with a diameter greater than 2 mm are regarded as glacial erratics and were excluded from the sediment analyses, except from those areas dominated by gravel and rock.

2. Despite poor sorting, a generalised sediment distribution pattern can be observed (fig. 8).

Sediments of high medium diameter (gravelly to sandy sediments) are found in the shallowest areas at Pennell Bank, on a shallow bank in Sulzberger Bay to the west of Guest Island, and immediately adjacent to the coasts of Victoria Land, Ross Island, and King Edward VII Peninsula. In these areas current action evidently washes out much of the mud fraction and thus increases the sand content of the sediments. On a shallow rise to the north-west of Pennell Bank, coarse sediments consist of unusually high concentrations of barnacle plates (Bullivant, 1959) and a sparse, fine grained sediment fraction of calcareous Foraminifera.

Muddy sediments with only relatively small proportions of sand form a near-shore belt in deep water throughout the length of Victoria Land and in front of the Ross Ice Shelf. Also, it seems, from the few samples examined, that dominantly muddy sediments occur in the outer Ross Sea below depths of approximately 2,000 m. Relatively small amounts of coarse sediments are found on the deep near-shore portion. This can probably be attributed to a low rate of deposition because of insufficient melting of the icebergs in which sediments

TABLE 3. Sediment Characteristics

Station	Description	Median Diameter (μ)	Sorting Coefficient So	Carbonate Percent
A 448	Mud	30	1·5	8·5
A 449	Silty mud	60	1·6	22·5
A 450	Muddy, fine sandy silt	240	2·6	13·0
A 451	Pebbly, muddy, fine sandy silt	240	3·1	8·5
A 452	Sandy mud	22	2·3	9·0
A 453	Mud	10	1·9	8·0
A 455	Muddy sand	240	3·1	20·0
A 456	Sandy mud	14	2·0	50·0
A 457	Silty mud	74	3·2	15·0
A 458	Muddy fine sand	98	2·1	10·0
A 459	Mud	11	1·5	7·0
A 460	Silty mud	33	2·5	9·5
A 461	Silty mud	50	2·8	6·0
A 462	Gritty mud (small sample)	40	3·2	9·0
A 463	Coarse shell sand (barnacle plates)	1,800	1·7	87·0
A 464	Pebbles and shell sand (barnacle plates)	450	1·8	75·0
A 465	Muddy sand with barnacle plates	170	2·3	38·5
A 466	Mud	5	1·6	13·0
A 467	Dominantly rocks	1,000	2·8	10·0
A 468	Dominantly rocks	..	..	..
A 469	Rocks, gritty mud	..	..	..
A 470	Rocks, muddy sand	..	..	..
A 516	Rocks	..	..	..
A 519	Volcanic gravel, sand and silty mud	340	2·9	3·0
A 520	Pebbles and sandy mud	170	1·6	22·0
A 521	Gravel, cobbles and mud	..	..	..
A 522	Muddy sand and pebbles	2,800	6·3	22·0
A 524	Mud	10	1·5	8·5
A 525	Dominantly rocks	..	..	..
A 526	Dominantly pebbles	..	..	..
A 527	Dominantly pebbles	4,000	2·0	18·5
A 528	Dominantly pebbles	1,050	2·2	27·0
A 529	Pebbles and coarse sandy mud	..	..	..
A 530	Muddy sand (small sample)	..	..	..
A 531	Dominantly pebbles	..	..	..
A 532	Volcanic rocks and muddy sand	..	..	..
A 533	Dominantly pebbles	..	..	..
A 534	Dominantly rocks	3,000	2·6	14·5
A 536	Dominantly rocks	..	..	..
A 537	Gravel and mud	..	..	21·0
A 538	Rocks and sandy mud	310	1·7	9·5
A 592	Sandy mud	32	3·4	13·0
A 593	Silty mud	21	3·8	11·0
A 595	Muddy sand	140	2·6	9·0
A 612	Mud	13	1·8	9·0
A 616	Silty mud	64	1·5	0
A 625	Medium-fine sand	230	1·7	4·5
A 641	Coarse-medium sand	640	1·8	10·0
A 644	Mud	14	2·7	15·0
A 645	Fine sand	130	1·9	10·0

are transported (Brodie, 1965). Iceberg sediments in these areas thus do not mask the more slowly accumulating fine grained sediments deposited by bottom currents.

The muddy sediments in deeper water grade into the coarse sediments of the Pennell Bank area.

3. Varying amounts of organic constituents are associated with the terrigenous sediments; sponge spicules, Foraminifera, and diatoms are the commonest.

4. Near Ross Island, McMurdo Sound sediments contain varying amounts of detritus of volcanic origin such as volcanic glass and ferromagnesium minerals.

5. The colour of the fine grained sediments (muds and silts) generally ranges from greenish black to black; sandier sediments are generally pale grey.

6. Calcium carbonate values of the sediment samples are closely related to the type of microfauna present. Samples dominated by arenaceous Foraminifera, diatoms, and sponge spicules, with calcareous organisms absent or rare, have relatively low carbonate percentages, averaging 8·5 percent, and ranging from 0–13 percent. Those samples with microfaunas dominated by calcareous Foraminifera have much higher carbonate percentages, averaging 23 percent, and ranging from 3–87 percent. In the two samples with the highest values (87% and 75%) however, nearly all the carbonate is contributed by barnacle plates; the highest carbonate value for a sediment without significant proportions of barnacle plates is 50 percent. Because dominantly calcareous

faunas occur in shallow water (< 550 m) and dominantly arenaceous faunas in deeper water, samples with high and low carbonate values are found in shallow and deep water respectively.

Where calcareous organisms are essentially absent, carbonate in samples is very likely to be in the form of detrital marble fragments and glacial rock flour with a calcareous component. The obvious sources of supply are nearby extensive Lower Paleozoic marble deposits occurring throughout the length of Victoria Land.

ECOLOGY AND DISTRIBUTION OF FORAMINIFERA

Previous Ross Sea Studies

Chapman (1916a) described Foraminifera in 13 samples from the British Antarctic Expedition of 1907–9 (table 5), mostly obtained from the northern McMurdo Sound area in depths from 200–1,200 m. Chapman's faunal lists of Foraminifera and Ostracoda show that all faunas are richly calcareous down to 310 m; below this all except one (640 m) are almost entirely arenaceous. From his sediment descriptions, it appears that the texture of bottom sediment shows no relation to faunal types.

Heron-Allen and Earland (1922), using samples obtained during the *Terra Nova* Expedition of 1910 (table 6), carried out a broad systematic study of the Foraminifera from the South Pacific-Antarctic area. They described the Foraminifera from 18 Ross Sea samples most of which came from the McMurdo Sound area.

Warthin (1934) discussed a foraminiferal fauna obtained from 512 m in the Bay of Whales, collected during the First Byrd Expedition of 1939. He noted the great dominance of arenaceous individuals (93%) compared with calcareous individuals.

McKnight (1962) carried out the first ecological study of Foraminifera of the Ross Sea (table 7). Of the 19 surface core samples he studied, 13 were obtained from the Ross Sea. The distribution of these samples was limited to two areas, one in the westernmost Ross Sea and the other close to the Ross Ice Shelf. Of the ecological parameters studied, he considered that depth, temperature, salinity, and mean grain size of sediment had little effect on the distribution of Foraminifera. He thought that organic carbon affected the distribution of some arenaceous forms, and that the spread of grain sizes in the sediment was important in 10 of 20 statistically tested species.

Pflum (1963) analysed 10 surface core samples from the eastern Ross Sea and found that most of the trends observed by McKnight also held good for the area he studied.

Scope of Present Study

Foraminifera from 48 sediment samples collected within the Ross Sea by the New Zealand Oceanographic Institute have been studied by the writer. The information from these samples, supplemented by that from a total of 60 samples of the previous workers, has enabled the foraminiferal distribution patterns to be reasonably well determined. More is now known of the Foraminifera of the Ross Sea than of any other area of comparable size in the Southern Hemisphere.

A total of 102 genera and 210 species have been identified in the present study. The distribution of foraminiferal species and their relative percentages in individual samples is shown in table 4 (in pocket.)

TABLE 5. Location, Depth, and Faunal Type of Foraminiferal Faunas Described by Chapman from S.Y. *Nimrod* during the British Antarctic Expedition (1907–9)

Nimrod Stations

Sample No.	Location	Depth (m)
Calcareous Faunas		
1	76°56′S, 164°51′E	201
2	76°55′S, 164°55′E	207
3	76°55′S, 164°45′E	221
4	McMurdo Sound, 1 mile from the outer end of Glacier Tongue, northern side.	280
5	77°1′S, 165°5′E	312
7	Information not given	411
8	76°49′S, 163°24′E	645
Arenaceous Faunas		
9	76°47′S, 163°22′E	658
10	76°48′S, 163°20′E	680
12	77°16′5″S, 165°55′E	841
13	76°46′S, 163°26′E	845
14	Cape Bird bearing N79°E (true). Distance 4½ miles.	863
15	Relief Harbour, N Drygalski Glacier about 20 miles off coast.	1,198

TABLE 6. Location, Depth, and Faunal Type of Foraminiferal Faunas Described by Heron-Allen and Earland from *Terra Nova* during the Terra Nova Expedition (1910)

Terra Nova Stations

Sample No.	Location	Depth (m)
Calcareous Faunas		
38	Off Cape Adare, mouth of Robertson Bay	86
46	Off Granite Harbour	91
47	77°5′S, 164°17′E	256
45	76°56′S, 164°12′E	292
49	77°10′8″, 164°13′E	342
53	Off Barne Glacier, McMurdo Sound	365
50	77°13′S, 164°18′E	378
54	5 miles north of Inaccessible Island McMurdo Sound.	420
48	Off Cape Bird, entrance to McMurdo Sound	457
55	77°46′S, 166°8′E	548
Arenaceous Faunas		
41	75°9′7″S, 173°39′8″E	459
44	76°02′7″S, 165°55′2″E	554
42	74°24′7″S, 174°1′3″E	572
43	75°25′S, 165°11′E	731
52	77°36′S, 165°30′E	760
51	77°22′5″S, 165°22′E	764
40	72°40′9″S, 172°37′5″W	3,505
39	72°S, 168°17′5″W	4,246

TABLE 7. Foraminiferal Faunal Data Calculated from McKnight's (1962) and Pflum's (1963) Quantitative Ross Sea Sample Data

				Of Benthonics		Of Total Assemblage		
Sample	Depth (m)	Number Arenaceous Species	Number Calc. Benthonic Species	Calc. Benthonic Percentage	Aren. Benthonic Percentage	Planktonic Percentage	Calc. Benthonic Percentage	Aren. Benthonic Percentage
Calcareous Faunas								
IBM 128	164	7	43	79·0	21·0	14·5	72·7	12·8
61-140	210	1	25	99·7	0·3	3·7	96·1	0·2
61-186	265	12	24	92·7	7·3	7·4	88·6	4·0
61-162	274	8	21	93·4	6·6	14·0	80·3	5·7
IBM 037	365	7	27	96·0	4·0	85·8	4·0	0·8
IBM 129	475	9	75	99·0	1·0	45·3	54·3	0·4
IBM 013	658	6	16	93·0	7·0	11·8	80·5	7·7
Arenaceous Faunas								
IBM 001	450	7	0	0	100	0	0	100
IBM 022	455	20	0	0	100	0	0	100
61-037	460	21	10	15·0	85·0	2·5	16·1	81·4
IBM 030	567	15	6	5·0	95·0	2·0	4·6	93·4
IBM 041	568	17	1	5·0	95·0	0	5·0	95·0
IBM 015	594	7	0	0	100	0	0	100
61-031	604	9	0	0	100	0	0	100
IBM 038	612	19	2	0·1	99·9	0·4	0·8	98·8
61-001	640	13	0	0	100	1·4	0	98·6
IBM 019	640	11	0	0	100	3·2	0	96·8
61-012	668	20	0	0	100	0	0	100
IBM 026	685	12	5	12	88·0	2·0	1·2	86·8
IBM 032	690	11	0	0	100	0	0	100
IBM 003	805	15	0	0	100	0	0	100
IBM 033	870	10	0	0	100	0	0	100
IBM 039	890	4	0	0	100	0	0	100
61-142	1,134	19	1	1·0	99·0	17·3	8·7	74·0
IBM 007	2,450	11	1	13·0	87·0	0	13·0	87·0
61-041	2,561	12	1	1·5	98·5	0	1·5	98·5
61-188	3,402	6	0	0	100	0	0	100

General Faunal Trends

BENTHONIC FORAMINIFERA

The most striking feature of the Ross Sea Foraminifera is the presence of two separate and greatly contrasting microfaunal groups:

1. Calcareous faunas made up of abundant calcareous Foraminifera, moderately abundant Ostracoda, Bryozoa, minute Mollusca, and other calcareous organisms but with relatively few arenaceous Foraminifera.
2. Dominantly non-calcareous, sparse faunas made up of arenaceous (agglutinated) Foraminifera, diatoms, and siliceous sponge spicules (fig. 9). Arenaceous Foraminifera build their tests from various materials such as sand grains and sponge spicules by cementing them together with a dominantly ferruginous cement of secretory character. These faunas, with more than 85 percent of the benthonics consisting of arenaceous Foraminifera, are here defined as arenaceous faunas.

Most calcareous faunas are restricted to depths shallower than 550 m, while all the arenaceous faunas occur deeper than 430 m.

Tables 5 to 8 list depth distribution of arenaceous and calcareous faunas obtained during *Nimrod*, *Terra Nova*, McKnight's, Pflum's, and N.Z.O.I. expeditions. Tables 7 and 8 show the number of calcareous and arenaceous species, the percentage of calcareous and arenaceous benthonics of the total benthonic fauna, and the percentage of calcareous and arenaceous benthonics and planktonics of the total foraminiferal assemblage, calculated from McKnight's, Pflum's, and the author's quantitative data. Plots of calcareous and arenaceous benthonic percentages against depth (figs. 9 and 10) show the close relations their distributions have to depth.

Approximately the same number of arenaceous species occur in calcareous and arenaceous faunas although the latter, by definition, have larger numbers of arenaceous individuals. Essentially the same arenaceous species occur in both the calcareous and arenaceous faunas, with some notable exceptions. Of these the species more characteristic of calcareous faunas are *Bathysiphon* sp. (with a test of aligned sponge spicules) and *Ammodiscus* cf. *anguillae* Höglund. The species more characteristic of the arenaceous faunas are: *Rhizammina indivisa* Brady, *Rhabdammina* sp. (coarse grained test with sponge spicules), *Bathysiphon filiformis* Sars, *Pelosina bicaudata* (Parr), *Glomospira charoides* (Jones and Parker), *Reophax distans* Brady, *Reophax spiculifer* Brady, *Adercotryma glomerata* (Brady), *Verneuilina minuta* Wiesner, and *Karreriella pusilla* Parr.

Abundance of Foraminifera generally depends on the proportions in which arenaceous and calcareous faunas are distributed. Areas of calcareous foraminiferal assemblages have high foraminiferal numbers and areas of arenaceous assemblages have low foraminiferal numbers (table 8).

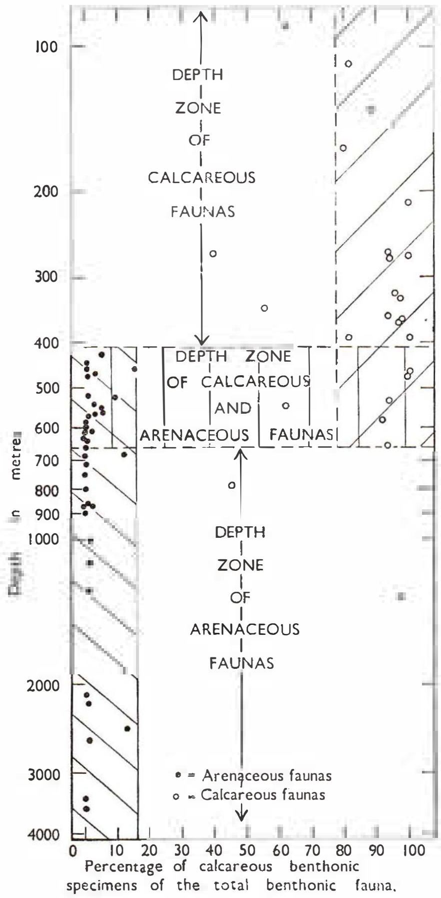


FIG. 9. Percentage of calcareous benthonic specimens of the total benthonic fauna in samples counted by the author, McKnight (1962) and Pflum (1963). Arenaceous faunas have less than 15 percent calcareous benthonic specimens and occur at depths greater than 430 m. Most calcareous faunas have more than 75 percent calcareous benthonic specimens and are restricted to depths shallower than 550 m.

Shallow areas with their associated calcareous faunas occur in McMurdo Sound, nearshore to Ross Island and Victoria Land, 193 km to the north-east of Ross Island, on Pennell Bank, and on shallow banks to the north-west of the Ross Sea and in Sulzberger Bay. Elsewhere, in deeper water, arenaceous faunas are found.

PLANKTONIC FORAMINIFERA

Abundant planktonic Foraminifera occur in all the calcareous faunas and make up 5–80 percent of the foraminiferal sample. In arenaceous faunas, they are generally absent and, in all but two of the samples in

TABLE 8. Foraminiferal Faunal Data Calculated from the New Zealand Oceanographic Institute Samples Collected from the Ross Sea

							Of Benthonics		Of Total Assemblage		
Sample	Depth (m)	Number Aren-aceous Species	Number Calcar-eous Benthonic Species	Number Plank-tonic Specimens	Number Aren-aceous Specimens	Number Calcar-eous Benthonic Specimens	Calcar-eous Benthonic Per-centage	Arenac-eous Per-centage	Plank-tonic Per-centage	Calcar-eous Benth. Per-centage	Arenac-eous Per-centage
Calcareous Faunas											
A 533	90	12	26	324	2,700	4,100	60·3	39·7	4·5	57·5	38·0
A 468	110	10	41	3,690	5,620	23,750	80·9	19·1	11·1	71·9	17·0
A 467	136	6	15	30	65	453	87·5	12·5	5·0	83·2	11·8
A 530	269	10	24	100	2,120	1,350	38·9	61·1	2·8	37·7	59·5
A 456	270	8	54	1,800	73	7,025	99·0	1·0	21·4	77·8	0·8
A 641	322	8	52	16,960	3,150	53,080	94·4	5·6	23·2	72·5	4·3
A 455	330	13	75	18,710	1,600	39,820	96·1	3·9	31·1	66·2	2·7
A 531	348	21	10	59	180	210	54·1	45·9	13·0	47·0	40·0
A 457	357	18	45	1,370	230	3,215	93·3	6·7	28·4	66·8	4·8
A 449	362	14	54	5,730	1,010	33,230	97·1	2·9	14·3	83·2	2·5
A 450	395	11	54	2,300	1,490	6,300	80·9	19·1	22·9	62·3	14·8
A 465	399	1	44	3,600	6	5,674	99·9	0·1	38·8	61·1	0·1
A 463	466	13	53	28,310	40	42,350	99·9	0·1	40·0	59·9	0·1
A 644	530	6	13	93	86	946	91·7	8·3	8·0	84·4	7·6
A 537	548	22	21	77	460	740	61·7	38·3	6·4	57·5	36·1
A 525	583	15	38	184	220	2,280	91·2	8·8	4·3	87·5	8·2
A 536	790	16	16	5	190	155	44·9	55·1	1·4	44·4	54·2
A 522	1,335	16	55	72,830	340	10,820	97·0	3·0	86·7	12·9	0·4
Arenaceous Faunas											
A 460	430	13	6	2	151	8	5·0	95·0	1·2	4·9	93·9
A 616	470	29	4	0	1,150	15	1·3	98·7	0	1·3	98·7
A 458	475	20	1	0	206	1	0·5	99·5	0	0·5	99·5
A 625	520	13	3	3	1,465	11	0·8	99·2	0·2	0·7	99·1
A 451	523	26	25	26	726	66	8·3	91·7	3·2	7·8	89·0
A 459	542	26	3	0	339	6	1·7	98·3	0	1·7	98·3
A 466	569	17	2	0	125	4	3·1	96·9	0	3·1	96·9
A 461	573	9	1	0	187	2	1·1	98·9	0	1·1	98·9
A 612	612	18	1	0	875	11	1·2	98·8	0	1·2	98·8
A 645	720	18	2	0	1,413	2	0·1	99·9	0	0·1	99·9
A 448	752	19	0	0	94	0	0	100	0	0	100·0
A 592	865	21	1	0	1,654	2	0·1	99·9	0	0·1	99·9
A 595	865	19	3	22	1,450	26	1·8	98·2	1·5	1·7	96·8
A 593	1,015	15	5	1	1,050	12	1·1	98·9	0·1	1·0	98·9
A 452	1,290	11	1	0	102	1	1·0	99·0	0	1·0	99·0
A 462	2,100	16	0	0	65	0	0	100	0	0	100·0
A 453	2,195	17	1	0	136	1	0·7	99·3	0	0·7	99·3
A 524	3,570	17	0	15	265	0	0	100	5·3	0	100·0

which they do occur, they are very rare, constituting less than 3 percent of the foraminiferal sample. The planktonics rapidly become increasingly abundant to almost 500 m, but below this they show a sharp decline with which is associated the appearance of dominant arenaceous faunas (fig. 10). Areas of abundance of planktonics thus occur in the shallow areas especially at depths between 300 and 500 m (fig. 11).

NUMBER OF GENERA AND SPECIES

Areas of abundance or paucity generally show a close correlation with the two faunal types (figs. 12, 13). Areas characterised by arenaceous assemblages have relatively few species and genera, while areas of calcareous foraminiferal assemblages have abundant species and genera.

Environmental Influence on General Faunal Trends

PROFILE STUDIES

Five selected cross sections across the Ross Sea (fig. 14) are presented to show the relations of Foraminifera to the environmental conditions.

In these sections the percentage of arenaceous and calcareous benthonic specimens, percentage of planktonics, number of calcareous and arenaceous species, and total number of genera are compared with various environmental factors. Where possible these include the bottom temperature and salinity, median diameter of the sediment, calcium carbonate percentage, and bottom topography. The same dominant environmental factors have been found in this study to affect the distribution of Foraminifera throughout the Ross Sea.

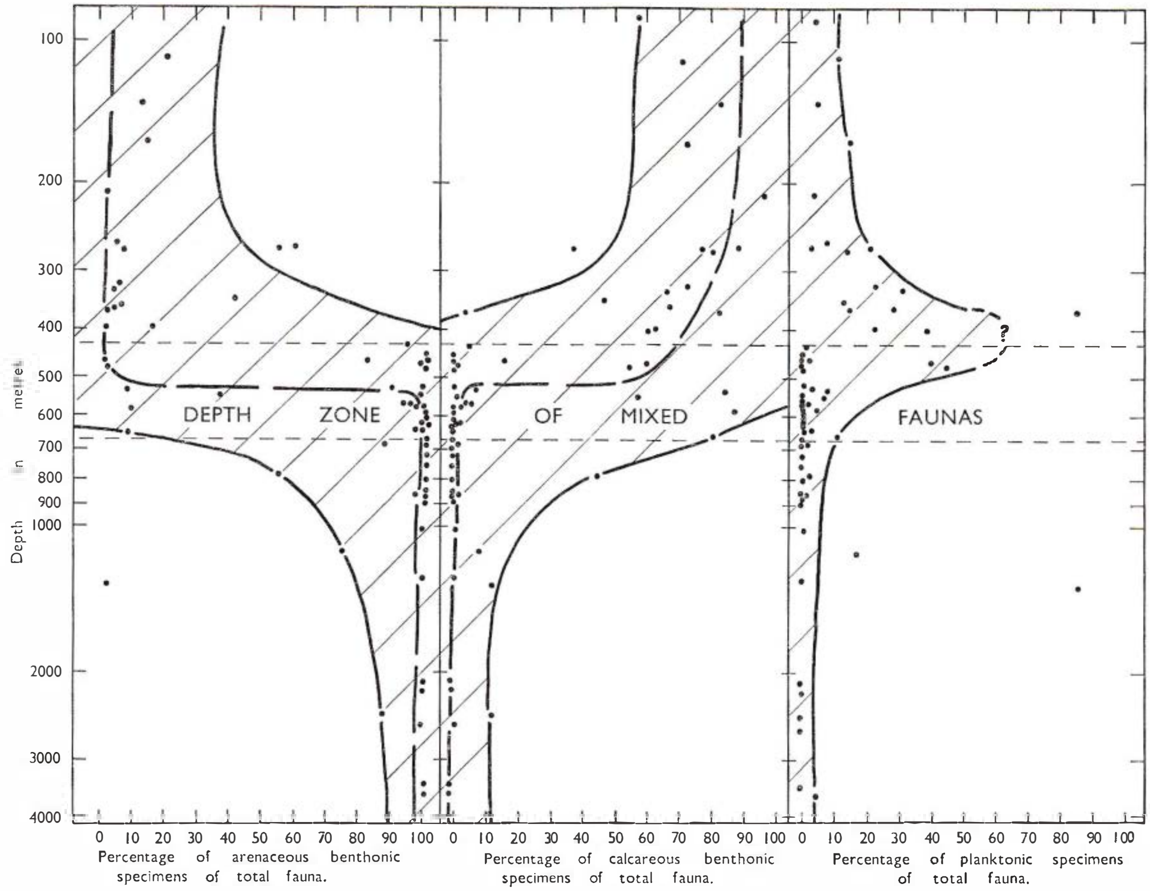


FIG. 10. Relative percentages of arenaceous benthonic, calcareous benthonic, and planktonic specimens in samples counted by the author, McKnight (1962), and Pflum (1963). Arenaceous and calcareous benthonics show an approximately reciprocal relationship; planktonics increase in abundance to about 500 m, then show a steep fall off due to solution effects. Most samples below 500 m contain very low percentages of calcareous Foraminifera.

Sections Studied

Section A–A1 running north-east from Ross Island to the deep water south-east of Pennell Bank (fig. 15), shows a close correlation between foraminiferal parameters and bathymetry.

The most obvious relation is that between bathymetry and test composition. In the shallow regions which have high foraminiferal numbers there is a great dominance of calcareous Foraminifera (mainly benthonics) whereas in deeper regions arenaceous tests almost completely dominate the fauna. At the shallow stations A 467, occurring near Ross Island, and A 449 and A 450 occurring on shoals in south central Ross Sea, the faunas are composed of 87·5, 97·1 and 80·9 percent calcareous benthonics respectively. In contrast, the faunas in the basin to the south-west and those at the edge of the continental shelf and on the slope have 99–100 percent arenaceous benthonics. The shallow and deep water microfaunal types are distinct, because of the obvious differences in the content of each, the small variation within each type, and the almost complete absence of gradation between types.

There is also a close relation between the two faunal types and the percentage of planktonic tests. The calcareous faunas in the central shoal areas have high planktonic percentages whereas planktonics are absent from all the arenaceous faunas except sample A 451, although the preservation of significant numbers of planktonics might have been expected over the whole area. The planktonic percentage in the assemblage near shore to the north of Ross Island is lower than in assemblages of the central shoal area. This is not unexpected, however, since there are many near-shore continental shelf areas throughout the world in which planktonics do not thrive.

A correlation between the two faunal types and the number of species and genera is apparent in the cross section. Areas with high numbers of genera and species correspond to areas of high percentages of calcareous tests. The numbers of arenaceous species are relatively

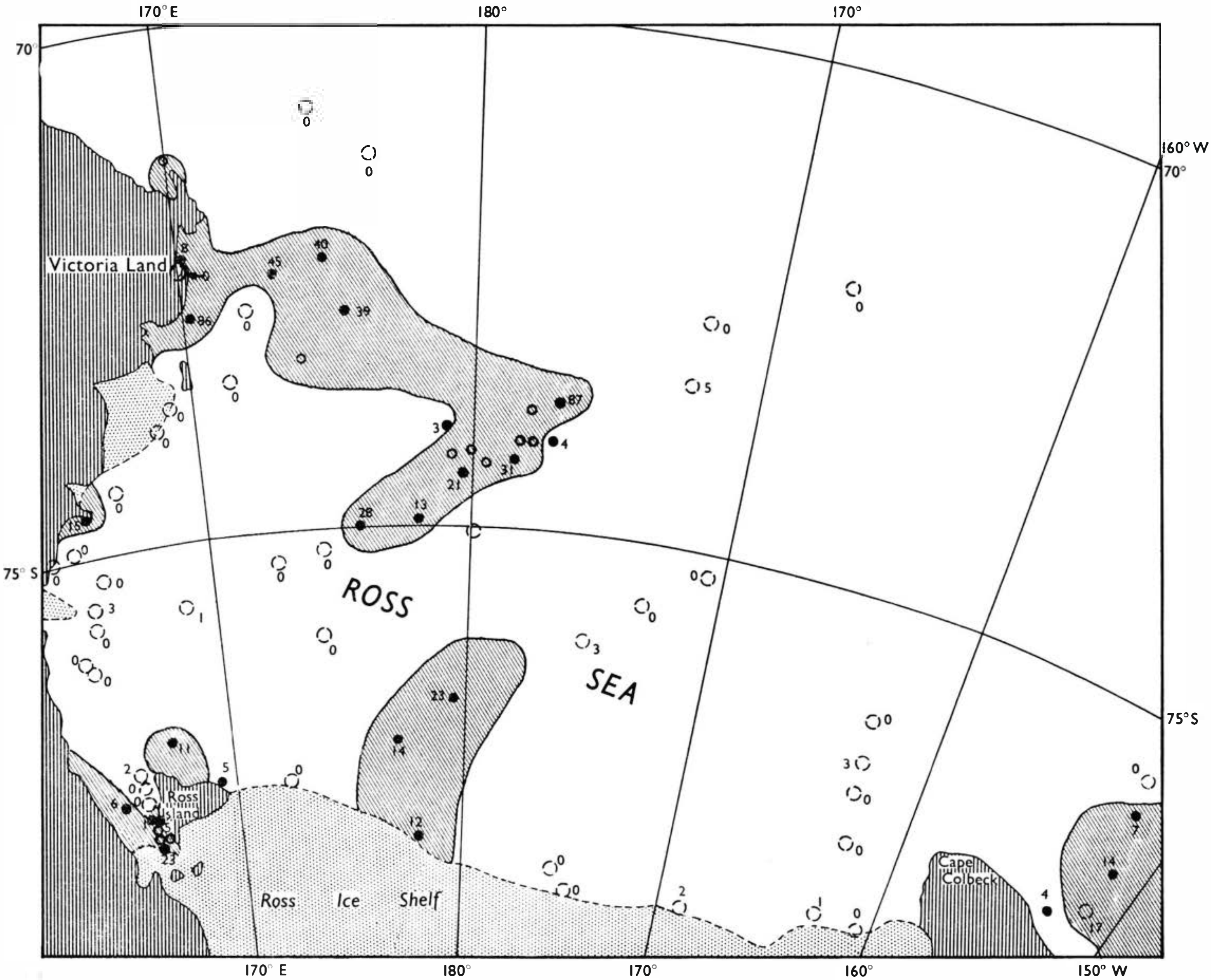


FIG. 11. Percentage of planktonic Foraminifera per station. Diagonal stripes indicate areas with values greater than 5 percent; solid circles, calcareous foraminiferal faunas; dashed circles, arenaceous faunas; open circles, samples not counted, but with high percentages.

uniform throughout most of the profile, and the marked rise in number of species in shallow areas is due to the increasing dominance of a calcareous faunal component which is essentially absent in the arenaceous faunas. The fauna from station A 451 is somewhat anomalous, for although it has a low calcareous benthonic percentage, it has much higher numbers of calcareous benthonic species than other arenaceous faunas. This situation is not altogether surprising, however, as station A 451 occurs at intermediate depths between areas of truly calcareous and truly arenaceous faunas.

To some extent the texture of the bottom sediments, reflected in median diameter, is dependent on bottom topography. Fine sediment occurs in the near-shore deep basins, on the slope, and on one of the off-shore shoals. Coarser sediments occur near shore and on the other off-shore shoals. No definite correlation has been found between bottom sediment type and test composition, although three of the four arenaceous faunas along this profile are from fine sediment areas and two of the three calcareous faunas are from coarser sediment areas.

There is a general correlation between the calcium carbonate content in the sediment and the foraminiferal parameters. Regions with assemblages composed mainly of calcareous Foraminifera and having high foraminiferal numbers usually have a higher calcium carbonate content.

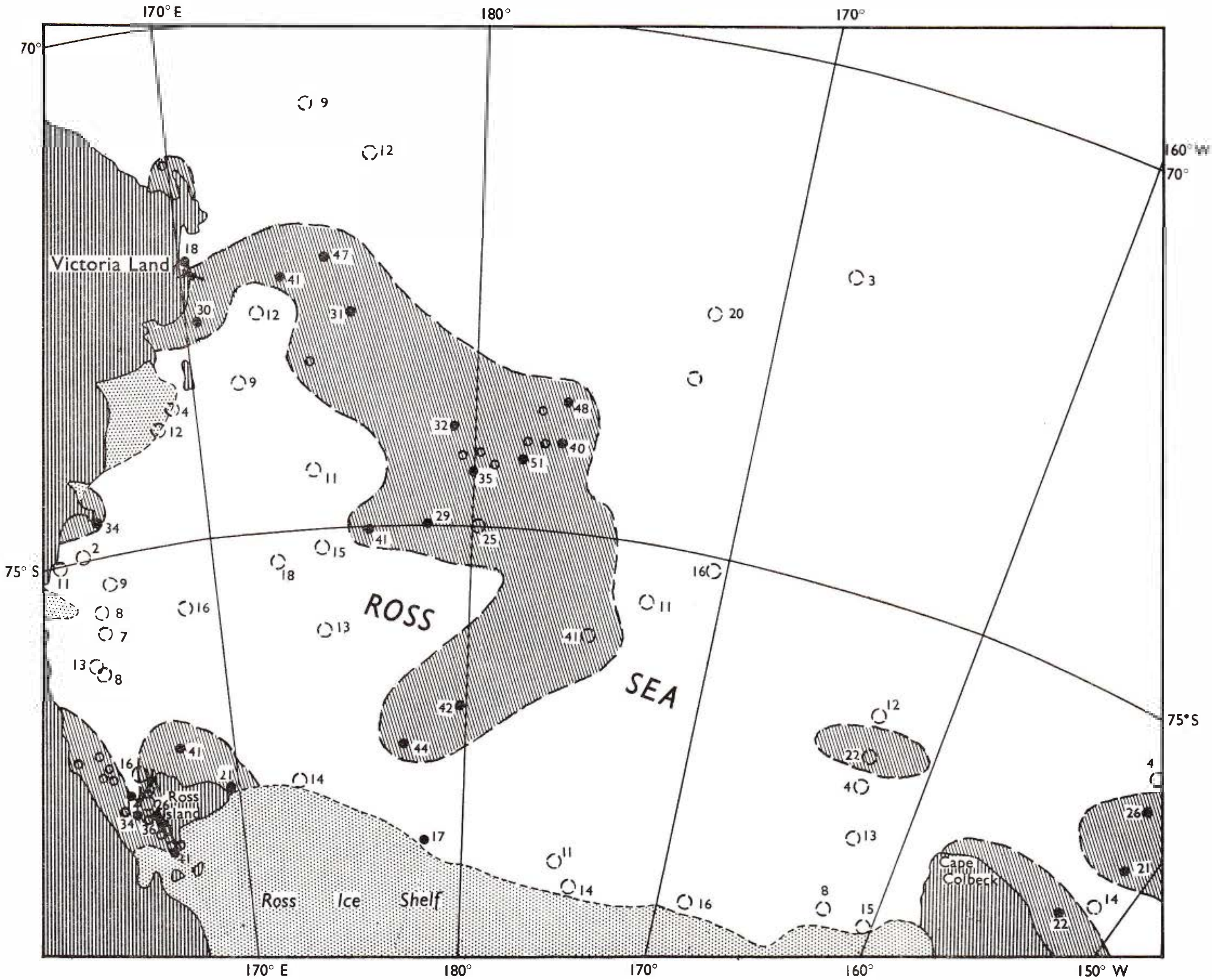


FIG. 12. Number of genera of Foraminifera per station. Diagonal stripes indicate areas of abundance; solid circles, calcareous foraminiferal faunas; dashed circles, arenaceous faunas; open circles, samples not counted, but with high numbers.

Bottom temperature in the profile shows no major correlation with the foraminiferal parameters. The bottom temperature is constant from $-1°$ to $-2°$c except over the continental slope where it rises to a range of $0°$ to $+2°$c, but this variation does not correspond to any systematic change in bottom fauna.

Section B–B1 is parallel to Victoria Land and extends from the southern Ross Sea near the Ross Ice Shelf to the north of the Ross Sea (fig. 16). This section displays most of the relations shown in Section A–A1.

Deep areas have high percentages of arenaceous tests, a lack of planktonic tests, low numbers of species and genera, low foraminiferal numbers, and low calcium carbonate percentages. Shallow areas show inverse relations to these.

Compared with Section A–A1, there is a much closer relation between bathymetry and texture of bottom sediment. Fine sediments occur in the deep shelf basin and on the slope, and coarse sediments on the off-shore shoals.

There is no major correlation between bottom temperatures and foraminiferal parameters. The coldest bottom temperatures occur in the deep basin on the shelf and a general temperature increase occurs towards

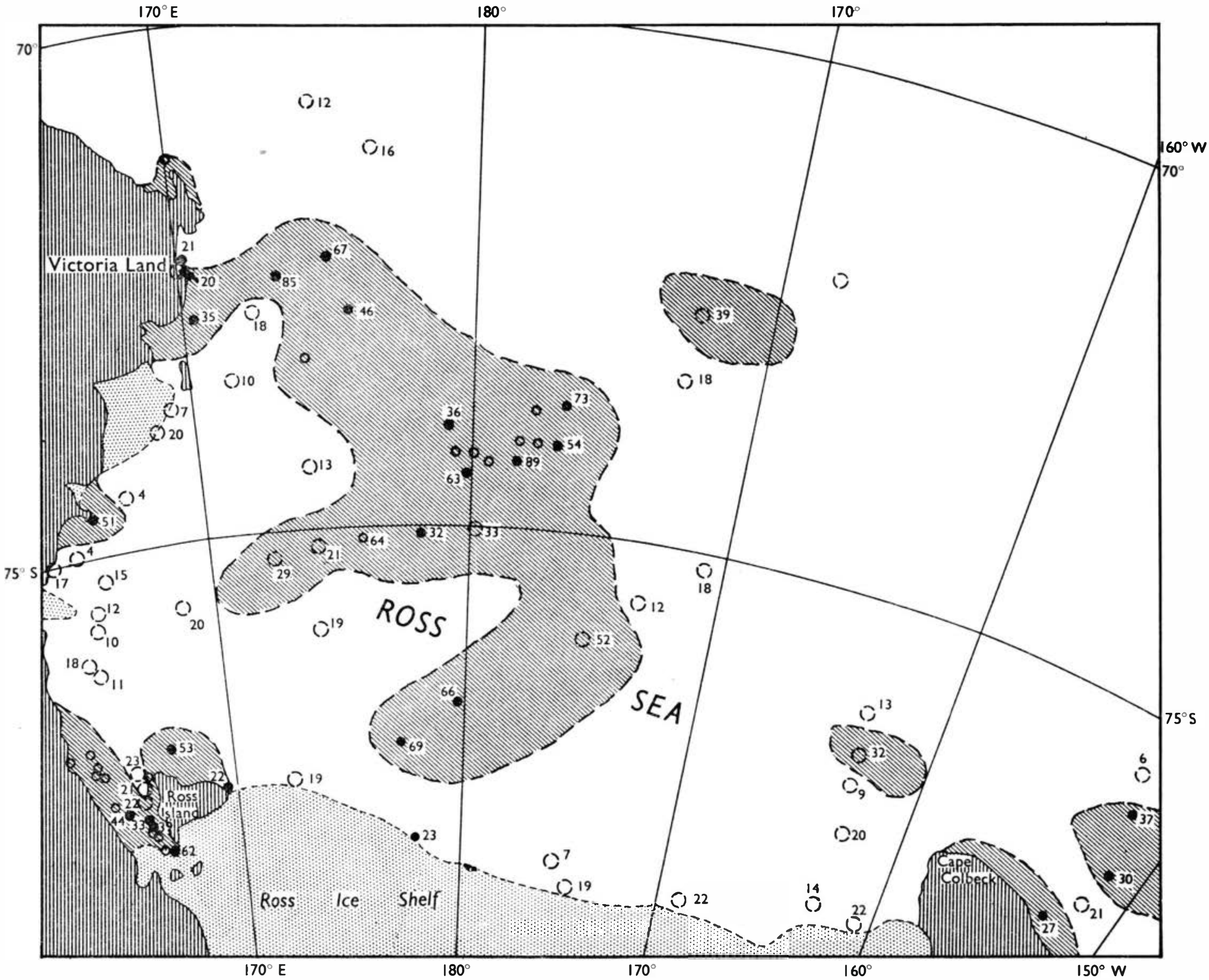


FIG. 13. Number of species of Foraminifera per station. Diagonal stripes indicate areas of abundance; solid circles, calcareous foraminiferal faunas; dashed circles, arenaceous faunas; open circles, samples not counted, but with high numbers.

the north of the Ross Sea as circumpolar waters are approached.

In the shallow areas of this profile, although approximately the same number of arenaceous species occur as in deep areas, arenaceous individuals are particularly rare, especially in the area north of the Ross Sea in which the bottom deposits are dominated by barnacle plates. There, shortage of sand probably makes it difficult for arenaceous forms to build tests and this would account for their paucity.

Section C–C1 extends from the south-west Ross Sea to the east of Pennell Bank (fig. 17). As before, there is good correlation between bathymetry and foraminiferal parameters. The deep basin on the western part of the shelf has high percentages of arenaceous tests, a general lack of planktonic tests, low numbers of species and genera, low foraminiferal numbers, and low calcium carbonate percentage. The shallow Pennell Bank area shows inverse relations to the deep basin.

Station A 525 to the east of Pennell Bank is the only sample in the profile in which the foraminiferal parameters are unusual considering the depth of the Station. Here a rich calcareous fauna occurs at a depth of 583 m, which is deeper than some of the arenaceous assemblages

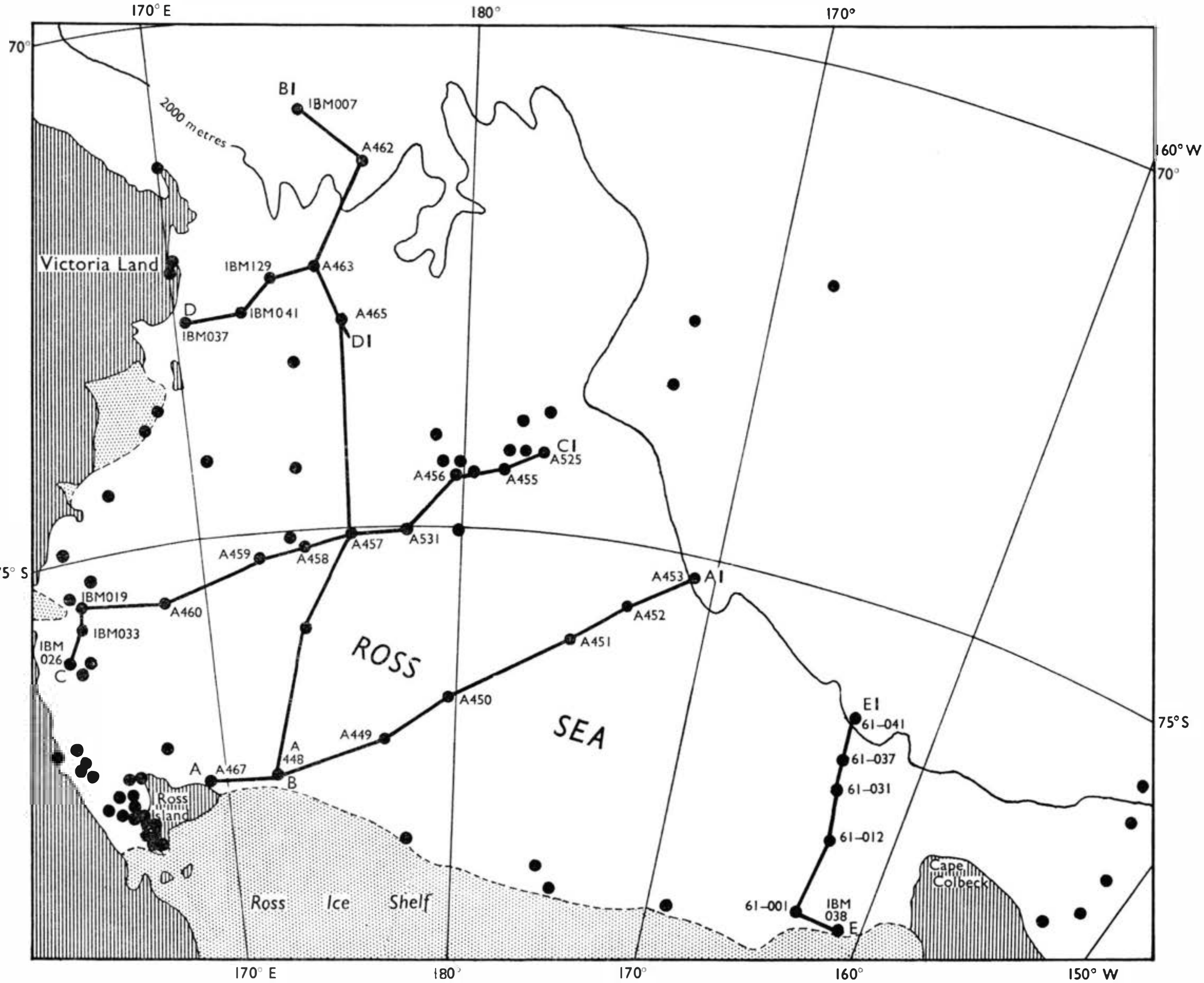


FIG. 14. Locations of cross sections selected to show the relations of Foraminifera to environmental conditions.

occurring in the profile. This and other anomalous samples are discussed later.

Differences in bottom water characteristics in this profile can be correlated with foraminiferal parameters. Areas of arenaceous faunas have lowest temperatures (—1·5 to —2°C) and highest salinities (34·7 ‰ to 35·1 ‰) while areas of calcareous faunas have highest temperatures (—1·0 to +0·0°C) and lowest salinities (34·5 ‰ to 34·7 ‰).

No definite correlation exists between texture of bottom sediment and foraminiferal parameters.

Section D–D1 is a short profile extending from a near-shore position north of Coulman Island, north-east into the Ross Sea, and then south-east towards Pennell Bank (fig. 18). This section also displays the more important relations shown by the previous profiles. The deep near-shore basin contains an arenaceous assemblage and no planktonic Foraminifera, and the shallower areas have a calcareous benthonic assemblage and high planktonic percentages.

There is no close correlation between sediment texture, bottom temperature and salinity, and the foraminiferal parameters. This is shown by a comparison between station IBM037 (365 m) which has a calcareous assemblage and station IBM041 (2,561 m) which has an arenaceous assemblage. Both are of similar sediment type

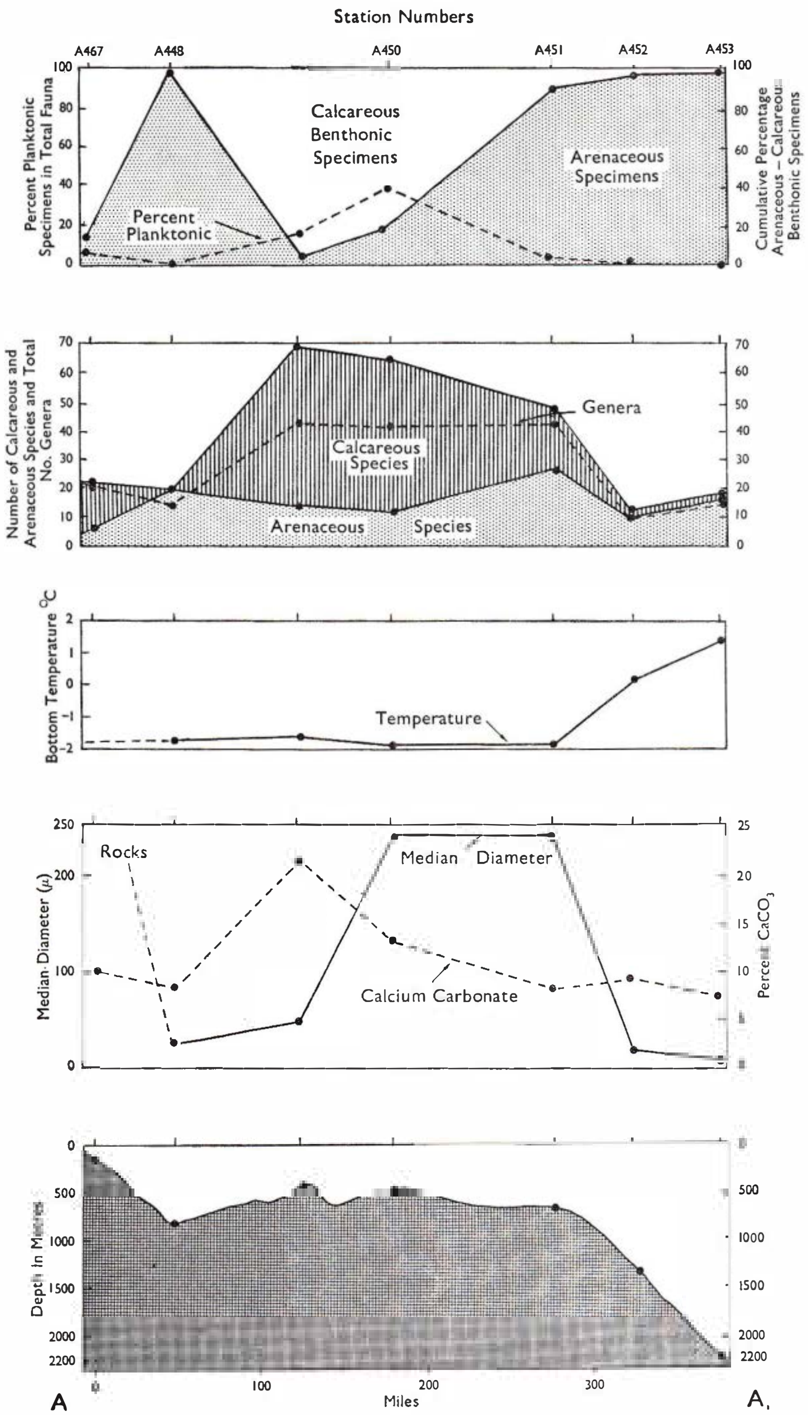


FIG. 15. Cross section from Ross Island to south-east of Pennell Bank showing relations between foraminiferal trends and environmental conditions.

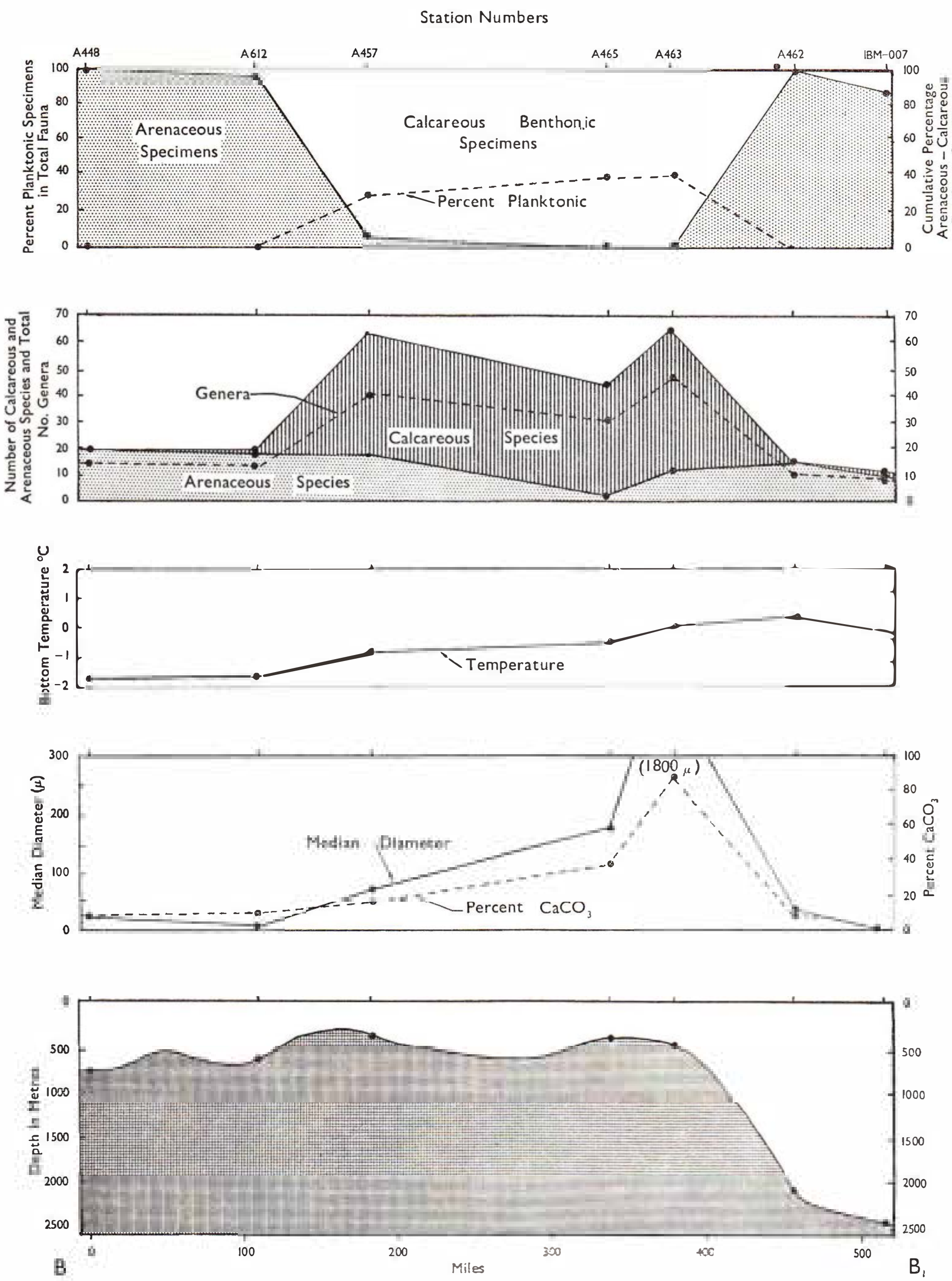


FIG. 16. Cross section from the Ross Ice Shelf to the north of the Ross Sea showing relations between foraminiferal trends and environmental conditions. (IBM station data from McKnight, 1962.)

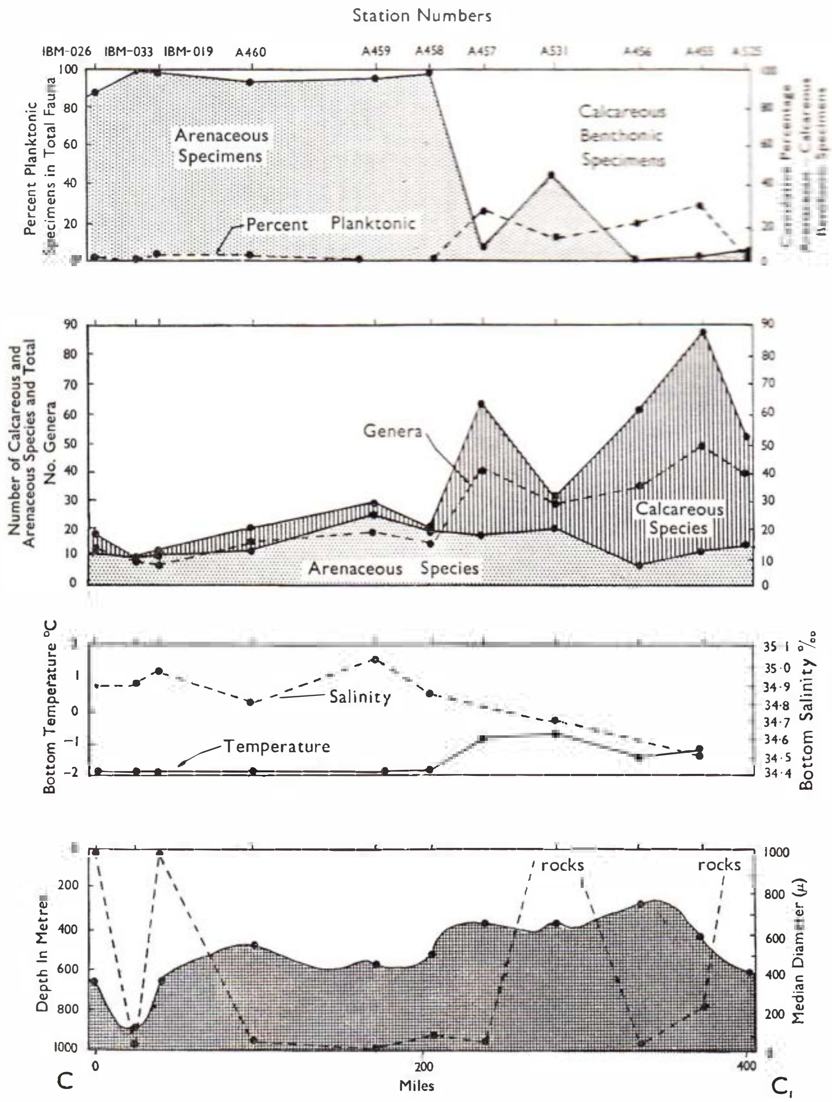


FIG. 17. Cross section from south-west Ross Sea to the east of Pennell Bank showing relations between foraminiferal trends and environmental conditions. (IBM station data from McKnight, 1962.)

and bottom temperature and salinity, but occur at widely differing depths. Bathymetry therefore appears to be the primary environmental factor influencing the distribution of the contrasting faunal assemblages.

Section E–E1, in the eastern Ross Sea, extends from the Bay of Whales north over the continental shelf to the continental slope (fig. 19). The profile figure has been constructed using the data of Pflum (1963). This section, from 460–2,561 m in depth, is distinct from those previously described in having, throughout its length, a dominant arenaceous fauna and very low planktonic percentages. The only significant occurrence of calcareous benthonics (16% of specimens, 30% of species) is in the shallowest area of the profile, suggesting that, as in all the other profiles, depth is the dominant factor controlling the major faunal distributions. It seems, therefore, that this profile is too deep throughout its length for calcareous faunas to exist.

Temperature and salinity are generally uniform but increase slightly to the north. Relatively uniform bottom water characteristics therefore correlate with relatively uniform distribution of faunal types.

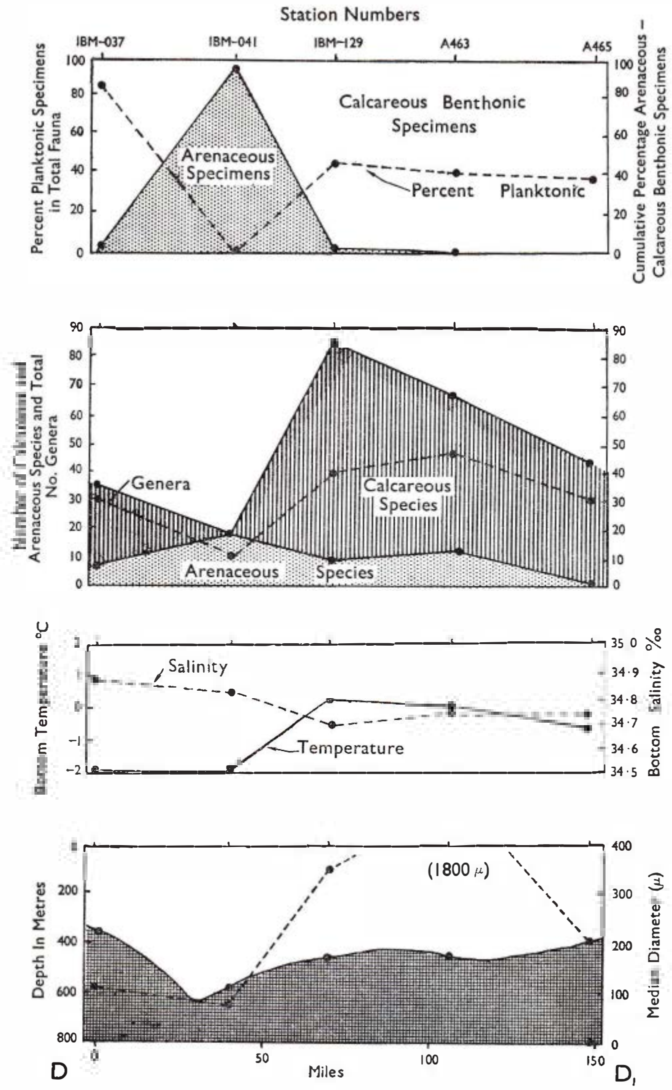


FIG. 18. Cross section from north of Coulman Island into the Ross Sea showing relations between foraminiferal trends and environmental conditions. (IBM station data from McKnight, 1962.)

Discussion of Sections

The five sections examined show that there exist important relations between certain environmental factors and foraminiferal trends. The most striking is the obvious correlation between bathymetry and test composition. On the whole, there is no definite relation between texture of bottom sediment and test composition. Even though most calcareous faunas were found associated with coarse sediment and most arenaceous faunas with fine sediment, the reverse situation was found in a reasonable number of stations, e.g., Sta. A 644 and A 645 from Moubray Bay. Sta. A 644 from 530 m, is represented by black mud (median diameter, 14 μ) and has a calcareous fauna, whereas Sta. A 645, from 720 m, is represented by black brown fine sand (median diameter, 130 μ) and has an arenaceous fauna. Some degree of correlation between calcareous faunas and coarse sediments might be expected, since coarse sediments tend to occur in shallow water, but there is no evidence that the nature of the sediment has any direct control over the fauna.

Calcium carbonate percentages in the sediment are often greatest in the regions of high calcareous foraminiferal percentages, but this is probably an effect of calcareous foraminiferal abundance rather than a controlling factor in distribution. In three of the five sections, salinity and temperature of the bottom water showed no apparent relations to faunal trends; in one section, areas of arenaceous faunas had lowest temperatures and highest salinities; and in the other, more or less uniformly cold, highly saline bottom water corresponded with a uniform occurrence of arenaceous assemblages.

CALCIUM CARBONATE SOLUTION BOUNDARY

The distribution of calcareous faunas shallower than 550 m and arenaceous (dominantly non-calcareous) faunas at depths greater than 430 m, plus evidence shown by solution effects on calcareous Foraminifera in arenaceous faunas, suggests the presence of a calcium carbonate solution boundary at a depth of approximately 500–550 m.

Solution Effects

Partial solution effects were observed on most of the calcareous Foraminifera which occur in the arenaceous faunas. In some of these faunas the sparse calcareous Foraminifera are often represented by casts, while in others, specimens are thin shelled, chalky in appearance, and easily broken. These effects are evident also on the rarely-occurring Mollusca in some of these samples.

Solution of the calcareous tests of Foraminifera in the deepest parts of the oceans is well known (Ericson *et al.* 1961; Phleger *et al.* 1953; Phleger, 1960). Carbonate solution at great depths is due to an increase in the solubility product of calcium carbonate caused by increase in hydrostatic pressure and decrease in temperature. In a study of Atlantic deep sea sediment cores, Ericson *et al.* found that where the depth of water was more than 5,000 m, the calcareous element was much reduced by solution and planktonic foraminiferal tests were almost absent. Such areas were correlated with red clay deposits (Murray and Renard, 1291). Between 5,000 and 4,000 m they found that, although Foraminifera may be common, many tests are fragile because of partial solution. Also, because fragile tests of some species were destroyed, the assemblages were at times dominated by heavy shelled forms of minor importance.

Solubility of calcium carbonate in sea water increases with increasing salinity and decreasing temperature (Wattenberg and Timmermann, 1936; Miller, 1952; Gibson, 19[illegible]). The effect of pressure has been regarded

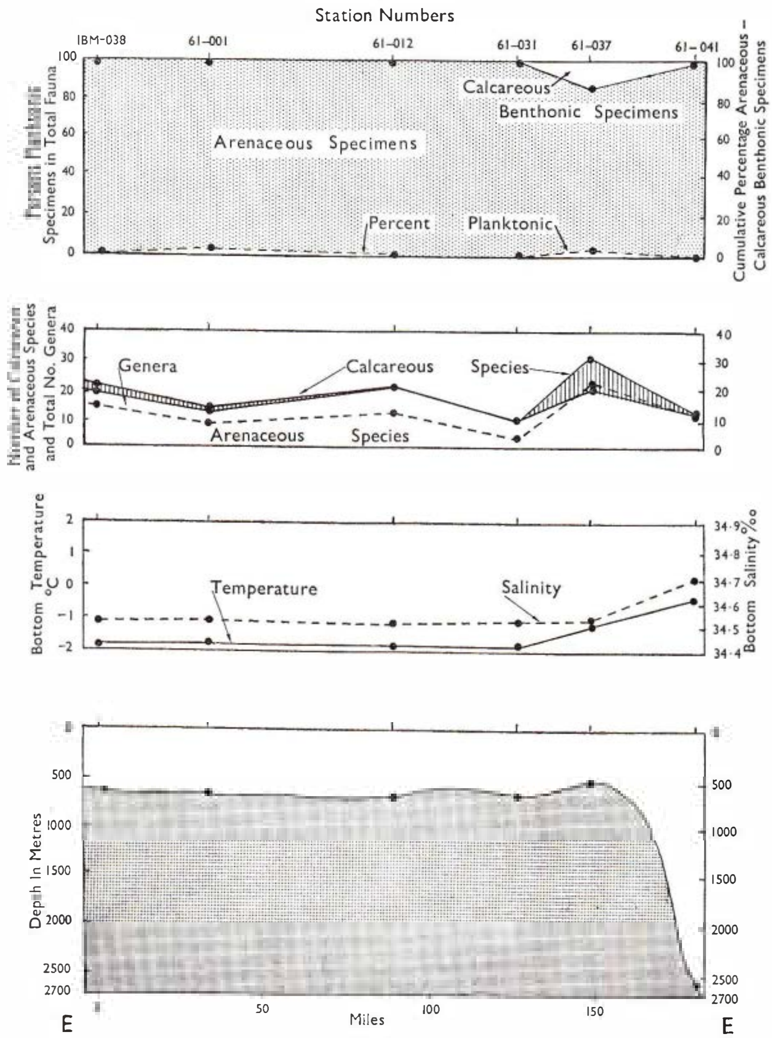


FIG. 19. Cross section from the Bay of Whales north into the Ross Sea, showing relations between foraminiferal trends and environmental conditions. (Data from Pflum, 1963.)

by some authors to be small (Wattenberg, 1933; Revelle, 1934), but recently Pytkowicz and Conners (1964) have shown that pressure is an important factor. There is an approximate threefold increase in the apparent solubility product on exposure to 1,000 atmospheres of pressure.

Reyment (1959) studied the Foraminifera in a sediment core collected from 7,710 m in the Mindanao Trench, in an area exposed to strong solution effects. He found that the benthonic species in the core had varying resistance to corrosion, and considered that certain species adapt themselves better than others to counter the effects of calcium carbonate solution. This may also be true for some of the benthonic species in the Ross Sea. Species which occurred in more than one arenaceous fauna (but not in more than four) and which may have a certain amount of resistance to solution are: *Trifarina earlandi*, *Epistominella exigua*, *Cibicides refulgens*, *Stainforthia complanata*, *Fursenkoina earlandi*, *Astrononion* n.sp., *Nonionella bradyi*, *Nonionella iridea* and *Pullenia subcarinata*.

Outside the Ross Sea in warmer, less saline circumpolar waters, rich calcareous benthonic foraminiferal faunas exist as deep as 4,000m (Saidova, 1961; Bandy and Echols, 1964). It follows that there the actual solution of calcium carbonate only occurs deeper than this, even though it has been shown by Pytkowicz (1965) that waters in the eastern South Pacific Ocean are generally undersaturated in calcium carbonate below the first few hundred metres.

Solution of calcareous Foraminifera, due to acidity of bottom sediment, and not to highly calcium-carbonate-undersaturated bottom waters, has been shown by

Bartlett (1964) from St. Margaret and Mahone Bays, Nova Scotia. He found that sediments below the top centimetre at most stations, especially black fetid-smelling oozes, are acidic with pH values as low as 5·0. The top centimetre, on the other hand, is alkaline or only slightly acidic (pH 7·2 to 6·8). This upper layer was found to be favourable for supporting a rich fauna including calcareous Foraminifera, whereas the lower acidic sediments are not conducive to life or to the preservation of calcareous tests. Calcareous Foraminifera in the acid layers are represented mainly by undissolved chitinous linings. A similar explanation for the solution effects found in the Ross Sea is not considered likely, because calcareous Foraminifera have not been found as significant faunal elements even in the top sedimentary layer of cores from arenaceous faunal areas (see also McKnight, 1962; Pflum, 1963). Also, nearly all cores studied by McKnight and Pflum show a general increase (not a decrease) in the percentage of calcareous specimens with depth.

Factors Causing Solution at Shallow Depths

Effective calcium carbonate solution in the Ross Sea at much shallower depths than outside is regarded as being due to the presence of highly undersaturated water below depths of about 550 m. This understuration is caused by a combination of factors.

1. The very low temperatures (0°c to −2°c) and very high salinities (34·75 ‰ to 35·00 ‰) of the Ross Sea bottom water (Shelf Water) favour the solution of calcium carbonate.
2. Very cold temperatures also would allow a substantial increase in the dissolved carbon dioxide content of the water which in turn would increase the solubility of calcium carbonate.
3. Carbon dioxide values of waters would be increased by the presence of an ice cover over the Ross Sea and lack of sunlight in the Antarctic for much of the year, limiting the activity of carbon dioxide - utilising phytoplankton to short periods during the summer.
4. Further increase in carbon dioxide values in the waters would be caused by the presence, immediately to the south below the thick Ross Ice Shelf, of a large water mass probably containing a high carbon dioxide content. This high content would be caused by the absence of phytoplankton due to permanent aphotic conditions existing beneath the ice shelf, and by the presence of an abundant carbon dioxide - producing fauna which has been reported from beneath the ice shelf, at least 28 km behind its leading edge (Littlepage and Pearse, 1962).

Although the relative importance of these factors cannot yet be assessed fully, it is highly probable that the observed solution of calcareous organisms below 550 m is due to high carbon dioxide concentration and low temperatures.

The basin-like shape of the Ross Sea floor, with the shelf sloping inland away from the relatively shallow ridge in the outer Ross Sea, may retain the dense, highly undersaturated bottom waters and reduce circulation (Deacon, 1937). However, the degree to which topography controls the distribution of bottom waters is yet uncertain because the relatively few faunas collected within the Ross Sea, but outside the Ross Sea shelf basin, appear to be under the same environmental influence as those collected from within the basin.

Anomalous Samples

Of 103 samples studied by the writer and others from the Ross Sea, 46 with calcareous faunas are from depths shallower than 550 m and only nine from depths greater than 550 m and below the solution boundary. Of these, two of McKnight's samples with high calcareous percentages can be disregarded, as one (IBM028 – 576 m) contained only one specimen and the other (IBM011 – 740 m) only one calcareous species. Of the remainder, three are from the north-east of Pennell Bank, three are from McMurdo Sound to the west of Ross Island, and one from a position 120 miles east of Ross Island, all except the last being from areas of steep slope. These atypical calcareous faunas are possibly the result of rapid burial due to displacement of bottom sediments and calcareous faunas from shallower waters. The important part played by rafting and displacement in the transport of shallow water sediment and faunas into deeper waters in the polar areas has been pointed out by various authors (Uchio, 1960; Bandy and Echols, 1964; Green, 1960). Slumps carrying shallow water sediments and organisms into deeper water might be initiated by the impact and movement of temporarily stranded icebergs such as those observed by Mr J. Bullivant (pers. comm.) on Pennell Bank in 1959. The area to the north-east of Pennell Bank, represented by stations A 325 and A 522 may be a recipient area of shallow water material transported by such a process. It is, however, not entirely certain that sample A 522 (1,335 m) is derived from shallower depths because, although it contains many species which are not found elsewhere in the Ross Sea deeper than 450–550 m, it also contains a few species (*Pyrgo murrhina*, *Cibicides bradii*, *Rupertina stabilis*, *Bulimina aculeata* and *Karreriella bradyi*) which have not yet been found there from shallower depths.

The area from which A 522 was obtained may in fact be under the influence of Circumpolar Water which is not so undersaturated in calcium, and this would account for its rich calcareous fauna. However, the few samples so far collected from the outer Ross Sea area contain arenaceous faunas, suggesting environmental control like that of the deep parts of the inner area. Many more foraminiferal samples need to be collected from the deep water in the north-eastern area in order to show more clearly the distribution patterns of the microfaunas. These in turn will throw more light on the dominant environmental controls.

Preservation of calcareous specimens not in chemical equilibrium with surrounding water could also be due to rapid burial because of high sedimentation rates, or of burrowing by benthonic animals.

Previous Theories

An explanation for the distribution of the contrasting faunas in the Ross Sea has been offered by McKnight (1962), and modified slightly by Pflum (1963), working with relatively small numbers of samples from fairly restricted areas. McKnight's hypothesis proposed a rather complicated mechanism involving a hypothetical current with high arenaceous and low calcareous foraminiferal percentages passing over the stations dominated by arenaceous Foraminifera (McKnight, loc. cit. p. 78). This bottom current was also supposed to have swept almost all planktonic Foraminifera out of the areas dominated by the arenaceous forms. The present work, however, shows that the calcareous faunas occur in shallow areas more likely to be exposed to current action. The distribution of calcareous and arenaceous faunas in the Ross Sea bottom sediments is more readily explained by the existence of a calcium carbonate solution boundary.

Because most of the solution of calcium carbonate would occur at or near the sediment/water interface, lower levels in a core should provide a clue to the conditions existing when any fauna was deposited. McKnight reported a percentage increase in calcareous benthonic specimens with depth in cores from the Ross Sea. He proposed two possible explanations for this phenomenon. Firstly, a situation was envisaged where arenaceous forms had not completed their migration into the Ross Sea, when the lower portions of the cores were being deposited. Secondly, he suggested that a change in water masses due to climatic change had caused a change in foraminiferal distribution. McKnight's second explanation is considered by the writer to be the more feasible in the light of present knowledge of Ross Sea Foraminifera. A change to colder climatic conditions would probably decrease the depths at which the calcium carbonate solution boundary lies. The increase reported by McKnight in calcareous benthonics with depth in cores is regarded as representing a warmer period in which the calcium carbonate boundary was at greater depths, or, alternatively, solution was less effective than it is now in the areas from which the cores were obtained. A study of the distribution of calcareous and arenaceous foraminiferal assemblages in long cores from the Ross Sea may provide evidence of the climatic history of the area.

Comparison with Macrofauna

In an account of the Ross Sea macrobenthos Bullivant (1966) points out that certain features appear unique. Such features are the extensive development of silicious sponges, of bryozoans and pycnogonids, and the complete absence of crabs. In addition, Mollusca are few and inconspicuous compared with those in areas of similar depths elsewhere in the world. When present, Mollusca usually have rather colourless shells many of which become badly eroded even in life (Dell, 1965). The large endemic pectenid *Adamussium colbecki* has a shell containing so little calcium that it is flexible in life.

Bullivant distinguished and mapped a number of faunal assemblages. There is a general correlation between the distribution of these assemblages and that of the microfaunal assemblages.

Arenaceous foraminiferal faunas are associated with the following macrobenthic assemblages:

- Deep shelf mud bottom assemblage.
- Deep ooze assemblage.
- Deep shelf mixed assemblage (in part).

These assemblages have sparse faunas like their microfaunal counterparts and have a high proportion of mobile organisms. Polychaetes and echinoderms are the dominant elements. These faunas are found in the deeper parts of the Ross Sea below the solution boundary.

Calcareous foraminiferal faunas are associated with the following macrobenthic assemblages:

- Pennell Bank assemblage.
- Shelf edge barnacle assemblage.
- Stylasterine coral assemblage.
- *Gardenaria antarctica* assemblage.
- Brachiopod assemblage.
- McMurdo Sound mixed assemblage.
- McMurdo Sound glass sponge assemblage.
- Deep shelf mixed assemblage (in part).

In contrast to those assemblages associated with arenaceous Foraminifera, these have rich and varied faunas with a high proportion of sessile organisms. These faunas, made up of combinations of bryozoans, ascidians, sponges, gorgonaceans, echinoderms, pycnogonids, cerianthids, molluscs, polychaetes, corals, and crustaceans, occur on hard substrates which are found in the shallower parts of Ross Sea and lie above the solution boundary.

In the macrofaunas associated with calcareous foraminiferal faunas, calcareous forms such as molluscs, bryozoans, and corals are a significant element. The macrofaunas associated with arenaceous foraminiferal faunas, as may be expected, contain few calcareous forms. However, even though the calcareous element is much reduced, solution is less apparent on the macrofaunas than on the microfaunas. This is shown by the occurrence below the solution boundary of calcareous macro-organisms in association with arenaceous foraminiferal faunas (A 459, A 458, A 461, and A 625). These calcareous macro-organisms are significantly important elements of the fauna, though much less important than in faunas collected above the solution boundary. In the samples quoted above, calcareous Foraminifera constitute less than 1·7 percent of the foraminiferal assemblage. However, certain animals living at great depths in the ocean are known to be able to secrete calcium carbonate for their shells (Bruun, 1957) even though they live in an environment of calcium carbonate undersaturation. It is significant that Bullivant compared the Ross Sea deep shelf mud bottom assemblage (with its general lack of calcareous Foraminifera) with the world-wide deep fauna, pointing out that the groups making up the two faunas are similar. *Umbellula* occurs in both faunas and both are dominated by polychaetes and echinoderms.

Bathymetric Foraminiferal Zonation

Benthonic Species

The analysis of samples for a depth zonation is restricted, in this study, to the Ross Sea area. The 75 samples collected by the New Zealand Oceanographic Institute, McKnight, and Pflum give good bathymetric control between the shallowest sample, obtained from 90 m, and the deepest, from 3,570 m. Figure 20 shows depth ranges of selected species. Many of these species have restricted depth ranges in the Ross Sea, but elsewhere in the Antarctic a number are known to extend into deeper water, especially the calcareous species. Their lower limits in the Ross Sea are controlled by the calcium carbonate solution boundary at about 500 m.

Because depth ranges of species differ markedly from those elsewhere in the Antarctic, it is not possible to define a foraminiferal depth zonation which will apply to the Antarctic as a whole. The area over which uniform depth zones extend is governed by the lateral extent of the controlling physical factors, and the Ross Sea is characterised by dominant physical factors which are not found in the Antarctic as a whole.

Several rather abrupt changes in the fauna take place with increasing depth, and the actual depths at which these changes occur form convenient boundaries to the various bathymetric faunal zones. The main changes occur at approximately 270 m, 450–550 m, 1,300 m, and 2,200 m.

The boundary at 270 m is marked by the upper depth limits of the following species:

Saccorhiza ramosa	*Dentalina communis*
Trifarina pauperata	*Triloculina trigonula*
Cassidulinoides parkerianus	*Reophax subfusiformis*
Parafissurina n.sp. A	*Psammophax consociata*
Parafissurina n.sp. B	*Cribrostomoides wiesneri*
Fissurina fissicarinata	*Adercotryma glomerata*
Oolina hexagona	*Verneuilina minuta*
Oolina heteromorpha	*Textularia earlandi*
Lagena wiesneri	*Reophax distans*
Lagena meridionalis	

The boundary between 450 and 550 m which is relatively broad, and represents the calcium carbonate solution boundary, is marked by the lower limits of almost every calcareous species. Arenaceous species which do not extend shallower than this boundary are:

Haplophragmoides rotulatum	*Haplophragmoides bradyi*
Glomospira charoides	*Karreriella pusilla*
Cyclammina pusilla	*Reophax spiculifer*
Reophax helenae	*Hemisphaerammina depressa*
Reophax nodulosus	*Bathysiphon filiformis*

Of these arenaceous species only *H. rotulatum* and *G. charoides* occur in any quantity at much greater depths. *Hyperammina novaezealandiae* and *Rhabdammina* sp. (coarse grained test with sponge spicules), although extending into shallower depths, occur abundantly only from the boundary to a depth of 2,200 m.

The boundary at 1,300 *m* is marked by the upper depth limits of *Cyclammina orbicularis* and *Cribrostomoides subglobosum*; the upper limit of abundance of *Glomospira charoides*; and the lower limits of *Karreriella pusilla*, *Reophax spiculifer* and *Hemisphaerammina depressa*.

The boundary at 2,200 *m* is marked by the upper depth limit of *Ammomarginulina ensis*; the upper limit of abundance of *Haplophragmoides rotulatum*; and the lower limits of *Hyperammina novaezealandiae*, *Rhabdammina* sp. (coarse grained test with sponge spicules), *Reophax subfusiformis*, *Bathysiphon discreta*, *Miliammina arenacea* and *Reophax subdentaliniformis*.

McKnight's and Pflum's depth zonations show some similarity to the present study, but theirs were based on samples from outside the Ross Sea as well as from inside. Boundaries approximately corresponding to those of the present study are at 475 m (recorded by McKnight) and at 515 m and 1,134 m (recorded by Pflum).

It is apparent that the most pronounced bathymetric zone boundary occurs at 450–550 m and represents the calcium carbonate solution boundary. The boundary at 270 m is well marked by the upper depth limits of numerous species; and the two deepest boundaries, although marked by only relatively few species changes, appear to be significant. As yet, the physical factors causing boundaries at the three last-mentioned depths are unknown.

Planktonic Species

A tendency towards depth zonation is apparent in the Ross Sea for the dominant planktonic species *Globigerina pachyderma.* Bé (1960), working on samples from the central Arctic Ocean area, considered that *G. pachyderma* was the only species of *Globigerina* present.

G. pachyderma was represented by a younger, thin shelled, and large apertured form living in depths shallower than 200 m, and an older, more typical form with thickened test and reduced final chamber living in depths greater than 200 m. The distribution of these two forms in the Ross Sea sediments suggests a relationship similar to that found by Bé in the Arctic. Samples from the Ross Sea shallower than 200 m mostly contained specimens of the young form, while specimens from samples deeper than this were mostly of the older thick-shelled form.

A similar situation seems to occur in the Adelie Land coastal area of Antarctica. Blanc-Vernet (1965) recognised two varieties of *G. pachyderma*, *G.* cf. "*bulloides*" and *G.* "*dutertrei*", which differ to some extent from the typical form (Blanc-Vernet, loc. cit. p. 199). Also, these varieties occurred in different bathymetric zones. The present writer considers that *G.* "*bulloides*" may in fact be the younger stage of *G. pachyderma*, while *G.* "*dutertrei*" is a subordinate variety of the older stage of *G. pachyderma*. In spite of this taxonomic uncertainty there is no reason to doubt the bathymetric zonation observed by Blanc-Vernet who found that *G.* "*bulloides*" was restricted mainly to samples from littoral stations and *G.* "*dutertrei*" and *G. pachyderma* restricted mainly to depths of more than 180 m. It appears, therefore, that the growth stages of *G. pachyderma* and their respective depth distributions which Bé observed in Arctic seas are also true for Antarctic seas.

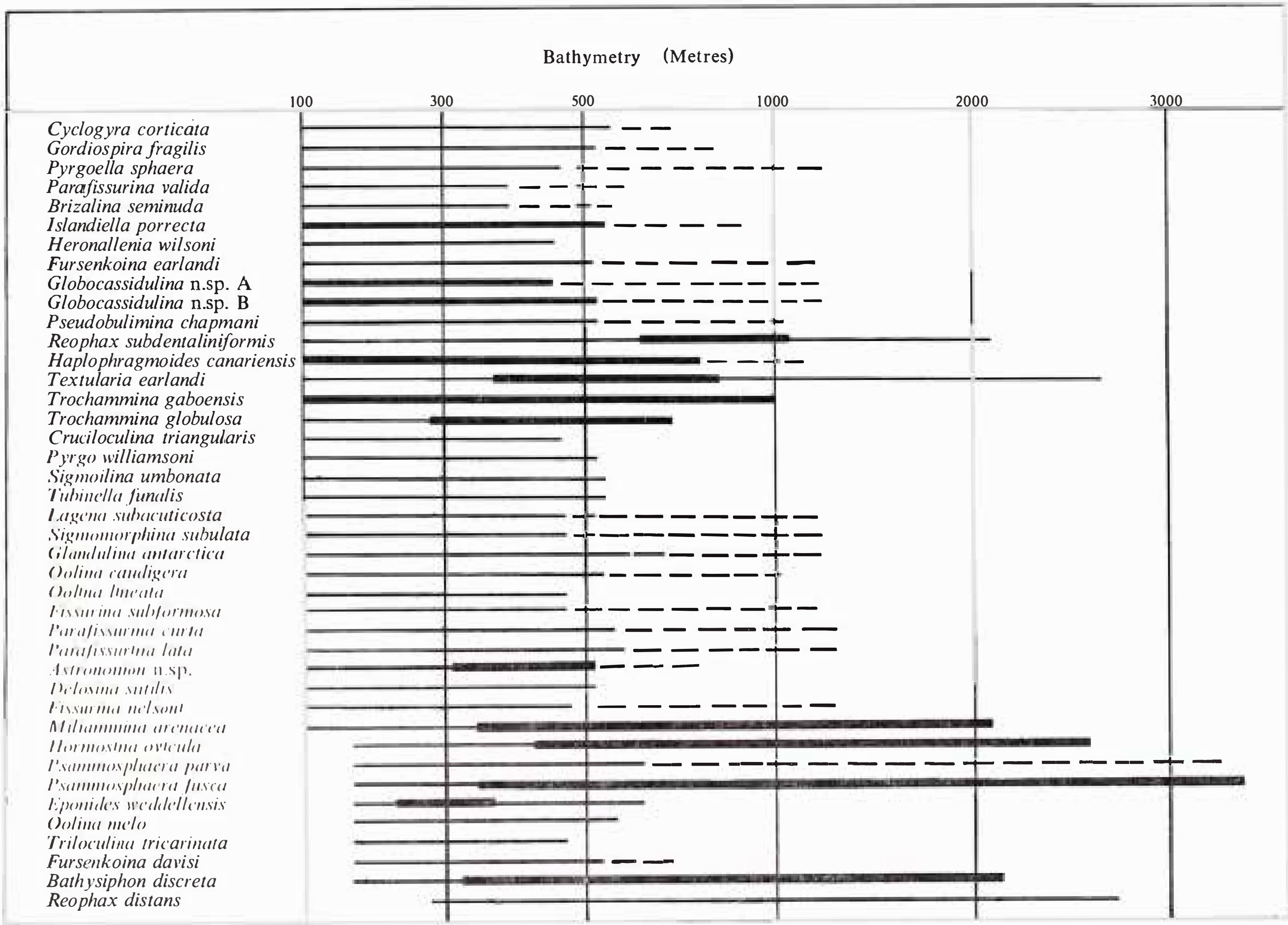


FIG. 20. Depth ranges of selected benthonic Foraminifera in the Ross Sea, from data of the writer, McKnight (1962), and Pflum (1963). The sparse occurrence of many calcareous species below 550 m, although shown, is based mainly on the content of a single sample (A522–1,335 m) that is probably derived from shallow water.
Note: Name changes: For *Globocassidulina* n.sp.B read *G. biora; Haplophragmoides canariensis—Cribrostomoides jeffreysi; Trochammina globulosa—Ammoflintina* n.sp.; *Lagena subacuticostata—L. subacuticosta; Eponides weddellensis—Gyroidina* sp.

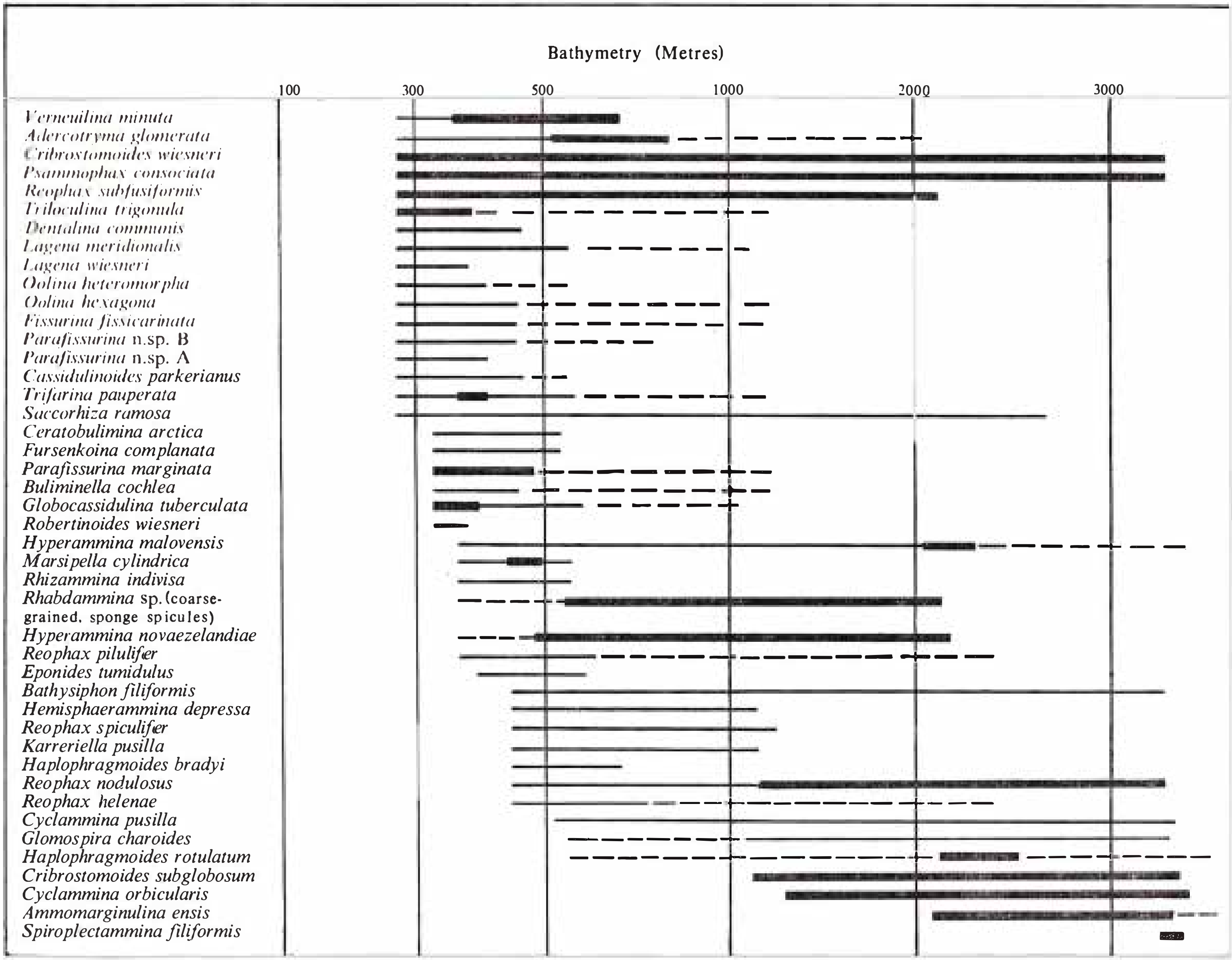


FIG. 20.—continued
Note: Name changes: For *Fursenkoina complanata* read *Stainforthia complanata; Eponides tumidulus—Eponides* n.sp.

SUMMARY

1. Microfaunas in the Ross Sea are of two separate and greatly contrasting types: *calcareous faunas* dominated by abundant and diverse calcareous Foraminifera; *arenaceous faunas* which are dominantly non-calcareous, sparse faunas with the Foraminifera almost entirely arenaceous.

2. A study of environmental factors affecting the distribution of the calcareous and arenaceous faunas reveals that depth is the dominant controlling factor. Most calcareous faunas are restricted to shallower than 550 m, while all arenaceous faunas occur deeper than 430 m. The few calcareous faunas found deeper than 550 m are probably due to displacement of bottom sediments and calcareous faunas from shallower water.

3. There is no evidence that the nature of the sediment has any direct control over the faunas. Even though most calcareous faunas were found associated with coarse sediment and most arenaceous faunas with fine sediment, the reverse situation occurs in a number of cases. Some degree of correlation between calcareous faunas and coarse sediments might be expected, since coarse sediments tend to occur in shallow water.

4. The depth distribution of the two faunal types, plus evidence shown by solution effects on calcareous Foraminifera in arenaceous faunas, suggests a calcium carbonate solution boundary at a depth of approximately 500 to 550 m. It is highly probable that this solution boundary at such shallow depths is due to relatively high carbon dioxide concentration and relatively low temperatures.

5. Calcium carbonate solution at such shallow depths in Antarctica is so far known to occur only in the Ross Sea. Outside the Ross Sea in warmer, less saline circumpolar waters, rich calcareous foraminiferal faunas exist as deep as 4,000 m with actual solution of calcium carbonate occurring deeper than this.

6. The distribution of calcareous and arenaceous foraminiferal faunas in long cores may provide evidence about the climatic history of the area. A change to warmer climatic conditions would probably increase the depths at which the calcium carbonate solution boundary lies. The increase, reported by McKnight, in calcareous benthonics with depth in cores is believed to represent a warmer period in which the solution boundary was at greater depths.

7. A comparison of the microfaunal distributions with that of the macrofaunal distributions shows that macrofaunas associated with calcareous foraminiferal faunas have a significant calcareous element. Those macrofaunas associated with arenaceous faunas on the other hand contain few calcareous forms. However, even though the calcareous element is much reduced, solution is less apparent on the macrofaunal than on the microfaunal organisms.

8. Planktonic Foraminifera occur abundantly in all the calcareous faunas whereas they are absent or very rare in arenaceous faunas. The distribution of the planktonics, like the calcareous benthonics, is controlled by the solution boundary.

9. The depth ranges of many species differ markedly from those elsewhere in the Antarctic and it is not possible to define a foraminiferal depth zonation which will apply to the Antarctic as a whole.

10. Several abrupt changes in the fauna take place with increasing depth and form boundaries to depth zones at approximately 270 m, 450–550 m, 1,300 m, and 2,200 m.

11. *Globigerina pachyderma* is by far the most dominant planktonic species. Young, thin-shelled forms of this species were found in samples from depths shallower than 200 m while samples deeper than this contained specimens which were mostly older thick-shelled forms.

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FAUNAL REFERENCE LIST OF ROSS SEA FORAMINIFERA

Adercotryma glomerata (Brady) = *Lituola glomerata* Brady, 1878, Ann. Mag. nat. Hist. ser. 5(1): 433, pl. 20, figs. 1a-c.
Ammodiscus cf. *anguillae* Höglund, 1947, Zool. Bidr. Upps. 26: 128, pl. 28, fig. 8; pl. 29, fig. 4.
Ammomarginulina ensis Wiesner, 1931, Dt. Südpol.-Exped., v. 20 (Zool. 12): 97, pl. 12, fig. 147.
Astrononion antarcticum Parr, 1950, Rep. B.A.N.Z. Antarctic Res. Exped. Ser. B (Zool., Bot.) 5(6): 371, pl. 15. figs. 13, 14a, b.
Astrorhiza triangularis Earland, 1933, Foraminifera, Pt. II—South Georgia, "Discovery" Rep. 7: 52, pl. 1, figs. 8, 9.

Bathysiphon capillaris de Folin, 1886, Les Bathysiphons; Premieres Pages d'une Monographie du Genre. Act. Soc. linn.Bordeaux, 40 (ser. 4, pt 10): 276, pl. 5, figs. 2a–e.
Bathysiphon crassatina (Brady) = *Astrorhiza crassatina* Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 233, pl. 20, figs. 1–9.
Bathysiphon discreta (Brady) = *Rhabdammina discreta* Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9 (Zool.): 268, pl. 22, figs. 7–10.
Bathysiphon filiformis M. Sars, 1872, Forh. VidenSelsk. Krist., p. 251.
Botellina goesii Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 78, pl. 2, figs. 23–26.
Botellina labyrinthica Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 279, pl. 29, figs. 8–18.
Brizalina decussata (Brady) = *Bolivina decussata* Brady, 1884, Rep. scient. Results explor. Voy. Challenger. 9: 423, pl. 53, figs. 12, 13.
Brizalina seminuda (Cushman) = *Bolivina seminuda* Cushman, 1911, Bull. U.S. natn. Mus. 71: 34, pl. 34, fig. 55.
Bulimina aculeata d'Orbigny, 1826, Annls Sci. nat. 7: 269.
Buliminella cochlea Wiesner = *Buliminella elegantissima cochlea* Wiesner, 1931, Dt. Sudpol.-Exped. 20 (Zool. 12): 124, pl. 19, fig. 237.

Cassidulina neocarinata Thalmann, 1950, Contr. Cushman Fdn foramin. Res. 1(3–4): 44.
Cassidulinoides parkerianus (Brady) = *Cassidulina parkeriana* Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 432, pl. 54, figs. 11–16.
Ceratobulimina arctica Green, 1960, Micropaleontology 6(1): 71, pl. 1, fig. 1.
Cibicides bradii (Tolmachoff) = *Planulina bradii* Tolmachoff, 1934, Ann. Carneg. Mus. 23: 333.
Cibicides grossepunctatus Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 184, pl. 8, figs. 39–41.
Cibicides refulgens Montfort, 1808, Conchyl. System. 1: 122.
Cribrostomoides jeffreysi (Williamson) = *Nonionina jeffreysii* Williamson, 1858, On the Recent Foraminifera of Great Britain. Ray Soc., Publs. London: 34, pl. 3, figs. 72–73.
Cribrostomoides subglobosum (G. O. Sars) = *Lituola subglobosa* G. O. Sars, 1872, Forh. VidenskSelsk. Krist, p. 253.
Cribrostomoides wiesneri (Parr) = *Labrospira wiesneri* Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 272, pl. 4, figs. 25–6.
Cruciloculina triangularis d'Orbigny, 1839, Foraminifères. *In:* Sagra, R. de la, "Histoire Physique, Politique et Naturelle de l'Ile de Cuba". p. 72, pl. 9, figs. 11, 12.
Cyclammina orbicularis Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 353, pl. 37, figs. 17–19.
Cyclammina pusilla Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 353, pl. 37, figs. 20–3.
Cyclammina tasmanica Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.), 5(6): 274, pl. 4, fig. 28.
Cyclogyra antarctica (Rhumbler) = *Cornuspira antarctica* Rhumbler, 1931, *In:* Wiesner, Dt. Südpol.-Exped. 20 (Zool. 12): 101, pl. 14, figs. 164–6.
Cyclogyra corticata (Chapman and Parr) = *Cornuspira involvens corticata* Chapman and Parr, 1937, Foraminifera. Scient. Rep. Australas. Antarct. Exped. Ser. C (Zool., Bot.) 1(2): 28, pl. 9, fig. 32.
Cyclogyra lacunosa (Brady) = *Cornuspira lacunosa* Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 202, pl. 113, fig. 21.

Dendronina aborescens Heron-Allen and Earland, 1922, Protozoa, Part II, Foraminifera. Nat. Hist. Rep. Br. Antarct. Terra Nova Exped. (Zool.) 6(2): 78, pl. 2, figs. 10–12.
Dendrophyra indivisa (Heron-Allen and Earland) = *Psammatodendron indivisum* Heron-Allen and Earland, 1932, Foraminifera, Pt. I—Falkland Islands, "Discovery" Rep. 4: 334, pl. 7, fig. 16.
Dentalina communis (d'Orbigny) = *Nodosaria* (*Dentaline*) *communis* d'Orbigny, 1826, Annls Sci. nat. Ser. 1, 7: 254.
Dentalina communis larva (Earland) = *Nodosaria communis larva* Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 167, pl. 7, figs. 40–1.
Dentalina translucens Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.), 5(6): 328, pl. 11, fig. 25.
Delosina sutilis Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 129, pl. 5, figs. 1–8.
Delosina wiesneri Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 130, pl. 5, figs. 9–15.
Discopulvinulina subcomplanata (Parr) = *Discorbis subcomplanatus* Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped., Ser. B (Zool., Bot.) 5(6): 355, pl. 14, figs. 1, 2.

Eggerella cf. *bradyi* (Cushman) = *Verneuilina bradyi* Cushman, 1911, Bull. U.S. natn. Mus. 71(2): 54, pl. 55, figs. 87a, b.
Eggerella superba Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 118, pl. 5, figs. 30–34.
Ehrenbergina glabra Heron-Allen and Earland = *Ehrenbergina hystrix glabra* Heron-Allen and Earland, 1922, Protozoa, Part II, Foraminifera, Nat. Hist. Rep. Br. Antarct. Terra Nova Exped. (Zool.) 6(2): 140, pl. 5, figs. 1–6.
Ehrenbergina pupa (d'Orbigny) = *Cassidulina pupa* d'Orbigny, 1839, "Voyage dans l'Amérique Méridionale, Foraminifères" 5(5): 57, figs. 21–3.
Epistominella exigua (Brady) = *Pulvinulina exigua* Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 696, pl. 103, figs. 13, 14.

Fissurina bisulcata (Heron-Allen and Earland) = *Lagena bisulcata* Heron-Allen and Earland, 1932, Foraminifera, Pt. I—Falkland Islands, "Discovery" Rep. 4: 380, pl. 11, figs. 29–32.
Fissurina cf. *clypeato-marginata* (Rhymer-Jones) = *Lagena vulgaris clypeato-marginata* Rhymer-Jones, 1874, Proc. Linn. Soc. Lond. 30: 58, pl. 19, fig. 37.
Fissurina cushmani (Wiesner) = *Lagena* (*Entosolenia*) *cushmani* Wiesner, 1931, Dt. Südpol.-Exped. 20 (Zool. 12): 121, pl. 19, fig. 225.
Fissurina fissicarinata Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 309, pl. 8, figs. 11a, b.
Fissurina aff. *kerguelensis* Parr. 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 305, pl. 8, fig. 7.
Fissurina nelsoni (Heron-Allen and Earland) = *Lagena stelligera nelsoni* Heron-Allen and Earland, 1922, Protozoa, Part II, Foraminifera, Nat. Hist. Rep. Br. Antarct. Terra Nova Exped. 6(2): 148, pl. 5, figs. 20–2.
Fissurina semimarginata (Reuss) = *Lagena marginata semimarginata* Reuss, 1870, Sber. Akad. Wiss. Wien 62(1): 468.
Fissurina subformosa Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 313, pl. 9, figs. 9a, b.

Fissurina texta (Wiesner) = *Lagena texta* Wiesner, 1931, Dt. Südpol.-Exped. 20 (Zool. 12): 121, pl. 19, fig. 230.

Fissurina cf. *trigono-marginata* (Parker and Jones) = *Lagena sulcata trigono-marginata* Parker and Jones, 1865, Phil. Trans. R. Soc. 155: 348, pl. 18, fig. 1a, b.

Fissurina cf. *wrightiana* (Brady) = *Lagena wrightiana* Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 482 pl. 61, figs. 6, 7.

Fursenkoina davisi (Chapman and Parr) = *Virgulina davisi* Chapman and Parr, 1937, Foraminifera, Scient. Rep. Australas. Antarct. Exped. Ser. C (Zool., Bot.) 1(2): 88, pl. 8, fig. 15.

Fursenkoina earlandi (Parr) = *Bolivina earlandi* Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 339, pl. 12, fig. 16a, b.

Gaudryina minuta Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 121, pl. 5, figs. 45–6.

Glandulina antarctica Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 334, pl. 12, figs. 8, 9.

Globigerina megastoma Earland, 1934, Foraminifera, Pt. III—Falklands, "Discovery" Rep. 10: 177, pl. 8, figs. 9–12.

Globigerina pachyderma (Ehrenberg) = *Aristerospira pachyderma* Ehrenberg, 1873, Abh. K. Akad. Wiss. p. 386, bl. 1, fig. 4.

Globocassidulina biora (Crespin) = *Cassidulina biora* Crespin, 1960, Sci. Rep. Tohoku Univ. Ser. 2. (Geol.) Spec. vol. 4: 28–29, pl. 3, figs. 1–10.

Globocassidulina pacifica Cushman, 1925, Contr. Cushman Fdn. foramin. Res. 1 (3): 53, pl. 9, figs. 14–16.

Globocassidulina tuberculata (Heron-Allen and Earland) = *Cassidulina subglobosa tuberculata* Heron-Allen and Earland, 1922, Protozoa, Part II, Foraminifera, Nat. Hist. Rep. Br. Antarct. Terra Nova Exped. (Zool.) 6(2): 138, pl. 4, figs. 36–8.

Globorotalia inflata (d'Orbigny) = *Globigerina inflata* d'Orbigny, 1839, *In:* Webb, P. B. and Berthelot, S., "Histoire Naturelle des Iles Canaries" (Zool.) 2(2): 134, pl. 2, figs. 7–9.

Globulotuba cf. *entosoleniformis* Collins, 1958, Foraminifera, Scient. Rep. Gt. Barrier Reef Exped. 6(6): 385, pl. 4, fig. 5a, b.

Glomospira charoides (Jones and Parker) = *Trochammina squamata charoides* Jones and Parker, 1860, Q. Jl geol. Soc. 16: 304.

Glomospira gordialis (Jones and Parker) = *Trochammina squamata gordialis* Jones and Parker, 1860, Q. Jl geol. Soc. 16: 304.

Gordiospira fragilis Heron-Allen and Earland, 1932, Jl R. microsc. Soc. Ser. 3, 52(3): 254, pl. 1, figs. 1–6.

Gyroidina neosoldanii Brotzen, 1936, Sver. geol. Unders, Afh. Ser. C, No. 396: 158, pl. 107, figs. 6, 7.

Haplophragmoides rotulatum (Brady) = *Haplophragmium rotulatum* Brady 1884, Rep. scient. Results explor. Voy. Challenger 9: 306.

Haplophragmoides cf. *sphaeriloculus* Cushman, 1917, Proc. U.S. natn. Mus. 51 (2172): 652.

Hemisphaerammina bradyi Loeblich and Tappan, 1957, Bull. U.S. natn. Mus. 215: 224, pl. 72, fig. 2a, b.

Hemisphaerammina depressa (Heron-Allen and Earland) = *Webbinella depressa* Heron-Allen and Earland, 1932, Foraminifera, Pt. I—Falkland Islands, "Discovery" Rep. 4: 329, pl. 7, figs. 10, 11.

Hemisphaerammina limosa (Earland) = *Webbinella limosa* Earland, 1933, Foraminifera, Pt. II—South Georgia, "Discovery" Rep. 7: 63, pl. 2, figs. 1, 2.

Heronallenia wilsoni (Heron-Allen and Earland) = *Discorbina wilsoni* Heron-Allen and Earland, 1922, Protozoa, Part II, Foraminifera, Nat. Hist. Rep. Br. Antarct. Terra Nova Exped. (Zool.) 6(2): 206, pl. 7, figs. 17–19.

Höglundina elegans (d'Orbigny) = *Rotalia* (*Turbinuline*) *elegans* d'Orbigny, 1826, Annls. Sci. nat. Ser. 1, 7: 276.

Hormosina ovicula Brady, 1884, Rep. Scient. Results explor. Voy. Challenger 9: 327, pl. 39, figs. 7–9.

Hyperammina cylindrica Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 254, pl. 3, fig. 5.

Hyperammina friabilis Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 258, pl. 23, figs. 1–3, 5, 6.

Hyperammina laevigata J. Wright = *Hyperammina elongata laevigata* J. Wright, 1891, Proc. R. Ir. Acad. Ser. 3, 4: 466, pl. 20, fig. 1.

Hyperammina malovensis Heron-Allen and Earland, 1932, Foraminifera, Pt. I—Falkland Islands "Discovery" Rep. 4: 333, pl. 8, figs. 12–14.

Hyperammina novaezealandiae Heron-Allen and Earland, 1922, Protozoa, Part II, Foraminifera, Nat. Hist. Rep. Br. Antarct. Terra Nova Exped. (Zool.) 6(2): 89, pl. 3, figs. 1–5.

Islandiella porrecta (Heron-Allen and Earland) = *Cassidulina crassa porrecta*, 1932, Foraminifera, Pt. I—Falkland Islands "Discovery" Rep. 4: 358, pl. 9, figs. 34-7.

Karreriella bradyi (Cushman) = *Gaudryina bradyi* Cushman, 1911, Bull. U.S. natn. Mus. 71 (2): 67.

Karreriella pusilla Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 283, pl. 5, figs. 25–6.

Lagena distoma Parker and Jones = *Lagena sulcata distoma* Parker and Jones, 1865, Phil. Trans. R. Soc. 155: 356, pl. 13, fig. 20.

Lagena heronalleni Earland, 1934, Foraminifera; Pt. III—Falklands, "Discovery" Rep. 10: 152, pl. 6, figs. 55–7.

Lagena laevis (Montagu) = *Vermiculum laeve* Montagu, 1803, "Testacea Britannica", p. 524.

Lagena meridionalis Wiesner = *Lagena gracilis meridionalis* Wiesner, 1931, Dt. Südpol.-Exped. 20 (Zool. 12): 117, pl. 18, fig. 211.

Lagena cf. *striatopunctata* Parker and Jones = *Lagena sulcata striatopunctata* Parker and Jones, 1865, Phil. Trans. R. Soc. 155: 350, pl. 13, figs. 25–7.

Lagena subacuticosta Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 302, pl. 8, fig. 3.

Lagena sulcata spicata Cushman and McCulloch, 1950, Allan Hancock Pacif. Exped. 6(6): 360, pl. 48, figs. 3–7.

Lagena wiesneri Parr = *Lagena striata wiesneri* Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 301.

Lagenammina longicollis (Wiesner) = *Proteonina longicollis*, Wiesner, 1931, Dt. Südpol.-Exped. 20 (Zool. 12): 82, pl. 6, fig. 55.

Laryngosigma williamsoni (Terquem) = *Polymorphina williamsoni* Terquem, 1878, Mem. Soc. geol. Fr. Ser. 3, 1: 37.

Martinottiella antarctica (Parr) = *Schenckiella antarctica* Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B. (Zool., Bot.) 5 (6): 284, pl. 5, fig. 27.

Marsipella cylindrica Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 265, pl. 24, figs. 20–2.

Miliammina arenacea (Chapman) = *Miliolina oblonga arenacea* Chapman, 1916, Rep. scient. Invest. Br. Antarct. Exped. 1907–9, Geol. 2(2): 59, pl. 1, fig. 7.

Miliolinella chukchiensis Loeblich and Tappan, 1953, Smithson. Misc. Collns 121 (7): 47, pl. 6, fig. 7.

Miliolinella circularis (Bornemann) = *Triloculina circularis* Bornemann, 1855, Z. dt. geol. Ges. 7: 349, pl. 19, fig. 4.

Neoglabratella wiesneri (Parr) = *Discorbis wiesneri* Parr, 1950, Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): 356, pl. 14, fig. 4.

Nonionella bradii (Chapman) = *Nonionina scapha bradii* Chapman, 1916, Rep. scient. Invest. Br. Antarct. Exped. 1907–9, Geol. 2(2): 71, pl. 5, fig. 42.

Nonionella iridea Heron-Allen and Earland, 1932. Foraminifera, Pt. I—Falkland Islands, "Discovery" Rep. 4: 438, pl. 16, figs. 14–16.

Oolina botelliformis (Brady) = *Lagena botelliformis* Brady, 1884, Rep. scient. Results explor. Voy. Challenger 9: 454, pl. 56, fig. 6.

Oolina borealis Loeblich and Tappan, 1954, J. Walsh. Acad. Sci., 44(12): 384.

Oolina caudigera (Wiesner) = *Lagena* (*Entosolenia*) *globosa caudigera* Wiesner, 1931, Dt. Südpol.-Exped. 20 (Zool. 12): 119, pl. 18, fig. 214.

Oolina heteromorpha Parr, 1950. Rep. B.A.N.Z. Antarct. Res. Exped. Ser. B (Zool., Bot.) 5(6): pl. 8, fig. 6.

Oolina hexagona (Williamson) = *Entosolenia squamosa hexagona* Williamson, 1848, Ann. Mag. nat. Hist. ser. 2, 1: 20, pl. 2, fig. 23.

Oolina lineata (Williamson) = *Entosolenia lineata* Williamson, 1848, Ann. Mag. nat. Hist. Ser. 2, 1: 18, pl. 2, fig. 18.

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Parafissurina lateralis (Cushman) = *Lagena laterlis* Cushman, 1913, Bull. U.S. natn. Mus. 71(3): 9, pl. 1, fig. 1.

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TABLE 4 - FORAMINIFERAL LIST AND PERCENTAGE OCCURRENCE IN EACH SAMPLE EXCLUSIVE OF *GLOBIGERINA*.

X = < 1% and less than 20 specimens. * = < 1% but more than 20 specimens. Other micro organisms. A = Abundant. C = Common. R = Rare.

The percentage of *Globigerina pachyderma* is of the *total* foraminiferal fauna (benthonics and planktonics).

	CALCAREOUS FAUNAS																		[illegible]																	
[illegible]	A533	A468	A467	A530	A456	A641	A455	A531	A457	A449	A450	A465	A463	A644	A537	A525	A536	A522	A460	A616	A458	A625	A451	A459	A466	A461	A612	A645	A448	A592	A595	A593	A452	A462	A453	A524
[illegible]	[illegible]	110	136	269	270	322	330	348	357	362	395	399	466	530	548	583	790	[illegible]	430	470	475	520	523	542	569	573	612	720	752	865	865	1015	1290	2100	2195	3570
Family ASTRORHIZIDAE																																				
Astrorhiza triangularis Earland																																				
Rhabdammina cf. linearis Brady																																				
sp. (coarse grained test with sponge spicules)																																				
Rhizammina indivisa Brady																																				
Bathysiphon capillaris de Folin																																				
crassatina (Brady)																																				
discreta (Brady)																																				
filiformis M. Sars																																				
sp. (aligned sponge spicules)																																				
Marsipella cylindrica Brady																																				
Hyperammina cylindrica Parr																																				
friabilis Brady																																				
laevigata J. Wright																																				
malovensis H-A. & E.																																				
novaezealandiae H-A. & E.																																				
Saccorhiza ramosa (Brady)																																				
Botellina goesii Earland																																				
labyrinthica Brady																																				
Dendrophyra indivisa (H-A. & E.)																																				
Dendronina arborescens H-A. & E.																																				
Family SACCAMMINIDAE																																				
Psammosphaera fusca Schulze																																				
cf. rustica H-A. & E.																																				
"Sorosphaera" sp.																																				
Saccammina atlantica (Cushman)																																				
cf. fragilis Le Calvez																																				
sphaerica G.O. Sars																																				
[illegible]																																				
Psammophax consociata Rhumbler																																				
Lagenammina longicollis (Wiesner)																																				
Pelosina bicaudata (Parr)																																				
cylindrica (Brady)																																				
variabilis Brady																																				
Pelosphaera cornuta H-A. & E.																																				
Thurammina albicans Brady																																				
compressa Brady																																				
corrugata Earland																																				
protea Earland																																				
Hemisphaerammina bradyi Loeblich & Tappan																																				
depressa (H-A. & E.)																																				
limosa (Earland)																																				
[illegible]																																				
Tholosina laevis Rhumbler																																				
Pseudowebbinella goesi (Höglund)																																				
Family [illegible]																																				
Ammodiscus cf. anguillae Höglund																																				
Glomospira charoides (Jones & Parker)																																				
gordialis (Jones & Parker)												X	-		X	-																				
Turritellella shoneana (Siddall)																																				
Family HORMOSINIDAE																																				
Hormosina ovicula Brady					X	X		X	X			X	-		X	-									3	8										
Reophax distans Brady																																				
fusiformis (Williamson)																																				
nodulosus Brady																																				
pauciloculatus Rhumbler																																				
pilulifer Brady																																				
spiculifer Brady																																				
subdentaliniformis Parr																						X	X	X	1		3	X	5	17	X	3				
subfusiformis Earland																			21	22	6		5	6	X		X	X	16	13					-	
sabulosus Brady																																				
Family RZEHAKINIDAE																																				
Ammoflintina n.sp.																				4	8	X	3	1			2	1								
Miliammina arenacea (Chapman)														X	2				42	7	27	3	4	33	9	60	31	9	21	7	6	21	7	19	-	
Family LITUOLIDAE																																				
Haplophragmoides [illegible] (Brady)																																			12	
cf. sphaeriloculus Cushman																																				
Adercotryma glomerata (Brady)																										1	5	2	X							

	[illegible]																		[illegible]																	
[illegible]	[illegible]	[illegible]	[illegible]	A530	A456	A641	A455	A531	A457	A449	A450	A465	A463	A644	A537	A525	A536	A522	A460	A616	A458	A625	A451	A459	A466	A461	A612	A645	A448	A592	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DEPTH IN METRES	90	110	136	269	270	322	330	348	357	362	395	399	466	530	548	583	790	[illegible]	[illegible]	[illegible]	[illegible]	520	523	542	569	573	612	720	752	865	865	1015	1290	2100	2195	3570
Cribrostomoides subglobosum (G.O.Sars)																																				
wiesneri (Parr)								X	X	X	X																									
jeffreysi (Williamson)	11	5	1					6	X	X	1	X		X	7	X																				
Recurvoides contortus Earland																							X	3	1	3										
Cyclammina orbicularis Brady																																				
pusilla Brady																																				
tasmanica Parr																																				
Ammomarginulina ensis Wiesner																																				
Family TEXTULARIIDAE																																				
Spiroplectammina filiformis Earland																																				
subcylindrica Earland																																				
Textularia cf. agglutinans d'Orbigny																																				
antarctica (Wiesner)																						18	10	9	5	-	19	24	3	14	24	24				
earlandi Parker																																				
Siphotextularia obesa Parr																																				
Family TROCHAMMINIDAE																																				
Trochammina alternans Earland																																				
antarctica Parr			1	22	*	4	2		2	2	11		X	4	11	6	18	-	6	8	30	56	28	17	19	8	29	27	7	34	43	25				
conica Earland																																				
[illegible] Parr																																				
inconspicua Earland																																				
cf. ochracea (Williamson)																																				
rossensis Warthin																																				
sorosa Parr																																				
squamata Jones & Parker																																				
tricamerata Earland																																				
Family ATAXOPHRAGMIIDAE																																				
Verneuilina minuta Wiesner																																				
Gaudryina minuta Earland																																				
Eggerella cf. bradyi (Cushman)																																				
superba Earland																																				
Karreriella bradyi (Cushman)																																				
pusilla Parr																																				
Martinottiella antarctica (Parr)																																				
Miscellaneous arenaceous spp. indet.																																				
Family FISCHERINIDAE																																				
Cyclogyra antarctica (Rhumbler)																																				
carinata (Chapman & Parr)																																				
lacunosa (Brady)																																				
Gordiospira fragilis H-A. & E.																																				
Planispirinoides bucculenta (Brady)																																				
bucculenta placentiformis (Brady)																																				
Family MILIOLIDAE																																				
Quinqueloculina cf. sigmoilinoides Vella																																				
sp. indet.																																				
Cruciloculina triangularis d'Orbigny					X	X	X																													
Pyrgo depressa (d'Orbigny)																																				
murrhina (Schwager)																																				
pisum (Schlumberger)																																				
williamsoni Silvestri				X	X	X	X																													
Pyrgoella sphaera (d'Orbigny)																																				
Sigmoilina obesa H-A. & E.						-	X																													
umbonata H-A. & E.					X	X																														
Triloculina oblonga (Montagu)																																				
trigonula (Lamarck)																																				
Miliolinella chukchiensis Loeblich & Tappan																																				
circularis (Bornemann)	2	2	1																																	
Miliolinella n.sp. (elongate, compressed, with high arched aperture)																																				
Scutuloris hornibrooki (Vella)																																				
serra (Crespin)																																				
Tubinella funalis (Brady)																																				
Family NODOSARIIDAE																																				
Dentalina communis (d'Orbigny)																																				
communis larva (Earland)																																				
translucens Parr																																				
[illegible]																																				
[illegible]																																				

Station number: [illegible], [illegible], A467, A530, A456, A641, A455, [illegible], [illegible], [illegible], A449, A450, A465, A463, A664, [illegible], A525, A536, A522 | A460, A616, A458, A625, A451, A459, [illegible], A461, A612, A645, A448, A592, A595, A593, A452, [illegible], A453, A524

Depth in metres: [illegible], [illegible], [illegible], 269, [illegible], 322, 330, [illegible], [illegible], [illegible], [illegible], [illegible], 466, 530, [illegible], 583, 790, 1335 | 430, [illegible], [illegible], 520, [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], 865, [illegible], 1015, 1290, [illegible], 2195, 3570

Family NODOSARIIDAE contd.
- Lagena distoma Parker & Jones
- heronalleni Earland
- laevis (Montagu)
- meridionalis Wiesner
- cf. striatopunctata Parker & Jones
- subacuticosta Parr
- sulcata (W & J) spicata Cushman & McCulloch
- wiesneri Parr
- Robulus asterizans Parr
- sp.
- sp. juv.
- Pseudonodosaria ? sp.
- Vaginulina subelegans Parr

Family POLYMORPHINIDAE
- Sigmomorphina subulata Chapman & Parr

Family GLANDULINIDAE
- Glandulina antarctica Parr
- Globulotuba cf. entosoleniformis Collins
- Laryngosigma williamsoni (Terquem)
- Oolina botelliformis (Brady)
- borealis Loeblich and Tappan
- caudigera (Wiesner)
- heteromorpha Parr
- hexagona (Williamson)
- lineata (Williamson)
- melo d'Orbigny
- pseudocatenulata (Chapman & Parr)
- squamososulcata (H-A. & E.)
- Fissurina bisulcata (H-A. & E.)
- cf. clypeato-marginata (Rhymer Jones)
- cushmani (Wiesner)
- fissicarinata Parr
- aff. kerguelensis Parr
- nelsoni (H-A. & E.)
- semimarginata (Reuss)
- subformosa Parr
- texta (Wiesner)
- cf. trigono-marginata (Parker & Jones)
- cf. wrightiana (Brady)
- n.sp. (wide keel, reflexed tube, large)
- sp.
- Parafissurina curta Parr
- [illegible]
- lateralis (Cushman)
- marginata (Wiesner)
- subcarinata Parr
- velata (Matthes)
- wiesneri Parr
- n.sp. A (tube strongly recurved up one side, peripheral flange)
- [illegible] strongly curved up front, broad aperture)
- [illegible]
- cf. Fissurina wilsoni (H-A. & E.)

Family [illegible]
- Buliminella cochlea [illegible]

Family [illegible]
- Brizalina decussata (Brady)
- seminuda (Cushman)

Family [illegible]
- Islandiella porrecta (H-A. & E.)
- Cassidulinoides parkerianus (Brady)

Family [illegible]
- Bulimina aculeata d'Orbigny
- Stainforthia concinnata (Eggar)
- Trifarina earlandi (Parr)
- pauperata (H-A. & E.)

Station number: A533, A468, A467, A530, A456, A641, A455, A531, A457, A449, A450, A465, A463, [illegible], A537, A525, A536, A522 | A460, A616, A458, A625, A451, A459, A466, [illegible], A612, A645, A448, A592, A595, A593, A452, A462, A453, A524

Depth in metres: [illegible], [illegible], [illegible], [illegible], [illegible], 322, 330, [illegible], 357, [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], 1335 | 470, [illegible], [illegible], 520, 523, [illegible], 569, [illegible], 612, 720, 752, [illegible], [illegible], 1015, 1290, 2100, 2195, 3570

Family DISCORBIIDAE
- Discopulvinulina subconplanata (Rzehak)
- sp.
- Epistominella exigua (Brady)
- Rosalina globularis d'Orbigny

Family GLABRATELLIDAE
- Heronallenia wilsoni (H-A. & E.)
- Neoglabratella wiesneri (Parr)

Family SPIRILLINIDAE
- Spirillina dimidiata Wiesner
- multispira Parr
- spinulosa Chapman & Parr
- wrightii H-A. & E.
- Patellina antarctica Parr

Family ROTALIIDAE
- Pegerina stabilis (Wallich)

Family ELPHIDIIDAE
- Elphidiella sp.
- Notorotalia sp. indet.

Family EPONIDIDAE
- Eponides n.sp.

Family CIBICIDIDAE
- Cibicides bradii (Tolmachoff)
- grossepunctatus Earland
- refulgens Montfort
- sp. indet.

Family CAUCASINIDAE
- Fursenkoina davisi (Chapman & Parr)
- earlandi (Parr)

Family [illegible]
- Delosina sutilis Earland
- wiesneri Earland

Family [illegible]
- Cassidulina neocarinata Thalmann
- Ehrenbergina glabra H-A. & E.
- pupa (d'Orbigny)
- Globocassidulina pacifica Cushman
- tuberculata H-A. & E.
- n.sp. A (small, subglobular. Slit joins aperture at right angle)
- biora (Crespin)
- [illegible]

Family [illegible]
- Astrononion antarcticum Parr
- antarcticum, compressed [illegible]
- n.sp. (short sutural plates)
- Nonionella bradii (Chapman)
- iridea H-A. & E.
- Pullenia subcarinata (d'Orbigny)

Family [illegible]
- Gyroidina sp.
- Gyroidina neosoldanii Brotzen
- Oridorsalis tenera (Brady)

Family CERATOBULIMINIDAE
- Ceratobulimina arctica Green
- Hoeglundina elegans (d'Orbigny)

Family ROBERTINIDAE
- Pseudobulimina chapmani (H-A. & E.)
- Robertinoides wiesneri (Parr)

Family [illegible]
- [illegible]

Family [illegible]
- Globigerina [illegible] Earland
- pachyderma [illegible]

DIATOMS

SPONGE SPICULES

BARNACLE PLATES

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]