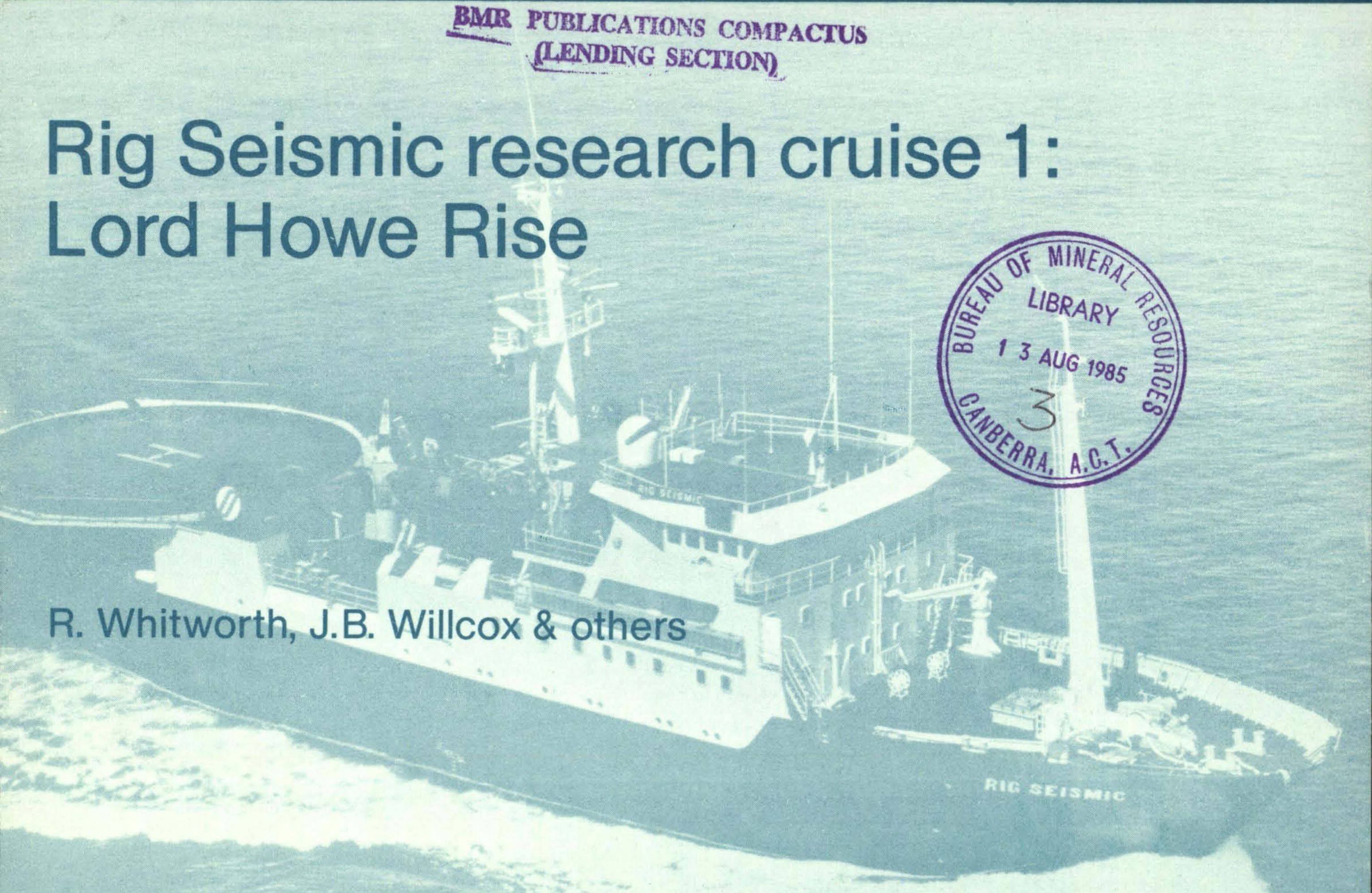
Report 266

Rig Seismic research cruise 1: Lord Howe Rise



R. Whitworth, J.B. Willcox & others

Bureau of Mineral Resources, Geology & Geophysics

Department of Resources & Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

REPORT 266

RIG SEISMIC RESEARCH CRUISE 1:

LORD HOWE RISE, SOUTHWEST PACIFIC OCEAN

by

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ABSTRACT

Preliminary interpretation of 1250 km of high-quality multichannel seismic and magnetic data, collected during the first cruise of BMR's newly acquired research vessel, Rig Seismic, has indicated that an extensive basin containing at least 3000 m of sediment may be present on the western flank of the Lord Howe Rise, southwest Pacific Ocean. Deep-seated fault blocks in the basin, previously thought to be basement, appear to be sediments, which could be prospective. Sedimentary facies are interpreted as ranging from graben-fill to shelf, slope, and bathyal, resulting from progressive subsidence of the southern Lord Howe Rise from Maastrichtian time onwards. The origin of the basin has yet to be determined.

Systems research was conducted periodically during the 9-day cruise. Some problems were encountered with the sonar doppler navigation system and the echo sounder.

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INTRODUCTION

The Lord Howe Rise survey was the first research cruise using the R/V Rig Seismic to be carried out under BMR's new initiative in marine geoscience. The vessel departed from Sydney at 1600 EST on 3 February 1985, and returned at 0700 EST on 12 February 1985.

This cruise was the first of a two-part research program. A second cruise was undertaken as a cooperative BMR/BGR project during February and March 1985, using the R/V Sonne.

The region under investigation includes the Tasman Basin, Dampier Ridge, Lord Howe Basin, and the Lord Howe Rise proper (Fig. 1), and forms a tract of Australia's legal continental shelf under the Convention of the Law of the Sea (Fig. 2). The total area of the legal continental shelf in the region is about 1.7 million km^2, approximately 20 per cent of the Australian land mass.

Approximately 1250 km (680 n miles) of multichannel seismic data were recorded over the western flank of the Lord Howe Rise, in an area 250 km southeast of Lord Howe Island (Fig. 1). The research program, consisting primarily of four parallel lines bearing 052° and 37 km (20 n miles) apart, was designed to evaluate basin margin configuration and intrabasinal structure of basins identified during the 1978 Sonne survey (Willcox & others, 1980). A magnetic gradiometer was deployed along the seismic lines, and a standard magnetometer was streamed along an additional 1400 km (770 n miles) of transit track between Sydney and the research area.

The cruise was shortened from the 2600 km (1400 n miles) envisaged in the original research proposal, as a result of time contraints imposed by the vessel's departure for the Heard-Kerguelen Plateau in March 1985. Some cruise time was also devoted to system development and to the establishment of operational techniques for future surveys.

Since the early 1950s, when the full extent and morphology of the Lord Howe Rise was first recognised, many kilometres of seismic traverse have been run across it. However, because of its size, only sparse coverage has yet been achieved and little is known of its geological history and petroleum potential: sedimentary basins of 'Gippsland type' proportions may yet be recognised. The origin of features to the west of the rise, the Dampier Ridge and the small Lord Howe and Middleton (bathymetric) Basins, is poorly understood. Likewise, little information is available on the relationship of the rise to the New Caledonia Basin and the ridges to its east. The few profiles of sufficient quality to reveal the deep sedimentary structure come from six sources: a United Geophysical Corporation (1970) line crossing the central rise; two BMR (1971) crossings of the central portion of the rise around Lord Howe Island; Shell (1971) M.V. Petrel lines, which broadly zig-zag the length of the rise; Mobil Oil Corporation (1972) Fred V.H. Moore lines, which mainly zig-zag across the southeastern part of the rise; Austradec 1/2 (1972/73) across the northern portion of the rise; and BGR/BMR data collected during a cooperative survey focussing on the southwestern part of the rise (Willcox, Symonds, & others, 1980). A summary giving details of all surveys is contained in Appendix 1.

Acknowledgement

The cooperation, skill, and seamanship of the ship's crew is gratefully acknowledged. It contributed greatly to the success of the cruise.

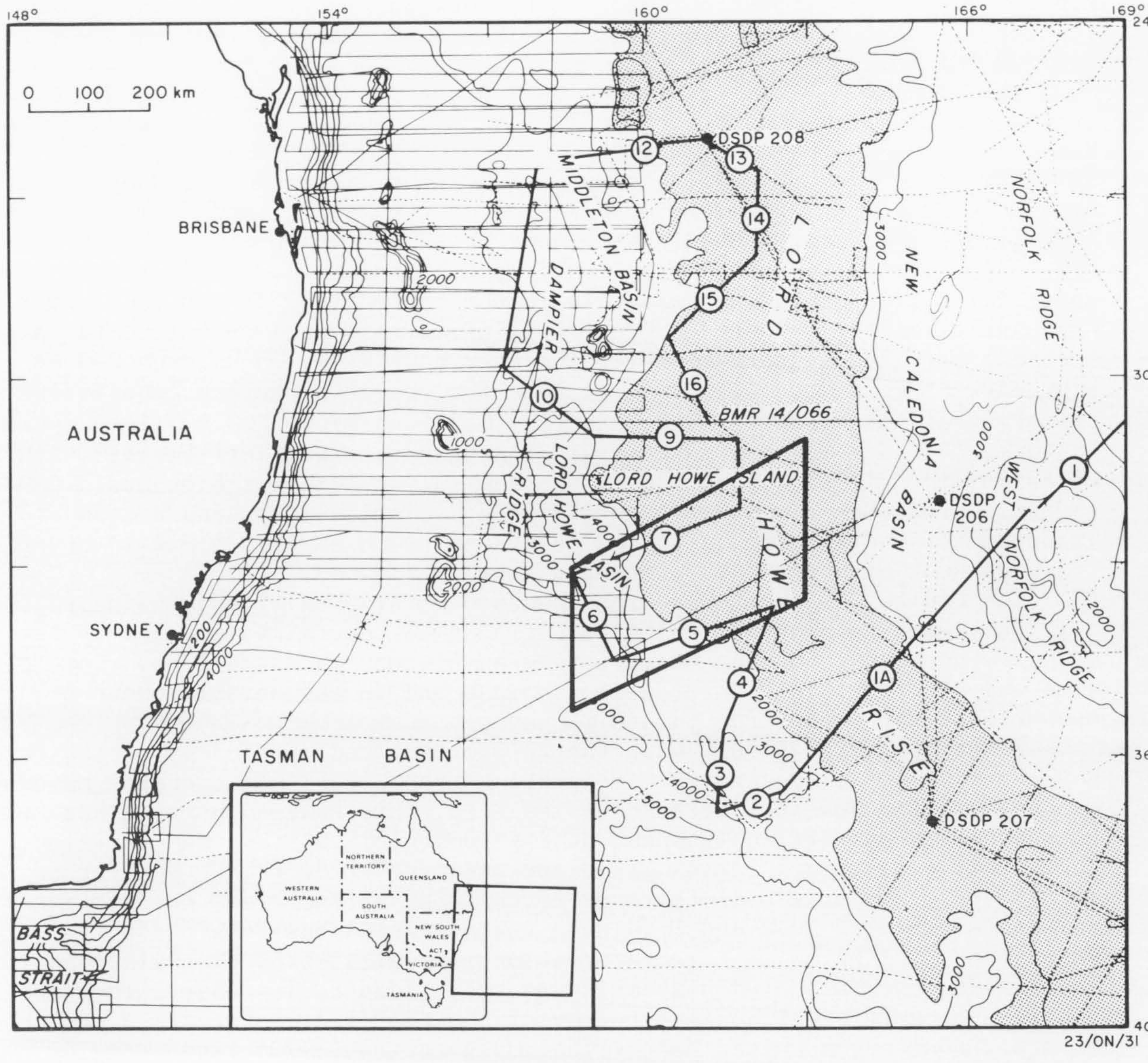


Figure 1. Bathymetry of the Tasman Sea.
After Ringis (1972), showing Rig Seismic cruise area, seismic reflection profiling tracks (BMR Continental Margin Survey lines solid; Sonne SO-7 lines heavy solid, 1 = Line SO7 - SO1 etc), BMR Line 14/066, and DSDP sites 206, 207 and 208.

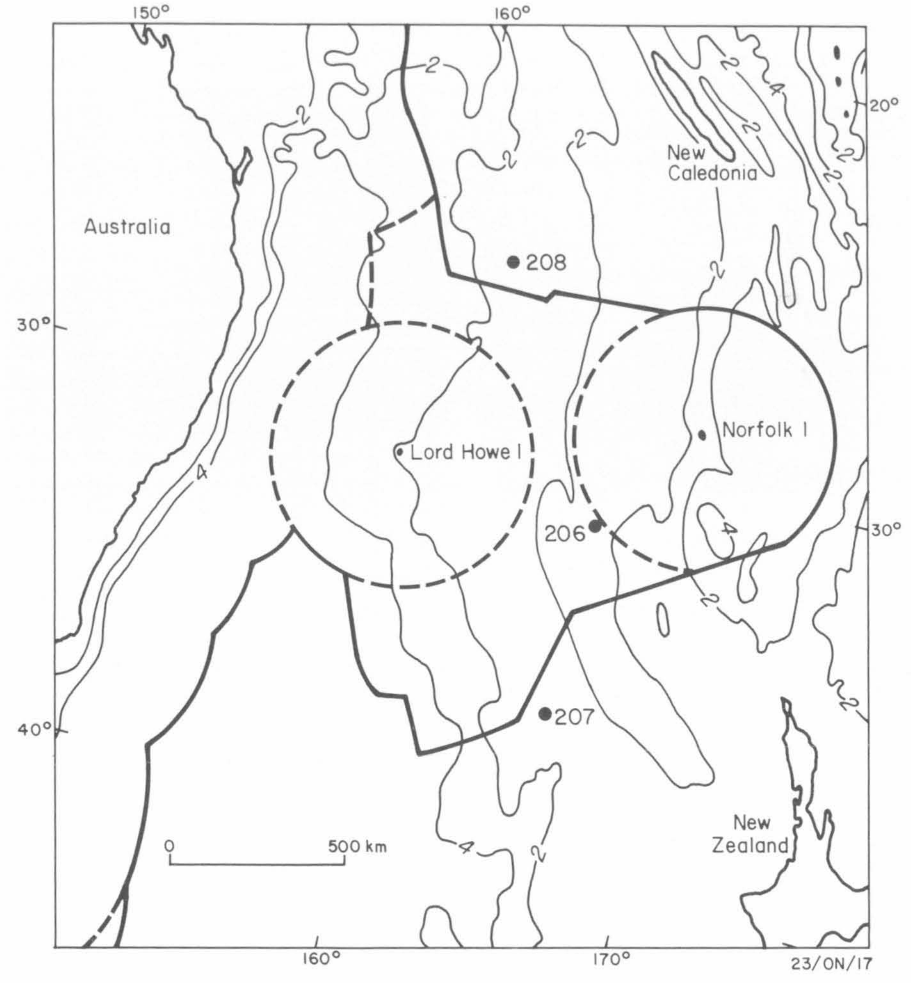


Figure 2. Australia's legal continental shelf in the Lord Howe Rise region. After Symonds & Willcox, in prep.

Crew of the R/V Rig Seismic

Captain	H. Foreman
Chief Officer	D. Harvey
2nd Officer	W. McKay
Chief Engineer	C. de Souza
2nd Engineer	P. Pittiglio
Electrical Officer	P. Jiear
E/A	K. Halliday
Chief Steward	R. Plenty
Cook	G. Conley
Steward	J. Caminitti
2nd Steward	S. O'Rourke
AB	L. Luscombe
AB	B. Marsh
AB	J. Sanderson

OBJECTIVES OF THE LORD HOWE RISE PROGRAM

Geological objectives

(i) Determine the nature, extent, and distribution of basins beneath the western flank of Lord Howe Rise, particularly a large basin about 250 km northeast of Lord Howe Island, discovered during the 1978 Sonne survey.

(ii) Determine the development history of the basins (see Basin evolution): are they pre-rift, rift, or wrench-controlled features?

(iii) Determine the nature and evolution of the Lord Howe and Middleton Basins: are they underlain by oceanic crust or extended continental crust?

(iv) Determine the nature and evolution of the northern Dampier Ridge. Is it a rift or post-rift volcanic feature, a sliver of rifted continental crust, or a combination of these?

(v) Determine the relationship of the southern Dampier Ridge and the volcanic ridge in the deep-water part of Gippsland Basin (Jones & Veevers, 1983; Willcox, 1984), which lie at opposite ends of a major transform fault. Also, the relationship of the southern Dampier Ridge to the Monowai Spur (Willcox & others, 1980).

(vi) Determine the structure and stratigraphy of the eastern margin of the northern Lord Howe Rise, and the nature of the ocean/continent boundary.

(vii) Dredging of possible outcrops for determination of basement type, and age and lithofacies of the sedimentary section, and to enable correlation with DSDP sites and piston-core sites.

Resource-related objectives

The petroleum potential of this deep-water region is almost entirely unknown, and needs to be assessed by:

(viii) Determination of basin origins for comparison with petroleum potential of other similar basins.

(ix) Evaluation of the style of structural entrapment within any potential fields.

(x) Total sediment volume computation, risk analysis, and reserve estimates, as appropriate.

(xi) Assessment of facies, largely from seismic data, to estimate the likely occurrences of source, reservoir, and seal horizons.

1985 RIG SEISMIC CRUISE OBJECTIVES

Geological & resource-related objectives

The geological and resource-related objectives for the *Rig Seismic* cruise were primarily those outlined under items (i), (ii), (viii), (ix), and (xi) above.

Systems-research objectives

Seismic acquisition system. The shortening of the geophysical shakedown cruise of Jan/Feb left the seismic acquisition system inadequately prepared and tested, and with unacceptably low reliability prior to departure on the Lord Howe Rise cruise. The high priority afforded to data acquisition on the cruise prevented much further system testing and refinement. Accordingly, the commissioning of the new 48-channel seismic acquisition system and the training of observers were principal aims on this cruise.

Non-seismic acquisition system. The Lord Howe Rise cruise provided an opportunity to test, under survey conditions, the recently upgraded data acquisition software and all of the newly installed equipment that had been interfaced with the computer. The cruise was also used to familiarise those members of the scientific and technical staff who had not been involved in the earlier shakedown cruise with the operations of the data acquisition and computer equipment.

CRUISE PLAN

The cruise plan (Fig. 3) for the *Rig Seismic* component of the Lord Howe Rise program was designed to obtain the maximum useful coverage of the western flank of the Lord Howe Rise in the 9 days available. Some time, mainly on the voyage to and from Sydney, was allocated to test equipment deployment techniques, cable noise levels in the main 2400 m streamer and a short 600 m streamer to be used on the Heard-Kerguelen survey, and installation of air-gun depth monitors and source-signature detectors.

Lines 1 and 12 are 30 km apart and extend east-west, across the Tasman Basin, from Sydney to an area about 250 km southeast of Lord Howe Island (Fig. 1, Table 1). They are essentially transit lines on which magnetic and bathymetric data only were collected. Line 2 is a short length of track taken up by deployment of the 2400 m streamer and air-gun system. Line 3 the Dampier Ridge, and Lines 4-10 are over the western flank of the Lord Howe Rise

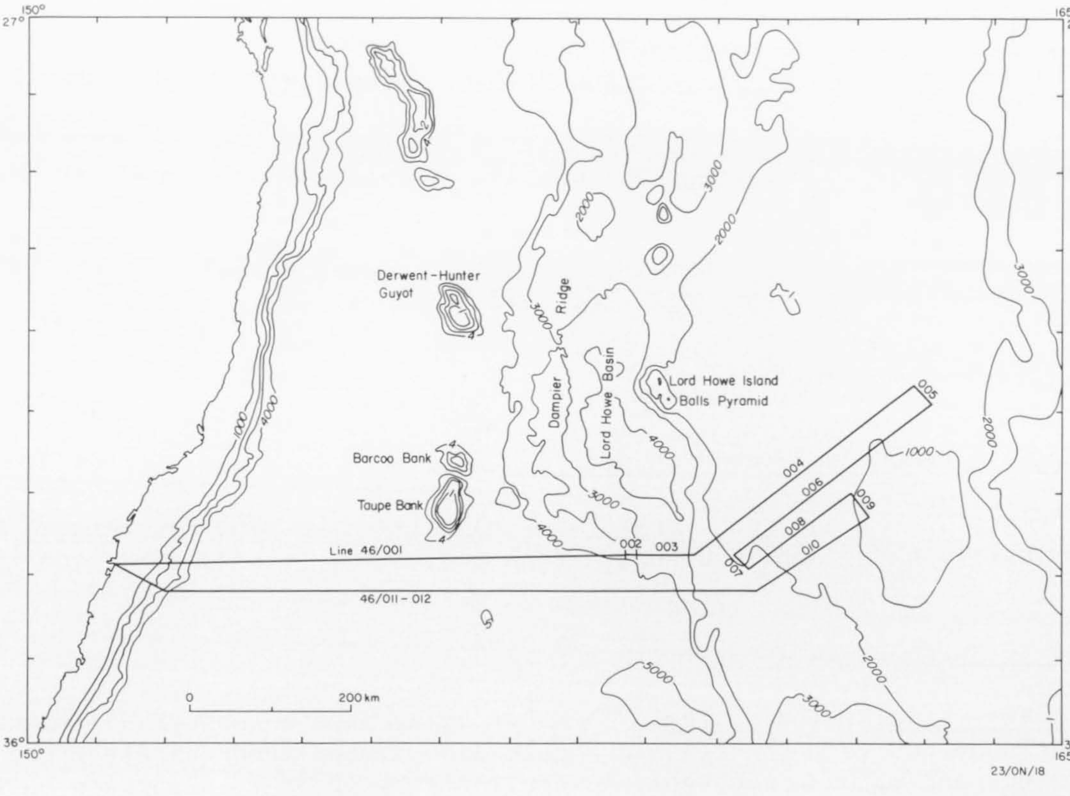


Figure 3. Rig Seismic cruise plan (Lines 46/001 to 46/012).

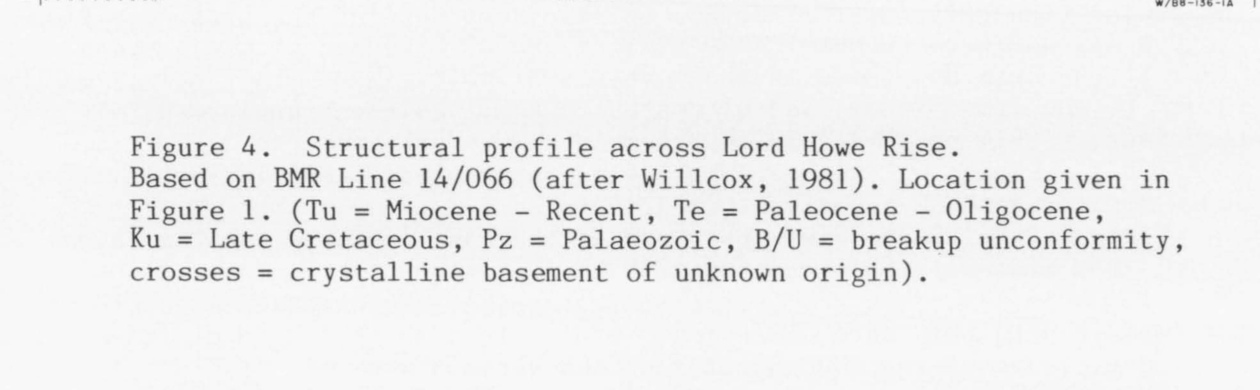


Figure 4. Structural profile across Lord Howe Rise.
Based on BMR Line 14/066 (after Willcox, 1981). Location given in Figure 1. (Tu = Miocene - Recent, Te = Paleocene - Oligocene, Ku = Late Cretaceous, Pz = Palaeozoic, B/U = breakup unconformity, crosses = crystalline basement of unknown origin).

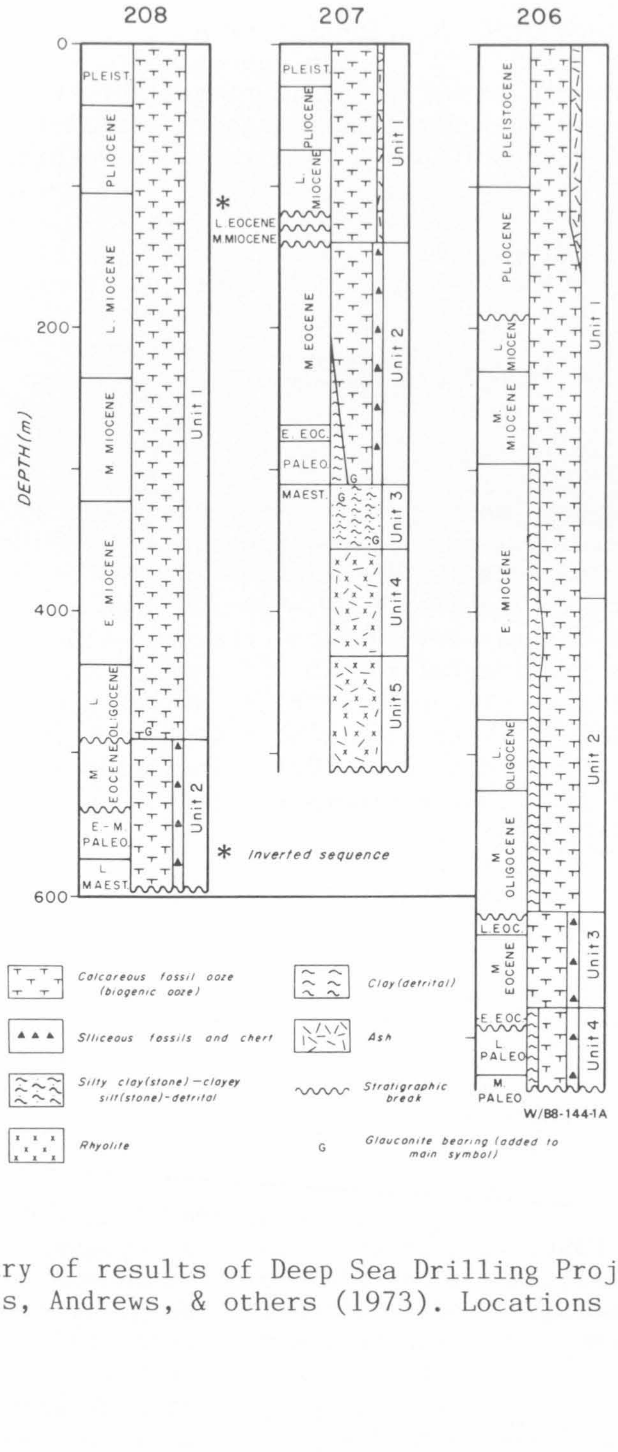


Figure 5. Summary of results of Deep Sea Drilling Project (DSDP) sites 206, 208. After Burns, Andrews, & others (1973). Locations given in Figure 1.

proper. Both multi-channel seismic and magnetic data were collected on Lines 3-10. Line 11 consisted of tests of a 600 m seismic cable at speeds up to 10 knots.

The principal lines over the rise (Lines 4, 6, 8 and 10) are separated by 37 km (20 n miles) and trend 052°, a configuration considered optimal for definition of basin margin geometry and intra-basinal trends, and to distinguish rift and wrench-controlled basins. A similar pattern will be run in the area around Lord Howe Island during the Sonne cruise. Total coverage is as follows:

Magnetics only	Lines 1,12	1400 km (770 n miles)
Seismic/magnetic	Lines 3-11	1250 km (680 n miles)

GEOLOGICAL BACKGROUND

General Structure

The Lord Howe Rise is most clearly outlined by the 2000 m isobath (Fig. 1), but in general its crest lies in water 750-1200 m deep. To its east, the New Caledonia Basin is flat floored and 3000 m deep. To its west, between 26° and 34° S, the smaller Middleton and Lord Howe Basins separate the rise from the Dampier Ridge. Beyond this, the 4000-4500 m deep Tasman Basin extends to the narrow continental margin off eastern Australia.

The crustal structure of Lord Howe Rise, as interpreted from seismic refraction measurements (Officer, 1955; Shor & others, 1971) and the gravity field (Dooley, 1963; Woodward & Hunt, 1971), indicates a continental origin and a thickness of 26 km. Shor & others (1971) have shown that it is largely composed of rocks with P-wave velocity of 6.0 km/s, which is similar to values found for the Australian continent.

Mutter & Jongsma (1978) computed the gravity response associated with the refraction model of Shor & others (1971) and showed that it gave a marked gravity gradient, unlike the relatively flat response on the BMR profiles and on profiles presented by Woodward & Hunt (1971). Using the refractors obtained by Shor & others (1971), Mutter & Jongsma (1978) presented a revised crustal model that satisfied the requirement of a flat gravity field. This showed a sharp division in both the deep and shallow crustal structure of the Lord Howe Rise, which they considered lent support to the concept of a rift zone on the western side with associated crustal thinning and alteration.

Two reconnaissance seismic profiles recorded by BMR in 1971 indicate that the central part of Lord Howe Rise may be divided longitudinally into an eastern province, characterised by an elevated and planed-off basement surface with thin sediment cover, and a western province, characterised by a more rugged structure, possibly composed of horsts and grabens. The greater depth of basement in the western province gives rise to a slightly quieter magnetic signature, and the possible horst and graben structures are reflected in the free-air anomaly profiles. Line drawings presented by Bentz (1974) indicate that this longitudinal division is less clear-cut in the southern part of the Lord Howe Rise.

1979 Sonne survey

The results of the joint BMR/BGR survey conducted in 1979 led Willcox, Symonds, & others (1980) to the conclusion that 'numerous small basins, some of which may have formed within grabens, underlie the western part of the Lord

Howe Rise. These probably trend north-northwest, range from 20-30 km wide, but are of uncertain length. The deepest basin contains in excess of 3000 m of sediment. Tensional features are also present on the Dampier Ridge and possibly within the Lord Howe and Middleton Basins.' They concluded that 'the Dampier Ridge is at least in part of continental origin'. They did not support Jongsma & Mutter's (1978) contention that 'a zone of horst and graben basement structures some 200 km in width' underlies the western part of the Lord Howe Rise, and that it represents the whole of the pre-Tasman Basin rift valley. The degree to which the Lord Howe Rise and Dampier Ridge are related to Tasman Basin rifting remains conjectural. This survey was successful in providing a crossing of relatively large and unknown sedimentary basin approximately 250 km northeast of Lord Howe Island.

Seismic stratigraphic analysis indicated that the eastern (New Caledonia Basin) flank, upon which 2000-3000 m of pre-Maastrichtian sediment was deposited, is the ancient continental slope of the Australia-Antarctic supercontinent. It seems probable that the Lord Howe and Middleton Basins were troughs in the Late Cretaceous, and that the Lord Howe Rise was a trough-bounded marginal plateau.

Geological correlations

The only direct information we have concerning the nature of the rocks forming the Lord Howe Rise has come from Lord Howe Island (Game, 1970), from dredging on one of the volcanic features on the southeastern side of the rise (Bentz, 1924), and from the Deep Sea Drilling Project (Burns, Andrews, & others, 1973).

Game (1970) described the Lord Howe Island rocks as typical alkali basalts and recognised at least three major eruptive periods, which he considered began as early as the mid-Tertiary and ended with an eruptive period, dated isotopically as mid-Pliocene (7.7 Ma). Rocks obtained from the dredging described by Bentz (1974) were olivine basalt, gabbro, and a mixture of hyaloclastic breccias and biomicrites (Launay & others, 1976).

There are three DSDP holes in the region under investigation: sites 206, 207, and 208 (Figs. 1 & 5). At site 206, on the floor of the New Caledonia Basin, a relatively uniform sequence of early Paleocence to ?late Pleistocene calcareous ooze overlies Late Cretaceous to early middle Eocene siliceous fossil-bearing chalk. Palaeontological evidence at both these sites indicates that normal oceanic conditions prevailed throughout the sequence sampled and that bathyal deposition was relatively continuous.

At site 207, on the southern Lord Howe Rise, a somewhat different lithological sequence was intersected. The hole bottomed in Upper Cretaceous rhyolitic lapilli tuffs and vitrophyric rhyolite flows, and Van der Lingen (1973) has suggested that at least some of these rocks may be of subaerial or very shallow marine origin. The rhyolites, which gave a mean K-Ar age of 94 Ma (McDougall & Van der Lingen, 1974), are overlain by a sandy sequence containing reworked rhyolitic material and then a Maastrichtian glauconitic silty claystone, which Burns, Andrews, & others (1973) considered was probably deposited in a shallow environment with restricted (non-oceanic) circulation. The remainder of the rocks intersected at this site are carbonate oozes of Paleocene to Pleistocene age, deposited well above the carbonate compensation depth. Palaeontological evidence at this site indicates that there has been a rapid increase in the depth of sedimentation from relatively shallow water in the Maastrichtian to depths similar to the present day (1400 m) by the early Eocene.

Using the DSDP results, it is possible to make a very general reconstruction of the geological history of the region. The results from site 206 indicate that the New Caledonia Basin existed as an oceanic basin at least as far back as the early Paleocene. The presence of reworked Late Cretaceous (?Maastrichtian) radiolarians near the base of the hole probably indicates an even older age for the basin. On Lord Howe Rise the geological history began with the eruption of rhyolites, possibly at or near sea level, 94 Ma ago (McDougall & Van der Lingen, 1974). This activity may have been related to the development of oceanic crust in the Tasman Sea 80 Ma ago (Hayes & Ringis, 1973). During the Maastrichtian, the silty claystone intersected at site 207 was deposited in a shallow marine environment with restricted circulation. In the south, true oceanic conditions began in the middle Paleocene and the rise continued to subside, reaching its present upper bathyal depth by the early Eocene. In the north, however, oceanic conditions prevailed in the Maastrichtian, and the rise had reached upper bathyal depths by latest Cretaceous. The Lord Howe Rise appears to have been stable along its length at about its present depth since the middle Eocene.

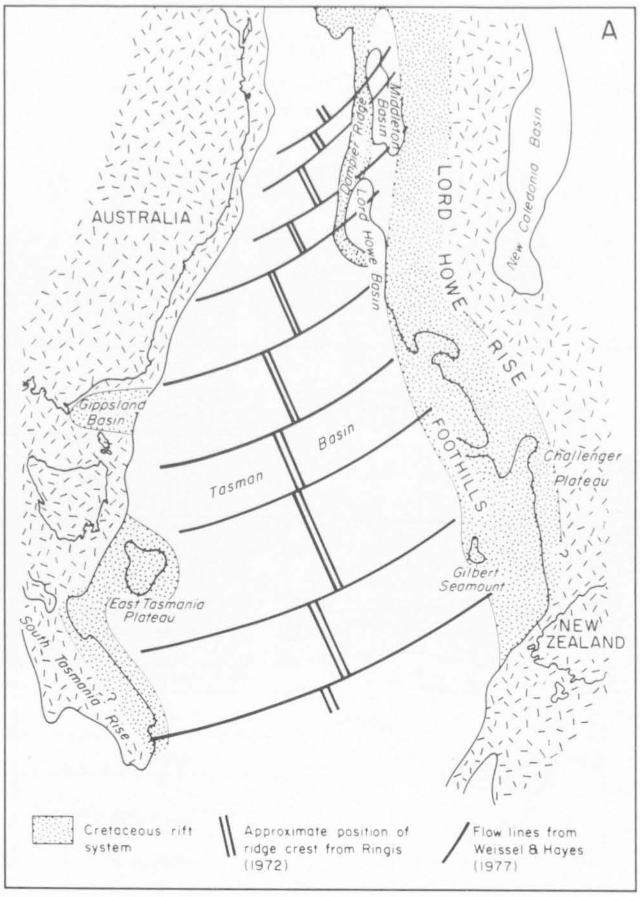
Evolutionary models proposed for the Tasman Sea and Lord Howe Rise

Hayes & Ringis (1973) identified linear west-northwest-trending magnetic anomalies 24-33 in the Tasman Basin, which were disposed about a buried basement ridge, thus indicating formation by seafloor spreading, about 80-60 Ma ago. In a reappraisal of the spreading pattern and age identification of the magnetic anomalies, Weissel & Hayes (1977) showed that the transform faults trend more northeast (Fig. 6A) than suggested by Ringis (1972), and that Ringis's proposed interval of subduction at the east Australian margin, between anomalies 27 and 24 (about 67.5-60 Ma ago) was no longer necessary. Weissel & Hayes (1977) supported the suggestion of Ringis (1972) that the oldest anomalies, 32 and 33, should be found within the Middleton and Lord Howe Basins and that a ridge jump had taken place after anomaly 32 time, probably leaving the Dampier Ridge as a stranded fragment of continental crust to the west of the 'Lord Howe Plate'. The most recent reconstruction of the Lord Howe Rise and eastern Australia is that by Shaw (1978).

An evolutionary model of the early rifting history of the Tasman Sea has been put forward by Jongsma & Mutter (1978). In essence, it suggests that the western half of the Lord Howe Rise and probably the whole of the Dampier Ridge constitute an entire Early Cretaceous rift-valley formed prior to seafloor spreading in the Tasman Sea (Fig. 6A). When new oceanic crust broke through the rift valley, it was not along its axis, as in most idealised models of rifting (e.g. Falvey, 1974), but along its western boundary fault. Jongsma & Mutter (1978) proposed such a model to account for a zone of apparent horst and graben structures along the western half of Lord Howe Rise (see, for example, Fig. 4) and the narrow continental margin and lack of rift basins along the eastern seaboard of Australia. In a later paper (Mutter & Jongsma, 1978) they envisaged the fragmentation as resulting from a 3-branch rift system in which the Gippsland Basin formed a failed arm (Fig. 6B). This implies that pre-breakup Gippsland Basin sediments, the Lower Cretaceous Strzelecki Group and lowermost Upper Cretaceous Latrobe Group (Threlfall & others, 1976) may have equivalents beneath Lord Howe Rise.

Seismic stratigraphy

The seismic stratigraphy of the Lord Howe Rise region has been discussed at some length by Willcox & others (1980), and their seismic sequences and correlations are reproduced in Figure 7.



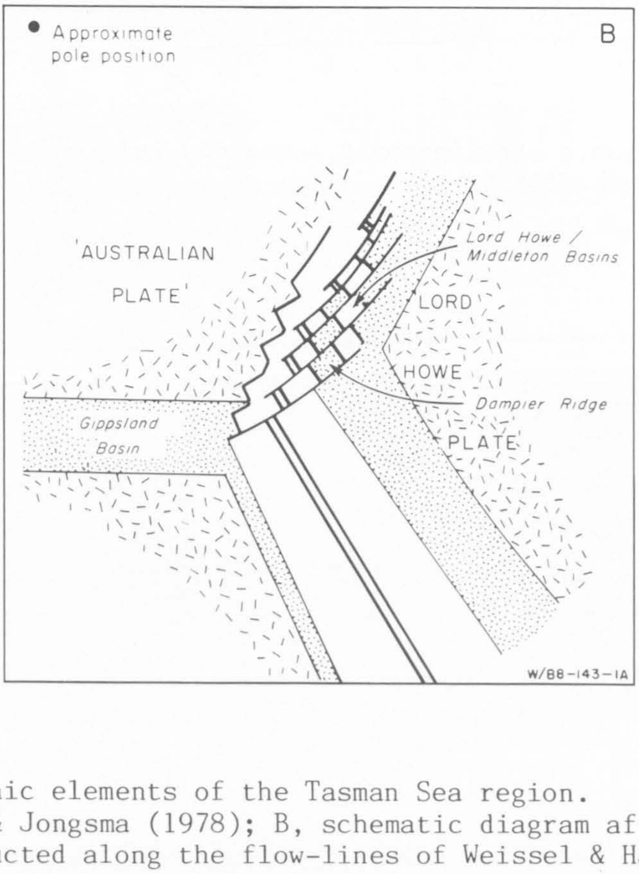


Figure 6. Tectonic elements of the Tasman Sea region.
A, after Mutter & Jongsma (1978); B, schematic diagram after Mutter & Jongsma (1978), reconstructed along the flow-lines of Weissel & Hayes (1977).

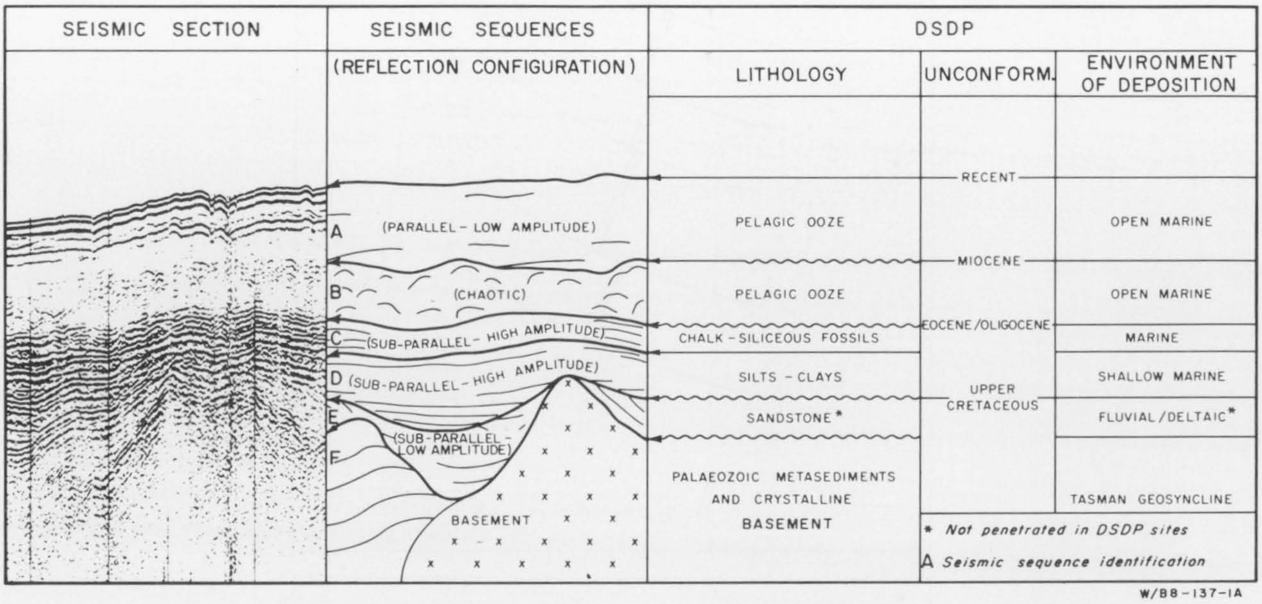


Figure 7. Seismic stratigraphic sequences related to DSDP data. After Willcox & others (1980).

The distribution of sequences and unconformities along selected Sonne profiles is shown in Figure 8.

Basin evolution

In continuing studies of the Lord Howe Rise area (Symonds, 1984), and in an interpretation of the deep water part of the Gippsland Basin (Willcox, 1984), several possibilities for the development of basins flanking the Tasman Sea have been discussed (Fig. 9):

(a) The rift stages of the Gippsland Basin (sometimes referred to as the Strzelecki Basin) and any basins along the western flank of Lord Howe Rise, once formed a bifurcating rift system, which eventually spread about a triple junction (Fig. 9A).

(b) The Lord Howe rift system overprinted the Gippsland system (Fig. 9B); a situation that is difficult to envisage and to accommodate within the time frame.

(c) Any basin on the western flank of Lord Howe Rise is essentially an extension of the Gippsland (Strzelecki Basin) offset by a transfer fault (Fig. 9C).

(d) Development of the South Tasman Basin was accommodated by a left-lateral wrench fault along the eastern Australia/Lord Howe plate boundary; basins on the western flank of Lord Howe Rise are, hence, wrench basins (Fig. 9D).

These four hypotheses can be tested by comparing the orientation of the basin margins with respect to their internal structural grain. For options (a) and (b), the internal grain should tend to parallel the western margin of Lord Howe Rise; for (c) the internal grain should be roughly perpendicular, i.e. trending northeastwards; and for (d) the internal grain should be approximately east-west. Recent mapping tends to favour the last.

Petroleum potential (based on Willcox & others, 1981; Symonds & Willcox, in prep.)

Western portion of Lord Howe Rise. The general absence of rift and pull-apart basins along the eastern seaboard of Australia has led to speculation that basins of this type became detached when the Tasman Sea Basin formed by seafloor spreading, and are now to be found along the western flank of Lord Howe Rise and possibly Dampier Ridge. Previous studies have shown that a zone of horsts and grabens, some 200 km wide, underlies these features; however, this zone is not unequivocally a product of rifting. As discovered above (Fig. 9), the horsts and grabens may have developed within a shear zone.

The structural grain along the western flank of Lord Howe Rise is still largely unknown. The grabens appear to be 20-40 km wide and probably extend over at least several tens of kilometres (Fig. 10). The thickness of their sedimentary fill is very variable, but reaches 3000-4000 m (2.8 s of reflection time) in places. The largest basin so far identified is more than 50 km across and located about 250 km northeast of Lord Howe Island (herein called the Lord Howe Rise Basin) (Fig. 11).

Depositional environments of the sediments deposited in the rift basins in the Early and Late Cretaceous are unknown. If the basins formed as described by the classical models for the development of Atlantic-type passive

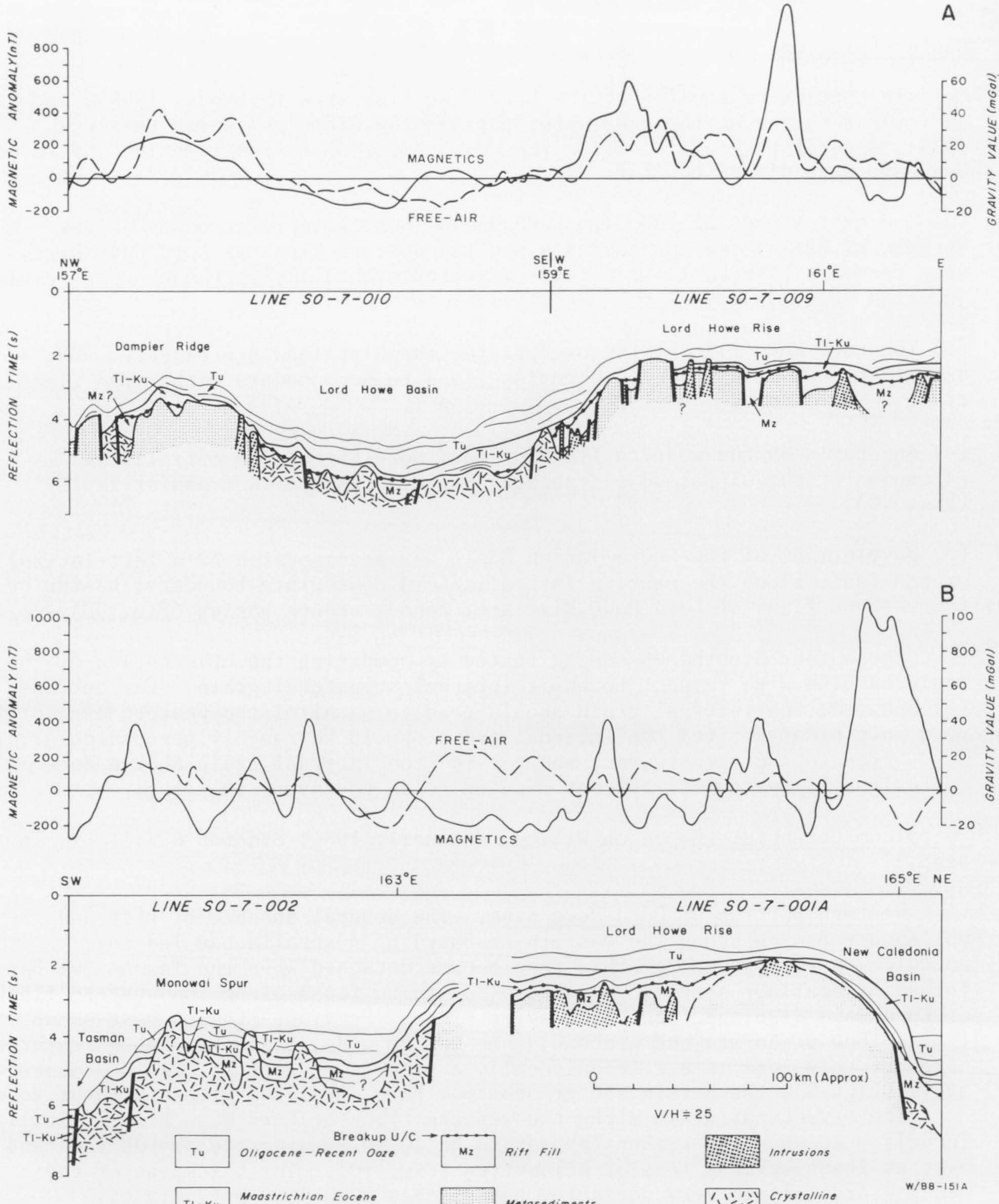


Figure 8. Structural profiles based on Sonne lines.
A. Lord Howe Rise - Dampier Ridge; B, Tasman Basin - Lord Howe Rise - New Caledonia Basin. After Willcox & others (1980). Shows seismic sequences A-F, unconformities, and apparent variation in basement types. Shows also free-air anomaly (FAA) and magnetic anomaly (MAG = total magnetic intensity minus IGRF). Locations given in Figure 1.

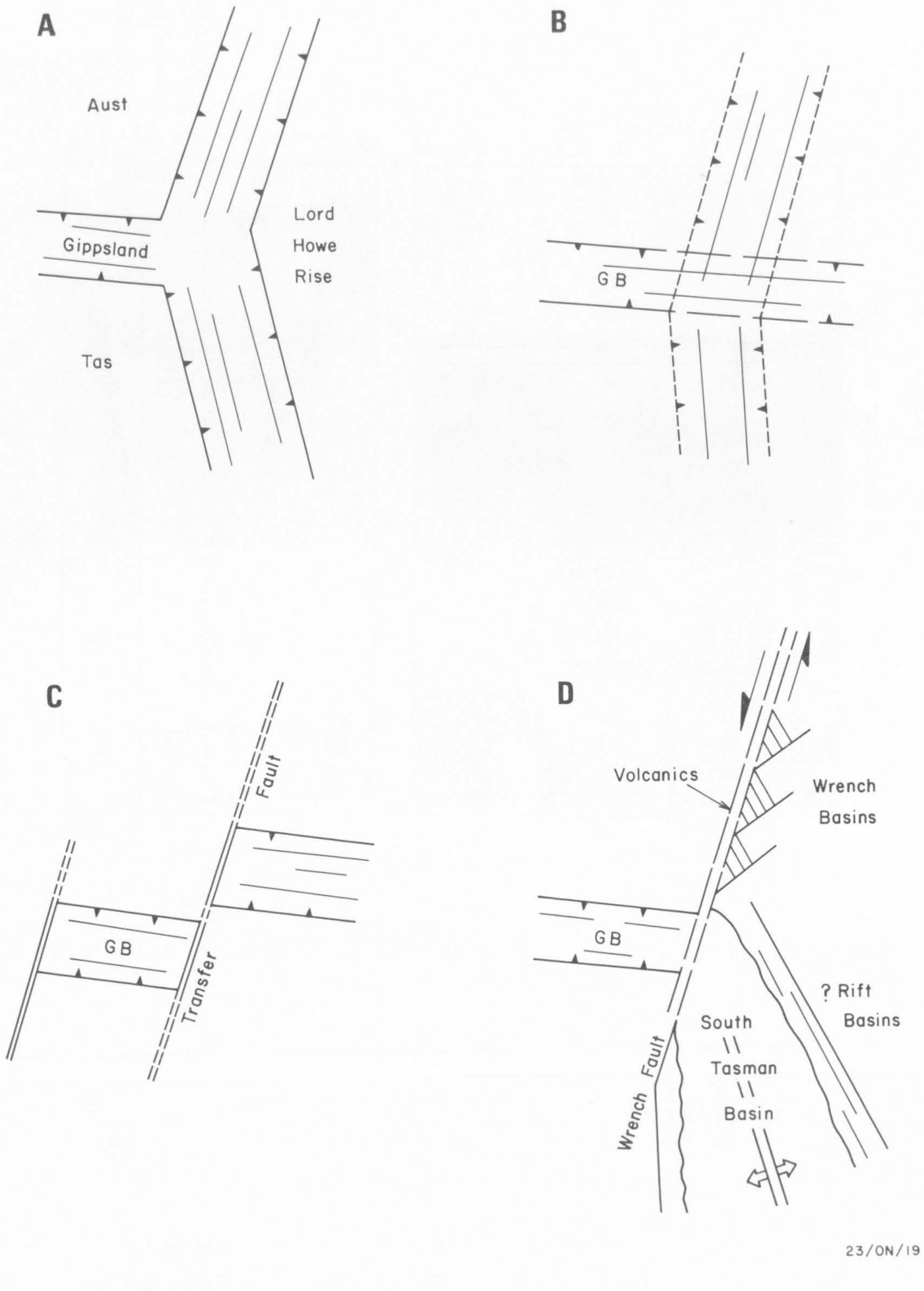


Figure 9. Hypotheses for development of basins on western flank of Lord Howe Rise. After Willcox (1984). A, bifurcating rift; B, rift overprint; C, basin offset along transfer fault; D, wrench basin development.

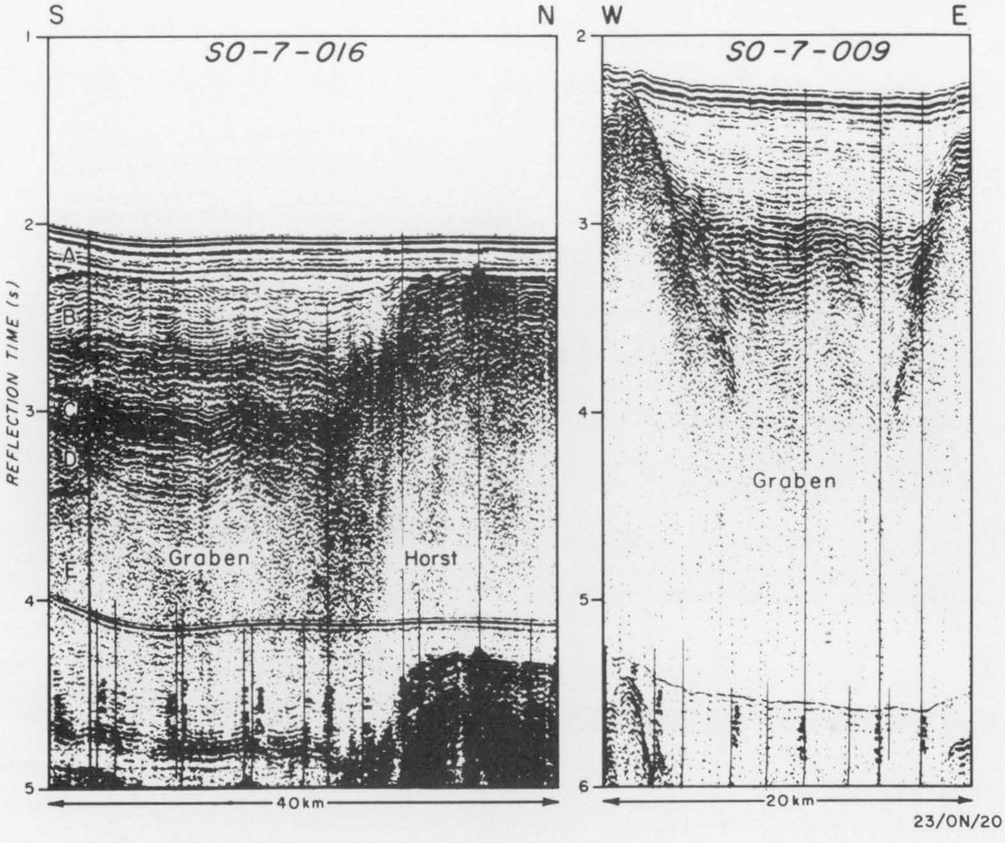


Figure 10. Seismic section of graben. After Willcox & others (1980).

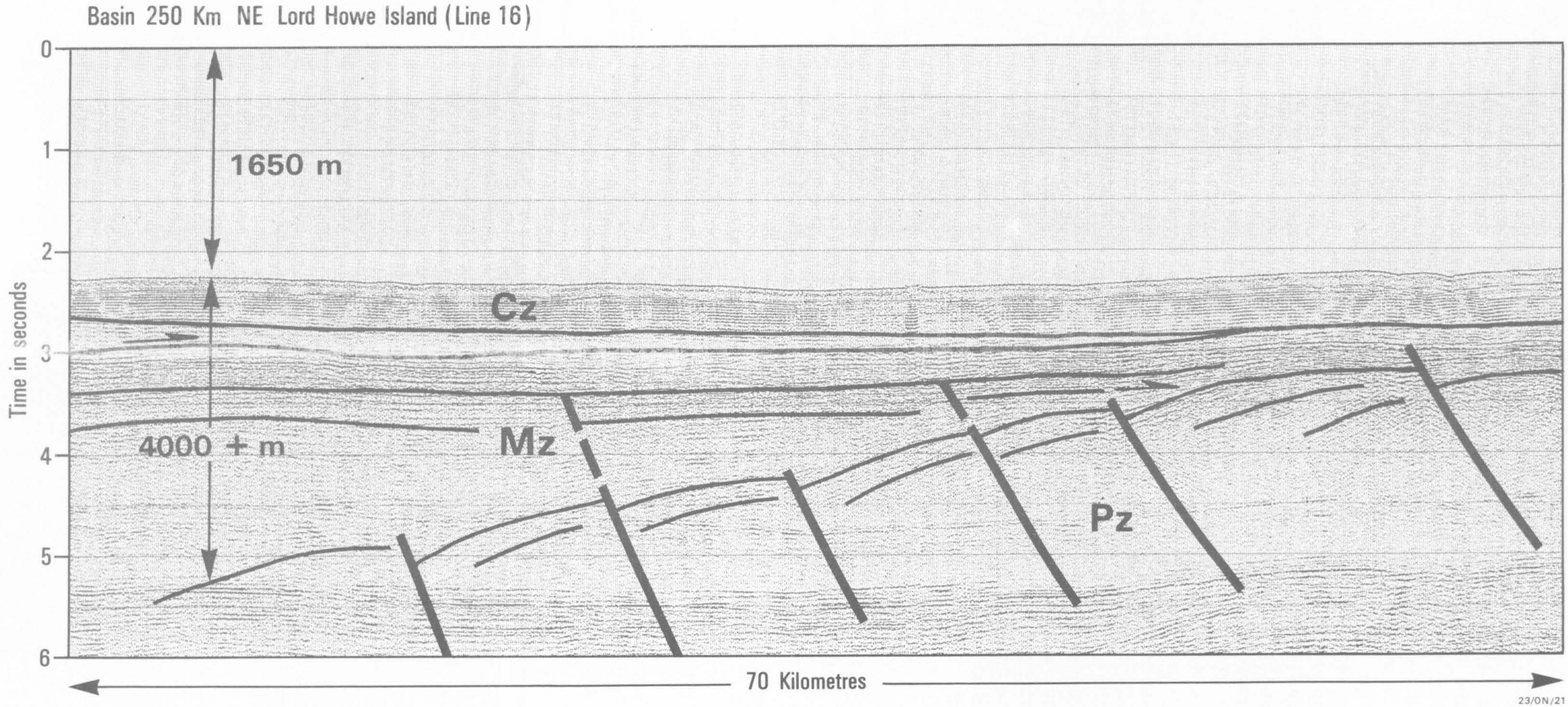


Figure 11. Seismic section of large basin 250 km NE of Lord Howe Island (Line S07 - 16). Location given in Figure 1.

continental margins, much of the sediment fill would probably have been deposited by rivers and in lakes, and could be expected to have contained a high proportion of land plant (gas-prone) source material.

However, on Lord Howe Rise at least the upper part of the rift-fill sequence may depart from the classical models. Evidence of wave-base erosion of several of the horst blocks during the Late Cretaceous implies that a shallow sea may have occupied the intervening grabens, and that anaerobic conditions favourable to deposition of petroleum source rocks may have prevailed, owing to restricted circulation. This would be expected to favour the deposition of some marine (oil-prone) source material along with the land plant source material.

Results from the Deep Sea Drilling Project (DSDP site 207) confirm the presence of restricted shallow marine silts and clays of Maastrichtian (post breakup) age overlying horst blocks. These match rocks of similar age and depositional environment recently dredged from the deep continental slope off New South Wales. Hence, up to 3000 m of sediment, containing potential petroleum source rocks, may occur in the basins of the western Lord Howe Rise, and these may vary from gas-prone land plant source material at the base to oil-prone marine source material at the top.

Interbedded sands within the fluviatile and shallow marine sequences are the most likely potential reservoir rocks. Lord Howe Rise has been subjected to several periods of volcanism, which may have adversely affected the quality of these reservoirs in some places. Major petroleum traps could occur within the larger folds and within sedimentary drape structures across the larger horsts. Seals may be provided by interbedded shales within the rift-fill sequence itself or by shales within the overlying marine post-breakup sequence.

In most places on Lord Howe Rise the drilled Maastrichtian shallow marine post-breakup sequence is overlain by less than 1000 m of overburden, which is probably insufficient for generation of hydrocarbons unless heat flow was abnormally high. Thus, in general, mature source rocks could only exist in the rift-fill sequence below the breakup unconformity. On the eastern flank of the Lord Howe and Middleton Basins, however, the sedimentary overburden is probably thick enough (up to 2000 m) to have allowed source material within the Maastrichtian sediments to have reached maturity.

Theoretically, the rift basins of Lord Howe Rise may be expected to have had high geothermal gradients at the inception of seafloor spreading (Klemme, 1975), and source rocks may well have matured with less overburden than would normally be required. There are some indications that heat flow may be abnormally high (Grim, 1969): the only heat flow measurements on the rise gave a value of about twice normal. Also, it has been suggested that the Tertiary volcanism in the region may be related to the northward drift over a mantle hot-spot, implying that a zone of high heat flow may be present on the western Lord Howe Rise.

A final consideration of the hydrocarbon potential of the western Lord Howe Rise relates to the Cretaceous pre-drift reconstruction of the central area of the rise (just south of the Dampier Ridge) against the Gippsland Basin. As previously stated, this implies that the rift basins of the rise may be analagous, at least in part, to the Gippsland Basin, which may have been initiated in the early Cretaceous as the failed-arm of a three-branched rift system, with the dissected remnants of the other arms now beneath the western Lord Howe Rise.

In the Gippsland Basin the Early Cretaceous is poorly known, but believed to consist of non-marine clastic sediments. The oil and gas fields occur in the overlying Latrobe Group, a mainly fluvio-deltaic sequence deposited from the Late Cretaceous to Eocene. The major exploration plays are associated with a strongly time-transgressive unconformity that occurs at the top of the Latrobe Group. Significant but smaller fields occur within the group. Hydrocarbon traps within the group are related to normal faulting, mainly active from Cretaceous to early Eocene, and the major top Latrobe Group traps are related to en-echelon anticlines developed during the late Eocene to early Oligocene and late Miocene. A regional seal to the top Latrobe Group traps is provided by fine-grained, easterly prograding marine sediments.

The DSDP results and Late Cretaceous or older wave-base erosion of the horst blocks on Lord Howe Rise indicate that subsidence and thus the transition from predominantly continental to predominantly marine deposition, would have occured earlier on the Lord Howe Rise than in the Gippsland Basin. Thus, non-marine shales and coals of similar type to those thought to source the hydrocarbons in the Gippsland Basin, but of somewhat greater age, may have been deposited deep within the basins on Lord Howe Rise. The development of successive shore-lines and palaeoslopes in the eastern part of the Gippsland Basin suggests that parts of the Latrobe Group may have a laterally equivalent shallow marine sequence (perhaps containing aquatic kerogen) to the east, on the western margin of the Tasman Basin rift. This is supported by the recent dredging of shallow marine ?Latrobe Group sediments from deep on the continental slope off the southeast coast of Australia. The Maastrichtian shallow marine, silty claystone at DSDP site 207 on Lord Howe Rise may represent the uppermost part of a similar sequence on the eastern margin of the rift.

It seems plausible that intra-Latrobe Group-type fault traps could occur within the rift basin on the rise; however, it is unlikely that top of Latrobe Group anticlinal type traps, which form the major fields of the Gippsland Basin, will be present on the rise. The later phase of structuring, which produced these traps, occurred at a time when the Lord Howe Rise was nearly fully separated from Australia as a result of seafloor spreading in the Tasman Sea. If the structuring was associated with a regional tectonic episode in southeastern Australia, it is unlikely that the same structuring would have occurred on the rise.

Eastern flank of Lord Howe Rise. The eastern flank of Lord Howe Rise may have been an ancient seaboard of the Australian-Antarctic subcontinent. A considerable thickness (about 2000 m) of clastic sediment was deposited across this margin during or before the Late Cretaceous (Willcox & others, 1977, fig. 7A). Most of this was probably derived from the now planate basement blocks to the west. The overburden of pelagic sediments ranges from about 1000 m on the eastern edge of the rise to as much as 3000 m in the New Caledonia Basin.

Depositional environments favourable for both the production and preservation of oil-generating aquatic organic matter may have existed on this continental slope, as is thought to be the case on many other continental slopes around the world (Dow, 1979).

Faulting, together with folding of the ?Late Cretaceous sediment wedge could have provided traps for petroleum, and the progradation observed on some profiles may incorporate stratigraphic traps. Petroleum migrating updip could have been trapped against the basement surface and unconformities, and sealed by the overlying pelagic ooze.

Middleton Basin. Considerable thicknesses of Late Cretaceous sediments, including potential source rocks, may occur on the flanks of the Middleton Basin in a manner similar to that previously described for the rift basins beneath the western Lord Howe Rise (Fig. 12). It has been suggested that for part of this time the Lord Howe Rise was a trough-bounded marginal plateau with the trough centred on the Lord Howe and Middleton Basins. This implies a stronger marine influence within the Middleton Basin than within the rift basins beneath the rise. The Late Cretaceous rocks are probably carbonate and terrigenous sediments deposited in a restricted, shallow to deep marine environment.

DATA AQUISITION SYSTEMS

Collection and documentation of data from the Lord Howe Rise cruise (BMR Survey No. 46) were designed to fulfill the dual requirements of the cruise program. The geological requirements were covered by four long, parallel, northeast-trending traverses, which took the major part of the cruise. The 20-km traverses connecting these main traverses and additional periods of data collection following the main survey were used for equipment testing and evaluation of new operating systems and procedures. Appendix 2 details the recording parameters for the seismic acquisition system, and Appendix 3 outlines the recorded data for the navigation, bathymetry, and magnetics systems.

Seismic data

Data were collected using the main 2400 m streamer (Fig. 13) to achieve maximum control for moveout corections and an appropriate CDP (Common Depth Point) spacing. It was considered desirable to collect 8-s records, giving approximately 6 s below seabed, and to use 2-ms sampling. The CDP-fold was then controlled by the following factors:

* ship speed (5-6 kn for acceptable noise)
* airgun recharge time (12.4 s for 2x500 cu. in., i.e. 2x8.2L)
* magnetic tape recording time

Table 2: Relationship of ship's speed, CDP fold & shot interval

Ship speed (kn)	Fold	Shot interval(s)
5	48	9.8
6	48	8.2
7	48	7.0
5	24	18.6
6	24	16.4
7	24	14.0

In order to operate at a practical ship's speed and have full energy output, the recording was constrained to be 48 channel with 24-fold CDP.

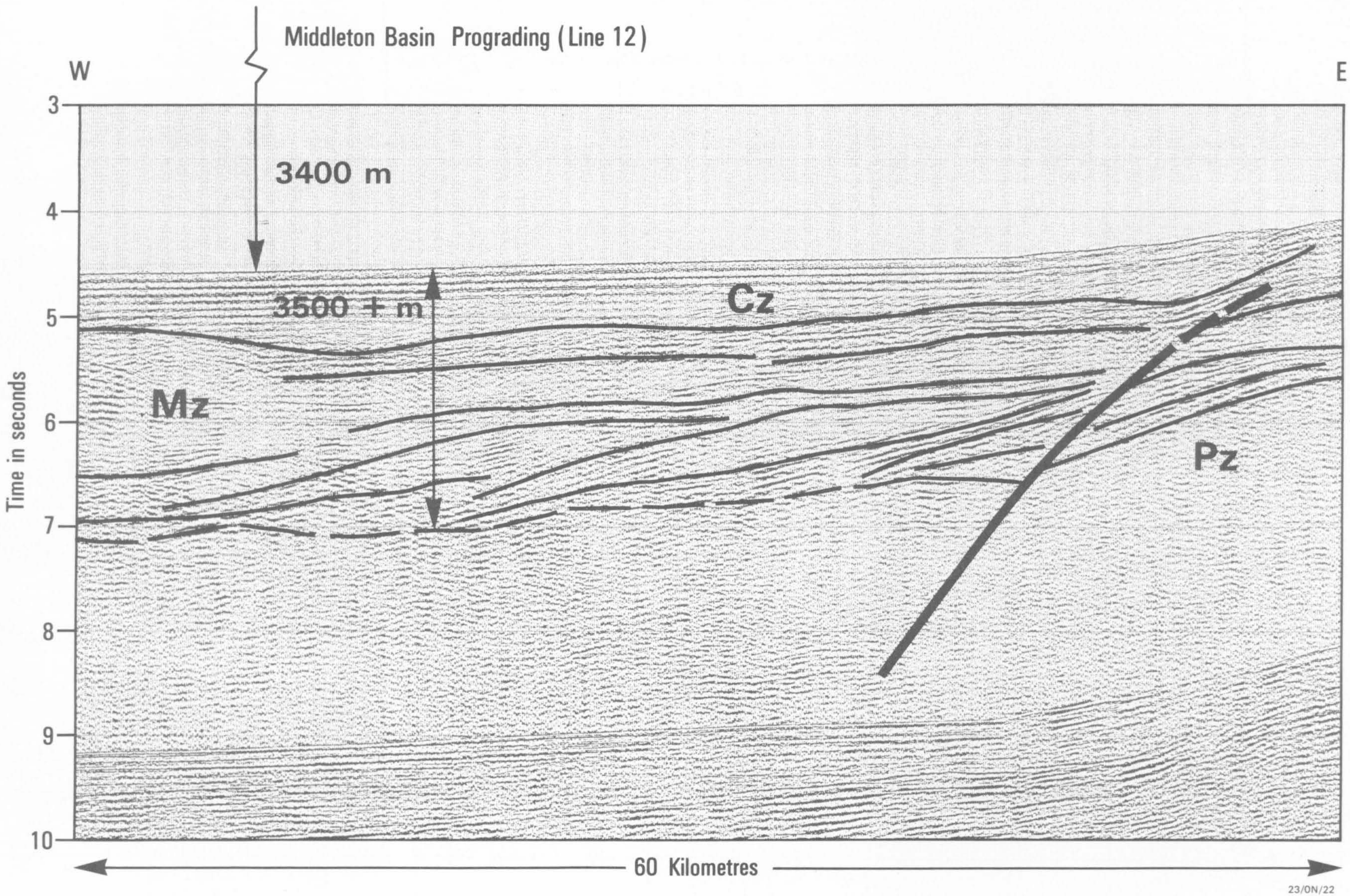


Figure 12. Seismic section showing progradation, Middleton Basin (Line S07 - 12). Location given in Figure 1.

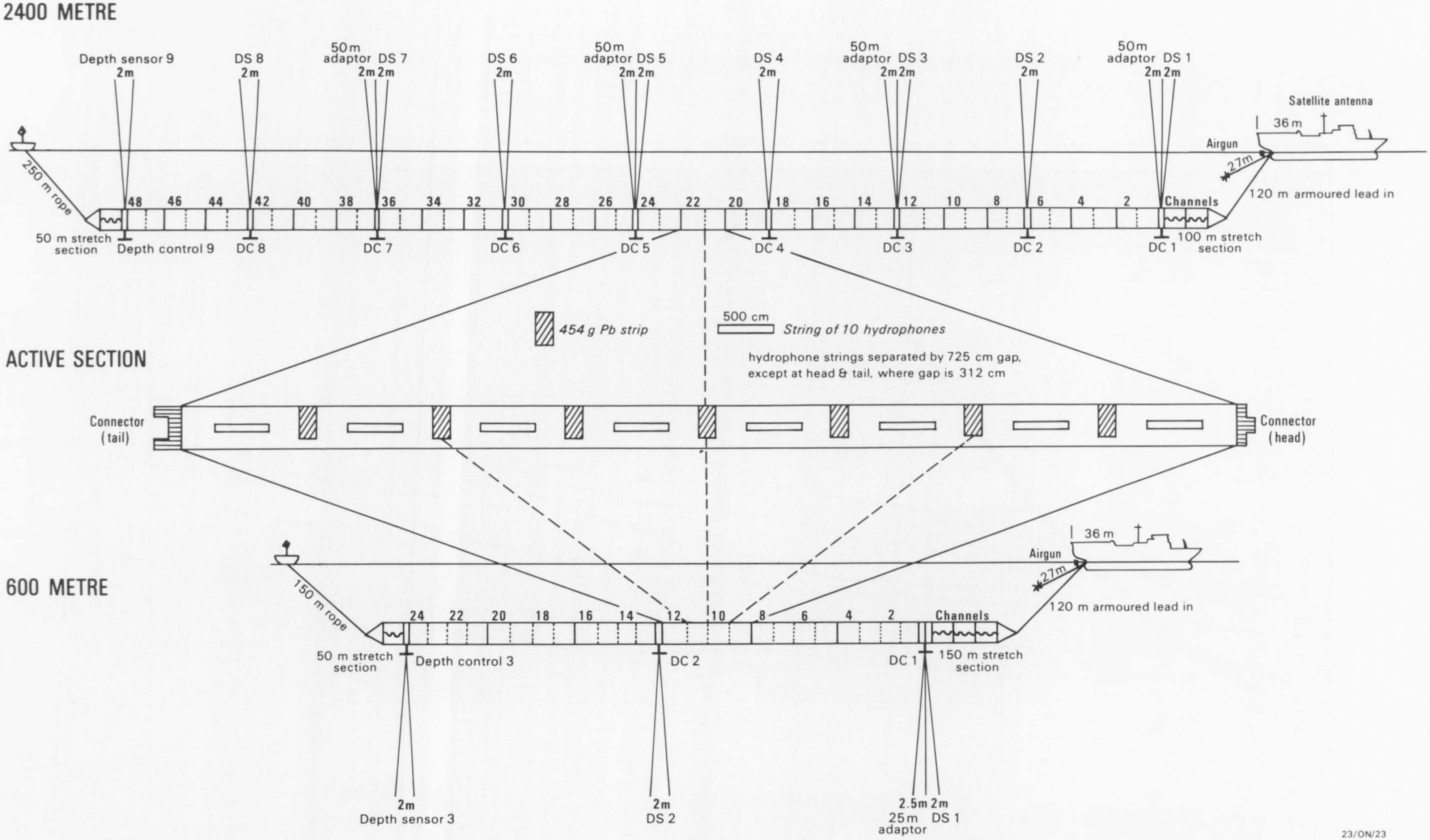


Figure 13. Seismic streamer configuration.

Magnetic data

A magnetic gradiometer was deployed during the long northeast-trending traverses. Although this equipment provided good results, the deployment and retrieval procedures were long and arduous as a result of the present inadequate winch facilities. Figure 14 shows a sample of results.

Navigation

Navigation used the high-quality dual-channel satellite navigator and the newly installed Magnavox sonar doppler unit. Both systems were a constant source of irritation, as the absence of electronic interface cards for the satellite system and the poor performance of the sonar doppler working in back-scatter mode reduced the accuracy of navigation well below the capabilities of the highly sophisticated data acquisition system (DAS). The efficacy of the excellent software for the DAS was therefore much reduced by these hardware faults.

Bathymetric data

The echo sounders were the least satisfactory units. The depth digitising unit connected to the 12-kH echo sounder had to be operated under manual control in deep water on certain ship headings, as the automatic tracking mode failed to provide adequate data, because of the inadequate signal-to- noise ratio under some sea conditions. The 3.5 kH echo sounder was not connected to the DAS. Records from the 3.5 kH unit provide some information within the soft sediment cover, but during certain ship headings and sea states cavitation and air bubble layers affected this sounder. The 3.5 kH signal was observed to interfere with the sonar doppler records and, accordingly, the 3.5 kH unit was not used during the major part of the survey. The echo sounder systems need an extensive period of cruise time so that electronic and physical procedures may be devised for optimum operation.

Air-gun experiments

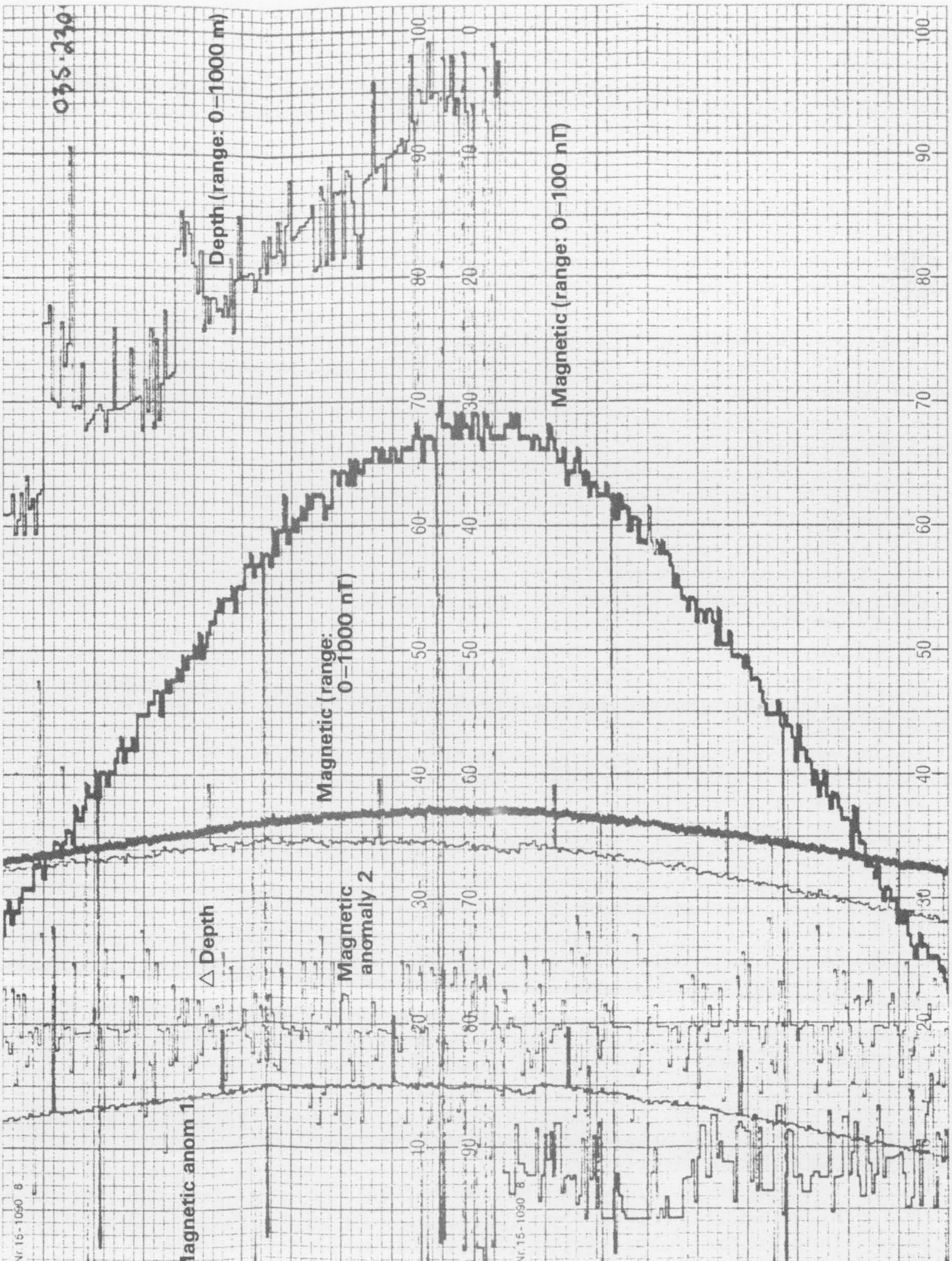
Two experiments were conducted to calculate the effect of gun volume and gun synchronisation variation on source signature. During these tests, two 8.2 L (500 cu. in) air guns were deployed on either side of the main cable. The experiments were carried out on Day 038, during a short transit (Line 46/005) along the crest of the Lord Howe Rise.

The first experiment compared the pulse length of port and starboard guns with the combined shot pulse. The section of traverse is shown in Figure 15. The second experiment compared the penetration and frequency content of data from the individual guns with the combined effect (Fig. 16).

The shot pulse was inspected by viewing the water bottom return at an expanded scale on a storage oscilloscope (Fig. 16). A direct measurement of the pulse shape was obtained from a hydrophone connected to the bridle of each airgun. The shapes of the water bottom reflection (Fig. 16a) and the direct bridle hydrophone (Fig. 16b) show the large component of water bubble reverberation in the pulse shape. The ratio of bubble to primary pulse amplitude of about 0.5 is surprisingly high, considering that the guns were fitted with wave shape kits.

During a later experiment, a shuttle sensor was connected to each gun as a first step to automatic shot-instant recording. The initiating shot pulse (Fig. 16c) shows that a 16 ms delay occurs between the shot instant and the

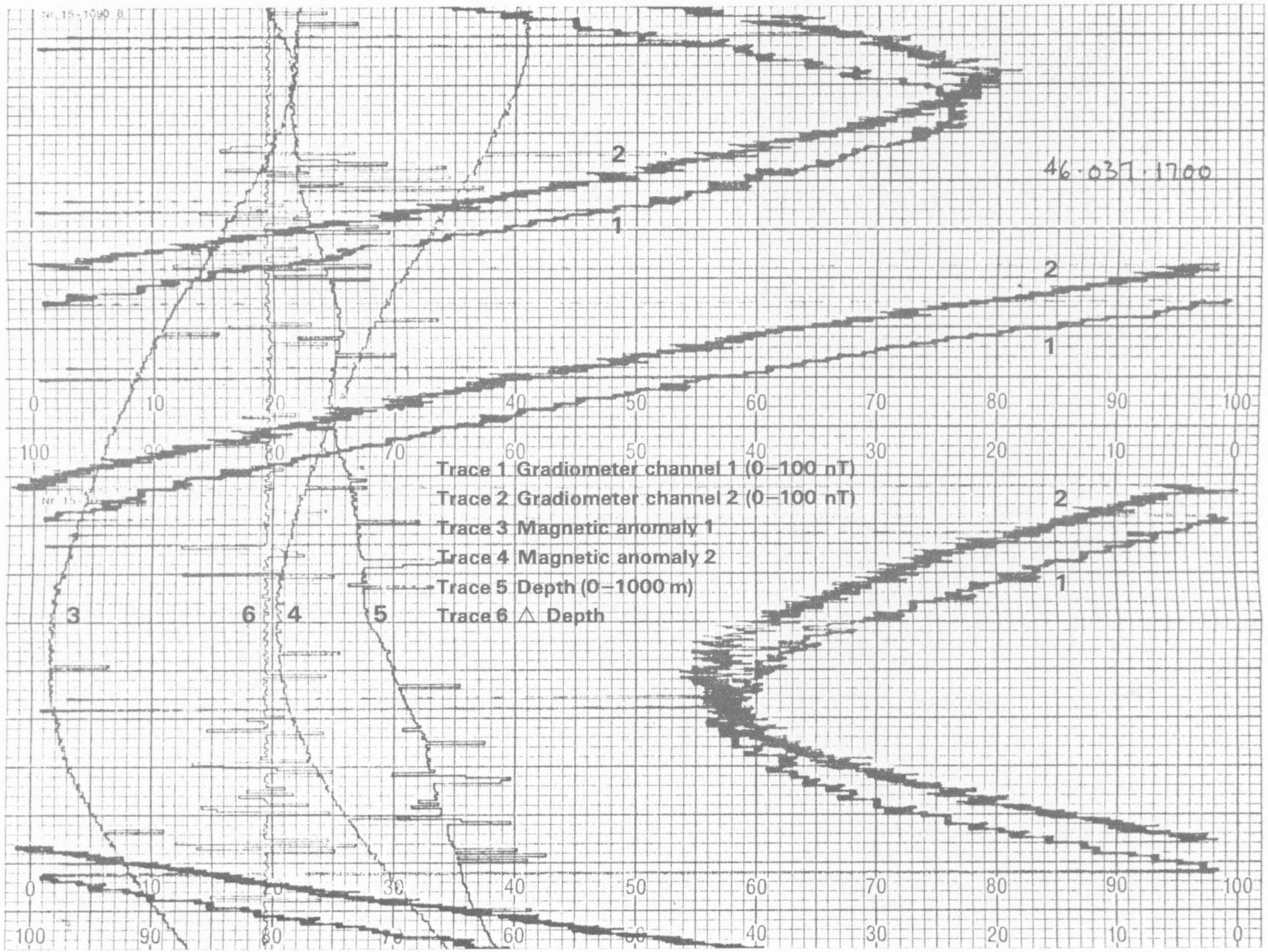
A



23/ON/24

Figure 14. Magnetic analogue record samples. (a) Single sensor (100 nT and 1000 nT ranges), also showing computed magnetic anomaly. (b) Dual sensors (1000 nT range), also showing computed magnetic anomalies, water depth, and water depth difference.

B


Nr. 15-1090 B
46·037·1700
Trace 1 Gradiometer channel 1 (0–100 nT)
Trace 2 Gradiometer channel 2 (0–100 nT)
Trace 3 Magnetic anomaly 1
Trace 4 Magnetic anomaly 2
Trace 5 Depth (0–1000 m)
Trace 6 △ Depth

23/ON/25

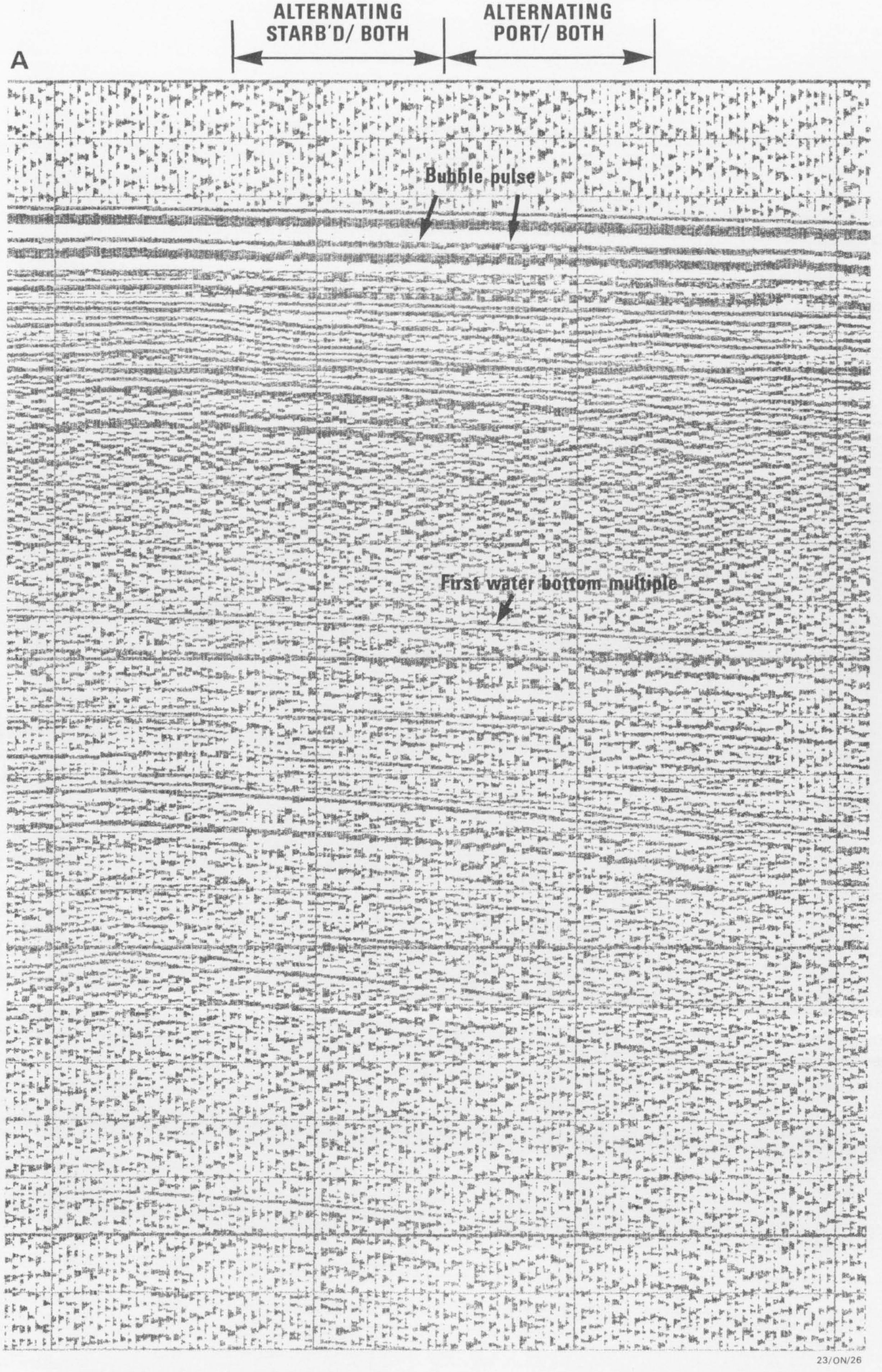
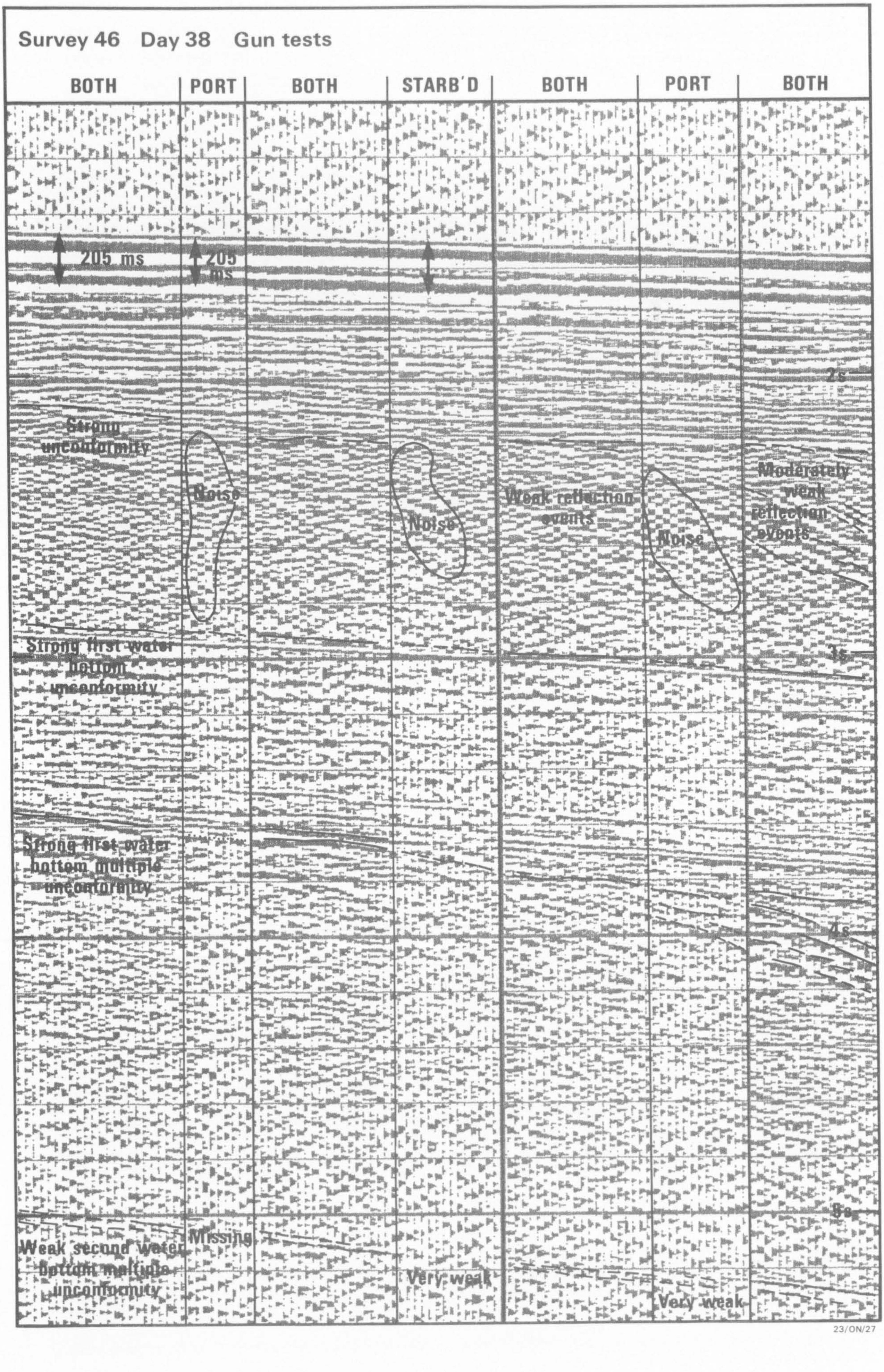


Figure 15. Air-gun comparison and synchronisation test records. (a) Seismic section, using single and dual guns. (b) Seismic section, comparing port and starboard guns.

B



Survey 46 Day 38 Gun tests
BOTH
PORT
BOTH
STARB'D
BOTH
PORT
BOTH
205 ms
205 ms
2s
Strong unconformity
Noise
Noise
Weak reflection events
Noise
Moderately weak reflection events
3s
Strong first water bottom unconformity
Strong first water bottom multiple unconformity
4s
5s
Missing
Weak second water bottom multiple unconformity
Very weak
Very weak

23/ON/27

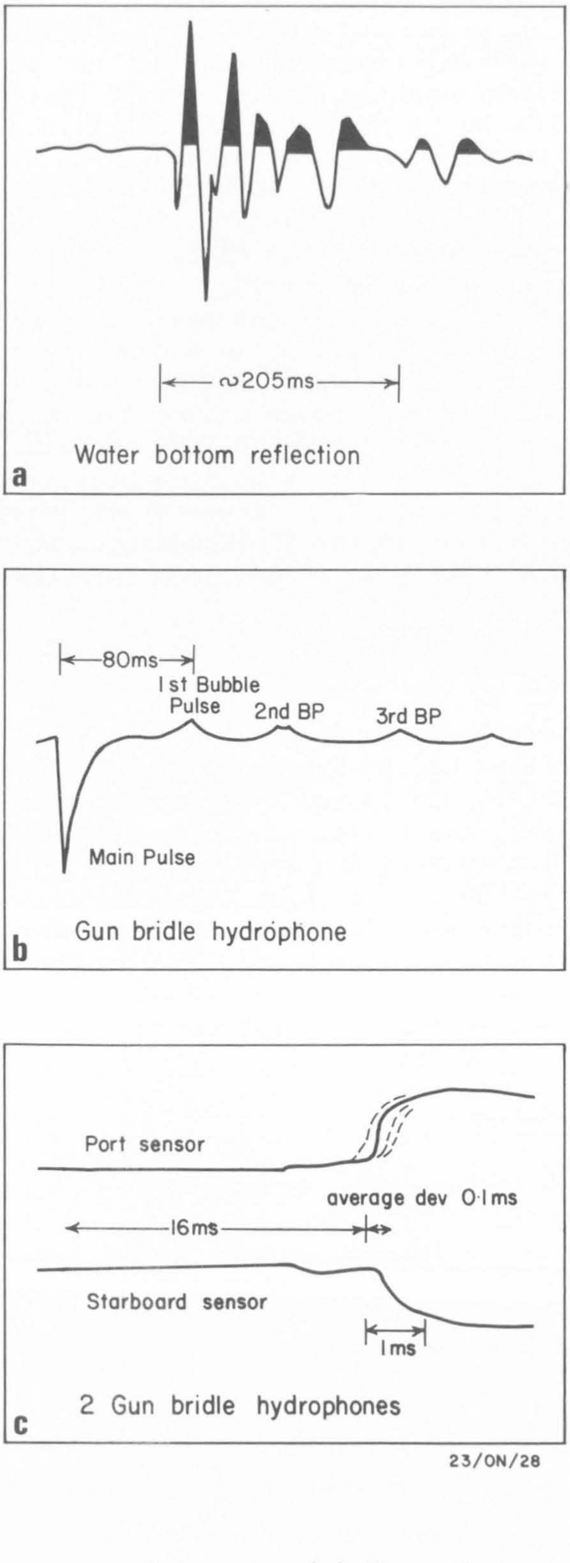


Figure 16. Air-gun source signature. (a) Water bottom reflection. (b) Source recorded on gun-bridle hydrophone. (c) Comparison and synchronisation of port and starboard guns, using bridle hydrophones.

hydrophone-detected shot pulse. This value must be considered in future processing.

The alternating guns experiment showed that the bubble pulse in the water bottom reflection arrived slightly earlier on the port gun than on the starboard gun. The display in Figure 15 shows this undulation of the bubble pulse from the water bottom, but no deviation of the first arrival from either gun or from the combined guns. While the results suggest that individual guns could have their own bubble characteristics, it is thought that small differences in gun depth (less than 0.5 m) caused by the prevailing swell and by ship's wash affected the bubble period.

The comparison of individual air-gun power compared with that of the combined guns is difficult to determine in a changing geological environment. Direct measurements show that the water bottom return was close to the anticipated two-fold amplitude increase expected from well-separated air guns. Figure 16 shows that the combined power of the two guns provides better definition below the deepest discernible unconformity. Noise interferes with the continuity of dipping events below the deepest unconformity, although such determinations are subjective in the field monitor records used in this experiment. The loss of energy is clearly demonstrated in the second and third water bottom multiples.

Sonobuoy experiments

Nine sonobuoys were tested and six deployed in order to evaluate sonobuoy data collection procedures on the Rig Seismic. Of the nine, three failed to transmit after 15 minutes, one failed to transmit after 20 minutes - as a result of a flat battery, two failed to deploy hydrophones, and three had batteries so flat that they were not deployed.

Two conclusions may be reached from these unsuccessful tests. Firstly, the supply and maintenance procedures for the sonobuoys need to be carefully reviewed. Secondly, sonobuoys need to be deployed from the side of the Rig Seismic and thrown well clear. This was the case for the buoy that transmitted the longest, whereas at least one of the sonobuoys deployed from the stern was fouled by the tail buoy.

Sonobuoy engineering tests

Owing to the high failure rate, a test box is needed that will test the power output, current drawn, hydrophone section, and the internal battery. This should minimise the failure of sonobuoys deployed. Unfortunately, there is no way of testing the detonator that is used to drop the hydrophone after the buoy has been deployed. If this becomes the only area of failure, the buoys will have to be deployed manually.

GEOLOGICAL RESULTS

Seismic sequences

Identification of seismic sequences in the single-channel monitor records is hampered by the relatively long air-gun pulse (110 ms). It is anticipated that this problem will be removed by deconvolution prior to stacking in the BMR processing centre. Nevertheless, six sequences can be readily identified in the Lord Howe Rise area and can be traced along the northeast-trending lines (Fig. 17). At this stage seismic sequences have not been related to previous studies, e.g. 1979 Sonne results.

Sequence 6. Consisting of basement-type blocks showing a highly reflective upper surface, a semi-transparent and incoherent internal reflection character, and usually associated with intense magnetic anomalies, sequence 6 is correlated with the planate block under the eastern flank of Lord Howe Rise and with intrusive bodies associated with faults and graben. The planate block is presumed to be made up of relatively old metamorphosed sediments.

Sequence 5. Characterised by subparallel dipping reflections, and with an associated magnetic signature more subdued than that of sequence 6, sequence 5 consists of eroded blocks of pre-rift sedimentary rocks of pre-Maastrichtian age.

Sequence 4A. A basin/graben-fill sequence on the margins of Lord Howe Rise, sequence 4A is characterised by low-amplitude/subparallel events at depth (?seismic penetration), which pass upwards into higher amplitude showing onlap at basin margins. The depositional environments in marginal grabens may have been largely alluvial fans.

Sequence 4B. A graben-fill sequence on Lord Howe Rise proper, sequence 4B is composed of relatively high-amplitude, parallel events, similar to those associated with deltaic and paludal rift-fill within southern margin basins.

Sequence 3. Consisting of subparallel to divergent high-amplitude reflectors, which onlap the Maastrichtian unconformity (tied to DSDP 207), sequence 3 shows evidence of progradation near the margin of Lord Howe Rise and grades into a less orderly deposit with cut-and-fill structures. The sequence is considered to represent the post-breakup marine transgression (Tasman Basin spreading), and includes both shelf and slope facies.

Sequence 2. This sequence, which is more than 600 m thick on the flanks of Lord Howe Rise, is characterised mainly by chaotic reflection events, showing mounds and cut-and-fill structures. Near the crust of the rise it passes laterally into progressively more ordered, higher-amplitude events. A tie to DSDP site 207 via the 1979 Sonne profiles indicates that sequence 2 consists of early Miocene pelagic sediment; however, this interpretation is not consistent with its reflection character and thickness variation. Rig Seismic lines 8 and 10 indicate that this sequence is probably composed of coalescing turbidite fans on the flanks of Lord Howe Rise, which pass laterally into slope and shelf facies above the area of planate basement.

Sequence 1. The uppermost sequence is partly obscured by the airgun pulse. It exhibits parallel, low-amplitude reflectors, which in places downlap onto a mid-Miocene unconformity. It correlates with the pelagic oozes intersected in DSDP Sites 207 and 208.

Structure

The structure of the survey area appears dominated by horsts and grabens, although some highs may have a volcanic origin. Pelagic sedimentation over rifted and possible volcanic features has resulted in a relatively strong correlation between structure and seafloor morphology. The timing of rifting is inferred as Cretacous or earlier, by reference to DSDP hole 207, which drilled Maastrichtian shallow marine sediments under pelagic material, suggesting that at that time the area could have been passing from uplifted rift-associated sedimentation into marine and then deep marine sedimentation, as the Lord Howe Rise moved to its present position. Volcanism could have been associated with extensional fault zones.

Rift sub-basins in the area appear to be relatively narrow, often the order of 20 km wide. They appear to contain 2-3 km of discernible sediment and are often separated by basement highs overlain by about 1 km of sediment. Some of the sub-basins coalesce to form basins in the order of 50 km wide between morphological highs. Preliminary examination of the data indicates that the principal structures trend north-northwest.

Faults in the basin are normal in character with some antithetic faults. Some minor extension of these faults into the pre-Cretaceous overlying strata may be the result either of later re-activation or differential subsidence over highs.

The age of strata underlying highs in the centre of the basin and on its margins is not known. In some instances the high amplitude and chaotic character of the unmigrated data are consistent with a volcanic origin. However, drape onto the edges of these features implies volcanic extrusions rather than sills, which could mask a deeper sedimentary section. In other instances the data are characterless, indicating possible continental basement. Sills can be seen, however, and are associated with fault zones. Their seismic character has high amplitude and end diffractions.

Apparent sediment dumps can be seen downthrown to large basin-margin faults at the base of what appears to be an intra-rift sediment column. They occur in a zone of little seismic character, underlying a core of higher-amplitude, more-continuous reflections, truncated, sometimes strongly, at the interpreted breakup unconformity. These dumps may have been deposited on the pre-rift surface as the first stage of intra-rift sedimentation. If this is the case, their relatively shallow burial, owing to the lack of post-Cretaceous clastic sedimentation, may render them of interest for petroleum exploration. Their equivalents in basins on the originally attached continental margin, on the other hand, may well occur at depths too great for exploration drilling.

These preliminary remarks need to be tested by the mapping of available data to examine the features in plan view. This should be possible, since the data collected on this cruise and the planned Sonne survey, together, with pre-existing data, provide a seismic data grid of about 20 x 40 km.

SYSTEMS RESULTS

Seismic system

Acceptance testing of seismic amplifiers. The new 48-channel amplifiers initially showed higher noise levels than would normally be expected. Much of the internal noise appeared to originate in the power supply. After modification of this, noise levels of 5 micro-volts equivalent at the input were achieved; this is considered marginally acceptable. These levels should be further reduced by the construction of a more robust power supply.

High-level interference at around 230 kHz was traced to cross-feed between the depth transducer circuits and the amplifiers. Scrupulous cleaning of the seismic cable connections and improved termination of the wires in the back plane of the amplifiers have largely eliminated this problem.

Acceptance testing is still continuing. The inability to reduce or remove DC offsets from the input signal is cause for some concern. A reduction in internal noise to around 1 micro-volt is highly desirable.

Cable depth measurement, control, and display. Monitoring of cable depth is an important step in control of seismic data quality. The BMR-designed depth monitoring system forms part of the amplifier system and needs to be expanded to at least 9 channels to allow all depth detectors to be accessed.

Direct control of the cable depth is now feasible using Syntron individually programmable depth controllers. However, it has been found necessary to set the controllers to run 5 m deeper than the required depth to obtain adequate performance.

Cable geometry is now displayed on a colour monitor, giving a graphic picture of depth along the cable. This has been a major aid in assuring that the cable is kept at approximately 10 m depth.

Despite these tools, difficulty was experienced in keeping the cable at the appropriate depth with a following sea.

Air-gun control. It is planned that a multi-gun array will be used for the seismic energy source within the next year. As a start, a two-gun system was successfully synchronised and monitored by means of:

(i) A gun-mounted shot sensor to detect shuttle movement;
(ii) A source signature hydrophone on the air-gun bridle to measure the air-gun signature;
(iii) A depth sensor, also mounted on the air-gun bridle.

The shuttle was found to move within 2-3 ms of the shot-firing pulse, while the main release of air occurred about 16 ms after shot instant. A variation of around 1 ms was noted, and is thought to be primarily a result of air-gun depth variation caused by swell.

Seismic monitor display. Two MX-100 printers operating in bit-graphics mode are used to give standard and compressed monitor sections. A cyclic display of all channels for data quality verification is provided on another printer. A fourth monitor will be introduced to give a hard-copy section for immediate on-board use and interpretation.

The software driving the monitors was upgraded to display either 1500 or 3000 data values, corresponding to 3 and 6 s of section, respectively, for data sampled at 2-ms intervals. Heavy 1 s timing lines have also been added to allow easier time-depth identification. A facility to permit variable time display has been built into the software for optimum record quality.

Computer system performance. System crashes plagued the computers for several weeks. A major overhaul by Hewlett Packard improved reliability, but stoppages prior to departure still occurred more frequently than should be expected. During the cruise, halts caused by spurious interrupts were largely eliminated by the use of a terminator card in the I/O Extender. Spurious formatter calls have never been specifically traced, but appear to have been eradicated by replacing all the I/O drivers.

A problem still exists with the extra time taken to write headers at the beginning of each magnetic tape. This occasionally delays processing sufficiently to cause overrun into the next shot interval, resulting in a program crash.

Observer training. All scientific staff on board received training in the use of the seismic acquisition system. While more training is needed, people should be proficient enough to operate the system as long as a technical expert is on call.

Improvements noted above should reduce the number of unpredictable failures to a level at which a moderately trained observer can cope.

Non-seismic data acquisition system

Computer system. The data acquisition system is based on a Hewlett Packard E-series computer fitted with an I/O extender to increase its interfacing capacity. As the collection and processing of data consume a small proportion of the computer's time, provision has been made to allow other users to utilise the free time for the purposes of system development, word processing, and quality control of the navigation data. This time-sharing system has operated very well, the only problem being an occasional loss of data during the acquisition of the satellite navigator data by the computer. This problem will be removed when navigation is performed solely by the computer and the satellite navigator is used only for updating positions after successful satellite fixes.

Navigation system. The primary navigation system is a Magnavox MX1107RS dual-channel satellite, obtaining its velocity from a dual-axis Magnavox 610D sonar doppler and its heading from an Arma-Brown gyrocompass. The secondary system is a Magnavox MX1142 single-channel satellite navigator coupled to a dual-axis Raytheon DSN-450 sonar doppler and a Robertson gyrocompass. Both sonar-doppler systems were found to suffer from a loss of track during only moderately rough seas. It was also noted that head seas led to a more degraded performance than did following seas, a possible reason being aeration under the ship's hull. Manually setting the depth from which the Magnavox sonar doppler received its water mass echo improved reliability of the velocity reading under poor conditions. This system was also adversely affected by the 3.5 kHz echo sounder, which tended to cause a suppression of the return signal of the Magnavox.

Echo sounders. Problems with the 3.5 kHz echo sounder were encountered for most of the cruise. This has been a problem for some time and has yet to be resolved. Aside from the interference to the sonar doppler, the 3.5 kHz echo sounder could not be made to track successfully at depths below about 3000 m for any length of time. The 12 kHz sounder gave consistent results down to 5000 m for most of the cruise, and, accordingly, was used as the primary depth source.

Magnetometers. Magnetic data were collected for most of the cruise by two magnetometers configured as a gradiometer. The system recorded good data with the only problem arising from interference between the two recorders during their polarisation periods. This was overcome by staggering the polarisation period of each recorder thereby removing the overlap.

CONCLUSIONS

The Lord Howe Rise cruise of the Rig Seismic was successful in meeting its primary objectives of research into basin configuration and petroleum potential. Specifically:

* About 1250 km of good quality seismic and magnetic data were acquired over the western flank of the Lord Howe Rise. Noise levels and the depth of penetration on monitor records are as good as or better than for previous surveys.

* Seismic sequences and facies are relatively easy to identify, and indicate the steady subsidence of Lord Howe Rise from emergent or shallow marine in the Maastrichtian to bathyal in the Eocene/Oligocene. Rift-fill, shelf, slope, turbidite, and pelagic facies appear to be present.

* The western flank of Lord Howe Rise appears to be underlain by a fairly extensive sedimentary basin with up to 3000 m of discernible section. Many of the fault blocks previously thought to be basement are probably composed of sedimentary rocks and could be prospective.

* The basin margin configuration appears to be zig-zag, and intra-basinal structural trends appear to be north-northwesterly.

* Problems in the satellite navigation and sonar doppler systems need attention.

* Bathymetic data collection is at present inadequate for sampling surveys, and more cruise time is needed to improve the echo sounding systems.

REFERENCES

BENTZ, F.P., 1974 - Marine geology of the southern Lord Howe Rise, Southwest Pacific. In BURK, C.A., & DRAKE, C.L. (Editors). THE GEOLOGY OF CONTINENTAL MARGINS. Springer-Verlag, New York, 537-47.

BURNS, R.E., ANDREWS, J.E., & others, 1973 - Initial reports of the Deep Sea Drilling Project, Volume 21. U.S. Government Printing Office, Washington.

DOOLEY, J.C., 1963 - Results of southwest Pacific submarine gravity survey 1956. Bureau of Mineral Resources, Australia, Record 1963/43.

DOW, W.G., 1979 - Petroleum source beds on continental slopes and rises. In WATKINS, J.S., MONTADERT, L., & DICKERSON, P.W. (Editors), GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS OF CONTINENTAL MARGINS. American Association of Petroleum Geologists Memoir, 29, 432-42.

FALVEY, D.A., 1974 - The development of continental margins in plate tectonics theory. The APEA Journal, 14(2), 95-106.

FRASER, A.R., & TILBURY, L.A., 1979 - Structure and stratigraphy of the Ceduna Terrace region, Great Australian Bight Basin. The APEA Journal, 91(1), 53-65.

GAME, P.M., 1970 - Petrology of Lord Howe Island, Part 1: the younger volcanics. Bulletin of the British Museum (Natural History) Mineralogy, 2, 223-84.

GEZE, B., 1963 - Observation tectoniques dans le Pacifique (Hawaii, Tahiti, Nouvelles-Hebrides). Bulletin of the Geological Society of France, 7, 154-64.
GRIM, P.J., 1969 - Heat flow measurements in the Tasman Sea. Journal of Geophysical Research, 74, 3933.
HARWOOD, R.J., 1977 - Oil and gas generation in laboratory pyrolysis of kerogen. AAPG Bulletin, 61, 2082-102.
HAYES, D.E., & Ringis, J., 1973 - Sea floor spreading in the Tasman Sea. Nature, 243, 454-8.
HEDBERG, H.D., MOODY, J.D., & HEDBERG, R.M., 1979 - Petroleum prospects of the deep offshore. AAPG Bulletin, 63(1), 286-300.
JONGSMA, D., 1976 - A review of marine geophysical investigations over the Lord Howe Rise and Norfold Ridge. Bureau of Mineral Resources, Australia, Record 1976/12.
JONGSMA, D., & MUTTER, J.C., 1978 - Non-axial breaching of a rift valley: evidence from the Lord Howe Rise and the southeastern Australia margin. Earth and Planetary Science Letters, 39, 226-34.
JONES, J.G., & VEEVERS, J.J., 1983 - Mesozoic origins and antecedents of Australia's eastern highlands. Journal of the Geological Society of Australia, 30, 305-322.
KARIG, D.E., 1971 - Origin and development of marginal basins in the western Pacific. Journal of Geophysical Research, 76, 2542-61.
KLEMME, H.D., 1975 - Geothermal gradients, heat flow, and hydrocarbon recovery. In FISCHER, A.G., & JUDSON, S. (Editors), PETROLEUM AND GLOBAL TECTONICS. Princeton Press, Princeton, New Jersey.
KROENKE, L.W., 1984 - Cainozoic tectonic development of the southwest Pacific. CCOP/SOPAC Technical Bulletin No. 6.
LABRECQUE, J.L., KENT, D.V., & CANDE, S.C., 1977 - Revised magnetic polarity time scale for Late Cretaceous and Cenozoic time. Geology, 5, 330-5.
LAUNAY, J., DUPONT, J., LAPOUILLE, A., RAVENNE, C., & DE BROIN, C.E., 1977 - Seismic traverses across the northern Lord Howe Rise and comparison with the southern part (South-west Pacific). In Symposium on International Geodynamics in Southwest Pacific. Noumea, New Caledonia, 27 August-2 September 1976. Editions Technip, Paris, 155-163.
McDOUGALL, I., & VAN DER LINGEN, G.J., 1974 - Age of the rhyolites on the Lord Howe Rise and the evolution of the southwest Pacific Ocean. Earth and Planetary Science Letters, 21, 117-26.
MUTTER, J.C., & JONGSMA, D., 1978 - The pattern of the pre-Tasman Sea rift system and the geometry of breakup. Australian Society of Exploration Geophysicists Bulletin, 9, 70-5.
OFFICER, C.B., - Southwest Pacific crustal structures. Transactions of the American Geophysical Union, 33, 499.
PACKHAM, G.H., & FALVEY, D.A., 1971 - A hypothesis for the formation of marginal seas in the western Pacific. Tectonophysics, 11, 79-109.
RINGIS, J., 1972 - The structure and history of the Tasman Sea and the southeast Australian margin. Ph.D Thesis, University of New South Wales
SHAW, R.D., 1978 - Sea floor spreading in the Tasman Sea: a Lord Howe Rise-eastern Australian reconstruction. Australian Society of Exploration Geophysicists Bulletin. 9, 75-81.
SHOR, G.G., KIRK, H.K., & MENARD, G.L., 1971 - Crustal structure of the Melanesian area. Journal of Geophysical Research, 76, 2562-86.
SYMONDS, P.A., 1984 - Geology and hydrocarbon potential of Australia's legal continental shelf beyond the Exclusive Economic Zone. Geological Society of Australia, Abstracts, 12, 506-608.

SYMONDS, P.A., & WILLCOX, J.B., in prep. - Potential hydrocarbon resources of Australia's 'legal continental shelf beyond the EEZ'.

THRELFALL, W.F., BROWN, B.R., & GRIFFITH, B.R., 1976 - Gippsland Basin, offshore. In LESLIE, R.E., EVANS, H.J., & KNIGHT, C.L. (Editors), ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA, 3 - PETROLEUM Australasian Institute of Mining and Metallurgy, Monograph 7, 41-66.

VAN DER LINGEN, G.J., 1973 - The Lord Howe Rise rhyolites. In BURNS, R.E., ANDREWS, J.E., & others - Initial Reports of the Deep Sea Drilling Project, Volume 21. U.S. Government Printing Office, Washington, 523-39.

WEISSEL, J.K., & HAYES, D.E., 1972 - Magnetic anomalies in the southeast Indian Ocean. In HAYES, D.E. (Editor), ANTARCTIC OCEANOLOGY II, THE AUSTRALIAN NEW ZEALAND SECTOR. Antarctic Research Series, American Geophysical Union, 19, 165-96.

WEISSEL, J.K., & HAYES, D.E., 1977 - Evolution of the Tasman Sea reappraised. Earth and Planetary Science Letters, 36, 77-84.

WILLCOX, J.B., 1981 - Petroleum prospectivity of the Australian marginal plateaus. Energy Resources of the Pacific Region. AAPG Studies in Geology, 12, 245-272.

WILLCOX, J.B., SYMONDS, P.A., HINZ, K., & BENNETT, D., 1980 - Lord Howe Rise, Tasman Sea - preliminary geophysical results and petroleum prospects. BMR Journal Australian Geology & Geophysics, 5, 225-236.

WILLCOX, J.B., SYMONDS, P.A., BENNETT, D., & HINZ, K., 1981 - Lord Howe Rise offshore Australia - some preliminary results of a co-operative BGR/BMR survey with R/V 'Sonne'. Bureau of Mineral Resources, Australia, Report 228.

WILLCOX, J.B., 1984 - Deepwater Gippsland Basin. Geological Society of Australia, Abstracts, 12, 551.

WOODWARD, D.J., & HUNT, T.M., 1971 - Crustal structures across the Tasman Sea. New Zealand Journal of Geology and Geophysics, 14, 39-45.

Table 1. Lord Howe Rise plan Rig Seismic cruise

Weigh points	Approx. speed* (kn)	Distance (n mile/km)	Duration (h)	Heading	Comment
Sydney Heads	118	350 (640)	30	090°	Line 1- Mag.only
158°52'E 33°45'S	2	15 (27)	8	090°	Line 2 - Deploy seismic
158°42'E 33°45'S	5	50 (92)	10	090°	Line 3 - Seismic run-in
159°40'E 33°45'S	5	200 (366)	40	052°	Line 4 - 24-fold mag.
162°50'E 31°40'S	5	18 (33)	4	142°	Line 5 - 24-fold mag.
163°04'E 31°54'S	5	170 (311)	34	232°	Line 6 - 24-fold mag.
160°14'E 33°45'S	5	15 (27)	3	142°	Line 7 - 24-fol mag.
160°26'E 33°56'S	5.5	90 (165)	16	052°	Line 8 - 24-fold mag.
161°56'E 33°00'S	5.5	22 (40)	4	142°	Line 9 - 24-fold mag.
162°10'E 33°17'S	5.5	98 (180)	18	232°	Line 10 - Testing 600 m cable
160°43'E 34°11'S	11.8	420 (770)	36	270°	Line 11/12 - mag. only
152°00'E 34°11'S	11.8	50 (92)	4	300°	
Sydney Heads					

* Ship's speed was generally somewhat higher than stated.

APPENDIX 1. Summary of previous surveys over Lord Howe Rise and Norfolk Ridge (after Jongsma)

Vessel	Cruise	Date	Seismic	Gravity	Magnetics	Miscellaneous
ARGO	NOVA	1967	Air gun	Yes	Yes	Refraction
BERGALL ISLAND (Deep Freeze)		1949	No	Pendulum	No	
CHALLENGER		1951	No	No	No	Refraction
CONRAD	C9	1964	Explosive	Yes	Yes	
CORIOLIS	C1	1971	Air gun	No	Yes	
"	C2	1971	Air gun	No	Yes	
"	AUSTRADEC 1	1972	Flexichoc	No	Yes	
"	AUSTRADEC 2	1973	Flexichoc	No	Yes	
ELTANIN	ELT 26	1966	Air gun	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 & Air-gun	Yes	Yes	Sonobuoys
GLOMAR CHALLENGER	DSDP 21	1971/72	Air gun	No	No	Sonobuoys Drilling
"	DSDP 29	1973	Air gun	No	No	Sonobuoys Drilling
HORIZON	NOVA	1967	Sparker	Yes	Yes	Refraction
KANA KEOKI		1971	Air gun Sparker	Yes	Yes	
KIMBLA	K3	1971	Air gun	No	Yes	
	K4	1971	Air gun	No	Yes	
LADY CHRISTINE	BMR 14/3	1971	Sparker	Yes	Yes	Sonobuoys
OCEANOGRAPHER		1967	No	Yes	Yes	
STRATEN 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	
SONNE	SO-7A	1979	Air-gun/ Array	Yes	Yes	Sonobuoys

APPENDIX 2. Seismic system

<u>Energy Source</u>

Air-guns 2 of 8.2 litre each (500 cu. in.)
30 m behind stern
4-6 m deep,
4286 kP pressure (2000 p.s.i.)

<u>Amplifiers</u>

Input digital controlled
Low cut 12 Hz (36 dB/octave)
High cut 256 Hz (72 dB/octave)

<u>Monitors</u>

a) TAXAN COLOUR -
System in use volume
Shot number
Shots on current tape
Cable depth plot
Cable depth at sensors
b) STORAGE CRO 611 -
Sequential display channels 1 - 48
Record length 2 s below delay
c) STORAGE CRO -
Water bottom return shape was 200 ms
d) 10 MHz CRO -
48 channel instantaneous
input channels
e) 505A CRO
Instantaneous analog
display of the depth
transducers

<u>Cable</u>

2500 metre teledyne
48 group
Offset behind stern with
220 m to first group, 10 m
deep.

<u>Recorders</u>

Magnetic tape drive
1600 b.p.i.
SEG Y format
8 s recorded length
2 ms sample rate

<u>Paper displays</u>

a) FAST -
37 cm/hr horizontal scale
3 seconds @ 10.5 cm/s on
vertical scale
6 seconds @ 5.25 cm/s on
day 037
b) SLOW -
8 cm/hr horizontal scale;
10.5 cm/s vertical scale.
c) CYCLING -
17 cm/hr horizontal scale;
sequential display, one
per shot, 1 to 48 traces;
10.5 cm/s vertical scale.
d) LINE PRINTER -
Cable depths every shot
Average & RMS signal level
in mV every 10th shot
e) OPERATOR LISTING -
Intervention parameters;
tape change data.

Notes:

Channel 29 dead, channels 10 and 26 have D.C. shift,
Satellite antenna to stern of ship is 36 metres.

APPENDIX 3. Data acquisition system

Input Units

MX 1107 Satellite
Varian Magnetometer 1
Varian Magnetometer 2
12 Hz Echo Sounder
Sonar Doppler - log unit
Brown Gyro
Clock 1
Clock 2
3.5 kHz sub-bottom profiler

Displays

Taxan colour:
Dead reckon position
Messages for bridge

CRO

Recorders

Tape 1 1600 b.p.i.
Tape 2 1600 b.p.i.
Tape 3 Facit Cassette
Tape 4 Facit Cassette

Monitors

DAC - 1:
d latitude
d longitude
heading
speed
course

DAC - 2:
Mag 1
Mag 2
AGRF - Mag 1 (anomaly)
AGRF - Mag 2 (anomaly)
Bathymetry (12kHz)

Storage CRO:
displays sonar-doppler
bottom & gate pulse

10 mHz CRO:
displays magnetometer
return signal

E.P.C. Recorder (x4):
1. Displays 3.5 kHz sub-bottom profile
2. (+ 2 repeaters) displays 12 kHz echo sounder

APPENDIX 4. Cruise work shifts

First shift

0000 - 0300 1300 - 1800	Steve SCHERL Rod McMAHON Ray TRACEY Jim BEDFORD John BRANSON Hugh DAVIES

Second shift

0300 - 0800 1800 - 2100	Norm JOHNSTON Roger CURTIS-NUTHALL John MOWAT Jenny STUART Paul WILLIAMSON David FEARY

Third shift

0800 - 1300 2100 - 2400	Lindsay MILLER John STRATTON Maureen O'CONNOR Ed CHUDYK Barry WILLCOX Peter DAVIES

Daylight hours

	Craig PENNY Roy WHITWORTH Peter WALKER

APPENDIX 5. Data lists

During the Lord Howe Rise cruise, the following data outputs were collected:

(1) Navigation
- (a) Operators teletype listing
- (b) Log listing
- (c) W & W recorder strip charts
- (d) Magnetic tapes (1 per day)
- (e) EPC charts

(2) Seismic acquisition system
- (a) Operators teletype listing
- (b) Seismic monitor records
  - fast single channel
  - slow single channel
  - cycling channel
- (c) Shot listing
- (d) Magnetic tapes (1 per 26 mins approx.)

APPENDIX 6. Allocation of data channels

The following list gives the data allocation for this cruise. Data are stored on magnetic tape in 450 real word blocks (30 x 15), each block spanning 2.5 minutes of processed data.

1. Clock (Survey and Day Number)
2. Acquisition time (GMT) from computer clock
3. Master clock time at acquisition
4. Latitude (radians)
5. Longitude (radians)
6. Speed (best current estimate)
7. Heading (best current estimate)
8. GMT from Magnavox 1107 sat nav
9. Dead Reckoned Time from 1107
10. Latitude (degrees) 1107
11. Longitude (degrees) 1107
12. Speed (knots) 1107
13. Heading (degrees) 1107
14. Set (degrees) 1107
15. Drift (knots) 1107
16. Set/Drift flag, 0=manual, 1=auto
17. Magnetometer no. 1
18. Magnetometer no. 2
19. Depth no. 1
20. Depth no. 2
21. Log reading from Magnavox sonar doppler (1 pulse = 0.463 m)
22. Not utilised
23. " "
24. " "
25. " "
26. " "
27. " "
28. " "
29. AGRF magnetic anomaly no. 1
30. AGRF magnetic anomaly no. 2

APPENDIX 7. Line numbers and times

Line	From	To (Time)	Data collected
46/001	034.0400	035.1030	Magnetics and depth
46/002	035.1030	035.1606	Deploy seismic
46/003	035.1600	036.0240	Seismic (W-E)
46/004	036.0240	037.1340	" (SW-NE)
46/005	037.1340	037.1705	
46/006	037.1705	039.0325	" (NE-SW)
46/007	039.0325	039.0540	
46/008	039.0540	039.1910	" (SW-NE)
46/009	039.1910	039.2250	
46/010	039.2250	040.1710	" (NE-SW)
46/011	040.1710	041.0830	Seismic tests
46/012	041.0830	042.0400	Magnetics and depth

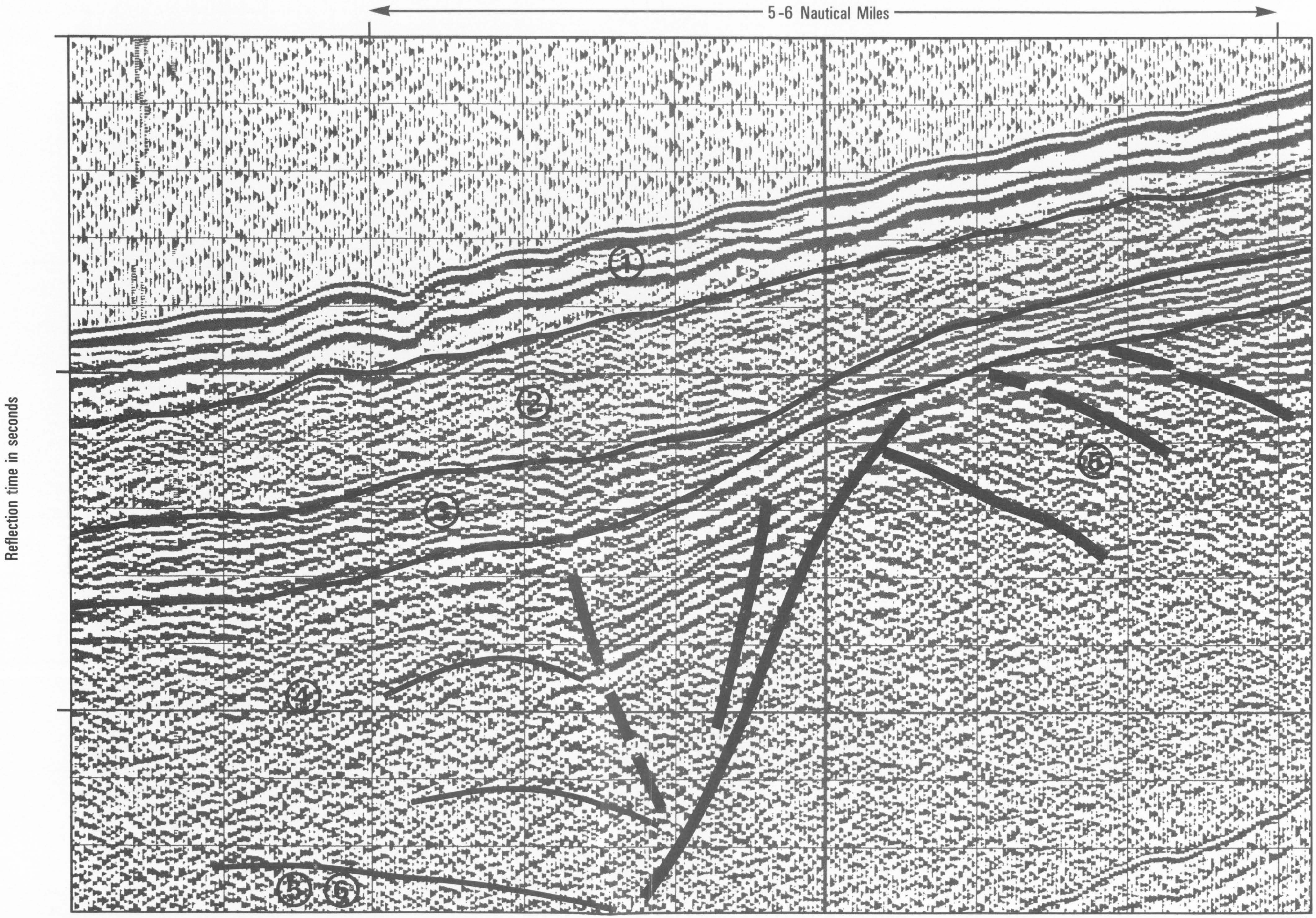


Figure 17. Seismic sequences 1 - 6 on seismic monitor record over western flank of Lord Howe Rise.

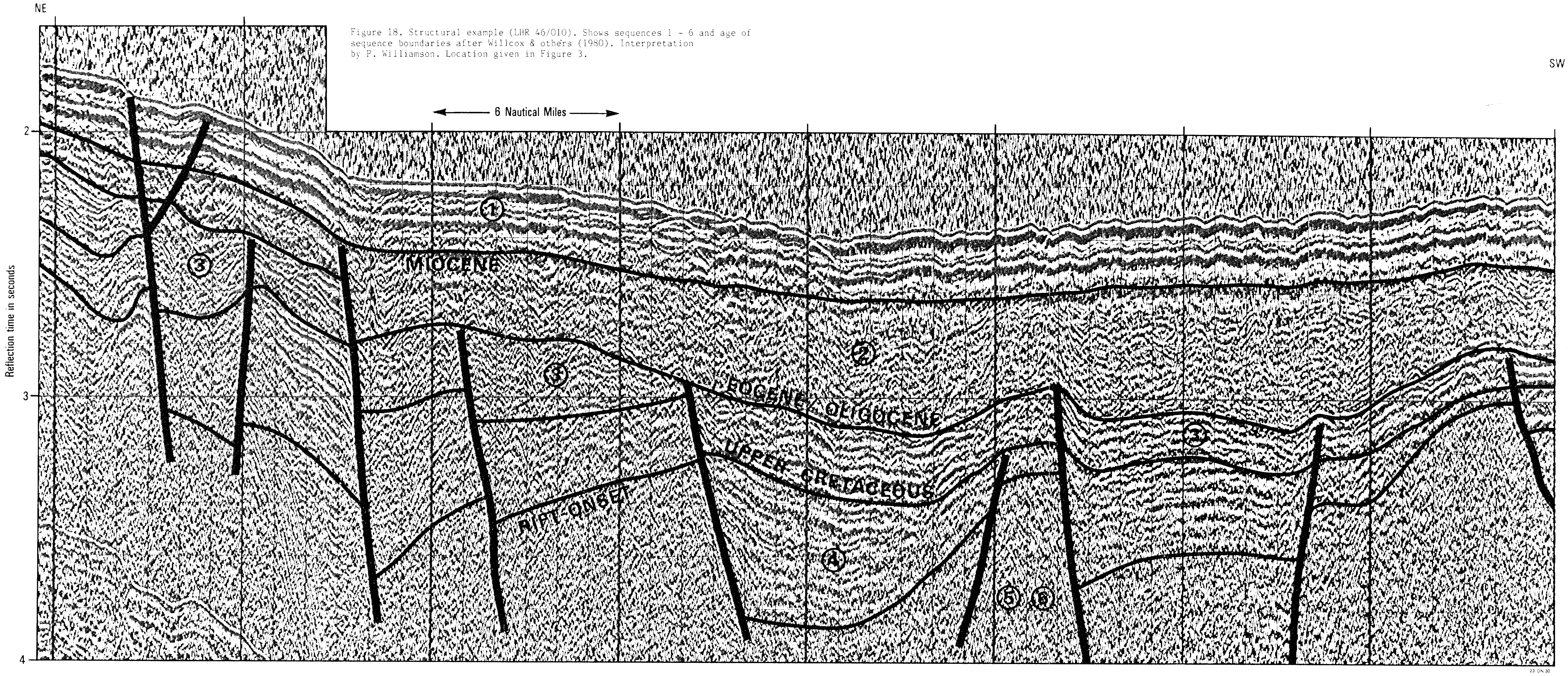


Figure 18. Structural example (LHR 46/010). Shows sequences 1 - 6 and age of sequence boundaries after Willcox & others (1980). Interpretation by P. Williamson. Location given in Figure 3.

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