DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1976/12

A REVIEW OF MARINE GEOPHYSICAL INVESTIGATIONS OVER THE LORD HOWE RISE AND NORFOLK RIDGE

by

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CONTENTS

FIGURES

FOREWORD

Reviews have been made of the geology and geophysics of most Australia's island territories, and other records in this series by the same author are:-

Record No.	1976/37	Christmas Island and the Christmas Rise.
" "	1976/39	Queensland Plateau
" "	1976/41	Marion Plateau
" "	1976/40	Area of Mellish, Frederick, Kenn and Wreck Reef and Cato Island.
" "	1976/36	Macquarie Island and the Maquarie Ridge complex
" "	1976/38	The Cocos Islands and Cocos Rise

SUMMARY

The Lord Howe Rise and the Norfolk Ridge are characterized by a continental-type crustal structure. Marine geophysical investigations and deep-sea drilling results support the theory that the Lord Howe Rise was part of the Australian continent before 80 m.y. B.P. Before its separation from Australia, with the formation of the Tasman Basin, the Lord Howe Rise was much shallower and would have received clastic sediments which form a potential hydrocarbon source. The origin of the Norfolk Ridge is more conjectural but it may also have been joined to the Australian continental margin and have separated from the Lord Howe Rise by opening of the New Caledonia Basin. Recent marine geophysical surveys have shown the existence of small basins with sediment cover of up to 3 km on the Lord Howe Rise. During the Tertiary and the Quaternary, sedimentation in the area resulted in deposits of biogenic ooze 0.5 to 0.75 km thick.

A compilation of the marine geophysical data over the Lord Howe Rise and Norfolk Ridge indicates that the sea-bed has been relatively sparsely surveyed. The existing spacing between seismic profiling tracks of about 100 km is insufficient to delineate potentially economic areas. Furthermore, much of the data collected before 1970 is of poor quality. A magnetic anomaly map of the Norfolk Ridge is the only reliable geophysical anomaly map available in the area.

INTRODUCTION

This report summarises the current geophysical and geological knowledge of the Norfolk Ridge and the Lord Howe Rise. The object of this study is to examine the extent of the coverage in the area and to review the data which have been collected in order to assess the economic potential of the area and to determine the need for future work.

Until 1970 the only marine geophysical surveys of the area were several single profiles recorded by a number of overseas research vessels; these have been catalogued by Riesz & Moss (1971). Within the last 5 years the survey coverage of the region has increased considerably. This coverage includes profiles recorded by research vessels which have passed through the area and a number of systematic studies. In addition a major contribution to the knowledge of the upper sedimentary column in the area was made during legs 21 and 29 of the Deep Sea Drilling Project.

BATHYMETRY

The Lord Howe Rise and the Norfolk Ridge are two submarine structures which trend northwest and north along the eastern side of the Tasman Sea. They are separated from each other by the New Caledonia Basin (Figs. 1 & 2). The Tasman Basin, which borders the narrow continental shelf of southeastern Australia, and the New Caledonia Basin have depths down to 4000 m and they are both flat-floored. The Lord Howe Rise and the Norfolk Ridge have elevations of between 1500 and 2500 m above the floors of these two basins.

The Lord Howe Rise extends between the Coral Sea and New Zealand and has a length of about 1600 km. At the northern end near latitude 21°S it runs into a northwest-trending topographic feature which has recently been named the Fairway Rise (Dubois et al., 1974). Its southern end is separated from the Challenger Plateau at about 37°S by a wedge-shaped 3000-m-deep depression called the Bellona Gap. The Lord Howe Rise varies in width from 250 to 600 km, and the crest depths vary generally between 750 and 1200 m. The main body of the Rise is characterized by very gentle relief, but it is bordered on the western side by a zone of irregular 'foothills'. The western flank generally has steeper slopes (up to 10°) than the eastern flank. Lord Howe Island and Balls Pyramid lie within a north-trending chain of volcanic seamounts that crosses the Lord Howe Rise.

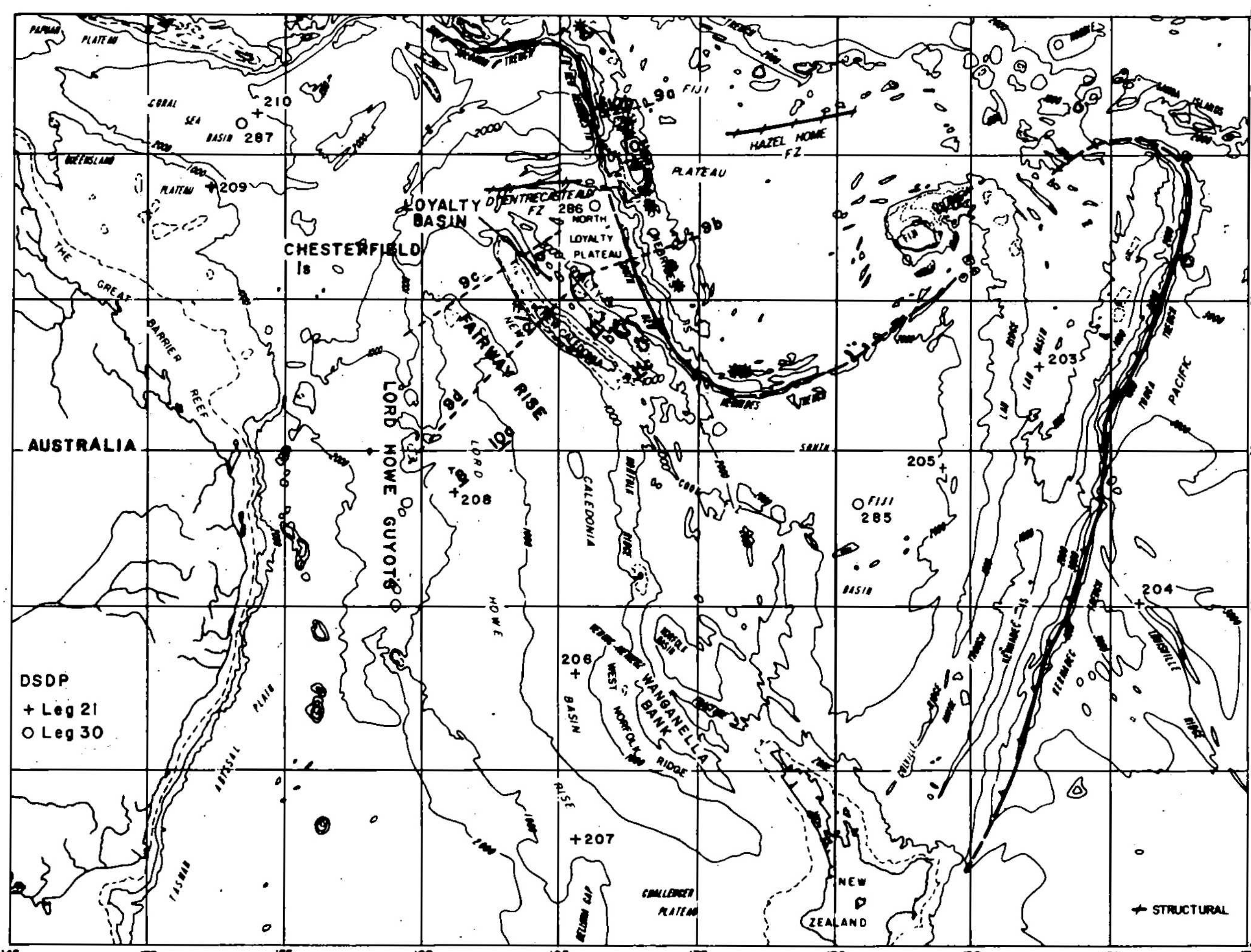
The Norfolk Ridge is about 75 km wide with steep sides and is narrower than the Lord Howe Rise. It extends between New Zealand and New Caledonia for about 1600 km. The southern part of the Ridge, which is offset by the Vening Meinesz Fracture Zone, is called the West Norfolk Ridge. The Norfolk Ridge has a much bolder relief than Lord Howe Rise, with the most positive features being Norfolk and Phillip Island, and the Wanganella Bank, which is less than 200 m deep.

MARINE GEOPHYSICAL SURVEYS

The available marine geophysical data over the Lord Howe Rise and the Norfolk Ridge were largely collected over the last 15 years. Accompanying this report are three maps which give compilations of the gravity (Pl. 1), the magnetic (Pl. 2) and the continuous seismic reflection (Pl. 3) profiling tracks. Extensive survey lines west of 160°30'E that were traversed by the Lady Christine during the BMR survey of the Australian continental margin are not included on these maps. The vessels involved in marine geophysical investigations over the area are listed in Table 1 together with the types of data collected and the year in which the work was done. This chapter summarizes the work which was done in the area and the institutions involved in the investigations.

Data up to 1960

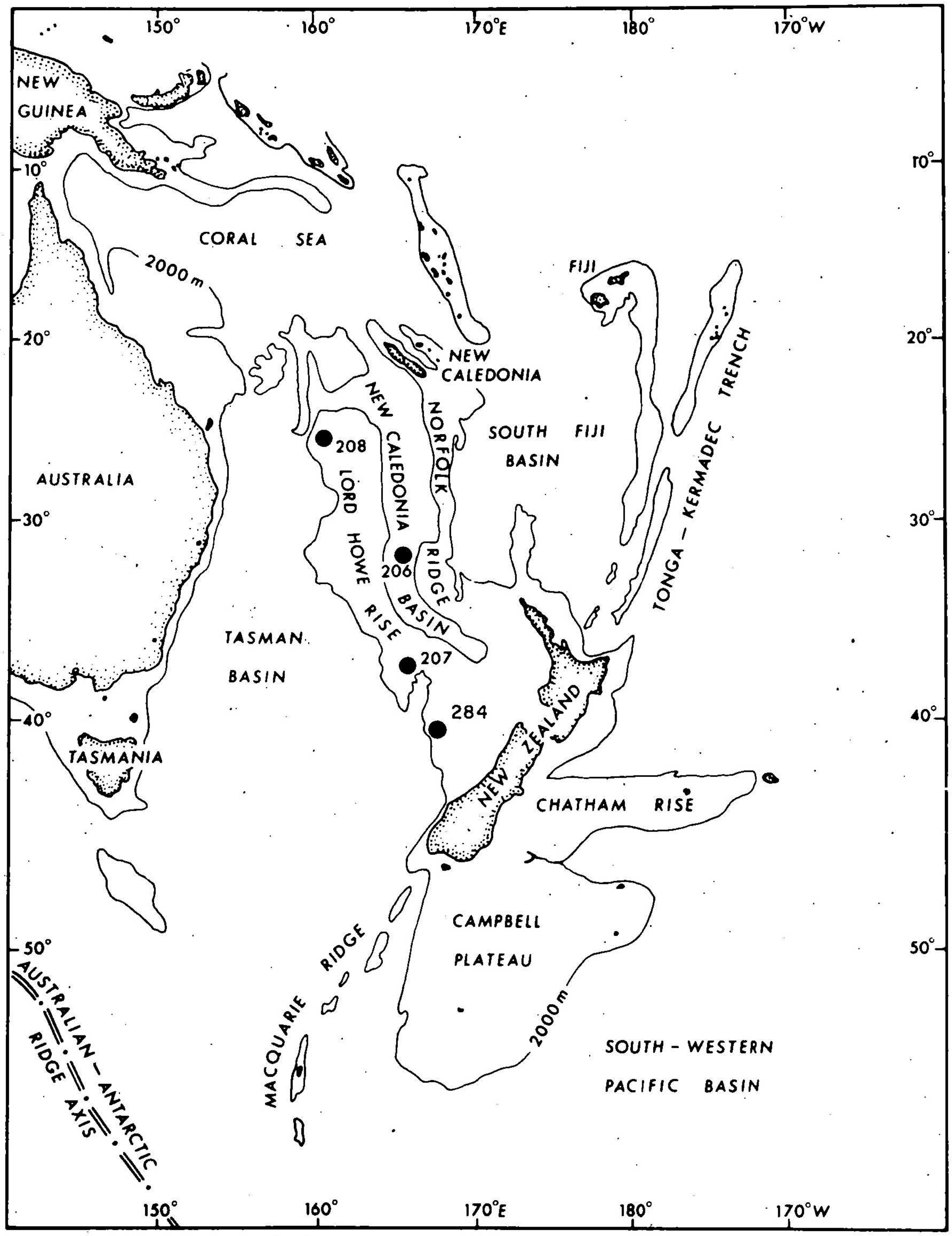
The earliest marine geophysical data in the region consisted of pendulum gravity measurements taken from submarines. Two submarines, the USNS Bergall (1949) and the HMS Telemachus (1956) took gravity measurements across the Lord Howe Rise and the Norfolk Ridge (Worzel, 1965; Dooley, 1963). A refraction seismic measurement was made west of New Caledonia during the cruise of HMS Challenger in 1951 (Gaskell et al., 1958).



LOCALITY MAP

8 *Location of profile shown in figure 9*

(from Dubois et al., 1974)



GENERALIZED MAP OF THE SOUTHWEST PACIFIC

● *DSDP site*

TABLE 1. SUMMARY OF SURVEY VESSELS AND TYPE OF DATA COLLECTED OVER THE LORD HOWE RISE AND NORFOLK RIDGE

Vessel	Cruise	Date	Seismic	Gravity	Magnetics	Miscellaneous
ARGO	NOVA	1967	Airgun	Yes	Yes	Refraction
BERGALL		1949	No	Pendulum	No	
BURTON ISLAND (Deep Freeze)		1961	No	No	Yes	
CHALLENGER		1951	No	No	No	Refraction
CONRAD	C9	1964	Explosive	Yes	Yes	
CORIOLIS	C1	1971	Airgun	No	Yes	
"	C2	1971	Airgun	No	Yes	
"	AUSTRADEC 1	1972	Flexichoc	No	Yes	
"	AUSTRADEC 2	1973	Flexichoc	No	Yes	
ELTANIN	ELT 26	1966	Airgun	Yes	Yes	
"	ELT 29	1967	"	Yes	Yes	
"	ELT 34	1968	"	Yes	Yes	
"	ELT 39	1969	"	Yes	Yes	Sonobuoys
"	ELT 47	1971	"	Yes	Yes	Sonobuoys
FRED V.H. MOORE	MOBIL	1972	HI/FES & Airgun	Yes	Yes	Sonobuoys
GLOMAR CHALLENGER	DSDP 21	1971/72	Airgun	No	No	Sonobuoys Drilling
"	DSDP 29	1973	Airgun	No	No	Sonobuoys Drilling
HORIZON	NOVA	1967	Sparker	Yes	Yes	Refraction
KANA KEOKI		1971	Airgun Sparker	Yes	Yes	
KIMBLA	K3	1971	Airgun	No	Yes	
	K4	1971	Airgun	No	Yes	
LADY CHRISTINE	BMR 14/3	1971	Sparker	Yes	Yes	Sonobuoys
OCEANOGRAPHER		1967	No	Yes	Yes	
STATEN ISLAND (Deep Freeze)		1960	No	No	Yes	
TARANUI		1966	No	No	Yes	
"		1967	No	No	Yes	
TELEMACHUS		1956	No	Pendulum	No	
UNITED GEOPHYSICAL		1970	Yes	Yes	No	
VEMA	V18	1962	Explosives	Yes	Yes	

Data from 1960–1969

The improvement in marine geophysical survey equipment such as sea-going gravity meters, seismic reflection profiling systems, and proton magnetometers during the 1960s resulted in a considerable increase in data over the area. This data was primarily recorded along single tracks run by vessels from Oceanographic Centres in the United States, i.e. Scripps and Lamont.

US Navy Hydrographic Office

USS Staten Island — During 1960 as part of Operation Deep Freeze the Staten Island ran a magnetometer track across the Norfolk Ridge and Lord Howe Rise (US Navy Hydrographic Office, 1962).

USS Burton Island — In 1961, Burton Island ran a magnetic line which crossed the southern Lord Howe Rise (US Navy Hydrographic Office, 1965).

Lamont Doherty Geological Observatory, New York

R.V. Vema — The R.V. Vema crossed the area in 1962. During cruise V18 magnetic and seismic reflection measurements were made over the southern part of the Lord Howe Rise near New Zealand (Houtz et al., 1967). The seismic recording and detection techniques on the Vema involved a slacked crystal hydrophone and an explosive sound source.

R.V. Conrad — This vessel made a crossing of the southern Lord Howe Rise and the West Norfolk Ridge in 1964 (Cruise C9). Gravity, magnetic, and seismic reflection profiles were recorded. Seismic profiling was done using an explosive sound source and a towed array of variable reluctance hydrophones (Houtz et al., 1967).

USNS Eltanin

The Eltanin crossed the southern Lord Howe Rise (cruise ELT 26), and the central Lord Howe Rise during December 1966, and Norfolk Ridge (cruise ELT 29) during July 1967. Three later cruises which were primarily in the Tasman Basin had tracks running onto the southern Lord Howe Rise (Cruises: ELT 34, June 1968, ELT 39, July 1969, and ELT 47, April, May 1971). Magnetic, gravity, and seismic profiles were recorded. The reflection profiling equipment included an airgun sound source and towed arrays with crystal hydrophones. Several sonobuoy stations on the Lord Howe Rise were shot during cruises 39 and 47; they are listed in the Appendix.

Scripps Institution of Oceanography, La Jolla

Nova expedition (M.V. Horizon and M.V. Argo)

During 1967 the two Scripps Institution research ships Argo and Horizon spent most of the year in the southwest Pacific area. The data gathered on this trip included seismic reflection, gravity, heat flow, magnetic measurements, and seismic refraction measurements (both sonobuoy and two-ship measurements). The general goal of the expedition and the chronicle of the researches have been told by Menard (1969). Two refraction profiles on the central and northern Lord Howe Rise and two on the central and northern Norfolk Ridge were made (Fig. 3) (Shor et al., 1971). Seismic reflection profiles across the Lord Howe Rise and Norfolk Ridge in about 6 places were made with a sparker on Horizon and an airgun on Argo. Gravity determinations along the track of R.V. Argo were done using a gimbal-mounted LaCoste & Romberg surface-ship gravimeter (Solomon and Biehler, 1969).

Pacific Oceanographic Research Laboratory, Seattle USA

R.V. Oceanographer

Gravity and magnetic measurements were made across the Lord Howe Rise and Norfolk Ridge during 1967 (Woodward & Hunt, 1971): the gravity meter used was an Askania GSS2 sea-gravimeter mounted on an Anschutz gyrotable. The magnetometer employed was a Varian V-4937 proton magnetometer.

New Zealand Oceanographic Institute, Wellington

M.V. Taranui

A systematic magnetic survey of the Norfolk Ridge and the southern Lord Howe Rise was undertaken in 1966 by the N.Z.O.I. from the vessel Taranui. A magnetic anomaly map of the Norfolk Ridge was produced by Van der Linden (1967, 1968). Fig. 4 shows the tracks run by the N.Z.O.I. In 1968 the Taranui traversed across the central Lord Howe Rise and Norfolk Ridge and recorded magnetics (Van der Linden 1969, 1970).

Data from 1970-1975

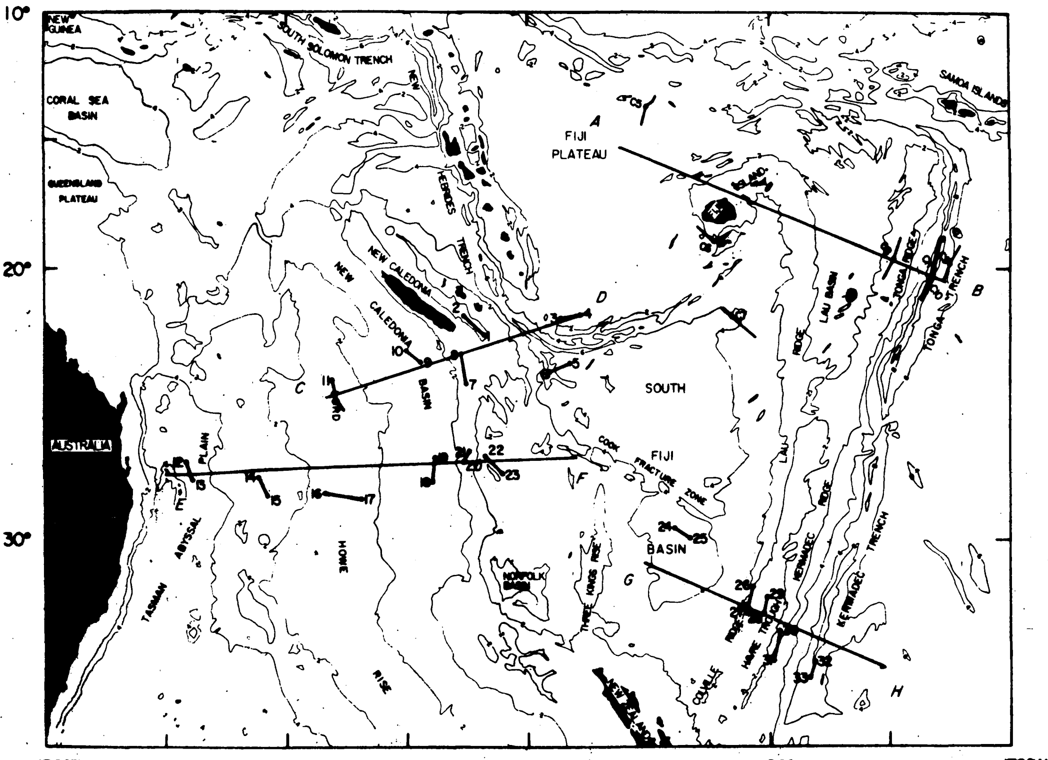
United Geophysical Corporation

During 1970 United Geophysical Corporation completed two seismic profiling tracks across the Lord Howe Rise and along the West Norfolk Ridge.

Bureau of Mineral Resources (BMR)

M.V. Lady Christine

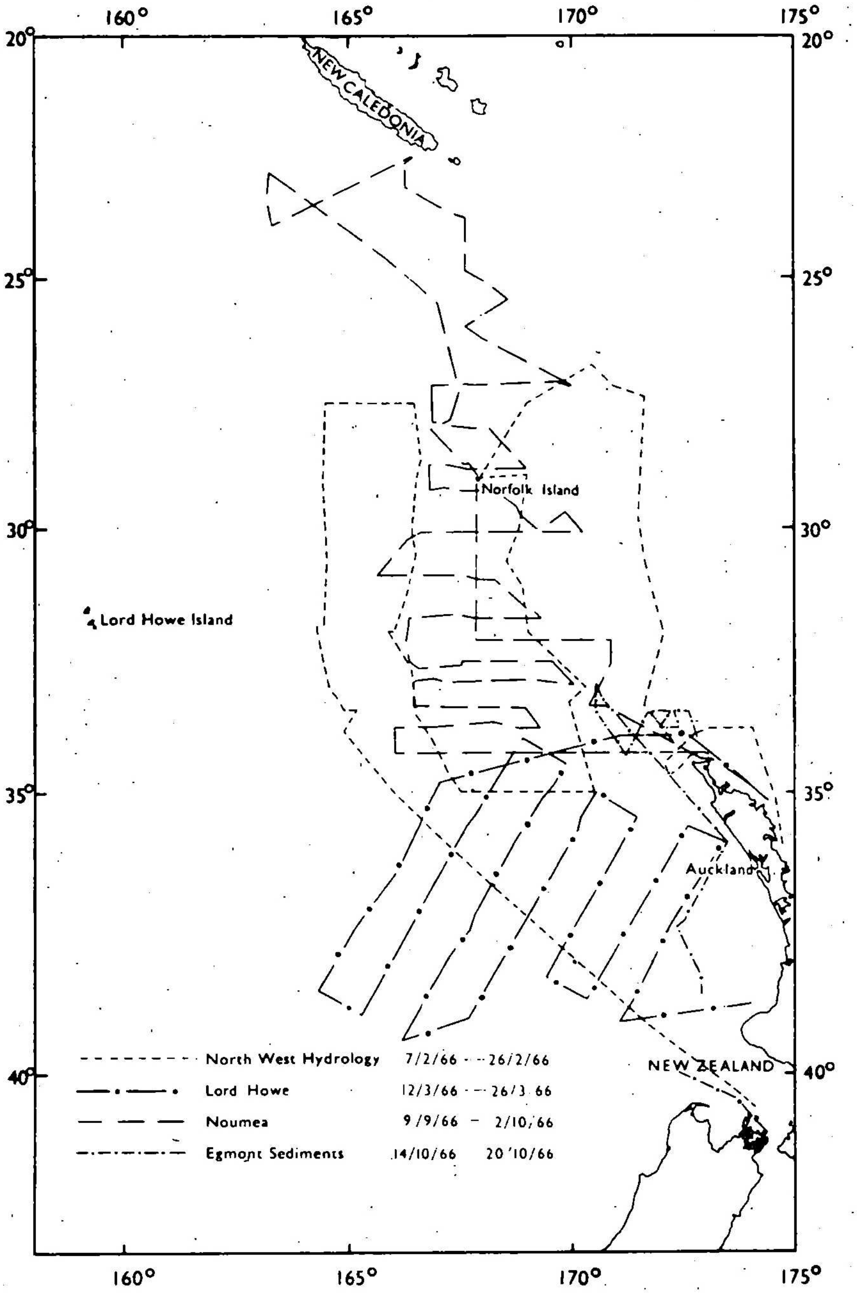
As part of the Continental Margin Survey BMR using the Lady Christine ran two crossings of the Lord Howe Rise in 1971. Magnetic and reflection seismic data, three Sonobuoy refraction measurements, and gravity data were collected along these lines. A 120-kJ sparker seismic source was used and reflected energy recorded via a 6-channel streamer onto analogue magnetic tape. These data are at present being interpreted.



LOCATION OF REFRACTION STATIONS

(from Shor et al., 1971)

FIGURE 4



MAGNETIC PROFILING TRACKS OF N.Z.O.I. OVER THE NORFOLK RIDGE

(from Van der Linden, 1967)

Office de la Recherche Scientifique et Technique Outre-mer

N.O. Coriolis — The Office de la Recherche Scientifique et Technique Outre-mer (ORSTOM) in Noumea did a survey west of New Caledonia over the extreme northern part of the Lord Howe Rise in 1971. Continuous seismic reflection profiling using a 650-cc airgun seismic source, and total magnetic field profiling using a proton magnetometer were recorded by Coriolis on these cruises (C1 and C2). Results of these are in press (Daniel et al., in press; Lapouille et al., in press).

University of N.S.W. (Australia)

HMAS Kimbla — The University of N.S.W. in cooperation with ORSTOM in 1971 surveyed several lines west of New Caledonia. The Kimbla collected magnetic and reflection seismic profiles during two cruises (K1 and K2).

University of Hawaii

R.V. Kana Keoki — During August and September 1971 the R.V. Kana Keoki carried out a pre-DSDP drilling survey in the region. The seismic profiling system comprised a 40-cu in airgun and a 9000-J sparker. Gravity and magnetic field measurements were also made. Some detailed surveying was completed in the area of the proposed drilling sites. Most of the results are incorporated in Vol. 21 of the preliminary drilling results (Burns et al., 1973).

Joint Oceanographic Institutions For Deep Earth Sampling (JOIDES)

D.V. Glomar Challenger — From 9 November 1971 to 11 January 1972 the Glomar Challenger drilled 8 holes in the southwest Pacific region. Two were on the Lord Howe Rise and one in the New Caledonia Basin (Fig. 2). Underway measurements included seismic profiling.

Mobil Oil Corporation

R.V. Fred H. Moore

In April 1972 the R.V. Fred H. Moore surveyed the southern Lord Howe Rise. Seismic reflection profiling was done using a high-frequency/high-resolution system. Disposable sonobuoy refraction profiles (Appendix 1), magnetic profiles, and gravity profiles were also recorded. The results of this survey are published (Bentz, 1974). A zig-zag traverse along the Norfolk Ridge was completed during this survey. In July several tracks were run by the R.V. Fred H. Moore across the extreme northern part of the Lord Howe Rise. Seismic, magnetic, and gravity profiling was completed. The magnetic results are incorporated in a paper which is in press (Lapouille et al., in press).

Austradec 1

N.O. Coriolis

In 1972 the northern part of the Lord Howe Rise and Norfolk Ridge were surveyed during the Austradec program. This program involved the co-operation between ORSTOM in Noumea and the Institut Francais du Petrole together with several French oil companies (SNPA, ELF-ERAP, CFP). Seismic profiles on the first Austradec cruise were run by the N.O. Coriolis using a Flexichoc system. Magnetic profiles were also recorded. The results of the first Austradec cruise were published by Dubois et al. (1974).

Austradec 2

N.O. Coriolis

A survey of the Norfolk Ridge was carried out by ORSTOM and the French Oil Companies (IFP, SNPA, ELF-ERAP, CFP) during 1973 using the N.O. Coriolis. A total of 6 profiles were run across the ridge during this second Austradec cruise. Magnetic and seismic(Flexi-choc) profiles were recorded along these lines.

COVERAGE AND QUALITY OF THE EXISTING DATA

The seismic profiling coverage over the Lord Howe Rise and Norfolk Ridge(Plate3) is sparse. The average distance between the tracks over the central part of the Lord Howe Rise and Norfolk Ridge is roughly 100 km. Near New Zealand and New Caledonia the coverage is somewhat better owing to the efforts of Mobil Oil Corporation and ORSTOM respectively.

The gravity coverage (Pl. 1) is similar to the seismic profiling coverage. Over most of the area the density of information is insufficient for production of reliable gravity maps. The magnetic coverage (Pl. 2) is also sparse over most of the Lord Howe Rise but it is of sufficient density (track spacing of about 50 km) over the Norfolk Ridge and southern Lord Howe Rise to have enabled a magnetic anomaly contour map on a scale of 1:2 000 000 to be produced (Van der Linden, 1968).

The quality of marine geophysical data over the area varies considerably. No systematic assessment of the gravity and magnetic data has been made and it is therefore not possible to state whether the available data could be made compatible. A preliminary inspection of the available seismic profiling data indicates that the material recorded before 1970 is suitable only for delineating the depth to pre-Tertiary basement. There is little or no definition in the upper sedimentary cover. The highest-quality data are those collected by ORSTOM using a Flexichoc system. Reflectors can be observed both in the upper undeformed sediment column and in some places within the basement. Dubois et al. (1974) have observed reflections from sediments in small basins below the Lord Howe Rise, which may be up to 3 km thick. The Mobil profiles on the southern Lord Howe Rise, which were recorded with a high-frequency/high-resolution system, show the sedimentary structure of the Tertiary sediment cover (about the upper 500 m) very clearly. They do not, however, show any detail within the basement owing to the limited penetration of the seismic system. The two crossings run by BMR using a 120-kJ sparker system also exhibit the upper structure very well. These survey lines were run at a ship speed of 10 knots, except for short sections during which the vessel slowed to 6 knots for disposable sonobuoy probes. The detail in the deeper section of the BMR seismic records improved considerably at slower speeds. It is likely that with slower speeds of the survey vessel and an improved seismic source deep reflections may be recorded.

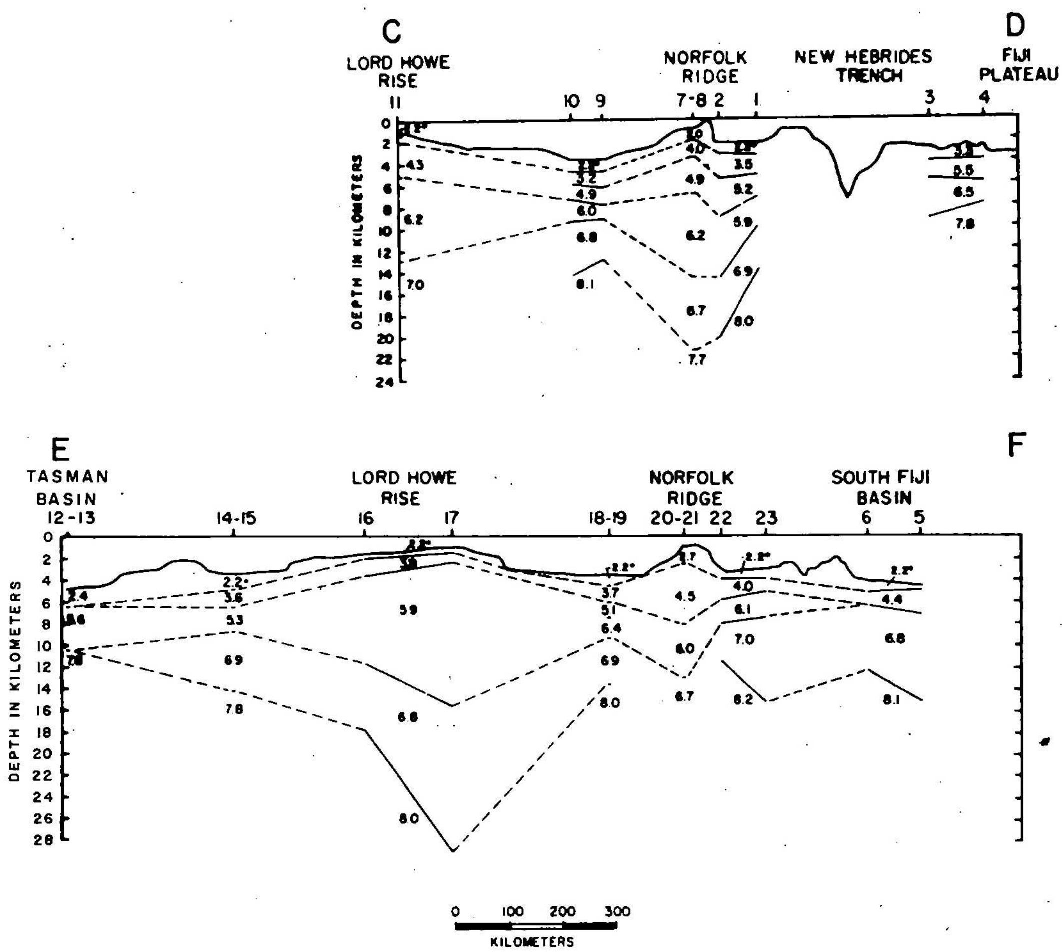
GEOLOGICAL AND GEOPHYSICAL SETTING

Crustal Structure

The crustal structure (Fig. 5) of the Lord Howe Rise and the Norfolk Ridge has been interpreted from seismic measurements (Officer, 1955; Shor et al., 1971) and the gravity field (Dooley, 1963; Woodward & Hunt, 1971). The latter found that the Lord Howe Rise and Norfolk Ridge have crustal thicknesses of 26 km and 21 km respectively. In contrast the crustal thickness under the Tasman Basin is of the order of 10 km, and under the New Caledonia Basin between 10 and 17 km. Shor et al. show that the Lord Howe Rise is largely composed of rocks with a P wave velocity of 6.0 km/s, which is similar to values found for the Australian continental crust. Rocks with a similar velocity are also present underneath the Norfolk Ridge. These results favour the interpretation that the Lord Howe Rise and Norfolk Ridge are fragments of continental crust. Rocks with compressional wave velocities of 6.8 km/s under the Lord Howe Rise and Norfolk Ridge, may correspond to layer 3 (the oceanic layer) similar to that observed by Raitt (1956) in the Pacific Basin.

Gravity data

The gravity information over the area is sparse (Pl. 1). Published accounts comprise a gravity traverse completed during the Nova expedition (Solomon & Biehler, 1969) and a track completed by the R.V. Oceanographer (Woodward & Hunt, 1971). The data available support the crustal structure discussed in the previous section (Fig. 6). As is the case for most ocean basins, the free-air anomaly over the Tasman Basin is negative but small. Over the Lord Howe Rise the free-air gravity is positive and up to 40 mGal. Short-wavelength (less than 25 km) anomalies which cannot be accounted for by topography occur on the western flank of the Rise. These are interpreted by Woodward & Hunt (1971) to be due to intrusions of dense rock into the near-surface material. Over the eastern part of the Lord Howe Rise there are no short-wavelength anomalies and the smooth topography is reflected in the gravity pattern. Bouguer gravity curves across the Lord Howe Rise are uneventful and generally reflect the crustal composition and thickness (Bentz, 1974). The Bouguer gravity anomaly rises from 100 mGal on the Lord Howe Rise to 200 mGal over the New Caledonia Basin.



CRUSTAL STRUCTURE

See figure 3 for location

(from Shor et al., 1971)

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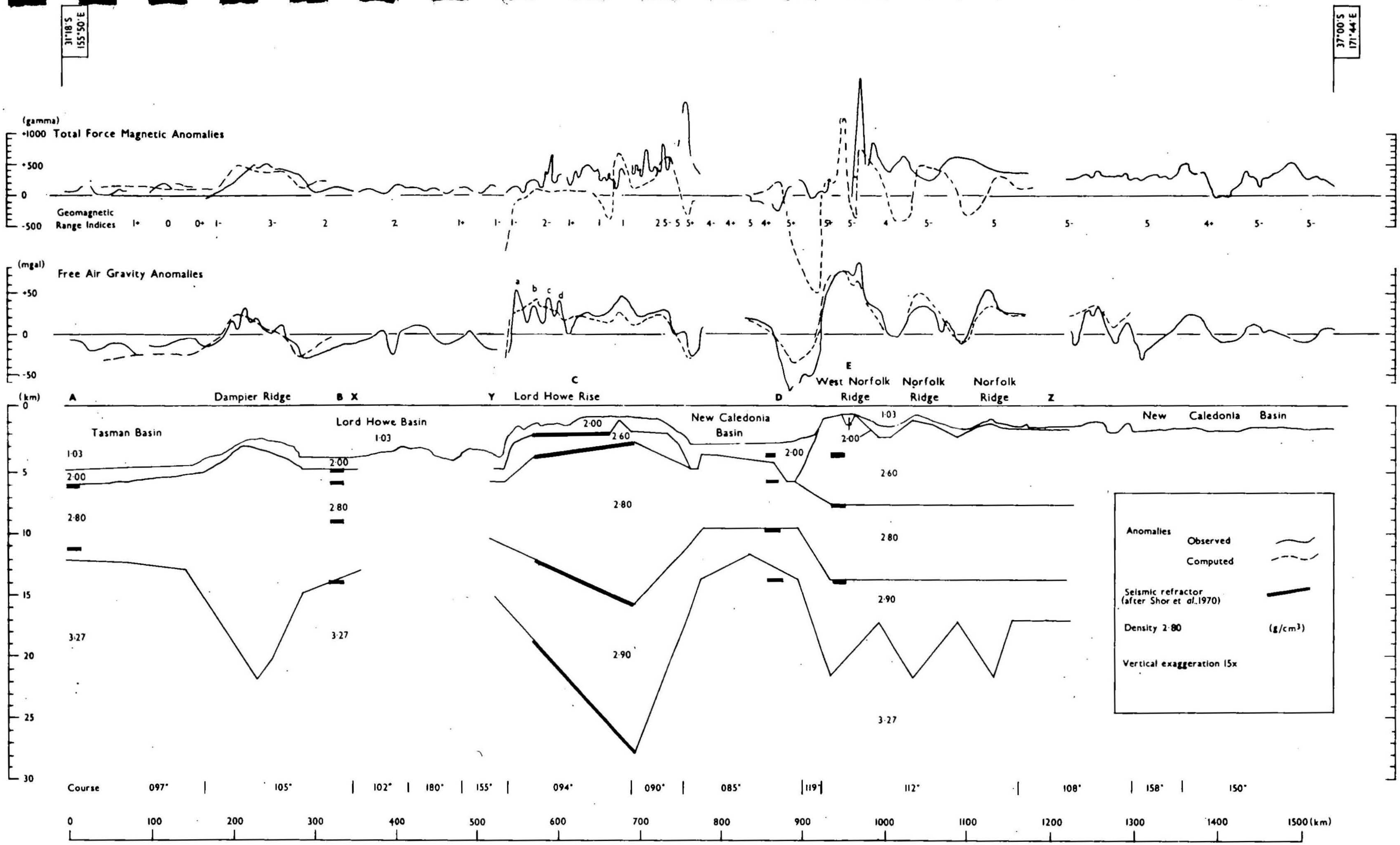


FREE AIR GRAVITY AND TOTAL FORCE MAGNETIC ANOMALIES WITH AN INFERRED CRUSTAL SECTION

(from Woodward and Hunt, 1971)

W/B8-56A

FIGURE 6

In the New Caledonia Basin the free-air gravity anomaly is largely negative (about -20 mGal) but small positive free-air anomalies (+20 mGal) are present in the central part. Over the edges of this basin there are steep gravity anomaly gradients.

The Norfolk Ridge has large gravity gradients over its flanks. The free-air anomaly rises to +75 mGal over the central part of the ridge (Solomon & Biehler, 1969). According to Woodward & Hunt (1971) a large gradient in the gravity anomaly on the western flank of the West Norfolk Ridge can be matched only if little or no sediment is present. It appears that the only appreciable sedimentary thickness may occur in a graben in the top of the Ridge.

Magnetic data

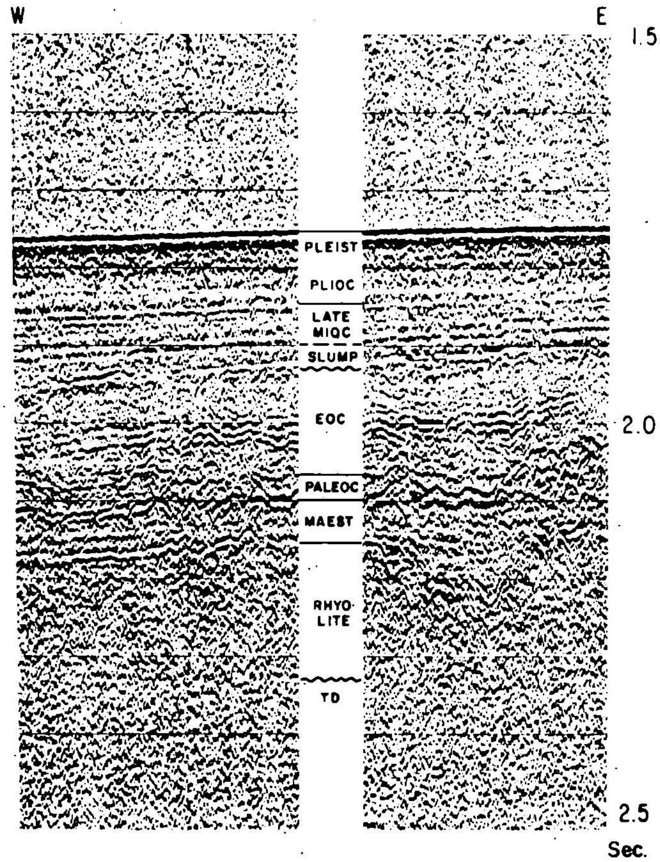
Magnetic measurements over the region have resulted in the identification of linear northwest-trending magnetic anomalies in the Tasman Basin which are related to a spreading centre (Hayes & Ringis, 1973). This has provided strong confirmatory evidence that the Tasman Sea was formed by a sea-floor spreading mechanism. According to Hayes & Ringis this spreading commenced 80 m.y. B.P. and continued until 60 m.y. B.P. Over the Lord Howe Rise and the Norfolk Ridge the magnetic field is relatively quiet and in general reflects the relief of the basement rocks. According to Lapouille et al (in press), the area of the Lord Howe Rise, Caledonia Basin, and Norfolk Ridge is characterized by large positive anomalies with wavelengths of about 100 km which may be readily correlated between adjacent profiles. This has led them to conclude that in this region crustal thicknesses are intermediate between true oceanic and true continental areas. This conclusion is supported by crustal thickness determinations mentioned previously. Superimposed on these large-scale features are short-wavelength anomalies which can also be correlated between profiles and are related to topography of the basement and occurrences of volcanic intrusives or other magnetic rocks within the basement (Van der Linden, 1967). A similar situation exists on the southern part of Lord Howe Rise (Bentz, 1974). Over the Norfolk Ridge extensive magnetic coverage (Van der Linden, 1968) shows a simple pattern of positive anomalies which trend northwest without steep gradients over the northern part. In contrast the magnetics over the West Norfolk Ridge south of the Vening Meinesz Fracture Zone consist of a strong positive (+1500 nT) double-crested anomaly. Hochstein (1967) and Van der Linden (1967) consider the anomalies to be due to a body of volcanics (basalts) overlying an older non-magnetic basement at a depth of 3-4 km. The intervening New Caledonia Basin is characterized by negative anomalies of long wavelength, which is indicative of deep magnetic basement (Lapouille et al., in press).

Volcanicity and heat flow

Rhyolite flows were intersected during the Glomar Challengers DSDP program and yielded ages of about 94 m.y. B.P., which is equivalent to the early part of the Late Cretaceous (McDougall & Van der Linden, 1974). Late Pliocene volcanism of basaltic composition formed Norfolk Island, and according to Bentz (1974) this volcanism is still active on the Lord Howe Rise. One oceanic heat flow measurement on the Lord Howe Rise (Grim, 1969) which gave a value of twice normal heat flow suggests that the Lord Howe Rise is associated with an anomolous thermal regime.

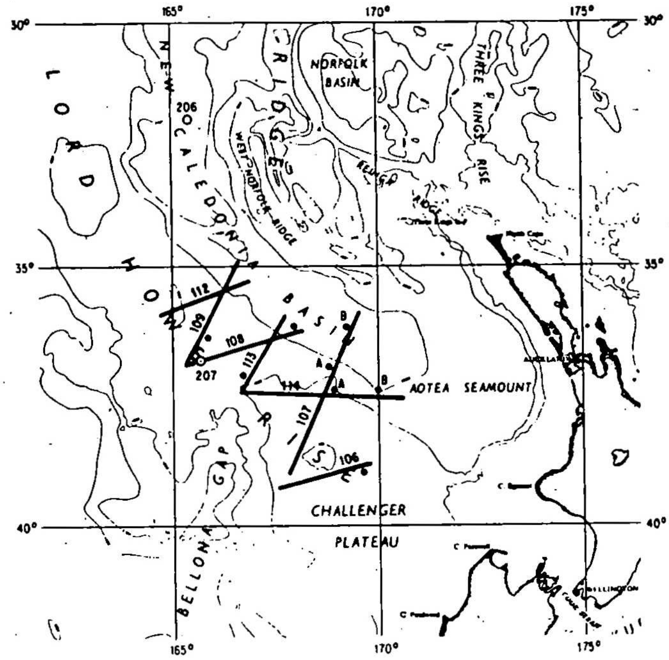
Sedimentary structure

Continuous seismic reflection profiles over the Lord Howe Rise and Norfolk Ridge exhibit an undeformed sedimentary cover which varies considerably in thickness and overlies folded sedimentary basement rocks of probable Mesozoic age. Over most of the southwestern Pacific there is, within the Tertiary sediments, a regional unconformity of middle Eocene to late Oligocene age (Burns & Andrews, 1973). The duration of this break in sedimentation is variable over the area and is greatest on the Lord Howe Rise. In reflection seismic profiles run over the southern Lord Howe Rise, Bentz (1974) has observed that Neogene sediments overlying the unconformity vary in thickness from 260 to 400 m. This is similar to thicknesses of 119 and 434 m observed in the two JOIDES drill sites on the Lord Howe Rise. Below the unconformity, Paleogene to Upper Cretaceous sediments vary in thickness from 950 to 1020 m according to Bentz (1974). However, locally these older sediments thin to 157 m over basement highs, as shown by JOIDES drilling. Correlation of reflectors seen in profiles over the southern Lord Howe Rise with the results of JOIDES drilling is shown in Figure 7. Several interpreted line drawings of these profiles are shown in Figure 8., and they show that erratic thickening and thinning of the Tertiary sediments is widespread (Bentz, 1974). This is due to several causes such as a variable stratigraphic

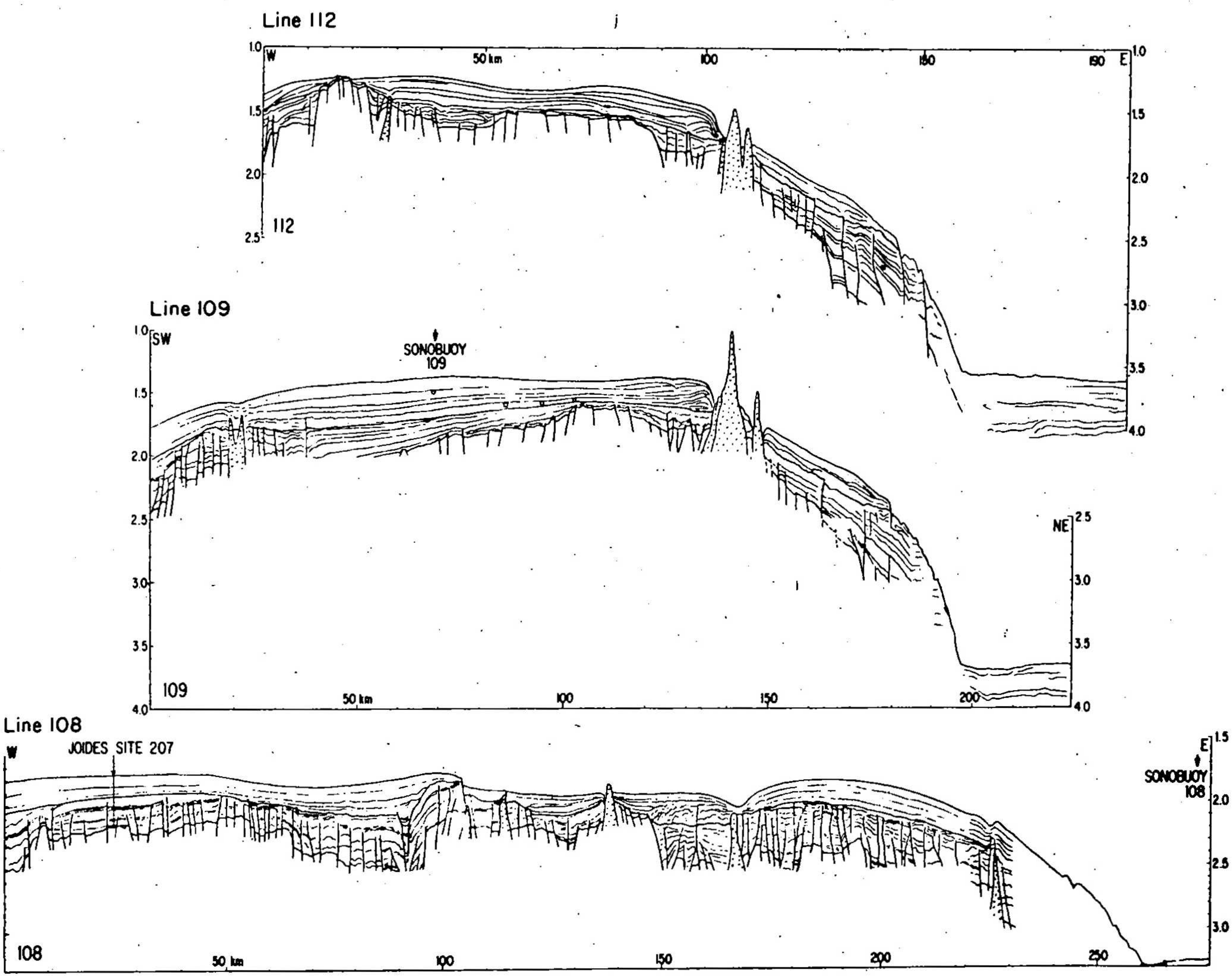


CORRELATION OF SEISMIC PROFILE WITH DSDP SITE 207

(from Bentz, 1974)



LOCATION



INTERPRETED HI/FES LINES OVER SOUTHERN LORD HOWE RISE

(from Bentz, 1974)

gap within the Neogene-Paleogene regional unconformity, nondeposition or continuous erosion on active basement highs, lateral depositional thickening of individual layers and units, and slumping. In addition the effect of volcanism can be clearly observed in reflection profiles over the southern Lord Howe Rise. The thickest sedimentary cover occurs in small basins within the basement of the Lord Howe Rise. Thicknesses of up to 3 km have been reported (Dubois et al., 1974) in the northern part of the Lord Howe Rise (Fig. 9).

The sediment cover over the Norfolk Ridge is also variable. Shor et al. (1971) report sediments with a velocity of about 2.73 km/s and thickness of 1.6 km at latitude 27°S, while Houtz et al. (1967) found a very thin cover (less than 0.1 km) on the West Norfolk Ridge. Seismic profiling by Glomar Challenger (Fig. 10) also shows that thicknesses of less than 1 km are present over the southern Norfolk Ridge and West Norfolk Ridge. Surveys over the Norfolk Ridge completed in recent years by ORSTOM (Noumea) and several French oil companies have delineated two structures within the Norfolk Ridge in which there is a considerable thickness of sediment (up to 3 km). One of these structures, which are in the form of elongated basins, occurs on the western flank of the Norfolk Ridge near New Caledonia and the other is located between the West Norfolk Ridge and the Norfolk Ridge. The latter is thought to be the tectonic result of the Vening Meinesz Fracture Zone. (Dupont & Launay, 1975).

Deep Sea Drilling Project results

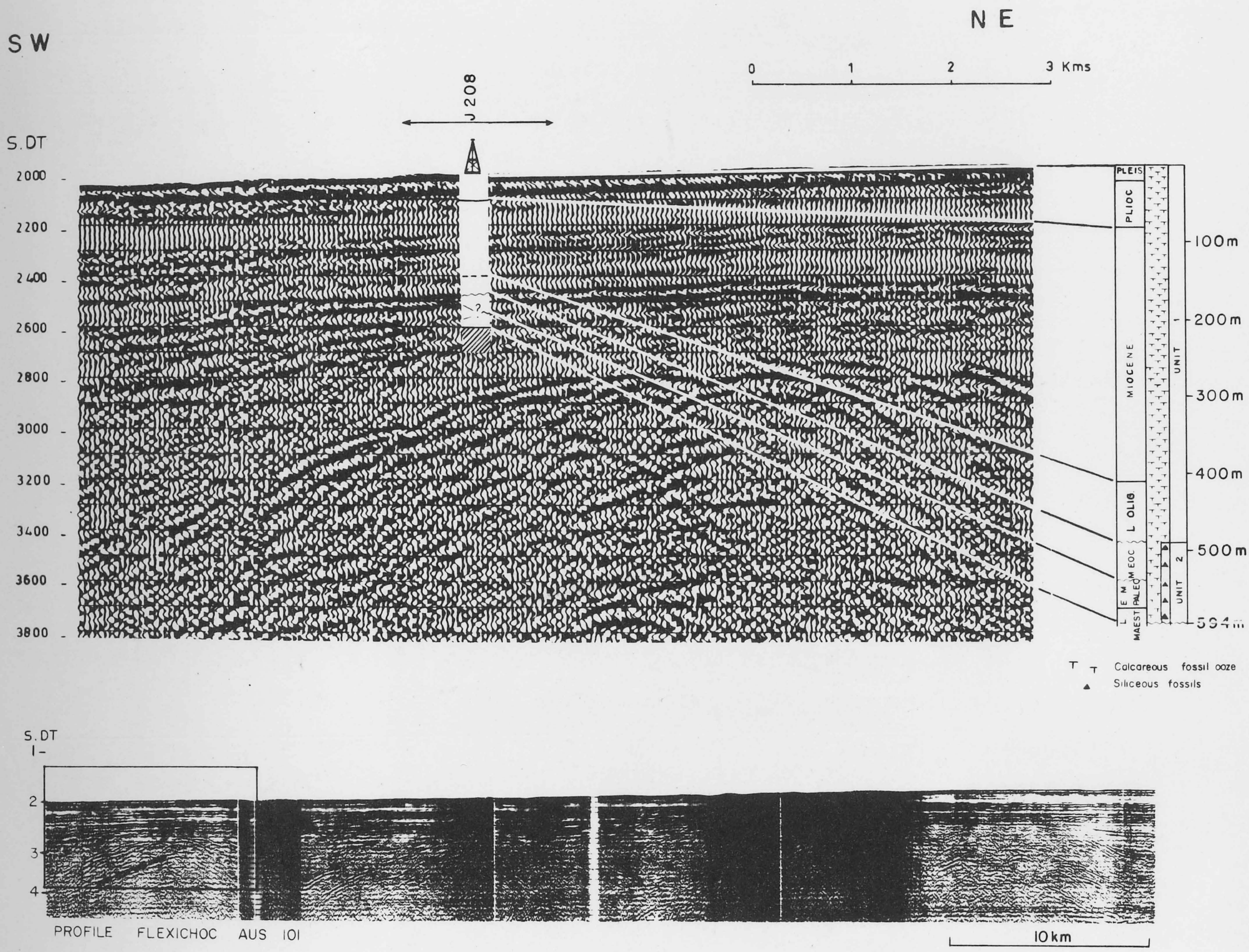
Several drill-holes in the region were completed during legs 21 and 29 of the Deep Sea Drilling Project (Fig. 1), and these holes have yielded much information on the nature of the Tertiary sediments and the possible evolution of the southwest Pacific. Three of the sites (207, 208, and 284) were located on the Lord Howe Rise and one (206) was situated in the New Caledonia Basin. The Tertiary sediments encountered in these drill-holes are composed of calcareous biogenic ooze. At site 208, which was drilled in the northern part of the Lord Howe Rise and which penetrated 594 m of sediment, the upper 488 m consisted of Pleistocene to late Oligocene foram nanno ooze. The lower 106 m at this site was composed of middle Eocene to late Maastrichtian chalk and silicitite (siliceous equivalent of chalk). Basement was not reached at site 208. At site 284, drilled during Leg 29 (Kennet et al., 1974), the maximum penetration was 208 m and the entire section consisted of latest Pleistocene to late Miocene foram ooze. A minor unconformity was observed in mid-Pleistocene but otherwise the sedimentation was continuous. On the southern Lord Howe Rise site 207 penetrated to 513 m and the following five lithologic units were distinguished (Fig. 11; Burns et al., 1973b).

1. Unit 1 (0–142 m) - middle Miocene to Pleistocene - calcareous biogenic sediments.
2. Unit 2 (142–309 m) Palaeocene to middle Miocene - calcareous and biogenic sediment with chert layers.
3. Unit 3 (309–357 m) Maastrichtian - glauconitic silty claystone (sandstone at very base).
4. Unit 4 (357–433 m) Upper Cretaceous - rhyolitic (pumiceous) lapilli tuffs and vitrophyric rhyolite flow (fragmented in part).
5. Unit 5 (433–513 m) Upper Cretaceous (93.7 ± 1.1 m.y., (McDougall & Van der Linden, 1974) - vitrophyric rhyolite flows, fragmented in part.

There is a hiatus between units 2 and 3, and probably between 3 and 4.

Evolution

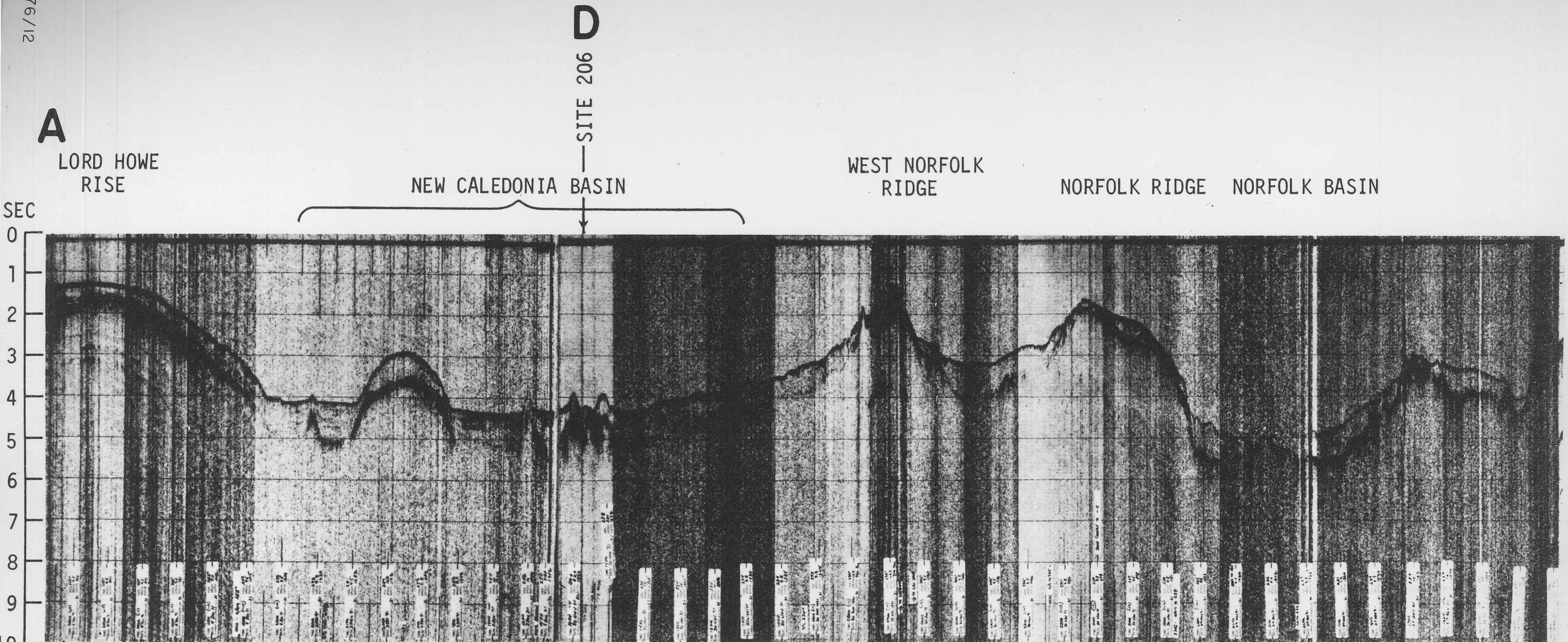
A general reconstruction of the history of DSDP site 207 fits well in the regional picture. According to McDougall & Van der Linden (1974) the rhyolites were erupted at or near sea level 94 m.y. B.P. while the Lord Howe Rise formed part of the Australian-Antarctic continent. This occurred just before the earliest development of oceanic crust in the Tasman Sea 80 m.y. B.P. (Hayes & Ringis, 1973), and the volcanic activity may be related to the early separation of the Lord Howe Rise from Australia. The silty claystones (Unit 3) indicate shallow restricted sea conditions with at least some of the material being derived from granitic and metamorphic sources of the Australian continent (Burns et al., 1973b). After the separation, oceanic conditions developed in the area, and the Tasman Basin began to form by sea-floor spreading with rotation of the Lord Howe Rise away from the margin of Australia. Subsidence of the rise continued until the early Eocene (about 50 m.y. B.P.), probably ceasing with the end of sea-floor spreading in the Tasman Basin. The middle Eocene-late Oligocene regional unconformity is thought to have been caused by the changing pattern of bottom currents and



CORRELATION OF SEISMIC PROFILE WITH DSDP SITE 208

(from Dubois et al., 1974)

28

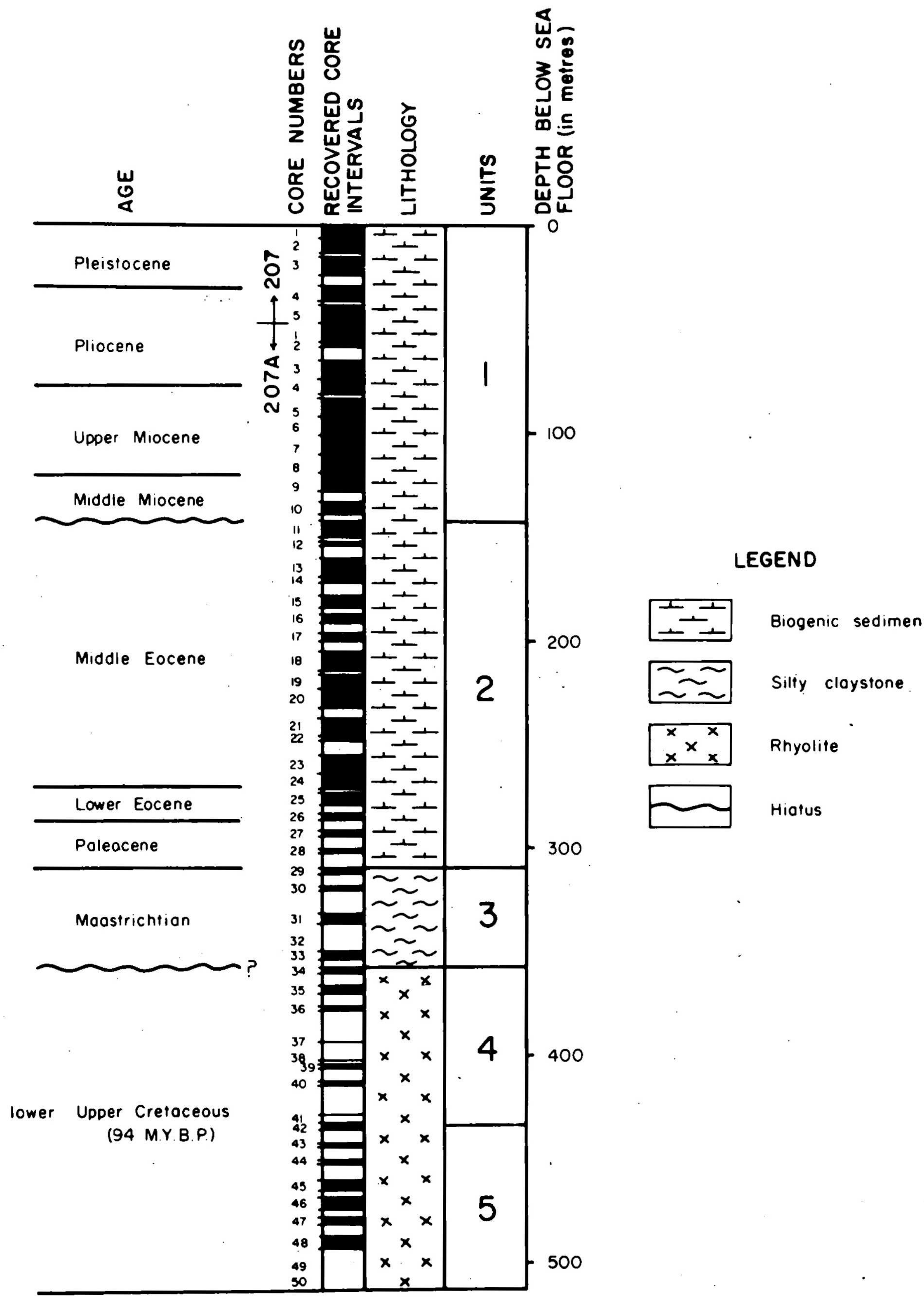


SEISMIC PROFILE OVER LORD HOWE RISE, NEW CALEDONIA BASIN, AND NORFOLK RIDGE

(from Burns et al., 1973)

FIGURE 10

FIGURE 11



SCHEMATIC STRATIGRAPHIC RECORD FOR DSDP SITE 207

(from Burns et al., 1973)

intensities, resulting from the separation of the Australian Plate from the Antarctic Plate (Burns et al. 1973a). The Indian-Antarctic Ridge on which this spreading commenced at about 55 m.y. B.P. (Weissel & Hayes, 1972) is presently active.

Several hypotheses have been advanced to explain the origin of the Norfolk Ridge and the New Caledonia Basin. These include the evolution of a complex arc system (Geze, 1963; Dubois et al., 1974), arc migration and the development of marginal basins (Karig, 1971; Packham & Falvey, 1971), and the creation of marginal basins owing to second-order adjustment at the limits of plates (Andrews et al., 1973). The presence of peridotites on New Caledonia, which may imply the existence of a fossil subduction zone, further complicates the situation. Whether the Norfolk Ridge was at one time also part of the Australian continental margin, and the New Caledonia Basin was formed by sea-floor spreading are at present not substantiated. However the results of the DSDP drilling program support the conclusion that the basins and ridges in the area were formed by the end of the Mesozoic (Burns & Andrews, 1973b).

ASSESSMENT OF ECONOMIC POTENTIAL AND SCIENTIFIC INTEREST

The economic potential of the Lord Howe Rise and Norfolk Ridge, particularly with respect to oil, is speculative. From the earlier discussion of the geological and geophysical evidence it seems fairly likely that the Lord Howe Rise was at one time part of the continental shelf of Australia. There is also good evidence that the Rise was at a much shallower depth before its separation from the Australian continent. It is therefore possible that oil is present within the sediments of the Lord Howe Rise. Recent DSDP drilling south of Tasmania on Leg 29 has shown the presence of hydrocarbons at sites 280 and 281 in water depths of about 4000 m (Kennet et al., 1974). These were merely traces, but they indicate the possibility that oil can be found at great water depths. Two other factors which upgrade the hydrocarbon potential of the Lord Howe Rise are the presence of a higher-than-normal temperature gradient in the sediments and the presence of suitable caprock provided by the volcanics in the sedimentary column.

Several points must be borne in mind which make the Lord Howe Rise less attractive for oil exploration. The first of these is its depth, which increases the cost of exploiting any possible oil resources, even if the capability to do this is reached within the next decade. Secondly, the upper sediments of Tertiary age (about 0.5 km thick) are composed of mainly biogenic oozes which have been deposited in a rather oxidizing environment, an unfavourable condition for the preservation of organic matter. Hence possible hydrocarbons can be expected to be generated only within the deeper section which, from seismic profiling, is known to be both folded and faulted. Small sedimentary basins, such as those observed in the northern Lord Howe Rise which contain up to 3 km of sediment, appear to be the most favourable targets for petroleum exploration.

Similar arguments apply to the Norfolk Ridge. Recent seismic profiling results show two sedimentary basins within the Norfolk Ridge with a much thicker sedimentary section than shown on earlier seismic profiles, which is encouraging.

Apart from the possible economic potential of the Lord Howe Rise and the Norfolk Ridge, there are several aspects which are of scientific interest. The first of these is a more detailed picture of the evolution of these two features. Of particular interest is the nature of the New Caledonia Basin. From limited coverage in the northern part this appears to have been a tensional area during most of the region's development. To establish this fact, magnetic anomaly and gravity maps are essential. The question as to whether the Norfolk Ridge, like the Lord Howe Rise, separated from the Australian continental margin has also not been solved. Further geophysical work could provide the answer to these problems, which would contribute greatly to our understanding of the development of marginal basins and of areas behind volcanic arcs in general.

PROPOSALS FOR FUTURE WORK

From the foregoing discussions it is evident that from both the economic and the scientific viewpoint the Lord Howe Rise and Norfolk Ridge are at present insufficiently surveyed. It is therefore recommended that a series of marine geophysical investigations should be undertaken which will result in clearer picture of the nature and economic potential of the area. The following are three broad proposals for further investigation in order of priority.

1. A preliminary investigation consisting of about 4 regional lines along which seismic reflection, seismic refraction, magnetic, and gravity data are recorded, perhaps with several heat flow measurements
2. A reconnaissance survey with a line spacing of about 50 km along east-west lines, and with the prime object of obtaining good-quality seismic sections.
3. More detailed surveys of particular areas to delineate the limits of small basins containing thick sediments.

1. Preliminary investigation

This investigation would involve 4 lines run between existing ones across the Lord Howe Rise, the New Caledonia Basin, and the Norfolk Ridge. Together with these additional traverses and the existing data from earlier tracks, it should be possible to draw preliminary gravity and magnetic anomaly contour maps of this region. It is recommended that the seismic profiling system uses either Flexichoc or a powerful airgun system to obtain deeper penetration in order that the presence of sedimentary basins below the Lord Howe Rise and Norfolk Ridge can be substantiated. Profiling speeds of about 6 knots and digital multiple-channel recording are suggested for maximum detail in the seismic sections.

Until now only one heat flow station has been occupied over these ridges, and this measurement gave a value of twice the normal heat flow. Several heat flow stations on these ridges are necessary to confirm the presence of an anomalous thermal regime.

In addition a deep seismic refraction profile to the south of the two existing ones would establish the continuity of these structures.

2. <u>A reconnaissance survey</u>

With the results of the preliminary investigation it should be possible to plan traverses so that a grid of seismic reflection profiles at a spacing of 50 km is achieved. The presence of small sedimentary basins with sediments as thick as the 3 km seen during the <u>Austradec</u> No. 1 cruise would be detected and these could be mapped. From the concurrent magnetic and gravity data a more accurate series of contour maps could be drawn.

3. <u>Detailed survey of particular areas</u>

This would be the stage in which the limits of potential oil reservoirs could be mapped using seismic profiling equipment.

The foregoing are only broad proposals without going into details of shiptime, cost, and line kilometres. However some order of magnitude of what would be involved for the first two proposals can be gleaned from the following rough calculations.

Proposal 1. 4 lines, each about 750 km in length (total 3000 km) approx 11 days steaming at 6 knots, contract survey cost at $65/km, $195 000.

2. 16 lines over the Lord Howe Rise (250 km wide) and Norfolk Ridge (75 km wide) between 25°S and 35°S total of about 6000 km approx 25 days, contract survey cost at $65/km, $390 000. The cost of seismic data processing has not been included; it would cost about the same as the survey rate, but only the most suitable sections would be processed. If only half of the sections were processed, the additional cost would be $292 5000, bringing the total cost to $877 500.

CONCLUSIONS

The results of marine geophysical investigations in the southwest Pacific indicate that the Lord Howe Rise and the Norfolk Ridge have a quasi-continental-type structure. Fairly convincing evidence has been presented for the hypothesis that at least the Lord Howe Rise once formed part of the Australian continental margin and has sunk since its separation. Likewise the possibility exists that the Norfolk Ridge was once joined to Australia. These rises are covered by a thin (0.5 to 0.8 km) veneer of deep-sea sediments in most places, but small basins with perhaps as much as 3 km of sediment occur within them. Below the veneer of Tertiary sediments folded sedimentary rocks are present. They therefore present potential areas for the recovery of hydrocarbons in the future.

Existing marine geophysical data over the area is sparse and seismic profiling is mostly of poor quality. Apart from the southern section of the Norfolk Ridge magnetic and gravity coverage is too limited for producing anomaly maps. In order that the economic potential can be more accurately assessed and several scientific problems can be solved it is recommended that marine geophysical investigations are undertaken.

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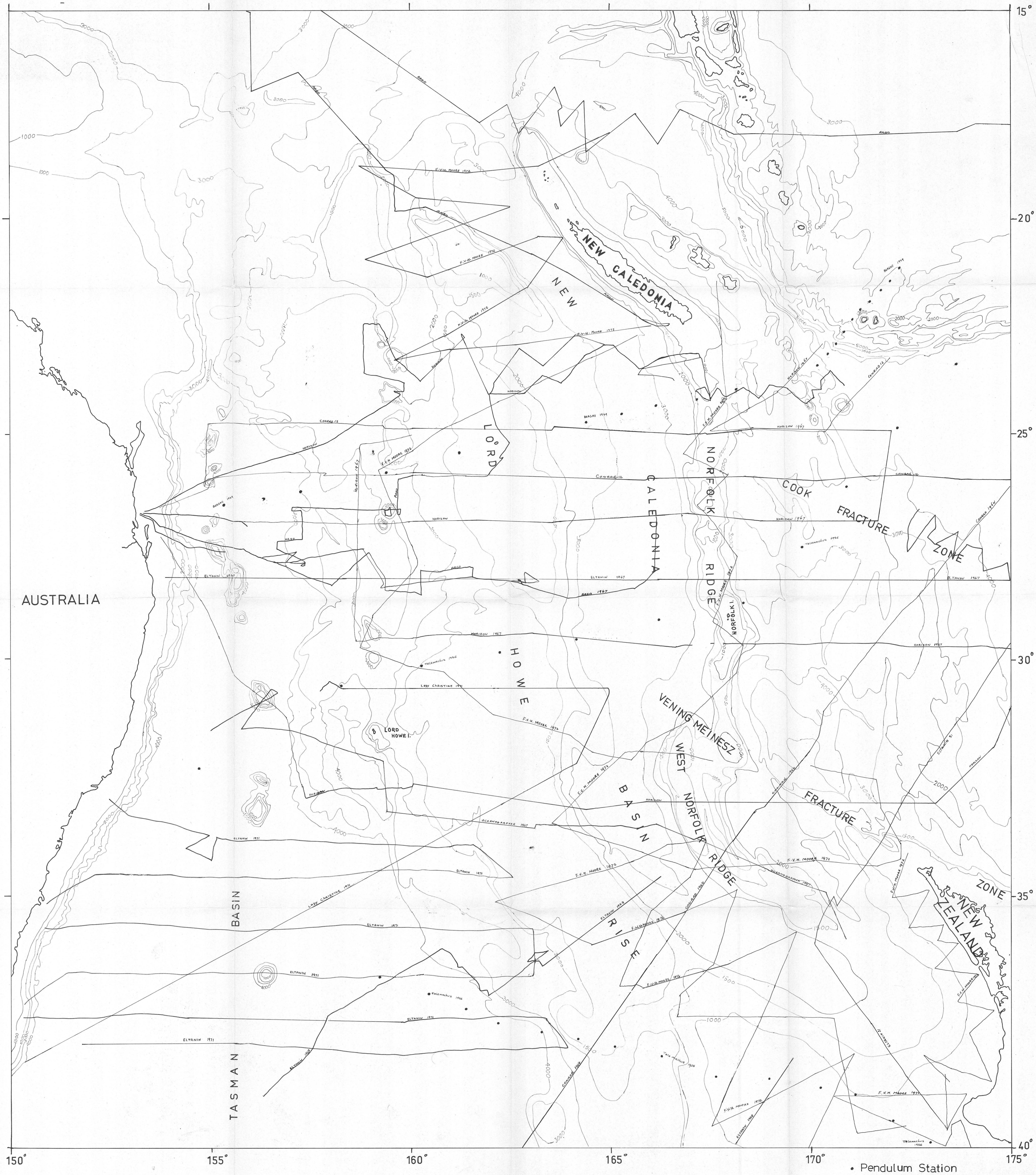
Appendix 1: SONOBUOY AND REFRACTION STATIONS

Cruise	Number	Latitude (S)	Longitude (E)
ELTANIN	29E47	37.59°	163.45°
	43E47	36.22	163.03
	46E47	34.04	160.12
	5E39	36.23	163.06
B.M.R.	14-671206	30°40'	162°09'
	14-671921	30°40'	162°52'
	14-682052	32°35'	162°48'
	14-690158	32°55'	162°20'
MOBIL	106	39°00'	169°40'
	107A	37°00'	169°
	107B	36°15'	169°15'
	108	36°15'	168°00'
	109	36°30'	166°00'
	113	37°10'	167°00'
	114A	37°30	169°00'
	114B	37°30'	170°00'
JOIDES	206	32°00.75	165°27.15'
	207	36°57.75'	165°26.06'
	208	26°06.61'	161°13.27'
NOVA REFRACTION	5	23°32'	171°48'
	6	23°54'	170°50'
	7	24°18'	167°26'
	8	23°09'	167°15'
	9	23°31'	165°38'
	10	23°00'	164°57'
	11	24°04'	161°53'
	12	27°06	155°52'
	13	27°47'	156°06'
	14	27°40'	28°24'
	15	158°54'	159°15'
	16	28°15'	161°32'
	17	28°25'	163°11'
	18	27°53'	166°05'
	19	26°56'	166°10'
	20	27°09'	167°20'
	21	26°41'	167°37'
	22	26°58'	168°11'
	23	27°37'	169°00'



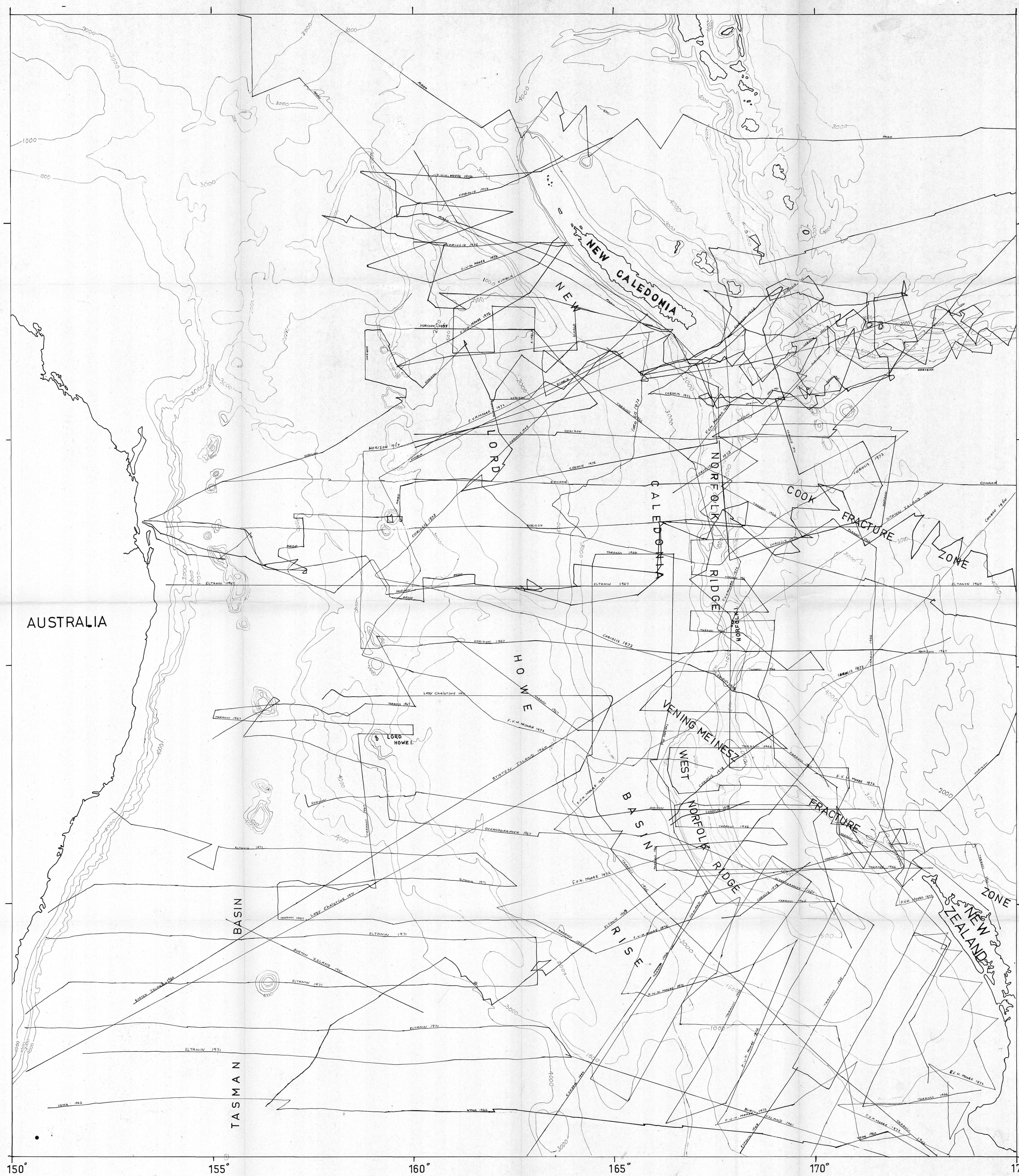
LOCATION OF GRAVITY PROFILES

0 100 200 KM

• Pendulum Station

Bathymetric Contours In Meters

Record No. 1976/12 Drawn by Author W/B8-64



LOCATION OF MAGNETIC PROFILES

0 100 200 KM

Bathymetric Contours In Meters

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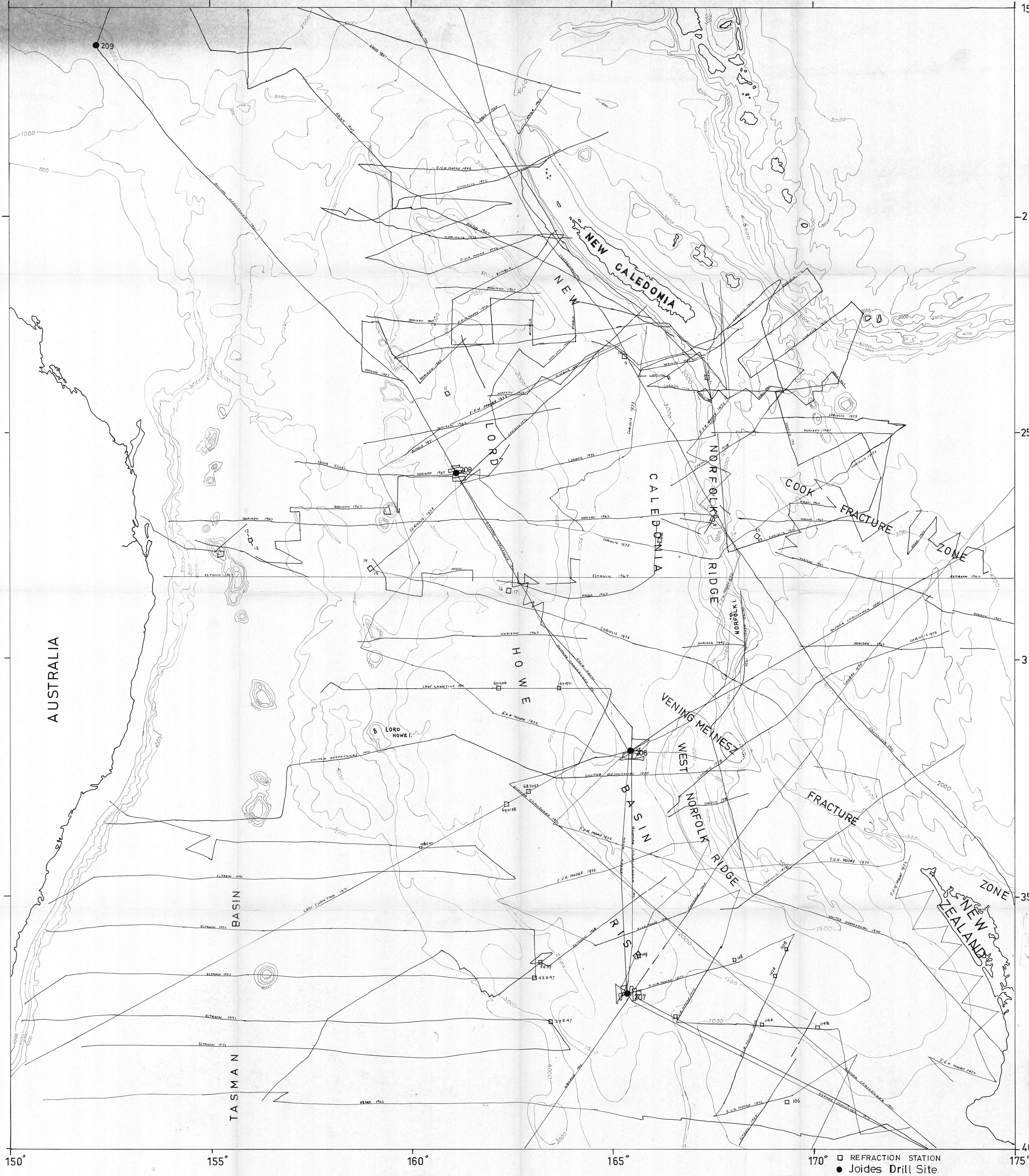

LOCATION OF SEISMIC PROFILES

Bathymetric Contours In Meters

Record No.1976/12 Drawn by Author N/B8-62