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# CONTINENTAL SHELF DEFINITION IN THE LORD HOWE RISE AND NORFOLK RIDGE REGIONS : LAW OF THE SEA CRUISE PROPOSAL

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# EXECUTIVE SUMMARY


The United Nations Convention on the Law of the Sea requires nations to justify claims to 'legal' Continental Shelf (LCS) beyond the 200 n mile Exclusive Economic Zone (EEZ), according to formulae set out in Article 76 of that Convention. The area between and adjacent to the EEZs generated by Lord Howe and Norfolk Islands is one example where Australia can make such a claim and is the subject of this survey proposal.

A program of seismic traverses has been designed which will cross the 2500 m contour (to define its location), the probable foot-of-slope, and areas beyond the foot-of-slope having potential to host sediment of significant thickness. These crossings will occur at a sufficient number of sites to allow:

(1) definition of the 100 n mile cut-off beyond the 2500 m contour,
(2) definition of the Hedberg Line 60 n mile beyond the foot-of-slope, and
(3) determination of the sediment thickness distribution.

The upper limit of seismic traverse length is estimated to be 3800 km, based on the assumption that most traverses will extend beyond the foot-of-slope to around the Hedberg Line, to test the sediment thickness criterion. This, however, is probably an overestimate. With knowledge of sediment thickness distribution gained during acquisition, some traverses may be truncated before the Hedberg distance is traversed.

Following a desk-top study conducted jointly with New Zealand scientists in May 1996, there is a high probability of this proposed work being done co-operatively with New Zealand, since they also have a requirement to define LCS beyond their EEZ in the same region. However, this proposal is designed to provide the additional data required by Australia independently of any participation by New Zealand.

# INTRODUCTION

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) defines a nation's legal seabed and subsoil jurisdiction as extending throughout its 'legal' Continental Shelf (LCS) (Appendix 1). Where the continental margin of a nation extends beyond 200 nautical miles, the outer limit of the LCS is defined by a series of rules contained within Article 76 of UNCLOS. The rules require definition of the foot of the continental slope, knowledge of sediment thickness and good bathymetric information defining the 2500 metre water depth contour. The LCS must be defined at least every 60 nautical miles around the parts of the margin extending beyond 200 nautical miles, and thus in these areas a comprehensive seismic and bathymetric database is essential to maximising LCS claims.

A preliminary analysis (Symonds & Willcox, 1989) of the extent of Australia's LCS under UNCLOS indicated that it could be at least 14.8 million square kilometres in area – nearly twice the size of the continent and one of the world's biggest. Eight areas of LCS, in total about 3.7 million square kilometres, extend beyond the 200 nautical mile Australian Exclusive Economic Zone (AEEZ). AGSO has been given responsibility by Cabinet to ensure that Australia has the necessary technical information to fully define its LCS under UNCLOS. AGSO has decided to adopt a 'safe minimum' approach to LCS definition in which bathymetric and seismic data are acquired on profiles spaced about 30 nautical miles apart over areas of margin extending beyond the AEEZ. Recent internal AGSO assessments have indicated that further data collection is needed in about six of the eight regions extending beyond the AEEZ. The necessary data collection will also contribute to an improved understanding of the geological framework and resource potential of these poorly known areas.

One such region is the Lord Howe Rise/Norfolk Ridge area, which is the subject of this proposal.

# PHYSIOGRAPHY AND GEOLOGY

Much of the following discussion on the geological background of the region is taken from Symonds & Colwell (1992).

## REGIONAL PHYSIOGRAPHY

The major submarine features in the region are, from west to east: the Tasman Basin, the Lord Howe Rise, the New Caledonia Basin, the Norfolk Ridge system, a basin and ridge complex in which the North and South Norfolk Basins are embedded, the Three Kings Ridge and the South Fiji Basin. These and other physiographic features are depicted in Figure 1.

## LORD HOWE RISE

The Lord Howe Rise 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.

## NEW CALEDONIA BASIN

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 – 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. This division is not supported by the GEBCO (IOC, IHO, & BODC, 1994) bathymetry used in Figure 1, and so the two troughs are not depicted, although the two ridges do exist adjacent to the northern and southern extents of the New Caledonia Basin.

## NORFOLK RIDGE SYSTEM

The Norfolk Ridge system is a complex feature, which extends from the northern tip of New Zealand to New Caledonia. The northern segment, which is north-trending, steep-sided and about 90 km wide, 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).

## BASIN AND RIDGE COMPLEX

Between the Norfolk Ridge to the west and the Three Kings Ridge to the east lie two small basins at about 3500 m water depth, the North and South Norfolk Basins. They are separated by a chaotic terrane of undersea features whose dimensions and orientations are poorly known but which may represent a prolongation of the Norfolk Ridge to the northeast and east, possibly to the Three Kings Ridge. The complex is bounded to the north and south by the Cook and Vening Meinesz Fracture Zones respectively.

## CRUSTAL STRUCTURE AND TECTONIC EVOLUTION

Seismic refraction and gravity anomaly measurements (Officer, 1955; Dooley, 1963; Shor and others, 1971; Woodward & Hunt, 1971), and seafloor spreading magnetic anomalies (Ringis, 1972; Weissel & Hayes, 1977; Shaw, 1978), indicate that the Tasman 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 (Shor and others, 1971) over Lord Howe Rise 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 and others, 1971). A recent study of marine magnetic anomalies in the Lord Howe Rise region (Schreckenberger and 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 is supported by dredging carried out by R/V *Sonne* (Roeser and Shipboard Party, 1985). The Lord Howe Rise and Dampier Ridge were detached from Australia during seafloor spreading, which commenced at about 80 Ma 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 and 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 and 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 (Gondwana), 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 and others, 1989; Lister and 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. Some support for this idea is provided by the study of Uruski & Wood (1991), which correlated seismic sequences and structures of the southernmost 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 suggest that the rifting may have been initially related to back-arc tectonism associated with Mesozoic subduction (Bradshaw and others, 1981; Korsch & 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. 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 and 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, 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 and 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 Palaeocene, 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 and 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 and others, 1989; Lister and 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, 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 Lord Howe Island, Ball's Pyramid (just SSE of Lord Howe Island), Norfolk Island and Phillip Island (just S of Norfolk Island); 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 as early as the mid-Tertiary and ended with an eruptive episode that was isotopically dated as Late Miocene (7.7 Ma). Norfolk and Phillip 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 of which are directly relevant to this study – Sites 206 and 207 of Leg 21 (Burns, Andrews and others, 1973), and Site 592 of Leg 90 (Kennett, von der Borch and others, 1986). At Site 206 in the New Caledonia Basin, a relatively uniform sequence of Early Palaeocene to ?Late Pleistocene calcareous ooze was intersected. Bathyal conditions 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 and 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 indicates that there was a rapid increase in the depth of 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 and others, 1977). Olivine basalts, gabbros, and a mixture of hyaloclastic breccias and biomicrites were obtained; the biomicrites contained planktonic foraminifera of mid-Miocene or younger age.

In 1985 a co-operative BGR/BMR 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 and 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/calcirudite, 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 and 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 and others, 1994).

Willcox and 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.

# 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 and others, 1980). Elsewhere, particularly beneath the eastern third of the Lord Howe Rise, mainly thin sediments overlie basement, which is commonly planated. The grabens are up to 50 km wide, several tens of kilometres long, and are best developed north of Lord Howe Island, where sediment fill is up to 4500 m in places (Roeser and Shipboard Party, 1985). Diapiric structures, which suggest the movement of shale or possibly salt, have been recognised in several of the grabens (Roeser and Shipboard Party, op. cit.). South of Lord Howe Island, the extensional basins appear to be less complex. Work by BMR in this area (Whitworth, Willcox and others, 1985) indicates that some of the horst blocks southeast of Lord Howe Island may contain dipping strata of Mesozoic age, 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 and others, 1980). Results from 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, Andrews and others, 1973). These sediments are similar in age and type to rocks dredged from the lower continental slope off southern New South Wales, 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 & Willcox, 1993). Faulted structural/stratigraphic traps 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, 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, 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). 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 and 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 & Willcox, 1993). Alternatively, Willcox and 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 and 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.

## EASTERN FLANK OF LORD HOWE RISE

It has been suggested that the eastern flank of Lord Howe Rise might have formed an ancient seaboard of the Australian-Antarctic supercontinent (Willcox and others, 1980). A considerable thickness (about 2000 m) of clastic sediment was deposited across this margin during or before the Late Cretaceous. Most of this sediment was probably derived from the now planated 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. 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. 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 and 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. 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 the 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 LCS. 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 a volcanic feature.

## 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. 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 greywacke 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.

### SOUTH NORFOLK BASIN

The South Norfolk or Norfolk Basin 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 represent a southeastern extension of the South Norfolk Basin (Eade, 1988).

## UNCLOS PROGRAM DESIGN

The area under investigation was identified as being potentially claimable LCS and its limits have been preliminarily defined (Symonds & Willcox, 1989). The aim of the presently proposed survey is to fill in the remaining data gaps so that the outer limits of the LCS can be more accurately defined, following the 'safe minimum' approach, as described earlier.

The LCS of Australia (from Lord Howe and Norfolk Islands) abuts the LCS of New Zealand along the Lord Howe Rise and the Norfolk Ridge. A preliminary median line has been drawn to separate the two areas (Fig. 2), but no official seabed boundary has yet been negotiated. Early in 1996, in anticipation of ratifying the Law of the Sea, New Zealand proposed a joint desk-top study to ascertain the quantity of new data required to fulfil each country's needs in this zone of common interest. This desk-top study was completed in May 1996, when two scientists (one from NIWA and one from IGNS) representing New Zealand visited AGSO in Canberra. The study showed that data acquisition to the extent of two cruises would be required, with Australia's share slightly more than half. At no stage was there any obligation on the part of New Zealand to carry out any work beyond the desk-top study. However, given that AGSO had already scheduled the Australian work for the spring of 1996, there were obvious economies for New Zealand to commit to the work at the same time. Since both countries have an interest in the areas southeast of Lord Howe Island and east of Norfolk Island, there were further economies possible by combining the data acquisition on each of the two proposed cruises. Again, it should be stated that there is no obligation on New Zealand at this stage, and AGSO is prepared to collect only the data required by Australia, if necessary.

The outermost limit of the survey area is the more distal of the 350 n mile cut-off and the cut-off 100 n mile downslope of the 2500 m isobath (Article 76, Appendix 1). Where possible, opportunities have been taken to tie to existing modern seismic traverses and also to integrate with a New Zealand proposal.

## ANALYSIS OF EXISTING DATA

The pre-cruise evaluation has yielded a first trend of the foot-of-slope (FoS) and/or the edge-of-abyssal-plain (EoAP), shown in relation to the EEZs (Fig. 2).

Relevant seismic and bathymetric data from which were derived candidate FoS/EoAP points included the 1970-73 BMR CMS lines. These latter data were the source of the FoS picks of previous workers (Symonds & Willcox, 1989), and this review resulted in confirmation and, in some cases, refinement of their picks.

In general, bathymetric data (highly variable in age and navigational precision) from hydrographic surveys (Fig. 3) by oceanographic institutes were examined for candidate FoS/EoAP locations. All picks are shown in Figure 2. The numbers in the figure refer to an entry (column E) in the table in Appendix 2 which identifies the source data from which FoS and EoAP have been interpreted. Appendix 2 also gives the pick precision (the resolution) in survey time intervals between data points. Water depth data collected by ships not using satellite navigation were given less weight than other data in the interpretation.

## PROPOSED LINES

New traverses have been proposed where the 2500 m contour is poorly controlled, where the foot-of-slope is undefined or poorly defined, and where there are indications that the sediment thickness rule might apply but reliable data are sparse. For the sediment thickness criterion to apply, there would normally have to be at least 1.1 km of sediment at the Hedberg Line (1% of 60 n mile or 111 km). This thickness is approximately equal to 1.0 second of two-way-time on seismic records. At this degree of sub-bottom penetration on some older, low-energy seismic data, it can be difficult to distinguish the boundary between sediment and underlying basement. Where possible, lines have been positioned to tie to existing good quality, multi-channel seismic lines (Fig. 4), while still fulfilling the objectives as stated above.

The proposed UNCLOS acquisition program is shown in Figures 5 to 8.

### (1) NE AREA

The primary aim is to maximise any possible claim to the east of the 200 n mile EEZ around Norfolk Island. This area of potential LCS is bounded in the north by the New Caledonia EEZ and an EEZ around Matthew and Hunter Islands; it is bounded in the south by the New Zealand EEZ. It is possible that Australia, France and New Zealand might all have a legitimate claim to at least a part of this area, in which case the final division would have to be settled by negotiation. No foot-of-slope is possible any further east than the edge of the South Fiji Basin abyssal plain.

This area is rather poorly surveyed, but from the satellite altimeter gravity image, it is clearly bathymetrically complex. The strategy is to demonstrate prolongation to the east from Norfolk Ridge, on which Norfolk Island stands. The North and South Norfolk Basins appear to be surrounded by elevated regions which are to be tested for continuity and for their connection to the Norfolk Ridge. It should be pointed out here that if prolongation beyond the Norfolk Island EEZ is established, the present survey will not be sufficient to accurately define the outer limit of any claimed LCS. Even with access to the data from proposed New Zealand lines in the same region, this area is considered too complex to allow understanding based on a series of simple profiles. Ideally, three-dimensional swath-mapping should be undertaken, if necessary, at some later date.

- Line LHRNR-B tests (and should confirm) prolongation from the Norfolk Ridge beyond the 200 n mile EEZ and onto the Three Kings Ridge by a path around the northern edge of the North Norfolk Basin. The line does not go as far east as the South Fiji Basin. Current New Zealand proposals will test the prolongation east of the Three Kings Ridge. At its western end the traverse provides modern crossings of the foot of slope on both sides of the New Caledonia Basin. These latter data will provide support for the complete claim south of the negotiated boundary with New Caledonia and west of the Norfolk Island EEZ.

- Line LHRNR-C tests prolongation from the Norfolk Ridge to the vicinity of the Matthew/Hunter EEZ. The complete test relies in part on the proposed NZ data set. The NE end is in a complex region where N-S trending features are truncated by the Cook Fracture Zone. The intention is to test whether the CFZ forms a boundary to prolongation in the northeast.

- Line LHRNR-D tests prolongation from LHRNR-C southeast to the Three Kings Ridge. Again, current NZ proposals test prolongation east to the South Fiji Basin.

For purely LOS needs, it may not be necessary for the prolongation to be established along all three pathways.

(2) SW AREA

A series of lines has been designed to define the outer limit of the LCS in the region southeast of the Lord Howe Island EEZ, as far south as the preliminary median line with New Zealand's LCS. There may be New Zealand lines in the area south of the preliminary median line. The AGSO proposal is sufficient in itself to provide the additional data required to make the most comprehensive Australian claim possible. The lines have been positioned to tie to modern seismic lines (Fig. 8), mainly AGSO Survey 114 (Marshall, Feary & Zhu, 1994), thereby also producing more useful scientific transects across the southern Lord Howe Rise.

- Lines LHRNR-E and F both cross seamounts clearly visible in the satellite altimeter gravity image. Each line may thus provide a more advantageous FoS position from which to draw a 60 n mile Hedberg arc. In addition, both lines will test the sediment thickness criterion at their SW ends.

- Lines LHRNR-G and H will define the 2500 m isobath at their NE ends, define the FoS, and also test for sediment thickness at their SW ends.

- Line LHRNR-I is to test the continuity of an E-W spur coming off the southern end of the Lord Howe Rise. In particular, we are interested in the shape of the 2500 m isobath, which could have implications for the 2500 m + 100 n mile cut-off, since this area is beyond the 350 n mile cut-off.

- Line LHRNR-J will provide FoS positions in a data gap on both the eastern side of the Lord Howe Rise and the opposite, western side of the West Norfolk Ridge.

## ACQUISITION PARAMETERS

**Navigation**

Continuous dGPS.

**Echo sounding**

Continuous 12 kHz and 3.5 kHz.

**Magnetics**

Continuous gradiometer (preferred) or single detector magnetometer; required for spreading anomalies.

**Gravity**

Continuous; required for scientific (deep) targets.

**Seismic**

Source : Two arrays of 10 x Sleeve guns (150 $in^3$ each ) = 3000 $in^3$ @ 1800 psi.
Source Depth : 10 m nominal.

Receiver, Reflection
Streamer : 4800 m, 25 m groups, 192 channels.
Streamer Depth : 10 m nominal.
Shot Frequency : 19.4 sec. at 5 knots.
Coverage : Shot interval 50 m for 48 fold coverage.
Data : Record length 16 sec. minimum.
Sample rate 2 msec.

Filter settings 4/180 Hz.
Receiver, Refraction ? Sonobuoys

## LIST OF WAY POINTS

| LINE NAME | COMMENT | WAY POINT | LATITUDE DD MM (S) | LONGITUDE DDD MM (E) | DISTANCE (Km) | |
|---|---|---|---|---|---|---|
| LHRNR-B | SOL | 1 | 27 09 | 163 30 | | |
| | TURN | 2 | 26 25 | 169 36 | 612.0 | |
| | TURN | 3 | 27 20 | 170 11 | 116.9 | |
| | TURN | 4 | 27 38 | 170 45 | 65.1 | |
| | EOL | 5 | 28 20 | 173 15 | 257.9 | 1051.9 |
| LHRNR-C | SOL | 1 | 29 58 | 167 55 | | |
| | TURN | 2 | 29 25 | 169 32 | 167.9 | |
| | TURN | 3 | 28 52 | 170 43 | 130.3 | |
| | TURN | 4 | 27 36 | 171 05 | 144.9 | |
| | EOL | 5 | 26 27 | 172 12 | 168.9 | 612.0 |
| LHRNR-D | SOL | 1 | 29 11 | 169 24 | | |
| | TURN | 2 | 29 17 | 170 30 | 107.5 | |
| | TURN | 3 | 29 45 | 171 38 | 121.4 | |
| | EOL | 4 | 30 06 | 173 08 | 149.9 | 378.8 |
| LHRNR-E | SOL | 1 | 33 51 | 160 48 | | |
| | EOL | 2 | 35 39 | 158 00 | 324.9 | 324.9 |
| LHRNR-F | SOL | 1 | 35 42 | 160 36 | | |
| | TURN | 2 | 36 06 | 160 12 | 57.2 | |
| | EOL | 3 | 36 54 | 158 42 | 161.1 | 218.3 |
| LHRNR-G | SOL | 1 | 35 39 | 163 57 | | |
| | EOL | 2 | 37 42 | 160 06 | 412.5 | 412.5 |
| LHRNR-H | SOL | 1 | 37 00 | 163 48 | | |
| | EOL | 2 | 38 30 | 160 51 | 308.7 | 308.7 |
| LHRNR-I | SOL | 1 | 37 09 | 163 45 | | |
| | EOL | 2 | 36 51 | 161 30 | 203.0 | 203.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| LHRNR-J | SOL | 1 | 32 39 | 166 41 | | |
| | TURN | 2 | 32 42 | 166 30 | 19.6 | |
| | TURN | 3 | 33 51 | 164 12 | 249.4 | |
| | EOL | 4 | 33 57 | 164 06 | 14.4 | 283.4 |
| | | | | | | **3793.5** |
| NZ-A | SOL | 1 | 39 14 24 | 161 00 00 | | |
| | TURN | 2 | 39 31 48 | 163 30 36 | 218.6 | |
| | TURN | 3 | 39 28 48 | 164 25 48 | 79.3 | |
| | EOL | 4 | 39 22 12 | 165 07 12 | 60.7 | 358.6 |
| NZ-B | SOL | 1 | 42 12 | 161 42 | | |
| | EOL | 3 | 42 06 | 163 12 | 124.5 | 124.5 |
| NZ-C | SOL | 1 | 42 06 | 163 12 | | |
| | TURN | 2 | 42 33 | 164 00 | 82.7 | |
| | TURN | 3 | 43 06 | 164 27 | 71.3 | |
| | EOL | 4 | 43 06 | 168 30 | 329.7 | 483.7 |
| NZ-D | SOL | 1 | 26 06 | 172 18 | | |
| | TURN | 2 | 26 24 | 172 51 | 64.2 | |
| | TURN | 3 | 26 45 | 172 57 | 40.0 | |
| | TURN | 4 | 27 27 | 172 45 | 80.1 | |
| | EOL | 5 | 27 57 | 172 57 | 58.8 | 243.1 |
| NZ-E | SOL | 1 | 27 57 | 172 57 | | |
| | TURN | 2 | 27 36 | 173 21 | 54.0 | |
| | TURN | 3 | 27 06 | 173 30 | 57.4 | |
| | EOL | 4 | 25 54 | 175 00 | 200.1 | 311.5 |
| NZ-F | SOL | 1 | 27 36 | 173 21 | | |
| | TURN | 2 | 27 33 | 174 54 | 153.2 | |
| | TURN | 3 | 27 30 | 175 18 | 39.9 | |
| | EOL | 4 | 27 06 | 175 54 | 74.1 | 267.2 |
| NZ-G | SOL | 1 | 27 54 | 175 48 | | |
| | TURN | 2 | 28 12 | 175 21 | 55.3 | |
| | TURN | 3 | 28 27 | 174 27 | 92.5 | |
| | EOL | 4 | 29 06 | 172 48 | 176.5 | 324.3 |
| NZ-H | SOL | 1 | 29 57 | 173 12 | | |
| | TURN | 2 | 29 57 | 173 45 | 53.1 | |
| | TURN | 3 | 29 54 | 174 00 | 24.8 | |
| | EOL | 4 | 30 00 | 176 00 | 193.4 | 271.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| NZ-I | SOL | 1 | 30 45 | 172 45 | | |
| | TURN | 2 | 30 54 | 174 15 | 144.5 | |
| | TURN | 3 | 30 54 | 174 30 | 23.9 | |
| | TURN | 4 | 31 21 | 175 15 | 87.2 | |
| | TURN | 5 | 31 21 | 175 45 | 47.8 | |
| | EOL | 6 | 31 21 | 177 15 | 142.7 | 446.1 |
| NZ-J | SOL | 1 | 39 58 12 | 161 08 24 | | |
| | EOL | 2 | 40 05 24 | 161 48 36 | 58.7 | 58.7 |
| NZ-K | SOL | 1 | 41 22 12 | 161 00 36 | | |
| | EOL | 2 | 40 51 00 | 162 00 00 | 101.2 | 101.2 |
| NZ-L | SOL | 1 | 41 33 36 | 161 10 12 | | |
| | EOL | 2 | 41 19 12 | 162 25 12 | 107.8 | 107 8 |
| NZ-M | SOL | 1 | 41 49 12 | 161 43 48 | | |
| | EOL | 2 | 41 19 12 | 162 25 12 | 80.0 | 80.0 |
| | | | | | | **3178.0** |

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# Appendix 1

## United Nations Convention on the Law of the Sea

*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 depth 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

**Summary of picks of foot-of-slope from previous surveys.**

**Numbers in column E refer to Figure 2**

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP,BOTH |
| 2 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER, ?) / NAV |
| 3 | USNS ELTANIN | | | | | | | | |
| 4 | LDGO 1967 | | | | | | | | |
| 5 | 1402 | 1 | cr 30 | 225/0612 | 101 | ZP/SCS | | 6 min | both / |
| 6 | 1403 | 3 | cr 31 | 348/1518 | 102 | ZP/SCS | | 6 min | both / |
| 7 | 1101 | | | 127/0520 | 103 | ZP/SCS | | 10 min | both / |
| 8 | 1101 | | | 125/1640 | 104 | ZP/SCS | | 10 min | both / |
| 9 | 1101 | | | 121/0710 | 106 | ZP/SCS | | 10 min | both / |
| 10 | LDGO 1969 | | | | | | | | |
| 11 | 1100 | 5 | | 213/0001 | 108 | ZP/SCS | | 20 min | FoS |
| 12 | 1100 | 5 | | 213/0930 | 109 | ZP/SCS | | 15 min | FoS |
| 13 | 1100 | 7 | | 210/1900 | 110 | ZP | | 15 min | EoAP |
| 14 | 1100 | 7 | | 210/1845 | 111 | ZP | | 15 min | FoS |
| 15 | LDGO 1971 | | | | | | | | |
| 16 | 1101 | 7 | | 119/2030 | 112 | ZP/SCS | | 10 min | both |
| 17 | 1101 | 7 | | 119/2240 | 113 | ZP/SCS | | 10 min | neither |
| 18 | 1101 | 7 | | 115/2100 | 114 | ZP/SCS | | 10 min | both |
| 19 | 1101 | 8 | | 114/0020 | 116 | ZP/SCS | | 10 min | both |
| 20 | 1100 | 6 | | 214/0025 | 117 | ZP/SCS | | 40 min | ? |
| 21 | 1100 | 6 | | 214/1900 | 118 | ZP/SCS | | 15 min | both |
| 22 | 1403 | 6 | | 348/2136 | 119 | ZP/SCS | | 6 min | ? |
| 23 | ARGO SIO 1967 | | | | | | | | |
| 24 | 1560 | 1 | | 233/1200 | 401 | ZP | | 5 min | FoS |
| 25 | | 1 | | 233/1315 | 402 | ZP | | 5 min | FoS |
| 26 | | 1 | | 233/2030 | 403 | ZP | | 5 min | FoS |
| 27 | | 1 | | 234/0830 | 404 | ZP | | 5 min | FoS |
| 28 | | 2 | | 243/1800 | 405 | ZP | | 5 min | FoS |
| 29 | | 2 | | 242/1900 | 406 | ZP | | 5 min | FoS |
| 30 | | 3 | | 248/0415 | 407 | ZP | | 5 min | FoS |
| 31 | | 3 | | 248/0030 | 408 | ZP | | 5 min | FoS |
| 32 | | 3 | | 247/2330 | 409 | ZP | | 5 min | FoS |
| 33 | | 3 | | 246/2350 | 410 | ZP | | 5 min | |
| 34 | | 3 | | 246/2100 | 411 | ZP | | 5 min | FoS |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 35 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP, BOTH |
| 36 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER) / NAV |
| 37 | ARGO SIO 1967 (cont) | | | | | | | | |
| 38 | | 3 | | 246/1005 | 412 | ZP | | 5 min | ? |
| 39 | | 3 | | 246/0645 | 413 | ZP | | 5 min | FoS |
| 40 | 1560 | | | 245/2155 | 414 | ZP | | 5 min | Both |
| 41 | | | | 245/1905 | 415 | ZP | | 5 min | Neither |
| 42 | | | | 245/1855 | 416 | ZP | | 5 min | Neither |
| 43 | | | | 245/1640 | 417 | ZP | | 5 min | FoS |
| 44 | | | | 245/1620 | 418 | ZP | | 15 min | FoS |
| 45 | | | | 245/1430 | 419 | ZP | | 5 min | FoS |
| 46 | CONRAD LDGO 1968 | | | | | | | | |
| 47 | 1377 | 1 | | 125/1410 | 201 | ZP | | 6 min | both |
| 48 | 1377 | 2 | | 128/0924 | 204 | ZP | | 6 min | both |
| 49 | 1377 | 2 | | 128/0230 | 205 | ZP | | 6 min | both |
| 50 | 1376 | 1 | | | 202 | | | | |
| 51 | 1376 | 2 | | 115/1230 | 203 | ZP | | 6 min | |
| 52 | 1376 | 2 | | 115/2257 | 206 | ZP | | 6 min | |
| 53 | 1376 | 2 | | 115/1554 | 207 | ZP | | 6 min | |
| 54 | CONRAD LDGO 1965 | | | | | | | | |
| 55 | 1358 | 5 | | 102/0800 | 208 | ZP | | 3 min | both |
| 56 | 1358 | 8 | | 103/1830 | 209 | ZP | | 3 min | both |
| 57 | 1376 | 3 | | 114/0200 | 210 | ZP | | 6 min | ? |
| 58 | 1376 | 3 | | 114/0430 | 211 | ZP | | 6 min | ? |
| 59 | 1376 | 3 | | 114/0530 | 212 | ZP | | 6 min | ? |
| 60 | 1376 | 3 | | 114/0730 | 213 | ZP | | 6 min | ? |
| 61 | 1376 | 3 | | 114/1030 | 214 | ZP | | 6 min | ? |
| 62 | 1377 | 3 | | 129/1500 | 215 | ZP | | 6 min | both |
| 63 | 1358 | | | 100/0825 | 216 | ZP | | 3 min | ? |
| 64 | HORIZON SIO 1967 | | | | | | | | |
| 65 | 1597 | 1 | | 235/0530 | 301 | ZP | | 5 min | FoS |
| 66 | 1597 | 1 | | 239/1200 | 303 | ZP | | 5 min | |
| 67 | 1597 | 2 | | 243/1835 | 305 | ZP | | 5 min | FoS |
| 68 | 1592 | 1 | | 121/0030 | 302 | ZP | | 5 mni | both |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 69 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP, BOTH |
| 70 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER) / NAV |
| 71 | 1592 | 2 | | 117/0240 | 304 | ZP | | 5 min | both |
| 72 | 1592 | 2 | | 117/1940 | 306 | ZP | | 5 min | FoS |
| 73 | 1593 | 4 | | 127/1720 | 307 | ZP | | 5 min | FoS |
| 74 | 1597 | 2 | | 242/1555 | 308 | ZP | | 5 min | FoS |
| 75 | 1592 | 2 | | 117/1625 | 309 | ZP | | 5 min | EoAP |
| 76 | 1593 | 2 | | 137/1610 | 310 | ZP | | 5 min | both |
| 77 | 1597 | 2 | | 242/2010 | 311 | ZP | | 5 min | ? |
| 78 | 1593 | 2 | | 136/2345 | 312 | ZP | | 5 min | both |
| 79 | 1593 | 5 | | 130/0045 | 313 | ZP | | 5 min | both |
| 80 | 1593 | 5 | | 130/1750 | 314 | ZP | | 10 min | |
| 81 | 1593 | 3 | | 134/0420 | 315 | ZP | | 6 min | ? |
| 82 | 1597 | 3 | | 247/1450 | 316 | ZP | | 6 min | both |
| 83 | 1592 | 3 | | 114/1640 | 317 | ZP | | 5 min | ? |
| 84 | 1592 | 3 | | 114/1900 | 318 | ZP | | 5 min | ? |
| 85 | 1592 | 3 | | 113/1640 | 319 | ZP | | 5 min | both |
| 86 | 1597 | 3 | | 227/2136 | 320 | ZP | | 6 min | both |
| 87 | 1592 | | | 116/0630 | 321 | ZP | | 5 min | ? |
| 88 | 1592 | | | 116/1130 | 322 | ZP | | 5 min | FoS |
| 89 | 1592 | | | 115/1910 | 323 | ZP | | 5 min | ? |
| 90 | 1592 | | | 115/1340 | 324 | ZP | | 5 min | ? |
| 91 | 1592 | | | 115/1110 | 325 | ZP | | 5 min | ? |
| 92 | 1592 | | | 115/0920 | 326 | ZP | | 5 min | ? |
| 93 | 1597 | | | 245/1530 | 327 | ZP | | 5 min | ? |
| 94 | 1593 | | | 132/1020 | 328 | ZP | | 5 min | FoS |
| 95 | 1593 | | | 132/1540 | 329 | ZP | | 5 min | FoS |
| 96 | 1593 | | | 133/1600 | 330 | ZP | | 5 min | neither |
| 97 | 1592 | | | 115/1455 | 331 | ZP | | 5 min | ? |
| 98 | 1597 | | | 245/1210 | 332 | ZP | | 5 min | ? |
| 99 | 1592 | | | 115/0130 | 333 | P | | 5 min | FoS |
| 100 | 1592 | | | 115/1825 | 335 | ZP | | 5 min | ? |
| 101 | | | | 115/0025 | 336 | ZP | | | |
| 102 | KANA KEOKI | | | | | | | | |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 103 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP, BOTH |
| 104 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER, ?) / NAV |
| 105 | SOEST 1971 | | | | | | | | |
| 106 | 1504 | 5 | | 248/2200 | 1601 | ZP | | 15 min | |
| 107 | COMBINATION | | | | | | | | |
| 108 | CONRD+KANA KK | | | | | | | | |
| 109 | 1968+1971 | | | | | | | | |
| 110 | 1376 + 1504 | 1 | | 17/2030 + 254/043 | 1 & 2 | | | NO | P |
| 111 | SONNE 7 BGR 1978 | | | | | | | | |
| 112 | 1031 | 1 | | 318/0257 | 501 | ZP | | 1 min | |
| 113 | | 4 | | 304/1657 | 502 | ZP | | 1 min | |
| 114 | | 4 | | 304/0456 | 503 | ZP | | 1min | |
| 115 | GULFREX | | | | | | | | |
| 116 | 1028 | 1 | | ? | 601 | | | CHECK | DATA UNPOSTED |
| 117 | VEMA | | | | | | | | |
| 118 | 1343 | 8 | | 312/0148 | 1901 | ZP | | 6 min | both |
| 119 | 1418 | 8 | | 209/2318 | 1902 | ZP | | 6 min | both |
| 120 | 1343 | 3 | | 304/1106 | 1903 | ZP | | 6 min | FoS |
| 121 | 1343 | 3 | | 304/0748 | 1904 | ZP | | 6 min | ? |
| 122 | 1343 | 3 | | 301/1548 | 1905 | ZP | | 6 min | ? |
| 123 | 1343 | 3 | | 301/0918 | 1906 | ZP | | 6 min | FoS |
| 124 | 1343 | 3 | | 301/0706 | 1907 | ZP | | 6 min | FoS |
| 125 | 1343 | 3 | | 301/0348 | 1908 | ZP | | 6 min | ? |
| 126 | 1043 | 3 | | 037/2018 | 1909 | ZP | | 6 min | ? |
| 127 | 1043 | 3 | | 037/1800 | 1910 | ZP | | 6 min | ? |
| 128 | 1343 | | | 308/2042 | 1911 | ZP | | 6 min | |
| 129 | 1343 | | | 308/1442 | 1912 | ZP | | 6 min | |
| 130 | 1343 | | | 307/0318 | 1913 | ZP | | 6 min | |
| 131 | TANGAROA | | | | | | | | |
| 132 | 1465 | | | 221/2350 | 2001 | ZP | | 10 min | FoS |
| 133 | | | | 221/1800 | 2002 | ZP | | 10 min | FoS |
| 134 | L'ATALANTE | | | | | | | | |
| 135 | 123 | | | 301/0251 | 2301 | ZP | | 1 min | both |
| 136 | | | | 301/0418 | 2302 | ZP | | 1 min | both |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 137 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP, BOTH |
| 138 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER, ?) / NAV |
| 139 | HAMME BMR 1971 | | | | | | | | |
| 140 | 12 | 4 | | 012/1527 | 741 | ZP | | 1 min | FoS |
| 141 | | 4 | | 008/1710 | 742 | ZP | | 1 min | FoS |
| 142 | | 4 | | 010/0900 | 743 | ZP | | 1 min | ? |
| 143 | | 4 | | 010/1726 | 744 | ZP | | 1 min | FoS |
| 144 | | 1 | | 083/0830 | 703 | ZP | | 1 min | ? |
| 145 | | 1 | | 081/1425 | 704 | ZP | | 1 min | FoS |
| 146 | | 1 | | 079/1812 | 707 | ZP | | 1 min | FoS |
| 147 | | 1 | | 078/0743 | 709 | ZP | | 1 min | FoS |
| 148 | | 1 | | 075/1902 | 710 | ZP | | 1 min | BOTH |
| 149 | | 1 | | 074/0550 | 711 | ZP | | 1 min | BOTH |
| 150 | | 1 | | 072/0840 | 712 | ZP | | 1 min | BOTH |
| 151 | | 1 | | 070/2130 | 714 | ZP | | 1 min | BOTH |
| 152 | | 1 | | 069/0650 | 716 | ZP | | 1 min | BOTH |
| 153 | | 1 | | 067/1220 | 717 | ZP | | 1 min | FoS |
| 154 | | 1 | | 058/1532 | 718 | ZP | | 1 min | NEITHER |
| 155 | | 1 | | 058/2010 | 719 | ZP | | 1 min | BOTH |
| 156 | | 1 | | 057/0354 | 720 | ZP | | 1 min | FoS |
| 157 | | 1 | | 055/0133 | 722 | ZP | | 1 min | FoS |
| 158 | | 1 | | 053/2022 | 723 | ZP | | 1 min | FoS |
| 159 | | 1 | | 051/2121 | 725 | ZP | | 1 min | FoS |
| 160 | | 1 | | 050/1250 | 727 | ZP | | 1 min | BOTH |
| 161 | | 4 | | 048/1852 | 728 | ZP | | 1 min | FoS |
| 162 | | 4 | | 048/1653 | 729 | ZP | | 1 min | NEITHER |
| 163 | | 4 | | 038/1900 | 730 | ZP | | 1 min | missed : retry 1800 ->2000 |
| 164 | | 4 | | 036/2000 | 731 | ZP | | 1 min | FoS |
| 165 | | 4 | | 035/0230 | 733 | ZP | | 1 min | FoS |
| 166 | | 4 | | 033/0600 | 734 | ZP | | 1 min | FoS |
| 167 | | 4 | | 029/0100 | 735 | ZP | | 1 min | missed : retry 028/2300 |
| 168 | | 4 | | 024/1730 | 737 | ZP | | 1 min | FoS |
| 169 | | 4 | | 024/1500 | 738 | ZP | | 1 min | FoS |
| 170 | | 4 | | 022/1930 | 740 | ZP | | 1 min | FoS |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 171 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP, BOTH, |
| 172 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER, ?) / NAV |
| 173 | HAMME | | | | | | | | |
| 174 | 13 | 4 | | 006/0242 | 801 | ZP | | 1 min | FoS |
| 175 | HAMME BMR 1971 | | | | | | | | |
| 176 | | 1 | | 010/2256 | 701 | ZP | | 1 min | FoS |
| 177 | | 1 | | 014/1703 | 702 | ZP | | 1 min | BOTH |
| 178 | RIG SEISMIC AGSO | | | | | | | | |
| 179 | 46 | 4 | | 035/0648 | 901 | ZP | | 1 min | ? |
| 180 | | | | 041/0610 | 902 | ZP | | 1 min | FoS |
| 181 | LADY CHRISTINE | | | | | | | | |
| 182 | BMR 1971 | | | | | | | | |
| 183 | 14 | 4 | | 069/2045 | 1101 | ZP | | 1 min | both |
| 184 | | 1 | | 007/1709 | 705 | ZP | | 1 min | FoS |
| 185 | | 1 | | 065/1534 | 724 | ZP | | 1 min | both |
| 186 | | 5 | | 068/0344 | 745 | ZP | | 1 min | both |
| 187 | | 5 | | 068/0558 | 746 | ZP | | 1 min | both |
| 188 | LADY CHRISTINE | | | | | | | | |
| 189 | BMR 1971 | | | | | | | | |
| 190 | 15 | 1 | | 053/0100 | 706 | ZP | | 1 min | missed : retry 052/2300 |
| 191 | | 1 | | 060/1739 | 708 | ZP | | 1 min | FoS |
| 192 | | 1 | | 062/0909 | 713 | ZP | | 1 min | BOTH |
| 193 | | 1 | | 064/0313 | 715 | ZP | | 1 min | BOTH |
| 194 | | 1 | | 065/2136 | 721 | ZP | | 1 min | FoS |
| 195 | | 1 | | 068/0300 | 726 | ZP | | 1 min | BOTH |
| 196 | | 4 | | 069/1920 | 732 | ZP | | 1 min | BOTH |
| 197 | | 4 | | 079/2153 | 736 | ZP | | 1 min | FoS |
| 198 | | 4 | | 078/0820 | 739 | ZP | | 1 min | FoS |
| 199 | SONNE BGR/AGSO | | | | | | | | |
| 200 | 77 | 4 | | 047/2202 | 1001 | ZP | | 1 min | FoS |
| 201 | SONNE BGR | | | | | | | | |
| 202 | 1031 | | | 299/0730 | 2201 | seismic | | | |
| 203 | | | | 298/1700 | 2202 | seismic | | | |
| 204 | | | | 297/0600 | 2203 | seismic | | | |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 205 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP, BOTH, |
| 206 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER, ?) / NAV |
| 207 | SONNE 36A | | | | | | | | |
| 208 | BGR 1985 | | | | | | | | |
| 209 | 52 | 2 | | 045/1236 | 1301 | ZP | | 1 min | both |
| 210 | | | | 124/2030 | 1302 | ZP | | 1 min | both |
| 211 | FRED MOORE | | | | | | | | |
| 212 | MOBIL 1978 | | | | | | | | |
| 213 | 1151 | 5 | | 212/0845 | 1401 | ZP | | 1 min | both |
| 214 | | 5 | | 118/0102 | 1402 | ZP | | 1 min | both |
| 215 | | 5 | | 118/1507 | 1403 | ZP | | 1 min | both |
| 216 | | 5 | | 094/0202 | 1404 | ZP | | 1 min | both |
| 217 | | 5 | | 092/2235 | 1405 | ZP | | 1 min | both |
| 218 | | 5 | | 096/0440 | 1406 | ZP | | 10 min | both |
| 219 | | 5 | | 096/1917 | 1407 | ZP | | 1min | both |
| 220 | | 5 | | 096/1402 | 1408 | ZP | | 3 min | both |
| 221 | | 5 | | 119/0605 | 1409 | ZP | | 1 min | both |
| 222 | | 5 | | 093/0635 | 1410 | ZP | | 5 min | both |
| 223 | | 5 | | 093/1615 | 1411 | ZP | | 1 min | both |
| 224 | | 5 | | 117/1040 | 1412 | ZP | | 1 min | both |
| 225 | | 5 | | 117/1620 | 1413 | ZP | | 1 min | both |
| 226 | | 5 | | 117/1813 | 1414 | ZP | | 1 min | both |
| 227 | RIG SEISMIC AGSO | | | | | | | | |
| 228 | 114 | 4 | | 317/2133 | 1201 | ZP/MCS | | 1 min | BOTH |
| 229 | | 4 | | 318/0220 | 1202 | ZP/MCS | | 1 min | EoAP |
| 230 | | 4 | | 320/2232 | 1203 | ZP/MCS | | 1 min | FoS |
| 231 | | 5 | | 323/0553 | 1204 | ZP/MCS | | 1 min | FoS |
| 232 | | 5 | | 328/2340 | 1205 | ZP/MCS | | 1 min | FoS |
| 233 | | 5 | | 328/1032 | 1206 | ZP/MCS | | 1 min | FoS |
| 234 | | 5 | | 323/2232 | 1207 | ZP/MCS | | 1 min | FoS |
| 235 | | | | 325/1624 | 1208 | ZP/MCS | | 1 min | FoS |
| 236 | | | | 327/0536 | 1209 | ZP/MCS | | 1 min | FoS |
| 237 | UMITAKA MARU | | | | | | | | |
| 238 | 1675 | 8 | | 315/1300 | 1801 | ZP | | 1 min | both |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 239 | SURVEY NUMBER | MAP | LINE | LOCATION | ID | DATA | METHOD | PICK | TYPE (FoS, EoAP, BOTH, |
| 240 | | SHEET | CRUISE | APPROXIMATE | | TYPE | | PRECISION | NEITHER, ?) / NAV |
| 241 | | 8 | | 315/1330 | 1802 | ZP | | | |
| 242 | GLOMR CHALLENGR | | | | | | | | |
| 243 | SIO 1972 | | | | | | | | |
| 244 | 1584 | 5 | LEG 21 | 354/2135 | 1501 | ZP | | 5 min | both |
| 245 | | 5 | | 337/1225 | 1502 | ZP | | 5 min | |
| 246 | | 5 | | 349/2120 | 1503 | ZP | | 5 min | both |
| 247 | | 5 | | 334/0255 | 1504 | ZP | | 6 min | ? |
| 248 | | | | 331/2206 | 1514 | ZP | | 6 min | ? |
| 249 | | | | 333/0740 | 1515 | ZP | | 5 min | |
| 250 | | | | 333/1010 | 1516 | ZP | | 5 min | |
| 251 | | 5 | | 337/0710 | 1510 | ZP | | 5 min | |
| 252 | | 5 | | 337/0955 | 1511 | ZP | | 5 min | |
| 253 | GLOMR CHALLENGR | | | | | | | | |
| 254 | SIO 1983 | | | | | | | | |
| 255 | 1589 | 5 | LEG 90 | 348/0935 | 1505 | ZP | | 5 min | |
| 256 | | 5 | | 358/0325 | 1506 | ZP | | 5 min | both |
| 257 | | 5 | | 358/1520 | 1507 | ZP | | 5 min | both |
| 258 | | 5 | | 347/2255 | 1508 | ZP | | 5 min | both |
| 259 | | 5 | | 348/0545 | 1509 | ZP | | 5 min | |
| 260 | | 5 | | 347/1445 | 1512 | ZP | | 5 min | FoS |
| 261 | | 5 | | 347/1225 | 1513 | ZP | | 5 min | FoS |
| 262 | VITYAZ | | | | | | | | |
| 263 | 1648 | 2 | | 010/0440 | 1701 | ZP | | 10 min | |
| 264 | | 2 | | 009/1640 | 1702 | ZP | | 10 min | |
| 265 | | 8 | | 021/0200 | 1703 | ZP | | | |

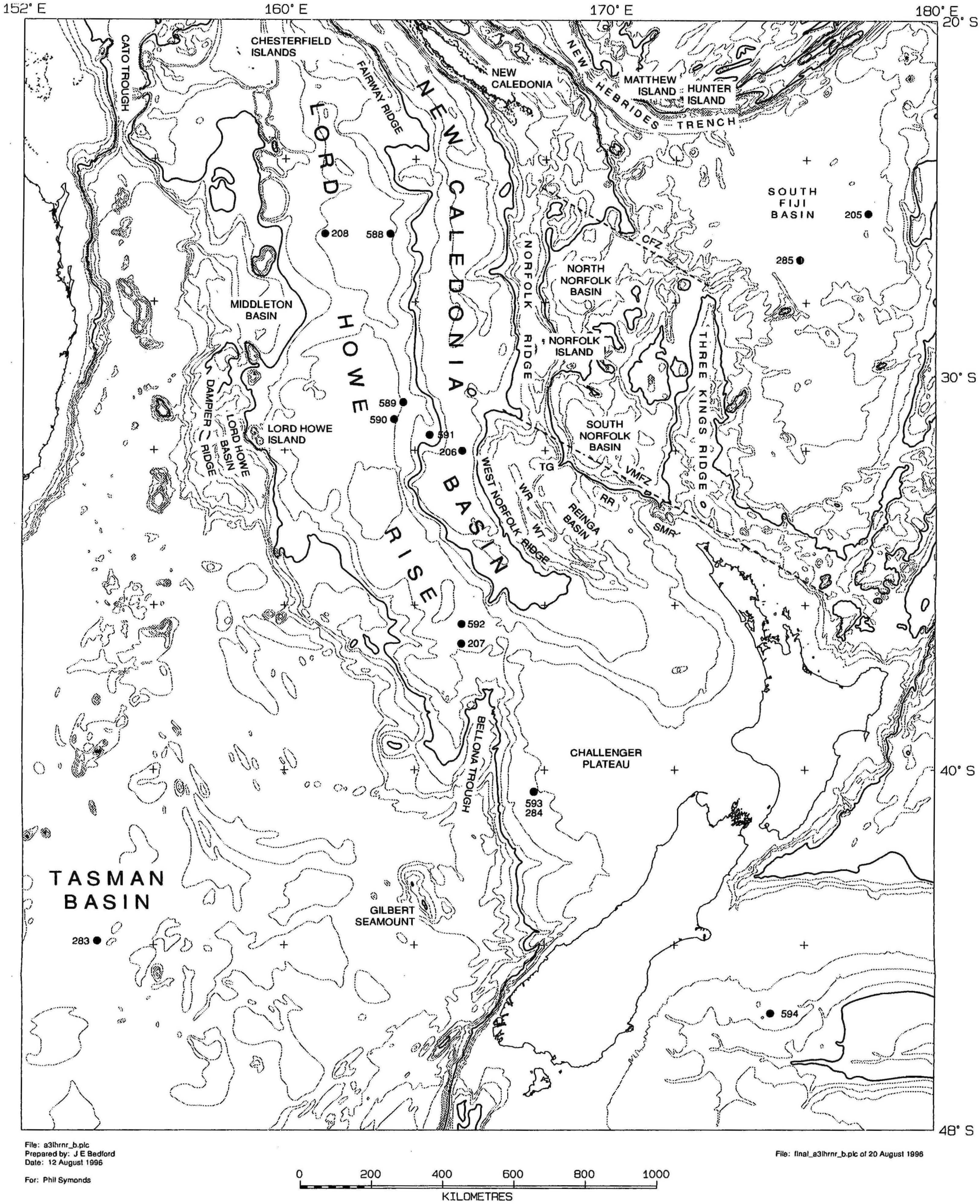
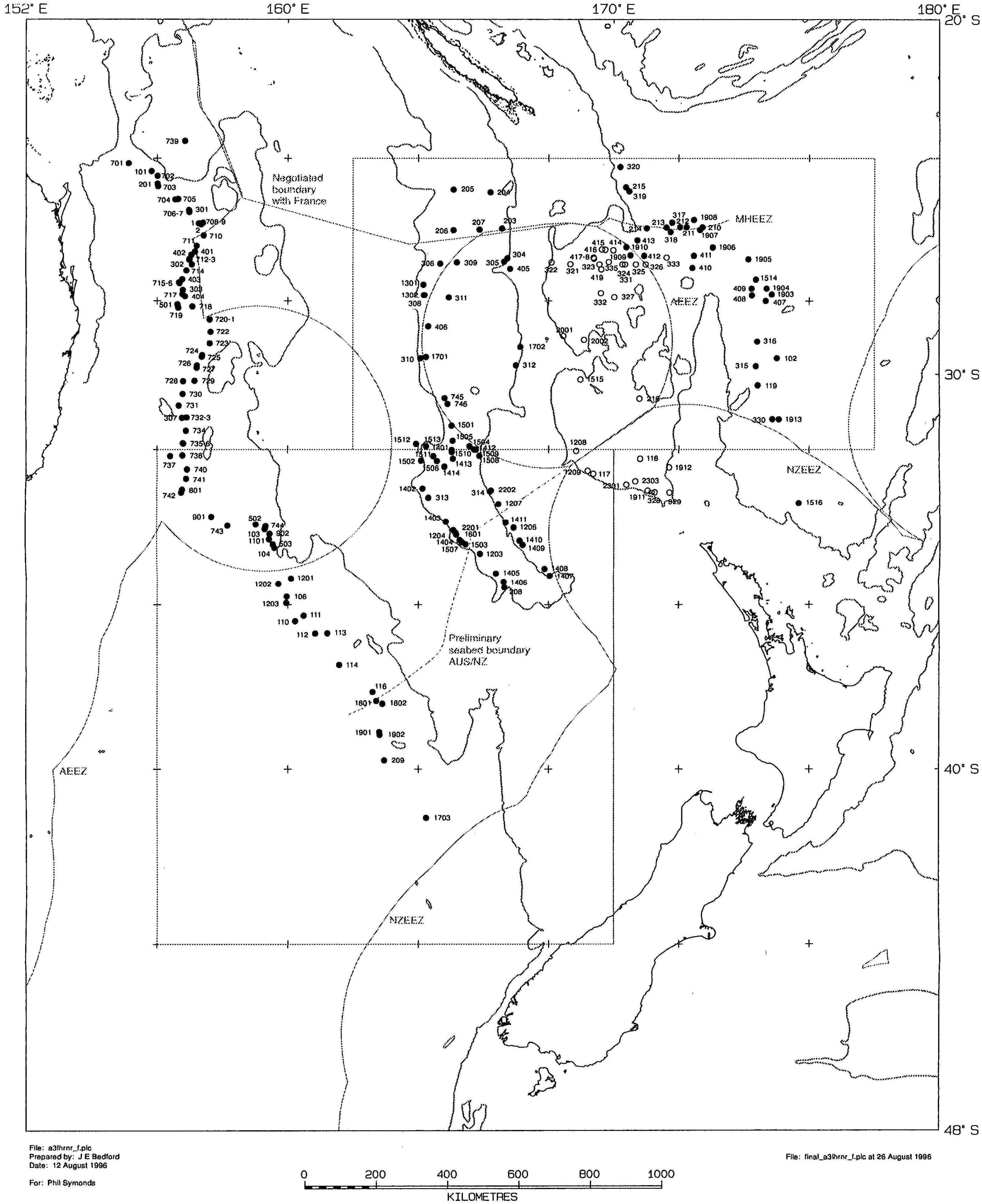



Figure 1 Physiography of the area. Bathymetry contours are from GEBCO, with 2500 m highlighted.
TG = Taranui Gap; WR = Wanganella Ridge; WT = Wanganella Trough; RR = Reinga Ridge; SMR = South Maria Ridge; CFZ = Cook Fracture Zone; VMFZ = Vening Meinesz Fracture Zone; = DSDP site.




File: a3lhrnr_f.plc
Prepared by: J E Bedford
Date: 12 August 1996

For: Phil Symonds

File: final_a3lhrnr_f.plc at 26 August 1996

Figure 2 Foot-of-slope picks (numbers correspond with column E of Appendix 2; o indicates internal FoS within North and South Norfolk Basins). Also depicts political boundaries, 2500 m isobath and survey areas as in Figures 5 and 6.
MHEEZ = Exclusive Economic Zone around Matthew and Hunter Islands.

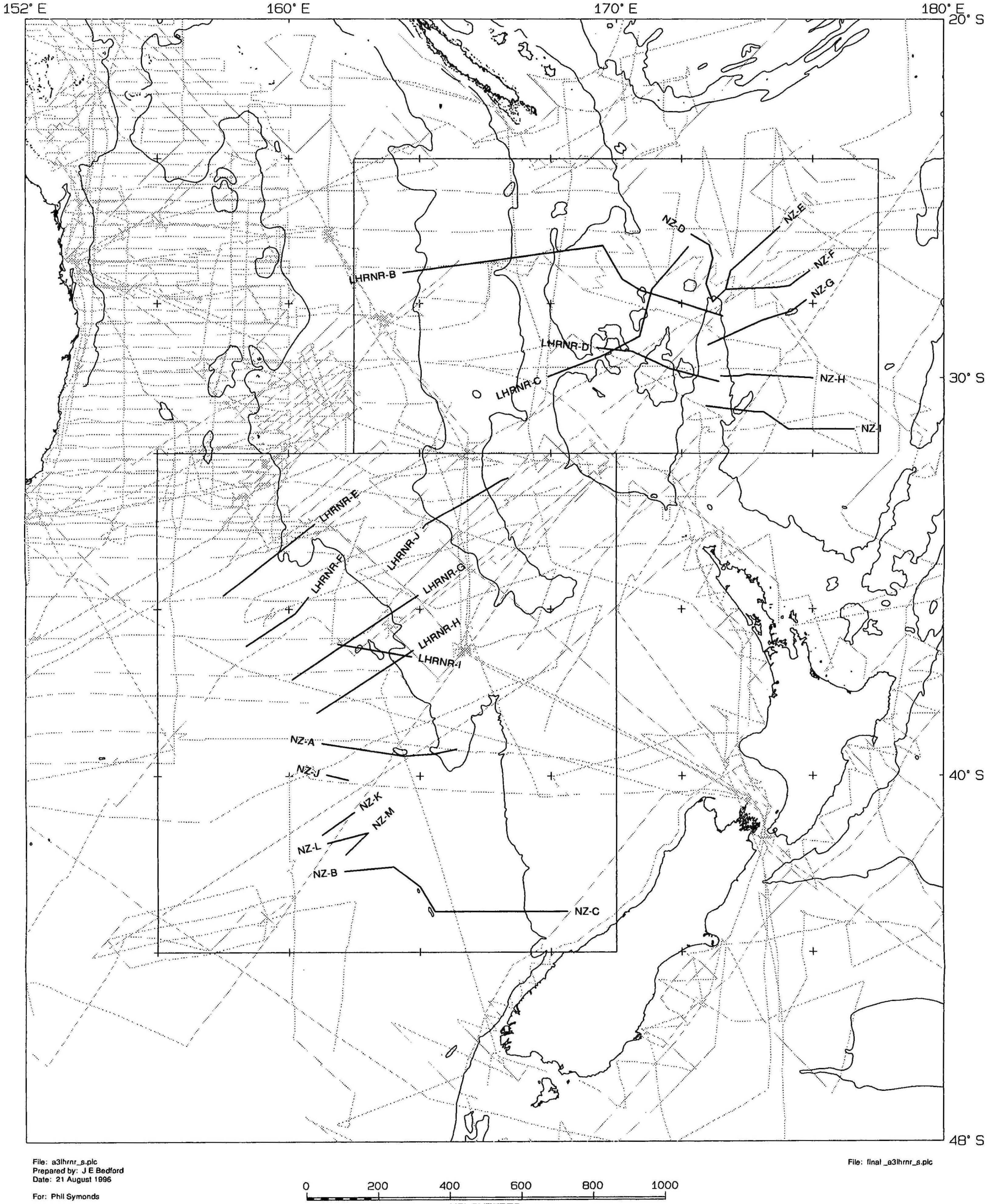



Figure 3 All survey lines from which relevant FoS picks were interpreted. Also depicts 2500 m isobath, survey areas and proposed survey lines. LHRNR prefix = proposed Australian lines; NZ prefix = proposed New Zealand lines.

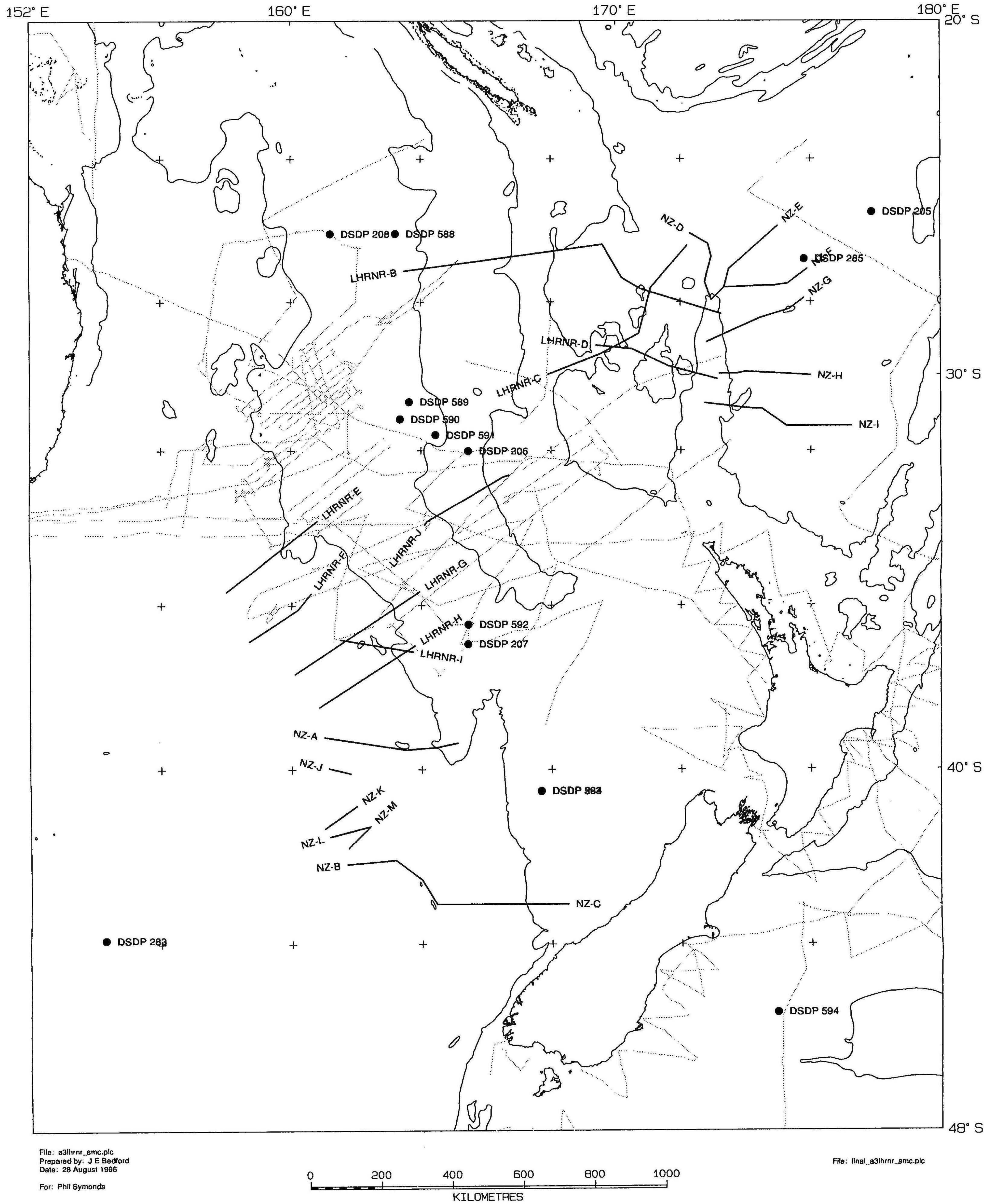



Figure 4 Proposed survey lines with respect to existing multi-channel seismic lines. Also depicts 2500 m isobath and DSDP sites.

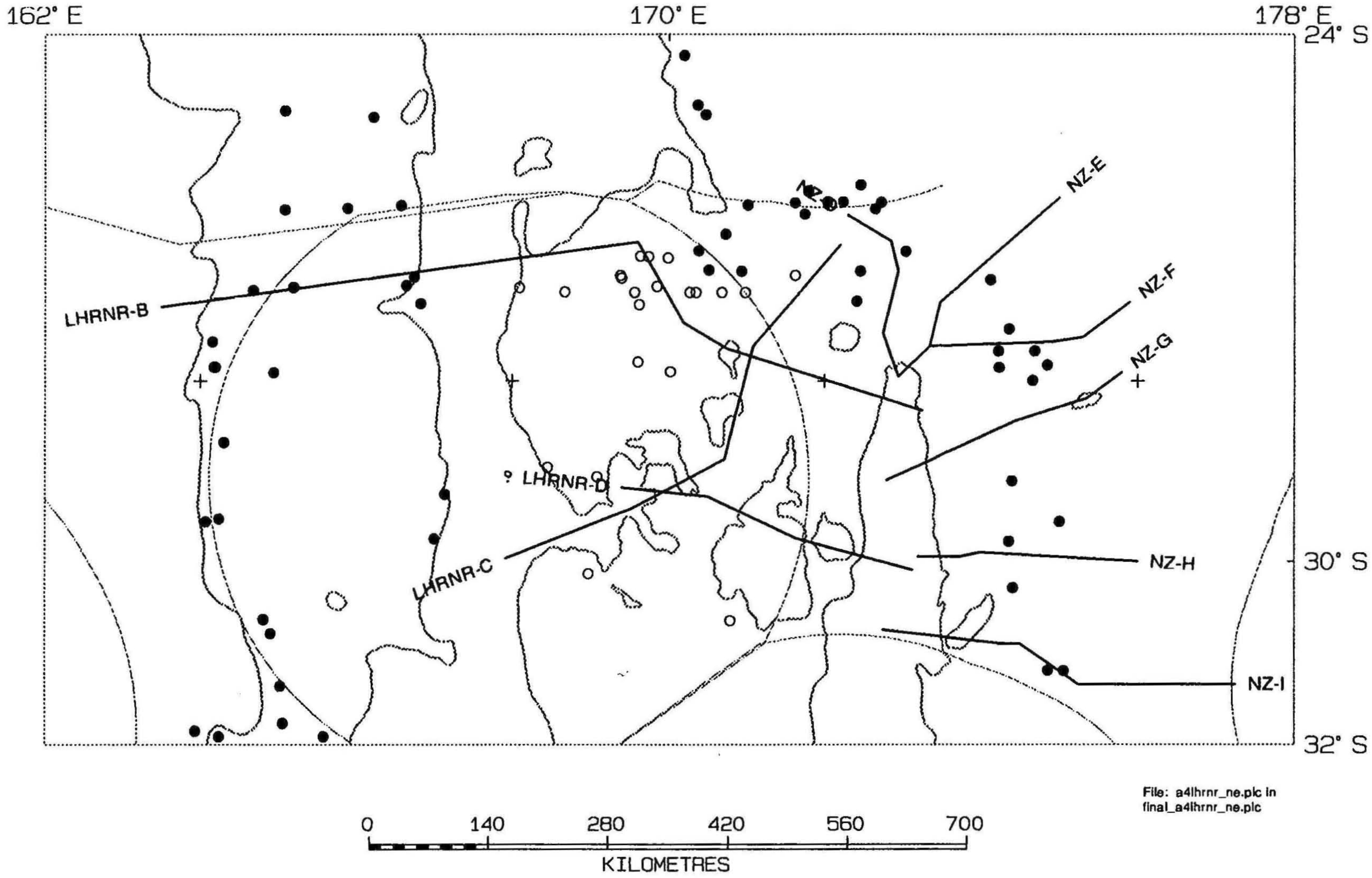



Figure 5 Northeast survey area. Shows FoS picks, political boundaries, 2500 m isobath and proposed seismic lines.

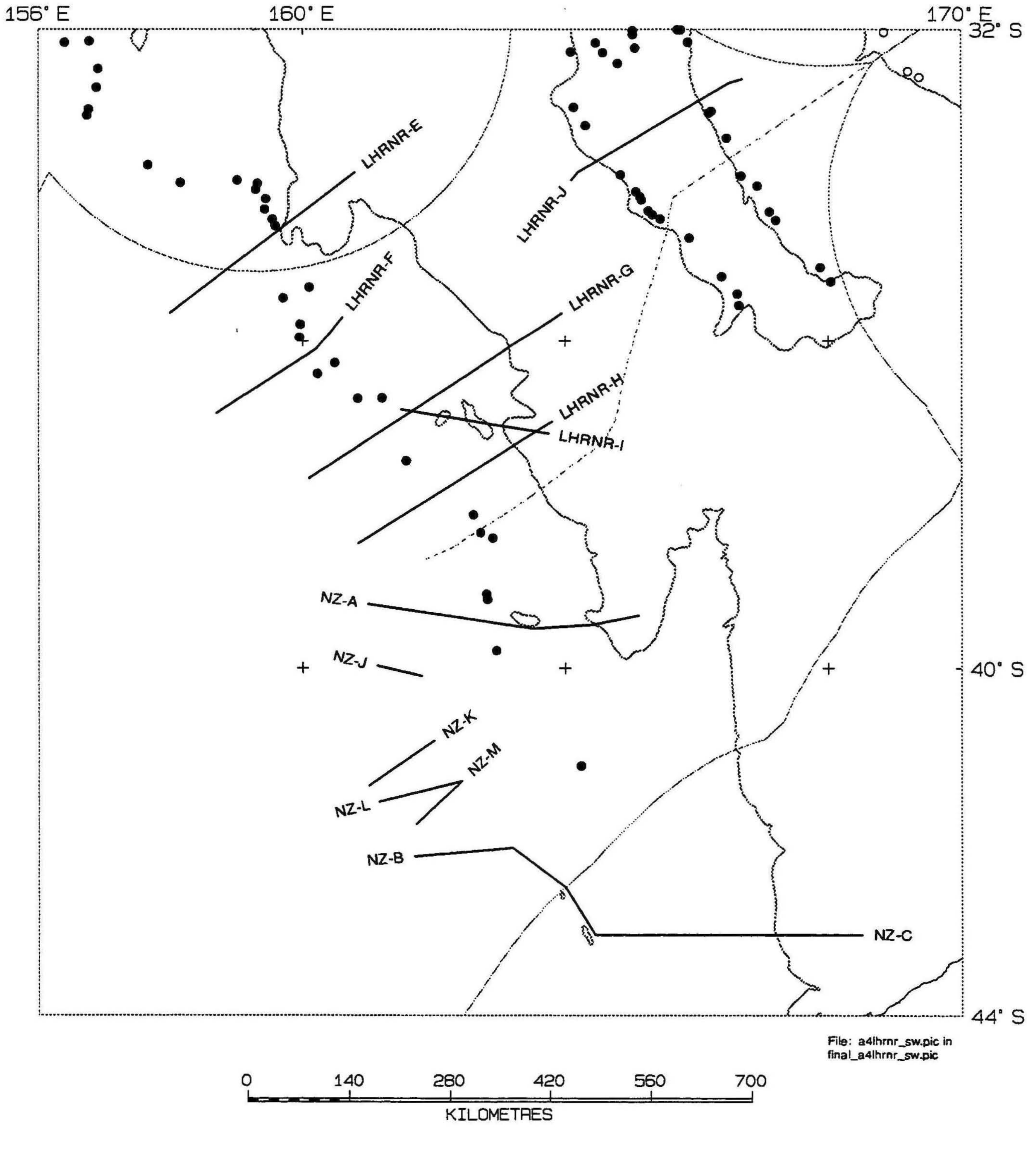



Figure 6 Southwest survey area. Shows FoS picks, political boundaries, 2500 m isobath and proposed seismic lines.

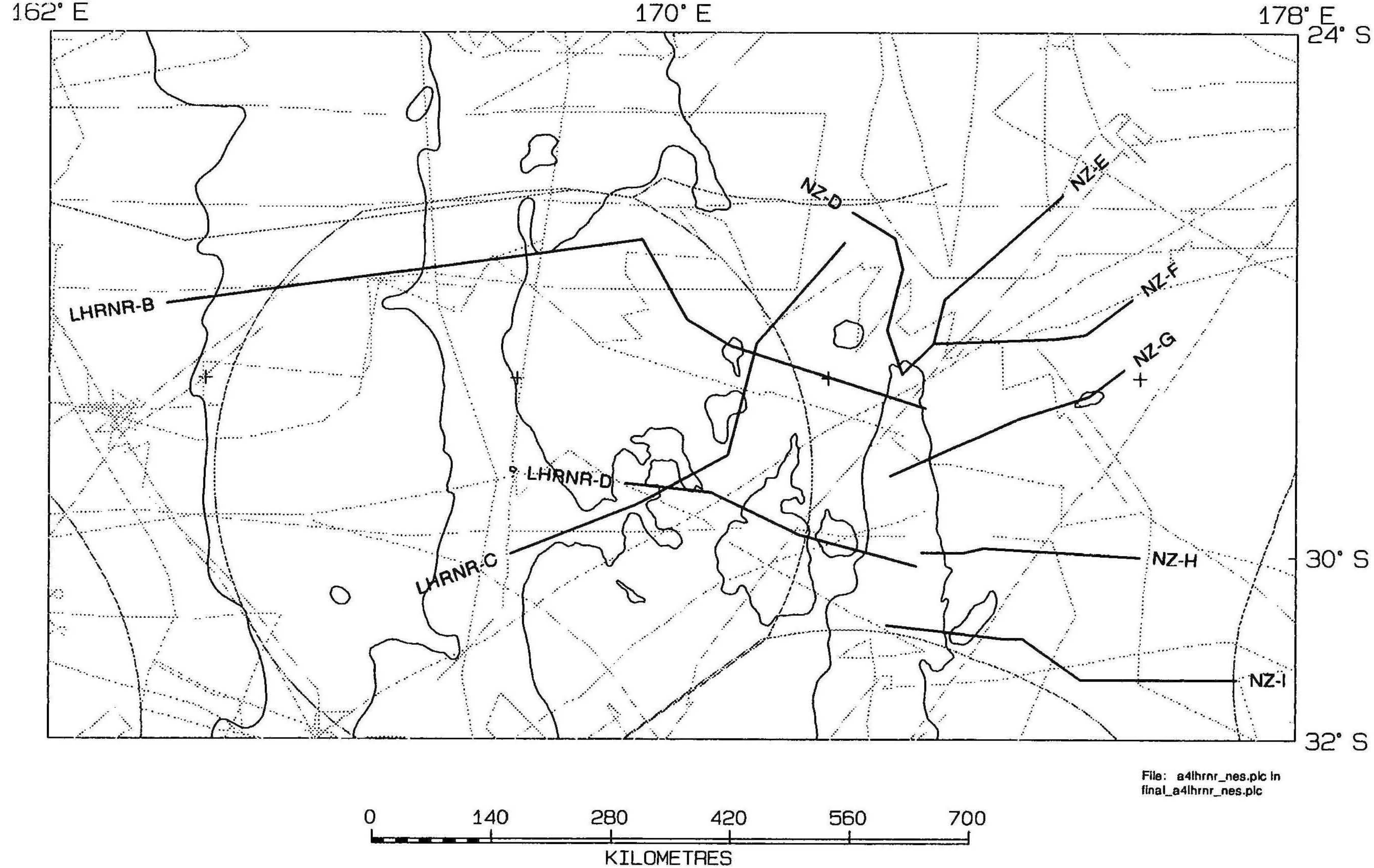



Figure 7 Northeast survey area. Shows existing seismic lines, political boundaries, 2500 m isobath and proposed seismic lines.

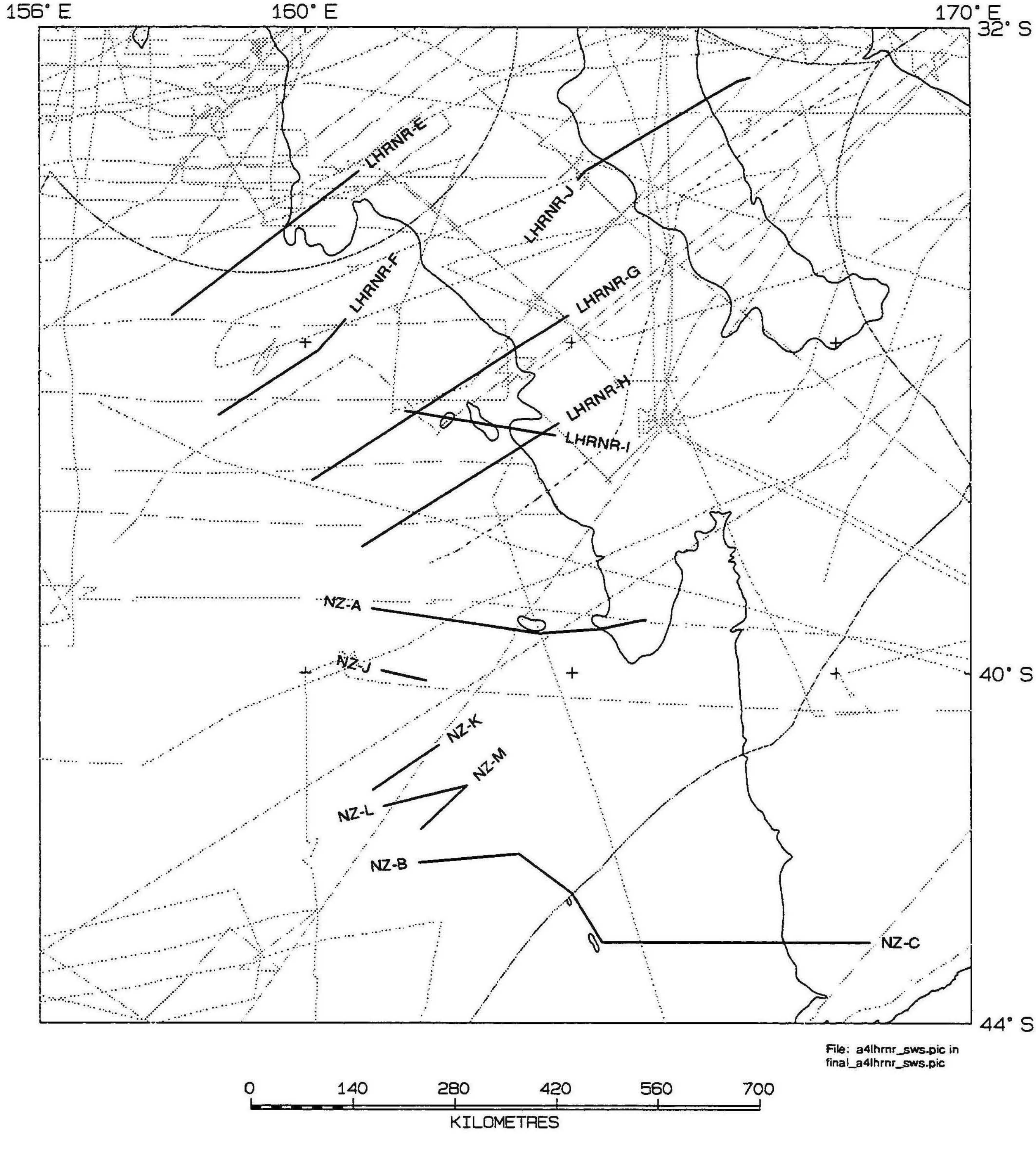



Figure 8 Southwest survey area. Shows existing seismic lines, political boundaries, 2500 m isobath and proposed seismic lines.