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DEEP STRUCTURE OF THE SOUTHERN NORTH WEST SHELF: SHALLOW-WATER BARROW SUB-BASIN SURVEY PROPOSAL

by

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Marine Geoscience and Petroleum Geology Program

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Project 121.17

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In mid-1991, the Bureau of Mineral Resources (BMR) commenced a program of deep seismic acquisition on the southern North West Shelf with the intention of providing a regional framework data set for explorers in this highly prospective segment of Australia's continental margin. In particular, the program has the following aims:

* To determine the broad regional structural framework of the southern North West Shelf by examining the boundaries between the major structural elements;

* To determine the deep crustal structure of the region;

* To assess the control of deep structure on the development of the major hydrocarbon fields and plays, and in particular the structural and depositional effects resulting from reactivation of these structures; and

* To acquire a set of high-quality seismic tie lines linking the deeper exploration wells throughout the region to allow regional seismic correlations.

To address these aims, a multi-cruise program has been devised during which deep seismic data (4800 m streamer; 16 sec record length; 3000 cu in seismic source) are being recorded. During the first cruise, SNOWS-I (for Southern North West Shelf), completed in June 1991, 1654 km of seismic data were acquired aboard the BMR's research vessel *Rig Seismic* along 10 widely spaced lines tied to 20 exploration wells in the Barrow, Dampier, and Exmouth Sub-basins, and on the inner flank of the Exmouth Plateau. Processing of the data was arranged through a commercial contractor. The data were processed by the second quarter of 1992, and frequently show basin structure down to a depth of at least 10 s TWT (>20 km); these are the first data recorded on the southern North West Shelf that show such deep structures.

SNOWS-II, programmed for June-July 1992, is intended to acquire up to 2765 km of deep seismic data tied to 22 exploration wells (of which 4 were also tied on SNOWS-I), while SNOWS-III, scheduled for mid- to late-1993, will carry out similar work in the offshore Canning Basin.

As the *Rig Seismic* is a deep-water research vessel, the data recorded so far is restricted to water depths of more than 20 metres. However, within the Barrow Sub-basin, in particular, the basin-forming structures landward of the main depocentre axis are frequently located in water depths of less than 20 metres. Since the landward basin-bounding faults in continental margin rift basins are critical to understanding the gross basin framework and the tectonic evolution it is important that data be collected in these areas, for maximum program effectiveness.

To overcome this problem, BMR is proposing to contract a commercial shallow-water seismic vessel to record extensions to the SNOWS-I and SNOWS-II lines across the basin-bounding faults of the Barrow Sub-basin, where possible. The proposed program comprises 405 km of data along 7 lines which also tie 11 exploration wells. These lines will largely be in waters that are under the jurisdiction of the state of Western Australia.

At this stage, the specific recording parameters will be dependent on the capabilities of available shallow-draft vessels. While it is expected that it will be impractical to record data with the same parameters used on SNOWS-I and SNOWS-II (particularly with regard to streamer length), the contract will require the largest source and longest streamer length commensurate with operating in restricted waters.

PROJECT BACKGROUND

The North West Shelf is a general term that refers to the suite of geologic provinces comprising the continental margin of northwest Australia, approximately from Northwest Cape to Darwin, a distance of some 2000 km and encompassing an area (including marginal plateaux) of approximately 800000 km^2 (Fig. 1). The principal sedimentary basins include, from south to north, the northern Carnarvon, offshore Canning, Browse, and Bonaparte Basins. While the majority of the sedimentary fill in most of these basins is of Mesozoic age, all of the basins probably began forming in the Palaeozoic.

As production of hydrocarbons from Bass Strait dwindles, the North West Shelf is certain to become the major source of hydrocarbon in Australia. To date, the principal discoveries are oil and gas in the Barrow Sub-basin, gas/condensate and more recently oil in the Dampier Sub-basin, gas/condensate in the Browse Basin, and oil and gas in the Bonaparte Basin. Current estimates suggest that the region contains undiscovered resources of 40-500 million kilolitres (280-3200 million barrels) of crude oil, 240-1300 billion cubic metres (8-45 tcf) of saleable gas, and 55-440 million kilolitres (350-2800 million barrels) of condensate, primarily in the Carnarvon, Browse, and Bonaparte Basins (BMR, 1989).

While portions of the North West Shelf have been quite intensively explored since the 1960's (particularly the Barrow-Dampier Sub-basins and parts of the Bonaparte Basin), there has been very little recent revision of its regional structural framework using modern extensional tectonic concepts, and large parts of the region, particularly the offshore Canning Basin, remain relatively under-explored. The Marine Geoscience and Petroleum Geology Program at the Bureau of Mineral Resources, as part of its study program on the North West Shelf, will acquire regional deep seismic data across and between the major sedimentary basins, with the aim of improving understanding of the linkages between the major structural elements and allowing revision of the gross structure of the region. This information will be critical in developing new exploration strategies, and will aid future basin framework and resource studies in the region.

To address the structural framework problems of the North West Shelf, a series of cruises by the BMR research vessel *Rig Seismic* have been allocated during a 3-year period. The program is as follows:

1) Bonaparte Basin - concentrating in the Vulcan Graben and adjacent areas - 1900 km of deep seismic data - completed November-December, 1990 (O'Brien & Williamson, 1990).

2) Bonaparte Basin (Petrel Sub-basin) - 2090 km of deep seismic data - completed April-May, 1991 (Willcox & Ramsay, 1991).

3) Northern Carnarvon Basin (Exmouth-Barrow-Dampier-Beagle Sub-basins and Exmouth

Plateau; SNOWS-I) - 1654 km of deep seismic data - completed May-June, 1991 (Stagg & others, 1991; Appendix 1; Fig. 3).

4) Northern Carnarvon Basin (Beagle-Dampier-Barrow Sub-basins; Exmouth Plateau; SNOWS-II); 2000+ km of deep seismic data scheduled for acquisition in mid-1992 (Fig. 4).

5) Timor Sea - 2000+ km of deep seismic data linking the two Bonaparte Basin surveys (1 and 2, above) with the planned deep seismic program in the Browse Basin (6, below).

6) Browse Basin - approximately 2000-2500 km of deep and conventional seismic data - scheduled for late 1992 / early 1993.

7) Offshore Canning Basin (SNOWS-III) - 2000+ km of deep seismic data - tentatively scheduled for mid- to late-1993.

Along most of the North West Shelf, the landward basin-bounding faults lie some distance offshore, in water depths greater than 20 metres. However, in the Barrow Sub-basin of the Carnarvon Basin, that part of the basin landward of the main depocentre axis lies near-shore in water depths consistently less than 20 m; these areas are not accessible to a conventional deep-water research vessel, such as the *Rig Seismic* (Fig. 5). Since the landward basin-bounding faults in continental margin rift basins generally provide key information to the understanding of basin evolution, it is critical that data be recorded in these areas. The only feasible method of accomplishing this in the near-shore Barrow Sub-basin is to contract a commercial shallow water seismic vessel.

By the end of the cruise program outlined here, there will be available a network of deep seismic data (recorded at up to 16 seconds TWT) for all of the major basins of the North West Shelf, from Northwest Cape to the Timor Sea. On the southern North West Shelf (northern Carnarvon Basin and offshore Canning Basin) the principal tectonic elements will be traversed by approximately 6000 km of deep seismic profiles.

EXPLORATION HISTORY

The initial oil exploration permits on the North West Shelf were granted to Ampol Petroleum Ltd in 1946. While these leases were primarily onshore, they did cover the offshore Carnarvon Basin out to a water depth of 100 fathoms (~183 m). In 1952, Ampol combined with Caltex to form West Australian Petroleum Pty Ltd (Wapet), and the new company drilled its first well (Cape Range-1) on a surface anticline in 1953. This well flowed oil from a small pool and provided a major impetus to exploration on the southern North West Shelf.

The first offshore seismic work was carried out by Wapet in 1961. In 1964, Wapet drilled a wildcat well on Barrow Island that discovered oil in Upper Jurassic sands. Subsequent appraisal drilling on Barrow Island showed the presence of a major oil field, principally reservoired in Cretaceous sands. In 1965, Wapet was granted acreage west of Barrow Island. At about the same time, Woodside (Lakes Entrance) Oil Co. (subsequently to become Woodside Petroleum) and associated companies were granted leases to the north and offshore from the Wapet leases. This general delineation of operations has persisted since the 1960's, with Wapet being considered the principal explorer in the Barrow Sub-basin, while Woodside is considered to be the prime explorer in the Dampier Sub-basin.

In 1968, Woodside made a non-commercial oil discovery at Legendre-1 on the landward flank of the Dampier Sub-basin. The major Woodside successes came in 1971, with major discoveries of gas/condensate at North Rankin-1, Goodwyn-1, and Angel-1 within or overlying fault blocks of the Rankin Platform. Wapet continued the run of success on the Rankin Platform with the discovery of a major gas/condensate field in the Gorgon structure at the southwestern extremity of the platform in 1980.

Since the early 1970s, as the full potential of the North West Shelf has become apparent, exploration lease sizes have been steadily reduced and more players have become involved in exploration. During the 1980s, there has been a number of small- to medium-scale commercial and sub-commercial oil discoveries in both the Barrow and Dampier Sub-basins (eg Harriet, Talisman, Saladin, Roller, Wanaea, Cossack, Ramillies, Wandoo), and the former distinction between an "inner oil trend" and an "outer gas trend" has become blurred.

During the second half of the 1980s, emphasis has been shifting away from conventional 2-D seismic surveys to 3-D surveys, for exploration as well as field evaluation. One consequence of this shift in seismic techniques, in conjunction with the change to smaller permit sizes, is that there are very few regional seismic lines of post-1970s vintage. As most of the industry data are recorded to 5 or 6 seconds reflection time, it is also very difficult to construct good-quality regional seismic transects that show basin-forming structures, other than at the basin margins.

By 1992, about 150000 km of conventional 2-D reflection seismic data have been recorded, and over 250 wells have been drilled on the southern North West Shelf; the line-km of 3-D seismic data is increasing exponentially. Of these data, less than 2000 km is conventionally recorded deep seismic data (record lengths > 10 seconds). These deep data consist of 2 lines in the central Dampier Sub-basin, recorded by Geophysical Services International (GSI) in 1986, and the 10 lines recorded by BMR during SNOWS-I in mid-1991 (Fig. 3). In addition, a single two-ship wide aperture CDP seismic line was recorded in 1986 by BMR and the Lamont-Doherty Geological Observatory from the Dampier Sub-basin, west-northwestwards across the Exmouth Plateau, to the Gascoyne Abyssal Plain (Williamson & others, 1990). Conventional multichannel seismic lines were recorded by BMR across the western and northern margins of the Exmouth Plateau by Williamson & Falvey (1988), Exon & Williamson (1988), and Exon & Ramsay (1990). These surveys were related to the drilling of six continuously cored Ocean Drilling Program Sites on the Exmouth Plateau (von Rad, Haq, & others, 1992).

SNOWS PROGRAM - GENERAL OBJECTIVES & SPECIFIC PROBLEMS

The broad objectives of the program proposed by Stagg & Willcox (1991) remain definitive and were as follows:

* To determine the regional structural framework of the northern Carnarvon Basin by examining the boundaries between major structural elements along key transects of the shelf.

* To determine the deep crustal structure of the sub-basins of the northern Carnarvon Basin and their relationship to the development of the continental margin adjacent to the southeastern Argo Abyssal Plain.

* To assess the effect of deep structure on the development of the major fields and petroleum plays in the region, and in particular the structural and depositional effects resulting from Tertiary reactivation of these deep structures.

* To provide modern regional seismic well-tie data to allow basin-wide seismic correlations.

At a more specific level, it was felt that the following geoscientific problems evident in the northern Carnarvon Basin and offshore Canning Basin could be addressed to varying degrees by the acquisition of deep seismic data (Stagg & Willcox, 1991):

1) Detachment Models: Recent models of the formation of passive continental margins propose that the formation of sedimentary basins takes place by extension above and below sub-horizontal detachment faults in the crust (Lister & others, 1986). Assuming such detachment models provide a plausible explanation for basin formation, where are the major detachment faults beneath the northern Carnarvon Basin and the Exmouth Plateau and how can detachment models be applied to the area?

2) Original Extension: What is the age, amount, and azimuth of the original extension that formed the nascent northern Carnarvon and Offshore Canning Basins (part of the Westralian Superbasin)? It now appears accepted that the main extensional phase on the North West Shelf took place in the Palaeozoic, no later than the Permo-Carboniferous,

and that the major faulting episode in the Late Triassic (often referred to as 'rift onset') was largely a reactivation phase with only minor extension.

3) Strike-Slip Movements: The *en echelon* character of the major fault system and the Rankin Trend fault blocks, and the existence of major anticlines (Barrow Island Anticline) and sedimentary deeps (eg Lewis Trough), has led to the obvious conclusion that strike-slip movement has been a major factor in the genesis of the northern Carnarvon Basin. What was the age, extent, and azimuth of these ?multiple phases of movement, and what is their relationship to any phases of simple basin-forming extension?

4) Transfer Faults: Major transfer faults in the Barrow-Dampier Sub-basins can be broadly identified or inferred and their reactivation effects may be visible in the bathymetry; however, they have not been delineated seismically. These transfer zones probably have significant effects on the distribution of reservoir and source rocks, on migration paths, and as trapping mechanisms. Is it possible to image these transfer zones in deep seismic data, such that, at a later stage of study, they can be mapped more accurately and related to the known hydrocarbon fields?

5) Late Reactivation: A number of hydrocarbon discoveries in the 1980s on the North West Shelf have been in traps that have been subjected to Cretaceous-Tertiary reactivation. How are these reactivation traps related to deep structures and can an understanding of such deep structures lead to a prediction of likely locations for late hydrocarbon trapping?

6) Inter-relationship of Sub-basins: There is a lack of a regional understanding of the relationships between the Exmouth, Barrow, Dampier, and Beagle Sub-basins. Can good-quality, deep strike lines allow the pre-Callovian histories of these four sub-basins to be better related?

7) Rankin Platform Gravity: The most prominent gravity feature of the southern North West Shelf is the positive southwest trending anomaly associated with the Rankin Platform, and it is obvious that the Rankin Platform is a structure that is fundamental to the genesis of the area. Why is the peak of the anomaly offset from the shallowest part of the Rankin Platform and what bearing does this have on extensional basin models?

8) Alpha Arch: At the southwest end of the Rankin Platform, the trend of the gravity high changes to south-southwest (overlying the Gorgon structure and the Alpha Arch). In addition to hosting the Gorgon gas field, the southern Rankin Platform/Alpha Arch is proving to be a fruitful exploration area for oil (Griffin, Chinook, Ramillies).What is the deep structure of this part of the Barrow Sub-basin and how does it control the distribution of hydrocarbon fields?

9) Beagle Sub-basin: While the Barrow and Dampier Sub-basins are both well-explored and hydrocarbon-rich, the same cannot be said for the next basin to the northeast, the Beagle Sub-basin. This complexly-structured basin has been little explored in the 1980s

and has been penetrated by a limited number of wells. What is the deep structure of this basin and what influence has this had on the lack of exploration success to date?

SNOWS-I - PRELIMINARY RESULTS

During SNOWS-I (Survey 101), a total of 1654 km of high-quality deep seismic data were recorded along 6 dip and 4 strike lines in the Dampier, Barrow, and Exmouth Sub-basins, and on the inner flank of the Exmouth Plateau. These lines were tied to 20 exploration wells throughout the region (Appendix 4; Fig. 3).

The SNOWS-I data consistently show unequivocal reflections down to 10 seconds (15-20 km), particularly offshore from the Rankin Platform and beneath the Exmouth Plateau. Deeper reflectors at 10-13 s are also observed, particularly beneath shallow crystalline basement; however these reflectors generally have low continuity and their correlation through the region is somewhat suspect.

The following preliminary interpretation notes on SNOWS-I lines in the Barrow Sub-basin are extracted from Stagg (1992).

LINE 7

Dip line across the central Barrow Sub-basin, from southwest of Barrow Island, across the Barrow depocentre, Gorgon structure, and Kangaroo Syncline, to the crest of the Exmouth Plateau. Ties to Robot-1A, Gorgon-1, and Jupiter-1.

Comments: Due to rapidly decreasing water depths, this line (and lines 6 & 5) had to be terminated at the Barrow depocentre. This depocentre is seen as a structural inversion with about 1s (~1.5 km) of positive relief at the Early Cretaceous level and about 1 s (~2 km) of negative relief at the base of the visible sedimentary section; most of this 'pod' of sediments is interpreted to be of Jurassic to Early Cretaceous age. Deep structural details of Gorgon Block are not immediately obvious; however, its development appears to be tied in with a major ?adjacent wrench-related anticline beneath the continental slope (Fig. 6). This anticline has its roots in dislocations in the underlying ?crystalline basement Horizon B and has been strongly eroded, probably in the Late Triassic or Early Jurassic. Horizon B can be traced through much of the Kangaroo Syncline and there are indications of its presence beneath the Exmouth Plateau Arch. If Horizon B marks the base of the sedimentary section, then there is more than 8 s of sediment underlying the Kangaroo Syncline; of this thickness, at least 6 s is Triassic and older.

LINE 6

Dip line across the southern Barrow Sub-basin, from the Barrow Depocentre, across the Alpha Arch, to the Kangaroo Syncline. Ties to Rosaliy-1A and Zeepard-1.

Comments: As with line 7, the Barrow Depocentre appears as a thick 'pod' of Jurassics sediments underlain, in this case, by a possible basement reflector at about 10 s. Horizon B is not readily identified on this line, though there are several indications of mid-crustal reflectors beneath the Exmouth Plateau. Careful analysis is required to determine which of these reflectors are primary events. Of particular interest on this line is the Triassic block on which Zeepaard-1 was drilled. This block has a strong synclinal form, both internally and at its upper surface on which Jurassic sediments are ponded. The southeast flank appears to be a compressional structure, while the northwest flank (site of Zeepaard-1) shows listric faulting.

LINE 5

Dip line across the northern end of the Exmouth Sub-basin, extending on to the southwest Exmouth Plateau. No direct well ties but it does tie to line 4, close to Jurabi-1.

Comments: This line is very different in character to the previous dip lines. The southeast end of the line is underlain by a band of strong crustal reflectors that deepen northwestwards from 8 to 10 s. The overlying Palaeozoic-Mesozoic section shows strong growth with the faults dipping to the southeast. In contrast the offshore end of the line, beneath the Exmouth Plateau, shows strong growth across faults dipping to the northwest. This polarity reversal may occur across an extension of the Long Island Fault, pointing to that fault being a transfer or accommodation zone.

LINES 4-3

Strike line from the northern end of the Exmouth Sub-basin, along the depositional axis of the Barrow Sub-basin. Ties to Jurabi-1, Bowers-1, Robot-1A, and Tryal Rocks-1.

Comments: It was anticipated that a strike line along the axes of the sub-basins would image the cross trends responsible for segmentation of the northern Carnarvon Basin. These cross-trends are probably present; however, their delineation will required detailed analysis of these lines in conjunction with examination of industry data.

PROPOSED PROGRAM

The program proposed here is shown in Figure 7, and comprises 7 lines (total length 405 km) tying 11 exploration wells in the inshore Barrow Sub-basin. The lines also tie into the existing SNOWS-I lines and the proposed SNOWS-II lines.

A summary of each line follows; way points for each line are included in Appendix 6. Line prefixes are 101/ for SNOWS-I, 110/ for SNOWS-II, and CBS/ for the survey proposed here.

Line CBS/1 (51 km)
Strike line at the northeast end of the Exmouth Sub-basin, crossing the Long Island transfer fault system, ending in the south west Barrow Sub-basin. Ties to Outtrim-1 and to lines CBS/2, CBS/3, and 110/11.

Line CBS/2 (45 km)
Dip line in the northeast of the Exmouth Sub-basin, crossing the Rough Range and Paterson Faults. No well ties; ties to lines CBS/1, 101/5, and 101/4.

Line CBS/3 (52 km)
Dip line across the northern end of the Exmouth and Gascoyne Sub-basins. Ties to Dailey-1, Caretta-1, and Santo-1 and to lines CBS/1 and 101/4.

Line CBS/4 (38 km)
Dip line across boundary of Barrow Sub-basin in the southwest, crossing the Flinders Fault System. Ties to Skate-1 and to line 110/12.

Line CBS/5 (43 km)
Dip line in the southwest Barrow Sub-basin, crossing the Flinder Fault System. Ties to Koolinda-1 and to line 101/6.

Line CBS/6 (63 km)
Dip line in the central Barrow Sub-basin, from the Barrow depocentre, crossing the Barrow Island Anticline and the Flinders Fault System, and ending on the Peedamullah Shelf. Ties to Pepper-1 and Ripple Shoals-1, and to line 101/7.

Line CBS/7 (113 km)
Dip line in the northeast Barrow Sub-basin, from the Barrow depocentre, across the Barrow Island Anticline and Flinders and Scholl Island Faults, to the southwestern end of the Lambert Shelf. Ties to Nyanda-1, Dorrigo-1, and Judy-1, and to line 101/2.

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APPENDIX 1
EXECUTIVE SUMMARY FROM SNOWS-I POST-CRUISE REPORT

(From BMR Record 1991/79)

While the northern Carnarvon Basin of the southern North West Shelf is one of Australia's most hydrocarbon-rich provinces, relatively little is known of its deep structure and the control this deep structure has on hydrocarbon occurrences. BMR *Rig Seismic* Survey 101 was designed to acquire deep-crustal seismic data along a series of dip and strike lines in the region, with the following aims:

* To determine the broad regional structural framework of the southern North West Shelf by examining the boundaries between the major structural elements;
* To determine the deep crustal structure of the southern North West Shelf and its relationship to the development of the continental margin; and
* To assess the control of deep structure on the development of the major hydrocarbon fields and plays in the region, and in particular the structural and depositional effects resulting from reactivation of these structures.

It is recognised that at least two cruises of deep-crustal seismic acquisition are needed to address these problems adequately on the southern North West Shelf (northern Carnarvon Basin and offshore Canning Basins). Survey 101, which departed Port Hedland on May 11 and arrived in Fremantle on June 10, 1991, was concentrated in the northern Carnarvon Basin. Technical difficulties prevented extension of the cruise into the offshore Canning Basin, as was originally intended.

During Survey 101, a total of 1654 km of presumably high-quality deep seismic data were recorded along 6 dip and 4 strike lines in the Dampier, Barrow, and Exmouth Sub-basins. These lines were tied to 20 exploration wells, thereby providing valuable modern regional ties of the principal seismic horizons throughout the region.

The seismic data were recorded from a 4800 m streamer, configured with 192 x 25 m active groups. The record length was 16 seconds, and the sample interval 4 msec. The seismic source consisted of dual 'sleeve' airgun arrays with a total volume of 50 l (3000 in^3). Shots were fired every 50 m at a ship speed of 4.5 knots, giving 48-fold coverage. Both streamer and airguns were towed at 10-11 m depth. Streamer noise levels were uniformly low, being generally less than 5-6 microbars for the first 32 channels, and less than 3 microbars for channels 33-192.

Navigation for the survey was provided by differential Global Positioning System (DGPS), using a shore reference station at Broome and a real-time satellite data link. DGPS data were recorded for 95.4% of the survey; during almost all the remaining time, stand-alone GPS was available. While detailed analysis of the navigation data has not yet been done, it is estimated that absolute positional accuracy should be better than +/- 10 metres.

In the Dampier Sub-basin, three dip lines were recorded, in the northwest, centre, and southwest of the sub-basin. These lines extended from the southern basin boundary to the inner Exmouth Plateau. Two dip lines were recorded across the Barrow Sub-basin, with one of the lines being extended to Jupiter-1 on the crest of the Exmouth Plateau. Shallow water at the near-shore ends of these lines precluded their being continued to the landward basin margin. In the Exmouth Sub-basin, a single dip line was recorded from the southern Exmouth Plateau to North West Cape, parallel to, and south of the Long Island Transfer Fault. Three linked strike lines were recorded from the Exmouth Sub-basin along the length of the Barrow and Dampier depocentres into the Beagle Sub-basin, to tie together the dip lines and to image the generally NW-SE cross trends at depth; these cross-trends (transfer fault direction) have probably had a major influence on the present-day structure of the southern North West Shelf. Advantage was taken of available transit time to record a second, shorter tie line from the Kangaroo Syncline to the deep-water Exmouth Sub-basin.

As the Tertiary carbonates on the North West Shelf make the area notoriously difficult for the recording of seismic data, particularly in shallow water, it was anticipated that only gross structural information would be visible in the monitor sections. This turned out to be the case and, while definite primary reflections can be identified down to 5-6 seconds TWT on some lines, strong water column and interbed reverberations generally overwhelm any deep information in the unprocessed data. The only open-file deep seismic data from the northern Carnarvon Basin (two lines across the central Dampier Sub-basin) show reflections down to 10-12 s TWT, with a shorter streamer and smaller seismic source than were used in Survey 101. We are therefore confident that, given the low streamer noise levels prevailing during the survey, the processed data should reveal valuable information on the basin-forming structures in the region.

APPENDIX 2
EXECUTIVE SUMMARY - SNOWS-II CRUISE PROPOSAL

(From BMR Record 1992/28)

While the southern North West Shelf has been one of Australia's most heavily explored areas for hydrocarbons in the past three decades, relatively little is known of its deep structure and the controlling effect this deep structure has on the occurrence of hydrocarbons. BMR Project 121.17 (Regional Structural Framework of the Southern North West Shelf and Offshore Canning Basin) seeks to rectify this shortcoming and has the following aims:

* To determine the broad regional structural framework of the southern North West Shelf by examining the boundaries between the major structural elements;

* To determine the deep crustal structure of the region;

* To assess the control of deep structure on the development of the major hydrocarbon fields and plays, and in particular the structural and depositional effects resulting from reactivation of these structures; and

* To acquire a set of high-quality seismic tie lines linking the deeper exploration wells throughout the region to allow regional seismic correlations.

To address these points, a program of three cruises of the RV *Rig Seismic* has been developed, during which deep seismic data are to be recorded (SNOWS-I to SNOWS-III). The first cruise, SNOWS-I, completed in June 1991, acquired 1654 km of seismic data along 10 widely spaced lines tied to 20 exploration wells in the Barrow, Dampier, and Exmouth Sub-basins, and on the inner flank of the Exmouth Plateau. The data were processed by March 1992, and show basin structure down to a depth of at least 10 s TWT (>20 km); these are the first data recorded on the southern North West Shelf that show such deep structures.

SNOWS-II, proposed here, is intended to acquire up to 2765 km of deep seismic data tied to 22 exploration wells (of which 4 were also tied on SNOWS-I). As with SNOWS-I, the data recording parameters will include a 4800 m streamer (192 x 25 m groups), 49 litre sleeve gun arrays, 16 second records, and 48-fold coverage. Four elements in the SNOWS-II program are proposed, as follows:

1) **Beagle Sub-basin:** 1184 km along 7 lines tied to 8 wells designed to cross the principal structural trends. These lines extend northeast on to the Bedout High, southeast into the Bedout Sub-basin, south to the Lambert Shelf, and north to the inner Exmouth Plateau. The lines also tie into the SNOWS-I grid in the Dampier Sub-basin to the west.

2) **Outer Basin Strike Line:** 448 km along 1 line tied to 3 wells (of which 1 well is also tied on Stage 3) from offshore of the Beagle Sub-basin, outside the Dampier Sub-basin, to the Kangaroo Syncline.

3) **Barrow and Dampier Sub-basins and inner Exmouth Plateau:** 717 km along 4 lines tying 10 wells (of which 1 well is also tied on Stage 2) that provide fill-in dip line coverage in the Barrow and Dampier Sub-basins and on the inner flank of the Exmouth Plateau.

4) **Exmouth Plateau:** 414 km along 2 lines tying 2 wells that provide a short strike line along the axis of the Exmouth Plateau Arch, and complete the North West Shelf to Gascoyne Abyssal Plain transect that was commenced on SNOWS-I.

The program proposed here assumes a 30 day cruiss. While the total of 2765 km of seismic data programmed for SNOWS-II is quite high for regional deep crustal work, in the event of good weather conditions and high equipment reliability, it should be possible to finish the program in the time available. However, in the event of adverse weather or serious equipment problems, or delays due to extrenal operational problems, it should be possible to complete at least Stages 1 and 2, and the most important parts of Stage 3.

APPENDIX 3
NORTHERN CARNARVON BASIN - OIL & GAS FIELDS
(Summarised from Cockbain, 1989)

Basin	Year	Company	Age	Trap[1]	Orig. Reserves[2] Gas	Cond	Oil
		PRE-BREAKUP FIELDS					
Barrow Deep	1973	Wapet	Ju	A	8	-	-
Dockrell	1979	Woodside	Tr	TiFB	-	-	0.8
Eaglehawk	1972	Woodside	Tr	HB	-	-	0.2
Goodwyn	1971	Woodside	Tr, Ju	TiFB	131	40	2
Goodwyn South	1973	Woodside	Tr	TrFB	-	-	3
Gorgon	1981	Wapet	Tr	HB	234	2	-
North Rankin	1971	Woodside	Tr, Ju	HB	225	1	-
N Rankin West	1972	Woodside	Ju	FB	7	1	-
Rankin	1971	Woodside	Tr	TiFB	6	-	-
Tidepole	1975	Woodside	Tr	TiFB	15	2	1
West Tryal Rocks	1973	Wapet	Tr	HB	81	4	-
Wilcox	1983	Woodside	Tr	FB	10	3	-
		POST-BREAKUP FIELDS					
Angel	1972	Woodside	Ju	D	36	11	-
Bambra	1982	Bond	Cret	A	1	-	-
Barrow Island	1964	Wapet	Ju, Cret	A	5	0.4	42
Campbell	1986	Bond	Cret	A	2	-	-
Chervil	1983	WMC	Cret	FA	-	-	0.7
Dixon	1984	Woodside	Ju	D			
Egret	1973	Woodside	Ju	F-C	-	-	1
Harriet	1983	Bond	Cret	F-C	1	-	6
Lambert	1974	Woodside	Ju	R			
Legendre	1968	Woodside	Cret	FA			
North Herald	1983	WMC	Cret	FA	-	-	0.3
Rosette	1987	Bond	Cret	A	1	-	0.3
Saladin	1985	Wapet	Cret	F-C	0.6	-	8
Scarborough	1979	Esso	Cret	Dome	350	-	-
South Chervil	1983	WMC	Cret	FA			
South Pepper	1983	WMC	Cret	FA	-	-	0.5
Spar	1976	Wapet	Cret	R	7	1	-
Talisman	1984	Marathon	Cret	F-C			
Tubridgi	1981	Otter	Cret	A	2	-	-

Notes

[1] Trap types as follows -

A	Anticline
TiFB	Tilted fault block
HB	Horst block
TrFB	Triangular fault block
FB	Fault block
D	Drape
FA	Faulted anticline
F-C	Fault-controlled
R	Rollover

[2] Units for reserves

Gas	x 10^9 m^3
Condensate	x 10^6 kL
Oil	x 10^6 kL

APPENDIX 4
WELLS TIED ON SNOWS-I

Well	Operator	Date	TD	Oldest Sequence	Status
Angel-3	Woodside/Burmah	1973	3780	U. Ju	Susp.; cond., gas
Arabella-1	Aust. Occidental	1983	2209	Lw. Perm	Dry
Bowers-1	Wapet	1982	4300	U. Tr	Dry
Brigadier-1	Woodside	1978	4292	Tr	Dry
Goodwyn-7	Woodside	1985	3446	U. Tr	Cond., gas
Gorgon-1	Wapet	1980	4401	U. Tr	Susp.; cond., gas
Hampton-1	Woodside/Burmah	1974	2584	Lw. Tr	Dry
Jupiter-1	Phillips	1979	4946	U. Tr	Dry
Jurabi-1	Esso	1982	3712	U. Tr	Dry
Lambert-1	Woodside/Burmah	1973	3700	Lw. Ju	Dry; o/g shows
Lawley-1	Hudbay Oil	1981	1120	M. Tr	Dry
Legendre-1	Burmah	1968	3473	M. Ju	Dry
Parker-1	Woodside	1979	4737	Lw. Ju	Dry
Robot-1A	BP	1988	3459	Lw. Cret	Dry
Rosaliy-1A	Wapet	1982	3066	Lw. Cret	Dry
Rosemary-1	Woodside/Burmah	1972	3909	Ju	Dry
Strickland-1	Hudbay Oil	1982	1050	Tr	Dry
Tryal Rocks-1	Wapet	1970	3695	Ju	Dry
Zeepard-1	Esso	1980	4215	U. Tr	Dry; show gas
Zeewulf-1	Esso	1979	3500	U. Tr	Dry; show cond/gas.

APPENDIX 5
WELLS PROGRAMMED TO BE TIED ON SNOWS-II

Well	Operator	Date	TD	Oldest sequence
*Arabella-1	Aust. Occidental	1983	2209	Early Permian
*Brigadier-1	Woodside	1978	4292	Triassic
Bruce-1	Stirling	1979	2168	Middle Triassic
Campbell-2	Bond	1986	2796	Jurassic
Cossigny-1	Woodside/Burmah	1972	3203	Middle Triassic
Delambre-1	Woodside	1980	5495	Late Triassic
Eendracht-1	Esso	1980	3410	Late Triassic
Gandara-1	Hudbay	1979	4361	Late Triassic
Investigator-1	Esso	1979	3745	Late Triassic
*Jupiter-1	Phillips	1979	4946	Late Triassic
Minilya-1	Woodside/Burmah	1974	2400	Jurassic
North Turtle-1	BP	1982	4420	Jurassic
Novara-1	Esso	1982	2753	Neocomian
Outtrim-1	Esso	1984	1725	Late Jurassic
Phoenix-1	BP	1980	4880	Middle Triassic
Picard-1	Woodside/Burmah	1972	4216	Middle Jurassic
Ronsard-1	Woodside/Burmah	1973	2848	Early Jurassic
Saturn-1	Phillips	1980	4000	Late Triassic
Scarborough-1	Esso	1979	2360	Berriasian
Sultan-1	Wapet	1979	3620	Late Triassic
Venture-1	Wapet	1990	3324	Late Triassic
*Zeewulf-1	Esso	1979	3500	Late Triassic

* signifies well also tied during SNOWS-I (Survey 101).

APPENDIX 6
WAY POINTS FOR BARROW SUB-BASIN SHALLOW PROGRAM

Line	Way pt	latitude	Longitude	Comments
CBS/1	1	21 55 00.0S	114 15 51.9E	SOL
CBS/1	2	21 31 52.7S	114 27 02.7E	Outtrim-1
CBS/1	3	21 30 00.0S	114 27 58.3E	EOL
CBS/2	1	21 40 56.5S	114 06 40.0E	SOL
CBS/2	2	21 52 01.6S	114 30 00.0E	EOL
CBS/3	1	21 32 00.0S	114 15 00.0E	SOL
CBS/3	2	21 33 15.0S	114 18 59.2E	Santo-1
CBS/3	3	21 36 25.7S	114 25 57.0E	Caretta-1
CBS/3	4	21 38 24.0S	114 33 25.4E	Dailey-1
CBS/3	5	21 41 05.0S	114 43 46.0E	EOL
CBS/4	1	21 24 34.2S	114 46 00.6E	SOL
CBS/4	2	21 35 53.9S	114 58 43.8E	Skate-1
CBS/4	3	21 38 47.0S	115 02 10.0E	EOL
CBS/5	1	21 14 07.1S	114 54 13.8E	SOL
CBS/5	2	21 23 45.7S	115 03 13.4E	Koolinda-1
CBS/5	3	21 31 21.1S	115 10 43.5E	EOL
CBS/6	1	20 50 29.9S	115 07 21.3E	SOL
CBS/6	2	21 03 28.0S	115 18 04.0E	Pepper-1
CBS/6	3	21 07 10.5S	115 24 06.7E	Ripple Shoals-1
CBS/6	4	21 14 15.2S	115 33 20.0E	EOL
CBS/7	1	20 24 27.6S	115 12 15.6E	SOL
CBS/7	2	20 37 01.0S	115 37 30.0E	Nyanda-1
CBS/7	3	20 39 50.3S	115 42 42.6E	Dorrigo-1
CBS/7	4	20 41 16.9S	115 46 17.9E	Judy-1
CBS/7	5	20 45 20.4S	116 12 15.6E	EOL

APPENDIX 7
WELLS PROGRAMMED TO BE TIED ON
BARROW SUB-BASIN SHALLOW SEISMIC SURVEY

Well	Operator	Date	TD	Oldest sequence
Caretta-1	Lasmo	1991	1782	
Dailey-1	Esso	1984	2541	Late Triassic
Dorrigo-1	Aust. Occidental	1982	2741	Late Triassic
Judy-1	Aust. Occidental	1983	2021	Middle Triassic
Koolinda-1	Wapet	1977	3732	Jurassic
Nyanda-1	Bond	1985	2467	Jurassic
Outtrim-1	Esso	1984	1725	Jurassic
Pepper-1	Wapet	1970	2743	Jurassic
Ripple Shoals-1	Wapet	1970	2279	Jurassic
Santo-1	BHPP	1985	1883	Jurassic
Skate-1	Wapet	1991	1332	

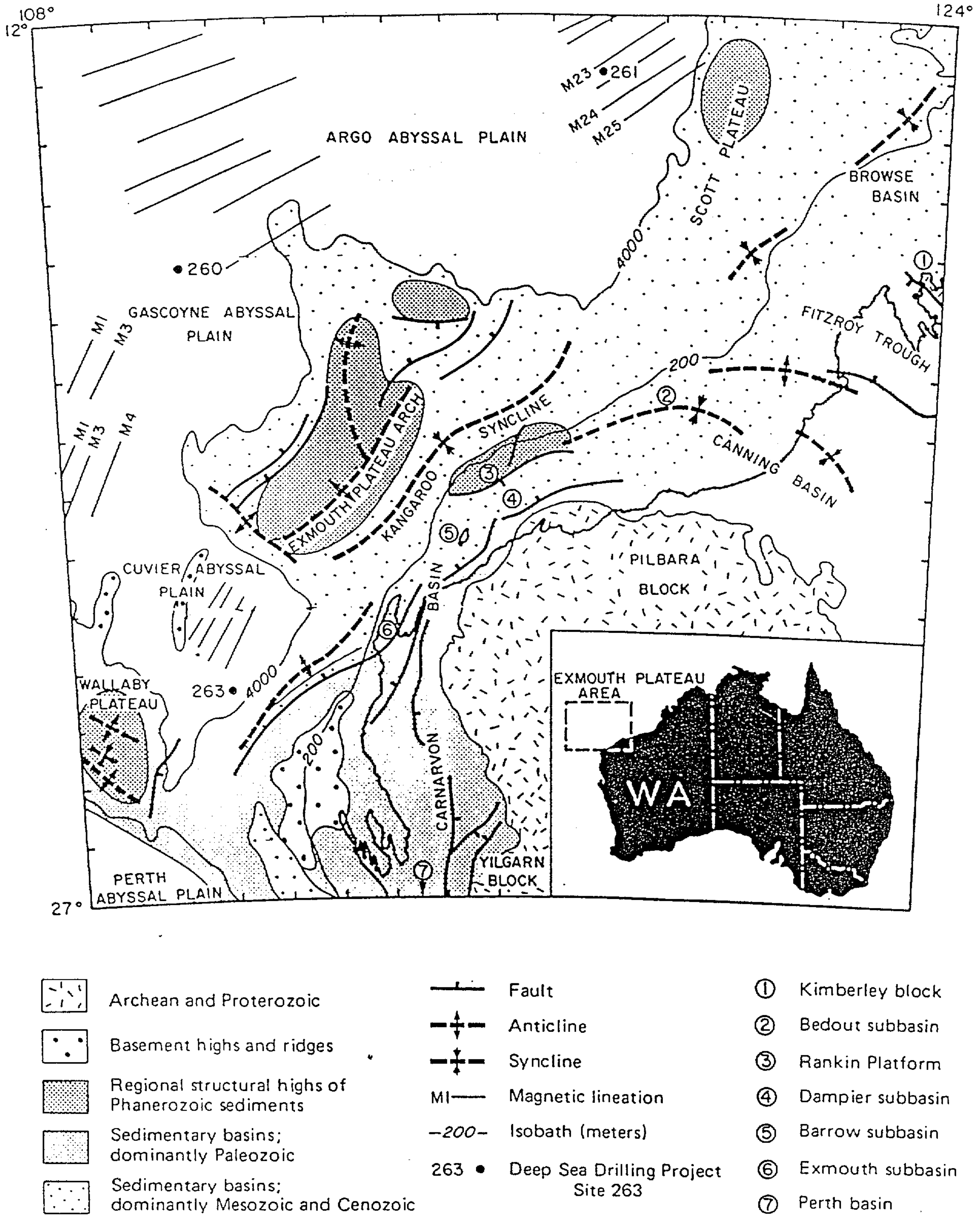

Figure 1: Regional setting of the North West Shelf (after Exon & Willcox, 1980).

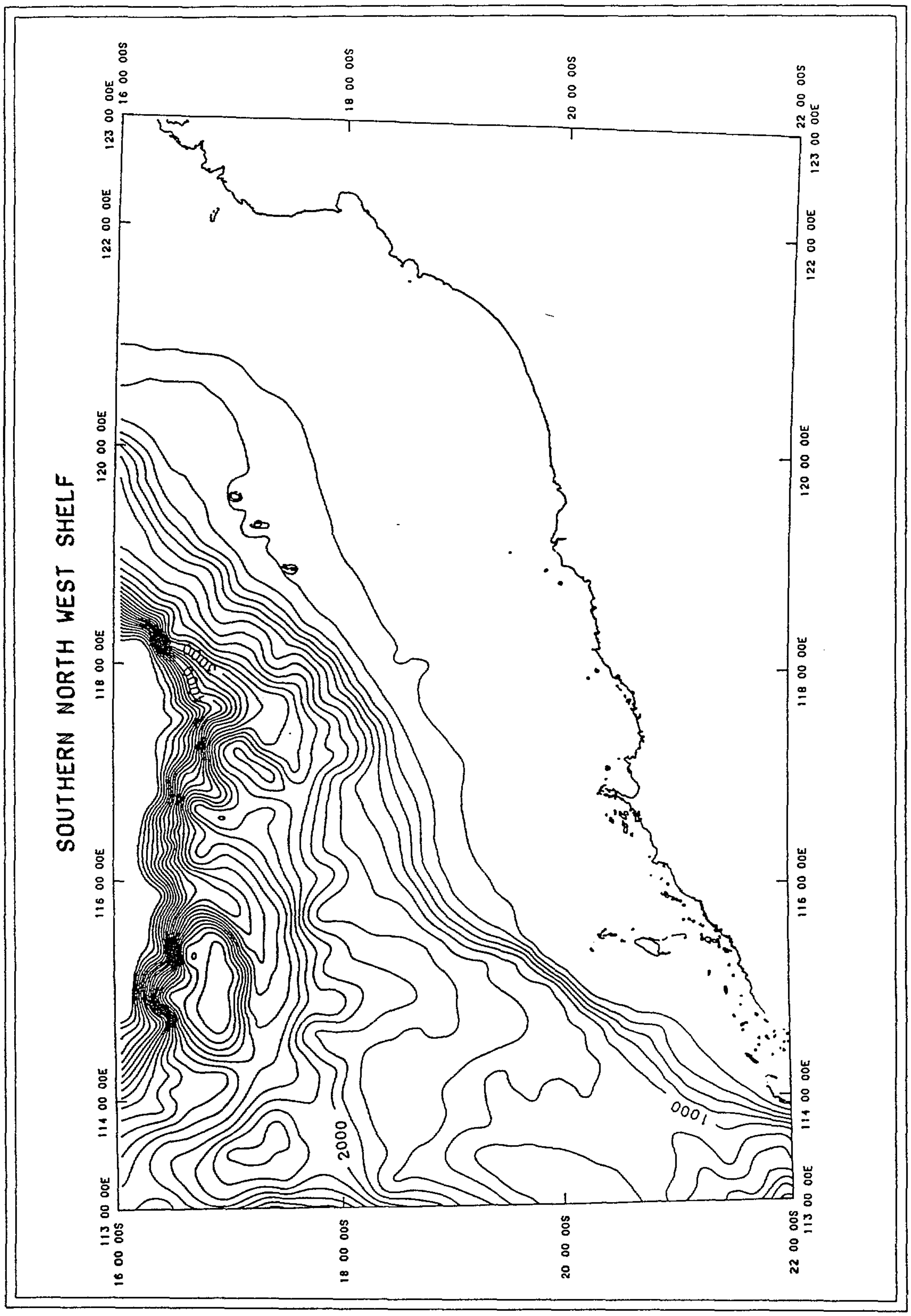

Figure 2: Bathymetry of the southern North West Shelf and Exmouth Plateau; contour interval 200 metres.

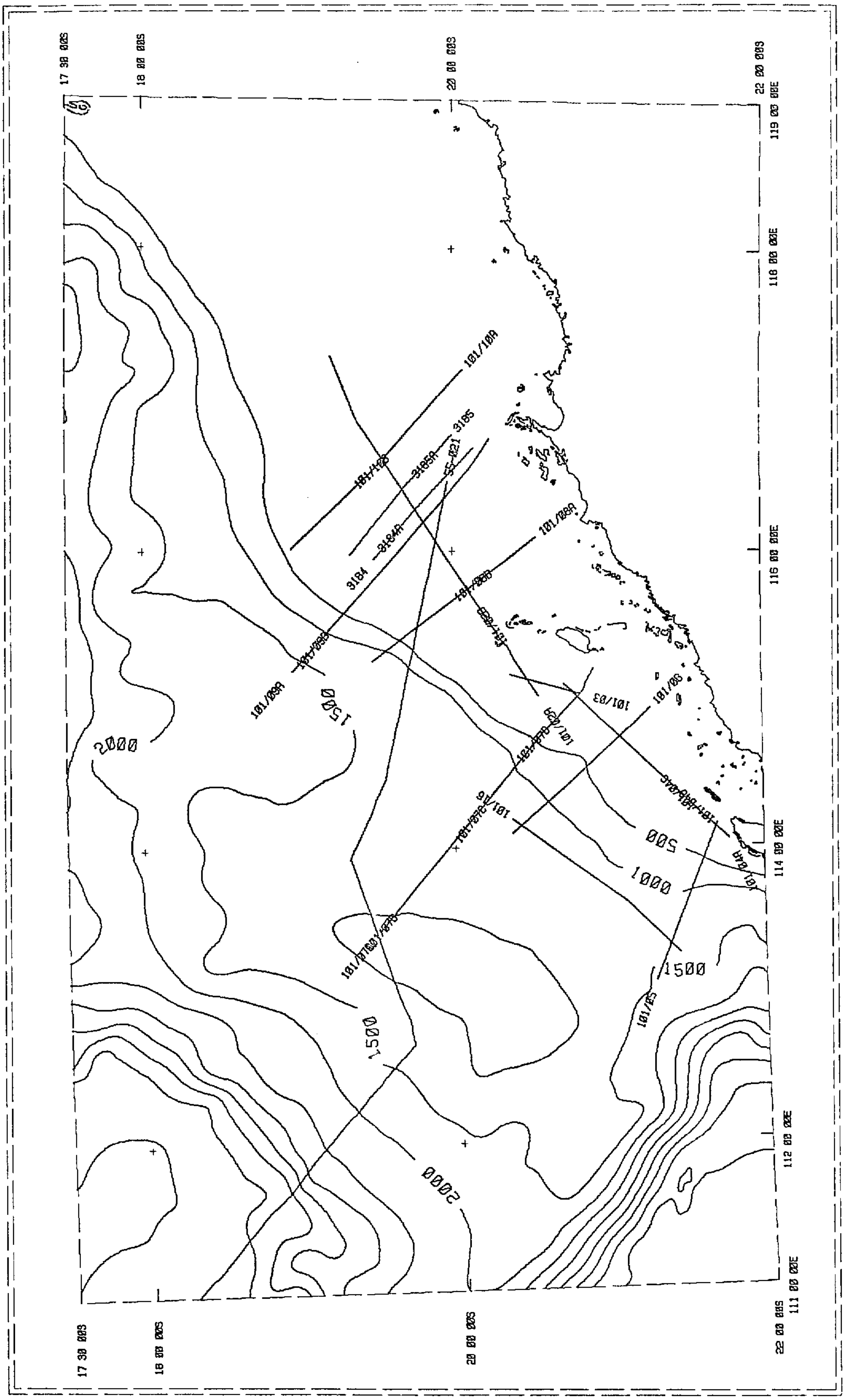

Figure 3: Locations of deep seismic lines on southern North West Shelf and Exmouth Plateau. 101/ prefix lines are BMR survey 101; 55-021 is 1986 BMR/Lamont-Doherty wide-angle CDP line; 3184 and 3185 lines are 1986 GSI survey.

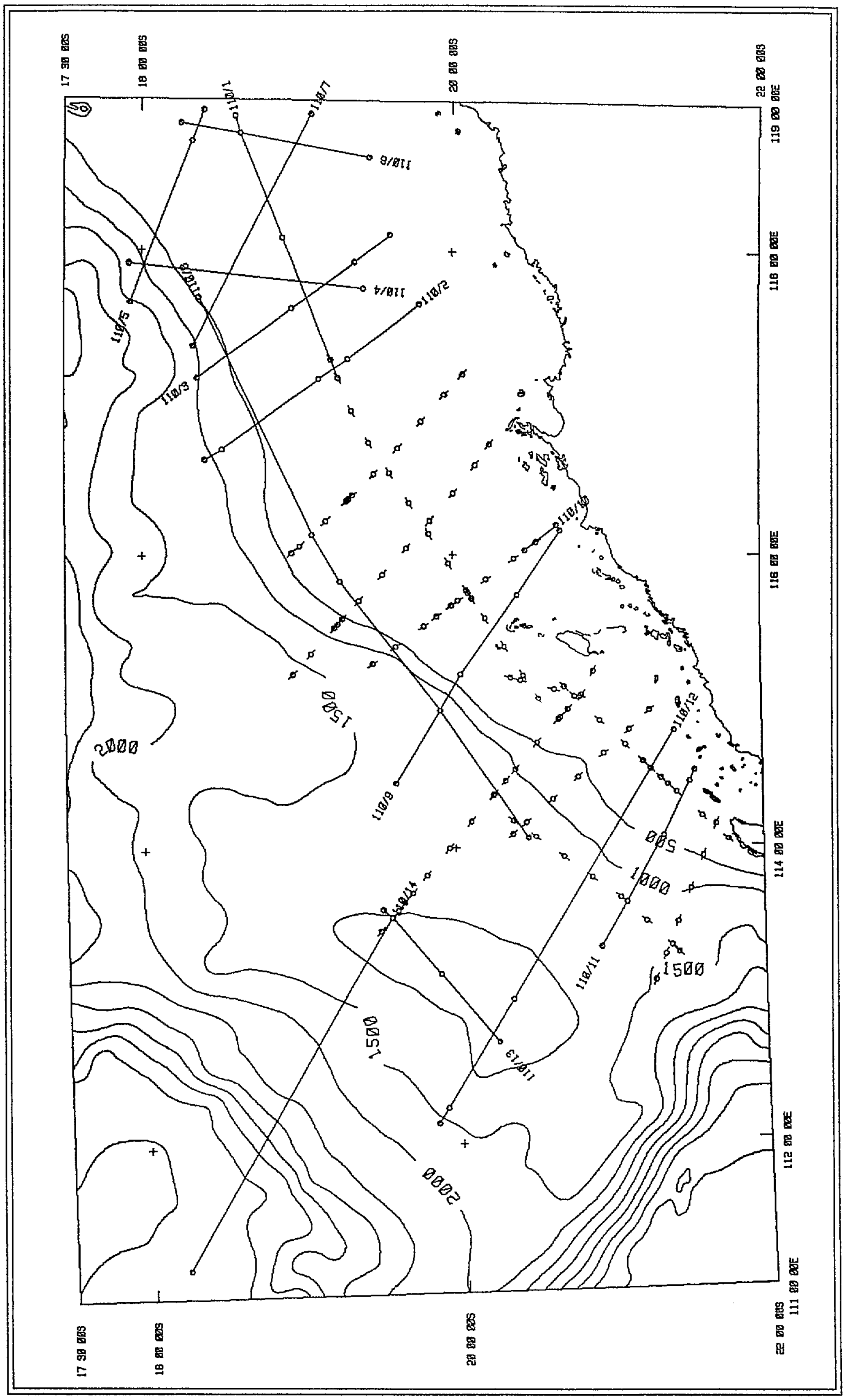

Figure 4: Program of seismic lines for SNOWS-II (solid lines). Shot-point symbols indicate lines recorded on SNOWS-I.

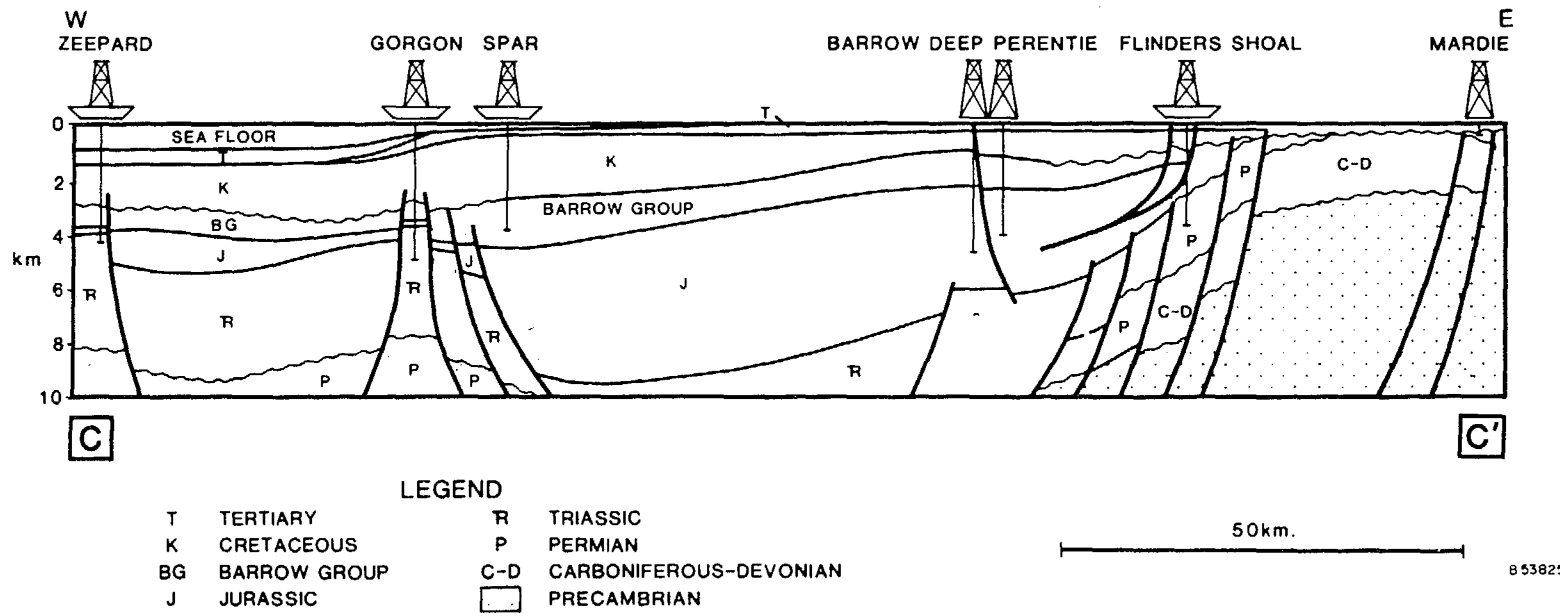

Figure 5: Depth profile across the Barrow Sub-basin (after Parry & Smith, 1988). Eastwards limit of SNOWS-I and SNOWS-II lines is approximately at the location of Barrow Deep, as shown on this profile.

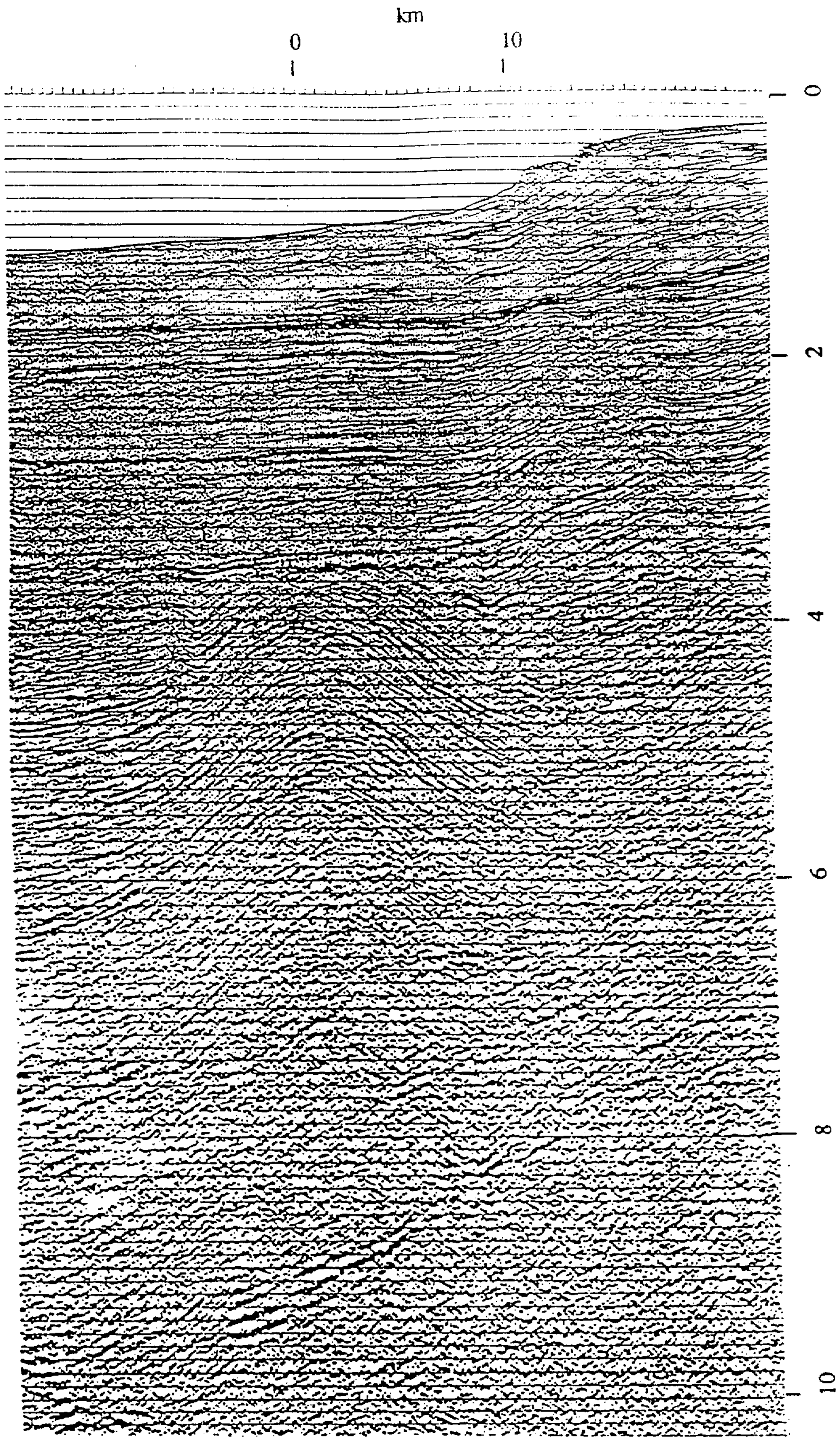

Figure 6: Portion of seismic section along SNOWS-I line 101/7, showing the quality of data in the vicinity of the Gorgon structure in the outer Barrow Sub-basin. Note the strong deep reflector at about 9 s TWT.

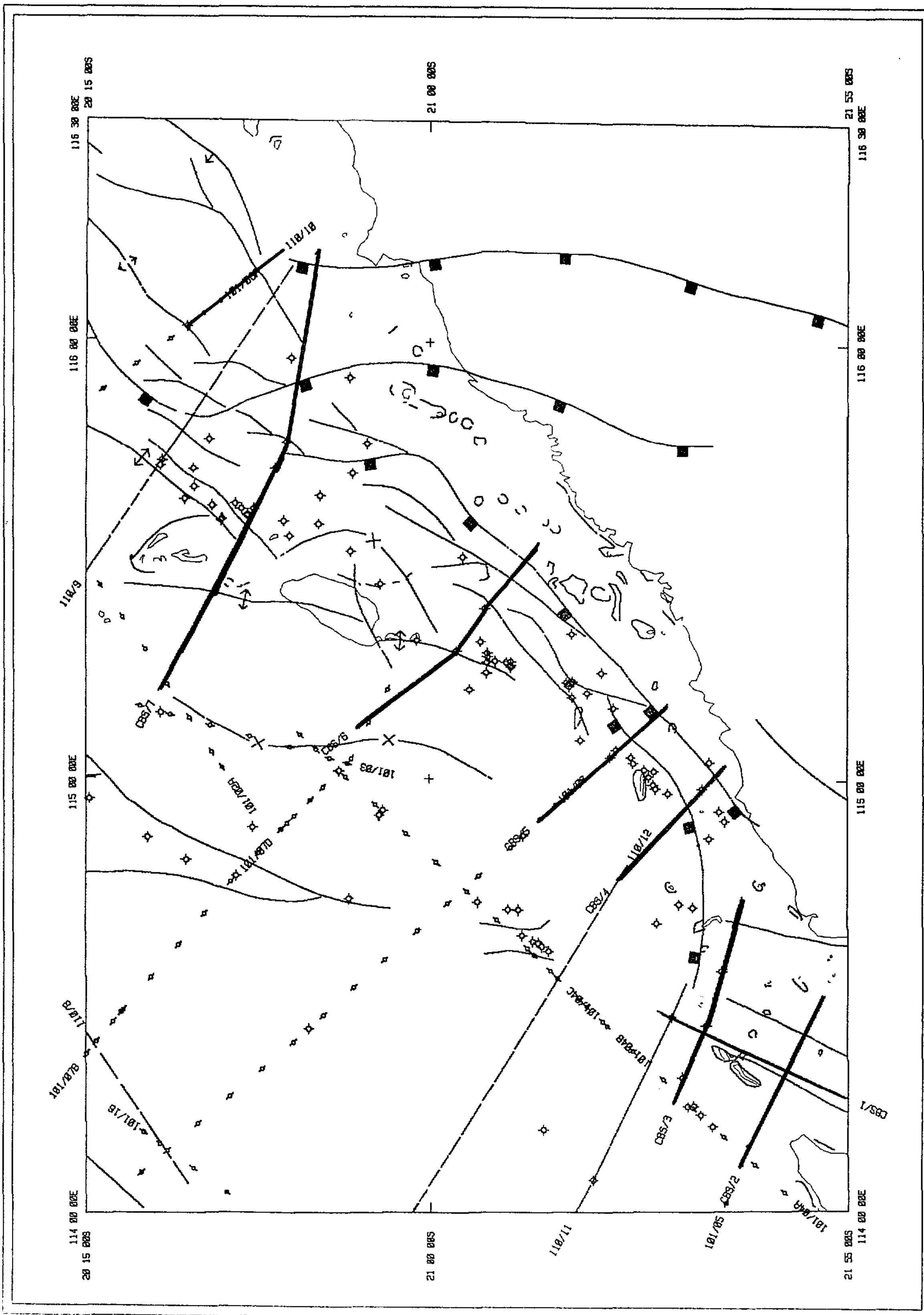

Figure 7: Proposed lines to be shot on shallow-water Barrow Sub-basin survey (CBS/). 101/ prefix lines are SNOWS-I lines previously recorded; 110/ prefix lines are those programmed for SNOWS-II.