Bureau of Mineral Resources, Geology & Geophysics

RECORD

BMR Record 1991/45

DEEP STRUCTURE OF THE BONAPARTE BASIN REGION PETREL SUB-BASIN CRUISE OPERATIONAL REPORT

Project 121.22
(Survey 100)

Principal Investigators

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Division of Marine Geosciences & Petroleum Geology

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Principal Investigators

J.B.Willcox & D.C.Ramsay

Scientists

J.H.Bishop, N.A.Johnston, R.Mohsin

Technicians

P.Davis, R.DeGraaf, B.Dickinson, L.Hatch, J.Kossatz,
C.Lawson, T.McNamara, L.Miller, S.Milnes, D.Pryce,
U.Rieke, D.Sewter, C.Saroch, G.Sparksman, C.Tindall,
P.Vujovic, S.Wiggins, B.Zygmunt

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SUMMARY

The Petrel Sub-basin cruise *(Petrel-1)* was a deep crustal seismic and 'sniffer' direct hydrocarbon detection (DHD) geochemical survey, largely within the Petrel Sub-basin of the Bonaparte Basin. Transects were also run from the Petrel Sub-basin to the Australia/Indonesia seabed boundary, a distance of over 500 km. The cruise, which was one of several designed to investigate the deep architecture of Australia's northern and northwest margins, was conducted with *R/V Rig Seismic*, departing from Darwin on 6th April and finishing in Port Hedland on 6th May 1991.

The cruise objectives were to determine the nature of basin-forming structures in the Bonaparte Basin, the relationship of the largely Palaeozoic to largely Mesozoic structural elements, and the effect of 'Australia/Timor' plate collision in reactivating these older features. DHD data would possibly provide information on hydrocarbon type (that is, gas versus oil) and the nature of migration pathways. It was considered that these objectives could be met by collecting a regional data grid of about 2600 km.

During the cruise, approximately 2090 km of deep-seimic, gravity and geochemical data were collected concurrently, together with 1250 km of magnetics and 349 km of geochemical 'sniffer only' data. Seismic recording was carried out with a 4800 m streamer, 192 channels, 48-fold, 8-64 Hz filters and 4 msec sampling. Twin arrays of 10 sleeve-guns per array were employed. Both streamer and guns were towed at approximately 10 m depth. All of the highest priority lines were recorded, which included seven out of the ten lines planned.

The unprocessed seismic monitor records generally show structural information in the first 0-6 secs, and in some instances possible coherent non-multiple energy in the 6-12 sec range. The broad configuration of the main structural elements is evident, and the footwall fault/detachment head and first major deep-seated tilt-block along the NE side of the Petrel Sub-basin is clearly recorded.

The geochemical profiling indicated seeps over the Tern and Petrel gas fields, as recorded during Cruise 99. As with Cruise 99, there appears to be a general lack of hydrocarbon seepage in the survey area as a whole; however, minor anomalies were detected between Bougainville-1 and Lacrosse-1, around Penguin-1, and near Curlew-1. A large butane anomaly was detected between SPs 510-525 on Line 100/01 (rerun), and somewhat elevated methane and ethane values occurred towards the NE end of Line 100/S1.

The *Petrel-1* survey was the first BMR operation to make use of a newly completed MicroVAX computer acquisition system, with 192 seismic channels. Also, the Fjord Instruments streamer was used in 4800 m/25 m group mode for the first time. It was also the first time that a satellite linked differential GPS navigation system had been used on other than a RACAL ship.

1. BACKGROUND

The Bureau of Mineral Resources (BMR) has an ongoing Continental Margins Program which is investigating the structural development and petroleum prospectivity of the continental margin of Australia and its territories. In recent years, a significant part of that program has been aimed at the acquisition of deep seismic data in order to image basin-forming structures and the architecture of large portions of the margin. It is considered that the actual mechanism of a basin's formation may provide clues to its relative prospectivity. Reactivation of the deep structures appears, in many cases, to be intimately linked to the development of hydrocarbon traps and migration pathways.

In the past year, the focus of BMR's program has switched to the northern Australian margin. Deep crustal programs have been conducted in the Arafura Basin and the Vulcan Graben. Within the next twelve months, further deep crustal surveys are programmed for the Australia/Indonesia Zone of Cooperation (Area A, Figure 2), the Browse Basin and the southern Northwest Shelf, including the offshore Canning Basin. These programs will provide an integrated deep-crustal data set for the region.

In addition to the deep crustal program, the BMR has also been acquiring underway water column geochemical data. This has employed a remote sensing tool which continuously measures the hydrocarbon content and composition in seawater which is pumped to the ship from near the sea bottom. This tool has proven effective in delineating the most prospective parts of sedimentary basins and can potentially discriminate between oil and gas-prone areas. Promising results have been obtained recently in the Vulcan Graben, the Sahul Syncline, the Malita Graben and the Petrel Sub-Basin.

This operational report for the *Petrel-1* cruise draws upon a research cruise proposal for the area, prepared by O'Brien (1991).

2. GEOLOGICAL SETTING OF THE BONAPARTE BASIN REGION

Structure of the Bonaparte Basin

The Bonaparte Basin is a fan-shaped depression underlying Joseph Bonaparte Gulf, with its apex lying just onshore (Figs. 1, 2 & 3). It extends northwards under the continental shelf of the Timor Sea, to an undefined northern limit somewhere beyond the Australia/Indonesia seabed boundary, but probably as far as the Timor Trough. Its main structural elements are the deep basinal areas - the Petrel Sub-basin, Vulcan Sub-basin, Sahul Syncline and Malita

Graben, and the more elevated/platform areas - the Ashmore Platform (Terrace), Londonderry High and Sahul Platform. Of these, most of the Sahul Platform, and part of the Sahul Syncline and Malita Graben, are within Area A of the Australia/Indonesia Zone of Co-operation (Figure 2).

Structural elements

In the southeastern part of the Bonaparte Basin, the major structural elements - principally the *Petrel Sub-basin* - trend northwest and define a broad trough which contains a largely Palaeozoic sedimentary fill, up to 17 km thick (Mory, 1988). The actual mechanism of formation for the Petrel Sub-Basin is not well understood. However, some workers (Lee & Gunn, 1988; Gunn, 1988) have proposed that it formed via rifting around a 'pivot-type' opening centred about the Bonaparte Gulf (Figure 4). Extension was progressively greater from south to north, and these workers proposed that oceanic crust actually formed within the northern Petrel Sub-Basin (Figure 4). In addition, they suggest that a major axial intrusion of upper mantle material was injected along the Sub-Basin as a precursor to 'crustal splitting'. These features, which would significantly affect the heat flow history of the area, would presently lie below the depth of penetration of the conventional seismic data in the area but, if present, should be resolvable by a deep crustal survey of the type reported herein. Interestingly, Gunn (1988) has also proposed that the Petrel Sub-Basin is sub-divided into a series of compartments which are separated by transfer faults. Again, deep crustal seismic may be able to test this model.

In the northwestern and northern parts of the Bonaparte Basin, the structural elements lie on a northeasterly trend, almost orthogonal to the axial trend of the Petrel Sub-basin. The northern set of grabens contains up to 10 km of Mesozoic to Cainozoic sediments and the adjacent elevated platform features over 4 km. The relationship of the older southern sub-basin to these northern features is poorly understood. Palaeozoic basins may also underlie the northern area and could have been reactivated during the Triassic and Jurassic, when Gondwana extension was underway. Such reactivation structures, together with those generated during plate collision in the Miocene, probably account for the relatively high prospectivity of the region: that is, the basins are of the poly-history type which on a world scale appear to be relatively rich in hydrocarbons.

Basin development

The Bonaparte Basin is thought to have been initiated by rifting, which began in the Devonian and terminated in the mid-Carboniferous (Gunn, 1988). This was followed by thermal subsidence with its accompanying sag-phase sedimentation. A second episode of extensional tectonics, which created structures sub-parallel to the present shelf-edge, occurred in the Mid-Triassic and again in the Mid to Late Jurassic. Uplift, associated with this event, is evident in the Callovian (Williamson & Lavering, 1990). It eventually led to continental breakup and seafloor spreading in the Late Jurassic (Figure 4).

During the Miocene, collision of the Australian Plate with the Timor region resulted in reactivation of the Mesozoic fault-systems; and according to Mory (1988), the development of a further fault-system sub-parallel to the Timor Trough, created by transpressional movements. It is the normal and reversed faulting of Miocene age which has led to the fault-bounded traps in the Jabiru and Challis oil accumulations (Wormald, 1988; MacDaniel, 1988; Figure 5, location Figure 2). These structural traps have been interpreted as 'hourglass structures', showing faults cross-cutting in the vertical plane, with a small graben overlying a horst (Woods, 1988).

Bonaparte Basin Stratigraphy

The stratigraphic units in the Bonaparte Basin range in age from Precambrian to Quaternary (Williamson & Lavering, 1990). The oldest sediments encountered are Permian and are characteristic of a carbonate platform environment (Figure 6). From Late Permian to Mid Triassic, sedimentation was of marine, marine shelfal and fluvio-deltaic origins. From Late Triassic to Early Jurassic, initially red-beds and then fluvio-deltaic sediments were deposited. Uplift and erosion of the platform areas took place in the Mid to Late Jurassic. By the Late Jurassic and Early Cretaceous, sedimentation in the flanking troughs had reverted to mixed clastics of marine origin. Thick shales and calcarenites are characteristic of the overlying Cretaceous Bathurst Island Group. During the Paleocene to Oligocene, the carbonate sediments retreated oceanward and were fringed landwards by a thin proximal zone of siliciclastics. Shelfal carbonate deposition was re-established in the Miocene, with associated reef growth through till the Holocene.

Hydrocarbon accumulations

The major hydrocarbon discoveries in the Bonaparte Basin region include oil at Jabiru, Challis, Skua, Puffin and Oliver in the Vulcan Graben and Londonderry High area, and gas at Petrel and Tern in the Petrel Sub-basin (Figure 2). The stratigraphic levels of the reservoirs are shown in Figure 6.

Reservoir rocks

Regionally, and particularly with respect to Zone A, Williamson & Lavering (1990) and Botten & Wulff (1990) concluded that the best reservoir potential occurs in mixed clastic and carbonate sequences of the Middle to Late Triassic Londonderry Formation. In Jabiru, significant accumulations of oil were encountered in the Early to Middle Jurassic Troughton Group (Plover Formation). Also, the shelfal shales and sands of the Late Jurassic to Early Cretaceous Flamingo Group are potentially important reservoirs. Late Cretaceous shelfal sandstones of Maastrichtian age may provide a favourable objective if their distribution can be resolved.

The typical fluvial facies of the *Plover Formation* commonly exceeds 300 m in thickness, has net to gross reservoir ratio greater than 75 percent, porosities averaging about 25 percent, and a permeability often more than one Darcy (Botten & Wulff, 1990). However, the Plover Formation is unlikely to constitute a good reservoir at depths greater than about 3000 m due to diagenesis and associated porosity reduction.

Turbidite sands of the *Flamingo Group*, shed from the adjacent high areas, could provide potential reservoirs. Sequences up to 120 m thick have been intersected in Flamingo-1, with porosities averaging about 16 percent.

Source rocks

Williamson & Lavering (1990) rate the source rock potential of the region as follows:

> Triassic - Early Jurassic: poorly known but probably fair,
> Middle Jurassic - Neocomian: ranging from poor to good, with best potential in depocentres,
> Cretaceous: TOC mostly less than 1%, ?early mature to mature in the main depocentres.

Botten & Wulff (1990) discuss three potential source rock intervals pertinent to the Zone of Co-operation. These include the paludal-lacustrine shales of the Middle Jurassic Plover Formation which yield TOC values often greater than 4 percent, and also the uppermost marine shales; the Late Jurassic-Early Cretaceous Flamingo Group which has yielded, in places, TOC values of around 2.4 percent; and the basal deep marine sediments of the Early Cretaceous Bathurst Island Formation.

Seals

The regional seal in the Timor Sea is the claystone and siltstone interval of the Bathurst Island Formation, although in the eastern area its effective sealing capacity is dependent on the age of fault movement within potential traps.

Potential traps

There appear to be two principal trap types in the region:
- firstly, fault-bounded and anticlinal Mesozoic closures, similar to those at Jabiru and Challis, which were created by the combined effects of Mesozoic 'rifting' and fault reversal triggered by the Miocene collisional tectonics (Figure 5), and
- secondly, anticlines and drape structures related to salt diapirism, which have to date been unsuccessful targets.

For the Petrel Sub-basin, Gunn (1988) also listed carbonate mounds and banks, reefs, turtleback anticlines, fault rollovers and flower structures as the structural objectives of

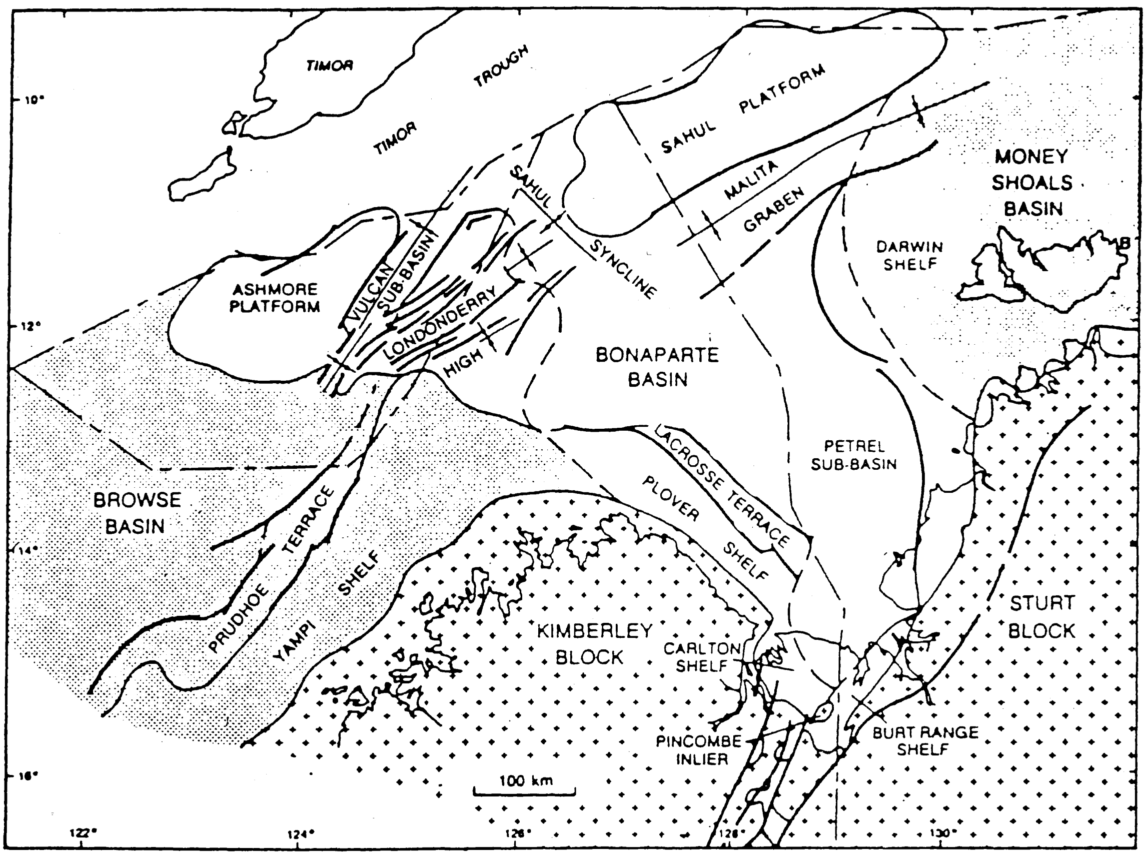


Figure 1. Structural sub-divisions of the Bonaparte Basin (modified after Bhatia & others, 1984).

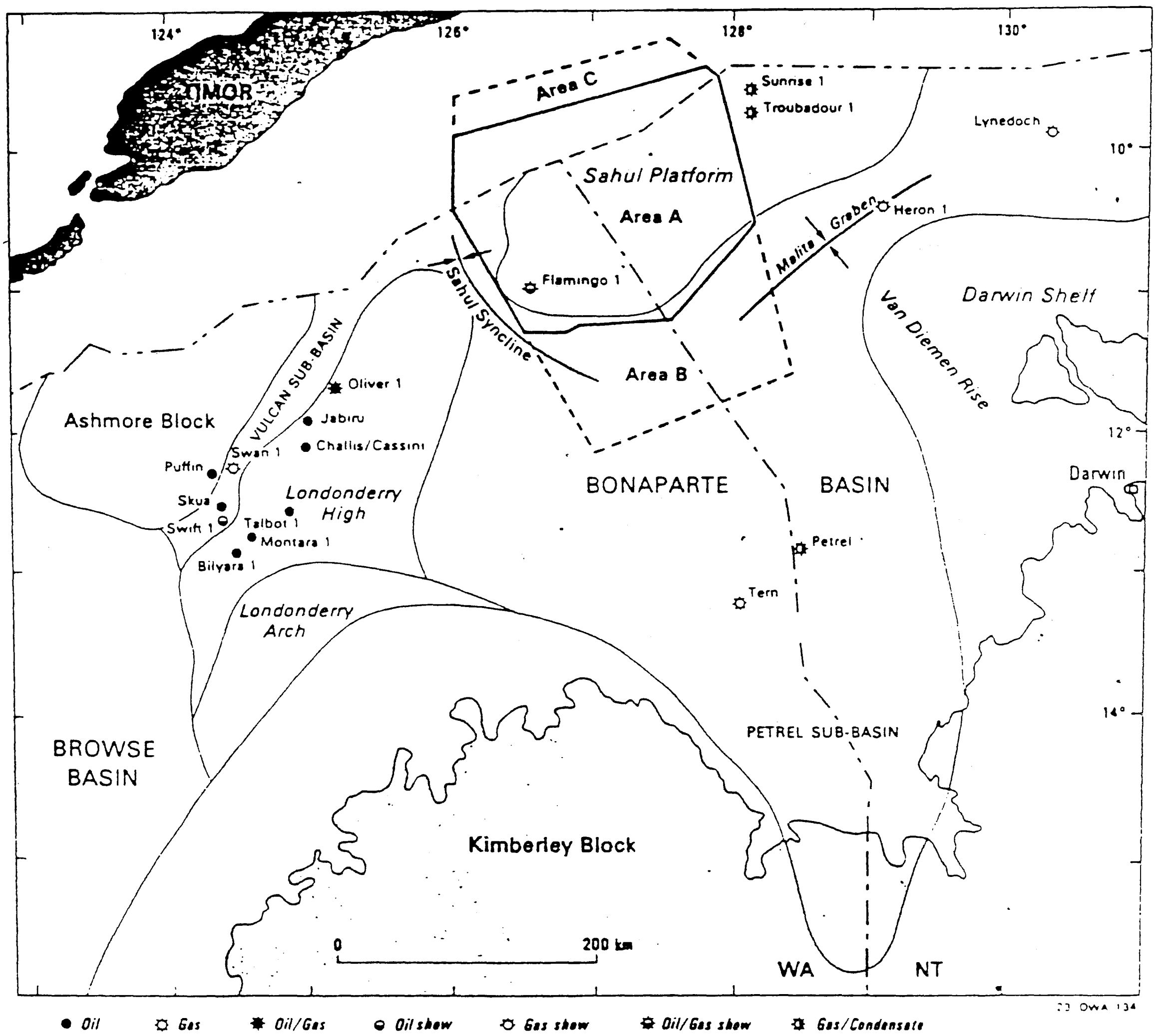


Figure 2. Location map showing structural elements, petroleum accumulations and the Australia/ Indonesia Zone of Cooperation (after Williamson & Lavering, 1990).

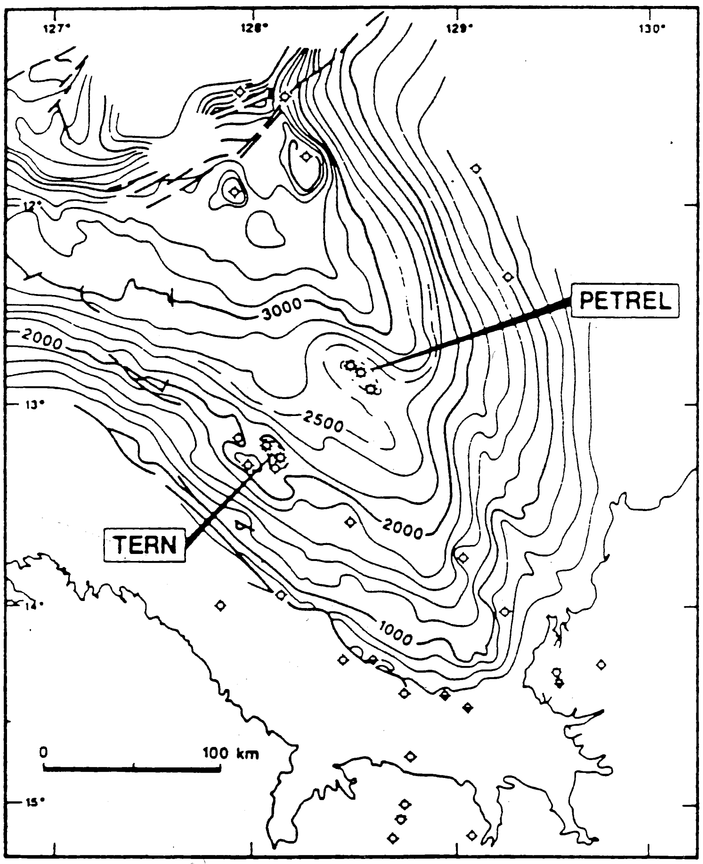
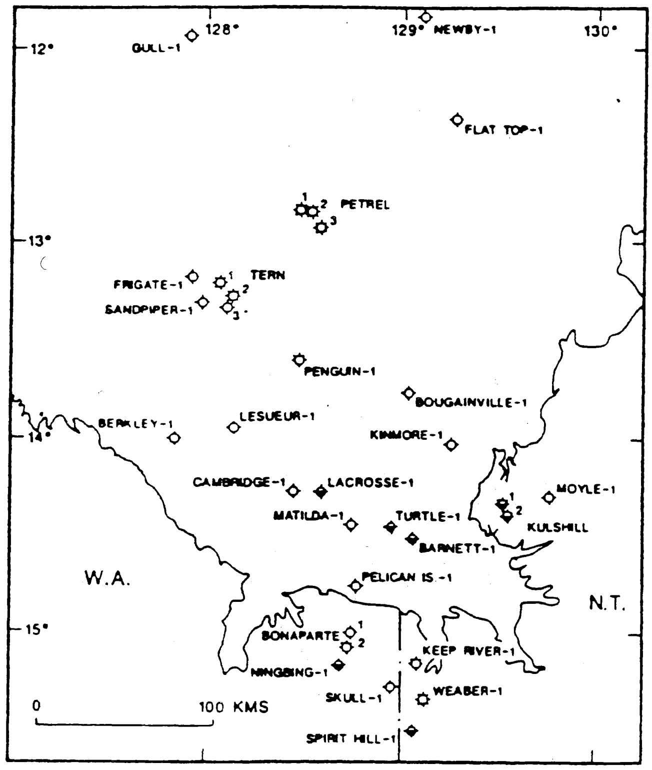


Figure 3. Fan-shaped basin configuration shown by two-way time to Late Permian (after Gunn, 1988).



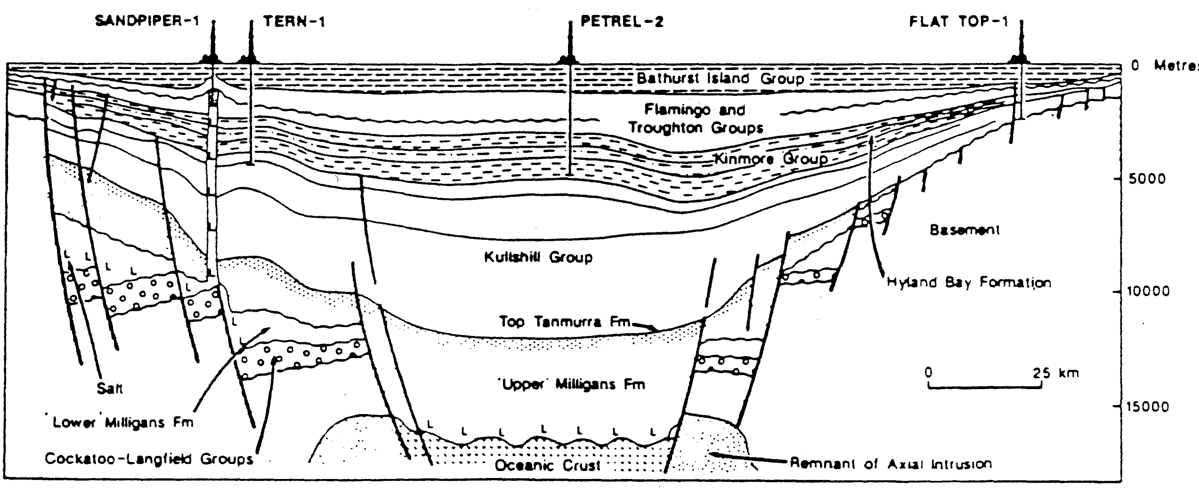


Figure 4. Well locations in the Petrel Sub-basin area, and cross-section through the Tern and Petrel gas fields (after Gunn, 1988).

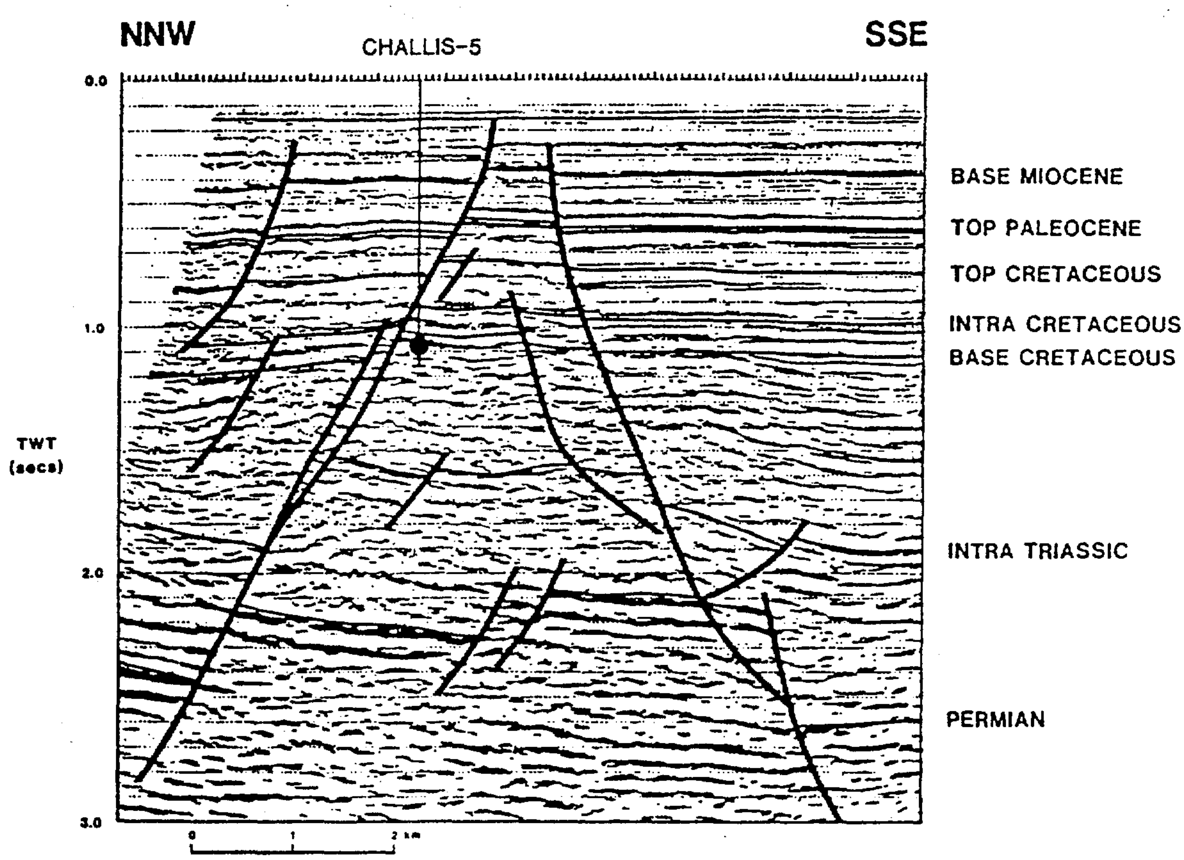


Figure 5. Seismic reflection profile through Challis-5 (after Williamson & Lavering, 1990; modified after Wormald, 1988).

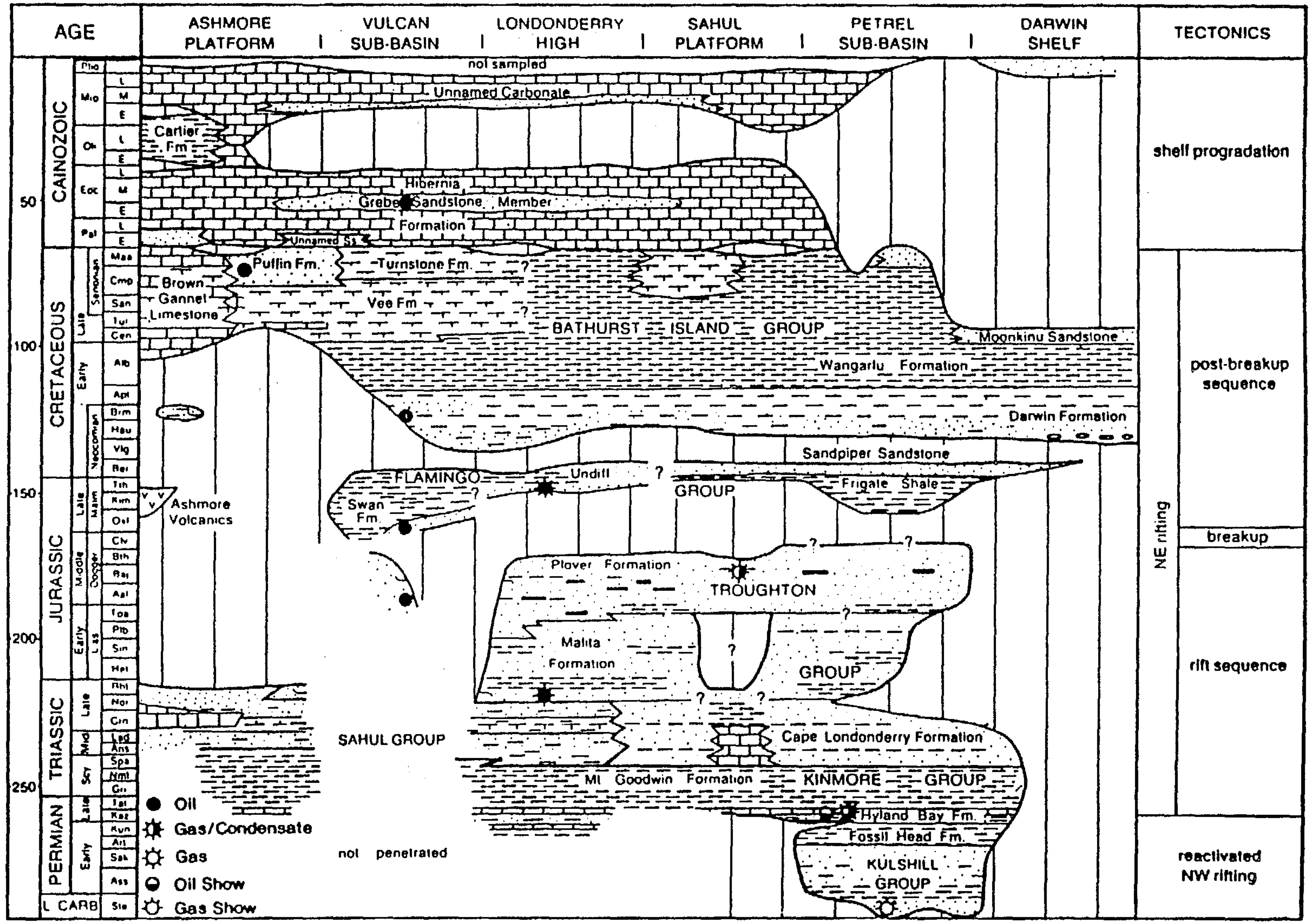


Figure 6. Permian to Cainozoic stratigraphy, tectonics, and hydrocarbon reservoirs of the Bonaparte Basin (after Williamson & Lavering, 1990; modified after Mory, 1988).

existing wells in the area. The possibility also exists of locating potential traps within 'deep sea fans' shed from the platform areas.

3. PROJECT OBJECTIVES AND RATIONALE

(i) Deep Crustal Seismic Reflection Data: to acquire, in and around the Bonaparte Basin, approximately 3000 line km of deep crustal seismic reflection data.

The deep crustal study has the objective of contributing to the definition of the three dimensional basinal architecture of the offshore Bonaparte Basin region, specifically the Petrel Sub-Basin, the Malita Graben, the Sahul Syncline and the Sahul Platform. This should enable these tectonic elements to be linked with elements in the adjacent areas which have been defined, or will soon be defined, in other BMR deep crustal surveys. It is anticipated that the seismic grid will be sufficiently detailed to allow definition of the major structural features in the region and to allow an understanding of the complex relationships that appear to exist between Palaeozoic features, such as the Petrel Sub-Basin, and Mesozoic overprinted structures, such as the Malita Graben. It may then be possible to determine how these major structures have controlled basin development, sedimentation history, petroleum trap formation (particularly traps created by reactivation), source rock accumulation, and the migration of hydrocarbons within the offshore Bonaparte Basin. The data will also provide regional stratigraphic ties, both between several key exploration wells and between the adjacent tectonic elements in the area.

The geological structures within the Bonaparte Basin reflect multiple periods of rifting and extension which relate to the formation of an initial Palaeozoic rift, later Mesozoic extension, and finally, continental margin formation. In addition, geologically recent structural reactivation, due to the interaction of the basin fabric with largely compressional stresses created by collision between the northern margin of Australia and Timor, was probably instrumental in providing Mesozoic structural traps and, importantly, expulsion and migration pathways for hydrocarbons, particularly in the northern Bonaparte Basin. The deep crustal data will potentially provide an indication of which deep-seated Palaeozoic and Mesozoic structural features were reactivated during the Tertiary, and consequently, which trends are most likely to be productive.

(ii) Remote Sensing Geochemical Data: To acquire, in and around the Bonaparte Basin, approximately 3000 line km of direct hydrocarbon detection (C_1 - C_8) *water column data.*

The Direct Hydrocarbon Detection (DHD) data will be collected simultaneously with the deep crustal seismic data, thereby allowing geochemical anomalies to be related to sub-seafloor geology. The DHD data will help to establish the nature and migration pathways of the hydrocarbon charge emanating from the Sahul Syncline and Malita Graben at the present day. This objective may be particularly important because of the possibility of flushing oil from reservoirs along the margins of the Sahul Syncline and Malita Graben with gas generated from source rocks which are now overmature.

The DHD program will also potentially provide information on the probable type (that is, gas versus oil) and distribution of hydrocarbon accumulations within the Sahul Syncline and Malita Graben and their margins. The survey will also aim to investigate hydrocarbon type on the northeastern Sahul Platform - Sunrise/Troubadour gas condensate discovery area. That feature extends westwards into 'Area A' of the Australia/Indonesia Zone of Cooperation.

In addition, the survey will collect DHD data to make comparisons between the southern oil-prone part of the Petrel Sub-Basin (around Barnett-1 & -2; Turtle-1 & -2) and the northern gas-prone area (around the Petrel & Tern gas discoveries).

Expected products from Project 121.22

The following products can be expected to result from this project:-

(i) Regional deep crustal seismic sections showing the main structural elements of the offshore Bonaparte Basin and their relationship to the surrounding structural elements.

(ii) Revised regional tectonic elements maps and structural sections.

(iii) Regional seismic stratigraphic ties, both between exploration wells and between the adjacent tectonic elements in the area.

(iv) Regional maps of the distribution of light hydrocarbons in the water column and the relationship of any detected geochemical anomalies to sub-seafloor geology.

(v) Basin-wide burial and thermal geohistory analyses of relevant exploration wells (and synthetically-generated locations) to constrain the timing of hydrocarbon generation and likely migration pathways.

4. CRUISE PLAN

The cruise plan (Figure 7) consisted of 10 lines: 5 dip lines, largely within the Petrel Sub-basin; and 5 'strike' lines to connect the main structural elements and determine their extent, two of which are long transects of the margin from near the coast in the Petrel Sub-basin to

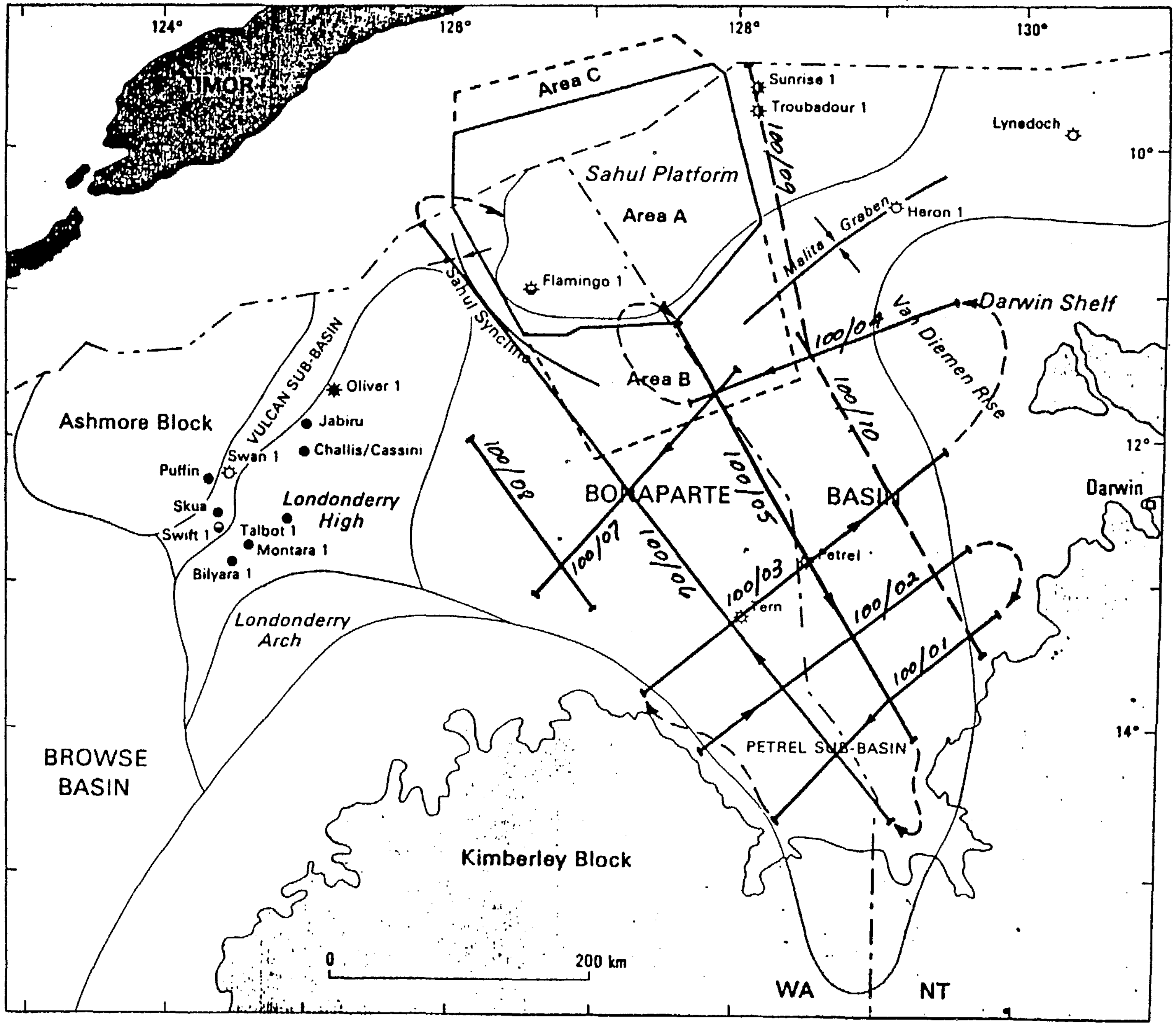


Figure 7. Cruise plan for the *Petrel-1* deep seismic/'sniffer' survey.

the Australia/Indonesia seabed boundary. The planned lines and their priorities were:

Line number	Approx. Length (km)	Orientation	Priority
100/01	210	NE-SW	High
100/02	270	NE-SW	High
100/03	310	NE-SW	High
100/04	180	ENE-WSW	High
100/05	370	NNW-SSE	High
100/06	530	NW-SE	High
100/07	220	NE-SW	High
100/08	150	NW-SE	Medium
100/09	120	NNW-SSE	Lowest
100/10	250	NNW-SSE	Lowest
	Total = 2610 km		

Petrel Sub-basin

The program of dip and strike lines within the Petrel Sub-basin was aimed at defining its limits and its relationship to the surrounding platform areas, particularly its structural relationship to the younger Malita Graben.

Sahul Syncline

The principal objective was to obtain a deep crustal line from the Australia/Indonesia border, along the centre of the Sahul Syncline, across the western extremity of the Malita Graben, and into the northern Petrel Sub-Basin (100/06). This line would assist in understanding the structural development of the Sahul Syncline and the relationship of the Syncline to the adjacent tectonic elements. The data would also be used to study the processes of structural reactivation associated with collision and foreland basin development along the northern margin of the Australian craton. The line was positioned so that it would tie with a previously acquired BMR deep crustal strike line within the northern Vulcan Graben (line 98/005).

Malita Graben

The Malita Graben program consisted of two lines linking the Londonderry High, the Sahul Syncline, the Malita Graben and Darwin Shelf, together with the cross-lines which should enable its axial extent to be determined.

Sahul Platform

A line (100/09 & 10) was planned to run from the Australia/Indonesia border (Sahul Platform), through the Sunrise and Troubadour gas/condensate discoveries to the Shearwater-1 well, through the Malita Graben and into the Petrel Sub-Basin. This line could be linked with a proposed BIRPS (British Institutes) deep crustal line which will soon be recorded across the Timor Trench.

5. OPERATIONS AND SYSTEMS PERFORMANCE

Non-Seismic Data Acquisition (N.A. Johnston)

The non-seismic data acquisition system (DAS) is based on a Hewlett-Packard 1000 F-series computer with 2 Mbyte of memory and 290 Mbyte of disk storage. This system collects navigation, bathymetry, magnetic and gravity data every 10 seconds. Data is stored onto 1600 bpi magnetic tape in blocks of 1-minute data. Tapes are changed daily at 0000 UTC. A list of the DAS channel allocations is given in Appendix 6.

DAS crashes occurred on days 097, 119, and twice on day 121, each resulting in the loss of about 5 minutes of data. On the last day of seismic acquisition (day 122) the DAS computer began crashing every 5 minutes. The system console reported backplane errors. The computer was stripped and all interface card slots were cleaned. The system then operated satisfactorily until Port Hedland.

Navigation

Navigation is obtained from five independent systems - three dead reckoning systems integrated into the US Navy Transit Satellite network via two Magnavox Satellite Navigators, and two systems using the NAVSTAR Global Positioning system. The DAS operated on a hierarchical system: calculating the dead reckoning position and overwriting it with the GPS positions if they are valid.

Dead reckoning:
The three dead reckoning systems are based on:

1. Magnavox MX610 Sonar Doppler and Sperry gyro compass
2. Raytheon DSN-450 Sonar Doppler and Sperry gyro compass
3. Paddle log and Sperry gyro compass

Prior to this cruise the Magnavox sonar doppler head was replaced. This system worked very well all through the cruise. The positions calculated by the Magnavox system during dead GPS periods were very good. The Raytheon system was operated for most of the cruise in 'water lock' in order to give the operators a reliable estimate of the ship's speed through the water; an essential requirement for maintaining the seismic cable at its correct depth and tension in an area prone to high current sets.

Global positioning system:
Two GPSs were used during this cruise:

1. Magnavox T-SET
2. RACAL differential system

The T-SET has been in use for about 6 years and still gives reasonable results despite its age. It was only required to be used for about 7% of the cruise due to the reliability of the RACAL system (refer to Appendix 8).

The RACAL system is a differential GPS which uses a Trimble 4000DL Differential Locator and a RACAL Skyfix data link. The data link broadcasts range corrections from a shore station in either Broome or Singapore via the MARISAT satellite communication system. The Skyfix system was found to be excellent and almost no problems were encountered due to the data link.

The navigation data from the RACAL system was fed into the DAS to give 10 second positions. The system gave between 85% and 95% differential GPS with the loss being due to poor satellite geometry.

Bathymetry

The 3.5 kHz and 12 kHz echo sounders, and the HADES program to the geochemical laboratory worked satisfactorily for the entire cruise.

Gravity

The Bodenseewerk Gravity Meter operated satisfactorily.

Magnetics

Magnetic data were collected with a Geometrics proton precession magnetometer. The magnetometer was only deployed from the second week of the cruise on, due to the shallow depth of the water. The noise level was of the order of 1-2 nT.

Seismic Data Acquisition System (N.A. Johnston)

System software

The new MicroVAX based Seismic Data Acquisition System was used for the first time this cruise along with 192 channels of modified charge-coupled amplifiers. For most of the cruise the system collected 16 seconds of 4 ms data of 192 seismic channels, 8 gun sensors and 3 water breaks plus 2 dummy channels for a total of 205 channels. One line was shot with 15 seconds of 2 ms data with 144 seismic channels. The system handled this task with no major problems. The seismic cable was 4800 metres of 25 metre groups giving 48 fold data when shot at 50 metre intervals.

6. DATA COLLECTED

During the *Petrel-1* cruise, approximately 2090 km of deep-seismic, gravity and geochemical DHD data were collected concurrently, together with 1250 km of magnetics (Figure 8). When transits were made between seismic lines and during breakdowns of the acquisition system, the collection of gravity, DHD and usually magnetic data, was continued. Additional lines (100/S1 & S2), during which only the 'sniffer system' was operative, were run in the southern Petrel Sub-basin. These totalled 349 km. A seismic test line (100/T1), about 100 km long, was run accross the Malita Graben, intersecting the northern end of Line 100/05. Its purpose was to test the 144-channel, 2 msec, data acquisition mode.

Of the ten lines planned for the cruise, the seven with the highest priority were completed.

Seismic data

The unprocessed seismic monitor records generally show structural information in the first 0-6 secs, and in some instances coherent non-multiple energy in the 6-12 sec range. The main structural elements of the region are readily distinguished. Examples of the monitor data are presented in Figures 9-13.

Petrel Sub-basin margin:
Figures 9 & 10 show the footwall block, and what appears to be the head of the master detachment fault, along the NE margin of the Petrel Sub-basin. The first major tilt-block is evident at about 4 secs record time, overlain by about 2 secs of synrift section. Reactivation faulting and folding are seen in the stratified section over the footwall block.

Central Petrel Sub-basin:
Figure 11 shows a deep-seated intrusive-like feature within the Petrel Sub-basin. Although

this may be associated with salt tectonics, it is more likely to be of igneous origin - possibly the 'oceanic' material postulated by Gunn (1988).

Tern gas field:
Figure 12 is an example of an asymmetric anticline, in this case the Tern structure, typical of many of the hydrocarbon bearing structures in the area. There is some evidence that the anticline is underlain by a basin-forming tilt-block of probable Palaeozoic age, indicating that it may be a reactivation structure associated with Mesozoic rifting and/or Australia/Timor plate collision.

Reactivation structures:
Figure 13 shows the end of Line 100/06 nearest the Australia/Indonesia seabed boundary. The many folds and faults which extend almost to seabed are probably associated with plate collision in the Miocene. They probably represent the reactivation of older structures.

Geochemical (J.H. Bishop)

Background values for hydrocarbons were very similar to those measured on Cruises 97 and 99 (Vulcan Graben 1 and Vulcan Graben 3), with total hydrocarbons (THC) around 8-10ppm, methane around 3-5ppm, and C2 and C3 hydrocarbons in the range 10-100ppb.

A brief summary of the anomalies detected is given below:
The seeps over the Tern and Petrel fields found during Cruise 99 were repeated, and although the magnitude of the seep over Petrel was greater, the compositional characteristics were very similar. As with Cruise 99, there appears to be a general lack of hydrocarbon seepage over most of the survey area, with the few exceptions outlined below:

100/001:
High levels of THC at the start of the line, decreasing during the line, probably caused by contamination from reterminating. Between Bougainville-1 and Lacrosse-1, a minor butane anomaly.

100/002:
Anomalous levels of methane and ethane, only just above background before and after Penguin-1, although no distinct anomaly over the well itself.

100/001 (rerun):
Large butane anomaly, with minor propane, at geochemical shotpoints 510-525, occurring more-or-less at the same point as the minor butane anomaly on the original line (100/001).

100/003:
Large C1-C4 anomaly over Petrel-1, THC to 40ppm, methane to 25ppm, ppb levels of C2-C4.

100/004:
Methane anomaly near Curlew-1.

100/005:
Major anomaly over Petrel-1 well, methane over 250ppm, THC estimated 350-400ppm, with C2-C4's in range 1-7ppm. Also smaller traces of heavier hydrocarbons (C5+).

100/006:
Methane and ethane higher than background towards end of line (prior to 100/0S1), but no distinct anomaly.

100/0S1: No anomalies.
100/0S2: No anomalies.

100/006A:
Methane and ethane higher than background at start of line (after 100/0S2), but no distinct anomaly.

100/0T1 (test) : No anomalies.

100/007:
Regional THC, methane, ethane and propane anomaly over 200 shotpoints (approx 30 miles), although low-level.

Further data processing and interpretation will be required before the significance of these anomalies can be established.

BMR MARINE SURVEY 100

PETREL-1

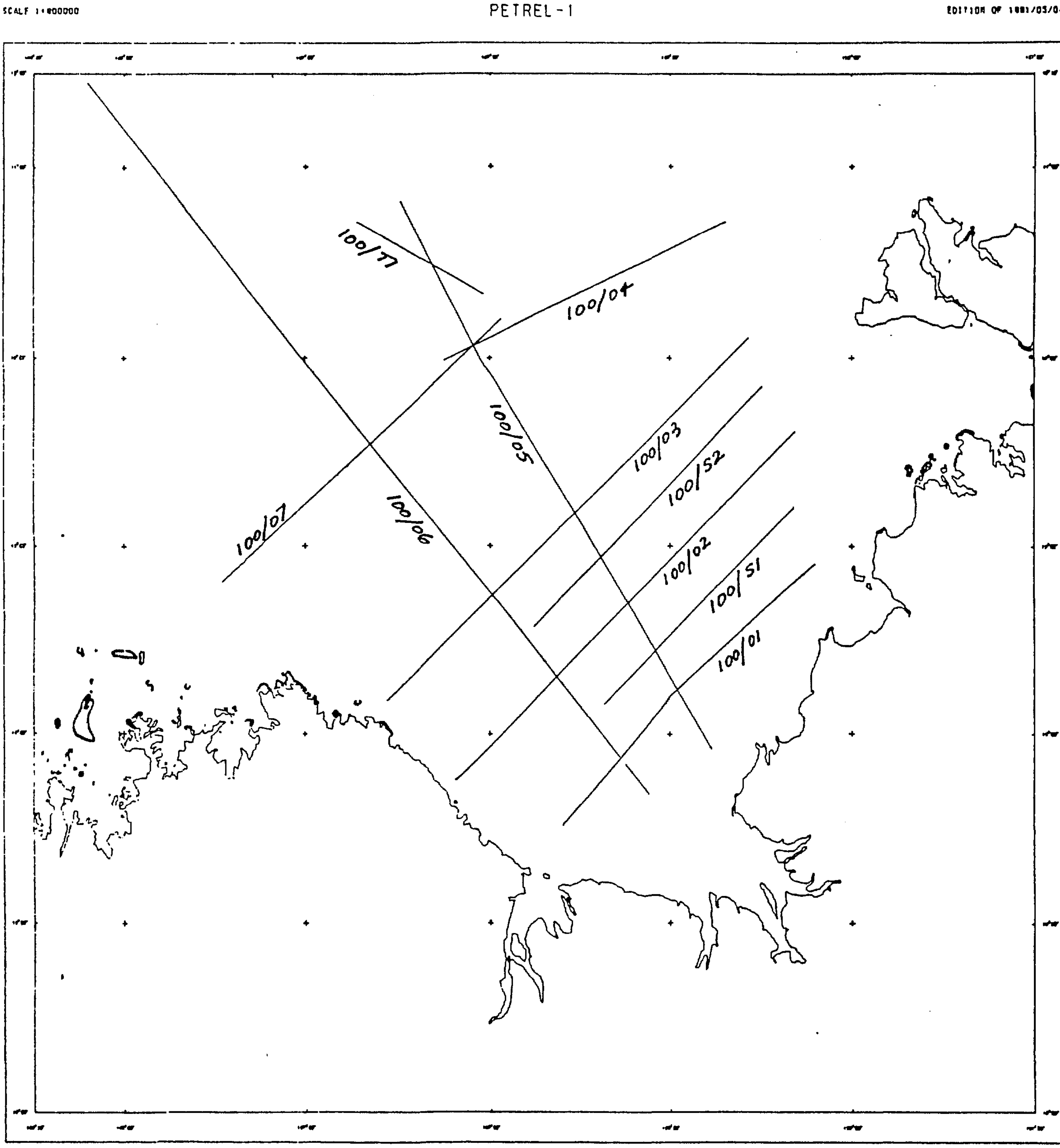


Figure 8. Actual track chart for the *Petrel-1* deep seismic/'sniffer' survey. Seismic lines 100/01-100/07; sniffer only 100/S1 & S2.

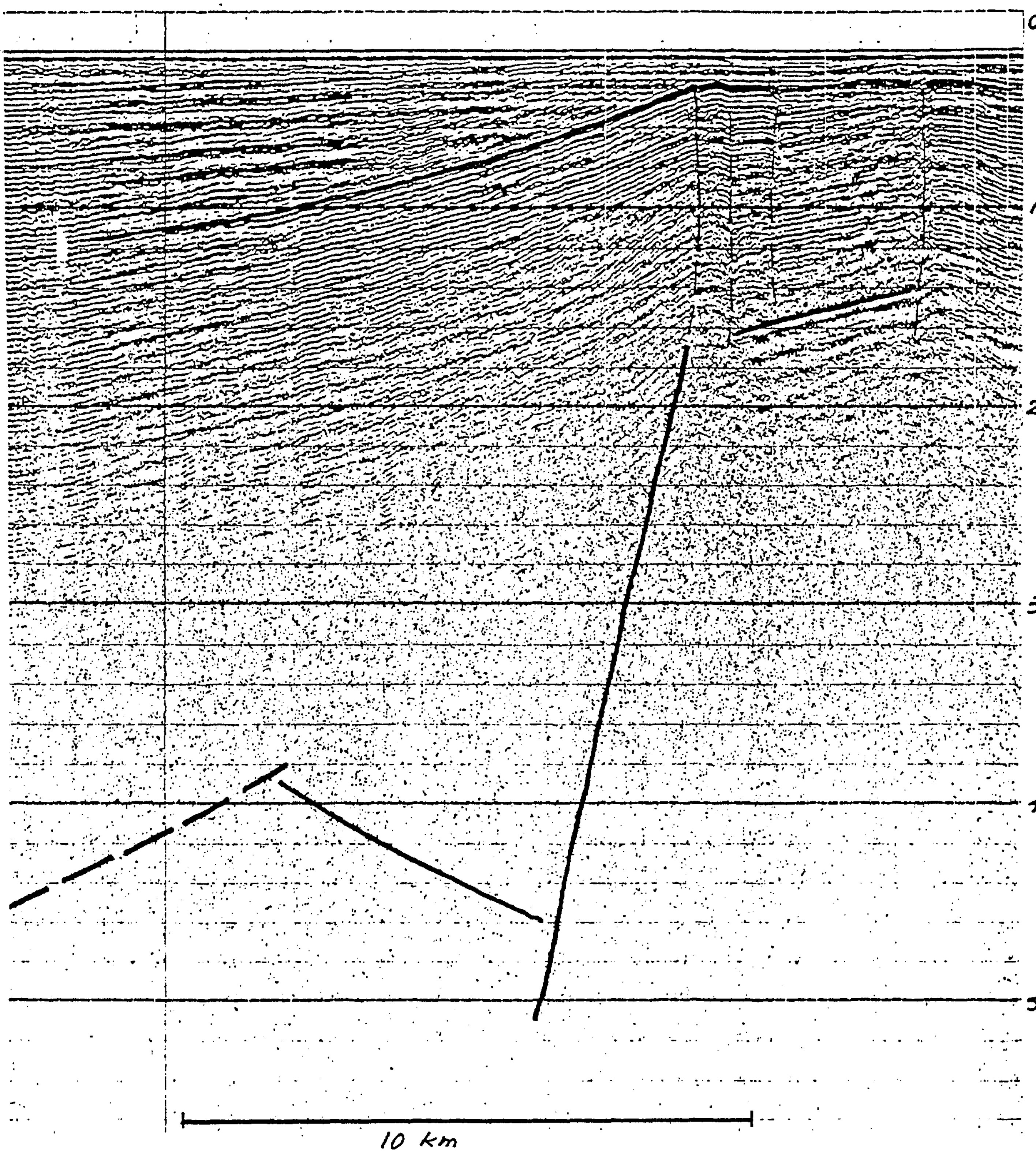


Figure 9. Seismic monitor (slow) for part of Line 100/01: shows NE edge of Petrel Sub-basin.

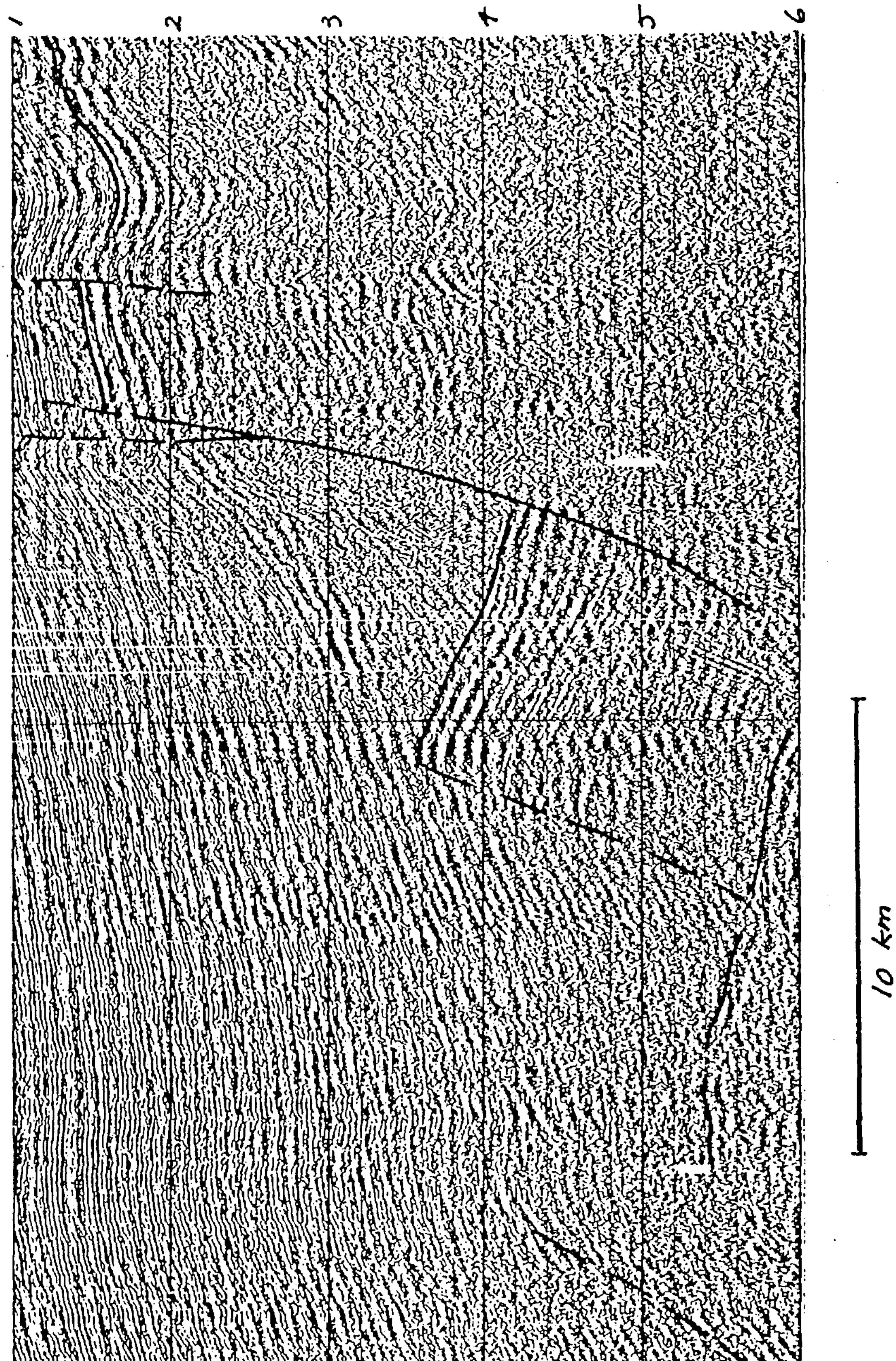


Figure 10. Seismic monitor (slow) for part of Line 100/03: shows NE boundary fault of Petrel Sub-basin and first deep tilt-block.

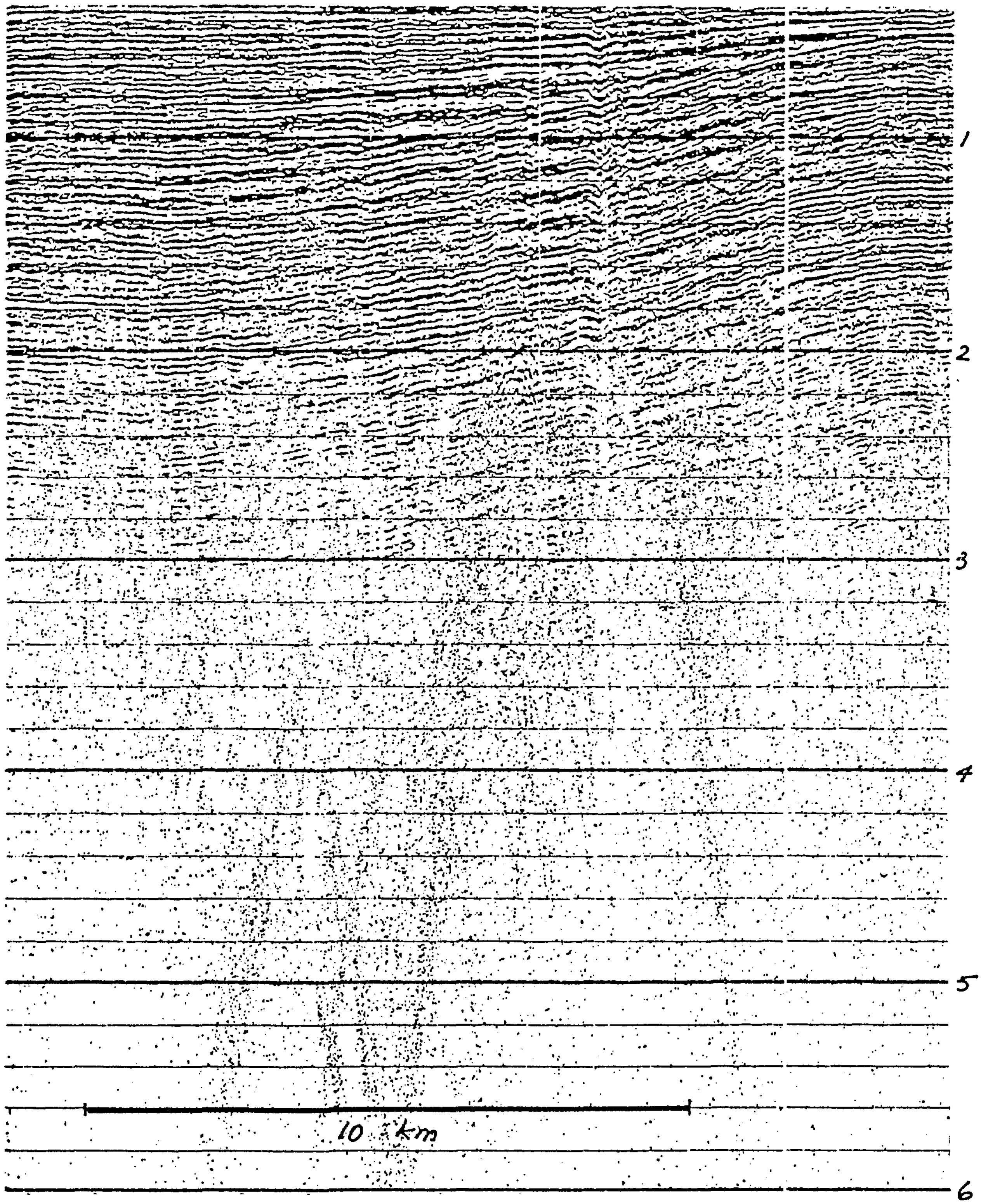


Figure 11. Seismic monitor (slow) for part of Line 100/01: shows ?deep intrusion or salt-related feature within Petrel Sub-basin.

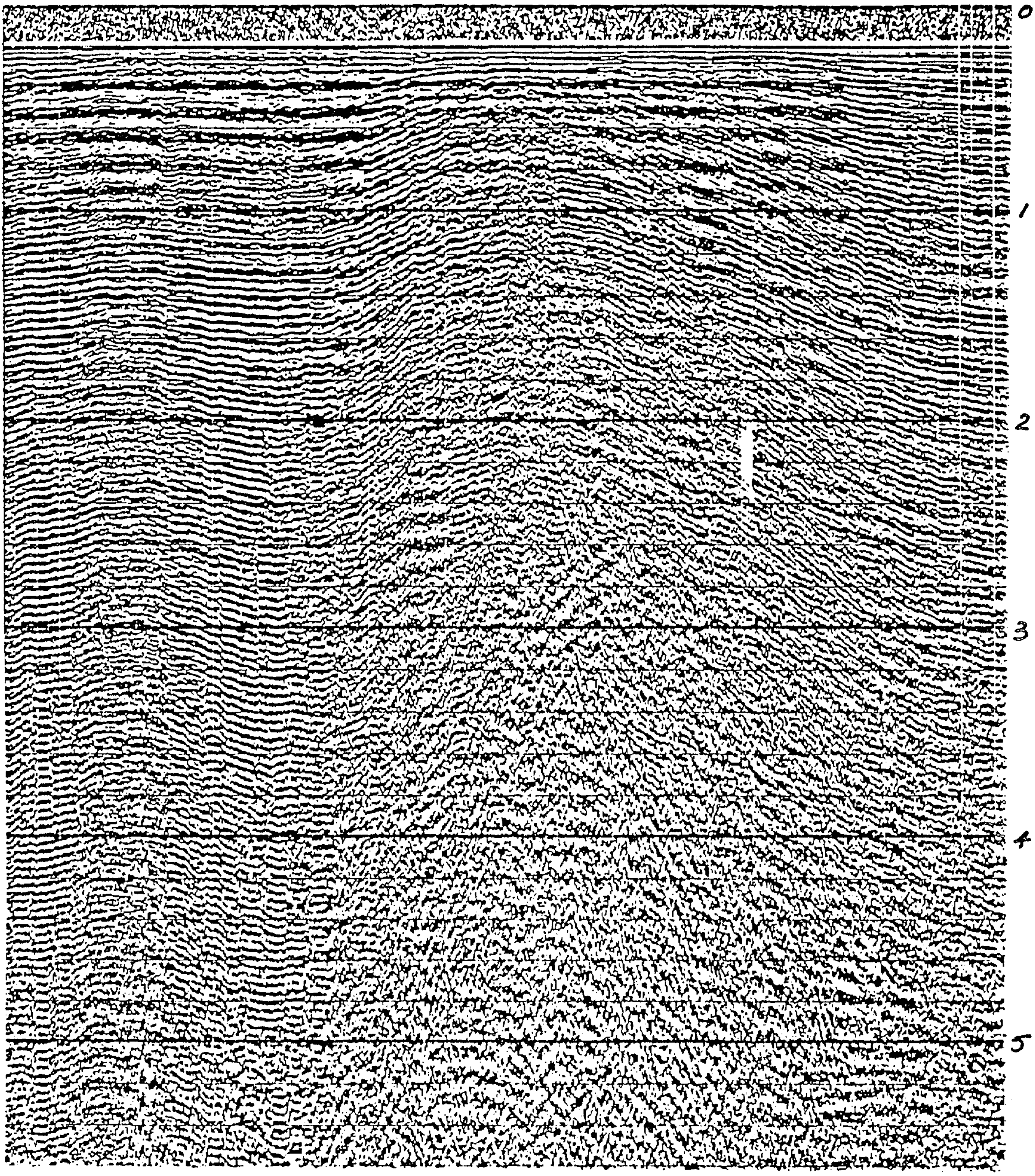


Figure 12. Seismic monitor (slow) for part of Line 100.03: shows anticlinal structure of Tern gas field.

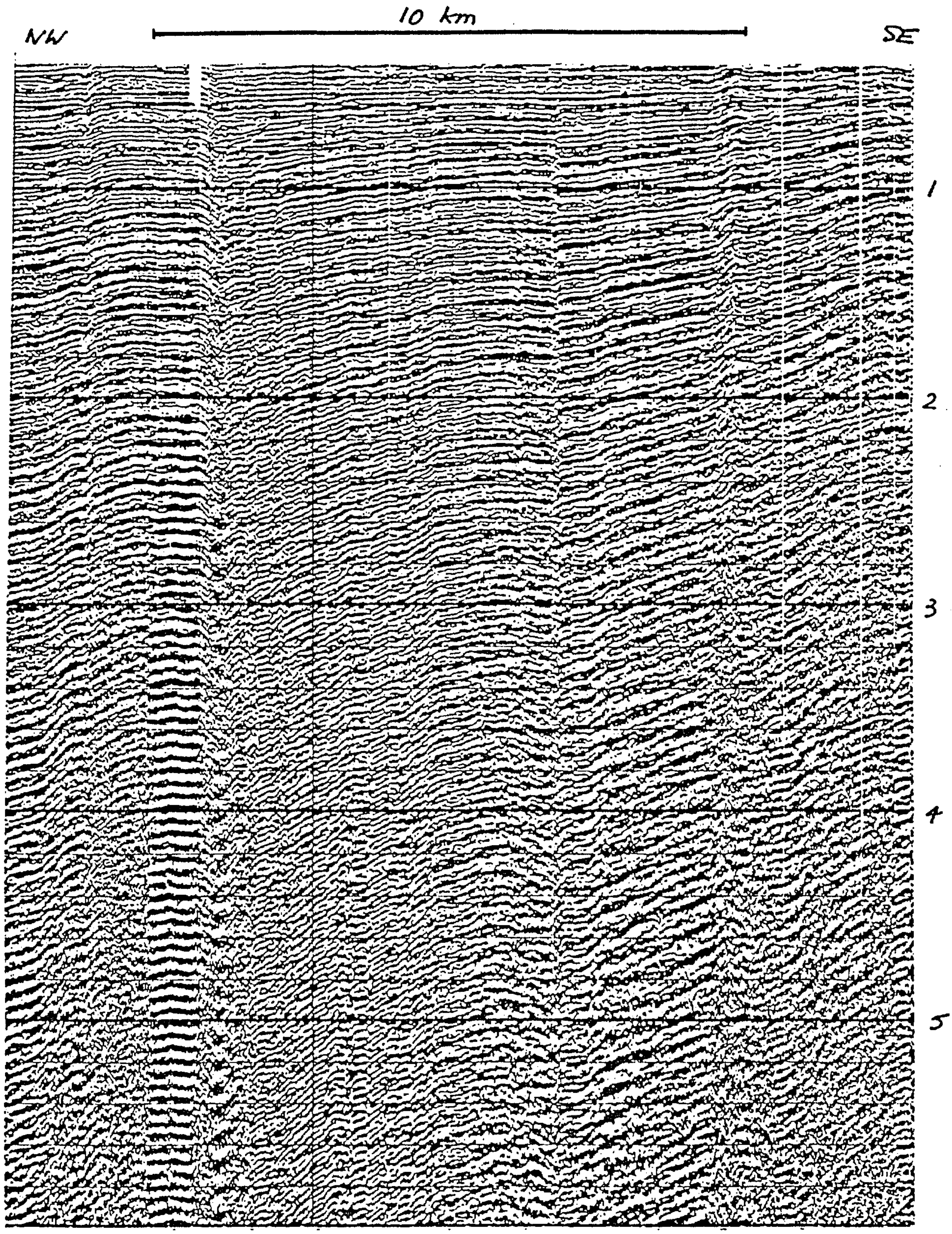


Figure 13. Seismic monitor (slow) for part of Line 100/06: shows possible late stage faulting/reactivation in the Sahul Syncline.

7. ACKNOWLEDGEMENTS

We thank the Master, Bob Hardinge, and crew of the *R/V Rig Seismic* for their skill and co-operation in bringing the *Petrel-1* cruise to a successful conclusion.

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Appendix 1:
SCIENTIFIC EQUIPMENT IN USE

General

Raytheon echo sounders: 3.5 kHz (2 kW) and 12 kHz (2 kW)
Geometrics G801/803 magnetometer
Bodenseewerk Geosystem KSS-31 marine gravity meter

Navigation

Trimble/RACAL satellite link differential GPS System
Magnavox T-set Global Positioning System
Magnavox MX1107RS and MX1142 transit satellite receivers
Magnavox MX610D and Raytheon DSN450 dual axis sonar dopplers
Arma Brown and Sperry gyro-compasses; plus Ben paddle log

Seismic streamer

Fjord Instruments, transformerless coupling
Maximum of 288 seismic channels, 12 auxiliary channels
10 Teledyne T-1 hydrophones per 6.25 metre group
Nominal sensitivity 20 Volts/Bar for standard group
6.25, 12.5, (18.75), and 25.0 metre groups available
Maximum towable length 6000 metres; 4800 m available

Recording instrumentation & recording options

Low noise charge-coupled preamplifiers
Preamplifier gain from 1 to 128 in 6 dB steps
Maximum of 320 channels including seismic and auxiliaries
LC filters : 8, 12, 24 and 48 Hertz at 18 dB/octave
HC filters : 64, 128, 256 and 512 Hertz at 72 dB/octave
Sampling rates : 0.5, 1, 2, and 4 millisecs
Record lengths : 2 secs to 20 secs
SEG -Y recording format
IFP operating at 200 kHz with special floating point format
Data recorded as 4-bit binary exponent and 12-bit mantissa

Water-column Geochemical equipment

The Direct Hydrocarbon Detection (DHD) method continuously analyzes C_1-C_8 hydrocarbons within seawater. Thermogenic hydrocarbons migrating up faults from source rocks and/or hydrocarbon reservoirs debouch into the seawater at the seafloor, producing higher concentrations of light hydrocarbons within the water column. These seep gases have molecular compositions that are distinctively different from that of the biogenically-produced hydrocarbons which are mainly produced by *in situ* processes in seawater. If the hydrocarbons are present in sufficient amounts, the molecular composition of the thermogenic hydrocarbons may be used to infer whether the primary source of the seep was oil, condensate or dry gas.

The method used on the RV *Rig Seismic* is as follows. Seawater is continuously delivered into the geochemical laboratory onboard the ship via a submersible fish (which is towed approximately 10 m above the seafloor). The seawater is degassed in a vacuum chamber and the resulting headspace gas is injected into three gas chromatographs which sequentially sample the flowing gas stream and measure a variety of light hydrocarbons. Total hydrocarbons (THC) are measured every thirty seconds, light hydrocarbons (C_1-C_4) are measured every two minutes, and C_5-C_8 are measured every 8 minutes. These data, as well as fish altitude (above the seafloor), the depth of the fish, hydrographic (temperature and salinity) and navigation data are recorded on computer. All these data are recorded and displayed continuously so that any hydrocarbon anomalies in the water column can be quickly recognised and additional measurements can be made when appropriate. Detection sensitivity is approximately 10 parts per billion in the stripped headspace sample. At a ship speed of 4 knots, the measurement of THC is made every 70 m, C_1-C_4 every 250 m, and C_5-C_8 every 1400 m.

Appendix 2:
4800 m SEISMIC STREAMER

The streamer cable was constructed by re-programming the 6.25 m group, 1200 m cable to 25 m groups, then adding this to the end of the existing 3600 m, 25 m group cable. The result was a cable with active length 4800 m, made up of 192 channels each of 25 metres. In addition, 3 water breaks (WBs) were positioned at intervals of 600 m, at the front of channels 1, 25 and 49; and 25 cable levelers with integral depth detectors (DTs) were placed at intervals of 200 m, at the front of channels 1, 9, 17, . . .185, plus at the front of the tail stretch section. Two stretch sections were used at the front of the cable, and one at the rear. Refer to Diagram 1.

Cable Balance

The ballasting of the cable was modified to have 2 x 1 kg sheets of lead per active, except for the rearmost section which had only one. This turned out to be almost ideal, with most of the cable length being slightly positively buoyant, except for a couple of heavy points including the tail. The table shows typical wing angles for the 25 cable levelers; small negative angles are considered ideal - a slight downward force to counteract the natural positive buoyancy.

Table: TYPICAL BIRD WING ANGLES

BIRD	ANGLE	BIRD	ANGLE	BIRD	ANGLE
1	var	10	-04	19	-02
2	-11	11	-07	20	-03
3	02	12	-04	21	-05
4	05	13	-04	22	00
5	03	14	00	23	01
6	-02	15	-01	24	03
7	-03	16	01	25	12
8	-04	17	-01		
9	-07	18	-04		

The depth of the front of the cable is determined almost entirely by the length of the tow leader and by the speed of the ship through the water. Ideally, the wing angle on bird #1 should be close to zero, thus giving the bird maximum flexibility to cope with small differences in speed through the water, without resorting to changes in the tow leader length. An 80 to 90 m tow leader was found to be appropriate for this cable length, at a speed through the water of 4.5 to 5 knots.

In the occasionally marginal to mostly excellent weather/sea conditions encountered on this

CABLE CONFIGURATION

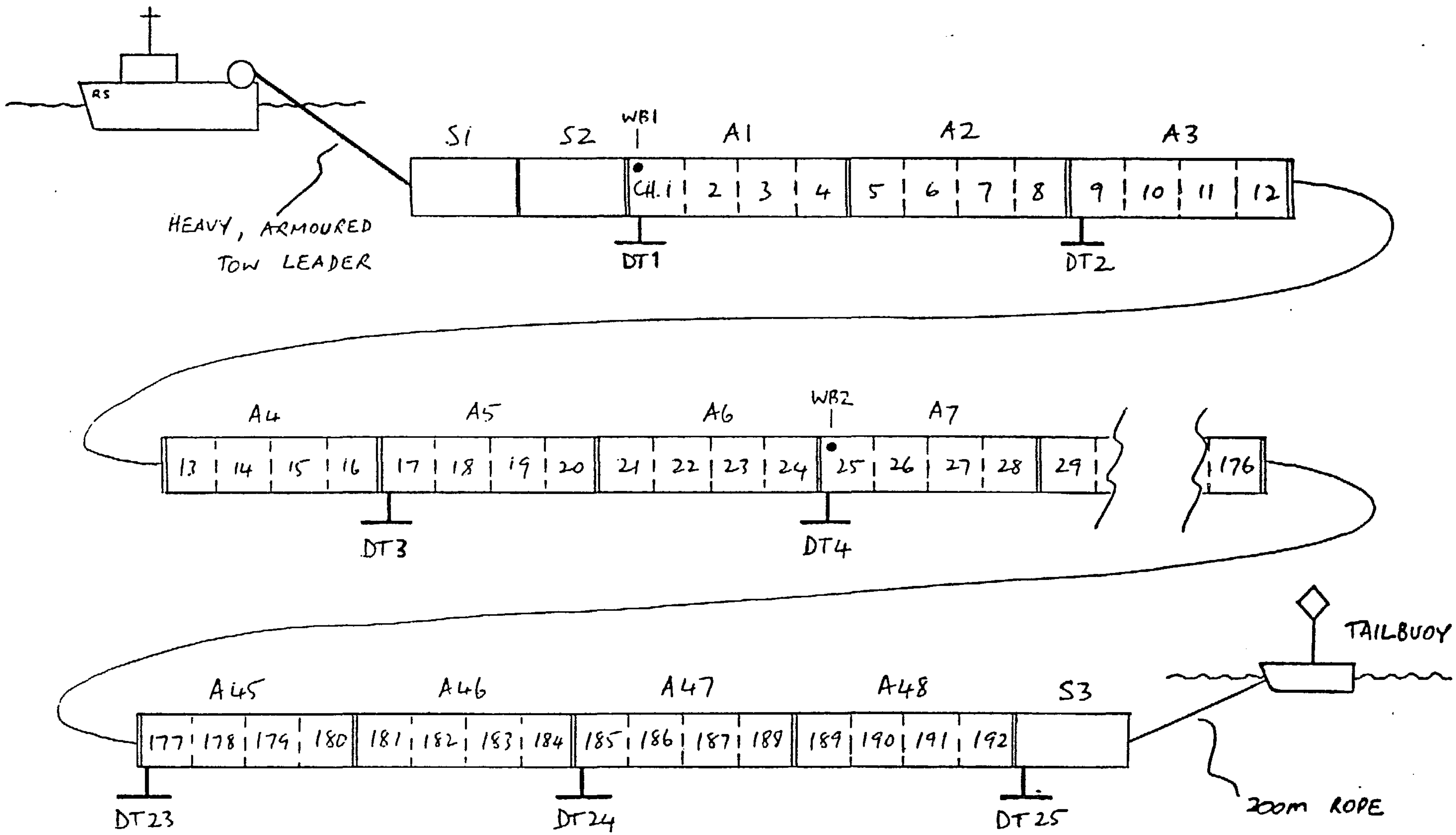


Diagram 1

cruise, the cable depth was observed to be at its desired depth of 10 m ± 0.3 m most of the time, and ± 0.2 m a lot of the time. This is a sure indication of a well ballasted and well controlled cable.
It is recommended that for future deployments of this cable in similar water temperatures, the ballasting be left alone, except to remove lead from at least the last active section. Also, more oil should be pumped into the tail stretch section, while keeping the tumescence within the bounds of modesty, in order to provide more buoyancy at the last bird. The bird plus rings weigh 2.7 kg, and the stretch normally weighs about 3 kg, so this will be an on-going problem, especially at slow ship speed, as when deploying or retrieving the cable. A torpedo-shaped flotation cannister, as offered as an option on older model birds might help, since this bird is aft of the last hydrophone group.

The more adventurous could try replacing the front two active sections, since there is heresay evidence, though no documentation, to suggest that the oil level in these sections was tampered with on a previous outing. This may account for the high negative wing angle on bird #2; the depth is well controlled, but the high angle presumably creates slightly more noise at that channel.

Appendix 3:
SEISMIC RECORDING PARAMETERS

The following geometry and recording parameters were used for the deep seismic survey of the Bonaparte Basin region:

Streamer geometry

Fjord Instruments transformerless: 4800 m active length
192 seismic channels plus 3 WBs plus 25 DTs
Group interval 25 m
Nominal depth 10 m
Near offset nominally 165 m
Far offset nominally 4940 m

Energy Source

16 x 150 cu.in. HGS sleeve gun per array; 2 arrays of 10 guns each in 4, 3, 2, 1 groups used
Pressure 2000 psi
Gun depths 10 m nominal

Recording parameters

<u>All lines except 100/200</u>

8 Hz - 64 Hz passband
4 ms demultiplexed
16 sec record length
48 fold at a nominal 5 knots (shot rate = 19.4 sec = 50 m)
Seismic data recorded in SEG -Y format, special floating point format: 4 bit binary exponent, 12 bit mantissa

<u>Test line 100/200</u>

8 Hz - 128 Hz passband
2 ms demultiplexed
15 sec record length
144 seismic channels only recorded
36 fold at a nominal 5 knots (shot rate = 19.4 sec = 50 m)

Appendix 4: WAYPOINTS

N.B. WGS84 SPHEROID USED ON *RIG SEISMIC**

Line 100/01 Shot NE-SW Approx. length = 210km (113 n.miles)

Start:	13° 08.000'S	129° 46.000'E
Bougainville-1 well:	13° 46.330'	129° 02.576'
Lacrosse-1 well:	14° 17.765'	128° 35.034'
End:	14° 29.000'	128° 25.000'

Line 100/02 Shot SW-NE Approx. length = 272km (147 n.miles)

Start:	14° 11.000'S	127° 53.000'E
Lesueur-1 well:	13° 57.073'	128° 07.617'
Penguin-1 well:	13° 36.382'	128° 28.167'
End:	12° 27.000'	129° 38.000'

Line 100/03 Shot NE-SW Approx. length = 308km (166 n.miles)

Start:	11° 54.000'S	129° 26.000'E
Petrel-1 well:	12° 49.498'	128° 28.518'
Tern-1 well:	13° 13.165'	128° 03.950'
End:	13° 51.000'	127° 25.000'

Line 100/04 Shot ENE-WSW Approx. length = 178km (96 n.miles)

Start:	11° 18.000'S	129° 17.000'E
Curlew-1 well:	11° 46.149'	128° 15.900'
Gull-1 well:	11° 56.398'	127° 54.684'
End:	(Heading maintained for approx. 15 km)	

FROM AREA A/B BORDER:

Line 100/05 Shot NNW-SSE Approx. length = 368km (198 n.miles)

Start (A/B border):	11° 13.000'S	127° 32.000'E
Gull-1 well:	11° 56.398'	127° 54.684'
Petrel-1 well:	12° 49.498'	128° 28.518'
Bougainville-1 well:	13° 46.330'	129° 02.576'
End (nominal):	14° 05.000'	129° 14.000'

(Shallow water SSE end re magnetometer, streamer, & turning space)

TO AUSTRALIA/INDONESIA BORDER:

Line 100/06	Shot SE-NW	Approx. length = 534km (288 n.miles)	
	Start:	14° 19.000'S	128° 53.000'E
	End:	10° 33.500'	125° 48.500'

Line 100/07	Shot NE-SW	Approx. length = 220km (119 n.miles)	
	Start:	(Approx. 15 km NE of Gull-1 well)	
	Gull-1 well:	11° 56.398'S	127° 54.684'E
	End:	13° 17.000'	126° 27.000'

'SNIFFER ONLY' LINES#

Line 100/S1	SW-NE	Approx. length run = 161km (89 n.miles)	
	Start (nominal):	14° 19.000'S	128° 11.000'E
	End:	12° 48.000'	129° 41.000'

Line 100/S2	NE-SW	Approx. length run = 188km (103 n.miles)	
	Start:	12° 14.000'S	129° 27.000'E
	End (nominal):	13° 53.000'	127° 48.000'

Notes:

- When crossing the well locations, about 2 streamer lengths (i.e. 9.6 km) were run before adjusting course for the next waypoint.

*** The well locations have been adjusted from the Australian Spheroid used in the Well Completion Reports to the WGS84 Spheroid used on *Rig Seismic*.**

 # Two 'sniffer only' lines, 100/S1 & 100/S2, were run approximately parallel to and midway between Lines 100/01 & 02 and Lines 100/02 & 03, during downtime on the seismic system. The 'actual' start point of 100/S1 and the end point of 100/S2 are close to their intersections with Line 100/06.

Appendix 5: CREW LIST

R. Hardinge	Master
L. Gillies	Mate
M. Gusterson	2nd Mate
R. Thomas	Chief Engineer
T. Ireland	2nd Engineer
W. Hanson	Electrician
R. Johnson	A.B.
T. Dale	A.B.
G. Pretsel	A.B.
P. Hutchinson	E.R.A.
H. Dekker	Chief Steward
W. Leary	Cook (until 24 April)
S. Stavely	Steward
S. O'Rourke	Steward/Seaman
B. Willcox	Co-Chief Scientist
D. Ramsay	Co-Chief Scientist
N. Johnston	Systems Scientist
R. Mohsin	Systems Scientist
J. Bishop	Geochem Scientist
C. Lawson	T.O. Science
J. Kossatz	T.O. Science
D. Pryce	T.O. Science
T. McNamara	T.O. Science
L. Hatch	T.O. Science
P. Vujovic	T.O. Science
C. Tindall	T.O. Science
G. Sparksman	T.O. Science
P. Davis	T.O. Science
L. Miller	T.O. Electronics
C. Saroch	T.O. Electronics
U. Rieke	T.O. Electronics
B. Zygmunt	T.O. Electronics (after 24 April)
R. DeGraaf	T.O. Mechanical
S. Wiggins	T.O. Mechanical
B. Dickinson	Mechanic
D. Sewter	Mechanic
S. Milnes	Mechanic

Appendix 6:
NON-SEIMIC DATA CHANNELS

The following is a list of channel allocations for the non- seismic data acquisition system:

1 - SS.DDD from RTE clock
2 - .HHMMSS from RTE clock
3 - .HHMMSS from master clock
4 - Latitude (rads), best estimate
5 - Longitude (rads), best estimate
6 - Speed (knts), best estimate
7 - Course (degs), best estimate
8 - Magnetometer no. 1
9 - Magnetometer no. 2
10 - Depth no. 1
11 - Depth no. 2
12 - F/A Magnavox sonar-doppler
13 - P/S Magnavox sonar-doppler
14 - F/A Raytheon sonar-doppler
15 - P/S Raytheon sonar-doppler
16 - Paddle log
17 - not used
18 - Instrument room gyro
19 - Bridge gyro
20 - not used
21 - Miniranger range 1
22 - Miniranger range 2
23 - Miniranger range 3
24 - Miniranger range 4
25 - Hifix Fine A
26 - Hifix Fine B
27 - Hifix Fine C
28 - Hifix Coarse A
29 - Hifix Coarse B
30 - Hifix Coarse C
31 - reserved for MPX data
32 - reserved for MPX data
33 - reserved for MPX data
34 - reserved for MPX data
35 - reserved for MPX data
36 - reserved for MPX data
37 - reserved for MPX data
38 - reserved for MPX data

39 - T-SET North std dev (m)
40 - T-SET East std dev (m)
41 - T-SET satellite numbers
42 - T-SET time (GMT seconds)
43 - T-SET Dilution of Precision (DOP)
44 - T-SET latitude (radians)
45 - T-SET longitude (radians)
46 - T-SET height above geoid (metres)
47 - T-SET speed (knots) x 10
48 - T-SET Course (degrees) x 10
49 - T-SET frequency bias
50 - T-SET GMT (.HHMMSS)
51 - Latitude calc. from Mag s.d.
52 - Longitude calc. from Mag s.d.
53 - Speed calc. from Mag s.d.
54 - Course calc. from Mag s.d.
55 - Latitude calc. from Rayth s.d.
56 - Longitude calc. from Rayth s.d.
57 - Speed calc. from Rayth s.d.
58 - Course calc. from Rayth s.d.
59 - Latitude calc. from spare log
60 - Longitude calc. from spare log
61 - Speed calc. from spare log
62 - Course calc. from spare log
63 - Latitude calc. from Radio nav
64 - Longitude calc. from Radio nav
65 - Speed calc. from Radio nav
66 - Course calc. from Radio nav
67 - GMT from MX1107 sat nav
68 - Dead Reckoned Time from 1107
69 - Latitude (radians) 1107
70 - Longitude (radians) 1107
71 - Speed (knots) 1107
72 - Heading (degrees) 1107
73 - GMT from MX1142 sat nav
74 - Dead Reckoned Time from 1142
75 - Latitude (radians) 1142
76 - Longitude (radians) 1142
77 - Speed (knots) 1142
78 - Heading (degrees) 1142
79 - Gravity (mGal * 100)
80 - ACX (m/s/s * 10000)
81 - ACY (m/s/s * 10000)

82 - Sea state
83 - Mag anomaly 1
84 - Mag anomaly 2
85 - Mag difference
86 - Shot time HHMMSSD
87 - Shot point number
88 - Northerly set/drift (radians/10 sec)
89 - Easterly set/drift (radians/10 sec)
90 - Miniranger 1 cumulative drift
91 - Miniranger 2 cumulative drift
92 - Miniranger 3 cumulative drift
93 - Miniranger 4 cumulative drift
94 - HIFIX A cumulative drift
95 - HIFIX B cumulative drift
96 - HIFIX C cumulative drift
97 - HIFIX D cumulative drift
98 - HIFIX E cumulative drift
99 - HIFIX F cumulative drift
100 - Miniranger 1 range 10-sec drift
101 - Miniranger 2 range 10-sec drift
102 - Miniranger 3 range 10-sec drift
103 - Miniranger 4 range 10-sec drift
104 - HIFIX A range 10-sec drift (centilanes)
105 - HIFIX B range 10-sec drift (centilanes)
106 - HIFIX C range 10-sec drift (centilanes)
107 - HIFIX D range 10-sec drift (centilanes)
108 - HIFIX E range 10-sec drift (centilanes)
109 - HIFIX F range 10-sec drift (centilanes)
110 - RACAL dGPS Time (GMT HHMMSS)
111 - RACAL dGPS Latitude (radians)
112 - RACAL dGPS Longitude (radians)
113 - RACAL dGPS Height (10 * m)
114 - RACAL dGPS Course (10 * degs)
115 - RACAL dGPS Speed (10 * knts)
116 - RACAL dGPS Number of satellites
117 - RACAL dGPS PDOP * 10
118 - RACAL dGPS HDOP * 10
119 - RACAL dGPS 3-D Position error (m)
120 - RACAL dGPS 2-D Position error (m)
121 - RACAL dGPS Differential quality (0=No corr,1=bad,9=good)
122 - RACAL dGPS Op mode, Rec mode, Rec Dynamics, Pos qual, Diff quality.

Appendix 7:
WELLS DRILLED IN THE TIMOR SEA

WELL NAME	LATITUDE	LONGITUDE
Allaru 1	12.093406	124.798173
Allaru 1 ST 1	12.093406	124.798173
Allaru 1 ST 2	12.093406	124.798173
Anderdon 1	12.646416	124.796593
Anson 1	12.502971	124.8035
Arunta 1	11.975496	124.951508
Ashmore Reef 1	12.180472	123.086277
Asterias 1	13.152305	124.119998
Augustus 1	11.683611	124.970276
Avocet 1	11.373053	125.755
Avocet 1A	11.372813	125.755001
Avocet 2	11.364093	125.757075
Barcoo 1 (Woodside)	15.343611	120.636721
Barita 1	11.443318	125.728054
Barnett 1	14.530556	129.0611
Barnett 2	14.532361	129.052138
Barnett 3	14.534238	129.050336
Barossa 1	12.020833	124.261111
Bassett 1	13.31111	123.42667
Bassett 1A	13.311583	123.425222
Bedout 1	18.244444	119.389611
Berkley 1	14.004721	127.831111
Berri 1	11.486111	124.563888
Bilyara 1	12.684654	124.505886
Bilyara 1 ST 1	12.684654	124.505886
Birch 1	12.460841	124.495348
Bougainville 1	13.773583	129.04181
Brecknock 1	14.436964	121.6725
Brewster 1	13.91361	123.2595
Brewster 1A	13.913706	123.259511
Brown Gannet 1	12.108056	123.856111
Buccaneer 1	13.616666	124.016666
Buffon 1	13.393869	122.183228
Cambridge 1	14.290431	128.432639
Cartier 1	12.244166	123.940276
Cassini 1	12.146501	124.968138
Cassini 1 ST 1	12.146498	124.968136
Cassini 2	12.148551	124.949416
Casuarina 1	12.052446	125.098658
Caswell 1	14.241306	122.4675

Caswell 2	14.242528	122.469522
Challis 1	12.123753	125.00446
Challis 2	12.121666	125.018333
Challis 2A	12.121286	125.018568
Challis 3	12.115125	125.022888
Challis 4	12.129268	124.995086
Challis 5	12.122263	124.996666
Challis 6	12.109661	125.034593
Challis 7	12.105366	125.040561
Challis 8	12.102161	125.047823
Challis 9	12.1091	125.035398
Challis 10	12.126736	125.017348
Challis 11	12.099143	125.054613
Champagny 1	12.487223	124.312601
Champagny 1 ST 1	12.487223	124.312601
Cockell 1	11.667278	125.039228
Cockell 1 ST 1	11.667278	125.039228
Coonawarra 1	12.080554	124.353333
Crane 1	12.125766	125.628168
Curlew 1	11.770556	128.263888
Cygnet 1	11.896124	125.939031
Darwinia 1	11.441854	127.934766
Darwinia 1A	11.442118	127.934921
Delamere 1	12.000475	125.304193
Delta 1	12.649066	123.970348
Dillon Shoals 1	11.239263	125.446997
Discorbis 1	12.882476	123.812796
Douglas 1	11.795833	124.946388
Drake 1	11.285013	125.835554
Dromana 1	12.274998	124.9125
East Mermaid 1	17.166944	119.822555
East Swan 1	12.301968	124.582249
East Swan 2	12.292674	124.583496
Echuca Shoals 1	13.750342	123.723617
Eclipse 1	12.271388	124.618609
Eclipse 2	12.238423	124.643611
Eider 1	11.389167	125.746389
Evans Shoal 1	10.081523	129.531999
Fagin 1	11.571388	125.137776
Flamingo 1	11.026111	126.481944
Flat Top 1	12.376472	129.265528
Frigate 1	13.18	127.923611
Fulica 1	11.088891	125.875276
Garganey 1	11.356596	125.916388
Garganey 1 ST 1	11.356596	125.916423
Grebe 1	12.451111	124.249444
Gryphaea 1	12.810646	123.739321

Gull 1	11.941389	127.910277
Heron 1	10.440833	128.95139
Heywood 1	13.462683	124.066725
Ibis 1	12.062021	125.346491
Jabiru 1	11.932181	125.005222
Jabiru 1A	11.933561	125.004081
Jabiru 2	11.934864	124.988837
Jabiru 3	11.925583	125.00885
Jabiru 4	11.921625	125.019882
Jabiru 5	11.940204	124.989593
Jabiru 5A	11.939861	124.990171
Jabiru 6	11.930321	125.012855
Jabiru 7	11.920548	125.017303
Jabiru 7 ST 1	11.917991	125.017401
Jabiru 8	11.936518	125.01038
Jabiru 8A	11.936526	125.010388
Jabiru 9	11.951113	124.980398
Jabiru 10	11.922358	125.026016
Jabiru 11	11.942079	124.993308
Jacaranda 1	11.470835	128.16388
Jarrah 1	11.289238	125.70328
Jarrah 1A	11.289333	125.703166
Kalyptea 1	13.032998	123.872388
Kambara 1	16.743011	122.437578
Katers 1	12.675416	124.744416
Keeling 1	12.620538	124.165036
Keraudren 1	18.907592	119.15423
Kimberley 1	12.60288	124.383086
Kinmore 1	14.033614	129.262448
Kite 1	12.067793	126.436761
Lacepede 1	17.088333	121.444721
Lacepede 1A	17.088439	121.444822
Lacrosse 1	14.2975	128.58278
Lagrange 1	18.274361	119.318916
Langhorne 1	11.979638	124.365721
Lesueur 1	13.95264	128.125833
Leveque 1	15.753312	122.004906
Lombardina 1	15.288942	121.537303
Londonderry 1	13.614769	124.51183
Longleat 1	12.563693	124.742111
Lorikeet 1	11.173676	125.617996
Lucas 1	12.260361	124.133804
Lynher 1	15.9401	121.083065
Maple 1	12.019916	124.538716
Matilda 1	14.454828	128.749747
Minilya 1	18.32465	118.732426
Minjin 1	16.802153	122.379092

Montara 1	12.689346	124.531661
Mount Ashmore 1	12.560276	123.20667
Mount Ashmore 1A	12.560276	123.20639
Mount Ashmore 1B	12.560081	123.20781
Nancar 1	10.988741	125.757818
Newby 1	11.835278	129.101944
Nome 1	11.655268	125.221291
North Hibernia 1	11.671953	123.324741
North Scott Reef 1	13.948054	121.974721
North Turtle 1	18.909806	118.087776
Octavius 1	11.847221	124.910555
Oliver 1	11.644801	125.008801
Osprey 1	12.219167	125.22084
Paqualin 1	11.980638	124.5069
Parry 1	12.270646	124.337516
Pascal 1	12.203	124.221898
Pearl 1 (Home Energy)	17.851387	122.02777
Peewit 1	12.656144	126.020894
Pengana 1	11.891433	125.029043
Penguin 1	13.607778	128.468333
Perindi 1	16.828358	122.26314
Petrel 1	12.826389	128.47418
Petrel 1A	12.831112	128.47223
Petrel 2	12.853889	128.51389
Petrel 3	12.935833	128.569498
Petrel 4	12.888441	128.494751
Phoenix 1	18.635292	118.7854
Phoenix 2	18.602193	118.842526
Plover 1	12.7125	126.368611
Plover 2	12.958056	126.174444
Plover 3	12.818156	126.115833
Pokolbin 1	11.519443	124.552776
Pollard 1	11.664721	124.56889
Prion 1	12.404444	124.151944
Prudhoe 1	13.748819	123.864203
Puffin 1	12.308333	124.333611
Puffin 2	12.363056	124.275277
Puffin 3	12.288783	124.35825
Puffin 4	12.292226	124.360668
Rainbow 1	11.937958	124.331913
Rainier 1	12.062463	125.023008
Rob Roy 1	13.971	124.199194
Rowan 1	12.498298	124.393698
Rutherglen 1	11.606943	124.470833
Sahul Shoals 1	11.427221	124.54723
Sandpiper 1	13.314722	127.976388
Scott Reef 1	14.076108	121.824655

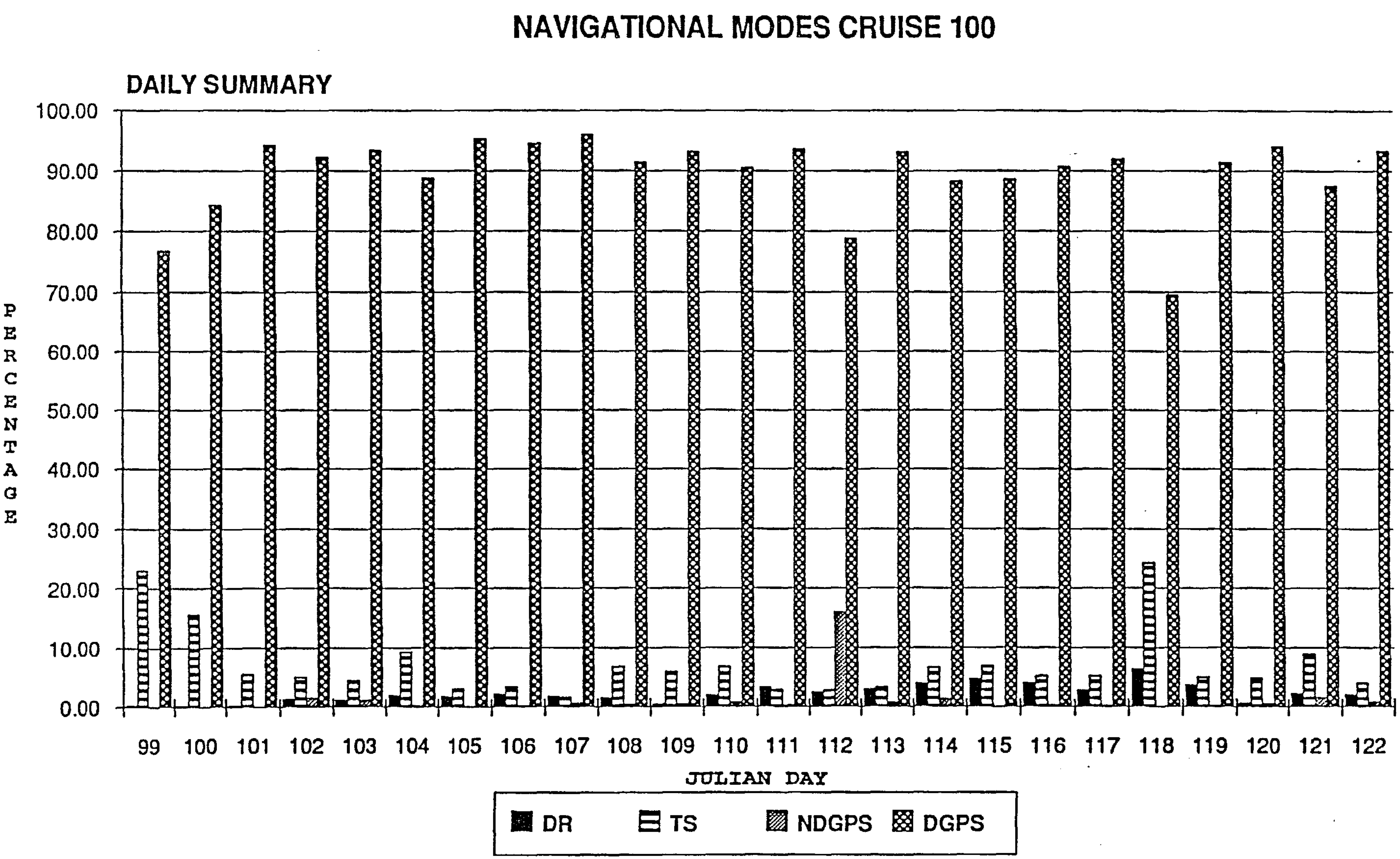
Scott Reef 2	14.101111	121.8575
Scott Reef 2A	14.101575	121.857803
Shearwater 1	10.513611	128.310278
Skua 1	12.505278	124.432777
Skua 2	12.509516	124.404346
Skua 3	12.506121	124.414663
Skua 4	12.493136	124.425766
Skua 5	12.473919	124.443666
Skua 6	12.487743	124.438568
Snowmass 1	11.994708	125.179466
Stork 1	11.491416	125.792638
Sunrise 1	9.590097	128.153789
Swan 1	12.188056	124.492777
Swan 2	12.194727	124.495677
Swift 1	12.537356	124.451507
Tahbilk 1	12.732758	124.503976
Talbot 1	12.453138	124.881616
Talbot 2	12.457133	124.870329
Taltarni 1	12.612863	124.579529
Tamar 1	11.870924	126.211144
Tancred 1	11.734743	125.323429
Tern 1	13.220833	128.064722
Tern 2	13.2789	128.132789
Tern 3	13.336026	128.104471
Troubadour 1	9.734394	128.123753
Turnstone 1	11.736944	125.295833
Turtle 1	14.476608	128.94484
Turtle 2	14.505891	128.945791
Voltaire 1	11.193351	125.331983
Vulcan 1	12.241993	124.549474
Vulcan 1A	12.242261	124.549964
Vulcan 1B	12.242642	124.550339
Wamac 1	17.240517	121.491563
Whimbrel 1	12.482778	125.378055
Willeroo 1	12.027721	124.897891
Woodbine 1	12.645206	124.147072
Yampi 1	14.558888	123.276077
Yarra 1	12.047804	124.360026
Yering 1	12.612888	124.517098

Appendix 8:
NAVIGATION MODE STATISTICS (D. Pryce)

NAVIGATION MODES CRUISE 100

TOTAL MINUTES						PERCENTAGE VALUES			
JULIAN DAY	DR	TS	NON DGPS	DGPS	TOTAL MIN	DR	TS	NDGPS	DGPS
99	3	331		1106	1440	0.21	22.99		76.81
100	2	226		1212	1440	0.14	15.69		84.17
101	3	79		1358	1440	0.21	5.49		94.31
102	19	71	22	1328	1440	1.32	4.93	1.53	92.22
103	16	64	16	1344	1440	1.11	4.44	1.11	93.33
104	28	133	2	1277	1440	1.94	9.24	0.14	88.68
105	25	43		1372	1440	1.74	2.99		95.28
106	30	47	2	1361	1440	2.08	3.26	0.14	94.51
107	25	22	9	1344	1400	1.79	1.57	0.64	96.00
108	22	97	6	1315	1440	1.53	6.74	0.42	91.32
109	7	84	7	1342	1440	0.49	5.83	0.49	93.19
110	28	97	12	1303	1440	1.94	6.74	0.83	90.49
111	48	41	3	1348	1440	3.33	2.85	0.21	93.61
112	35	40	230	1135	1440	2.43	2.78	15.97	78.82
113	42	48	10	1340	1440	2.92	3.33	0.69	93.06
114	56	95	19	1270	1440	3.89	6.60	1.32	88.19
115	67	98		1275	1440	4.65	6.81		88.54
116	58	73	3	1306	1440	4.03	5.07	0.21	90.69
117	40	73	3	1324	1440	2.78	5.07	0.21	91.94
118	91	349		1000	1440	6.32	24.24		69.44
119	53	71	1	1315	1440	3.68	4.93	0.07	91.32
120	9	69	8	1354	1440	0.63	4.79	0.56	94.03
121	31	128	23	1258	1440	2.15	8.89	1.60	87.36
122	29	56	12	1343	1440	2.01	3.89	0.83	93.26

	DR	TS	NDGPS	DGPS
SURVEY TOTALS	2.22	7.05	1.12	89.61


NAVIGATIONAL MODES CRUISE 100
DAILY SUMMARY
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
PERCENTAGE
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
JULIAN DAY
DR
TS
NDGPS
DGPS

NAVIGATIONAL MODES - CRUISE 100