Sahul Shoals processes: Neotectonics and Cainozoic environments: Cruise proposal

by
John Marshall

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AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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Marine Geoscience and Petroleum Geology Program

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SAHUL SHOALS PROCESSES: NEOTECTONICS AND CAINOZOIC ENVIRONMENTS

CRUISE PROPOSAL

Project 121.41

John Marshall

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

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EXECUTIVE SUMMARY

Cruise 122 is intended to investigate the surficial and shallow subsurface geology of the Sahul Shelf of the Timor Sea, in particular, the Sahul Shoals and Cartier Trough, the Lambert Shelf Valley and the Bonaparte Depression. The R.V. *Rig Seismic* will depart Fremantle on 8 October, 1993 and arrive Darwin on 15 November, 1993. The cruise will involve participants from the Department of Geology and Geophysics of the University of Sydney.

The cruise objectives are to examine the structure, seismic stratigraphy, sedimentology and diagenesis of the Tertiary and Quaternary carbonate sequence in the region. It is hoped that this will elucidate both the potential for carbonate reservoirs in the subsurface and the physical and acoustic properties of the carbonates in relation to velocity analysis and reservoir delineation.

A variety of geophysical and geological techniques will be employed to achieve these objectives, including high resolution multichannel seismic reflection profiling, high resolution single channel (boomer) seismic reflection profiling, side scan sonar, dredging, coring, seafloor current meter deployments and underwater photography.

The survey is divided into three areas, with most focus on the Sahul Shoals and Cartier Trough. The two other areas, the Lambert Shelf Valley and Bonaparte Depression, occur within and near Zone B of the ZOC. The survey will not be entering Zone A of the ZOC.

INTRODUCTION

The Timor Sea, located on the north-western margin of Australia (Fig. 1), is one of Australia's most promising hydrocarbon provinces. The region is structurally complex, with a rifting history extending from the Late Devonian to the Late Jurassic. More recently, collision between the Australian and Eurasian plates in the Tertiary has switched the area from a simple passive (divergent) margin to an oblique collisional (convergent) one (O'Brien, 1993). The region consists of a number of sub-basins, platforms and grabens which are often of vastly different age, orientation and structural style..

To help unravel the region's complexities and improve exploration efficiency, AGSO has been carrying out a major research program in the Timor Sea. The major focus of AGSO's study is the acquisition of deep crustal (14 sec TWT) seismic reflection data. So far, up to 10 000 km of deep seismic data has been acquired between 1990 and 1993 within the Timor Sea region. In addition, 20 000 km of aeromagnetic data was acquired in and around the Vulcan Sub-Basin in 1989. A series of high resolution seismic reflection surveys, coupled with direct hydrocarbon detection (sniffing), were carried out in the Vulcan and Petrel Sub-Basins by AGSO in 1990/91. Some 5 000 km of high resolution data was shot during these surveys. AGSO has been building a large data-base of regional gravity and bathymetry/topography data, which has been image-processed and integrated with the results from the deep crustal seismic and aeromagnetic data (O'Brien and others, 1992).

The proposed survey differs from AGSO's other surveys in the Timor Sea in that it is predominantly geological. However, much of the survey is aimed at answering questions that are relevant to the geological development of the area as a whole. Some of the objectives relating to these questions are as follows:

1. What is the potential for the development of carbonate reservoirs in the Timor Sea? The Tertiary sequence is extremely thick in places such as the Cartier Trough. Collisional reactivation has the potential to produce fracture porosity in

carbonate sequences, that in turn could be sealed by fine grained, diagenetically altered limestones.

2. What is the sequence stratigraphy of the Tertiary section of the Vulcan Sub-Basin, particularly the relationship between regional unconformities and sea level change? What effect have these had on carbonate diagenesis and, ultimately, on seismic parameters such as sequence velocities and true depth determination of key horizons?

3. What has been the effect of collisional reactivation since the Miocene on sedimentation and structure in the Sahul region? Are tectonic processes continuing at present, and what is their manifestation?

4. Compared with the Great Barrier Reef of northeastern Australia, the northwest shelf has virtually no coral reefs. However, there are a series of carbonate platforms on the edge of the Sahul Shelf, and the shelf is mantled by tropical carbonates (including ooids). We know that the platforms have been in existence since at least the Miocene. The platforms rise to 20-25 m below sea level. However, with few exceptions, there are no hermatypic corals. What is the major carbonate producer on these platforms? What are the rates etc? The flanks of the platforms are mantled by periplatform oozes, which contain both high resolution sea level and palaeoceanographic signals. The Cartier Trough will contain a lower resolution, but longer record. Are we seeing a Bahamian analogue or a completely new type of carbonate buildup that has significance for petroleum exploration models?

5. The Sahul Shelf is dissected by a number of narrow depressions. The most prominent is the Malita Shelf Valley. They appear to be part of a major subaerial drainage pattern. Some of the valleys drain seawards, but others, including the Malita and the Lambert shelf valleys, drained towards a large topographic depression, the Bonaparte Depression, on the shelf. Other valleys are blind at both ends. How have these valleys formed? What controlled and maintained the

drainage pattern? How old is the Bonaparte Depression, and has it been a region of organic carbon accumulation in the past?

6. What is the history of development of carbonate buildups during the Cainozoic in the Timor Sea, and what is their potential for hydrocarbon accumulation?

Previous Work

The first regional geological survey in the region was undertaken in 1960-61 by van Andel & Veevers (1967), during which sea bottom sediments, morphology and shallow structure were examined on the Sahul Shelf and in the Timor Trough . A similar survey of the North West Shelf was undertaken by Jones (1973). Since then most geological work has been in relation to hydrocarbon exploration, mainly related to the stratigraphy, structure and petroleum potential of the region (e.g. Powell, 1976; Patillo and Nicholls, 1990; O'Brien and others, 1992)

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Geoff O'Brien (AGSO) and Ian Lavering (BRS) kindly provided background material for this report and reviewed the manuscript.

REGIONAL GEOLOGY

Morphology

The Sahul Shelf is an extremely broad, shallow platform, some 300 to 500 km in width. This shelf is atypical of most modern continental shelves in three ways:

(i) there are a series of shelf-edge banks which rise to depths of 20-30 m
(ii) the presence of a number of narrow, but relatively deep valleys
(iii) instead of uniformly increasing in depth from the shoreline, the shelf forms a broad shallow depression

However, while the shelf is unusual in this regard, it does tend to be typical of some ancient shelves, such as those bordering Tethys in the Jurassic.

In places, the banks form a nearly continuous barrier along the shelf edge. Others form a complex of banks that are grouped together. Individual banks can be as small as 1-2 km in diameter, whereas the larger banks are of the order of 10-30 km wide. Some of the larger banks, such as Echo Shoal, appear to be an amalgamation of several smaller banks. The characteristics of the banks have been tabulated by van Andel and Veevers (1967). In general, they are steep-sided (15-20°) and rise from 200-300 m water depth to 20-30 m. The depth of the top of the banks is remarkably uniform and they are typically flat-topped, with very few indications of pinnacles. Other than Ashmore, Cartier and Hibernia Reefs near the southern end of the Sahul Shoals, none of the banks support coral reefs.

The outer part of the shelf is cut by a series of narrow channels. These channels vary in length from about 10 km to over 150 km in the case of the Malita Shelf Valley. While the larger valleys tend to extend across the Sahul Rise from the edge of the shelf to the Bonaparte Depression, many of the smaller channels are "blind" at both ends. The two largest channels are the Malita Shelf Valley and the Lambert Shelf Valley. The Malita Shelf Valley extends from Troubadour Shoal, at the northern end of the Sahul Rise, to the Bonaparte Depression (Fig.1). The Lambert Shelf Valley extends from the shelf edge to the south of Echo Shoal to the Bonaparte Depression. The alignment of the shelf valleys as a whole tends to suggest some form of drainage pattern extending from the Sahul Rise and Van Dieman Rise into the Bonaparte Depression on one hand and to the shelf edge on the other. While van Andel and Veevers (1967) and van der Kaars (1991) have related these channels to subaerial exposure in the Late Pleistocene, the bathymetry suggests that this was not a simple drainage system. The valleys tend to be deeper in the middle than at either end. For example, the Lambert Shelf Valley is at a depth of about 100 m at the ends, but is up to 240 m deep in the middle. The impression is that the valleys are narrower and more incised where they cross the Sahul Rise.

The Bonaparte Depression covers some 15 000 km^2 of the mid shelf. The depression is a relatively gentle downwarp with depths of 100-160 m (av. depth 120 m) in the centre compared to 60-100 m at the margins. According to van Andel and Veevers (1967), the margins are bounded by small stepped scarps. Previous shoreline positions on the Sahul Shelf west of the Van Diemen Rise at 110 to 130 metres below sea level were dated at 18 000 years B.P. (van Andel & Veevers, 1967). At that time most of the shelf was exposed and the carbonate banks on the shelf edge formed a string of islands seaward of the coastline. At this time it is believed that the Bonaparte Depression, formed an estuarine embayment with a depth of up to about 18 to 28 metres. This was connected to the sea by a number of narrow and sinuous channels up to 150 kilometres long and 5 kilometres wide (Lavering, 1993). The orientation of the embayment and size of the channels connecting it with the Timor Sea suggest that only a minor amount of seawater circulation was possible in the Bonaparte Depression. The presence of brackish-water bivalves in the embayment supports such a view (van Andel & Veevers, 1967).

Climate and Oceanography

All of northern Australia's coastal regions are presently subject to a monsoon climate, with a wet season during the austral summer and a dry season from May to October during which the southeast trade winds prevail. Rainfall varies from 720 mm to 1920 mm per year. Mean temperatures in the wet season are in the high 20 to 30's (°C) with high humidity, down to 18 to 20 °C in the dry season (low humidity). Thunderstorms occur on average 85 days per year in Darwin (summer). At sea, the mean average evaporation rate is approximately twice the average annual rainfall (Wyrtki, 1961). The Timor Sea has a mean annual precipitation of 900 mm and a mean annual evaporation of 1716 mm. Tropical cyclones lasting from 12 to 24 hours occur in the period December to April. Wind velocities of 50 to over 90 knots are developed, even as high as 140 knots. Squalls in the dry season rarely last longer than 3 hours and develop winds of 30 to 100 knots (van Andel & Veevers, 1967).

The southeast trade winds can generate moderate to rough seas, the main swell being from the southeast. During much of the monsoon season seas are calm and smooth except for the disturbance caused by tropical cyclones. Swells developed during cyclones come from the southwest, west and northwest.

The Sahul Shelf is one of the world's largest tidally dominated shelf environments (Harris and others, 1991). The shelf is macro tidal between Dampier and Darwin with mean spring tides increasing up to 9 m towards the coast. The tidal currents flow northeast-southwest across the shelf. Surface circulation is driven by the southeasterly trade winds from April to November, and modified somewhat by the northwest monsoon in summer.

Surface Sediments

Surficial sediments on the Sahul Shelf are largely coarse grained, particularly on the rises and the shelf edge banks; the only area of fine grained sediments is restricted to the Bonaparte Depression. Gravel-size components within the sediments consist of relict carbonate nodules, and biogenic components, such as molluscs, *Halimeda*, bryozoans, corals and larger foraminifera. Most of the non-carbonate components are fine-grained The carbonate content of the sediments varies between 15 to 100 percent (van Andel and Veevers, 1967).

Of the 17 variables measured by van Andel and Veevers (1967) for the Sahul Shelf sediments, correlation coefficient measurements of positive and negative covariance found the following groupings between the various major components of the samples:

corals/bryozoans
algae/forams
molluscs/echinoids

Halimeda cluster separately, to the other calcareous algae. The mollusc/echinoid group is dominant in and around the Bonaparte Depression and may be partly a remnant Late Quaternary estuarine assemblage (van Andel & Veevers, 1967). The coral/bryozoan group is present on the banks and rises of the western Sahul Rise and Van Diemen Rise although it is limited to the seaward edge of the major groups of banks. The algal/foraminifera group, together with *Halimeda*, is present only on the tops of the shelf-edge banks and the shoals of the Van Diemen Rise. There is a notable absence of corals on these banks.

Since most of the shelf appears to be covered by relict deposits and there appears to be little modern sedimentation over large areas of the shelf, van Andel and Veevers (1967) concluded that the post-glacial transgression was a significant factor in the distribution pattern of the surficial sediments. In terms of modern sedimentation on the shelf, the effects of tidal currents are strongest on the inner shelf and possibly the tops of the shelf edge banks. Elsewhere, deposition appears to be confined to drift deposits within the shelf valleys and fine-grained accumulation in the Bonaparte Depression.

Tectonic Development

The oldest basin in the Timor Sea is the Petrel Sub-Basin, a NW-trending rift basin located within the Joseph Bonaparte Gulf . This sub-basin was initiated during crustal extension (rifting) in the Late Devonian to Early Carboniferous (Lee and Gunn, 1988; O'Brien and others, 1993) and contains numerous salt diapirs and other salt-related structures. Two large, but undeveloped, gas-condensate accumulations (the Tern and Petrel fields) have been discovered within the Petrel Sub-Basin. Both fields produce from Late Permian sandstones.

Further offshore, the Petrel Sub-Basin is orthogonally overprinted by NE- and ENE-trending tectonic provinces (O'Brien and others, 1993) which traditionally have been related to the rifting and ultimate break-up of Gondwanaland in the Middle Jurassic. One of these provinces is the Malita Graben, an ENE-trending depression which defines the known north-western limit of the Petrel Sub-Basin. The Sahul Platform was structurally positive throughout much of the Late Jurassic, with sediments of this age being thin due to non-deposition and/or erosion (Botten and Wulff, 1990). The south-west margins of both the Sahul Platform and the Malita Graben are defined by the NW-trending Sahul Syncline (Fig. 1). Immediately to the south-west is the Vulcan Sub-Basin, a NE-trending Late Jurassic depocentre which is flanked by two Permo-Triassic blocks, the Londonderry High and the Ashmore Platform (Pattillo & Nicholls, 1990).

AGSO's deep seismic data indicates that the principal crustal extension in the Timor Sea region was not in the Jurassic, as originally believed, but took place prior to the Late

Permian, probably in the Late Carboniferous to Early Permian. This probably occurred during the formation of the Westralian Superbasin (Yeates and others, 1986). While the exact age of the initiation of the Westralian Superbasin is not well-constrained, a number of observations point to a Late Carboniferous age for the initiation of the rift/crustal extension stage (O'Brien, in press).

The post-rift Permo-Triassic sequence was deposited on moderately to highly extended continental crust beneath virtually the whole of the northwest Australian margin. In the Timor Sea region, the rift system is considered to have had an upper plate geometry which developed orthogonally to, and overprinted, the northern part of the older, NW-trending Petrel Sub-Basin rift system (O'Brien and others, 1993). There appears to have been comparatively little crustal-scale deformation since that time. The Jurassic event, which traditionally has been considered the major rifting event in the area, was relatively minor. However, the present day structural disposition of the major tectonic elements within the Timor Sea is essentially the result of reactivation of the basic geometry established during the Westralian Superbasin event during the Mesozoic and Cainozoic.

Low strain reactivation of the deeper architecture during the Mesozoic strongly shaped the structures which are presently being actively explored in the Timor Sea. The Mesozoic reactivation events ranged from compressional (Late Triassic/Early Jurassic; Tithonian-Berriasian) to extensional (Late Callovian-Early Oxfordian). The Late Callovian-Early Oxfordian event, while of small magnitude, was critical because the transtensional reactivation of the older faults produced rapidly subsiding grabens at the same time as eustatic and post-breakup thermal subsidence was producing a relatively rapid rise in sea-level.

The post-rift sequence ranges in age from late Valanginian to Quaternary. This sequence reflects the thermal subsidence phase development of a passive continental margin, with the sequence becoming progressively more marine with time. During the Late Miocene, the northward-moving Australasian plate collided with the Eurasian plate, introducing a compressional regime in the Timor Sea. This collision reactivated many of the earlier faults particularly in the more northerly part of the Vulcan Sub-Basin, where the collisional effects are most pronounced. The collision resulted in the formation of the Cartier Trough and mobilised the Palaeozoic salt which is present within the Paqualin and Swan Grabens (Patillo and Nicholls, 1990).

CRUISE PLAN

The cruise will be broken into three components related to geographic areas (Fig. 2). These areas are:

1. The Sahul Shoals and Cartier Trough
2. The Lambert Shelf Valley
3. The Bonaparte Depression

Most effort will be focussed on Area 1; the other areas will not be covered in any detail (particularly because of the vast distances that would need to be covered), but will concentrate on key sites. It is intended to place current meters at specific sites one metre above the seafloor in order to measure bottom currents and their effect on sedimentation. The intention is to position the current meters on top of the carbonate banks, on the shallow part of the shelf on the Sahul Rise, in the approach to the Lambert Shelf Valley, and in the vicinity of the amphidromic point in the Bonaparte Depression. The intention would be to deploy the current meters at various times during the survey, retrieving them when we move on to a new area. The various tasks to be completed in each area are outlined below:

Area 1 - Sahul Shoals and Cartier Trough

This area covers the outer shelf/upper slope between 11°-12°S and 124°-126°E. The following tasks will be carried out in this area:

- multichannel high resolution seismic reflection profiling (approx. 1000 km)
- shallow high resolution (boomer) profiling (approx. 450 km)
- coring (approx. 40 vibrocores, 10 gravity/piston cores)
- grab sampling (approx. 50 sampling stations)
- dredge sampling (approx. 5 stations)
- underwater camera (approx. 12 stations)

Area 2 - Lambert Shelf Valley

This area occurs very close to the western boundary of the Zone of Cooperation. However, it will not be necessary to enter Zone A, whereas some lines will cross into Zone B. The following tasks will be carried out in this area:

- shallow high resolution (boomer) profiling (approx. 200 km)
- sidescan sonar (approx. 60 km)
- coring (approx. 20 vibrocores)
- grab sampling (approx. 30 stations)
- underwater camera (approx. 6 stations)

Area 3 - Bonaparte Depression

The intention here is to run a transect across the depression from about 12° 00'S, 127° 05'E to 11° 30'S, 128° 15'E. The following tasks will be carried out in this area:

- coring (approx. 10 vibrocores)
- grab sampling (approx. 10 stations)

If time permits, some boomer and sidescan will be attempted.

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APPENDIX 1

General Details:-Research Vessel *Rig Seismic*

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

Gross Registered Tonnage:	1545 tonnes
Length, overall:	72.5 m
Breadth:	13.8 m
Draft:	6.0 m

Engines:	Main: Norma KVMB-12	2640 HP/825 rpm
	Aux: 3x Caterpillar	564 HP/482 KVA
	1x Mercedes	78 HP/56 KVA
	Shaft generator:	AVK 1000KVA; 440 V/60 Hz
Side Thrusters:		2 forward, 1 aft, each 600 HP
Helicopter Deck:		20 m diameter
Accommodation:		36 single cabins 3 double cabins

APPENDIX 2

Scientific Equipment

GEOPHYSICAL SCIENTIFIC EQUIPMENT

NON-SEISMIC SYSTEMS

General
Raytheon echo sounders: 3.5 Khz (2 KW) and 12 Khz (2 KW)
Geometrics G801/803 magnetometer/gradiometer
Bodenseewerk Geosystem KSS-31 marine gravity meter

Navigation
Differential GPS System - 2 Trimble model 4000DL receivers
MX100 Magnavox GPS receiver
Magnavox MX 610D and Raytheon DSN 450 dual axis sonar dopplers
Arma Brown and Robertson gyro-compasses; plus Ben paddle log

SEISMIC SYSTEM

Seismic cable:
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
Oil blocks to reduce low frequency noise
6.25, 12.5, (18.75), and 25.0 metre groups available
288 seismic channels, 12 auxiliary channels

Energy Source:
SSI GI gun array, allowing for single or multiple (up to 5) configuration
Gun depths 3 to 5 metres, spacing 2.5 metres
16 x 150 cu.in. HGS sleeve gun array (2 arrays)
Gun depths 5 to 15 metres, spacing 0.5 metres
Gun groups separated by 2.5 metres
Various gun groupings available
Configured as 6, 5, 3, and 2-gun groups
Usually fired as 4, 3, 2, and 1-gun groups
Compressor capacity 1200 scfm nominal at 2000 psi

RecordingParameters:
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 4, 8, 16, and 32 Hertz at 18 dB/octave
HC filters 90, 180, 360 and 720 Hertz at 140 dB/octave
Sampling rates of 0.5, 1, 2, and 4 millisecs
Record lengths from 2 secs to 20 secs
SEG-Y recording format with extension
IFP operating at 200 khz with special floating point format
Data recorded as 4-bit binary exponent and 12-bit mantissa

SEISMIC SYSTEM CONFIGURATION FOR HIGH RESOLUTION PROGRAM

Source
SSI GI gun array
2000 psi air pressure
gun spacing 2.5 metres
gun depth 3 to 5 metres.

Streamer
Fjord Instruments transformerless.
10 Teledyne T-l hydrophones per 6.25m group.
1200 m cable, 144 seismic channels,
group interval 6.25 m.
depth 5m nominal.

Field Data
8 hz - 360 hz passband
1 ms blocked multiplexed
up to 3 sec record length
nominal 4.85 second shot rate
shot interval 12.5m for 36 fold CDP coverage
Shot-to-group 1 offset : 100 m if achievable

Seismic data supplied in SEG-Y format, special floating point format, 4 bit binary exponent, 12 bit mantissa. Conversion routinessupplied.

GEOLOGICAL SCIENTIFIC EQUIPMENT

Australian Winch and Haulage deep-sea winch with 10 000 m of 18 mm wire rope
Australian Winch and Haulage hydrographic winch with 4000 m of 6 mm wire rope
Gravity/piston corer, 1000 kg weight stand, 5-15 m barrel length, 90 mm core diameter
Palaeomagnetic corer, 1000 kg weight stand, 6-9 m barrel length, 50 mm core diameter
Submersible Services (Ausat.) vibrocorer, 3-6 m barrel, 75 mm core diameter
Van Veen-type grab samplers, capacity 20 litre
Pipe dredges
Chain bag rock dredges

Aanderaa RCM-4 and RCM-7 model self-recording current meters
Yeo-Kal submersible data logger, temp. salinity, dissolvedO_2, pH and turbidity
Benthos deep sea camera and flash
EG&G Uniboom deep tow single channel boomer (modified with ORE-type plate)
ORE boomer with Benthos single channel hydrophone streamer
EG&G. model 990 side scan sonar with 1000 m coaxial cable

APPENDIX 3

Wells Drilled in the Timor Sea

WELL NAME	LATITUDE (oS)	LONGITUDE (oE)	WATER DEPTH (m)
Allaru 1	12.093406	124.798173	-125
Allaru 1	12.093406	124.798173	-125
Allaru 1	12.093406	124.798173	-125
Anderdon 1	12.646416	124.796593	-97
Anson 1	12.502971	124.8035	-99
Arunta 1	11.975496	124.951508	-122
Ashmore Reef 1	12.180472	123.086277	-39
Asterias 1	13.152305	124.119998	-194
Avocet 1	11.373053	125.755	-105
Avocet 1A	11.372813	125.755068	-105
Avocet 2	11.364093	125.757075	-106
Barita 1	11.443318	125.728188	-94
Bassett 1	13.31111	123.42667	-372
Bassett 1A	13.311583	123.425222	-372
Bilyara 1	12.684654	124.505886	-82
Bilyara 1 ST1	12.684654	124.505886	-82
Birch 1	12.460841	124.495348	-87
Brewster 1	13.91361	123.2589	-256
Brewster 1A	13.913706	123.259511	-256
Brown Gannet 1	12.108056	123.856111	-110
Browse Island 1	14.112555	123.549193	2.9
Buccaneer 1	13.616666	124.016666	-149
Cartier 1	12.244166	123.940276	-100
Cassini 1	12.146501	124.968138	-116
Cassini 1	12.146498	124.968136	-116
Cassini 2	12.148551	124.949416	-113
Casuarina 1	12.052446	125.098658	-95
Challis 1	12.123753	125.00446	-108.2
Challis 2	12.121666	125.018333	-98
Challis 2A	12.121286	125.018568	-105
Challis 3	12.115125	125.022888	-102
Challis 4	12.129268	124.995086	-108
Challis 5	12.122263	124.996666	-107.3
Challis 6	12.109661	125.034593	-99
Challis 7	12.105366	125.040561	-104
Challis 8	12.102161	125.047823	-103
Challis 9	12.1091	125.035398	-100
Challis 10	12.126736	125.017348	-98
Challis 11	12.099143	125.054613	-101

Champagny 1	12.487223	124.312601	-70
Cockell 1	11.667278	125.039228	-265.5
Cockell 1ST1	11.667278	125.039228	-265.5
Crane 1	12.125766	125.628168	-78
Cygnet 1	11.896123	125.939029	-80
Delamere 1	12.000475	125.304193	
Delta 1	12.649066	123.970348	-205
Dillon Shoals 1	11.239264	125.446997	-125
Discorbis 1	12.882476	123.812796	-199
Drake 1	11.285013	125.835438	-103
Dromana 1	12.274998	124.9125	-96
East Swan 1	12.301968	124.582249	-103
East Swan 2	12.292674	124.583496	-104
Echuca Shoals 1	13.750342	123.723617	-194
Eclipse 1	12.271388	124.618609	-109
Eclipse 2	12.238423	124.643611	-109
Eider 1	11.389167	125.746389	-100
Fagin 1	11.571388	125.137776	
Flamingo 1	11.026111	126.481944	-96
Fulica 1	11.088891	125.875183	-136
Garganey 1	11.356651	125.91643	-100
Grebe 1	12.451111	124.249444	-69
Gryphaea 1	12.810646	123.739321	-200
Heywood 1	13.462683	124.066725	-35
Ibis 1	12.062021	125.346491	-95
Jabiru 1	11.932181	125.005222	-120
Jabiru 1A	11.933561	125.004081	-120
Jabiru 2	11.934864	124.988837	-118
Jabiru 3	11.925583	125.00885	-115
Jabiru 4	11.921625	125.019882	-119
Jabiru 5	11.940204	124.989593	-120
Jabiru 5A	11.939861	124.990171	-120
Jabiru 6	11.930321	125.012855	-118
Jabiru 7	11.920548	125.017303	-119
Jabiru 7 ST1	11.917991	125.017401	-119
Jabiru 8	11.936518	125.01038	-118
Jabiru 8A	11.936526	125.010388	-118
Jabiru 9	11.951113	124.980398	-118
Jabiru 10	11.922358	125.026016	-118
Jabiru 11	11.942079	124.993308	-118
Jarrah 1	11.289238	125.70328	-108
Jarrah 1A	11.289333	125.703166	-108
Kalyptea 1	13.032998	123.872388	-214
Katers 1	12.675416	124.744416	-90
Keeling 1	12.620576	124.165043	-189
Kite 1	12.067793	126.436761	
Londonderry 1	13.614769	124.51183	-90
Lorikeet 1	11.173676	125.617996	-108
Lucas 1	12.260361	124.133804	-90

Maple 1	12.019916	124.538716	-125
Montara 1	12.689346	124.531661	-85.1
Mount Ashmore 1	12.560276	123.20667	-623
Mount Ashmore 1A	12.560276	123.20639	-623
Mount Ashmore 1B	12.560081	123.20781	-623
Nancar 1	10.988741	125.757818	
Nome 1	11.655268	125.221291	-122
North Hibernia 1	11.671953	123.324741	-33
Octavius 1	11.847221	124.910555	-155
Oliver 1	11.644804	125.008801	-305
Osprey 1	12.219167	125.22084	-101
Paqualin 1	11.980638	124.5069	-125
Parry 1	12.270646	124.337516	-96
Pascal 1	12.203	124.221898	-100
Peewit 1	12.656144	126.020894	-85.8
Pengana 1	11.891433	125.029043	-117
Plover 1	12.7125	126.368611	-58
Plover 2	12.958056	126.174444	-59
Plover 3	12.818156	126.115833	-74.7
Pollard 1	11.664444	124.56889	
Prion 1	12.404444	124.151944	-70
Prudhoe 1	13.748819	123.864203	-175
Puffin 1	12.308333	124.333611	-102
Puffin 2	12.363056	124.275277	-78
Puffin 3	12.288783	124.35825	-98
Puffin 4	12.292226	124.360668	-98
Rainbow 1	11.937958	124.331913	-135
Rainier 1	12.062463	125.023008	-110
Rob Roy 1	13.971	124.199194	-112
Rowan 1	12.498298	124.393698	-300
Sahul Shoals 1	11.426667	124.54723	-28
Skua 1	12.505278	124.432777	-80
Skua 2	12.509516	124.404346	-81.7
Skua 3	12.506121	124.414663	-78.5
Skua 4	12.493136	124.425766	-81
Skua 5	12.473918	124.443666	-85
Skua 6	12.487498	124.438498	-82
Snowmass 1	11.994708	125.179466	-112
Swan 1	12.188056	124.492777	-109
Swan 2	12.194727	124.495677	-108
Swift 1	12.537356	124.451507	-81
Talbot 1	12.453138	124.881616	-111
Talbot 2	12.457133	124.870329	-103
Taltarni 1	12.612863	124.579529	-76
Tamar 1	11.870924	126.211144	-64
Tancred 1	11.734743	125.323429	-108
Turnstone 1	11.736944	125.295833	-118
Voltaire 1	11.193351	125.331983	-331
Vulcan 1	12.241993	124.549474	-108

Vulcan 1A	12.242261	124.549964	-108
Vulcan 1B	12.242642	124.550339	-109
Whimbrel 1	12.482778	125.378055	-77
Willeroo 1	12.027721	124.897891	-114
Woodbine 1	12.645206	124.147072	-189
Yering 1	12.612888	124.517098	

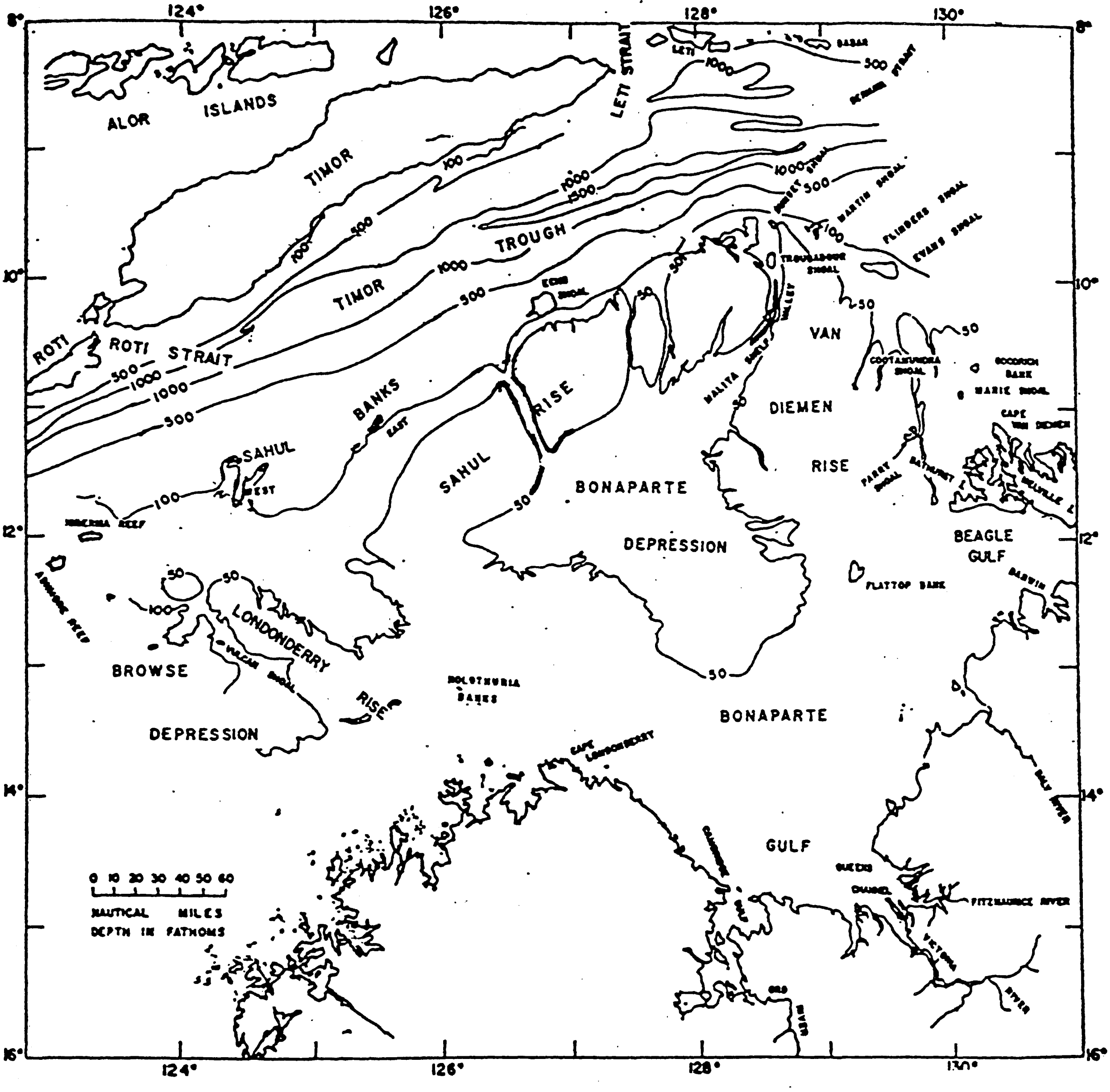

Figure 1. Map of the Timor Sea showing the major physiographic provinces (after van Andel and Veevers, 1967)

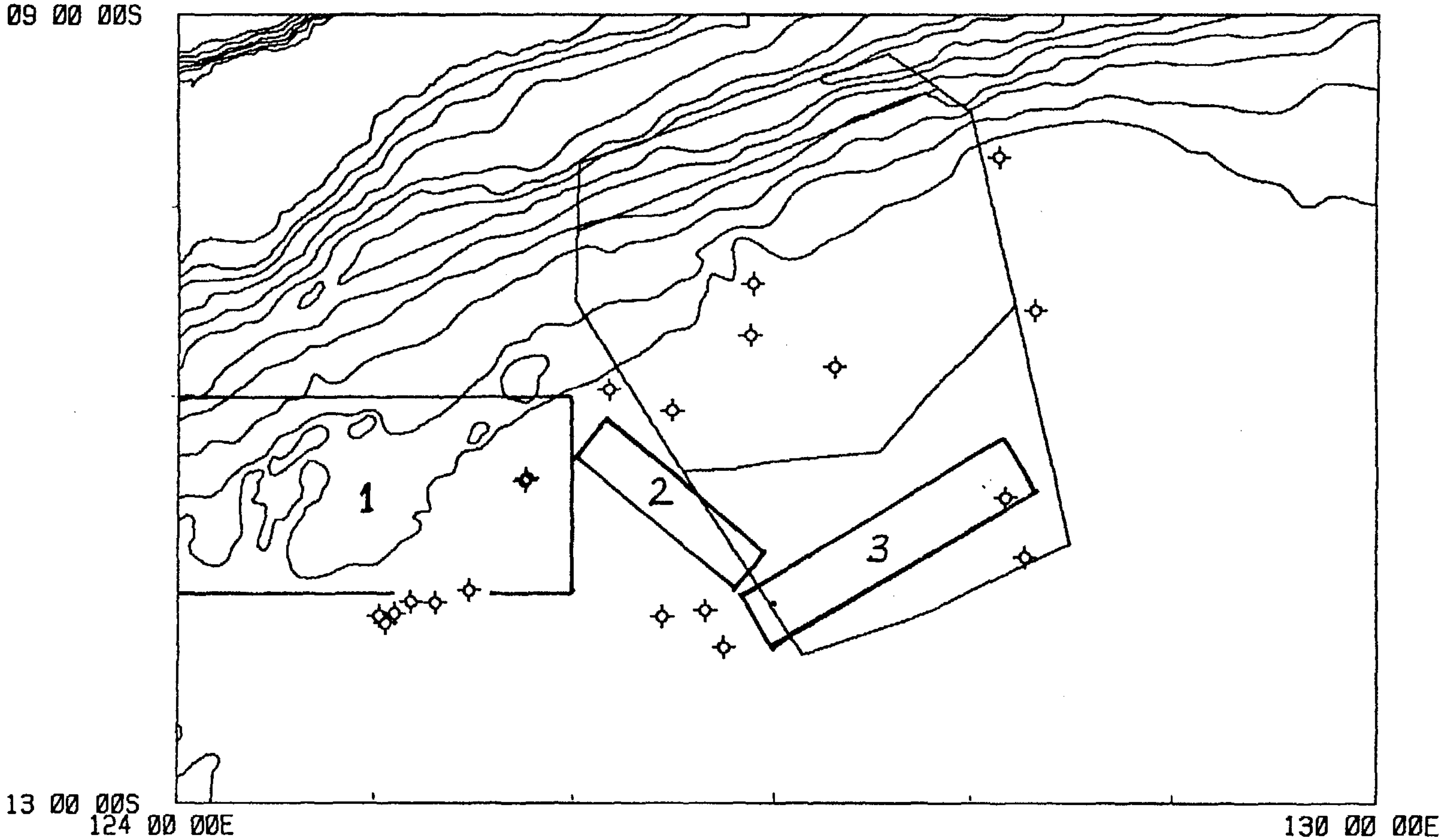

Figure 2. Map showing the general locations of Areas 1, 2 and 3, and their proximity to the Zone of Cooperation (ZOC)