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Executive Summary

Australian Geological Survey Organisation marine survey 206 took place between 21 April and 24 May, 1998. It represents the start of a collaborative arrangement between Australia and France to improve the understanding of the geological framework of the crust and contained sedimentary basins between the eastern Australian margin and the New Hebrides Trench system.

The major objectives of the cruise were:

- to understand the geological framework and tectonic evolution of the region; and
- to determine the distribution, nature, tectonic development and resource potential of sedimentary basins;
- to acquire data to enhance French and Australian claims for legal Continental Shelf beyond their respective Exclusive Economic Zones, adjacent to the agreed Australia-France seabed boundary.

A total of some 4600 km of deep seismic coverage was obtained, along with continuous bathymetry and gravity data; magnetic data were only acquired on seismic lines. Navigation was provided by two independent differential GPS systems.

A preliminary interpretation of the data has primarily identified:

- continent-ocean boundaries for the eastern flank of the Lord Howe Rise and the western edge of the Dampier Ridge;
- a probable Mohorovicic discontinuity event to the west of New Caledonia and beneath the continent-ocean boundary between the Norfolk Ridge and west New Caledonia Basin; and
- an extensive bottom-simulating reflector in the area of the Fairway Basin, between the eastern flank of the Lord Howe Rise and Fairway Ridge, indicating the widespread presence of gas hydrates.

Interpretation of seismic data provides strong evidence for the continental nature of the Lord Howe Rise crustal element, which will serve to strengthen the argument for natural prolongation of the continental margins beyond the respective Exclusive Economic Zones of Australia and France.

Introduction

Over the past few years, discussions between Australian and French scientists have focussed on a ship-time exchange program as a means of promoting collaborative geoscientific studies in the northern Lord Howe Rise/Norfolk Ridge/New Caledonia region: areas of mutual national interest. As a result of this, an agreement was reached in mid-1997 to conduct two surveys over parts of these areas.

The first of an initial two-survey program was operated by the Australian Geological Survey Organisation (AGSO), using the marine vessel RV *Rig Seismic* (Appendix 3), and was to be carried out in the first half of 1998. Its broad objectives were three-fold (Lafoy et al., 1998):

- from a scientific perspective, to examine the deep structure of submarine ridges and basins located between Australia, New Caledonia and the New Hebrides Trench (NHT) complex, in order to understand the geological framework and tectonic evolution of the region;

- from a resource prospectivity perspective, to better assess the hydrocarbon potential of the region's deep-water sedimentary basins - the stratigraphy and structural characteristics; and

- from a seabed jurisdiction perspective, to acquire data to enhance claims under the United Nations Convention on the Law of the Sea (UNCLOS) for 'legal' Continental Shelf (CS) beyond the respective Exclusive Economic Zones (EEZs), adjacent to the agreed Australia-France seabed boundary.

The second survey of the collaborative program is to be carried out by the Institut Français de Récherche pour la Exploitation de la Mer (IFREMER), using its marine vessel, the NO *l'Atalante*. At this stage, it will take place in the second half of 1999 and concentrate in the Norfolk Ridge region, with the following broad objectives:

- to obtain a clearer picture of the area of complex morphology to the east of the Norfolk Ridge and west of the Three Kings Ridge, as an aid to understanding the tectonic evolution and resource potential of the region; and

- to examine the extent and nature of possible Australian and French CS to the east and southeast, respectively, of their EEZs.

The first survey aimed to meet its objectives using deep-seismic techniques, while the second will acquire multi-beam swath bathymetry.

This report[1] presents the preliminary results of the first of the two-survey collaborative project. It was conducted as AGSO Law of the Sea Survey 206. The cruise began in

[1] The data, and the interpretations based on that data, contained in this report are preliminary only. It is not necessarily indicative or representative of the final information that might be used by Australia to support the location of the outer limit of the continental shelf beyond 200 nautical miles.

Noumea, New Caledonia on 21 April, 1998, and ended in Brisbane, Australia on 24 May, 1998. A total of some 4600 km of deep-seismic data were collected along four transects. Furthermore, bathymetry, gravity and magnetics data were generally acquired continuously for the cruise duration. Navigation was provided by two independent differential GPS systems. The weather on the survey was mostly fine with short periods of high-swell sea states producing moderate levels of cable noise.

Geological Framework

The survey area, located within the Southwest Pacific region, extends from the eastern margin of Australia to the southern part of the New Hebrides Arc complex. The survey area is approximately bounded by longitudes 153° E and 172° E, and by latitudes 20° S and 30° S. From a plate tectonic viewpoint, it is broadly defined by the subduction of the Indo-Australian Plate beneath the New Hebrides Arc (NHA), which forms an active convergent margin for ocean-ocean crust at the edge of the Pacific plate. The direction of convergence trends WSW-ENE and occurs at a rate of 12 cm/yr (Dubois et al., 1977).

The overall tectonic setting of the survey area is understood to be the result of successive openings of marginal basins since the late Cretaceous. That is, progressive rifting occurred at the eastern margin of the Australia-Antarctic supercontinent (Gondwana), followed by continental break-up and seafloor spreading, island arc development and the creation of new ocean basins by continued spreading (Symonds et al., 1997). This process began with the opening of the Tasman and New Caledonia marginal basins (Weissel & Hayes, 1977; Mignot, 1984), which acted to isolate two major ribbon continents: the Lord Howe Rise (LHR) between the oceanic Tasman Basin and New Caledonia Basin (NCB), and to the east of the NCB, the Norfolk Ridge. In summary then, the break-up produced, from west to east across the survey area, the following submarine features: the east Australian continental margin, Tasman Basin, Dampier Ridge, Middleton and Lord Howe basins, LHR, Fairway Basin, Fairway Ridge, NCB, western NCB, Norfolk Ridge, Loyalty Basin, Loyalty Ridge, South Fiji Basin (SFB) and New Hebrides Trench.

Stratigraphic control in the region is provided by five Deep Sea Drilling Project (DSDP) holes. Two holes are located within the northern part of the survey area: one on the northern LHR at site 208 (Burns, Andrews et al., 1973; Van der Lingen et al., 1973) and the other at site 587 (Kennett & Von der Borch, 1985) on the Lansdowne-Fairway Ridge. The other three holes were drilled to the south: site 206 in the NCB, site 207 and site 592 on the LHR. Seismic stratigraphy frameworks were developed by Willcox et al. (1980), and Uruski & Wood (1991), for the central LHR region and southern NCB, respectively.

Survey Objectives and Line Design

The broad objectives of Survey 206 are outlined above. These can be further developed into a series of specific issues that the design of the survey aimed to address (Lafoy et al., 1998):

1. the nature of the continent-ocean crust transitions across the eastern margin of the Tasman Basin to the western margin of the LHR;

2. the structural style, depositional history and tectonic development of the sedimentary basin system on the LHR;

3. the nature of the crustal transition across the eastern margin of the LHR into the western margin of the Fairway Basin;

4. the occurrence of compressive tectonics that may have affected the NCB during obduction of ophiolitic nappes in the late Eocene;

5. the nature of the crustal transition across the eastern margin of the NCB into the western margin of the Norfolk Ridge;

6. the evidence for remnants of the Loyalty Basin lithosphere along the eastern flank of the Norfolk/New Caledonia ridge system;

7. the still unknown genesis and nature of the Loyalty Ridge;

8. the macro-level effects, westwards, of the NHA collision system;

9. the nature of compressional tectonics due to the apparent resistance to subduction by the Loyalty Ridge and its effects on the subduction process;

10. the potential for hydrocarbon generation and entrapment in the basin systems within the region, particularly beneath the western LHR and flanks of the NCB, Fairway Basin and Loyalty Basin;

11. the collection of data, so as to support arguments for the extended continental crust nature of the LHR and Norfolk Ridge submarine features, and so enhance claims for respective CS up to the agreed Australia-France seabed boundary.

Given the vast size of the region and the time constraints imposed by one 4-5 week-long marine survey, the objectives were considered to be best targeted by the appropriate positioning of four deep-seismic transects. These lines were named LHRNC-A, LHRNC-B, LHRNC-C and LHRNC-D (Appendix 5). Their layout in relation to the general bathymetry and broad morphological features is presented in Figures 1 and 2, respectively. A discussion of the aims to be targeted by these individual lines is given below.

Seismic line LHRNC-A
Line LHRNC-A was designed to commence on the western New Caledonia continental margin and end further to the west, via a dogleg on the Fairway Ridge, over the western flank of the LHR. A deep seismic transect of the NCB, Fairway

Ridge, Fairway Basin and most of the LHR was desired. This line addressed issues 2, 3, 4 and 10 above.

Seismic line LHRNC-B
Line LHRNC-B trends NNW-SSE over the northern half of the LHR and was intended to provide a view of the contained sedimentary basins and underlying deep crust. A small dogleg provided ties mid-way down the line at DSDP site 208 and at the southern end with Shell *Petrel* seismic line 1001/704. It was also intended to serve as a seismic tie for the three NE-SW seismic transects. Issues 2, 10 and 11 above were addressed.

Seismic line LHRNC-C
Line LHRNC-C was designed as a major transect across LHR, Fairway Basin, Fairway Ridge, NCB, western NCB, Norfolk Ridge, Loyalty Basin, Loyalty Ridge, SFB and NHT crustal features. It addressed issues 2-11 outlined above.

Seismic line LHRNC-D
Line LHRNC-D provides the most detailed deep-seismic profile, to date, of the crustal elements making up the Australian plate, from its subduction zone below the Pacific Plate in the east across to the eastern Australian margin in the west. It addressed all the issues outlined above.

Survey Line Summary

The following listing summarises the lengths for the seismic lines on Survey 206, and is given in acquisition order. The way points proposed and actually implemented are found in Appendix 5.

Line (proposed name)	Length (km) proposed	Length (km) actual	Alterations
206/01 (LHRNC-A)	~ 668	~ 672	lengthened slightly
206/02 (LHRNC-B)	~ 727	~ 727	none
206/03 (LHRNC-C)	~ 1340	~ 1215	shortened at the western end
206/04 (LHRNC-D)	~ 1815	~ 1950	small dogleg at Walpole Island; direction changed and lengthened, near end-of-line, towards the west
Total:	~ 4550	~ 4564	

The proposed and actual seismic lines are depicted in Figure 1.

Onboard Line Descriptions

To facilitate descriptions of the geological framework of the region three of the four lines have been subdivided. Line LHRNC-A is divided into lines LHRNC-A1 and LHRNC-A2 at the dogleg over the Fairway Ridge. Line LHRNC-C is divided into lines LHRNC-C1 and LHRNC-C2 at the dogleg over the same feature. Line LHRNC-D is divided into lines LHRNC-D1, LHRNC-D2 and LHRNC-D3 at the eastern dogleg over the LHR and the western dogleg over the Tasman Basin, respectively (see Figure 1). Although this report presents these lines as subdivisions of lines LHRNC-A, LHRNC-B, LHRNC-C and LHRNC-D, the proposed lines were actually recorded as lines 206/01, 206/02, 206/03 and 206/04, respectively.

It should be emphasised that both the line descriptions and dating of seismic sequences presented (Lafoy et al., 1998) is based on a preliminary interpretation of onboard brute stacks and single-channel monitor records - usually channel 1. The descriptions of lines LHRNC-A1, LHRNC-A2, LHRNC-B and LHRNC-C2 are taken from onboard-processed brute stacks, while those for LHRNC-C1, LHRNC-D1, LHRNC-D2 and LHRNC-D3 are interpretations of single-channel monitor sections.

In the following discussion all references to depths and thicknesses given in time are with respect to seismic two-way time.

Line LHRNC-A1 - profile from western New Caledonia margin to Fairway Ridge

Line LHRNC-A1 is a 222 km profile representing that part of line LHRNC-A trending NE-SW, from the western New Caledonia margin to the Fairway Ridge (SPs 1000-5440, Fig. 3(a)). The line was commenced several kilometres to the NE from the proposed start-of-line (SOL) position. This enabled a tie to be made to a deep-seismic survey acquired in 1995 (Blake, 1996) over the Gouaro anticline on the New Caledonian western coast.

Preliminary Description
From NE to SW, line LHRNC-A1 successively profiles: a) the western margin of New Caledonia; the NW-SE trending NCB; and c) the northeastern flank of the similarly trending Fairway Ridge. For the following discussion refer to Figure 3(a):

a) On the western margin of New Caledonia the line starts near Gouaro Bay, in about 2000 m water depth. The continental slope then descends rapidly into the eastern margin of the NCB, with its base at 3300 m depth (SP 1700), and is underlain by about 3000 ms of sediment. Reflectors here are largely masked by diffractions off the rugged sloping seafloor.

b) The 120 km-wide, NW-SE trending NCB is characterised by a flat sea floor that averages 3650 m in depth. The basin formed is bounded to the east by a steep, west-facing normal fault (SP 1600), and shows a deep horst and graben morphology, with a central horst dominating at SPs 2800-3200. This horst is overlain by sedimentary units up to 1.3 s thick. A weak curvilinear reflection event underlying it, at a depth of about 8.4 s, is possibly Moho. To the east, the central horst is flanked by an 85 km-wide deep graben (SPs 1600-2400) containing over 4 s of sediment. West of the central horst, a 20 km-wide graben holds about 2.3 s of sediment (SPs 3300-3700).

Four main seismic sequences, more or less folded, can be identified within the NCB. These are:

- Sequence 4, a unit with a maximum thickness of about 1.2 s, found at the base of the main graben;

- Sequence 3, a unit that onlaps out on the eastern margin of the Fairway Ridge and is well expressed in the main graben, where it averages 400 ms in thickness;

- Sequence 2, a 1.8 s-thick unit at the base of the New Caledonian margin that gradually thins westwards averaging 200 ms, before pinching out on the eastern flank of the Fairway Ridge; and

- Sequence 1, with the related underlying sequence 1', averages 1.3 s in thickness. On the cruise, sequence 1' was only distinguished from sequence 1 in areas where deposits are thick, such as in basins.

c) The western margin of NCB ends at the foot of the NW-SE trending Fairway Ridge (SP 3800) and is defined by an east-facing normal fault. From about SP 3800 to the end-of-line (EOL), the slope climbs the Fairway Ridge. The sedimentary units on the flank average a total of 1.5 s in thickness and thin to 600 ms on the crest of the ridge, where the water depth is about 2100 m. Only sequences 2, 1' and 1 appear to extend up the flank.

Seismic Sequence Dating

According to both the evidence from DSDP site 206 (Burns, Andrews et al., 1973) drilled in the southern part of the NCB, and the studies of Uruski & Wood (1991), the unconformities bounding the sequences can be dated. Seismic sequences 4 and 3 are likely to be of Cretaceous/pre-Cretaceous age, in agreement with the correlation by Uruski & Wood (1991) of the seismic sequences in the southernmost part of the NCB. The reflector at the base of seismic unit 3 probably represents a change in facies within the Cretaceous, while that between seismic units 3 and 2 is interpreted to be of middle Palaeocene/middle Eocene age. Further up the stratigraphic column, the unconformity between sequences 2 and 1' is interpreted to represent the late Eocene/middle Oligocene regional unconformity. Sequence 1', present mainly within deeply sedimented areas such as basins (Mignot, 1984), probably corresponds to early Oligocene deposits resulting from the sub-aerial erosion of shallow uplifted features.

Preliminary Interpretation

Throughout the NCB, the folding of the deeper seismic sequences probably results from convergent tectonism to the east. That is, the thrusting of the ophiolite nappe over the New Caledonia mainland. The deep curvilinear reflector beneath the basin central horst, identified above, lies about 2 s beneath acoustic basement, and suggests an average thickness of 6 km (based on a Vp of 6 km/sec) for the probable oceanic crust at the base of the NCB.

The bulge-like morphology of the eastern flank of the Fairway Ridge indicates the existence of a compressive regime throughout. Data from DSDP sites 206 and 208 (Burns, Andrews et al., 1973), suggest that the compression is likely synchronous with the late Eocene obduction of the New Caledonian ophiolites, as previously suggested by Lafoy et al. (1994), and might have been active up to the present.

Line LHRNC-A2 - profile of Fairway Ridge to western LHR flank

Line LHRNC-A2 is an approximate 450 km-long profile across the Fairway ridge and basin system extending to the western flank of the LHR. It represents that part of line LHRNC-A trending ENE-WSW from the dogleg over the Fairway Ridge (SPs 5440-14200, Fig. 3(a)). It intersects line LHRNC-B at about SP 11550.

Preliminary Description
From ENE to WSW the line successively crosscuts: a) the crest and western flank of the Fairway Ridge; b) the Fairway Basin; c) the broad plateau of the N-S trending LHR; and d) the depression that lies between the LHR and the guyots dotting its western flank - see Figure 2. For the following discussion refer to Figure 3(a):

a) Beneath the Fairway Ridge, acoustic basement defines a 45 km-wide horst (SPs 5100-6000), slightly tilted to the west, and overlain by about 800 ms of sediment. At SP 6000 the acoustic basement drops from about 4.2 s to 5 s, on a west-facing normal fault. The Fairway Ridge is about 115 km-wide and shows a transverse asymmetric morphology defined both by a basement uplift partly rotated to the west, and an easterly flank that is covered by about 1.5 s of sediment. A deep seismic event beneath the ridge, at about 5.3 s and SP 5450, is too shallow to be Moho.

b) The 160 km-wide Fairway Basin (SPs 6000-9000) shows a smooth topography at the sea floor, with a slight bulge at its centre (SPs 6600-7800), and an average depth of 2300 m. About 40 km in from its eastern edge, the basement is dominated by a 35 km-wide graben complex (SPs 6700-7400) that forms a depocentre containing up to 3 s of sediment. Five seismic sequences can be interpreted in the basin:

- Sequence 4, a unit that is separated from the overlying sequence 3 by a reflector that might represent a change in facies within the Cretaceous, and reaches a maximum thickness of 300 ms in the basin's main depocentre;

- Sequence 3, a unit reaching a maximum thickness of 1 s in the depocentre, and extending to the east where it directly overlies acoustic basement;

- Sequence 2, a unit with an average thickness of 600 ms to a maximum of 900 ms over faulted basement at about SP 7900;

- Sequence 1', a generally 400 ms-thick unit that appears to thin and continue on over the Fairway Ridge and pinches out to the west at about SP 9500; and

- Sequence 1, a unit 600 ms thick on average that appears to continue across the Fairway Ridge from the NCB, and over the LHR as well.

c) The LHR extends from about SP 9000 across to EOL in the west. At SP 9100, sequence 1' disappears and sediment thins on the crest of the ridge to about 400 ms, where it abuts a seamount. The existence of compressive faulting along the eastern flank of the LHR, as evidenced both by Lafoy et al. (1994) to the north and by Marshall et al. (1994) to the south, may be confirmed on the final processed data. In addition, possible thrusting is interpreted from SPs 9100-9500. The narrow eastern flank of the LHR overlies a couple of westward-tilted horsts (near SP 7900) that lie along the western edge of the Fairway Basin. Sedimentary thickness here averages 1.8 s.

Over the crest of the ridge, thin sediments (300 ms) overlie planated basement (SPs 9500-10400). The crest is dominated by two volcanic peaks at SPs 10200 and 10400, which culminate at depths of 450 m and 1000 m, respectively. The western peak is flanked by a west-facing normal fault that bounds the central ridge to the west. This area was previously extensively surveyed with swath bathymetry and other geophysical techniques by the N/O *l'Atalante* in the ZoNéCo 4 program (Le Suavé et al., 1996). From the late Eocene to middle Oligocene, the ridge began subsiding contemporaneously with the late Eocene development of the New Caledonian ophiolites. This was then followed by a volcanic phase that started in the late Oligocene and ended with the recent termination of subsidence (Van de Beuque et al., 1998).

The western LHR province is dominated by a horst and graben morphology, with numerous half-grabens, 10-15 km-wide and average 2 s sediment-fill, tilted towards the west. In the range SPs 13100-13900, the acoustic basement shallows and is overlain by sequences 1 and 2, averaging 1 s in thickness. Parts of this western zone of the LHR are characterised by faulting through to the seabed, indicating that extensional tectonics have probably been active to the present.

d) The line ends within the depression that lies between the western province of the LHR and the line of guyots along its western flank. This depression is underlain by sediments of an average 1.4 s thickness.

Preliminary Interpretation
According to data from DSDP sites 208 (Burns, Andrews et al., 1973) and 592 (Kennett & Von der Borch, 1985) drilled on the LHR, as well as Willcox et al. (1980), unconformities bounding the seismic units can be dated. Line LHRNC-A2 confirms the presence on the western LHR, beneath sequence 1 (dated mid-late Oligocene to the Recent), of a series of horst and graben structures rotated westwards. These contain faulted and folded sediments that are likely to be of late Cretaceous to late Eocene age.

Line LHRNC-B - profile along Lord Howe Rise ridge

Line LHRNC-B is a 727 km-long seismic transect trending NNW-SSE, sub-parallel to the general N-S trend of the LHR. Apart from providing a deep-crustal view of the rise, it was designed to tie the other three lines of the survey to each other and to the stratigraphy established at DSDP site 208. At its northern end, it ties to seismic profiles MOBIL 298-299 and West New Caledonia 111, surveys recorded in 1972 and 1981, respectively. At its southern end, it ties to seismic profiles SHELL 1001/704 and RV *Sonne* Cruise 306 (Roeser et al., 1985).

Preliminary Description

From N to S along profile LHRNC-B, the western province of the LHR is characterised by an average water depth of 1560 m, and reaches a high-mark of 1270 m at about SP 6600. The western LHR is characterised by an along-strike horst and graben morphology, which is locally pierced by volcanic intrusions. Seismic sequence 1, dated from the mid-Oligocene to Recent, is present over the whole line with a constant thickness of 700 ms. From N to S, the line can be divided into three main parts: a) the northwestern LHR; b) the central-western LHR; and c) the southwestern LHR. For the following discussion refer to Figure 3(b):

a) The northwestern LHR can be taken from SOL to SP 4550. It is characterised by a series of southwards-tilted horst and graben structures that end at the north-facing normal fault centred at SP 4500. The sedimentary section generally thickens to the south and reaches a maximum of about 2 s at about SP 4400, within a 30 km-wide half-graben (SPs 3950-4550) pierced by a volcanic intrusion near SP 4200.

b) The central-western part of the LHR can be taken from SP 4550 to 9800. In the SP range 6350-6900, the dominant feature is a 35 km-wide southerly-rotated basement block with a planated top at about 2.2 s depth, overlain by a 400 ms-thick pile of sediments. South of this feature, a 140 km-wide graben structure (SPs 7200-10000), possibly intruded, is overlain by a sedimentary section that reaches a maximum thickness of 2.2 s (SP 8100). The southern flank of the horst bounding this feature to the north was drilled at DSDP site 208. Results from this site (Burns, Andrews et al., 1973) and site 592 (Kennett & Von der Borch, 1985), together with an interpretation of reflectors on line AUSTRADEC 101 (Ravenne et al., 1973), suggest the following for the sequence boundaries present:

1) the acoustic basement, at 3.8 s depth, could be an unconformity within the Cretaceous;

2) the reflector at about 3.6 s (base of sequence 3) is interpreted to represent a late Cretaceous unconformity;

3) the reflector at about 3.3 s (base of sequence 2) is an unconformity of middle Palaeocene/middle Eocene age;

4) the reflector at about 3.1 s (base of sequence 1) is interpreted to represent the late Eocene/middle Oligocene regional unconformity; and

5) the internal discontinuous reflector within sequence 1, at about 2.8 s, probably represents a change in facies within the Miocene.

(c) The southwestern LHR can be taken from SP 10000, where it starts on a narrow horst, flanked by sediments of sequence 1, to EOL. This part of the ridge is characterised by a series of northward-tilted horst and graben structures overlain by a sedimentary series that generally thickens to the north. It is dominated by a major fault-bounded depocentre in the range SPs 10400-11400, where sediment thickness reaches a maximum of 3 s.

Preliminary Interpretation
Line LHRNC-B is tied to DSDP site 208, which enables dating of the sequence boundaries. Overlying locally faulted, folded and intruded Cretaceous sediments is the post-Palaeocene to middle Eocene sequence 2, and more extensive post-Oligocene sequence 1. The tilted horst and graben morphology indicates a period of extensional tectonics for the western LHR region.

Line LHRNC-C1 - profile from western LHR flank to Fairway Ridge

The 475 km-long profile LHRNC-C1 represents that part of line LHRNC-C trending WSW-ENE, from SOL over the western LHR to the dogleg on the Fairway Ridge (SPs 1000-10500, Fig. 3(c)).

Preliminary Description
Line LHRNC-C1 successively intersects, from west to east: a) the western province of the LHR; b) the central LHR; c) the eastern flank of the LHR; and d) the Fairway Basin. For the following discussion refer to Figure 3(c):

a) The western LHR extends from SOL to about SP 4600. From SOL to SP 1850 it profiles the depression that lies between the LHR guyots and the western flank of the central rise. Water depth gradually shallows to the east as the profile extends over the main elevated plateau region of the rise. This region shows a dominant horst and graben morphology, overlain by a faulted and folded sequence averaging 1.6 s in thickness, and pre-dating the late Eocene.

b) The central LHR region lies between SPs 4600-6400 in an average water depth of 1200 m. A section of elevated planated basement stretches for about 90 km and lies at about 2 s. It is flanked on either side by westward-tilted horsts. Overlying basement, sequence 1 is about 1.4 s thick and may have been affected at the summit by extensional tectonics as suggested by the development of three small grabens at the seafloor, centred at SPs 4800, 5150 and 6150.

c) The narrow eastern LHR region can be taken to extend between SPs 6400-7000, starting in the west over a westward-tilted half-graben and ending to the east against a steep, east-facing normal fault. This fault may define the continent-ocean boundary (COB) between the continental ridge and oceanic crust at the base of the Fairway Basin. Furthermore, east of the fault, a reflector at about 4 s depth is characterised by strong reflectivity and diffractions, both typical of an oceanic crust signature. Sediments to the east of SP 7000 average 2 s in thickness and are defined by strong amplitude and continuous reflections. These strata probably represent the uplifted western margin of the Fairway Basin.

d) The Fairway Basin (sensu stricto) can be taken to lie between SPs 9000-10500, though its western flank extends up the LHR margin to about SP 7000. Deepening to the east, the western edge is characterised by an easterly-dipping sedimentary series. Likewise, the uppermost sequence 1 thickens from 600 ms at SP 7000 to 900 ms at SP 8300. The top of sequence 1 is affected by numerous small-scale normal faults. From SP 8500 to EOL, the Fairway Basin shows a constant water depth of about 3000 m and variable sediment thickness, reaching a maximum of 2 s in a depocentre centred at SP 9450, over uplifted and faulted basement.

Preliminary Interpretation
Line LHRNC-C1 is intersected by AGSO Survey 177 line LHRNR-B (Ramsay et al., 1997) at approximately SP 9600 over the Fairway Basin. On a migrated version of this line available on board, we could identify a strong, deep reflector at a depth of 9 s. We interpret this to possibly represent the Mohorovicic discontinuity beneath the Fairway Basin. With an observed depth of 3.5 s below acoustic basement and an average crustal velocity of 6 km/sec, a crustal thickness of 10 km results. This is slightly high for oceanic crust and quite low for continental crust, which could be accounted for by crustal stretching and subsequent thinning below the basin.

A bottom-simulating reflector (BSR) was identified down the eastern flank of the LHR across the Fairway Basin and over the Fairway Ridge (SPs 7000-11500). It tracks the sea floor at a depth of approximately 600 ms. Post-cruise analysis suggested that it likely represents the base of a zone of gas hydrates[3].

Line LHRNC-C2 - profile from Fairway Ridge to New Hebrides Arc complex

The 740 km-long profile LHRNC-C2 trends SW-NE and represents that part of line LHRNC-C to the northeast of the dogleg over the Fairway Ridge. It affords an excellent deep-crustal view of the tectonic elements defining the subducted zone of a convergent margin.

Preliminary Description
Line LHRNC-2 successively traverses: a) the southern end of the Fairway Ridge; b) the NCB; c) the West New Caledonia Basin (WNCB); d) the Norfolk Ridge; e) the Loyalty Basin; f) the Loyalty Ridge; g) the South-Fiji Basin (SFB); and h) the NHT system. In the following discussion reference should be made to Figure 3(c):

[3] Gas hydrates are a frozen crystalline mixture of methane and water.

a) The southern end of the Fairway Ridge trends NNW-SSE in the area crossed by this line. It averages 3000 m in depth, is about 15 km wide and is associated with a basement uplift event culminating in a peak at 4.5 s at about SP 10700. A reflector at 7.4 s is evident here but is probably too shallow to represent Moho.

b) The NCB (sensu stricto) is taken to lie in the SP range 10900-12900. It is bounded to the west by a steep east-facing normal fault that flanks the Fairway Ridge and ends in the east against a steep west-facing normal fault that also defines the transition to an area dominated by an elevated basement platform. In the west, the NCB commences as a bulged section over faulted and uplifted basement (SPs 10900-12000). In the east it is defined as a narrow 45 km stretch of mostly flat-lying strata with a horizontal seabed. The maximum thickness of sediment is 2 s, filling a graben between SPs 12400-12800. A reflector at 8.9 s below SP 12300 might represent Moho at about 3 s below acoustic basement. Using a crustal velocity of 6 km/s this represents a crustal thickness of 9 km beneath the NCB, which, as mentioned above, may be thinned oceanic or stretched continental crust.

c) The WNCB lies immediately east of the NCB and is spread from SP 12900 to about SP 15200. This 110 km-wide transitional feature that links the NCB to the Norfolk Ridge and thickens slightly to the east, is comprised of two parts. Between SPs 13000-14000 it is defined by a discontinuous sedimentary series, folded and faulted up to the surface. Between SPs 14000-15200 it is characterised by a west-dipping sedimentary cover of more continuous reflectors, partly affected by faulting, that reaches a maximum thickness of 1.8 s at the base of the Norfolk Ridge.

d) The Norfolk Ridge extends from SP 15200 to SP 20100. This broad, 245 km-wide, submarine ridge reaches a depth of 1050 m and can be divided into three parts: 1) the western Norfolk Ridge for SPs 15200-17600; 2) a 100 km-wide perched basin for SPs 17600-19600; and 3) an eastern Norfolk Ridge complex for SPs 19600-20100:

> 1) The 160 km-wide western Norfolk Ridge is bounded to the west and east by normal faults. It is characterised by a broad asymmetric bulge shape with a steeper western flank. It is capped by a sedimentary series averaging 1 s in thickness and increasing to the east. A reflector at 7.4 s below about SP 15200 was noted and may represent Moho close to a possible COB. If a crustal velocity of 6 km/s is used, the 3.5 s gap to basement represents a crustal thickness of 10-11 km below the west Norfolk Ridge.
>
> 2) The northeast-tilted perched basin is filled by sediments that reach a maximum thickness of 1.3 s over faulted basement. The reflections are continuous and of strong amplitude. Faulting carries up through the section and has reached the sea floor at about SP 19100.

3) The eastern Norfolk Ridge complex appears to be a broad volcanic intrusion peaking at a water depth of 1200 m. The development of flanking faults may be related to subsequent cooling and contraction.

e) The Loyalty Basin extends from SP 20100 to SP 21200 and has an average seabed depth of 1850 m, though it deepens to the west. The west-dipping sedimentary series thickens slightly to the west and reaches a maximum thickness of 2.4 s at about SP 20300. Here, the onlapping seismic sequences end with angular discordances on the eastern flank of the Norfolk Ridge, where they have affected post-Oligocene sedimentation. These discordances are also present on AUSTRADEC line 104, to the north. Oceanic lithosphere on the floor of the basin was overthrust on the Norfolk/New Caledonia Ridge during the late Eocene.

f) The Loyalty Ridge is 20 km wide and extends from SP 21200 to about SP 21700. It is characterised by an asymmetric transverse morphology, with a steeply faulted and stepped western flank. The observed asymmetric and fractured nature supports the finding of Lafoy et al. (1996) in stating that the ridge morphology is the result of collision along the New Hebrides Arc complex.

g) The SFB is about 55 km wide and extends from SP 21700 to SP 22800. On this line it can be described as a fault-bounded, easterly-dipping perched basin. It deepens to the east from 2250 m to 3750 m and contains an average sediment cover of 1 s. The basin is bounded to the east by a large horst that appears to have blocked Loyalty Ridge derived sediment from filling the NHT. East of this feature the slope plunges steeply into the trench environment and so represents the leading edge of the subducted Australian Plate. The margin here appears to be devoid of sediment, where bulging and gently dipping morphology commonly identify the leading edge of a subducted plate.

h) The NHT system comprises, from west to east: 1) the trench; 2) the trench inner wall; and 3) the frontal arc:

1) The trench itself is only 10 km wide (SPs 23300-23500) and is of asymmetrical shape as the western scarp is steeper than its counterpart to the east. It is devoid of sediments and reaches a maximum depth of about 6930 m.

2) The inner wall of the trench system is defined by a very narrow imbricate zone, which continues from the trench itself to an upper slope discontinuity (SP 23800). An accretionary prism is absent here. Between the upper slope discontinuity and the frontal arc there is a westward-tilted mid-slope depression (SPs 23900-24400). It lies at an average depth of 5250 m and is devoid of sediment.

3) The frontal arc, whose axis is defined by the highest topography along the leading western edge, is 2250 m deep at its summit

(SP 24600). It represents a horst at the western edge of an eastward-tilted basin that is pierced by a seamount (SP 25100).

Preliminary Interpretation
Several deep reflection events may be Moho, but will have to await final processing of the data for confirmation. The steep dip of the western scarp of the NHT system may indicate a period of deceleration for the subduction process.

Line LHRNC-D1 - profile from New Hebrides Arc complex to central LHR

The 1000 km-long profile LHRNC-D1 trends NE-SW and represents that part of transect LHRNC-D extending from the northeastern end over the NHA to the dogleg in the southwest, over the LHR (Figure 1). In scope, it approximately parallels the combined extent of lines LHRNC-C1 and LHRNC-C2, and has similar objectives.

Preliminary Description
On this line the only available sonobuoy was launched, in the vicinity of Walpole Island, to gain some insight into deep crustal velocities. Unfortunately, recording had to cease soon afterwards due to streamer problems.

From northeast to southwest, the line successively intersects: a) the NHT system; b) the SFB; c) the Loyalty Ridge; d) the Loyalty Basin; e) the Norfolk Ridge; f) the WNCB; g) the NCB; h) the Fairway Ridge; i) the Fairway Basin; and j) the LHR. In the following discussion reference should be made to Figure 3(d):

a) The NHT system extends from SOL to about SP 3100. Its characteristics are similar to those described previously for line LHRNC-C2. However, the trench is narrower here, and has a shallower maximum depth of 6450 m.

b) The SFB extends from SP 3100 to SP 4300 and forms a perched, easterly-dipping basin at the top of the western scarp of the NHT. It comprises a sedimentary series that averages 1 s in thickness and is affected by basement-controlled faulting. At about SP 3800, a prominent volcanic intrusion pierces sediment through to the seafloor.

c) The Loyalty Ridge extends from SP 4350 to SP 4700 and is asymmetric with a slight eastwards tilt. Probable indurated coral deposits cap the planated summit, which culminates at 600 m.

d) The Loyalty Basin lies in the range SPs 4700-5850, with slight bulging in the centre. It is made up of an average 2 s thick sedimentary cover that is intensely folded and faulted. Acoustic basement shallows slightly to the west and rises as faulted steps onto the Norfolk Ridge. Interpretation off the single-channel monitor made seismic sequence identification and dating difficult.

e) The Norfolk Ridge is about 170 km wide here (SPs 5900-9300) and has a horst and graben morphology that can be divided, as on line LHRNC-C2, into: 1) an eastern ridge; 2) a perched basin; and 3) a western ridge:

1) The eastern ridge extends from SP 5900 to SP 6250, with its summit at 300 m depth, and probably capped by indurated coral deposits.

2) The 100 km-wide perched basin extends from about SP 6250 to SP 8000. It lies at an average depth of 1100 m and is tilted to the east. The sedimentary series is gently folded, but widely disturbed by intrusives, particularly a large guyot (SP 6700) that rises to a depth of 320 m.

3) The western ridge extends from SP 8000 to SP 9300. It is arched and underlain by a faulted sedimentary series that thickens to the east.

f) The 105 km-wide WNCB is a perched basin on an elevated and heavily faulted basement platform at the foot of the Norfolk Ridge (SPs 9300-11400). It deepens from 2250 m at its eastern end to 3450 m at its western. The sedimentary section reaches a maximum thickness of 2 s in a graben at the foot of an east-facing fault (SP 11500). Here, seismic sequences 3, 2, 1' and 1 (see above for dating) overlie acoustic basement at about 5 s.

g) The NCB (sensu stricto) extends from SP 11500 to SP 14100, and shows a flat sea floor at about 3800 m depth. Here, it forms a wide graben filled with sediments that deepen slightly to the east, where a maximum thickness of 2.2 s is reached (SP 11450) against the east bounding fault. Midway, at SP 12600, a volcanic intrusion pierces sequences 3 and 2, with folding in the base of the overlying sequence 1'.

h) The 55 km-wide Fairway Ridge (SPs 14100-15300) culminates at a depth of 1800 m. It is an arch-like feature that is strongly faulted and intruded. The sedimentary cover averages 1 s in thickness and dips to the east.

i) The Fairway Basin can be taken to extend from SP 15300 to SP 16500. The sea floor shallows to the west while sediment fill thickens to about 2 s in the same direction.

j) The eastern margin of the LHR is profiled from SP 16500 to SP 18300, where it is characterised by an eastwards-dipping and thickening, gently-folded sedimentary series. It is widely affected by intrusions that extend high up into the cover and have promoted faulting. The central elevated platform of the LHR, however, can be taken from SP 18300 to the end of this line at about SP 20700. Here, the ridge reaches the shallowest depth of 1120 m over sediment on uplifted and planated basement (SPs 18300-19300). Further to the west, it is characterised by horst and graben structures having a maximum sediment fill of 1.4 s at SP 20700.

Preliminary Interpretation
As suggested previously, the steep morphology of the NHT, the SFB and the Loyalty Ridge seem to indicate a period in which the subduction process slowed down.

The BSR, noted on line LHRNC-C1, is also present on LHRNC-D1, from the Fairway Ridge up the eastern flank of the LHR. This probably indicates the widespread presence of gas hydrates in the southern Fairway Basin.

Line LHRNC-D2 - profile from central Lord Howe Rise to Tasman Basin

The 740 km-long profile LHRNC-D2 trends ENE-WSW and represents that part of transect LHRNC-D extending from the dogleg over the LHR to the dogleg in the southwest, over the Tasman Basin (Figure 1). As a continuation of line LHRNC-D1, it affords an excellent view of the crustal elements from the east Australian margin to the plate convergence boundary along the New Hebrides Arc complex.

Preliminary Description
From northeast to southwest, the line successively intersects: a) the western LHR; b) the Middleton Basin; c) the Dampier Ridge; and d) the Tasman Basin. In the following discussion reference should be made to Figure 3(e):

a) The western LHR can be taken to extend from SP 20600 to a west-dipping fault at about SP 26000. The ridge commences in the east on uplifted basement blocks and deepens to the west to reach a depth of 2250 m, on the axis of guyots along its western edge. Over the dominant horst and graben structure, sediment reaches a maximum thickness of 2 s near SP 24000. Possible volcanic intrusions at SP 25200 and SP 25500 could represent hotspot activity defining the zone of guyots along the western flank of the LHR (Figure 2).

b) The Middleton Basin stretches from SP 26000 to SP 28300. It deepens slightly to the west, where it averages 3400 m, and is filled by at least 2.4 s of sediment. The character of the basement and overlying reflections was difficult to discern due to the noisy state of the single-channel monitor record.

c) The Dampier Ridge is a broad basement arch that extends from SP 28300 to a steep west-facing fault at SP 31000. Its highest point lies at 2550 m on a seamount (SP 28900) to the east of the central axis. The eastern half of the ridge is characterised by a thick sediment cover that averages 1.2 s in thickness and is extensively pierced by intrusives. On the western half, however, the ridge is characterised by a rugged and planated basement that is down-faulted to the west, and supports a sedimentary cover from 200 ms at its apex to about 1 s thickness down the western margin.

d) The Tasman Basin is taken to extend from SP 31000 to the dogleg at SP 35600. It deepens to the west to reach an average abyssal plain depth of 4800 m. The basin is filled by a sedimentary series overlying strongly faulted oceanic crust. A maximum thickness of 1.8 s is attained in the SP range 34200-34600. There appear to be some small-scale intrusions. Basement at the eastern margin is block-faulted and partly rotated, thereby providing some evidence for initial rifting prior to seafloor spreading.

Preliminary Interpretation
The commencement of an oceanic crust-type signature for basement below SP 31000 may indicate a COB.

Line LHRNC-D3 - profile from Tasman Basin up east Australian margin

The 210 km-long profile LHRNC-D3 trends W-E and represents that part of line LHRNC-D from the dogleg over the Tasman Basin to EOL near the Australian coastline. It affords an excellent view across a passive, steep-sloped continental margin.

Preliminary Description
The Tasman Basin extends from SP 35600 to the foot-of-slope on the Australian margin at SP 38200 (Fig. 3(f)). It is characterised by an average sediment cover of 1-1.5 s thickness over faulted and uplifted oceanic basement. At least three megasequences are present, with the middle one characterised by reflectors of a more chaotic appearance. A wide seafloor bulge at about SP 37000 is likely a contourite mound.

From the western edge of the Tasman Basin to EOL, the profile is dominated by the steep slope and shelf system of Australia's eastern continental margin. A moderate sedimentary section is developed down-slope and abuts against a probable seamount at its base. Basement and sedimentary reflections are difficult to discern on the shelf because of masking effects by multiple water-bottom reflections.

UNCLOS Issues

Clear foot-of-slope candidates are possible on all the lines surveyed, though this was not an essential part of the survey as bathymetric and seismic coverage was already of a sufficient standard in the area, prior to Survey 206, to establish positions for the required UNCLOS parameters (Appendix 1). However, the issue regarding the natural prolongation of the LHR feature has to be addressed before those parameters can be successfully promoted as defining areas of CS. Therefore, profile LHRNC-B was planned as a deep-seismic image along the axis of the LHR. It shows a dominant horst and graben morphology reminiscent of pull-apart tectonics on continental margins. This, coupled with later processing that may show continental-style crustal characteristics, would strongly support the continental nature of the rise. As a result, arguments for natural prolongation of the extensive LHR margin away from the land territories of Lord Howe and the Chesterfield islands, for Australia and France, respectively, could be made. These arguments would then enhance the respective claims of both Australia and France for CS up to the agreed Australia-France seabed boundary.

Conclusions

AGSO marine Survey 206 primarily acquired about 4600 km of multi-channel seismic reflection data. Although complete interpretations and scientific results of the survey will have to await examination of the final reduction of the datasets, considerable information has been extracted from the onboard seismic outputs. The significant findings, from northeast to southwest, are highlighted below:

The NHT system
The NW-SE trending trench system, between 22° S and 22° 30' S, is non-accretionary. It corresponds to a Mariana-type convergent margin, with no bulge and a deep and narrow trench deepening to the south. The steepness of the inner wall and probable associated steep-dipping downthrust Australian Plate indicates the possible slowing-down of the subduction process.

The SFB
There is a marked transition from the high-perched basin style of the SFB on the downthrusted Australian Plate, and the adjoining deep NHT system.

The Loyalty Ridge and Basin system
The Loyalty Ridge and Loyalty Basin system comprises a narrow, discontinuous, and fault-bounded ridge. This ridge deepens to the south, and is bounded on the west by a basin that is slightly concave to the north and also is both tilted to the southwest and deepens to the south. The survey data confirm previous studies (Monzier, 1993; Lafoy et al., 1996) that interpret the faulting on the ridge and uplift of the basin as resulting from the "Loyalty-New Hebrides collision" centred at 22° S and 169° E.

The Norfolk Ridge
The NNW-SSE trending Norfolk Ridge, overlain by a perched basin, and characterised by horst and graben morphology, deepens and widens to the south, where it is covered by coral deposits. We interpret the perched basin that bisects the Norfolk Ridge to correspond to the northward prolongation of the North Norfolk Basin.

Beneath the western Norfolk Ridge, a northeast-dipping reflector at about 7.4 s might represent Moho at the base of probable 10-11 km-thick crust.

The NCB
The NCB system comprises a perched basin on a basement terrace to the east, the western NCB, and the deeper NCB (sensu stricto). The NCB (sensu stricto) that narrows and deepens to the south, shows a maximum sedimentary fill of 3.9 s within a buried graben at the foot of the western margin of New Caledonia. This thins to an average thickness of 2 s in the south.

Two reflectors, at depths of 8.4 s and 8.9 s, interpreted to be possible Moho events, were identified at the northeastern and eastern edges of the basin, respectively. Assuming an average velocity of 6 km/s, the thickness of the crust (oceanic or thinned and stretched ?continental) could vary from 6 to 9 km between the northeastern and eastern edges of the basin, respectively.

The Fairway Ridge
The Fairway Ridge narrows and deepens to the south. The strongly reflective and diffracted nature of acoustic basement confirms that the ridge is made of a volcanic/oceanic substratum overlain by a sedimentary series (Ravenne et al., 1973; Mignot, 1984; Lafoy et al., 1994). A reflector interpreted beneath the ridge at about 7.4 s appears to be too shallow to be Moho.

The Fairway Basin
The Fairway Basin widens and deepens southward. In the north it is slightly bulged in its central part, while in the south it is affected by normal faulting that extends to the seafloor. Also in the south, a sediment thickness of 2 s is observed on acoustic basement at 6 s.

A probable crustal boundary between the oceanic Fairway Basin and continental LHR was observed on lines LHRNC-C and LHRNC-D. These lines also confirmed the presence of a BSR event, already identified on AGSO Survey 177 line LHRNR-B. This event likely represents the widespread presence of gas hydrates for this part of the Fairway Basin and eastern margin of the LHR.

According to our onboard interpretation of AGSO Survey 177 line LHRNR-B (Ramsay et al., 1997), which intersects with line LHRNC-C, a strong reflector identified at 9 s could represent the Mohorovicic discontinuity beneath the Fairway Basin. If an average velocity of 6 km/s is used, the oceanic crust underlying the basin could be 10 km thick.

The LHR
The eastern flank of the LHR widens to the south and deepens to the east. It is characterised by horst and graben structures covered by an east-dipping sedimentary series. An easterly-facing, thin prograding sequence down the flank, identified on line LHRNC-C, was interpreted as a transgressive progradational phase on a shelf margin, which has been identified further to the south (Willcox et al., 1980). This would support a continental origin for the LHR.

On the western LHR, horst and graben basement morphology dominates, overlain by an average 2 s-thick westerly-dipping sedimentary section.

Both flanks of the rise contain late Cretaceous to late Eocene sediments in the lower sequences. Up-dip fault closures and overlying anticlinal closures on fault-blocks are strong candidates for hydrocarbon entrapment.

The Dampier Ridge and Tasman Basin
The Dampier Ridge is characterised by rugged and locally planated basement, which is pierced by intrusives down its eastern margin. A clear transition to

oceanic-type basement in the Tasman Basin was observed and represents a probable COB.

Basement in the Tasman Basin clearly shows extensional effects associated with rifting and subsequent seafloor spreading. The relatively undisturbed nature of the overlying sediments indicates the long-term passive nature of Australia's rifted eastern margin.

Petroleum Potential

The LHR is the most interesting tectonic element for petroleum entrapment in the area. This is due both to its relatively shallow water depths and favourable structural style. It is underlain by likely late Cretaceous to late Eocene sediments averaging 1.2 s and 0.8 s in thickness within the half-grabens on the western and eastern flanks, respectively. In addition, the relatively thick sedimentary series developed along the western LHR has been described as containing potential source rocks (Symonds & Willcox, 1989). The small progradational wedge identified at the top of the eastern flank on line LHRNC-D may point to the possibility of up-dip stratigraphic traps for source kitchens lying down the eastern flank and into the deeper Fairway Basin.

The substantial sediment volume in the NCB is of interest from a petroleum prospectivity viewpoint. However, this view must be balanced by the uncertainties in the basin's origin (thinned-continental or oceanic crust) and the depositional environment of the sediments. Limited water circulation in an enclosed marine environment at the time of basin formation could have favoured the preservation of organic matter.

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Appendices

Appendix 1

1982 United Nations Convention on the Law of the Sea (UNCLOS)

Article 76 : Definition of the continental shelf

1. The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance.

2. The continental shelf of a coastal State shall not extend beyond the limits provided for in paragraphs 4 to 6.

3. The continental margin comprises the submerged prolongation of the land mass of the coastal State, and consists of the seabed and subsoil of the shelf, the slope and the rise. It does not include the deep ocean floor with its oceanic ridges or the subsoil thereof.

4. (a) For the purposes of this Convention, the coastal State shall establish the outer edge of the continental margin wherever the margin extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by either:

   (i) a line delineated in accordance with paragraph 7 by reference to the outermost fixed points at each of which the thickness of sedimentary rocks is at least 1 per cent of the shortest distance from such point to the foot of the continental slope; or

   (ii) a line delineated in accordance with paragraph 7 by reference to fixed points not more than 60 nautical miles from the foot of the continental slope.

   (b) In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point of maximum change in the gradient at its base.

5. The fixed points comprising the line of the outer limits of the continental shelf on the seabed, drawn in accordance with paragraph 4 (a) (I) and (ii), either shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured or shall not exceed 100 nautical miles from the 2,500 metre isobath, which is a line connecting the depths of 2,500 metres.

6. Notwithstanding the provisions of paragraph 5, on submarine ridges, the outer limit of the continental shelf shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured. This paragraph does not apply to submarine elevations that are natural components of the continental margin, such as its plateaux, rises, caps, banks and spurs.

7. The coastal State shall delineate the outer limits of its continental shelf, where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by coordinates of latitude and longitude.

8. Information on the limits of the continental shelf beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured shall be submitted by the coastal State to the Commission on the Limits of the Continental Shelf set up under Annex II on the basis of equitable geographical representation. The Commission shall make recommendations to coastal States on matters related to the establishment of the outer limits of their continental shelf. the limits of the shelf established by a coastal State on the basis of these recommendations shall be final and binding.

9. The coastal State shall deposit with the Secretary-General of the United Nations charts and relevant information, including geodetic data, permanently describing the outer limits of its continental shelf. The Secretary-General shall give due publicity thereto.

10. The provisions of this article are without prejudice to the question of delimitation of the continental shelf between States with opposite or adjacent coasts.

Appendix 2

Informal terms relating to Article 76

Application of Article 76 of United Nations Convention on the Law of the Sea (UNCLOS) raises several concepts and terms which will be referred to frequently in interpretations of seismic/bathymetric survey lines for the purposes of 'legal' Continental Shelf (CS) definition. Following are simplified definitions of the more important terms that we commonly use. Some aspects of the application of Article 76 remain unclear, and will only be resolved following further deliberation by the Commission on the Limits of the Continental Shelf.

Firstly, a *Hedberg arc* may be drawn, with a radius of 60 n miles, from an interpreted foot-of-slope (FoS) position. The location at which this arc intersects the seaward extension of the survey line is called the *Hedberg point.* With a series of FoS positions established around a continental margin, at a spacing of less than 120 n miles, a series of intersecting Hedberg arcs may then be constructed. Clearly, as the spacing between survey lines (and therefore, the FoS positions) decreases, the envelope of the intersecting Hedberg arcs approaches a 60 n mile buffered locus of the FoS, except in some cases where the latter contains embayments. This is part of the reason for AGSO's 'safe minimum' approach, where we aim to space survey lines ~30 n mile apart, where logistically possible. The final outcome, the true *Hedberg Line* (the informal name for the line that defines the outer edge of the 'legal' continental margin, as contained in Article 76, paragraph 4(a)(ii), of UNCLOS), is constructed by joining selected points on the Hedberg arcs by straight lines, not more than 60 n mile long. This would normally be done in a manner so as to maximise the size of the enclosed 'legal' continental margin. This true Hedberg Line will normally only intersect the survey line at the Hedberg point where the locus of the FoS points is a straight line. Such situations are unusual in the context of CS beyond 200 n mile, since it is normally associated with irregularly shaped marginal plateaus.

Secondly, a *Sediment Thickness point* may be determined, by interpretation of a seismic survey line (or possibly by drilling), where the 1% sediment thickness criterion is satisfied. That is, the point at which the thickness of sedimentary rocks is at least 1% of the shortest distance from such point to the FoS. In contrast to the Hedberg arc, this is strictly a single point, which may be joined to adjacent Sediment Thickness points to form the *Sediment Thickness Line* (the informal name for the line that defines the outer edge of the 'legal' continental margin, as contained in Article 76, paragraph 4(a)(i), of UNCLOS), or to selected points on Hedberg arcs, again by straight lines, not more than 60 n mile in length.

Finally, the fixed points (not more than 60 n mile apart) comprising the line which defines the outer limits of the CS, may not lie beyond one or other of two cut-offs. The first cut-off is 350 n mile from the baseline (informally called the *350 n mile cut-off line*), and the second is 100 n mile beyond the 2500 m isobath (informally called the *isobath cut-off line*). The former is purely a geometrical construction from the Territorial Sea baselines, whereas the latter depends on definition of the 2500 m isobath.

Appendix 3

Description of RV *Rig Seismic*

The research vessel RV *Rig Seismic* is chartered and equipped by the Australian Geological Survey Organisation (AGSO) of the Australian Commonwealth Government. Its mission is to support the primary geoscientific requirements of acquiring data for Australia's Law of the Sea claims and the Australian Ocean Territory Mapping Program. It was constructed in Norway in 1982 and later commissioned by AGSO in 1984. The vessel is registered in Newcastle, New South Wales, and is operated for AGSO by the Australian Maritime Safety Authority (AMSA).

Gross tonnage:		1545 tonnes
Length:		72.5 metres
Breadth:		13.8 metres
Draft:		6.0 metres
Engines:		
	Main:	Bergen KVMB-12
		2640 H.P./825 r.p.m.
	Auxiliary:	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 forward, 1 aft; each 600 HP
Helicopter Deck:		20 metres diameter
Accommodation:		3 double-berth cabins
		38 single-berth cabins

Appendix 4

Crew list for Lord Howe Rise/New Caledonia - Survey 206

Australian Maritime Safety Authority

Master	Bob Hardinge
1st Mate	Otto Weysenfeld
2nd Mate	Ray Stevens
Chief Engineer	Peter Pittiglio
1st Engineer	John Vitner
Electrician	Dennis Cashman
Chief IR	Graeme Pretsel
IR	Frank Rochford
IR	Dave Kane
IR	Matt Stapleton
Chief Cook	Geoff Conley
Cook	Alex King
Catering Attendant	Adrian Clark
Catering Attendant	George Lilja

Australian Geological Survey Organisation

Ship Manager	Paul Lashko
Australian Client Representative	George Bernardel
Quality Control	Mike Sexton
Seismic Processor	Bill Plumridge
Science Technician	Andrea Cortese
Science Technician	Linda Philippa
Science Technician	Peter Davis
Science Technician	Fleur Wiley
Science Technician	Duncan Palmer
Science Technician	Lindon O'Grady
Electronics Technician	Phil Doolan
Electronics Technician	Paul Conroy
Gun Mechanic	Simon Milnes
Gun Mechanic	Nick Boylan
Gun Mechanic	Brian Dickinson
Gun Mechanic	John Keyte
Visiting Student	Simon Gray

French Scientists

French Client Representative	Yves Lafoy
Support Scientist	Sabrina Van de Beuque
Support Scientist	Francois Missegue
Support Scientist	Alex Nercessian

Appendix 5

Survey Way Points - proposed and actual way points for Survey 206

Line Name	Proposed		Actual (approximate)		
	Latitude	Longitude	Latitude	Longitude	
LHRNC-A	21.7000	165.4000	21.7000	165.4000	
	23.2000	164.0000	23.2000	164.0000	dogleg on Fairway Ridge
	24.4000	159.8000	24.4000	159.8000	
LHRNC-B	23.0000	161.0000	23.0000	161.0000	
	26.1102	161.2212	26.1102	161.2212	DSDP site
	26.1552	161.2244	26.1552	161.2244	small dogleg
	29.5131	161.0921	29.5131	161.0921	Shell line1001/704 tie
LHRNC-C	28.5000	159.6500	28.0248	160.9609	start further to east
	26.4000	165.4000	26.4000	165.4000	dogleg on Fairway Ridge
	22.0000	170.7000	22.0000	170.7000	
LHRNC-D	21.7000	170.3000	21.7000	170.3000	
			22.6480	168.9527	dogleg at Walpole Island
	26.8788	162.3574	26.8788	162.3574	dogleg on LHR
	30.0000	154.7000			original EOL
			29.6666	155.5283	dogleg on Tasman Basin
			29.6667	153.3657	actual EOL

Appendix 6

Seismic Acquisition Parameters - Survey 206

Recording:		
	Type:	AGSO MUSIC Recording System
	Format:	Demultiplexed (AGSO modified) SEG-Y
	Shooting speed:	5 knots, nominal
	Shot interval:	50 m
	Fold:	see Streamer below
	Length:	16 s
	Sample rate:	4 ms
	Low-cut filter:	5 Hz at 12 dB/octave
	High-cut filter:	103 Hz at 550 dB/octave
Navigation:		
	Navigation System:	AGSO DAS Navigation System
	Primary Navigation:	Racal Multifix 2 DGPS
	Secondary Navigation:	Racal Multifix 1 DGPS
Streamer:		
	Type:	single Hydroscience Digital Streamer
	Length:	3300 m for lines LHRNC-A to LHRNC-C1 3100 m for line LHRNC-C2 3500 m for lines LHRNC-D1 to LHRNC-D2 2900 m for line LHRNC-D3
	Group Length:	12.5 m
	Depth:	10-14 m, depending on sea state
	Fold:	equivalent to cable length in metres divided by 100
Energy source:		
	Method:	Single high pressure air point source array
	Type:	Seismic Systems HG Sleeve guns, model 2
	Volume:	3000 cubic inches for 20 guns
	Pressure:	1800 psi, nominal
	Array:	2 x 10 gun array with 12 spares
	Depth:	10 m

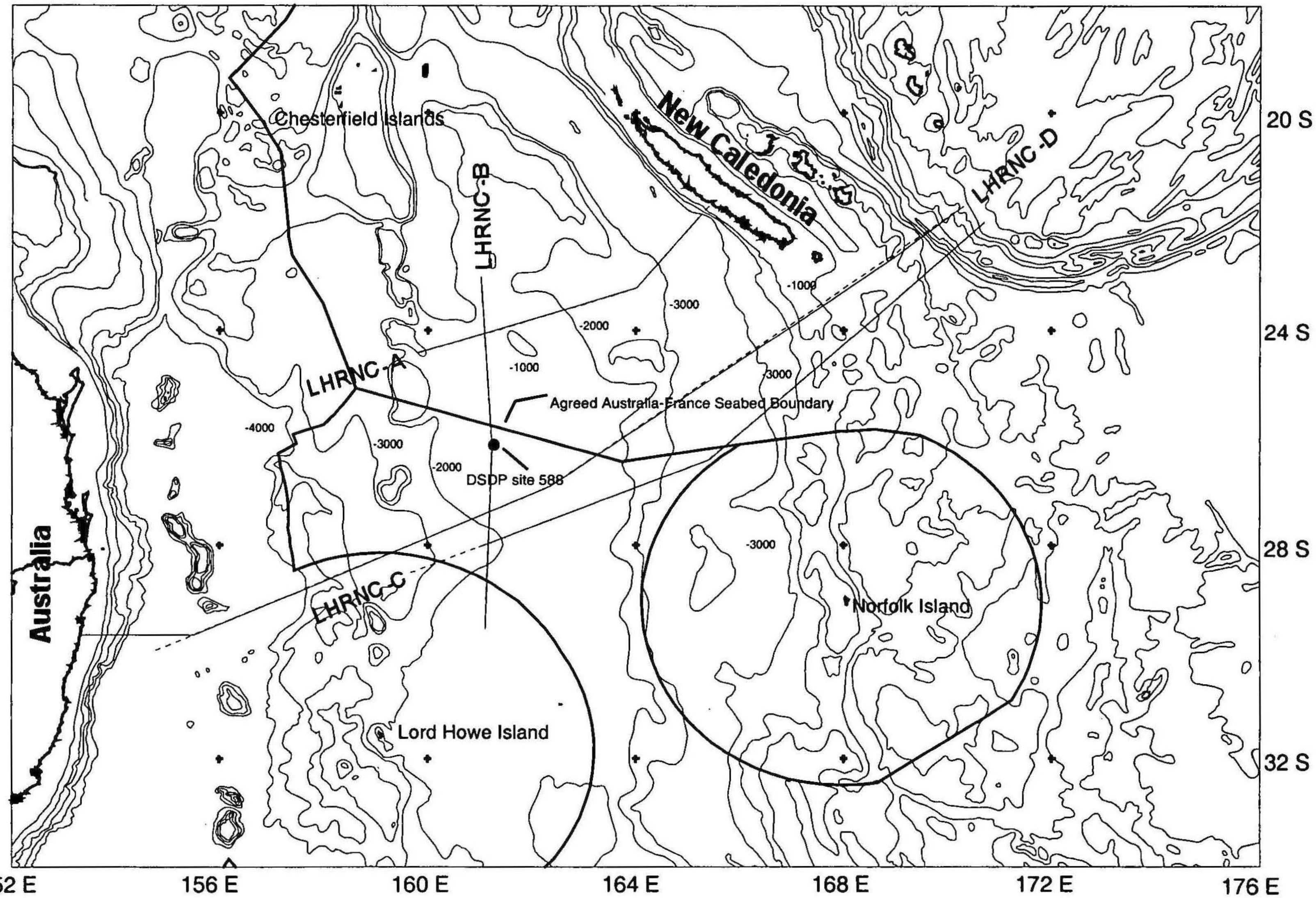


Figure 1. Location map of Survey 206 area. Shown are proposed lines (dotted), actual lines (solid), EEZs and general bathymetry from GEBCO (Jones et al., 1997).

Figure 2. Location map as in Figure 1, based on a sun-shaded image of predicted bathymetry (Smith & Sandwell, 1997) to show broad crustal elements.

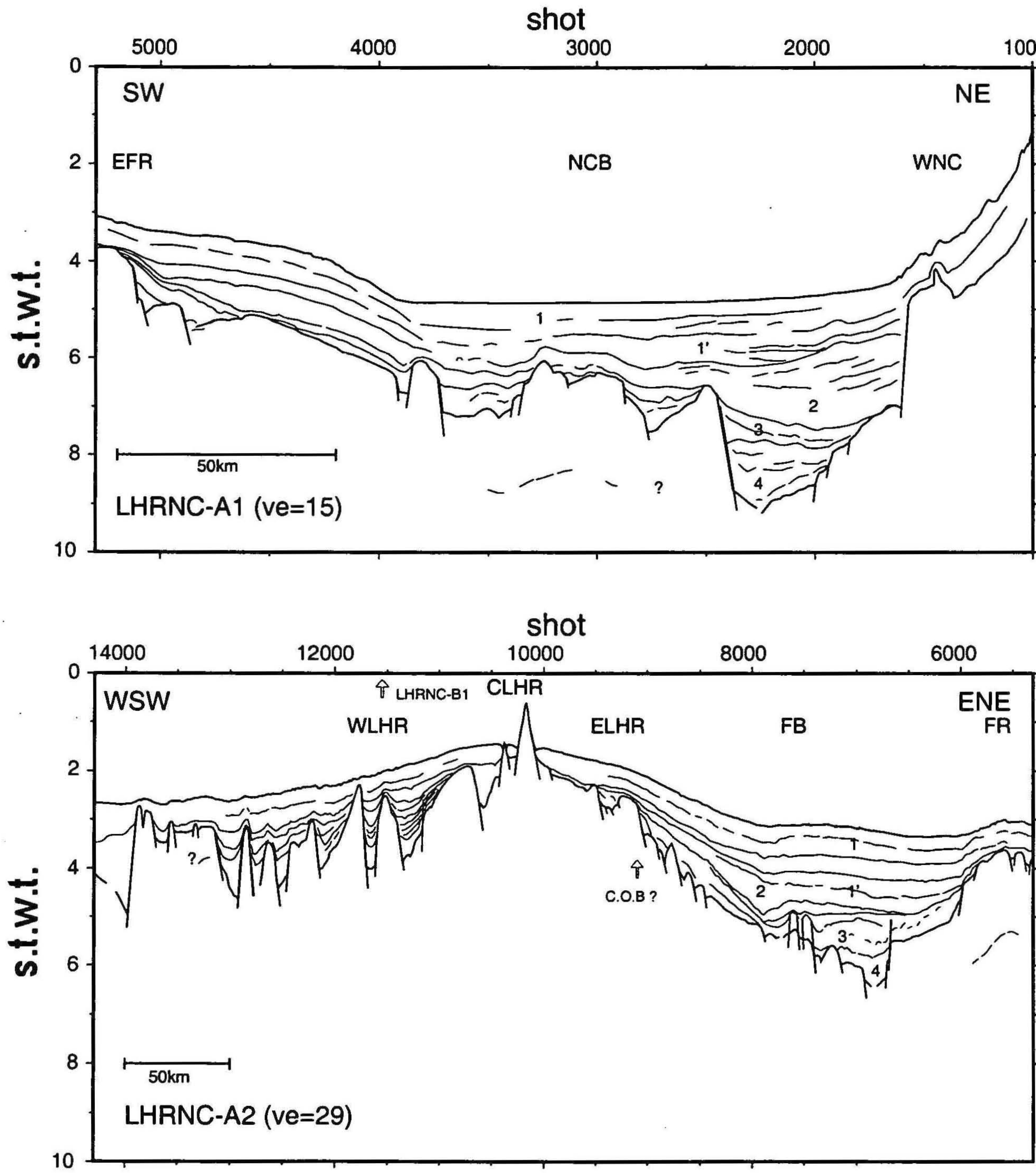


Figure 3(a). Seismic line LHRNC-A.

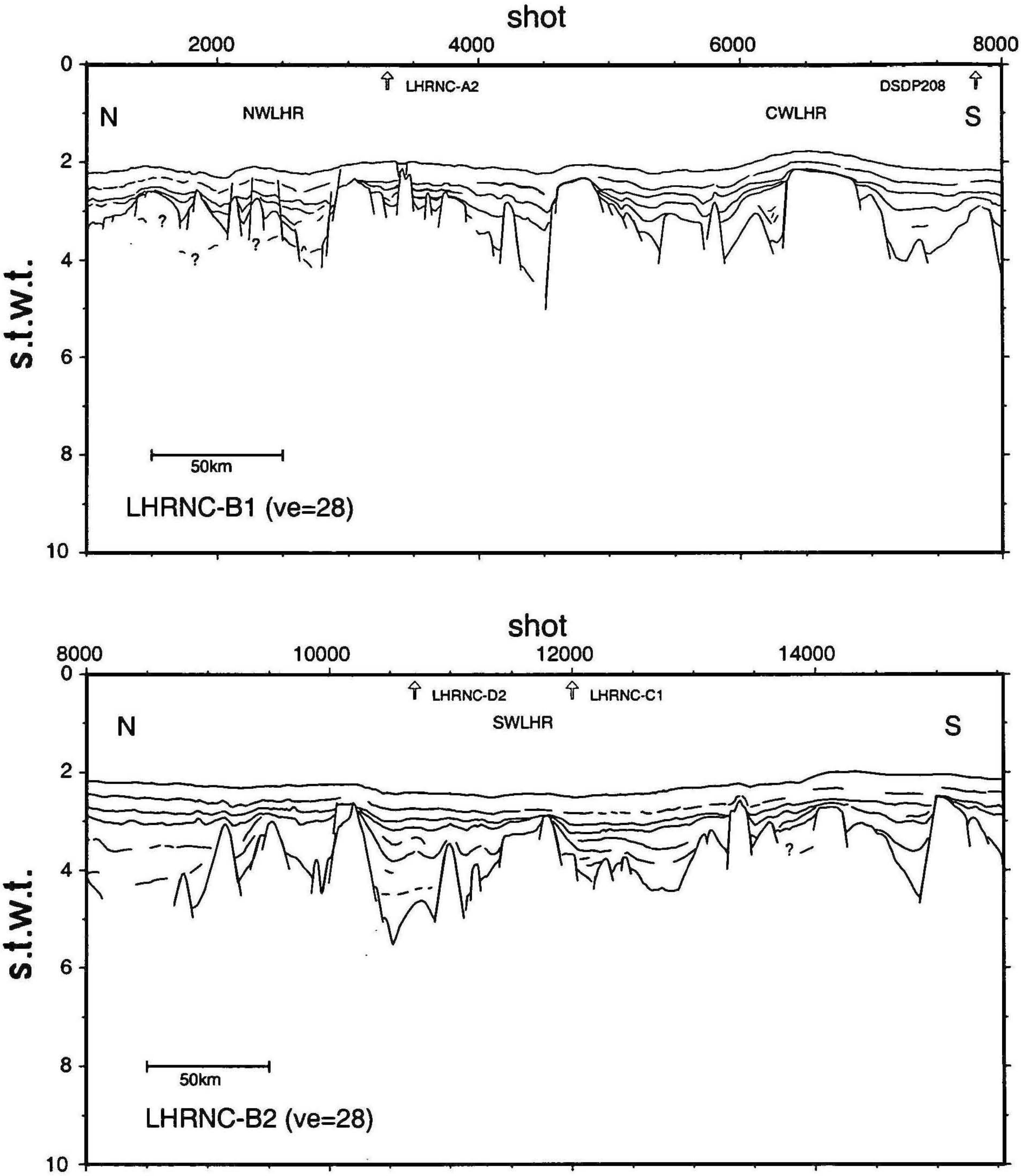


Figure 3(b). Seismic line LHRNC-B.

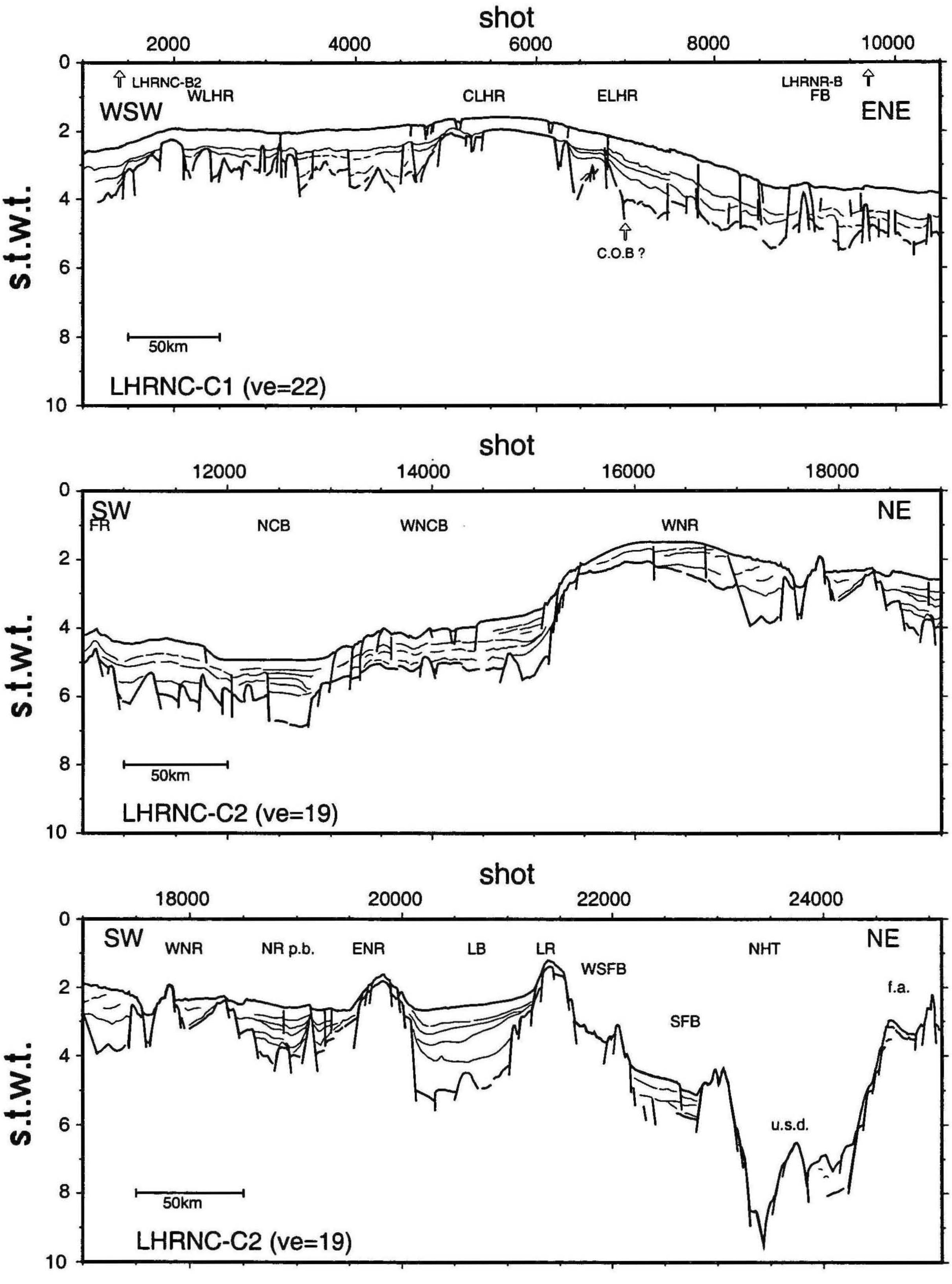
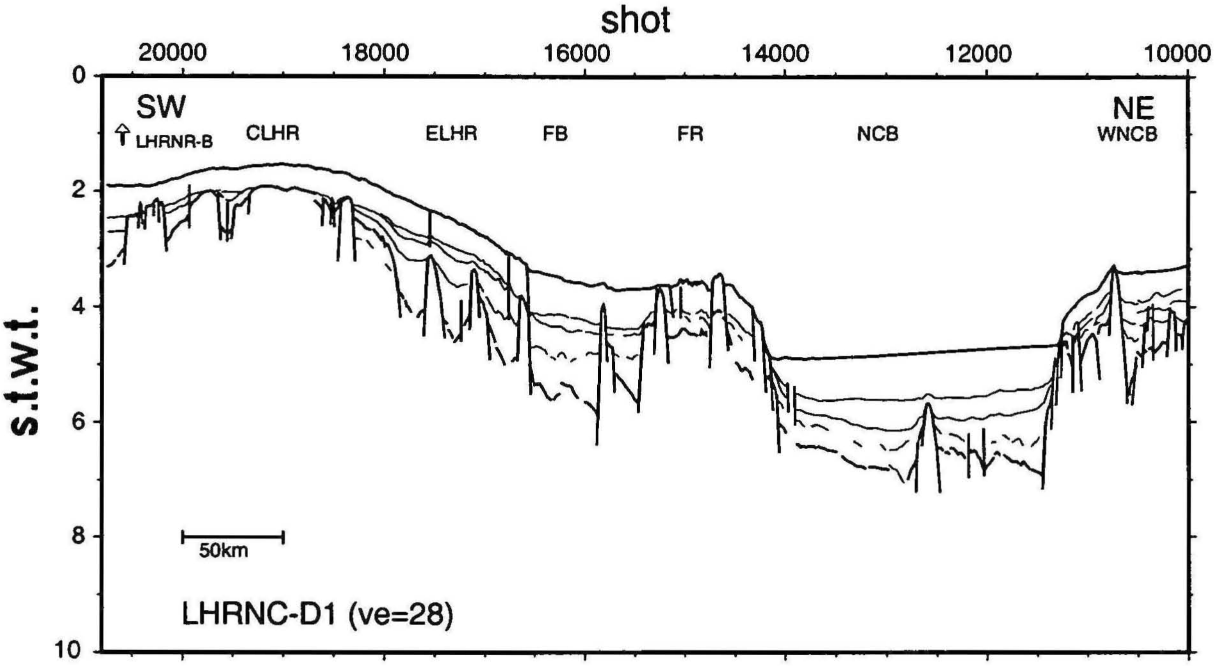


Figure 3(c). Seismic line LHRNC-C.



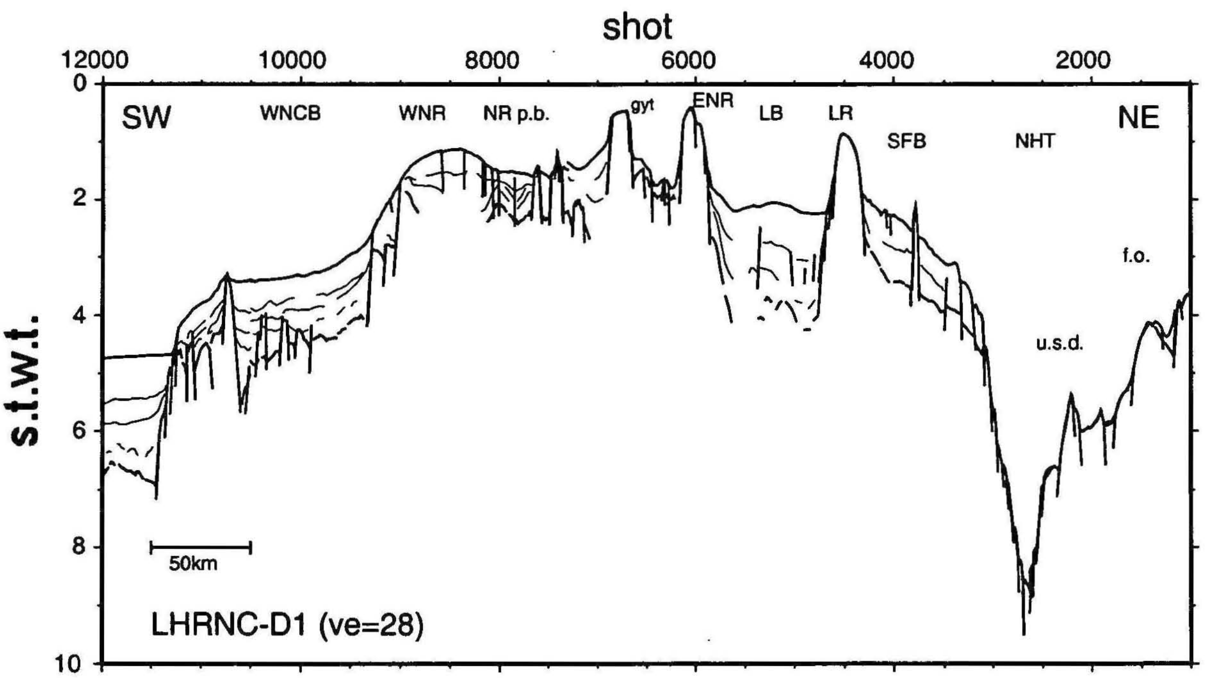
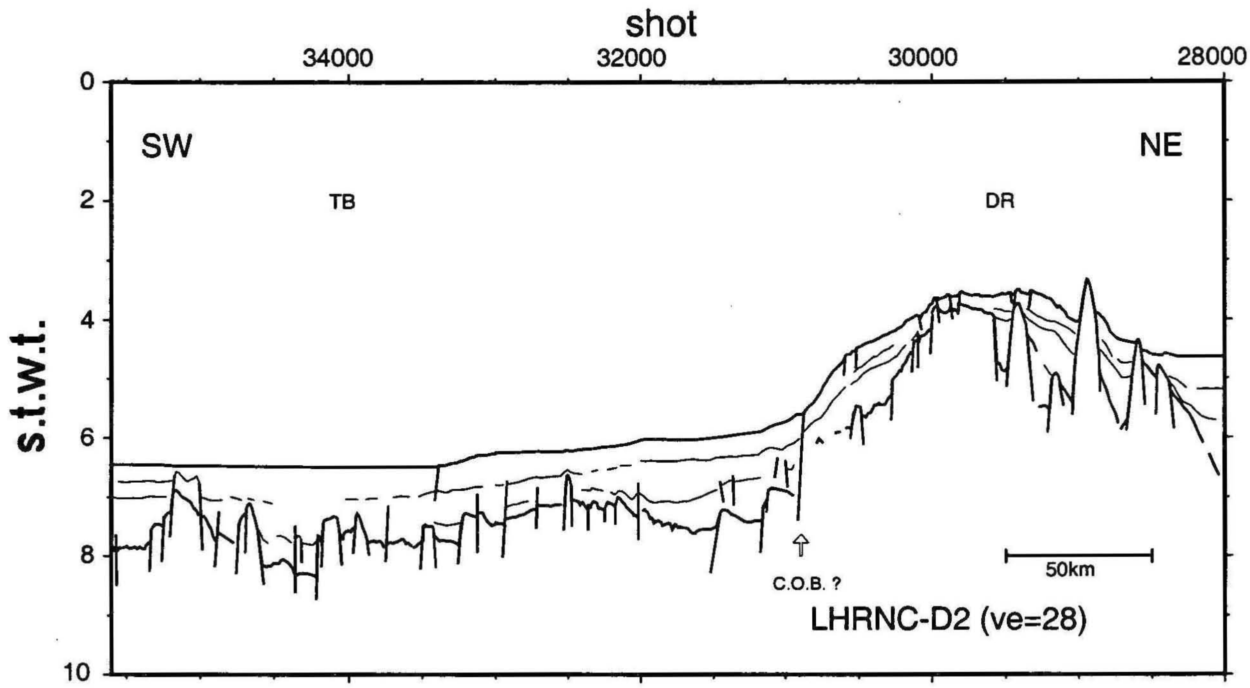


Figure 3(d). Seismic line LHRNC-D1.



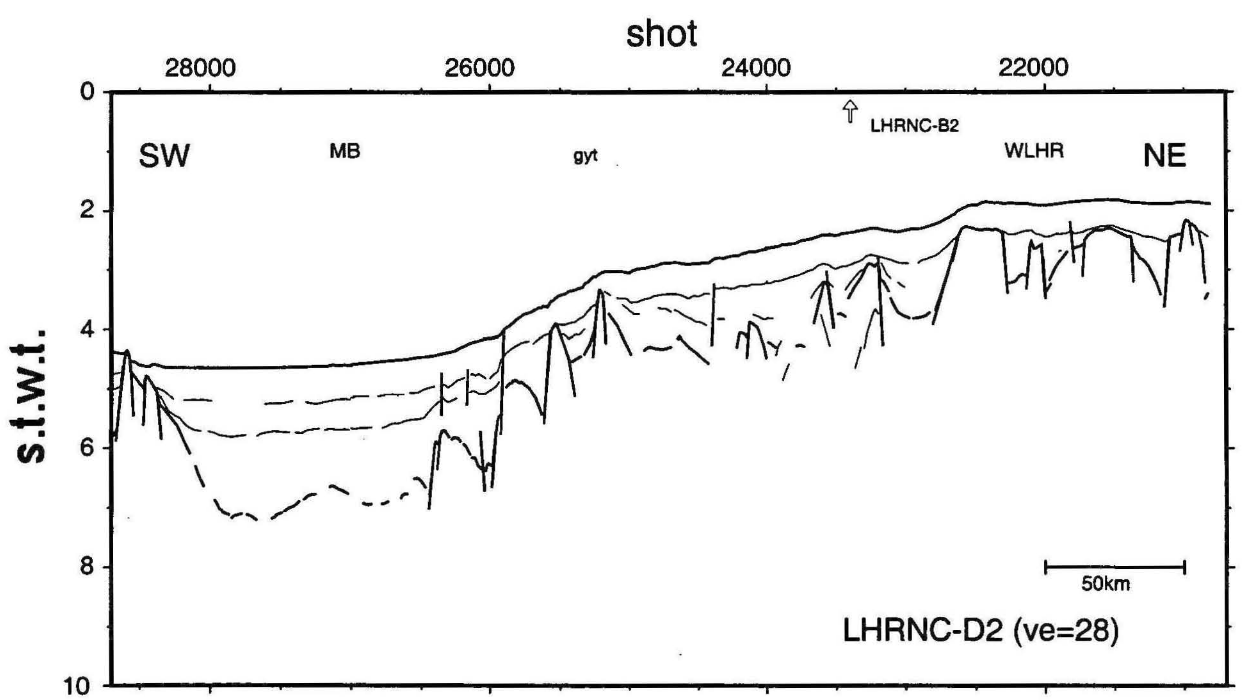


Figure 3(e). Seismic line LHRNC-D2.

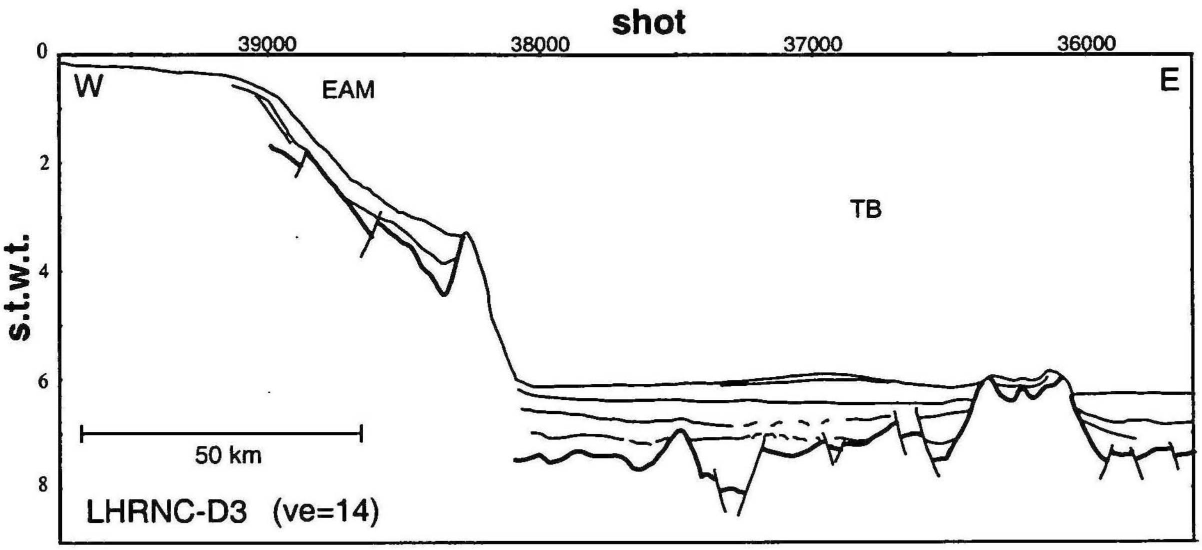


Figure 3(f). Seismic line LHRNC-D3.

Figure 3. Line diagrams of onboard interpreted seismic lines (a) LHRNC-A, (b) LHRNC-B, (c) LHRNC-C, (d) LHRNC-D1, (e) LHRNC-D2 and (f) LHRNC-D3.

For the diagrams the following abbreviations are used:

WNC	- West New Caledonia margin;
NCB	- New Caledonia Basin;
FR	- Fairway Ridge;
FB	- Fairway Basin;
LHR	- Lord Howe Rise;
NR	- Norfolk Ridge;
WNCB	- western New Caledonia Basin;
NR p.b.	- Norfolk Ridge perched basin;
LB	- Loyalty Basin;
LR	- Loyalty Ridge;
SFB	- South Fiji Basin;
NHT	- New Hebrides Trench;
u.s.d.	- upper slope discontinuity;
gyt	- axis of guyots;
MB	- Middleton Basin;
DR	- Dampier Ridge;
TB	- Tasman Basin;
EAM	- East Australian Margin; and
C.O.B.	- continent-ocean boundary.