AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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GEOLOGICAL FRAMEWORK OF THE SOUTHERN LORD HOWE RISE/WEST NORFOLK RIDGE REGION

CRUISE PROPOSAL

by

P. A. Symonds and J. B. Colwell

Project 121.30

Marine Geoscience and Petroleum Geology Program

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Australian Geological Survey Organisation

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: The Hon. Alan Griffiths
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EXECUTIVE SUMMARY

The Lord Howe Rise region is an enormous area of complex seabed lying 500-1500 km east of Australia. It includes relatively shallow water features such as the Lord Howe Rise, and the Norfolk, West Norfolk and Dampier Ridges, and intervening deeper water areas such as the Lord Howe, Middleton and New Caledonia Basins. Based upon the UN Law of the Sea Convention, Australia has a large seabed claim in this region because of Lord Howe, Norfolk and Philip Islands, which are Australian territory and would all generate 200 nautical mile Exclusive Economic Zones and related 'legal' Continental Shelf areas. There is a negotiated seabed boundary in the north separating French and Australian territory, but as yet there is no negotiated seabed boundary separating New Zealand and Australian territory in the south.

Owing to its vast size, many features within the Lord Howe Rise region remain sparsely covered by seismic data. Analysis of available data has defined several areas that may have long-term petroleum potential. The most significant of these are the rift system beneath the western Lord Howe Rise, the New Caledonia basin and the Taranui Sea Valley area of the southern Norfolk Ridge.

The Australian Geological Survey Organisation (AGSO - formerly the Bureau of Mineral Resources, BMR) Project 121.30 (Lord Howe Rise and Norfolk Ridge 'Law of Sea' Study) seeks to improve our understanding of the geological framework of the southern part of the Lord Howe Rise region in the vicinity of the Australia/New Zealand seabed boundary zone. Its major objectives are:

- To investigate the structure, stratigraphy and basin development of the southern Lord Howe Rise, southern New Caledonia Basin, and West Norfolk Ridge in the Australia/New Zealand seabed boundary zone.
- To assess the resource potential of the major structural features within the region.
- To determine the tectonic framework, crustal characteristics and evolution of the region, and attempt to understand the processes that have produced narrow strips of thinned and extended continental lithosphere ("ribbon continents"), separated by narrow ocean basins.
- To acquire data to assist with the definition of Australia's 'legal' Continental Shelf on the southwestern margin of Lord Howe Rise.

To address these objectives it is proposed that RV *Rig Seismic* be used to acquire approximately 3250 km of multichannel seismic and associated geophysical data, and conduct dredging operations, during a cruise in the southern Lord Howe Rise/West Norfolk Ridge region (Survey 114). The seismic data will be recorded on eight lines (including four very long regional lines) using a 3000 m streamer (120 x 25 m groups), 49 litre sleeve gun arrays, 16 second records, and 30-fold coverage. Four main elements are proposed for the program, as follows:

1. **Western Lord Howe Rise rift system:** Four dip-line segments and one strike-line over the complex zone of fault blocks and grabens/half grabens beneath the western Lord Howe Rise. The strike-line will attempt to cross the dip-lines in the area of thickest section to the west of the planated basement high, and will tie to Deep Sea Drilling Project (DSDP) Site 207 at its southeastern end.

2. **Lord Howe Rise/West Norfolk Ridge transect:** Two very long (about 1000 and 800 km) lines across the whole province from the Tasman Basin in the southwest to the South Norfolk Basin in the northeast.

3. **Southwest margin of Lord Howe Rise:** Two segments of line cross the southwest flank of Lord Howe Rise to acquire data necessary for definition of a 'legal' continental shelf.

4. **Lord Howe Rise/West Norfolk Ridge sampling:** Two areas where it may be possible to sample basement by dredging have been identified on the present data on the western margin of both Lord Howe Rise and the West Norfolk Ridge. It is likely that other sites will also be located on the lines proposed here.

The program proposed here assumes a 28 day cruise. It is recognised that the 3247 km of deep seismic data planned is considerably more than is normally acquired on AGSO's petroleum basin studies. However, it is expected that with careful scheduling of seismic equipment maintenance, particularly the sleeve gun arrays, and the use of quality control guide-lines appropriate to a regional framework study, it should be possible to complete the program. Clearly, extended periods of adverse weather conditions or serious equipment problems will require adjustment of the cruise plan.

The RV *Rig Seismic* cruise proposed has been developed in consultation with the Sea Law and Ocean Policy Group of the Department of Foreign Affairs and Trade; the Petroleum Division and Offshore Minerals & Policy Co-ordination Group of the Department of Primary Industries and Energy; and the New Zealand Institute of Geological & Nuclear Sciences Limited, and with approval from the New Zealand Ministry of External Relations and Trade. The project will be carried out in collaboration with New Zealand scientists from the Institute of Geological & Nuclear Sciences.

INTRODUCTION

The Lord Howe Rise region is an enormous area of complex seabed lying 500-1500 km east of Australia, and extending over 20° of latitude (approximately 2200 km). It includes relatively shallow water elongate plateaus and ridges such as the Lord Howe Rise, and the Norfolk, West Norfolk and Dampier Ridges, and intervening deeper water basins such as the Lord Howe, Middleton and New Caledonia Basins (Figs 1 and 2). The region is bounded in the west by the Tasman Basin and in the east by the North and South Norfolk Basins. Under the terms of the United Nations Law of the Sea Convention, Australia has a large seabed claim in this region because of its territorial ownership of Lord Howe Island, on the western Lord Howe Rise, and Norfolk and Philip Islands, on the Norfolk Ridge. Each of these islands would generate a 200 nautical mile Exclusive Economic Zone and related 'legal' Continental Shelf. There is a negotiated seabed boundary in the northern part of the region separating French and Australian territory, but as yet there is no negotiated seabed boundary separating New Zealand and Australian territory in the south. The total area of Australia's 'legal' Continental Shelf in the Lord Howe Rise region would be about 1.65 million km^2 - about 20% of the area of the Australian land mass.

Although many line kilometres of seismic data have been collected throughout the Lord Howe Rise region, because of its vast size, coverage of most features remains sparse. Much of the seismic data was shot in the 1970's and is only of poor to fair quality. A summary of pre-1985 surveys in the region is given in Appendix 1. The most recent data sets were recorded in 1985 and 1989. In 1985 AGSO's R V *Rig Seismic* acquired 1250 km of 24 fold multichannel seismic data over the western Lord Howe Rise to the south of Lord Howe Island (Whitworth, Willcox & others, 1985; Fig. 1). These data were recorded using a 2400 m streamer with 48 channels and two 500 cubic inch airguns. In 1985 Germany's Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) in co-operation with AGSO used the R V *Sonne* to undertake a survey of the western Lord Howe Rise to the northeast of Lord Howe Island (Roeser & Shipboard Party, 1985; Fig. 1). This survey collected 3600 km of 24 fold multichannel seismic data using a 2400 m streamer with 48 channels, and a 25.6 litre airgun array. In 1989 the Geophysics Division, Department of Scientific and Industrial Research, New Zealand, shot a grid of 1700 km of single-channel, digitally recorded seismic data over the southernmost part of the New Caledonia Basin (Uruski & Wood, 1991).

Analysis of these data has defined several areas that may have long-term petroleum potential. The most significant areas are the rift system beneath the western Lord Howe Rise, the New Caledonia basin and the Taranui Sea Valley area of the southern Norfolk Ridge. The eastern flank of Lord Howe Rise and the western flank of the West Norfolk Ridge are also considered to have some petroleum potential.

As part of the Australian Government's Continental Margins Program, the Australian Geological Survey Organisation (AGSO - formerly the Bureau of Mineral Resources, BMR) seeks to improve the understanding of the geological framework of the southern part of the Lord Howe Rise region. The RV *Rig Seismic* cruise proposed here (AGSO Survey 114) will complement earlier work by focussing on the southern part of the region, and tying back into data sets collected over the more intensively studied central Lord Howe Rise area around Lord Howe Island. Specifically, it will tie into 1972 Mobil (*Fred Moore*), 1979 BGR/AGSO (*Sonne*), 1985 AGSO (*Rig Seismic*) and 1985 BGR/AGSO (*Sonne*) seismic data, as well as DSDP Site 207 and possibly Site 592. The proposed work is the data acquisition part of AGSO Project 121.30 (Lord Howe Rise and Norfolk Ridge 'Law of Sea' study) and has three major aims: to investigate the structure, stratigraphy, basin development and resource potential of major features within the southern Lord Howe Rise / West Norfolk Ridge region in the vicinity of the yet-to-be-negotiated Australia/New Zealand seabed boundary; to help understand the tectonic framework, crustal characteristics and evolution of the region; and to acquire data to assist with the definition of Australia's 'legal' Continental Shelf on the southwestern margin of Lord Howe Rise.

GEOLOGICAL BACKGROUND

Much of the following discussion on the geological background of the region is taken from Willcox & others (1980) and Symonds & Willcox (1989).

REGIONAL PHYSIOGRAPHY

The major submarine feature in the region, the Lord Howe Rise (Figs 1 and 2), extends north-northwest from the south island of New Zealand to Lord Howe Island and then north to the Chesterfield Island group at about 20°S. Lord Howe Rise is a plateau-like feature, which is most clearly defined by the 2000 m isobath - the crest of the rise is generally 750 to 1200 m below sea level. The small Middleton and Lord Howe Basins separate the northern Lord Howe Rise from the Dampier Ridge to the west. Beyond this, the 4500 m deep Tasman Basin extends to the narrow continental margin of eastern Australia. Lord Howe Rise is separated from the Norfolk Ridge to the east by the 3000-3500 m deep New Caledonia Basin. Eade (1988) divides the New Caledonia Basin into two parts - the New Caledonia Trough in the northeast and the Fairway Trough in the southwest (Fig. 2). These troughs are separated by a north-northwest-trending ridge system consisting of the Fairway Ridge in the north and an extension of the West Norfolk Ridge in the south.

The Norfolk Ridge system is a complex feature, which extends from the northern tip of New Zealand to New Caledonia (Fig. 2). The northern segment, which is north-trending, steep-sided and about 90 km wide, it is called the Norfolk Ridge. The southern, northwest-trending segment is offset to the west and forms a complex triple-ridge system about 200 km wide. The western part of the ridge complex is generally referred to as the West Norfolk Ridge, the central part as the Wanganella Ridge (Eade, 1988), and the eastern part as the Norfolk-Reinga-South Maria Ridge system (Eade, 1988). The crestal relief of the Norfolk/West Norfolk Ridge is more rugged than that of the Lord Howe Rise, and the crestal depth ranges generally from about 500 to 1500 m. The West Norfolk and Wanganella Ridges are separated by a narrow, 1500 m deep bathymetric trough, the Wanganella Trough. The Wanganella and Norfolk-Reinga-South Maria Ridges are separated by the poorly known Taranui Gap (Sea Valley), which lies on the eastern flank of the ridge system, near its point of offset, and the Reinga Basin (Eade, 1988). The 3500 m deep North Norfolk, or Kingston Basin, lies to the east of Norfolk Ridge to the northeast of Norfolk Island, and by the South Norfolk, or Norfolk Basin, to the east of the Norfolk-Reinga Ridge system.

CRUSTAL STRUCTURE AND TECTONIC EVOLUTION

Seismic refraction and gravity anomaly measurements (Officer, 1955; Dooley, 1963; Shor & others, 1971; Woodward & Hunt, 1971), and seafloor spreading magnetic anomalies (Ringis, 1972; Weissel & Hayes, 1977; Shaw, 1978), indicate that The Tasman Sea Basin is a normal oceanic basin. The crust beneath the New Caledonia, Middleton and Lord Howe Basins is commonly considered to be oceanic, though it is slightly thicker than typical oceanic crust.

Seismic refraction surveys and gravity modelling over Lord Howe Rise (Shor & others, 1971) indicate that the crust is 26 km thick and of continental origin. The rise is largely composed of crust with a P-wave velocity of 6.0 km/s, which is similar to values found for the Australian continent (Shor & others, 1971). A recent study of marine magnetic anomalies in the Lord Howe Rise region (Schreckenberger & others, 1992) provides further evidence for the continental origin of both the Rise and Dampier Ridge, and indicates strong magnetisation of the lower crust. Thus the Lord Howe Rise is a fragment of continental crust, with a velocity structure that is indistinguishable from the Australian continent. The complex nature of basement rocks beneath Lord Howe Rise, as shown by their seismic character and magnetic response, indicates that these rocks may once have formed part of the similarly complex Tasman Fold Belt of eastern Australia.

The Dampier Ridge is thought to be a continental fragment altered by rifting and igneous intrusions, and this theory seems to be confirmed by dredging carried out by R/V *Sonne* (Roeser & others, 1985), which recovered granite, microdiorite and feldspathic sandstone (Symonds & others, 1988). The Lord Howe Rise and Dampier Ridge were detached from Australia during seafloor spreading, which commenced some 80 Ma ago and formed the Tasman Basin, and possibly the Middleton and Lord Howe Basins.

There is general agreement that at least part of the Norfolk Ridge system was rifted and separated from Gondwanaland, probably during the Late Cretaceous (Willcox & others, 1980; Kroenke, 1984). However, several hypotheses have been advanced to explain the Tertiary development of New Caledonia and its marine continuation southward, the Norfolk Ridge, and the adjacent New Caledonia Basin. These include the evolution of a complex arc system (Dubois & others, 1974; Kroenke, 1984), and arc migration and marginal basin development (Karig, 1971; Packham & Falvey, 1971). The pre-Permian metamorphic and sedimentary rocks forming the core of New Caledonia were once part of the ancient Australian (Gondwanaland) continent, so it is most probable that the core of the Norfolk Ridge is also continental. Kroenke (1984) proposed that by middle Eocene time north-south convergence had developed between the Australia and Pacific Plates resulting in subduction of the Australia Plate beneath the northwest-trending parts of the Norfolk Ridge system adjacent to New Caledonia and the West Norfolk Ridge. Eade (1988) argued that the convergence in the southern part of the region resulted in buckling of the oceanic, proto-New Caledonia Basin forming the Fairway, West Norfolk and Wanganella Ridges. This model infers that basement beneath the southern sector of the Norfolk Ridge system is oceanic.

The plate tectonic model for the evolution of this part of the southwest Pacific appears to have been one of progressive rifting of the eastern margin of the Australia-Antarctic supercontinent (Gondwanaland), followed by continental break-up and seafloor spreading, island arc development and the creation of new ocean basins by further seafloor spreading. The fragments of continental crust that were rifted, thinned and left stranded between the Tasman Basin and the New Caledonia Basin during this process subsided to form a complex zone of troughs and plateaus, extending from New Zealand in the south, through Lord Howe Rise, to the Queensland Plateau in the north. Recently, the region has been interpreted in terms of a detachment model (Etheridge & others, 1989; Lister & others,1991) in which southeastern Australia is an underplated upper plate margin, with the Lord Howe Rise/Norfolk Ridge region being its complementary lower plate margin. This implies that a detachment system underlies the whole region, and that the Lord Howe Rise and Norfolk Ridge are composed of areas of extended upper continental crust, bounded by detachment branches, and underpinned by extended lower crust and upper mantle. The small intervening ocean basins may be floored by highly thinned lower continental crust and upper mantle (Fig. 3d). Some support for this idea is provided by the study of Uruski & Wood (1991), which correlated seismic sequences and structures of the southern-most part of the New Caledonia Basin with those of the adjacent Taranaki Basin, and concluded that this part of the New Caledonia Basin is a continental rift, that was active during the Cretaceous and may have been initiated in the Jurassic. They suggested that the rifting may have been initially related to back-arc tectonism associated with Mesozoic subduction (Bradshaw & others, 1981; Korsh & Wellman, 1988), and later to extension preceding breakup, seafloor spreading and continental margin formation.

SEAFLOOR SPREADING HISTORY

Seafloor spreading in the Tasman Basin resulted in the separation of Lord Howe Rise from Australia, and the development of the east Australian and Lord Howe Rise conjugate margins (Fig. 4). In the central Tasman Basin, breakup commenced about 80 Ma (Hayes & Ringis, 1973; Weissel & Hayes, 1977; Shaw, 1978, 1979), although Johnson & Veevers (1984) suggest that it may have occurred as early as 95 Ma, with the 95-80 Ma oceanic lithosphere remaining attached to Lord Howe Rise as a result of a ridge jump to Australia. Off the New South Wales margin, early seafloor spreading probably lay to the east of the Dampier Ridge, which has now been confirmed as a continental fragment (Symonds & others, 1988). A ridge jump to the west at about 69 Ma started seafloor spreading in the northern Tasman Basin, with some margin segments initially having a significant strike-slip component of separation (Shaw, 1978, 1979). Seafloor spreading adjacent to the Capricorn Basin did not commence until around 63 Ma, about the same time as in the Coral Sea Basin. The Coral/Tasman spreading ridges were presumably connected by a series of transform/ridge segments (Weissel & Watts, 1979; Shaw, 1979) through the Cato Trough (Fig. 4), although the spreading pattern has not yet been defined in this area. This single spreading system continued until 56 Ma, when the entire ridge system ceased activity.

A seafloor spreading, magnetic anomaly pattern has not been recognised in the New Caledonia Basin; however, Willcox & others (1980) suggested that it is somewhat older than the Tasman Basin, whereas Kroenke (1984) suggested that it began to open at about the same time but finished somewhat earlier - in the early Paleocene, rather than the early Eocene as in the Tasman Basin. The age of the North and South Norfolk Basins, to the east of the Norfolk Ridge, is also a matter of speculation. Launay & others (1982) defined magnetic anomalies 34 and 33 in the limited data set over these basins, giving them a Late Cretaceous (Campanian) age like the Tasman Basin. Eade (1988) recognised that the depth to basement in the North and South Norfolk Basins supported a Late Cretaceous age of breakup. Kroenke (1984), however, speculated that these basins formed during the late Eocene.

As mentioned above, part of this region has recently been interpreted in terms of a continental margin detachment model (Etheridge & others, 1989; Lister & others, 1991). This model implies that a detachment system underlies the whole region, and that the Lord Howe Rise and Norfolk Ridge are mainly composed of variously extended upper continental crust and thinned lower crust/upper mantle, whereas small intervening basins such as the New Caledonia Basin, those separating Lord Howe Rise and the Dampier Ridge (Figs 3 and 10a), and perhaps the Cato Trough, may be floored only by highly thinned lower continental crust. This model tends to simplify the breakup history of the region by removing the need for small isolated areas of spreading and associated spreading ridge jumps.

REGIONAL STRATIGRAPHY

The only direct information on the nature of rocks in the Lord Howe Rise region comes from outcrop on Ball's Pyramid, and Lord Howe, Norfolk and Philip Islands; the Deep Sea Drilling Project (DSDP); dredging of a volcanic feature (Bentz, 1974) on the southeastern part of the Lord Howe Rise; and coring and dredging on the central Lord Howe Rise and southern Dampier Ridge during a 1985 BGR *Sonne* survey.

Lord Howe Island and Ball's Pyramid are volcanic features and form part of the Lord Howe Seamount Chain, which runs along the western margin of Lord Howe Rise. Game (1970) described at least three major eruptive periods on the islands, and considered that they began a early as the mid-Tertiary and ended with an eruptive episode that was isotopically dated as Late Miocene (7.7 Ma). Norfolk and Philip Islands, on the central Norfolk Ridge, were formed by Pliocene volcanic activity dated at 3.1-2.3 Ma (Jones & McDougall, 1973; Aziz-Ur Rahman & McDougall, 1973).

There are a number of DSDP holes in the region; three are directly relevant to the proposed cruise - Sites 206 and 207 of Leg 21 (Burns, Andrews & others 1973), and Site 592 of Leg 90 (Kennett, von der Borch & others, 1986) (Figs 5 and 6). At Site 206 in the New Caledonia Basin a relatively uniform sequence of Early Palaeocene to ?Late Pleistocene calcareous ooze was intersected. Bathyal conditons prevailed throughout the deposition of the sampled units. At Site 207 on the southern Lord Howe Rise, the basal unit consisted of Upper Cretaceous rhyolitic lapilli tuffs and vitrophyric rhyolite flows; van der Lingen (1973) suggested that at least some of the flows were of subaerial or very shallow marine origin. The rhyolites, which have a mean potassium-argon age of 94 Ma (McDougall & van der Lingen (1974), are overlain by a sandy sequence containing reworked rhyolitic material, and then by a Maastrichtian glauconitic silty claystone. The rarity of planktonic fossils in this claystone led Burns, Andrews & others (1973) to suggest that it was probably deposited in a shallow marine environment with restricted (non-oceanic) circulation. The remaining rocks at this site are mostly carbonate oozes of Palaeocene to Pleistocene age which were deposited well above the carbonate compensation depth. Palaeontological evidence at this site indicates that there was a rapid increase in the depth sedimentation from relatively shallow water in the Maastrichtian to depths similar to present day (1400 m) by the Early Eocene. The major regional Eocene-Oligocene hiatus is present at both Sites 206 and 207, but is somewhat ill-defined at Site 207 because of mixing or slumping.

Site 592 is also on the southern Lord Howe Rise about 50 km north of Site 207. The bottom of the hole consists of Late Eocene to Early Oligocene ooze and chalk, overlain by middle Lower Miocene to Quaternary nannofossil ooze. The regional Eocene-Oligocene hiatus is well represented and corresponds with a significant angular unconformity on seismic data over the site.

Further direct evidence of the rocks forming Lord Howe Rise comes from dredges on the flank of a volcanic feature described by Bentz (1974) on the southwestern margin of the Rise (Launay & others, 1977). Olivine basalts, gabbros, and a mixture of hyaloclastic breccies and biomicrites were obtained; the biomicrites contained planktonic foraminifera of mid-Miocene or younger age.

In 1985 a co-operative BGR/AGSO sampling and geochemical cruise using R V *Sonne* conducted dredging and coring operations over the central Lord Howe Rise and the southern Dampier Ridge (Roeser & Shipboard Party, 1985). The dredging on Lord Howe Rise occurred on a major northwest-southeast structural lineament about 250 km northeast of Lord Howe Island and yielded Mn/Fe nodules containing pebbles of sandstone, quartzite, coralline and ?algal limestone, phyllite and granite. A large block of shallow water calcarenite/calcrudite thickly encrusted by Mn/Fe was also obtained. The presence of intercalated mineralised layers within a complex stratigraphy of dark and dense Mn/Fe crusts may indicate that hydrothermal activity was associated with the structural zone (Roeser & Shipboard Party, 1985). Dredging on the eastern margin of the southern Dampier Ridge obtained fragments of slightly metamorphosed granite and ?microdiorite or andesite, together with feldspathic sandstone, and confirmed for the first time that this feature is, at least in part, an elongate piece of continental crust. U-Pb, K-Ar and Rb-Sr dating of the igneous samples gave precise ages mainly in the range 250 to 270 Ma - mid Permian (McDougall & others, in prep.)

Willcox & others (1980) developed a seismic stratigraphic framework which allowed them to carry the direct site-related information described above throughout the central Lord Howe Rise region. Uruski & Wood (1991) developed a seismic stratigraphic framework for the southern New Caledonia Basin based on seismic ties to the exploration wells in the Taranaki Basin off northwest New Zealand.

GEOLOGY AND PETROLEUM POTENTIAL

WESTERN LORD HOWE RISE

The general absence of Cretaceous rift basins along the eastern seaboard of Australia has led to speculation that the basins may have separated from Australia during breakup and seafloor spreading in the Tasman Basin, and may now be located beneath the western flank of Lord Howe Rise (Jongsma & Mutter, 1978). A zone of horst and graben structures of probable Cretaceous age, and some 200 km wide, exists on the western Lord Howe Rise in water depths of 1000-2000 m (Willcox & others, 1980; Figs 3 and 7). Elsewhere, particularly beneath the eastern third of the Lord Howe Rise, mainly thin sediments overlie basement, which is commonly planated. The graben are up to 50 km wide, several tens of kilometres long, and are best developed north of Lord Howe Island (Fig. 8), where sediment fill is up to 4500 m in places (Roeser & others, 1985). Diapiric structures (Fig. 9c), which suggest the movement of shale or possibly salt, have been recognised in several of the grabens (Roeser & others, op. cit.). South of Lord Howe Island, the extensional basins appear to be less complex. Work by AGSO's *Rig Seismic* in this area (Whitworth, Willcox & others, 1985) indicates that some of the horst blocks southeast of Lord Howe Island may contain dipping strata of Mesozoic age (Fig. 9b and11b), possibly comparable to the Strzelecki Group of the Gippsland Basin (Symonds & Willcox, 1989).

The nature of the sediments filling the basins on the Lord Howe Rise is a matter of conjecture. The sediments are generally assumed to be of late Mesozoic age, but correlation with the older sedimentary basins of eastern Australia cannot be completely ruled out (Symonds & Willcox, 1989). If the basins developed along the lines of classical models for rifted ('Atlantic-type', 'passive') margins, much of the earliest sediment fill would have been of fluvial-lacustrine origin, and may have contained a high proportion of organic material. However, at least the upper part of the Lord Howe Rise rift-fill section may depart from 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 favouring the deposition of petroleum source rocks may have prevailed due to restricted circulation (Willcox & others, 1980). Results from the DSDP Site 207 on the southern Lord Howe Rise confirm the presence of restricted shallow-marine silts and clays of Maastrichtian age overlying horst blocks (Burns & others, 1973). These sediments are similar in age and type to rocks dredged from the lower continental slope off southern New South Wales (G. Packham, Sydney University, pers. comm.), but are younger than similar marine sediments dredged from the eastern part of the Gippsland Basin (Marshall, 1988, 1990).

Up to 3000 m of sediment containing potential source rocks may occur in the basins of the western Lord Howe Rise. In general, the Maastrichtian shallow marine sequence has less than 1000 m of overburden, probably insufficient for petroleum formation. However, petroleum generation may have taken place in older sediments at depth within the grabens, or at shallower levels if, as suggested by the only heatflow measurement on the rise (Grim, 1969), heatflow was anomalously high. Despite the sparse knowledge of the area, three potential petroleum plays can be identified on the western Lord Howe Rise (Symonds & others, in prep.). Fault structural/ stratigraphic traps (Fig. 9a) within the fluvial to shallow-marine, rift-fill sediments (Symonds & Willcox, 1989) are the most widespread potential play identified to date. Sub-unconformity traps created by dipping reflectors within the horst blocks (Fig. 9b), potentially sealed by the rift and post-breakup section, would be dependent on a source within the pre-rift 'Strzelecki equivalents' or older section. Potential plays are associated with diapir-like structures (Fig. 9c), which occur northeast of Lord Howe Island, in water depths of 1500 m. Because of the age of movement of the 'diapirs', this play is only valid if there has been late (?post-Oligocene) maturation and migration.

The eastern flank of the Gippsland Basin reconstructs against the western margin of the Lord Howe Rise south of Lord Howe Island prior to seafloor spreading in the Tasman Sea (Shaw, 1978; Fig. 7). It has been suggested that the Gippsland Basin formed within the failed-arm of a three-branched rift system (Burke & Dewey, 1973), and this implies that dissected remnants of the other arms should occur beneath western Lord Howe Rise. Etheridge & others (1985, 1987) suggested that the Gippsland Basin was the product of NNE-SSW oriented extension in the Early Cretaceous. If such a phase of basin development affected Lord Howe Rise then today, following seafloor spreading in the Tasman Basin, the normal extensional faults would trend approximately northeast and any transfer faults or accommodation zones would trend northwest. These proposed trends are nearly perpendicular to those that have been mapped to the northeast of Lord Howe Island (Symonds & others, in prep; Fig. 8). More recently Willcox & others (1992) proposed that the Gippsland Basin formed as a transtensional basin during the Late Jurassic and Early Cretaceous, by NW-SE transport sub-parallel to the basin's axis. This implies that any Lord Howe Rise basins formed by a similar process would be bounded today by ENE-WSW trending major strike-slip fault systems. This is not a trend that has been recognised to date beneath western Lord Howe Rise. Willcox & others (1992) also suggested that a Late Cretaceous phase of movement along major ENE to NE-trending strike-slip faults associated with rifting along the future locus of Tasman Basin breakup resulted in extension in Bass Strait forming the Boobyalla Sub-basin, and compression and wrenching in the Gippsland Basin. This phase of tectonism could produce the NE-SW-trending transfer or strike-slip faults and NNW-SSE normal faults as mapped to the northeast of Lord Howe Island (Fig. 8).

MONOWAI SEA VALLEY AND MONOWAI SPUR

The Monowai Sea Valley is bounded by the Monowai Spur to the west, on the southwestern margin of the Lord Howe Rise in 1500-3000 m of water (Fig. 10b). The Monowai Sea Valley lies at a similar depth and has similar seismic characteristics to the Lord Howe Basin, although its magnetic signature is more intense. The Monowai Spur, unlike the Dampier Ridge, appears to be composed entirely of crystalline basement. The structural trend, depths and morphology of the Monowai Spur and Sea Valley indicate that a feature similar to, but narrower than the Dampier Ridge/Lord Howe Basin system, may extend beneath the southwestern slope of Lord Howe Rise (Fig. 10).

EASTERN FLANK OF LORD HOWE RISE

The eastern flank of Lord Howe Rise might have formed an ancient seaboard of the Australian--Antarctic supercontinent (Willcox & others, 1980). A considerable thickness (about 2000 m) of clastic sediment was deposited across this margin during or before the Late Cretaceous (Fig. 11c). Most of this sediment was probably derived from the now planate basement blocks to the west. The sedimentary (?pelagic) overburden ranges from about 1000 m on the eastern edge of the Lord Howe Rise to more than 2000 m in the New Caledonia Basin.

Depositional environments favourable for both the production and preservation of marine petroleum source rocks may have occurred on this continental slope, as is thought to be the case on many other continental slopes around the world (Dow, 1979). Faulting, and folding of the ?Late Cretaceous sediment wedge, could provide structural traps for petroleum. The progradation observed on some profiles may give rise to stratigraphic traps (Fig. 11c). Petroleum migrating up dip could be trapped against the basement surface and at unconformities, and sealed by the overlying pelagic oozes.

NEW CALEDONIA BASIN

The New Caledonia Basin may contain at least 4000 m of sediment (3 seconds of reflection time) in places and, near its margins, the basal 2000 m of this section probably consists of Cretaceous marginal and shallow marine terrigenous sediments (Fig. 11c). This sequence was gently folded throughout the basin during the Late Cretaceous and early Tertiary, perhaps in response to convergent tectonics to the east. The basal sequence is overlain by deep-sea biogenic ooze.

The prospectivity of the New Caledonia Basin is difficult to assess, as both its origin and the depositional environment of the deeper sediment are uncertain. In theory, small enclosed ocean basins are among the most promising areas for petroleum accumulation (Hedberg & others, 1979). Proximity to land ensures deposition of thick sedimentary sections, where both terrestrial and marine organic matter accumulate, even in the centre of the basins. The restricted nature of the basins limits circulation and favours the preservation of organic matter, and favourable reservoirs are to be expected in deltaic and submarine fan sediments.

WEST NORFOLK RIDGE SYSTEM

The western part of the West Norfolk Ridge is underlain by relatively planar basement, which has been downfaulted to form flanking grabens which, in places, contain up to 3000 m of sediment (Fig. 12). The sediments in the grabens are probably very similar to those already described within the rift basins beneath the Lord Howe Rise; however, on the West Norfolk Ridge, the rift-fill sediments have been folded, resulting in a larger variety of structural petroleum plays than on the Lord Howe Rise. The northern end of the Wanganella Trough, to the east of West Norfolk Ridge, is underlain by at least 1500 m of sediment containing mounded and progradative facies.

This might be a deltaic sequence deposited along the trough during subaerial erosion and planation of the northern West Norfolk ridge. This sediment undoubtedly thickens to the south beyond Australia's putative Legal Continental Shelf. The Wanganella Ridge appears to be an area of shallow basement, and is flanked to the east by a narrow trough and ridge, which could be volcanic feature (Fig. 12).

TARANUI GAP (SEA VALLEY)

Up to 4000 m of faulted and folded sedimentary rocks occur in a complex graben-like feature beneath the head of the Taranui Gap, in less than 2000 m of water (Figs 11d and 12). Several prominent angular unconformities occur throughout the sedimentary section, but both the nature and depositional environment of the sediments, and the nature of the underlying basement are unknown. The structural style of the basin suggests wrench tectonics, and could indicate that the sediments were deposited in a dextral strike-slip zone which was responsible for the offset of the Norfolk Ridge.

NORFOLK-REINGA-SOUTH MARIA RIDGE SYSTEM

Small pockets of sediment cover basement on the Reinga Ridge (Davey, 1977). Dredging on the South Maria Ridge has recovered fine-grained volcanics of the Cretaceous Whangakea Volcanic Series, indurated graywackes of probable pre-Cretaceous age, and Tertiary sandstone and siltstone (Summerhayes, 1969). Eade (1988) suggested that the whole Norfolk-Reinga-South Maria Ridge system is a continental sliver which connects New Zealand to New Caledonia along the Norfolk Ridge (Fig. 13).

SOUTH NORFOLK BASIN

The South Norfolk or Norfolk Basin (Fig. 13) is thought to be an oceanic basin formed by Late Cretaceous seafloor spreading (Eade, 1988). A Cretaceous age is supported by the existence of obducted oceanic crust and deep-sea sediments as old as 102 Ma in Northland, New Zealand (Brothers & Delaloye, 1982), which were emplaced from the northeast and presumably represents a southeastern extension of the South Norfolk Basin (Eade, 1988).

PETROLEUM POTENTIAL OF THE REGION

Symonds &Willcox (1989) used a volumetric/analogue approach to assess the potential petroleum of various features within the region, and concluded that the western Lord Howe Rise, the New Caledonia Basin and the Taranui Sea Valley areas are the most interesting from the view of long-term potential. They considered the western Lord Howe Rise basins, although promising in terms of total potential recovery, individually less attractive, because they appear to be mainly small and consequently may only contain relatively small quantities of source rock. The few larger grabens and basins so far identified might be the most promising areas: both the diapiric structures in the basin northeast of Lord Howe Island (Gower Basin; Roeser & others, 1985), and possible Mesozoic pre-rift sequences in fault blocks southeast of Lord Howe Island (Whitworth & Willcox, 1985) warrant further investigation. Symonds & Willcox (1989) rated the western Lord Howe Rise basins as having fair potential.

From the point of view of sediment volume the New Caledonia Basin may have significant deep water potential. However, the exploration possibilities associated with this feature, which lies in relatively deep water, perhaps partially on oceanic lithosphere, are totally unknown. The northern Taranui Gap (Sea Valley) with its relatively thick (4000 m) sediment, and apparent structural complexity in moderate water depth (about 1600 m), has been rated as having fair potential (Symonds & Willcox, 1989).

OBJECTIVES OF STUDY

The work program described in this document (part of AGSO Project 121.30 - Lord Howe Rise and Norfolk Ridge 'Law of Sea' Study) seeks to improve our understanding of the geological framework of the southern part of the Lord Howe Rise region in the vicinity of the Australia/New Zealand seabed boundary zone. Its major objectives are:

- To investigate the structure, stratigraphy and basin development of the southern Lord Howe Rise, southern New Caledonia Basin, and West Norfolk Ridge in the Australia/New Zealand seabed boundary zone.
- To assess the resource potential of the major structural features within the region.
- To determine the tectonic framework, crustal characteristics and evolution of the region, and attempt to understand the processes that have produced narrow strips of thinned and extended continental lithosphere ("ribbon continents"), separated by narrow ocean basins.
- To acquire data to assist with the definition of Australia's 'legal' Continental Shelf on the southwestern margin of Lord Howe Rise.

Specific scientific problems that will be examined by the study are:

1. The structural style, depositional history and tectonic development of the basin system beneath the western Lord Howe Rise.
2. The nature of the ocean/continent transition across the western margin of Lord Howe Rise to the Tasman Basin.
3. The nature of the basement ridge and basin system (Monowai Spur and Sea Valley) beneath the

western Lord Howe Rise. Are these features a similar but less extended version of the Dampier Ridge and Lord Howe basin to the north?

4. The nature of the transitions across the eastern margin of Lord Howe Rise and the western margin of the West Norfolk Ridge into the New Caledonia Basin. Is the basin formed over oceanic lthosphere or highly extended continetal lithosphere?

5. The structural style, depositional history and tectonic development of the West Norfolk, Wanganella and Norfolk-Reinga-South Maria Ridge system. Are these features formed on continental lithosphere, or in part by uplifted and deformed oceanic crust as suggested by Eade (1988)?

6. The nature of the transition from the Norfolk Ridge into the South Norfolk Basin. Is this basin formed on oceanic crust?

7. The petroleum potential of basin systems within the region, particularly beneath the western Lord Howe Rise, the flanks of the New Caledonia Basin, the West Norfolk Ridge, and the Taranui Gap.

An examination of many of the above questions should result in a greater understanding of the processes that produce narrow strips of thinned and extended continental lithosphere - ribbon continents (e.g. the Lord Howe Rise, Dampier Ridge and Norfolk Ridge) - which are separated by narrow ocean basins (e.g. the New Caledonia, Lord Howe and Middleton, and Tasman Basins). Some of these basins appear to be underlain by ocean crust formed by normal seafloor spreading processes, and others may be underlain by highly extended continental crust. This study will attempt to test the various hypotheses that have been proposed to explain such feaures in a region where they are well represented. Extension in the Lord Howe Rise/Norfolk Ridge region may have occurred by 'pure shear' and the continental strips were left stranded as a result of a jump of the locus of extension followed by seafloor spreading and ocean basin formation; or the region may have form by 'simple-shear' processes utilising a major crustal detachment fault system with the various continental slithers bounded by major branches of the detachment. Some of the continental fragments may be similar to the core complexes described in exposed continental extensional terranes.

In addition to the above scientific questions, there are two aspects to the definition of Australia's seabed boundary in the southern Lord Howe Rise/Norfolk Ridge region which need resolution:

- ❑ The definition of a 'legal' Continental Shelf (LCS) along the southwestern margin of Lord Howe Rise to the south of the 200 nautical mile Exclusive Economic Zone (EEZ) around Lord Howe Island (Fig. 14).

- ❑ The definition of a negotiated seabed boundary between Australia and New Zealand resulting from overlapping EEZ's with respect to Norfolk Island and mainland New Zealand, and overlapping LCS's with respect to Lord Howe Island and mainland New Zealand.

Article 76 of the 1982 United Nations Convention on the Law of the Sea provides a series of rules to determine a 'legal' outer limit for the LCS. Full application of these rules requires location of the foot-of-continental-slope, knowledge of sediment thickness to a least the edge of the continental rise, and good bathymetric information defining the 2500 isobath. The outer limit of the LCS must be defined at least every 60 nautical miles around parts of the margin extending beyond the EEZ. Seismic and bathymetric information are required over the southwestern Lord Howe Rise to ensure optimum defnition of an Australian LCS.

Knowledge of the geological framework and resource potential of the southern Lord Howe Rise and West Norfolk Ridge will contribute to seabed boundary negotiations between Australia and New Zealand in this region.

PROPOSED PROGRAM

The proposed lines for the southern Lord Howe Rise/West Nofolk Ridge survey (AGSO Survey 114) are shown in Figure 15, togeher with two possible dredging locations. These lines total 3247 km and tie DSDP Site 207 on the southern Lord Howe Rise. The lines are designed to address the projects objectives by examining the major structural elements in the region, and acquiring data to aid seabed boundary definition. Eight lines are proposed, including four long regional lines.

Way points for the survey lines are given in Appendix 2; a breakdown of the cruise schedule is given in Appendix 3; and the seismic acquisition parameters that will be used during the survey are given in Appendix 4. Four main elements are proposed for the program, as follows:

1. **Western Lord Howe Rise rift system:** Four dip-line segments (lines 1, 3, 5 and 7) and two strike-lines (lines 6 and 8) over the complex zone of fault blocks and grabens/half grabens beneath the western Lord Howe Rise. All of the dip-lines will extend west from the zone of planated 'basement' beneath the eastern Lord Howe Rise, and two of the lines will extend over the oceanic crust of the Tasman Basin. Strike-line 8 will attempt to cross the dip-lines in the area of thickest section to the west of the planated basement high, and will tie to Deep Sea Drilling Project (DSDP) Site 207 at its southeastern end. Dip line 7 will also tie DSDP Site 207. Depending on survey progress it may also be possible to tie DSDP Site 592.

2. **Lord Howe Rise/West Norfolk Ridge transect:** Two very long (about 1000 and 800 km) lines across the whole province from the Tasman Basin in the southwest to the South Norfolk Basin in the northeast (lines 3 and 5). These lines will link all the main structural elements in the region, and will examine the southern extension of the Taranui Sea Valley on their northeastern ends.

3. **Southwest margin of Lord Howe Rise:** Two segments of line (lines 1 and 3) cross the southwest flank of Lord Howe Rise to acquire data necessary for definition of a 'legal' continental shelf. These lines will fill a data gap and allow foot-of-continental-slope points to be determined at least every 60 nautical miles as required by the continental shelf definition contained within Article 76 of the 1982 United Nations Convention on the Law of the Sea.

4. **Lord Howe Rise/West Norfolk Ridge sampling:** Two areas where it may be possible to sample basement by dredging have been identified on the present data on the western margin of both Lord Howe Rise and the West Norfolk Ridge (Areas A and B). It is likely that other sites will also be located on the lines proposed here. Given the time constraints and the large transits required it will probably only be possible to dredge the western flank of Lord Howe Rise during the cruise.

The program proposed here assumes a 28 day cruise. It is recognised that the 3247 km of deep seismic data planned is considerably more than is normally acquired on AGSO's petroleum basin studies. However, it is expected that with careful scheduling of seismic equipment maintenance, particularly the sleeve gun arrays, and the use of more relaxed quality control guide-lines appropriate to a regional framework study, it should be possible to complete the program. Clearly, extended periods of adverse weather or serious equipment problems will require adjustment of the cruise plan.

The RV *Rig Seismic* cruise proposed has been developed in consultation with the Sea Law and Ocean Policy Group of the Department of Foreign Affairs and Trade; the Petroleum Division and Offshore Minerals & Policy Co-ordination Group of the Department of Primary Industries and Energy; and the New Zealand Institute of Geological & Nuclear Sciences Limited, and with approval from the New Zealand Ministry of External Relations and Trade. The project will be carried out in collaboration with New Zealand scientists from the Institute of Geological & Nuclear Sciences. The information submitted to the New Zealand Ministry of External Relations and Trade to support our request to enter and collect data within New Zealand's Exclusive Economic Zone is given in Attachment 1.

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APPENDIX 1

SUMMARY OF PRE-1985 SURVEYS IN THE LORD HOWE RISE/WEST NORFOLK RIDGE REGION.

Vessel	Cruise	Date	Seismic	Gravity	Magnetics	Other
BERGALL ISLAND (Deep Freeze)		1949	No	Pendulum	No	
CHALLENGER		1951	No	No	No	Refraction
TELEMACHUS		1956	No	Pendulum	No	
STRATEN ISLAND (Deep Freeze)		1960	No	No	Yes	
VEMA	V18	1962	Explosives	Yes	Yes	
CONRAD	C9	1964	Explosives	Yes	Yes	
ELTANIN	ELT 26	1966	Air gun	Yes	Yes	
TARANUI		1966	No	No	Yes	
TARANUI		1967	No	No	Yes	
ELTANIN	ELT 29	1967	Air gun	Yes	Yes	
ARGO	NOVA	1967	Air gun	Yes	Yes	Refraction
HORIZON	NOVA	1967	Sparker	Yes	Yes	Refraction
OCEANOGRAPHER		1967	No	Yes	Yes	
ELTANIN	ELT 34	1968	Air gun	Yes	Yes	
ELTANIN	ELT 39	1969	Air gun	Yes	Yes	Sonobuoys
UNITED GEOPHYSICAL		1970	Yes	Yes	No	
CORIOLIS	C1	1971	Air gun	No	Yes	
CORIOLIS	C2	1971	Air gun	No	Yes	
ELTANIN	ELT 47	1971	Air gun	Yes	Yes	Sonobuoys
KANA KEOKI		1971	Air gun,sparker	Yes	Yes	
KIMBLA	K3	1971	Air gun	No	Yes	
KIMBLA	K4	1971	Air gun	No	Yes	
LADY CHRISTINE	BMR14/3	1971	Sparker	Yes	Yes	Sonobuoys
GLOMAR CHALLENGER	DSDP 21	1971/72	Air gun	No	No	Sonobuoys Drilling
CORIOLIS	AUSTRADEC 1	1972	Flexichoc	No	Yes	
FRED V H MOORE	MOBIL	1972	HI/FES,air gun	Yes	Yes	Sonobuoys
CORIOLIS	AUSTRADEC 2	1973	Flexichoc	No	Yes	
GLOMAR CHALLENGER	DSDP 29	1973	Air gun	No	No	Sonobuoys Drilling
SONNE	SO-7A	1979	Air gun array	Yes	Yes	Sonbuoys

APPENDIX 2

WAY POINTS FOR LORD HOWE RISE 'LAW OF SEA' STUDY (SURVEY 114)

Seismic Lines

Way Point	Lat.°S	Long.°E	Line #	Length (NM)	(Km)
1	33° 56'	164° 02'			
			1	251	465
2	35° 35'	159° 21'			
			2	31	57
3	36° 03'	159° 37			
			3A	245	454
4	34° 38'	164°19			
			3B	302	560
5	31° 47'	169° 17'			
			4	34	62
6	32° 15'	169° 39'			
			5	412	764
7	36° 29'	163° 05			
			6	101	186
8	37° 41'	164° 33'			
			7A	60	112
9	36° 57.75'	165° 26.06'	DSDP Site 207		
			7B	14	26
10	36° 48'	165° 38'			
			TURN		
11	37° 00'	165° 39'			
			8A		
12	36° 57.75'	165° 26.06	DSDP Site 207		
			8B	37	68
13	36° 47'	164° 42'			
			8C	147	273
14	34° 36'	163° 19'			
			8D	108	200
15	33° 37'	161° 30'			
				Total: 1753	3247

APPENDIX 3

BREAKDOWN OF CRUISE SCHEDULE

Transit Sydney to near start of survey (W.P. 1):	640 nmi, 1185km	2.6 days at 10kts
Deployment and testing of seismic gear etc		2.5 days
Seismic program	1753nmi,.3247km	14.6 days at 5kts 2.5 contingency
Retrival of seismic gear etc and transit to dredge sites		1.5 days
Dredging		2.0 days
Transit from western side of Lord Howe Rise to Sydney	500mni, 920km	2.1 days at 10kts
		------------
	Total	27.8 days

APPENDIX 4

SEISMIC ACQUISITION PARAMETERS FOR SURVEY 114

Seismic streamer configuration:

Standard	length	3000 m
	group length	25 m
	number channels	120

Seismic source

sleeve gun capacity	50 litres (3000 cu in)
gun pressure	1800 psi (normal)
	1600 psi (minimum)
shot interval	19.4 sec @ 5 knots

Recording parameters

fold	3000%
record length	16 s
sample interval	2 ms

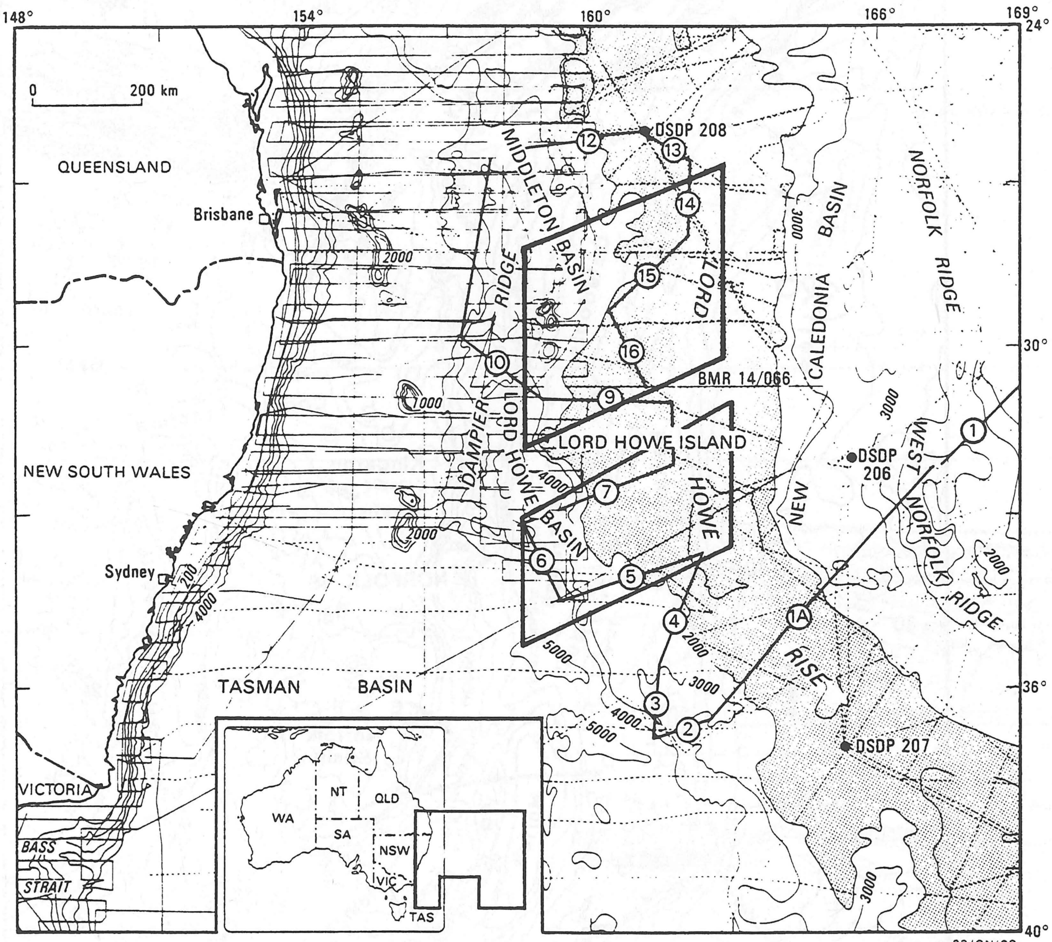

Figure 1. Bathymetry of the Tasman Sea (after Ringis, 1972).

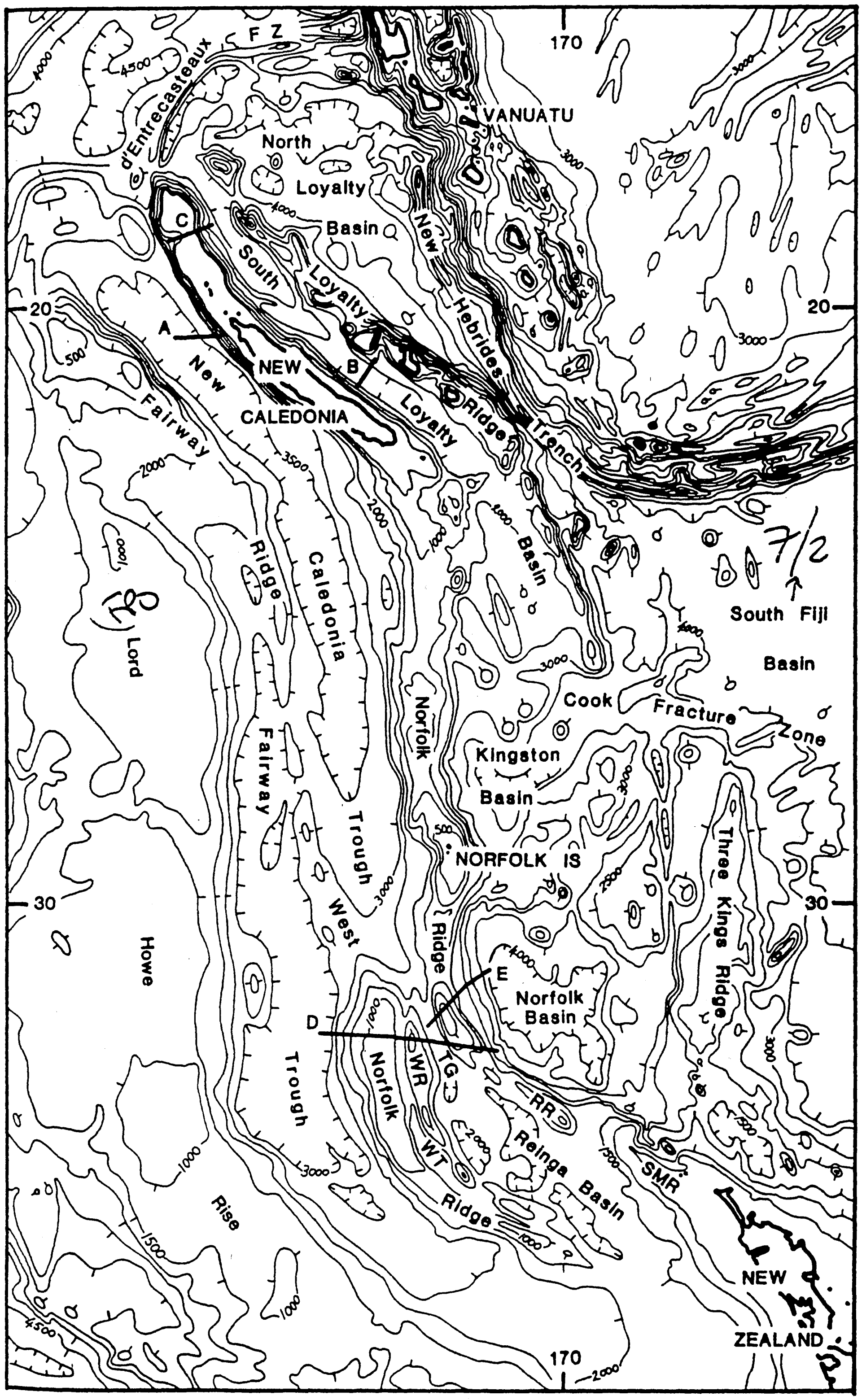

Figure 2. Bathymetry of the Norfolk Ridge region (after Eade, 1988). WR=Wanganella Ridge, WT=Wanganella Trough, TG=Taranui Gap, RR=Reinga Ridge, SMR=South Maria Ridge.

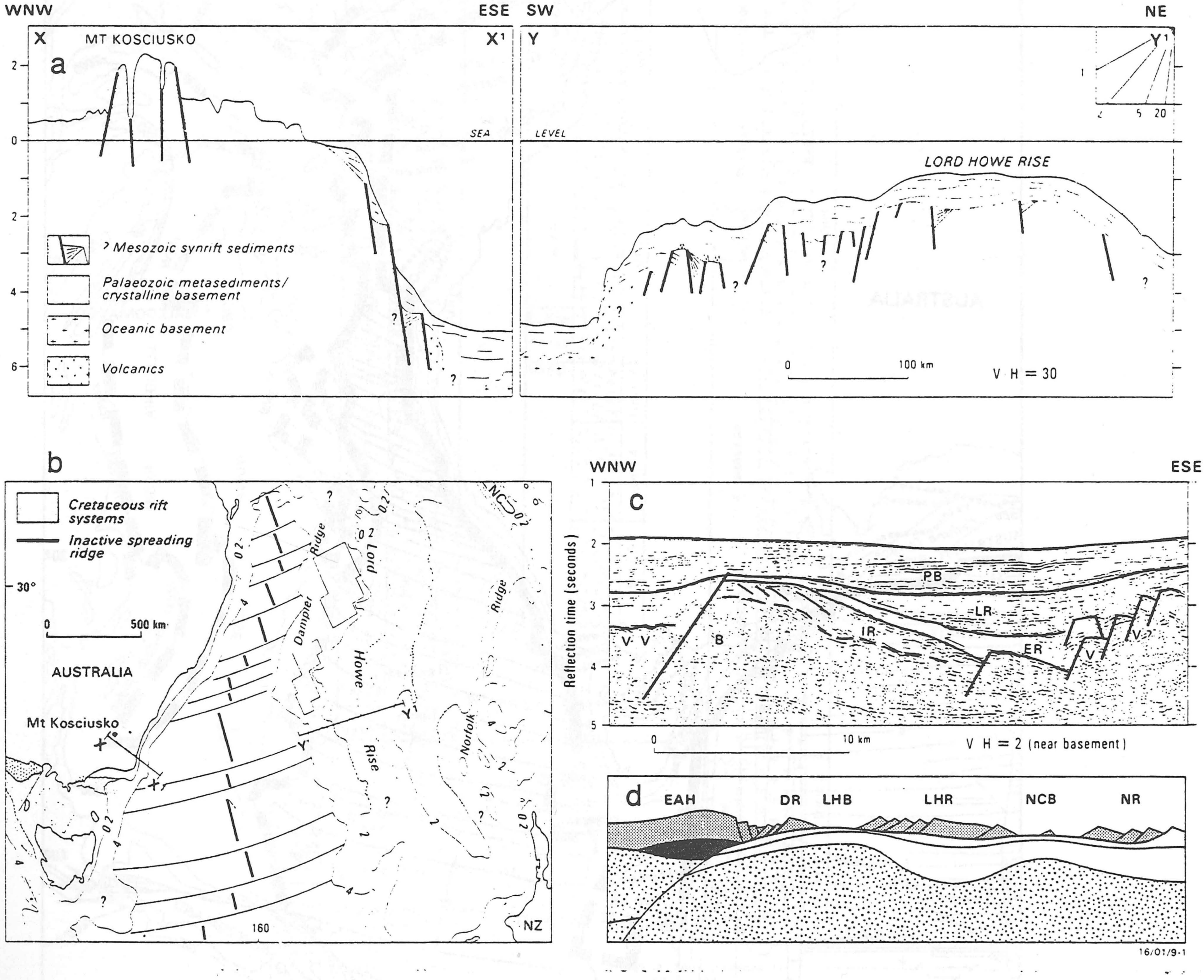

Figure 3. **Reconstructed schematic section and detachment model for theTasman Sea extensional orogen (after Etheridge & others, 1989). (a) has about 800km of oceanic crust removed. Location of section shown in (b). (c) Seismic section across the rift system of western Lord Howe Rise. (d) Schematic detachment model for the region from the Norfolk Ridge to eastern Australia. EAH=Eastern Australian Highlands, DR=Dampier Ridge, LHB=Lord Howe Basin, LHR=Lord Howe Rise, NCB=New Caledonia Basin, NR=Norfolk Ridge.**

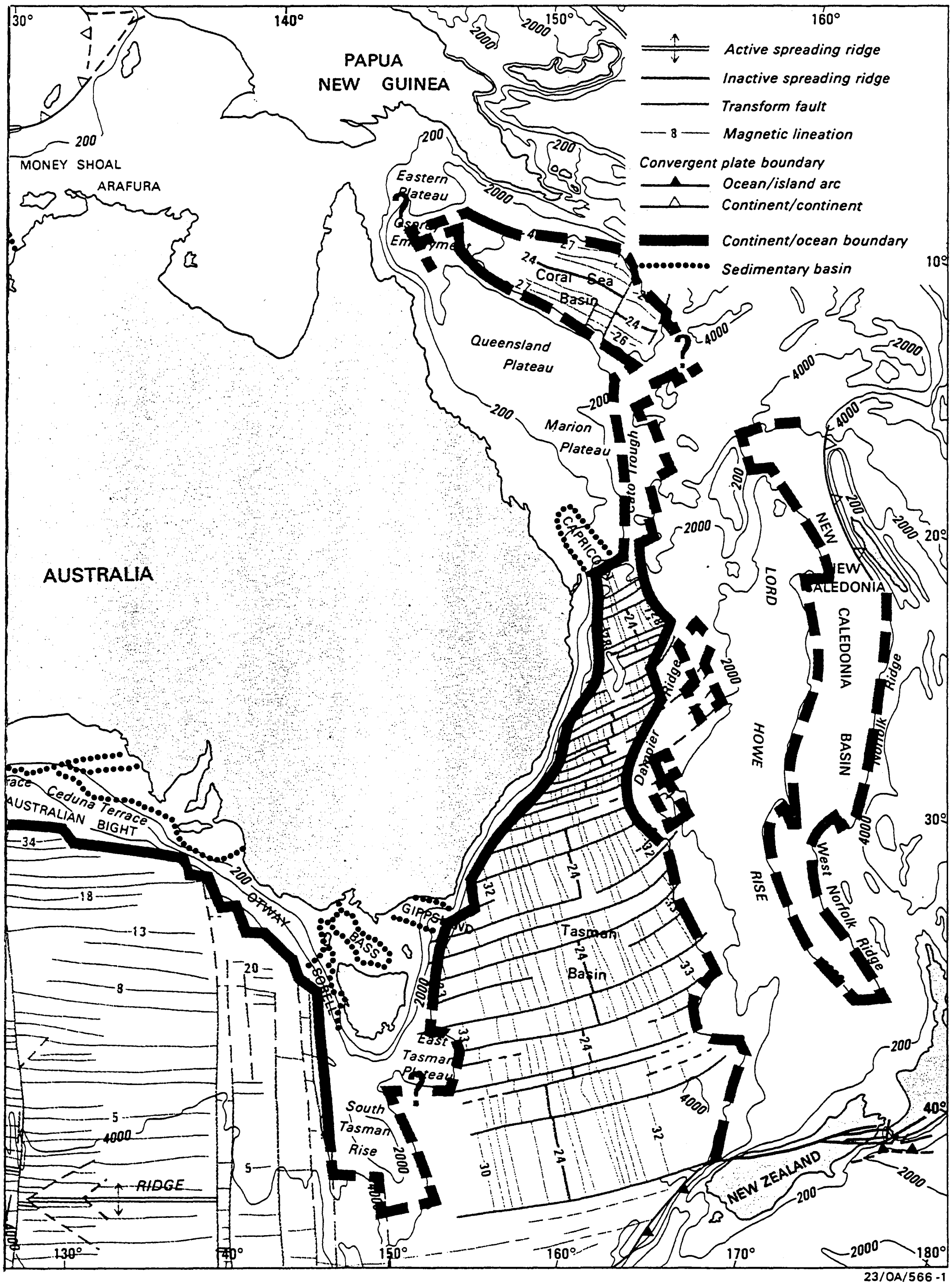

Figure 4. Seafloor spreading magnetic lineation pattern off eastern Australia. Tasman Basin lineations after Shaw (1978, 1979).

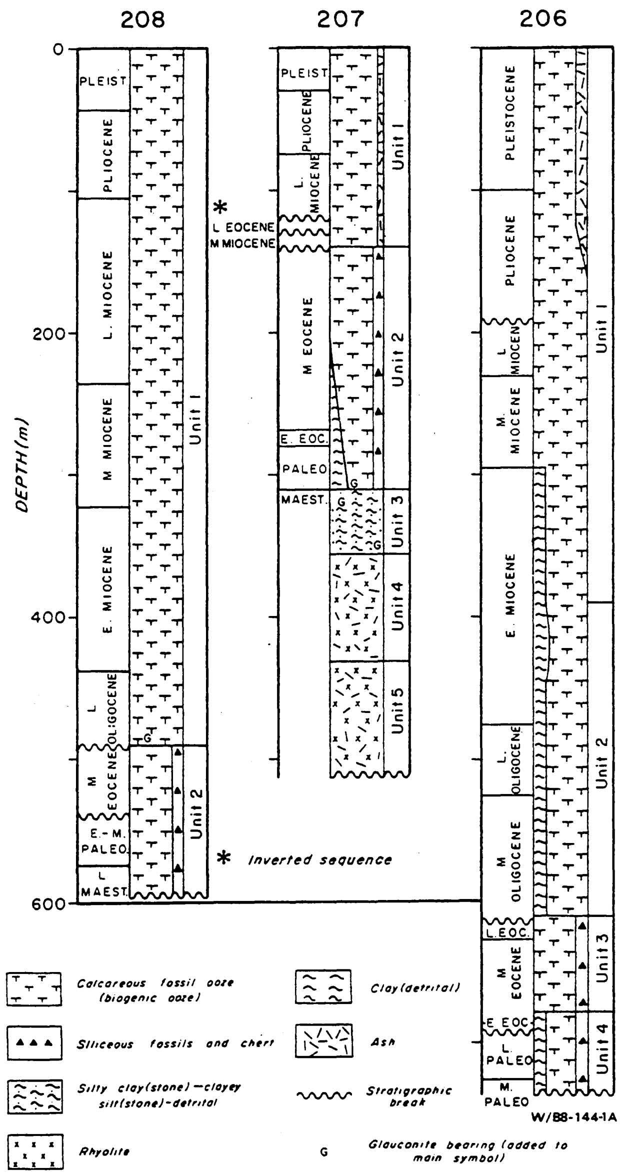

Figure 5. Summary of drilling results at Deep Sea Drilling Project (DSDP) Leg 21 Sites 206, 207 and 208 (after Burns, Andrews & others, 1973).

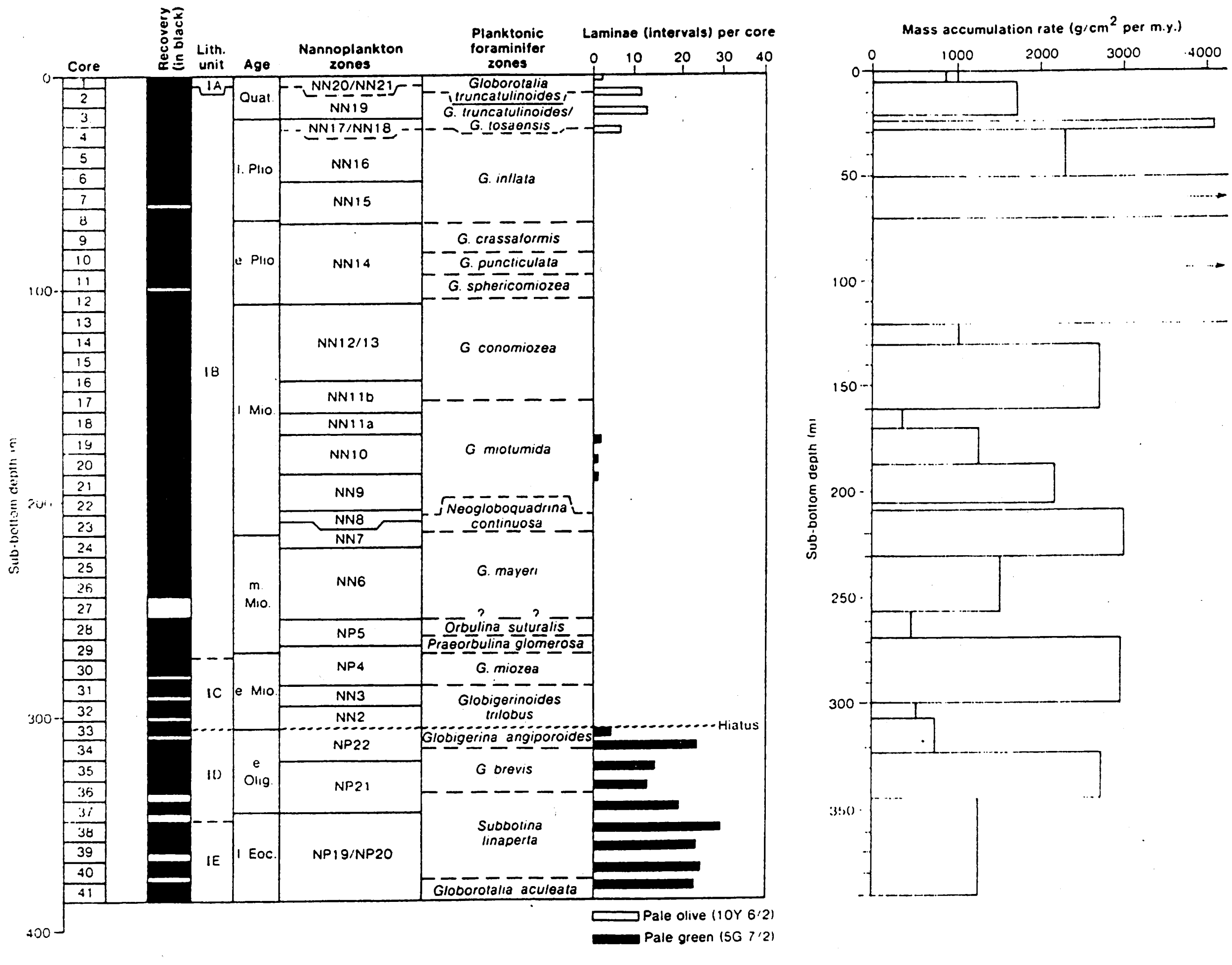

Figure 6. Summary of drilling results at DSDP Leg 90 Site 592 (after Kennett, von der Borch & others, 1986).

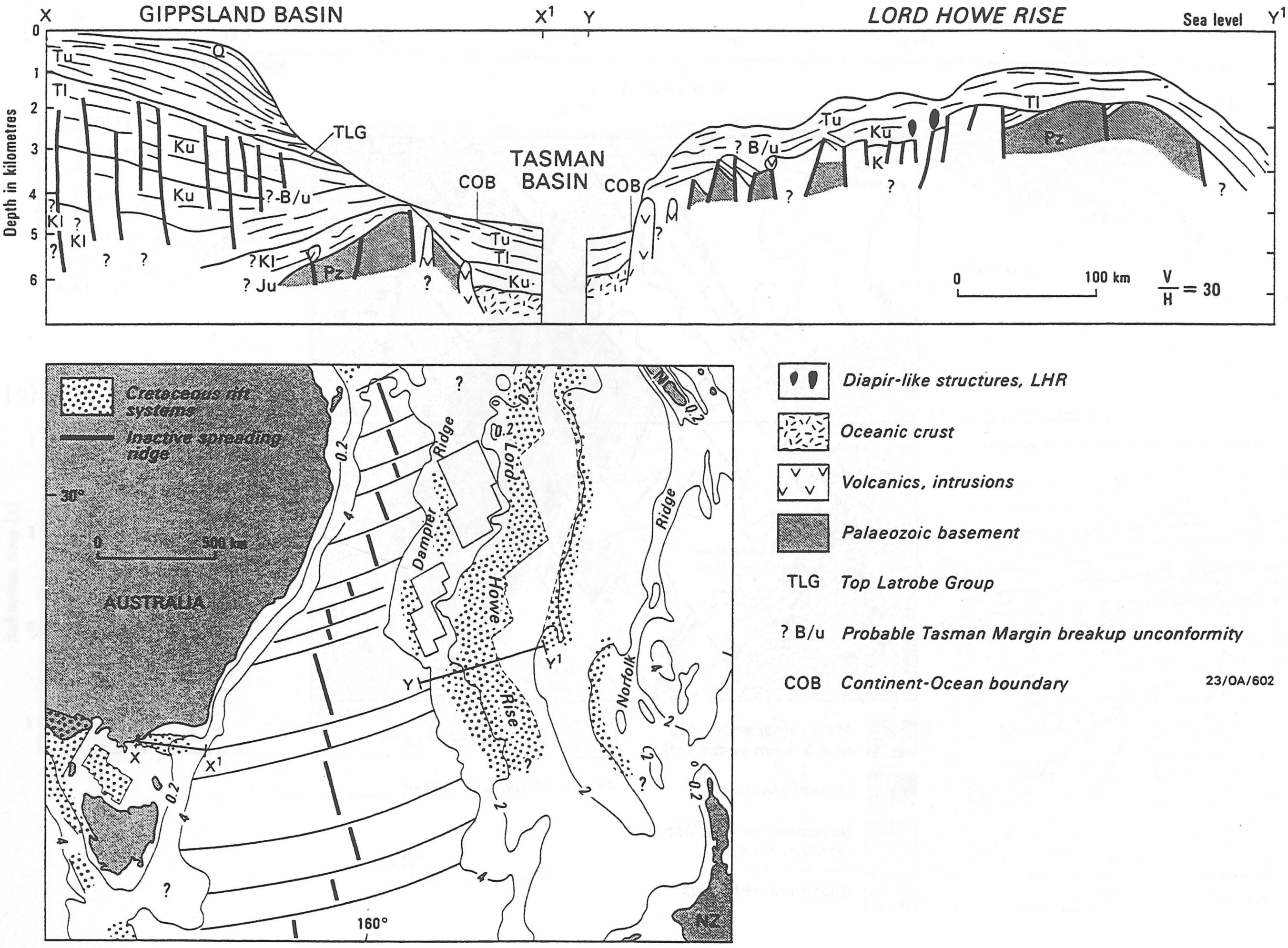

Figure 7. Reconstructed schematic section of the Gippsland Basin and Lord Howe Rise (after Symonds & others, in prep.).

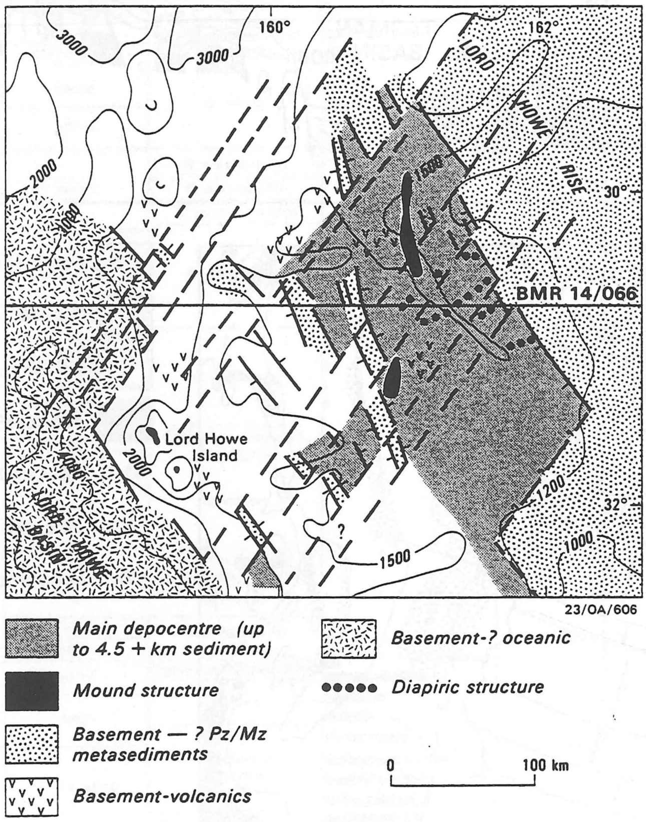

Figure 8. Tectonic elements of part of the central Lord Howe Rise (after Symonds & others, in prep.).

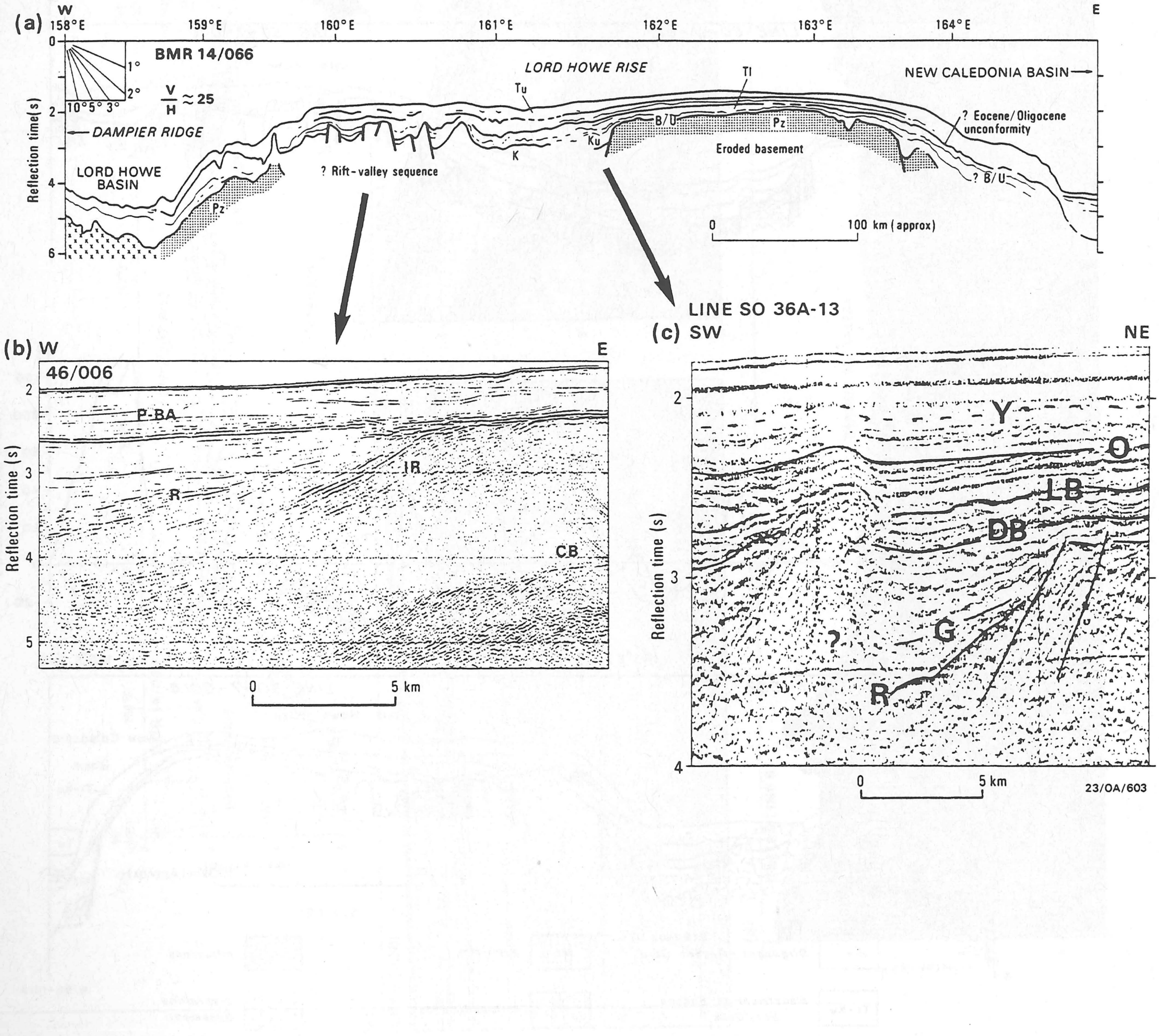

Figure 9. Line drawing and seismic sections over Lord Howe Rise (after Willcox & others, 1980, and Symonds & others, in prep.).

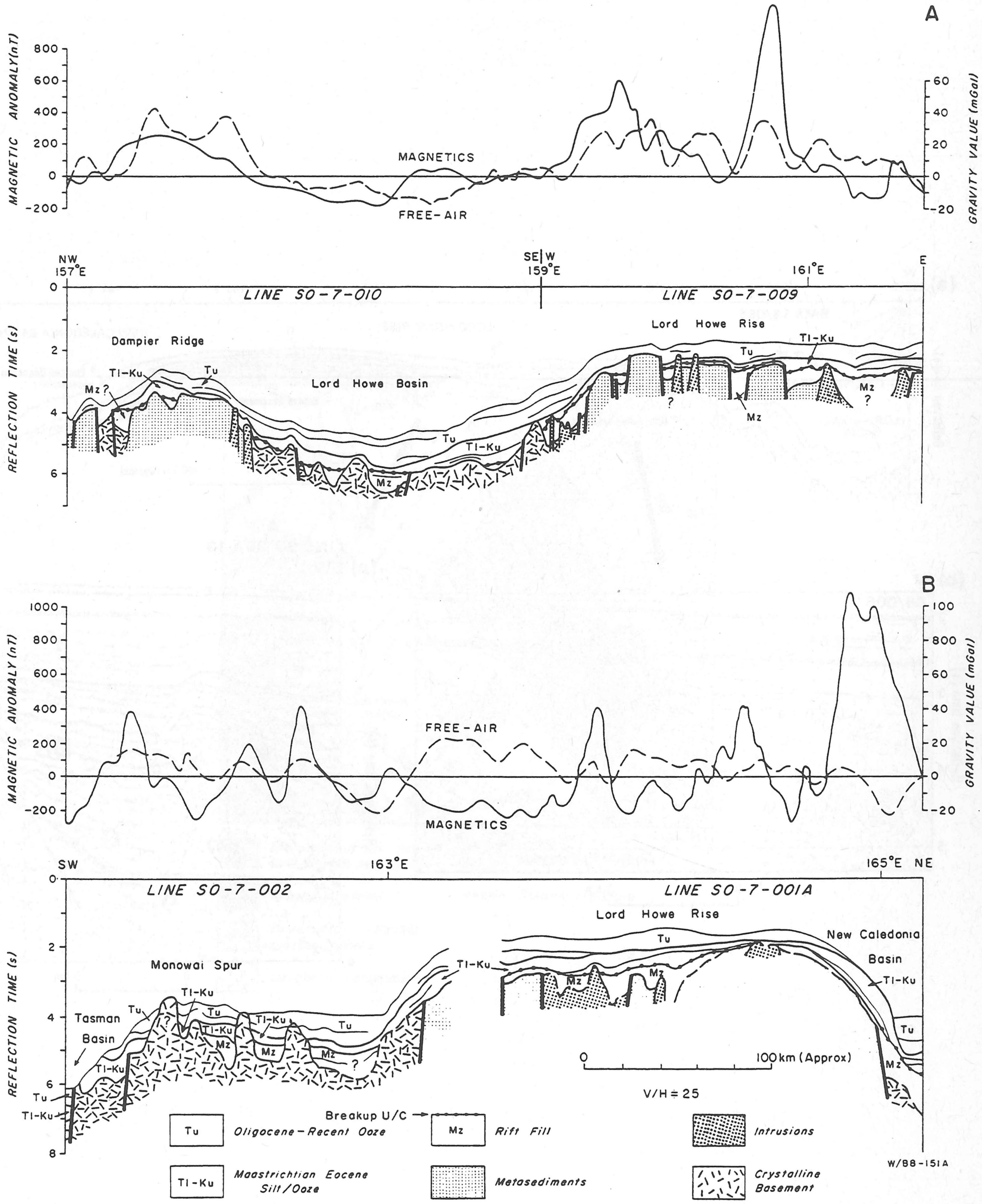

Figure 10. Line drawings of *Sonne* seismic profiiles across Dampier Ridge-Lord Howe Rise and Monowai Spur-Lord Howe Rise (after Willcox & others, 1980).

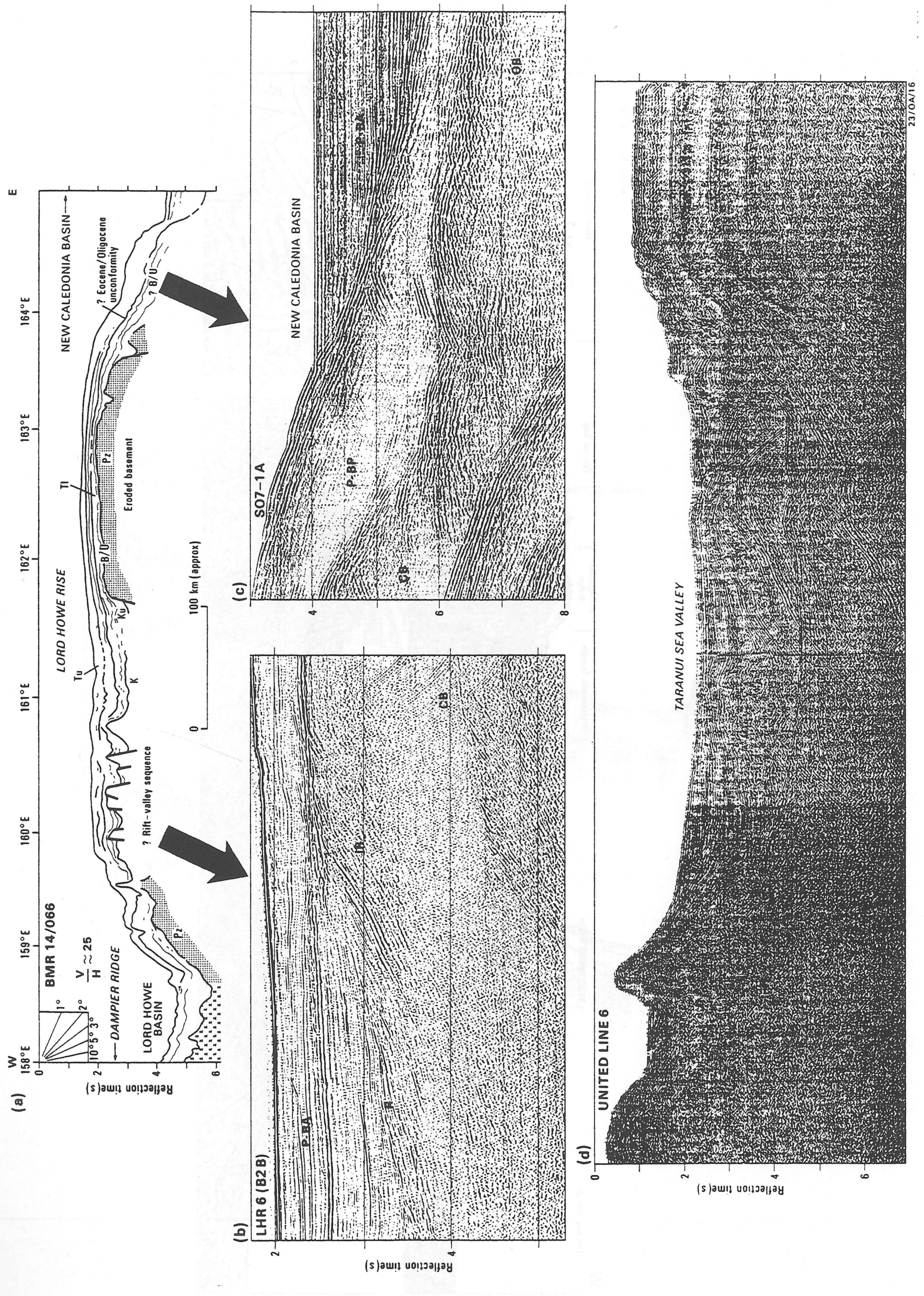

Figure 11. Seismic sections across Lord Howe Rise, the western margin of the New Caledonia Basin and the Taranui Sea Valley (after Symonds & Willcox, 1989).

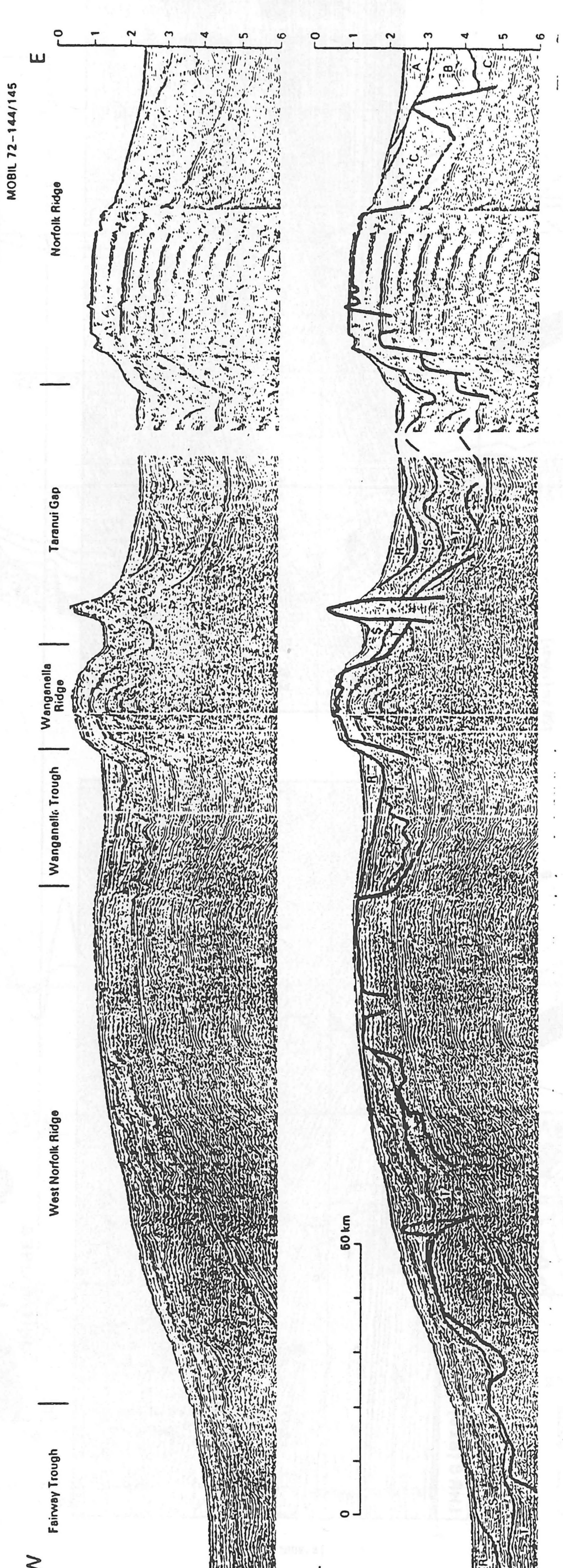

Figure 12. Seismic profile across the West Norfolk-Wanganella Ridge system (after Eade, 1988).

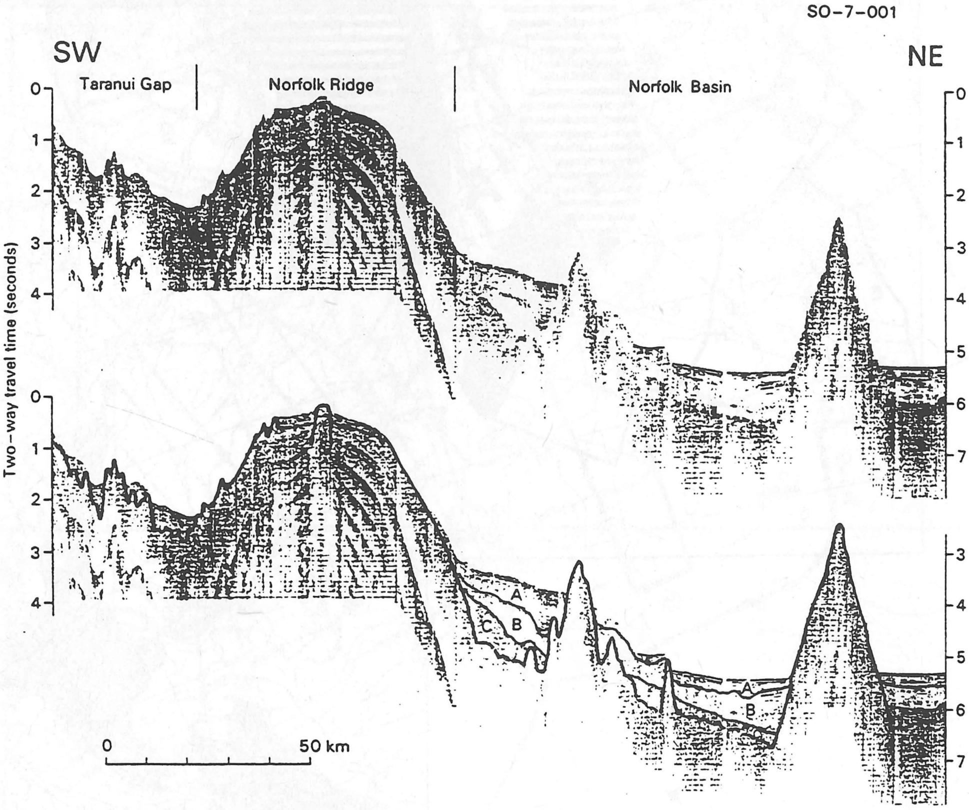

Figure 13. *S*eismic profile across the southern Norfolk Ridge and South Norfolk Basin (after Eade, 1988).

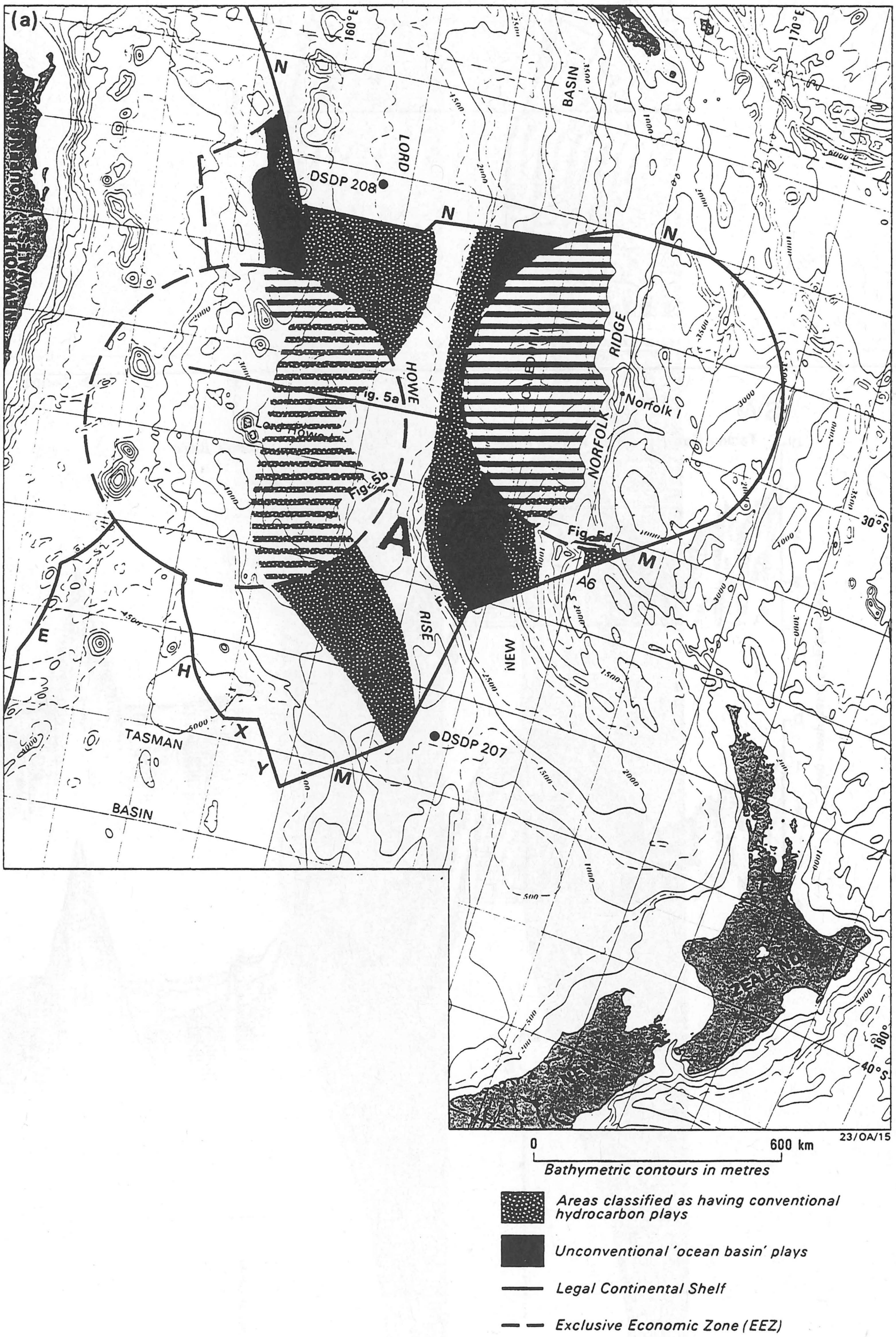

Figure 14. **An Australian EEZ and Legal Continental Shelf in the Lord Howe Rise/Norfolk Ridge region (after Symonds & Willcox, 1989).**

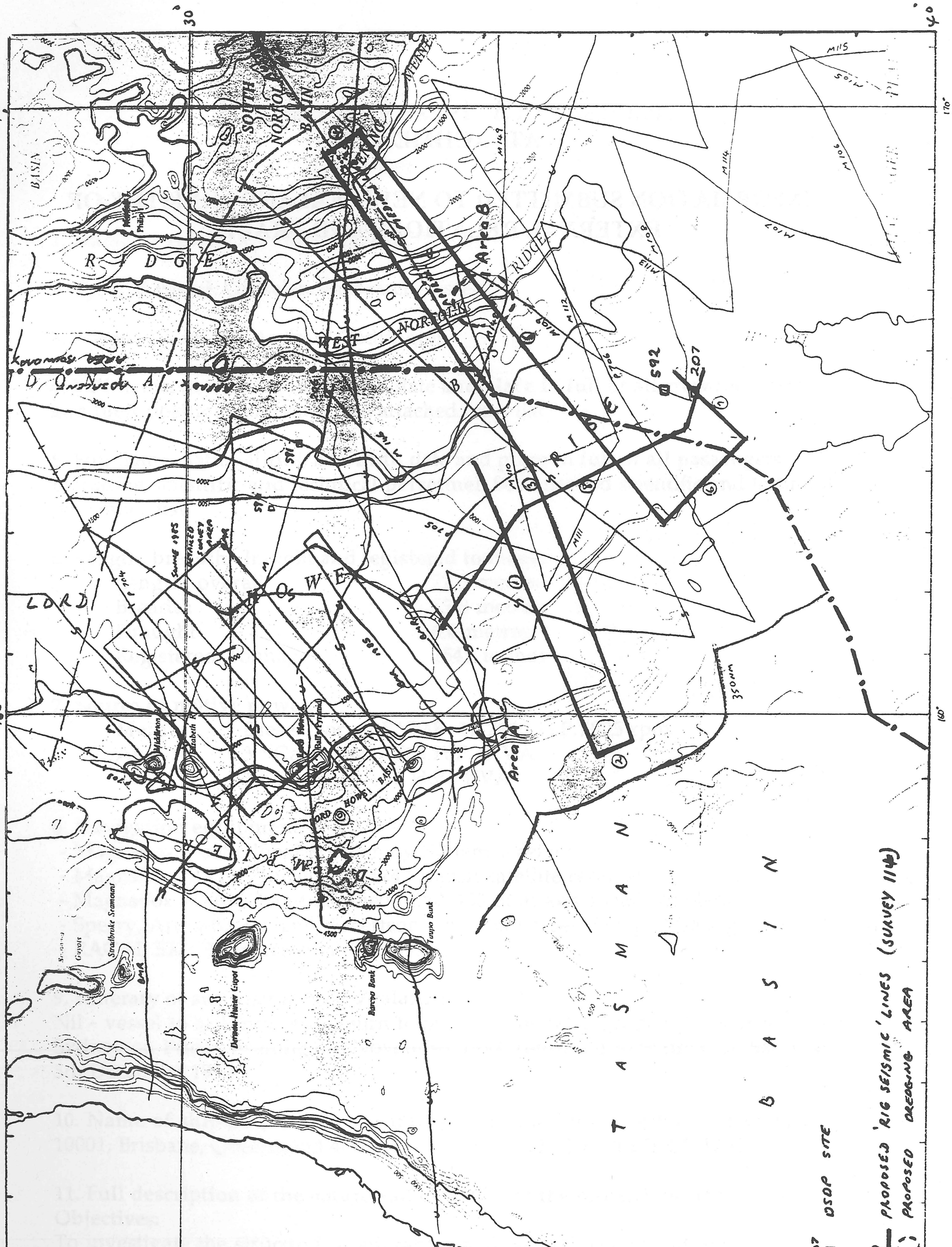

Figure 15. Track map of proposed RV Rig Seismic lines in the southern Lord Howe Rise/West Norfolk Ridge region. Also shows regional bathymetry; the locations of previous seismic lines and DSDP/ODP drilling sites (□ - 207); and the approximate positions of the Australian Adjacent Areas line (—·—) and possible median line between Australia and New Zealand (—··—).

ATTACHMENT 1

INFORMATION SUBMITTED TO NEW ZEALAND MINISTRY OF EXTERNAL RELATIONS AND TRADE

Research Vessel *Rig Seismic*

Cruise Plan - Survey 114
November - December 1992

1. **Name of vessel:** R.V. *RIG SEISMIC*

2. **Type of vessel:** Geoscience research vessel

3. **Name of Captain:** Andrew Codrington

4. **Full name, nationality, and birth date and place in full of all crew members, and their positions on board:** See attached crew list

5. **Full name, nationalities, and birth date and place in full of all passengers including scientific and technical personnel:** See attached scientific and technical personnel list

6. **Length, breadth, draught and registered tonnage.**

Length, overall	:	72.5 metres
Breadth	:	13.8 metres
Draught	:	6.0 metres
Registered Tonnage	:	1545 tonnes

7. **Source of motive power.**

Main:	Diesel Norma KVMB -12 2640 H.P./825 rpm
Aux:	3 * Caterpillar - 564 H.P./KVA
	1 * Mercedes - 78 H.P./KVA

8. **Navigation equipment.**
- Magnavox T-set Global Positioning System receiver
- Magnavox MX1107RS and MX1142 transit satellite receivers
- Magnavox MX610D and Raytheon DSN450 dual axis sonar dopplers
- Sperry, Arma-Brown and Robertson gyro-compasses; Ben paddle log
- RACAL SKYFIX differential GPS system

9. **Itinerary of any visit to New Zealand port.**
Nil - vessel to sail from and return to Sydney Australia. Proposed departure from Sydney on Friday evening 6th November 1992, returning to Sydney on Saturday 5th December 1992.

10. **Name of ship's agent:** The Australian Maritime Safety Authority; P.O. Box 10001, Brisbane, Queensland 4000. Ph. (617) 835-3600; Fax. (617) 832-1202.

11. **Full description of the nature and objective of the research project.**
Objectives:
To investigate the structure, stratigraphy, and basin development of the southern Lord Howe Rise, southern New Caledonia Basin, and West Norfolk Ridge in the Australia / New Zealand boundary zone. In addition, to determine

the major tectonic fabric of the region including the nature of the crust (continental or oceanic) underlying the New Caledonia Basin (see attached Executive Summary).

Relevance:
This project is of direct relevance to the definition of the seabed boundary between Australia and New Zealand on the south western margin of the Lord Howe Rise, as well as to increase our understanding of the evolution of the Tasman Sea and the adjacent plateaus and basins.

Expected outcomes:
An enhanced understanding of the geological framework and resource potential of the area likely to be the subject of negotiations for an Australia-New Zealand seabed boundary.

12. Method and means to be used and a description of the scientific equipment.
See attached technical list of *Rig Seismic* specifications

Equipment to be used on the cruise:
- 2400-3200m, 96-128 channel, seismic streamer
- 2x16 element airgun arrays with a normal operating capacity of 3000 cubic inches
- echo sounders, magnetometer, marine gravity meter
- rock dredges and sediment corers

13. Details of any radioactive or hazardous substances on board:
Nil.

14. Precise geographical areas in which the activities are to be conducted:
See attached survey area map.

15. Sponsoring institution:
Australian Geological Survey Organisation (formerly the Bureau of Mineral Resources, Geology and Geophysics), Department of Primary Industries and Energy.

Head of program:	Dr Neville Exon	61 6 249 9327
Project leaders:	Mr Phill Symonds	61 6 249 9490
	Mr Barry Willcox	61 6 249 9273
Cruise Leader	Mr John Marshall	

Ships No.s'

Fax	(Marisat)	0015 872 1545120
Voice	(Marisat)	0015 872 1545121
Cellular phone		018 620 515

RV RIG SEISMIC - FIT OF RADAR, RADIO, and SONAR TRANSMITTERS

RADARS

1 X - BAND 3CM

1 S - BAND 10CM

RADIOS

INMARSAT 'A' SHIP ID 1545120

INMARSAT 'C' SHIP ID 450300183

1 SAILOR MF/HF TRANSCIEVER LISTENING ON 4125.0 KHz FITTED WITH AUSTRALIAN RADPHONE FREQUENCIES

SEISMIC CABLE TAILBUOY FITTED WITH:

RADIO MODEM TO A 2 WATT Tx @ 162.25 MHz TRANSMITTING EVERY 2 SECONDS

ARGOS Tx @ 401.650 MHz TRANSMITTING EVERY 60 SECONDS

SONARS

MAGNAVOX MX610D/DX	DOPPLER SONAR	FREQUENCY 150 KHz
RAYTHEON DSN 450 MARK2	DOPPLER SONAR	FREQUENCY 450 KHz

ECHO SOUNDERS

12 KHz DEEP SEA SOUNDER	2 KILOWATTS
3.5 KHz SUB BOTTOM PROFILER	2 KILOWATTS

CALL SIGN

VMMR

Research Vessel Rig Seismic

R.V. *Rig Seismic* is a seismic research vessel with dynamic positioning capability, chartered and equipped by BMR to carry out the Continental Margins Program. The ship was built in Norway in 1982 and arrived in Australia to be fitted out for geoscientific research in October 1984. It is registered in Newcastle, New South Wales, and is operated for BMR by the Australian Maritime Safety Authority.

Gross Registered Tonnage:			1545 tonnes
Length, overall:			72.5 metres
Breadth:			13.8 metres
Draft:			6.0 metres
Engines:	Main:	Norma KVMB-12	2640 H.P./825 r.p.m.
	Aux:	3 x Caterpillar	564 H.P./482 KVA
		1 x Mercedes	78 H.P./56 KVA
	Shaft generator:		AVK 1000 KVA; 440 V/60 Hz
Side Thrusters:			2 foward, 1 aft, each 600 H.P.
Helicopter deck:			20 metres diameter
Accommodation:			39 single cabins and hospital

Scientific equipment

FJORD Instruments seismic receiving array: 6.25 m, 12.5 m, 18.75 m and 25 m group lengths, up to 288 channels; up to 6000 metres active streamer length

Syntron RCL-3 cable levellers; individual remote control and depth readout

Haliburton Geophysical Service 32 x 150 cubic inch airguns in two 16 gun arrays; the normal operating array is 2 x 10 guns, giving a total of 3000 cubic inches normal operating array volume

Seismic Systems S-15 and S-80 high resolution water gun array consisting of 5 x 80 cubic inch

Air compressor system: 6 x A-300 Price compressors, each providing 300 scfm at 2000 psi (62 litres/min at 14 MPa)

Digital seismic acquisition system designed and built by BMR running on DEC µVAX 3500:

- 0.5msec-4msec sampling interval, 2sec-16sec record length
- Phoenix A/D converter and instantaneous floating point amplifier
- Data stored on Telex tape drives (6250bpi, 75ips), *soon to be updated to Fujitsu 3480 cartridge tape drives*
- Data in demultiplexed (modified) SEG-Y format.

Reftek and Yaesu sonobuoy receivers

Raytheon echo sounders: 3.5 KHz (2 K.W.), 16 transducer sub bottom profiler and 12 KHz (2 K.W.)

Geometrics G801/803 magnetometer/gradiometer

Bodenseewerk Geosystem KSS-31 marine gravity meter

E.G. & G. model 990 sidescan sonar with 1000 m of cable

Nichiyu Giken Kogyo model NTS-11AU heatflow probe

Australian Winch and Haulage deepsea winch with 10 000 metres of 18 mm wire rope and hydrographic winch with 4000 m of 6 m wire rope

Coring and rock dredging systems (various) and vibracorer

Light hydrocarbon extractor and gas chromatographs for continuous DHD (direct hydrocarbon detection) in bottom water

Hydrocarbon gas analyses in sediments

Geochemical analysis equipment for environmental monitoring.

15 metre A frame with a 12.5 ton load capability, using a variety of winches, supporting towed arrays and future capability for large scale deep coring and drilling

Navigation equipment

Magnavox T-Set Global Positioning System navigator

Magnavox MX 1107RS and MX 1142 transit satellite receivers

Magnavox MX 610D and Raytheon DSN 450 dual axis sonar dopplers

Sperry, Arma Brown and Robertson gyro-compasses; plus Ben paddle log

RACAL SKYFIX differential GPS system