AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

APIRA
AUSTRALIAN PETROLEUM SYSTEMS

BARROW-EXMOUTH SUB-BASINS MODULE

Volume 1

by
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with
scientific and technical contributions from
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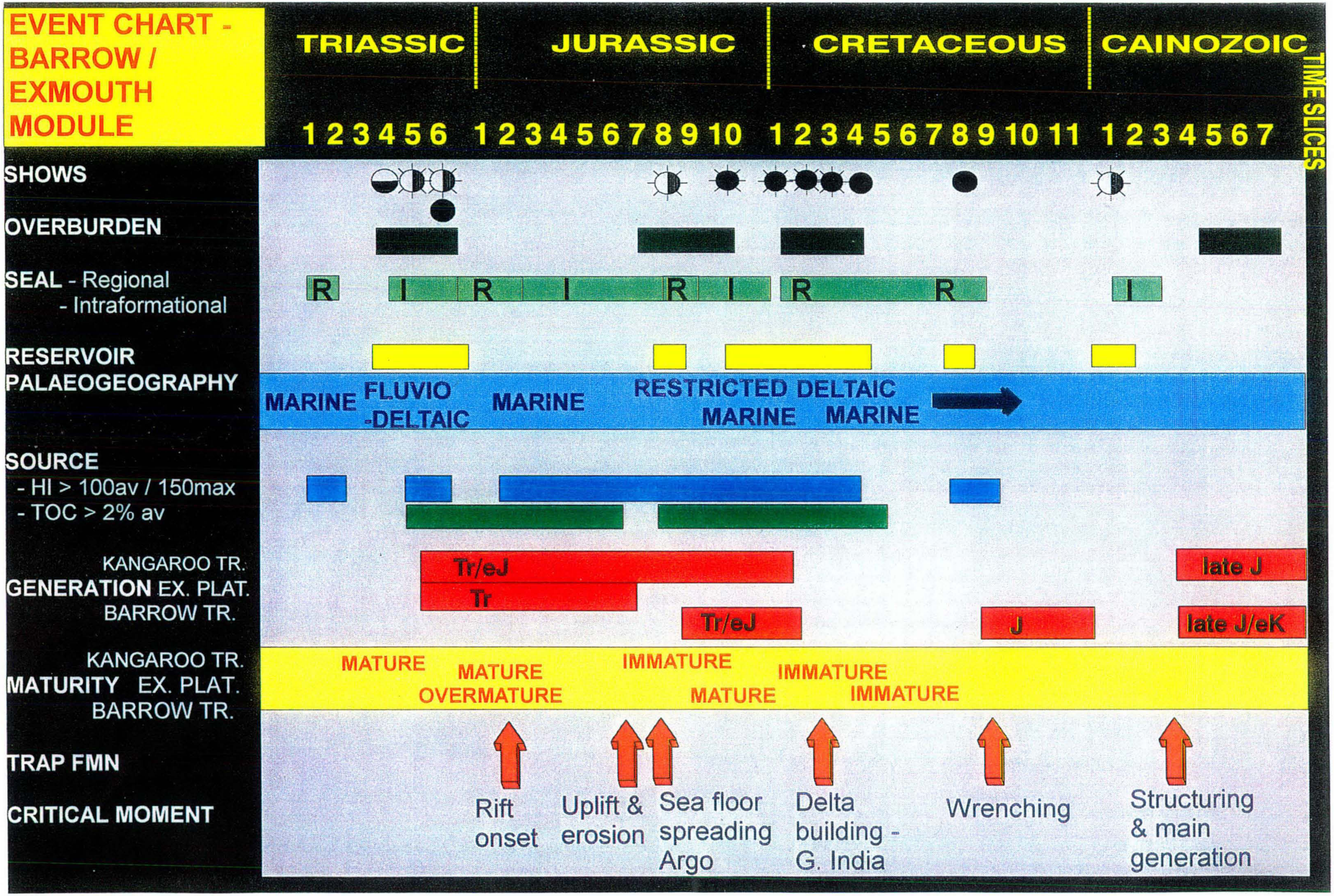
EVENT CHART - BARROW / EXMOUTH MODULE
TRIASSIC
JURASSIC
CRETACEOUS
CAINOZOIC
TIME SLICES
1 2 3 4 5 6
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10 11
1 2 3 4 5 6 7
SHOWS
OVERBURDEN
SEAL - Regional
- Intraformational
R
I
RESERVOIR
PALAEOGEOGRAPHY
MARINE
FLUVIO -DELTAIC
MARINE
RESTRICTED MARINE
DELTAIC MARINE
SOURCE
- HI > 100av / 150max
- TOC > 2% av
KANGAROO TR.
GENERATION EX. PLAT.
BARROW TR.
Tr/eJ
Tr
Tr/eJ
J
late J
late J/eK
KANGAROO TR.
MATURITY EX. PLAT.
BARROW TR.
MATURE
MATURE
OVERMATURE
IMMATURE
MATURE
IMMATURE
IMMATURE
TRAP FMN
CRITICAL MOMENT
Rift onset
Uplift & erosion
Sea floor spreading Argo
Delta building - G. India
Wrenching
Structuring & main generation

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ENCLOSURES

Enclosures 1 - 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, and 50 are missing from the hardcopy of Record 1994/19.

ENCLOSURE 20:
TIME SLICE TR6 : TIME SLICE DATA MAP.

ENCLOSURE 21:
TIME SLICE TR6 : PALÆOGEOGRAPHIC INTERPRETATION MAP.

ENCLOSURE 22:
TIME SLICE J1 : TIME SLICE DATA MAP.

ENCLOSURE 23:
TIME SLICE J1 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 24:
TIME SLICE J2 : TIME SLICE DATA MAP

ENCLOSURE 25:
TIME SLICE J2 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 26:
TIME SLICE J3 TO J6 : TIME SLICE DATA MAP

ENCLOSURE 27:
TIME SLICE J3 TO J6 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 28:
TIME SLICE J7 : TIME SLICE DATA MAP

ENCLOSURE 29:
TIME SLICE J7 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 30:
TIME SLICE J8 : TIME SLICE DATA MAP

ENCLOSURE 31:
TIME SLICE J8 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 32:
TIME SLICE J9 : TIME SLICE DATA MAP

ENCLOSURE 33:
TIME SLICE J9 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 34:
TIME SLICE J10 : TIME SLICE DATA MAP

ENCLOSURE 35:
TIME SLICE J10 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 36:
TIME SLICE K1 : TIME SLICE DATA MAP

ENCLOSURE 37:
TIME SLICE K1 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 38:
TIME SLICE K2 : TIME SLICE DATA MAP

ENCLOSURE 39:
TIME SLICE K2 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 40
TIME SLICE K3 : TIME SLICE DATA MAP

ENCLOSURE 41
TIME SLICE K3 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 42:
TIME SLICE K4 : TIME SLICE DATA MAP

ENCLOSURE 43
TIME SLICE K4 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 44
TIME SLICE K5 - K7: TIME SLICE DATA MAP

ENCLOSURE 45
TIME SLICE K5 - K7 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 46
TIME SLICE K8 : TIME SLICE DATA MAP

ENCLOSURE 47
TIME SLICE K8 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 48
TIME SLICE K9 : TIME SLICE DATA MAP

ENCLOSURE 49
TIME SLICE K9 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 50
TIME SLICE K10 : TIME SLICE DATA MAP

ENCLOSURE 51
TIME SLICE K10 : PALÆOGEOGRAPHIC INTERPRETATION MAP

ENCLOSURE 52
TIME SLICE Cz1-Cz7: SIMPLIFIED ISOPACH MAP

APPENDICES

APPENDIX 1:
STRATDAT DATABASE

APPENDIX 2:
AGE/DEPTH PLOTS

APPENDIX 3:
POROSITY DATABASE

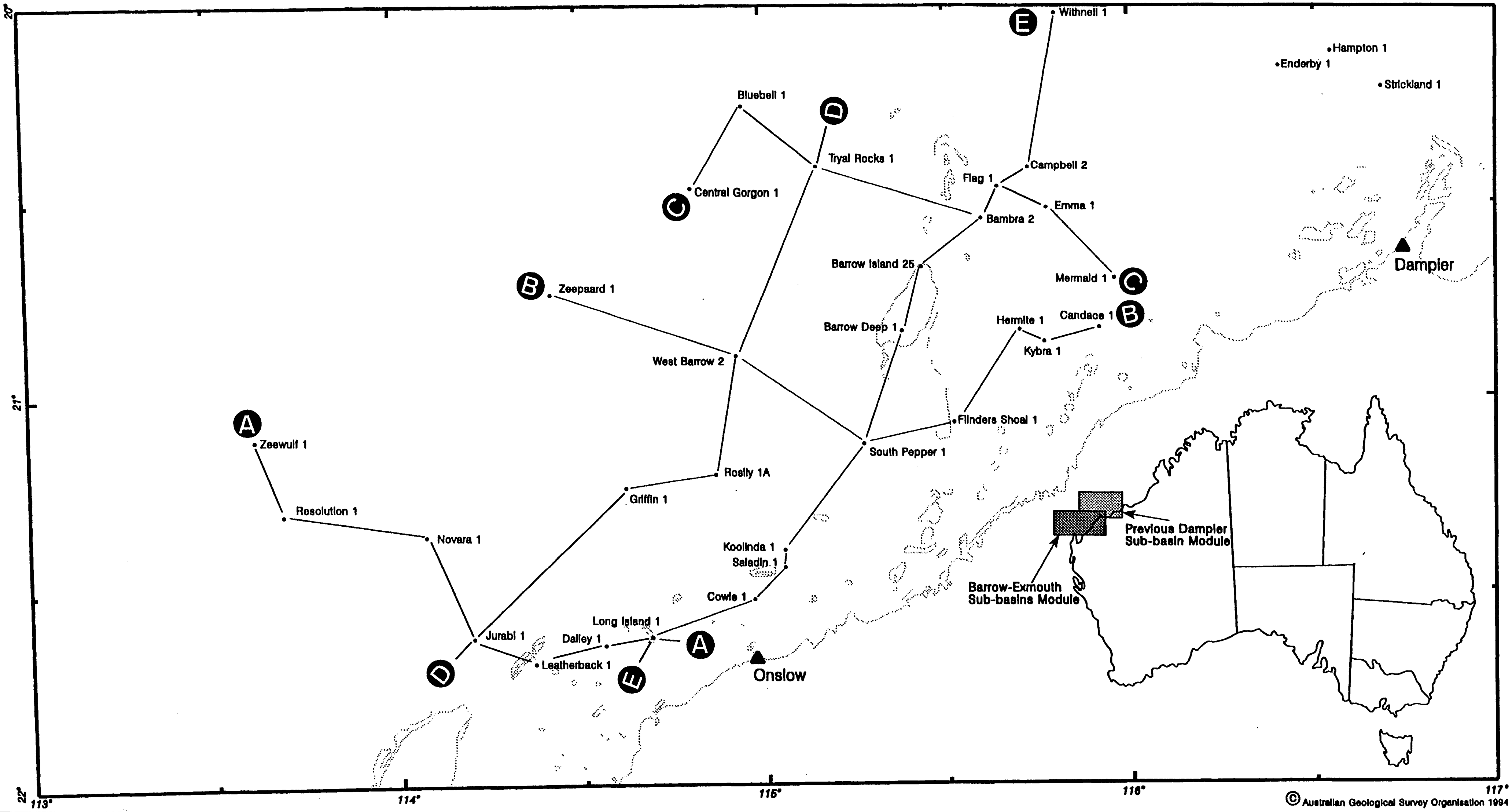
APPENDIX 4:
PERMEABILITY DATABASE

APPENDIX 5:
HYDROCARBON SHOWS DATABASE

APPENDIX 6:
GEOCHEMISTRY DATABASE SUMMARY MAPS
- TOC DATA MAPS
- VITRINITE REFLECTANCE DATA MAPS
- HYDROGEN INDEX DATA MAPS
- S2 -(Potential Generation-Kilograms Hydrocarbon/Tonne) MAPS

APPENDIX 7:
PALÆOENVIRONMENTAL DATABASE

NB: THESE APPENDICES HAVE BEEN COMPILED INTO VOLUME 2 - AND ARE AVAILABLE AS DIGITAL DATABASES IN BOTH SPREADSHEET AND RELATIONAL (ORACLE) FORMAT.



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Module & Cross Sections Location Diagram.

Figure 1

Australian Petroleum Systems Project 1994: EXMOUTH-BARROW SUB-BASIN MODULE

INTRODUCTION

PURPOSE

The project aim is to apply the time slice palæogeographic concept to the Barrow-Exmouth Sub-basins area. The time slice concept was developed in, and is based on the work of the BMR-APIRA Palæogeographic Maps and Phanerozoic History Projects. For each time slice defined palæogeographic interpretation, the project has examined the controls on source, seal, reservoir distribution, structural and potential maturation history. The analysis is based on information from 29 wells and examination of approximately 1500 km of seismic line data. Results are presented as time slice data and palæogeographic interpretation maps, regional well log cross sections and summary tabulations.

ACKNOWLEDGMENTS

In the preparation of this report and the accompanying enclosures, significant time and effort was contributed by members of the Australian Petroleum Systems Group and others within AGSO. Without their help, the project would have been less extensive.

Lynton Spencer and John Needham are the senior authors of this report and were mainly responsible for the geological and geophysical interpretation respectively. In conjunction with other members of the Group, the senior authors have been involved in most of the other aspects of the study.

John Bradshaw is the manager and coordinator of the Australian Petroleum Systems Group. He was responsible for the organisation of geological and geophysical information for the project study and producing various output from the STRATDAT, RESFACS and ORGCHEM databases for analysis. Based on his experience in the previous Projects, John has provided valuable technical information and assistance to the Stage III Project.

Marita Bradshaw, based on her experience in the previous Palæogeographic Map Projects, synthesised the results of the Barrow-Exmouth Sub-basin analysis into a petroleum system framework and wrote much of the sections on petroleum systems concepts. She also provided valuable technical information and editing assistance.

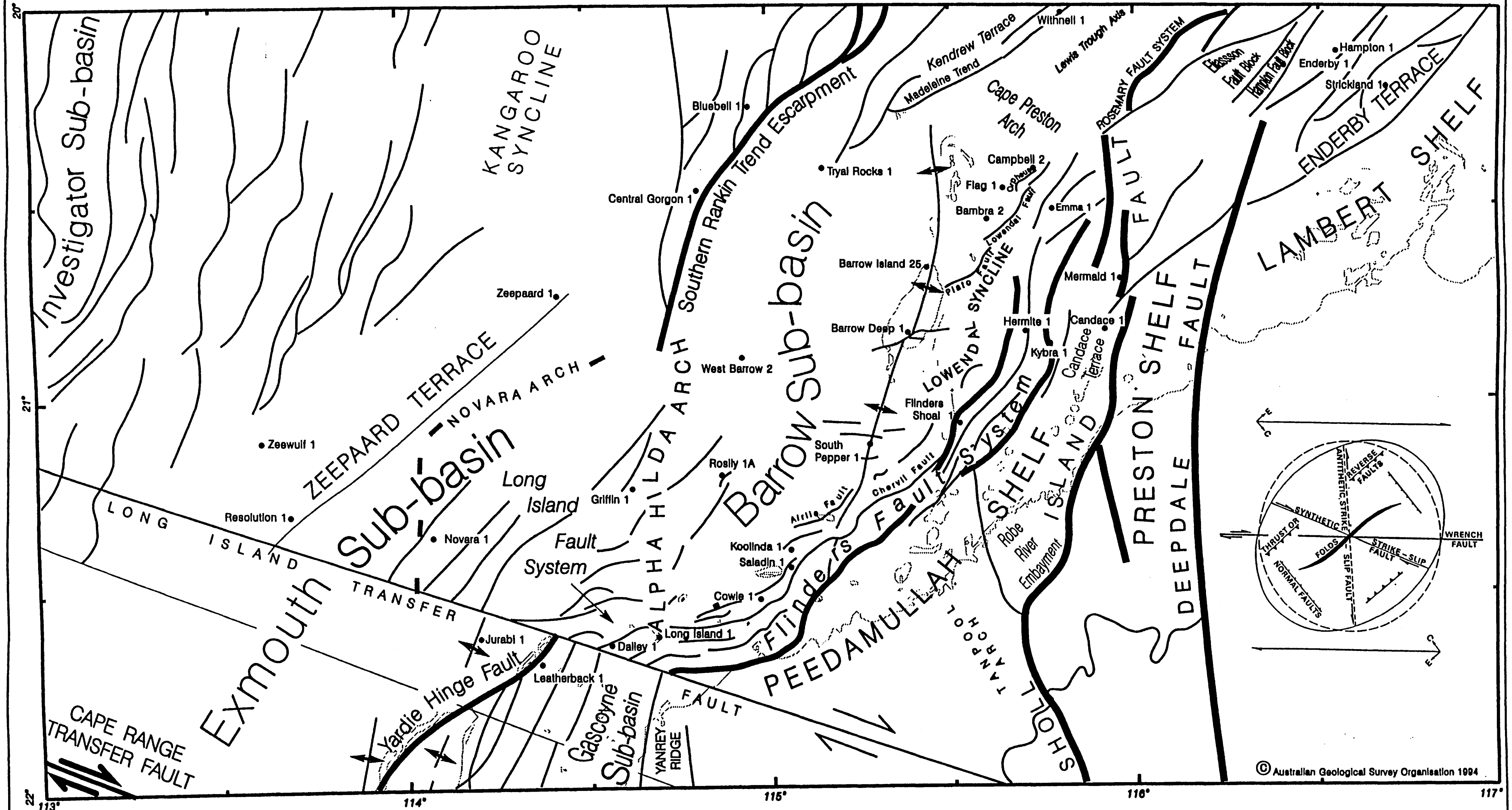
Clinton Foster was involved with the organisation of the STRATDAT database and contributed towards the analysis of the biostratigraphic data that was synthesised by consultant Alan Partridge.

Technical support was provided by Scott Edgecombe, John Noonan and Giuliana Zuccaro. This ranged from data collation to writing software programs to generating the various products.

Others who provided technical and scientific assistance include; Chris Johnston who granted permission for the use of AGSO seismic lines; Howard Stagg who gave an overview of the deep regional structural framework of the Barrow-Exmouth Sub-basin based on AGSO deep seismic lines. John Wilmot and Steve Winn were colleagues who worked on the Papuan Basin Module, they provided the introductory sections on methodology and time slice data used in this report. Andrew Murray provided assistance with geochemical interpretation of the data. Bob Nicoll provided help with the explanations of the dating of the early Carnarvon Basin sediments.

BASIN DEFINITION

The Barrow-Exmouth Sub-basins lie offshore at the northern extremity of the Northern Carnarvon Basin on Australia's North West Shelf. These Sub-basins share a common depositional history with the Dampier Sub-basin. Together the three Sub-basins form one tectonostratigraphic entity, a result of the Jurassic to Cretaceous two stage breakup of Gondwanaland into Greater India and Australia along the Westralian margin (Kopsen & McGann, 1985). The basins commenced development during the earliest Jurassic (Sinemurian - Pliensbachian) with major tectonic peaks during early Callovian to early Oxfordian and fault reactivation during mid Kimmeridgian and Tithonian times. The separation of Greater India along the Cape Range Fracture Zone commenced during earliest Cretaceous and by late Cretaceous the Westralian Margin had entered a passive continental margin sag phase. **The location of the area of the module, the cross-section locations and the location of the adjacent earlier Dampier Sub-basin module is shown on Figure 1.**



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Regional Tectonic Elements Map

Figure 2

DAMPIER SUB-BASIN MODULE OVERLAP

The wells, Withnell 1, Strickland 1, Hampton 1 and Enderby 1 are common control points between this module and the earlier Dampier Sub-basin module. They are additional to the twenty nine wells used in this study and for the most part are not refered to in the text. For a discussion of these wells see the Dampier Sub-basin module. The overlap aided in combining the palæoenvironmental interpretations of the Dampier Sub-basin module with the interpretations for the current Barrow-Exmouth Sub-basin module. To facilitate a comparison between the Dampier Sub-basin and the Exmouth- Barrow Sub-basins a brief summary of the Dampier Sub-basin module results is included within each Time Slice section of this report.

WELL LOG CROSS-SECTIONS AT 1:5000 & 1:7500 SCALE

The main cross-section set is generated at a scale of 1:7500 (see Enclosures 4 to 8). Practical limitations on plotter paper width and plot scale meant that it was difficult to provide full well depth cross-sections at the same vertical scale as those created for the Dampier Sub-basin module. To overcome this problem a second set of cross-sections, that did not include the Cainozoic section, were constructed at 1:5000 scale and datumed on the top of Time Slice K3 (see Enclosures 9 to 13). These can be directly compared with the Dampier Sub-basin module set that are at this scale.

NOTES ON TIME SLICE DEFINITION AND BOUNDARIES

The biostratigraphic schemes used in this study are the:

- Integrated dinoflagellate and spore-pollen zonation of the Australian Mesozoic developed by Helby et al (1987).
- Foraminiferal zonation for the North West Shelf (Wright, 1977; Heath & Apthorpe,1981,1984; Apthorpe, 1988).
- Foraminiferal zonation for the Cainozoic (Blow, 1969, 1979; Berggren, 1969; Kennett & Srinivasan, 1983).
- Australian Phanerozoic Timescales Volume 1 - 10 (Shergold, 1989; Webby & Nicoll, 1989; Strusz, 1989; Young, 1989; Jones, 1989; Archibold & Dickens, 1989; Balme, 1989; Burger, 1989a; Burger, 1989b; Truswell et al, 1989).

These schemes are referenced to the Harland 1982 Time Scale (Harland et al, 1982).

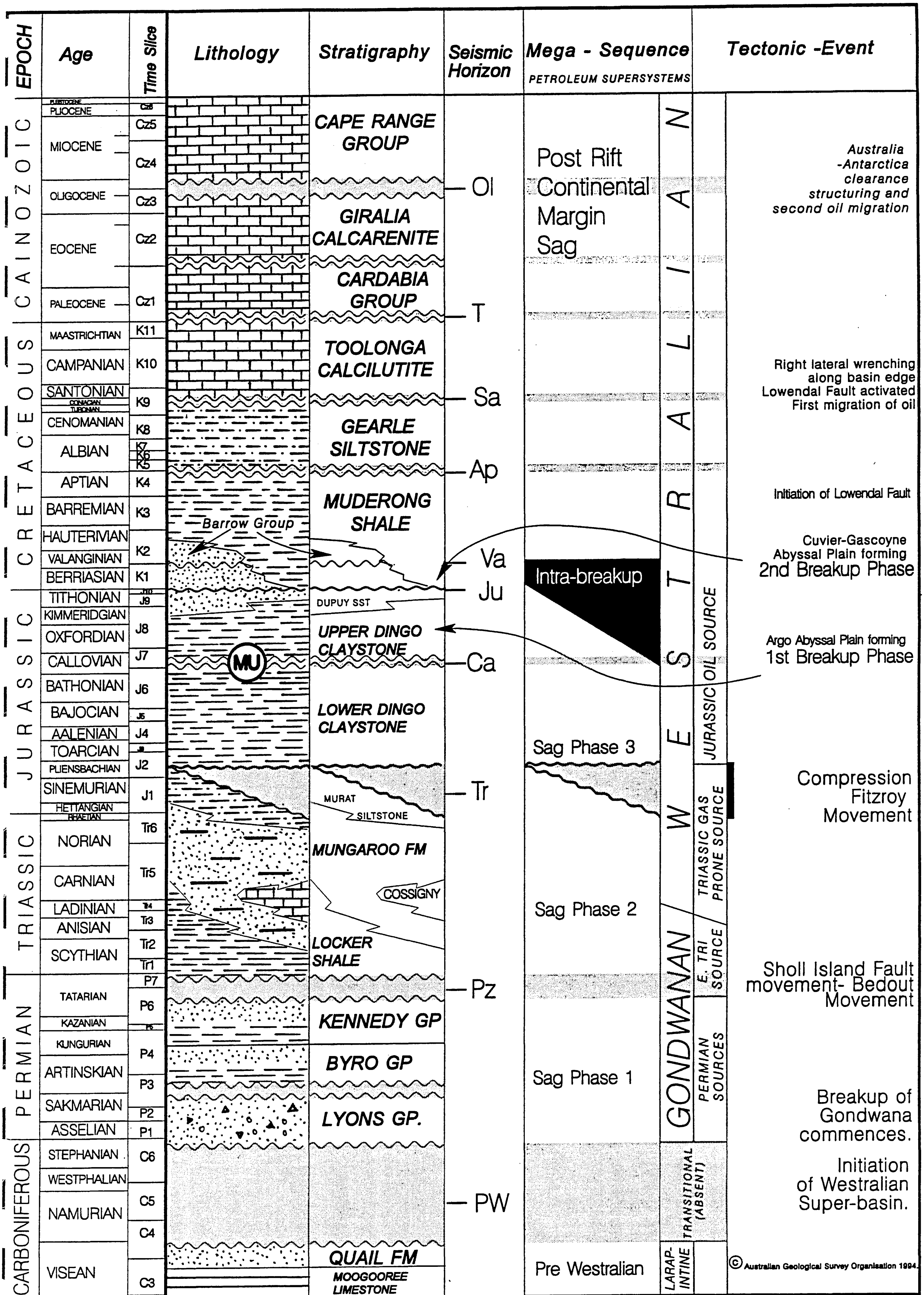
The time slice boundaries occur at natural breaks in sedimentation or changes in facies that are common to several basins. Some time slices are representative of geological events that have continent wide effects.

However, there are difficulties in selecting time slices that are applicable across Australia, due to contrasting depositional and tectonic regimes, as well as differences in biostratigraphy such as the spore-pollen zonation in Eastern Australia and the dinoflagellate zonation in western Australia.

The precise correlation, duration and absolute ages of the time slices were derived from lengthy consultation with many biostratigraphers, industry sponsors and the State Geological Surveys. The time slices are the basis of the products in both the Palæogeographic Maps Project and the Phanerozoic History of Australia project. Thus the details presented in this study can immediately be related to more regional concepts and maps already produced.

Key time slices interpreted in the Barrow-Exmouth Sub-basin study are within the pre -Triassic, Triassic, Jurassic, Cretaceous and Tertiary periods. A total of six time slices for the Triassic, ten time slices for the Jurassic and eleven for the Cretaceous are used and are consistent with the data set from the previous and adjacent Dampier Sub-basin module. To aid linking the two data sets some overlap between the map sheets is provided. ***The four northern wells on the map sheets - Withnell 1, Strickland 1, Enderby 1 and Hampton 1 have been carried across from the Dampier Sub-basin project.***

The selection criteria for these time slices are discussed in the following sections. They are derived from Bradshaw & Yeung 1992 and Bradshaw et al (1994). Detailed definitions of the pre-Triassic & Triassic are not yet available. Enclosure 3 summarises the spore-pollen, dinoflagellate and foraminiferal zones and related Time Slice boundaries. ***In this report the time slice definitions have been included with the appropriate time slice section.***



modified after Stagg & Colwell 1994 (in press)

Summary Stratigraphic Diagram.

Figure 3

NOTES ON HARLAND AGES APPLIED TO THE CAINOZOIC IN THIS MODULE

In Stage I of this project the Cretaceous used the Harland (1982) time scale with the K/T boundary at 65.0 MA while the Cainozoic used Berggren with a K/T boundary at 66.4 Ma. This inconsistency was explained in the notes. In Stage II the project opted for a mixed time scale, Harland (1982) for the pre-Cainozoic and Berggren for the Cainozoic. The change was at the K/T boundary taken at 66.4 MA so that the Harland defined Maastrichtian was shortened. The development of STRATDAT, where Time Scales can be selected from a list, necessitated the development of a Harland (1982) based time scale for the Cainozoic that was applicable to the North West Shelf.

The specific palæontology used to define the Cainozoic Time Slices is given in the table below (Foster 1994 pers comm). Extrapolation of the ages of the *P* and *N* foraminiferal zones are all from Harland (1982). In most cases the ages are directly quoted from Harland but a few are extrapolated from tables. The ages of the *T* series was extrapolated from Cainozoic cycle chart (BMR Record 1989/40), using the *P* series as the common reference.

TABLE 1: DEFINITION OF TOPS OF CAINOZOIC TIME SLICES.

Time Slice	Top defined as	Old Berggren Scale MA	Harland (1982) Age MA
Cz1	top of P9	52.0	50.5
Cz2	middle of P17	36.6	38
Cz3	boundary P21a/P21b	30.0	32.8
Cz4	middle N14	10.4	10.43
Cz5	top N17	5.3	4.79
Cz6	top N21	1.6	2.0
Cz7	now	0.0	0.0

NOTES ON TECTONIC HISTORY

In this report the relevant tectonic events have been described, both regional and local within the section for the appropriate Time Slice. During the interpretation of the Exmouth Sub-basin area a new tectonic element, named the Zeepaard Terrace was identified. It flanks the northwest margin of the Exmouth Sub-basin and may be a correlative of the Kendrew Terrace. For a description of this feature see the tectonics section of Time Slice J7.

EXPLORATION HISTORY OF STUDY WELLS

The Barrow-Exmouth Sub-basin has a drilling history that dates back to 1964. The exploration history of the area has been summarised in Kopsen & McGann (1985) and Table 2 summarises the most basic data of the wells used in this study.

TABLE 2: WELLS USED IN STUDY

WELLNAME	OPERATOR	STATUS AT TD DATE	TD (m KB)	TD DATE
Bambra 2	AOP	Suspended Oil & Gas	4591	27-Aug-83
Barrow Deep 1	WAPET	Suspended Oil Con & Gas	4650	19-Jun-73
Barrow Island 25	WAPET	Unknown	2534	17-May-66
Bluebell 1	WAPET	Dry g,o	4605	28-Apr-83
Campbell 2	BOND CH	Suspended Cond & Gas	2796	1-Mar-86
Candace 1	AOP	Dry	2063	30-Sep-82
Central Gorgon 1	WAPET	Suspended Gas	4598	18-Jul-83
Cowle 1	WAPET	Suspended Oil & Gas	1145	22-Dec-89
Dailey 1	ESSO	Dry g	2541	5-Aug-84
Emma 1	AOP	Dry g	2352	2-May-83
Flag 1	WAPET	Dry g	3803	30-Jan-70
Flinders Shoal 1	WAPET	Dry g,o	3616	9-Jul-69
Griffin 1	BHPP	Suspended Oil & Gas	3400	14-Feb-90
Hermite 1	WAPET	Dry g	3300	25-Nov-77
Jurabi 1	ESSO	Dry g	3712	1-Jul-82
Koolinda 1	WAPET	Dry c,g,o	3732	2-Apr-78
Kybra 1	BOND P	Dry	2562	11-Dec-87
Leatherback 1	LASMO	Suspended Oil	2258	21-Jun-91
Long Island 1	WAPET	Dry g,o	2158	31-Oct-66
Mermaid 1	WAPET	Dry	1271	9-May-78
Novara 1	ESSO	Dry g,o	2753	25-Oct-82
Resolution 1	ESSO	Dry g	3884	8-Nov-79
Rosily 1A	WAPET	Dry g	3066	3-May-82
Saladin 1	WAPET	Suspended Oil & Gas	1830	19-Jun-85
South Pepper 1	MESA	Suspended Oil & Gas	2550	12-Dec-82
Tryal Rocks 1	WAPET	Dry	3695	16-Aug-70
West Barrow 2	BHPP	Dry	3437	24-Jul-85
Zeepaard 1	ESSO	Dry f,g	4215	16-Oct-80
Zeewulf 1	ESSO	Dry c,g	3500	3-May-79

List of Operators

AOP	Australian Occidental Petroleum
BHPP	BHP Petroleum
BOND CH	Bond Corp Holdings Ltd
BOND P	Bond Petroleum
ESSO	Esso Explor and Prod Aust Ltd
LASMO	Lasmo Oil Co Aust Ltd
MESA	Mesa Aust Ltd
WAPET	WAPET

List of Codes

f = fluorescence
c= condensate
g= gas
o=oil

PALÆOGEOGRAPHIC INTERPRETATION

METHODOLOGY

Biostratigraphic data from Well Completion Reports and published information were reviewed by consultant biostratigrapher Alan Partridge. Interpretation of the ages of palynological and palæontological assemblages were conducted for the Barrow-Exmouth Sub-basin wells and loaded into the STRATDAT database. Depths of occurrences of species zones were plotted against ages, with associated codes representing highest or lowest known occurrences and youngest or maximum age determinations. Age/depth plots were constructed to provide quick-look interpretations of apparent changes in the rate of sedimentation, presence of condensed sections, unconformities, and fault intersections at well locations. An example of an interpreted age/depth plot is shown in Figure 4, and an example illustrating age/depth plot interpretations is shown in Figure 5. Depths of time slice boundaries are derived from age/depth plots and correlated with wireline logs.

The interpreted picks of the time slice boundaries from the age/depth plots have coincided with key sequence boundaries and marine flooding surfaces with reasonable consistency, thus providing confirmation of the picks of the chronostratigraphic surfaces from the log correlations and palæogeographic maps.

Palæoenvironmental interpretations were made mainly from gamma ray and sonic log signatures. Lithological descriptions from ditch cuttings, sidewall cores and conventional cores were used with log correlations to determine the facies type and depositional environments for each time slice. Biostratigraphic data were also used to provide additional information on the environment of deposition from fossil content such as the ratio of spore-pollen to marine microfossils. Palæoenvironments and palæogeographies are reconstructed for selected time slices with codes representing the various depositional environments and landform elements provided in Figure 6 and Table 3.

Time slice data maps and palæogeographic interpretation maps have been constructed over a range of thirty eight time slices ranging in age from Visean to Latest Cretaceous. Nineteen time slice data maps, four of which cover a composite of more than one time slice, have been drawn. Biostratigraphic control and environments of deposition have been interpreted for each time slice. For the Cainozoic an isopach map has been constructed.

Each time slice data map shows the location of the twenty nine wells used in the study as well as the four additional wells from the Dampier Sub-basin module. At each well location is shown a symbol to indicate whether the Time Slice is present or absent or not penetrated by the well. Hydrocarbon indications within the time slice are shown by the well symbol. For wells that intersected the time slice a shaded gamma ray log section, at a vertical scale of 1:10,000 has been posted near and if possible immediately below, the well symbol. A table has been included that shows KB depths to the top and base of the time slice, thickness of the time slice and subsea depths to the top of the time slice.

A summary of the organic chemistry data was synthesised from A.G.S.O.'s ORGCHEM database and is shown as time slice maps of Total Organic Carbon (TOC), Hydrogen Index (HI), Potential Generation(S2) and Vitrinite Reflectance (VR) in Appendix 6. When referring to the stages for generation of hydrocarbons, we have followed the scheme and cut-off points used by Tobin (1991).

Palæogeographic interpretation maps have been compiled for those time slices with sufficient information to allow an interpretation. These maps are based on the time slice data map series and are self explanatory. Detailed descriptions for each time slice data and Palæogeographic interpretation map are provided in the following section, together with a brief discussion of prospectivity.

Five well log cross sections showing detailed time slice correlations have been constructed. Figure 1 shows the locations of these cross sections. These cross sections are in two sets at different scales and should be referred to in conjunction with the palæogeographic interpretation maps (see Enclosures 4 to 13).

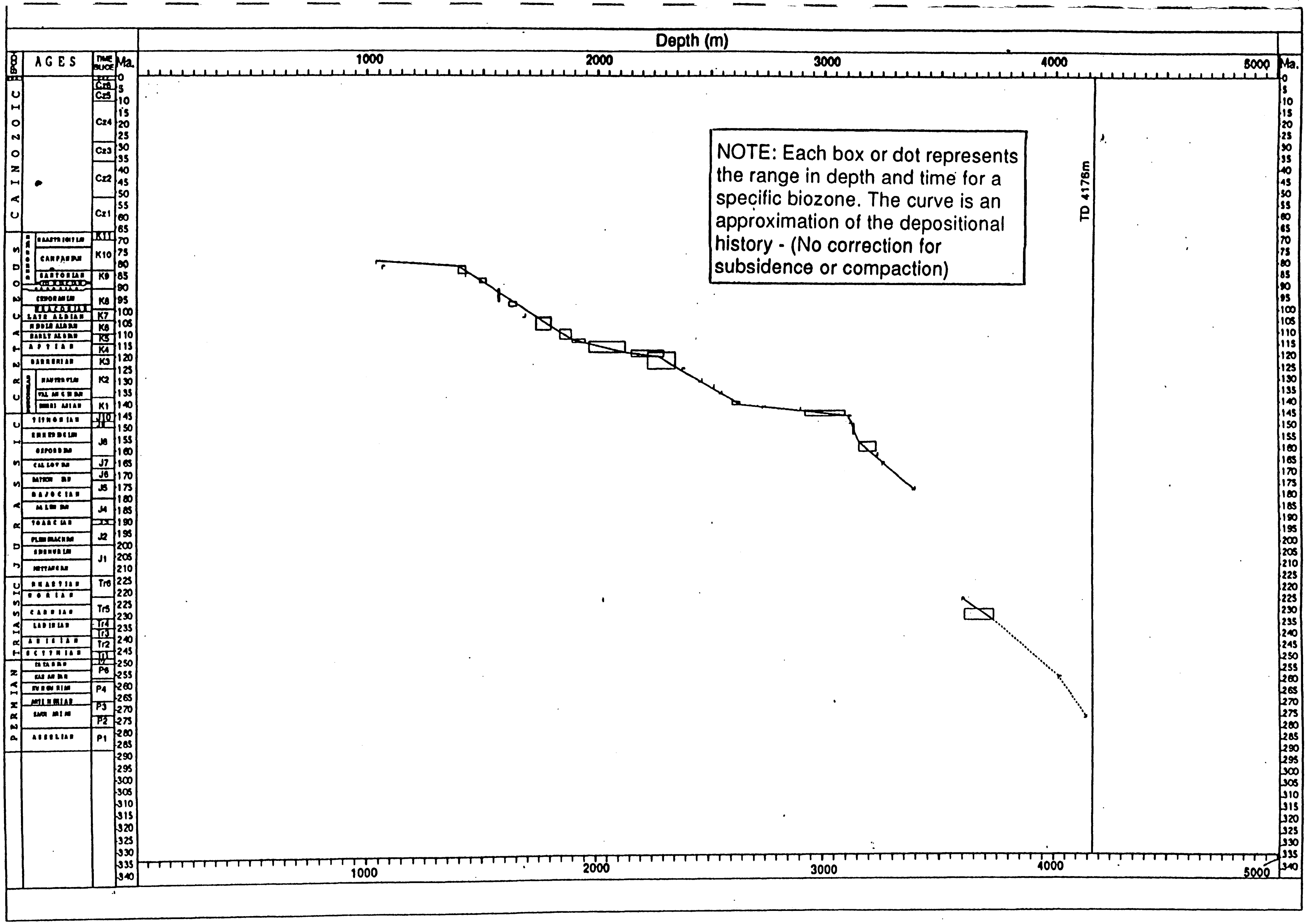


Figure 4 Age/Depth Plot Interpreted Example.

Because of the large number of wells in the module area and the existence of several major recent works relating to palæogeographic reconstructions it was decided to compile preliminary interpretation maps based on these works and to modify or discard the interpretations on the basis of the work done in this module. The authors whose diagrams and interpretations have been used are:

APTHORPE (1979), APTHORPE (1988), ARDITTO (1993), BENTLEY (1988), BOOTE & KIRK (1989), BRADSHAW & YEUNG (1990), BRADSHAW & YEUNG (1992), BRADSHAW ET AL (1988), BRAKEL & TOTTERDELL (1990), CAMPBELL ET AL (1984), HOCKING (1992), HOCKING ET AL (1978), HOCKING ET AL (1987), HOCKING ET AL (1988), HOCKING(1988), KIRK (1985), KOPSEN & MCGANN (1985), MCCLURE ET AL (1988), PARRY & SMITH (1988), PARRY (1967), TAIT (1985), THOMPSON (1990), VINCENT & TILBURY (1988), WISEMAN (1979), WULFF(1992), WOODSIDE (1988).

Because of the time slice approach the palæogeographic reconstructions are of necessity a composite interpretation rather than an instantaneous interpretation of a point in time and this should be borne in mind when viewing them. **In particular we have attempted to illustrate the range of environments and scale of the features interpreted within the time slice, even though these environments may not have been contemporaneous.**

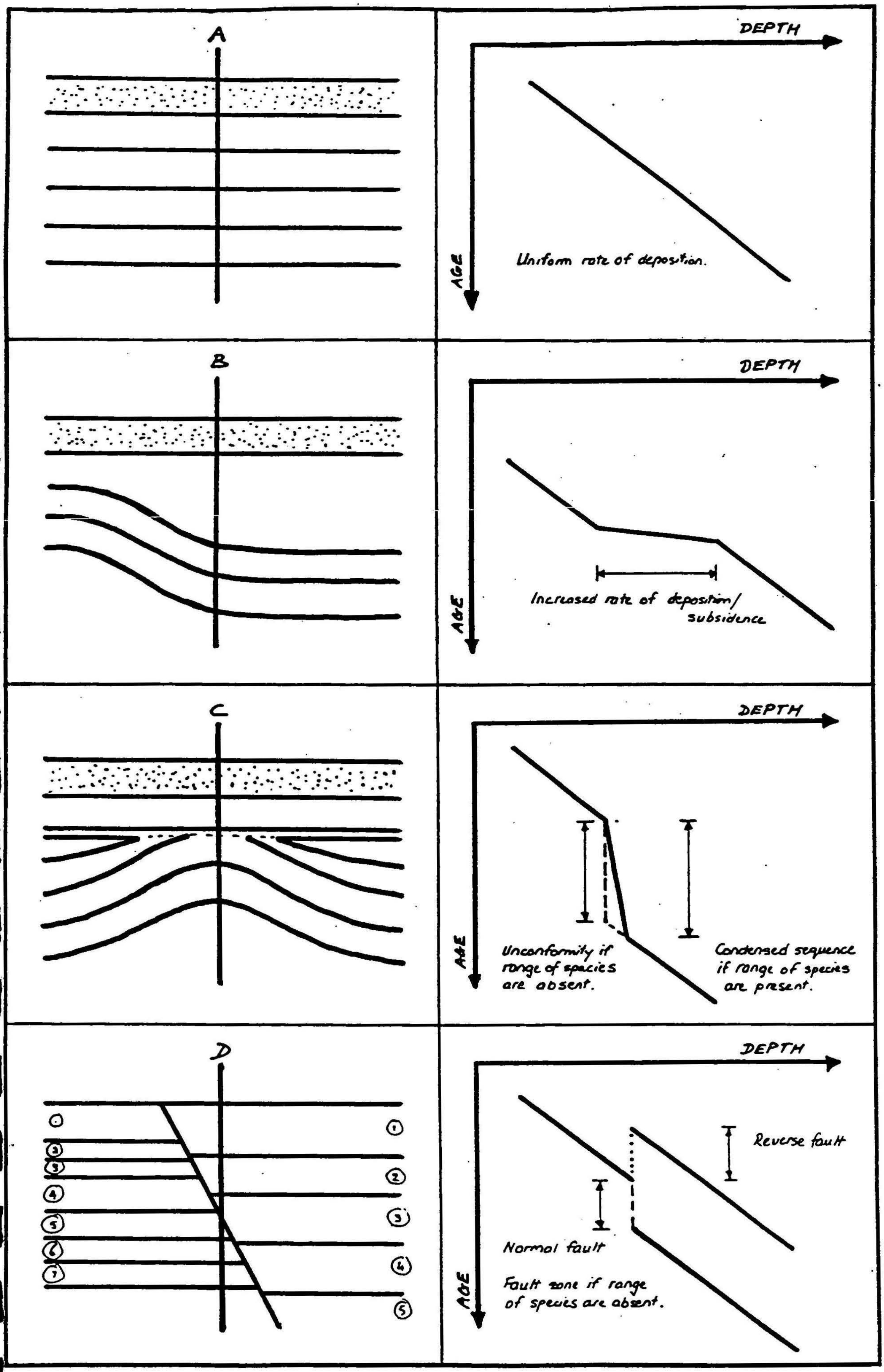
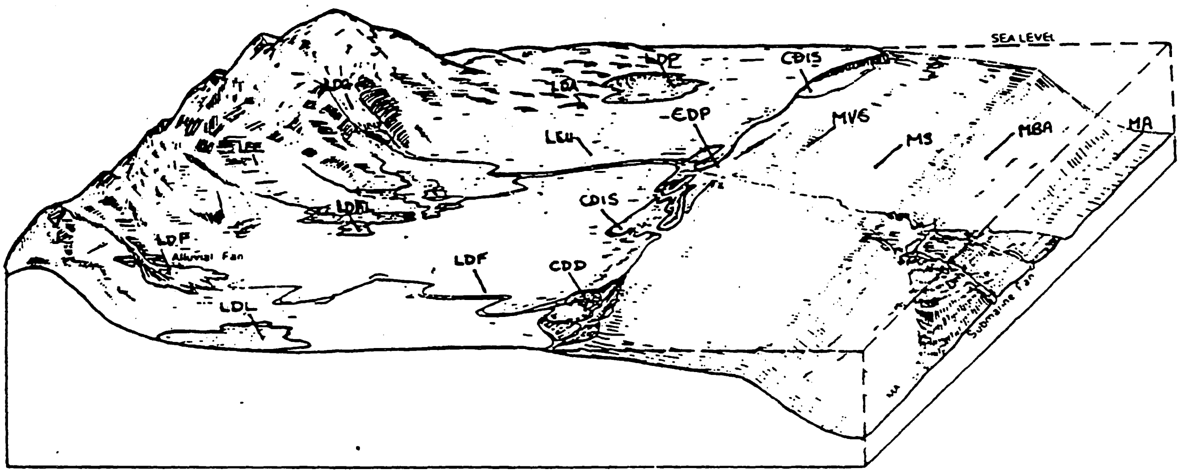


Figure 5 Age/Depth Plot Interpretation Schematic

CODE	ENVIRONMENT	WORKING DEFINITION
Land & land depositional environments		
LEU	Unclassified	Areas with no preserved sediments of time-slice age, interpreted as land, for example the Ashmore Platform. Also areas that are largely unknown that may have Jurassic sediments, such as the Queensland Plateau.
LEE	Erosional	Highland areas of sediment erosion, indicated by palaeocurrents, provenance studies, tectonic setting and the presence of igneous intrusions, for example the Arbum Arch.
LDF	Depositional, Fluvial	River deposits such as alluvial fans, braided and meandering channel deposits and coarser overbank sediments, and sand-dominated continental sequences with no evidence of aeolian or lacustrine deposition.
LDFL	Depositional, Fluvio-Lacustrine	Sediments deposited in low-energy river environments such as channels, overbanks, backswamps and shallow lakes on low-gradient floodplains; typically sequences dominated by fine-grained sediments and coal, with sheet geometry.
LDL	Depositional, Lacustrine	Deposits of deep, persistent lakes, usually in tectonically controlled basins. Distinguished from LDFL by thicker shales and more restricted distribution.
Coastal depositional environments		
CDP	Paralic	Deposits of coastal or marginal marine environments. Includes the range of environments situated at the land/sea boundary such as lagoonal, beach, intertidal, deltaic, etc., and is recognised by a variety of depositional facies ranging from coarse cross-bedded beach sand, to sand deposited in tidal deltas, to finely laminated organic sediment deposited in lagoons and estuaries (includes deltaic and intertidal-supratidal environments).
CDIS	Intertidal-Supratidal	Sediments deposited in the tidal zone, indicated by the presence of finely interlaminated fine and coarse detritus, herringbone cross-bedding, flaser bedding, evidence of periodic exposure, etc.
CDD	Deltaic	Deltaic deposits indicated by isopach patterns, upward-coarsening sequences and the map pattern of adjacent environments. Cuspate or lobate form of deltas on maps in some cases follows isopach pattern.
Marine environments		
MVS	Very Shallow (0-20 m water depth)	Marine sediments with evidence of deposition above wave base and/or occasional emergence, e.g. oolites, cross-bedding.
MS	Shallow (0-200 m water depth)	Marine sediments deposited on the continental shelf or on flanks of volcanic islands, e.g. sand, mud and limestone containing fossils that typically lived in shallow water; also includes areas along young, active spreading ridges (includes MVS).
MBA	Bathyal to Abyssal (> 200 m water depth)	Marine sediments with indicators of deep-water deposition, e.g. condensed sequences, turbidites, monotonous shale, and the presence of deeper-water organisms (includes abyssal environments).



Schematic Diagram Showing
Classifications of Depositional Environments

Figure 6 Depositional Environments Classification Diagram (after BMR Palaeogeography group 1990).

TABLE 3
Environment & Landform Elements Codes

ENVIRONMENT CODES | LANDFORM ELEMENT CODES

LAND	LEU	Unclassified						
	LEE	Erosional						
	LUD	Unclassified Depositional			V	Volcano		
					LF	Lava Field		
					VM	Volcano Mixed		
	LDF	Fluvial	LDFB	Braided	C	Channel		
					AF	Alluvial Fan	AFT	Fan Toe
							AFD	Debris Flow
							AFS	Sheet Flow
			LDFM	Meandering	PB	Point Bar		
					AC	Abandoned Channel		
					LE	Levee		
					CS	Crevasse Splay		
					BS	Backswamp		
	LDL	Lacustrine			LD	Lacustrine Delta		
	LDFL	Fluvial-Lacustrine			OD	Overbank Deposits		
		Upper Shoreface						
	LDP	Playa			SF	Salt Flat		
					MF	Mud Flat		
					P	Pond		
	LDA	Aeolian			D	Dune		
					S	Swale		
	LDG	Glacial			GD	Glacial Deposit		
COASTAL	CDP	Paralic						
	CDIS	Intertidal / Supratidal			B	Beach		
					BR	Beach Ridge		
	CDD	Deltaic	CDDU	Upper Delta Plain	SMB	Stream Mouth Bar		
			CDDL	Lower Delta Plain	IDB	Interdistributary Bay		
			CDDF	Delta Front	SML	Submarine Levee		
			CDDP	Pro Delta	CE	Chenier		
	CDE	Estuarine			M	Marsh		
					LA	Lagoon		
	CSF	Shoreface	CSFU	Upper Shoreface				
			CSFM	Middle Shoreface				
			CSFL	Lower Shoreface				
MARINE	MU	Unclassified						
	MSS	Starved Shelf						
	MS	Shallow (0-200m)			OB	Offshore Bar		
					BB	Barrier Bar		
					BI	Barrier Island		
					F	Fan	FP	Fan Proximal
							FM	Fan Mid
							FD	Fan Distal
			MVS	Marine Very Shallow (0-20m)	R	Reef	RT	Reef Toe
							RF	Reef Front
							RB	Reef Back
					CSH	Continental Shelf	CSHI	Continental Shelf Inner
	MBA	Bathyal to Abyssal (>200m)					CSHM	Continental Shelf Middle
							CSHO	Continental Shelf Outer
					CSL	Continental Slope		
					TF	Turbidite Fan	TFP	Turbidite Fan Proximal
							TFM	Turbidite Fan Mid
							TFC	Turbidite Fan Complex
							TFD	Turbidite Fan Distal
			MA	Marine Abyssal			MFD	Mixed Fan Distal
					AP	Abyssal Plain		

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

PRE-TRIASSIC SECTION

TIME SLICES P7 to C1:

PRE-TRIASSIC: (+248 MA): SEE ENCLOSURES 14 & 15.

Petroleum System: Larapintine

Ordovician (potential source rock) intervals are established as being present in the Carnarvon Basin to the south (Gorter 1994). They could exist beneath the Peedamullah Shelf and deeper offshore areas. Some of the Permian Kennedy and Byro Group sediments have source rock potential (Bentley, 1988). These rocks are interpreted to be in currently mature to overmature on the Peedamullah Shelf area and overmature in the deeper areas. No known hydrocarbon occurrences in the module area have been attributed to Larapintine source rocks. Very speculative interpretation is that these source rocks entered the generative window in late Triassic to Early Jurassic times- but additional work is required. Traps in place at these times might be prospective for this source group. As a reservoir section the Larapintine System is prospective on the Peedamullah Shelf.

Formation Synonyms:

Kennedy Group, Byro Group, Lyons Group, Quail Formation, Moogooree Limestone.

Regional Definition of Time Slice:(see Enclosure 3).

The Permian Time Slices are defined in detail in Brakel & Totterdell (1990). They are based on the palynological stages of Price (1983) and Price and others (1985). The Carboniferous is not defined here.

<u>TIME SLICE C3:</u> CARBONIFEROUS: Visean(340.0 to 328.0 MA).

<u>TIME SLICE C4:</u> CARBONIFEROUS: Late Visean to Early Namurian(328.0 to 321.0 MA).

<u>TIME SLICE C5:</u> CARBONIFEROUS: Late Namurian to Early Westphalian(321.0 to 310.0 MA).

<u>TIME SLICE C6:</u> CARBONIFEROUS: Middle Westphalian to Stephanian(310.0 to 286.0 MA).

<u>TIME SLICE P1:</u> PERMIAN: Asselain (286.0 to 277.0 MA).
Biostratigraphically equivalent to palynological zone *PP1*. Carnarvon Basin areas are in high latitudes, approximately 55 degrees south. Thick glacial ice cap retreating from Pilbara Craton area.

<u>TIME SLICE P2:</u> PERMIAN: early - middle Sakmarian (277.0 to 271.0 MA).
Biostratigraphically equivalent to palynological zone *PP2.1*. Ice retreat and final deglaciation and sea level rise. Isostatic uplift due to unloading of craton probable.

<u>TIME SLICE P3:</u> PERMIAN: late Sakmarian - Middle Artinskian (271.0 to 266.0 MA).
Biostratigraphically equivalent to palynological zone *PP2.2*.

<u>TIME SLICE P4:</u> PERMIAN: Middle Artinskian - Kungurian (266.0 to 258.0 MA).
Biostratigraphically equivalent to palynological zones *PP4.2, PP4.1* and *PP3*

<u>TIME SLICE P5:</u> PERMIAN: Early Kazanian (258.0 to 256.0 MA).
Biostratigraphically defined by the lower three quarters of the range of palynological zone *PP4.3*. Major transgression in much of eastern Australia.

<u>TIME SLICE P6:</u> PERMIAN: Middle Kazanian to Middle Tatarian (256.0 to 250.0 MA).
Biostratigraphically defined by palynological zones *PP5* upper PP4. The top occurs near the top of *PP5.2* and the base occurs near the top of *PP4.3*

TIME SLICE P7: PERMIAN: Late Tatarian (250.0 to 248.0 MA).

Biostratigraphically defined by palynological zone *PP6* and *PP5.2*. The top of the zone is the top of palynological zone *PP6* and the base occurs near the top of *PP5.2*.

Palæontology:(see Enclosure 2)

Only four wells intersected sediments older than Triassic. These are Flinders Shoal 1, Kybra 1, Candace 1 and Mermaid 1. Kybra 1 intersected the oldest sediments, interpreted to be Carboniferous (Visean: Time Slice C3: approximately 328-340 MA). Generally the biostratigraphic data is considered to be of fair quality but age ranges of defined zones are large and resolution of the Time Slice boundaries is correspondingly poor.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

The regional tectonic framework is dominated by the north to south trending grain established by the Darling and Sholl Island Faults. An intracratonic basin existed to the west of these faults probably from the Late Cambrian and certainly since the Early Ordovician (Gorter et al 1994). The Sholl Island Fault is listric and indicative of major east to west extension.

Local

Cross-section B-B' illustrates that growth occurred on the Sholl Island Fault throughout Time Slices P3 to P7 and probably into the basal Triassic. The Sholl Island Fault does not appear to have been active in the Carboniferous. (see Enclosure 5). The Sholl Island Fault appears to have been active in the early Jurassic.

Lithology:

Time Slices C3: Quail Formation and Moogooree Limestone:

The limestone is dominantly algal mudstones and limestones with relict ooid and pelletal packstone and wackstone textures. The Quail Formation is a sandstone medium to coarse grained and moderately well sorted.

Time Slices P1-P3: Lyons Group:

A major thick glacial ice cap existed in the Pilbara Region. Clasts have been transported over 250km. (Brakel & Totterdell 1994). The sequence in the module area is mainly glaciomarine deposits consisting of poorly sorted sandstone, siltstone, tillite and minor limestone and calcareous sandstone with boulder and conglomerate layers, clasts and erratics. The sequence was deposited under transgressive conditions. It is interpreted as the distal northern part of a glaciomarine, rapidly deposited, alluvial fan delta setting, that was associated with additional deposition from a retreating floating ice shelf. The Lyons Group could act as a seal facies though this requires further work to clarify. The Lyons Group is not an indicated source rock. It is worth noting that source rocks commonly occur in immediate post glacial settings (e.g. the lower Patchawarra Formation (non marine) in the Cooper Basin (Lavering, 1985)). Isostatic uplift is the probable cause of erosion of the latest section in late P3 times.

Time Slices P4-P6: Byro & Kennedy Groups:

Both these groups represent deposition in a shallow marine environment, the Kennedy Group being conformable on the Byro Group. Both groups are comprised of sandstones and skeletal carbonates. The Byro Group appears to be a middle to inner shelf sequence and the Kennedy Group an inner shelf to shoreface sequence. Both show indications of high wave energy or storm action.

Thickness Variations:

There are insufficient data to allow meaningful interpretation of the thickness variations.

Palæodepositional Environments:(see Enclosures 14)

There is no regional palæogeographic interpretation for any of the Time Slices included in this section. The Sholl Island Fault seems to have acted as a depositional hingeline or basin margin throughout most of the period and depositional environments characteristically parallel this trend. In the vicinity of Candace Terrace the environments tend to be coastal to marginal marine with a likely water depth increase to the west.

Palæogeography:(see Enclosure 15)

The map has been grossly generalised. The Sholl Island Fault is seen as defining the boundary between continental and marine environments, with a tendency towards coastal and shallow marine environments to the immediate west of the fault.

Geochemistry

There are no ORGCHEM geochemical data for the pre Triassic Time Slices.

Shows/Porosity/Permeability:

There are no significant porosity or permeability data for the pre Triassic Time Slices

Prospectivity: FAIR TO GOOD: GOOD SOURCE ROCKS AVAILABLE AND ON MIGRATION PATHWAYS; GOOD RESERVOIR QUALITY SANDS AVAILABLE; LATERAL AND VERTICAL SEALS ARE MAIN PROBLEM; STRATIGRAPHIC TRAPS MOST LIKELY SUCCESSFUL TRAPS.

The prospectivity of this area would appear to be good in terms of access to hydrocarbons. All hydrocarbons generated from Barrow Sub-basin source rocks, east of the axis of the Lowendahl Syncline, will migrate in this general direction. There is however a complicating factor. Most of the Jurassic source rock section of the Barrow Sub-basin is overpressured (Thomas 1978). In the absence of a detailed study it appears it is possible that the hydraulic gradient, along which fluids migrate, has a downdip component. This could effectively force the migrating hydrocarbons to follow a migration pathway through the Flinders Island Fault zone directly into the Pre-Triassic section. Recent work (Gorter 1994) raises the possibility of Ordovician source rocks beneath the Peedamullah Shelf on the downthrown side of the Sholl Island Fault and the Permian section and possibly the early Triassic could also be potential source rocks.

Traps and Plays:

- Rollover anticlines into the Sholl Island Fault - tested by Candace 1
- Structural stratigraphic canyon trap- tested by Kybra 1- the concept was that shelf edge canyons cut into the Kennedy Group(reservoir) would have lateral seal, in the canyons, and top seal provided by the Locker Shale. Faulting would also provide an additional necessary seal. Although there may be several reasons why this well failed, it would appear that one is that the canyon fill is sandy and not acting as a lateral seal.
- Stratigraphic traps would appear to be abundant but difficult to define.

EARLIER SEDIMENTATION:

Introduction

There is evidence for sediments as old as Early Ordovician existing beneath the Barrow-Exmouth Sub-basins. If present such rocks raise the prospect of Ordovician source rocks being present, the Ordovician being a known source rock interval in the Amadeus and Canning Basins. However none of the wells used in the module intersected sediments older than the Early Carboniferous. The discussion which follows is therefore a summary and interpretation of the literature.

Oldest Dated Sediments in Module Area.

The oldest dated sediments in the Carnarvon Basin are late Silurian (Hocking 1991, p85). These are Pridolian-Ladlovian dated rocks from the Dirk Hartog 17B well near Shark Bay approximately 500km to the south of the module area.(Philip 1969). These ages have been recently confirmed as valid (Gorter et al 1994). Hocking (1991, p84) argues that the northern most examples of Silurian aged sediments occur in Marrilla 1 and in Peedamullah 1. Marrilla 1 well is approximately 100km south of the study area and Peedamullah 1 is within the area near the Robe River Embayment (see Figure 2). The Marrilla 1 section is not dated and the age is based on lithological correlations. The proposed Silurian section in Peedamullah 1 is lithologically similar to other established Silurian aged sections (the Dirk Hartog Formation) but has not been dated. It is from a cored section just above basement and beneath early Devonian aged section.

On the basis of the lack of a definitive age date for the basal Peedamullah 1 section and the differing time scales used by Hocking (1991) and this project, it is concluded that the oldest dated sediments within the module area are late Silurian.

Oldest Probable Sediments in Barrow-Exmouth Sub-basins

The oldest rocks forming basement in the adjacent areas of the Pilbara Block are Archaean. These rocks are not considered potential source rocks but there are definite possibilities for reservoir section. Rocks of a similar age form basement on the Peedamullah Shelf, the Preston Shelf and the Candace Terrace. These rocks may be juxtaposed against mature source in the area of the Flinders Fault System and migration pathways from the mature sources of the Barrow Sub-basin appear to exist.

In the southern Carnarvon Basin, 500km south of the module area, a thick section of sandstones crop out beneath definite Dirk Hartog Formation. This section is considered to be Silurian age as it is interpreted to be conformable on the Dirk Hartog Formation (Hocking, 1991). Hocking (1991, p85) considers that the unit must be younger than 434±16 MA but Schmidt and Hamilton (1990, p 384) show that these ages are unreliable. These authors further suggest an early Ordovician age based on palæomagnetic evidence.

Recently Gorter et al (1994) have conclusively established a late Cambrian to Early Ordovician age for the Tumblagooda Sandstone. More importantly they establish that the lower Dirk Hartog Formation is the age equivalent of the Ordovician source rocks of the Canning and Amadeus basins.

TRIASSIC TIME SLICES

TIME SLICE TR1 TO TR4:

EARLY TRIASSIC: Scythian to Ladinian (248.0 to 231.0 MA). SEE ENCLOSURES 16 & 17.

Petroleum System: Gondwanan

The Perth Basin is the only place in the Gondwanan Super System where a proven oil source exists in the earliest Triassic, and is in sediments of marine facies. Locker Shale may, by analogy, be an oil source here. The oil in the first sand above the Locker Shale in Long Island 1 should be tested for source type.

Formation Synonyms:

Locker Shale, Mungaroo Formation, K (See Bint and Helby 1988, p593 for a discussion of Woodside letter codes), Cunaloo Member.

Regional Definition of Time Slices:(see Enclosure 3).

Combined Time Slice TR1 to TR4 is biostratigraphically defined by spore pollen zones *L. pellucidus, P. semoilovichii, T. playfordii, S. quadrifidus* and Lower *S. speciosus*. Detailed definitions of the Triassic time slices are not yet available.

Palæontology:(see Enclosure 2)

Time Slices TR1 to TR4 were intersected in six of the study wells. Age control is generally poor due to the coarse definition of the zones afforded by the Triassic spore-pollen assemblages. Mermaid 1 intersected all four time slices, though it is bounded above and below by unconformities so the section is incomplete. The others wells either have no Time Slice TR4, and possibly TR3, under the unconformity, or they reached total depth before penetrating the lowermost Triassic. There is no well information west of the Long Island Fault System.

There is an hiatus at the top of Time Slice TR4 that is widely recognised as a regional unconformity (see the Browse Basin module). This is the boundary between the Gondwanan and Westralian Supersystems.

Dampier Sub-basin Summary:

The earliest Triassic may have been a period of volcanic activity as Enderby 1 has probable early Triassic age rhyolites. A diachronous marine transgression occurred across the Permian/Triassic unconformity. The basal transgressive unit is represented by either a recrystallised limestone or reworked transgressive sandstone, or both. This basal fining upwards, fine grained, silty quartz sandstone is overlain by a thick marine shale or claystone, with minor limestone interbeds (the Locker Shale) and subsequently the sandier fluvial Mungaroo Formation. Deposition generally occurred in a shallow marine environment that possibly had restricted circulation. The basal transgressive sandstone is a potential reservoir facies sealed by the potentially mature and source prone Locker Shale.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

Initially Triassic sediments were deposited in a broad interior sag basin with comparatively little contemporaneous faulting (Kopsen and McGann 1985, pp157). By Time Slice TR4, uplift and tilting of strata in the Canning Basin, to the north, contributed sufficient sediment to initiate the Rankin Delta with the fluvio-deltaics of the Mungaroo Formation becoming widespread. (BMR Palæogeographic Group, 1990, pp58).

Local
Basin sag was probably accentuated by sediment loading.

Lithology:

The Locker Shale is a thick marine claystone interbedded with minor siltstone and carbonate interbeds. There is a basal transgressive unit that consists of a coarse, paralic sandstone and a thin shelf limestone overlain by sandy shales. The Cunaloo Member is a thin and widespread carbonate layer that was deposited during a brief episode of sediment starvation associated with the transgression early in Time Slice TR2.

The transition from the basinal clays and shales of the Locker Shale to sandier fluvial and deltaic sediments known as the Mungaroo Formation was time transgressive, and appears as early as mid Time Slice TR2 (Candace 1), to as late as early in Time Slice TR4. Other authors see the shale facies persisting in places through Time Slice TR5 (Hocking, 1988, pp 106).

At Candace 1, the Mungaroo Formation conformably overlies the Locker Shale and contains numerous shale and sandstone interbeds The boundary with the Mungaroo Formation is conformable here, but there are intraformational uncomformities

Thickness Variations:

The thickest intersection occurs in Candace 1 (1038m). None of the wells had a full Time Slice TR1 to TR4 section. Although Mermaid 1 has Time Slice TR1 to TR4 present, it is bounded above and below by unconformities; both Long Island 1 (+820m) and Hermite 1 (+675m) reached total depth within this interval. No wells west of the Flinders Fault System penetrated to this section. Seismic indicates in excess of 2000m of early Triassic was deposited in the Exmouth Sub-basin near Zeewulf 1.

Palæodepositional Environments:(see Enclosure 16)

An unconformity occurs at the Permian and Triassic boundary. This may be limited to the eastern margin as Flinders Shoal 1 shows continuous sedimentation throughout this time. Maximum regression occurred at this time and canyons, greater than 250m deep, were incised into the shelf near Kybra 1 on the Candace Terrace (Kopsen and McGann, 1985, pp157).

Marine transgression commenced in early Time Slice TR1. An outer shelf environment covered most of the study area with coastal and very shallow marine environments occurring on the eastern margin, e.g. beach at Kybra 1 and an offshore bar at Candace 1. The transgression peaked early in Time Slice TR2, when the Locker Shale (a middle to outer shelf siltstone and claystone) was most widespread.

During Time Slice TR2 and early Time Slice TR3 a fluvial system built into the area; environments recognized in Hermite 1 are backswamps and fluvial channels with some evidence of a marine influence. In late Time Slice TR3, regression commenced reaching a maximum at the end of Time Slice TR3.

In Time Slice TR4 a major fluvio-deltaic system sourced in the northeast started to dominate deposition (Mungaroo Formation). Coastal and deltaic, especially tidal, and paralic environments, and fluvial meanderbelt environments dominate the area throughout Time Slice TR4 and into Time Slices TR5 and TR6 (also see Thompson et al, 1990).

Palæogeography:(see Enclosure 17)

The Locker Shale-Mungaroo Formation interface was time transgressive and at any particular time, the facies boundary between the marine shales and the fluvio-deltaic sands was irregular in map view.

Time Slice TR1-2 was a transgressive phase, with outer shelf to bathyal conditions prevailing, and the Locker Shale becoming ubiquitous, with a maximum distribution occurring in early Time Slice TR2. The sea level regression from Time Slice TR2 continued into TR3, and fluvial progradation led to significant fluvio-deltaic sediments from the ancient equivalents of the Pilbara River Systems.

At the end of Time Slice TR3, a time of maximum regression, the basinal shale (Locker) persisted between lobes of increasingly widespread fluvial (Mungaroo Formation) sedimentation. In Time Slice TR4 another pulse of eustatic sea-level rise commenced. The palæogeographic maps illustrate a snapshot in early Time Slice TR4 where the shoreline had been shifted landward in comparison to Time

Slice TR3 in response to this sea level rise. Diastrophism provided the sediment source for continued progradation of the sandy Mungaroo facies into Time Slices TR5 and TR6.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).

The mean TOC range from 0.6% to 1.2%, with a maximum of 2.9% in Candace 1. The mean HI values range from 71 to 125 with a maximum of 304 in Candace 1. The mean S2 values range from 0.06 to 1.58 with a maximum of 5.92 in Candace 1. These are fair to good TOCs. The rocks are generally gas prone but oil generative potential is seen in three of the four wells, which reaches fair in Kybra 1 and good in Candace 1. The vitrinite reflectance data suggest that the sediments are marginally mature to mature here on the basin flanks, but BHT data suggest the section is immature (Mermaid 1 is 63°C at TD). The higher TOC values correspond to continental shelf environments.

The kerogen composition of the Triassic is predominantly coaly and humic. However, several zones are enriched in sapropel and have distinct oil generating potential, particularly some thin zones above the basal transgressive sandstone in the Locker Shale along the eastern margin (Kopsen & McGann 1985, pp157). The eastern margin is of course the only area where the Early Triassic has been intersected, and the palæogeography of this unit suggests that it may well have oil generative potential towards the basin axis.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

Candace 1 recorded TR1(an abandoned fluvial channel) a trace of gas only, whereas in Long Island 1, there was an thin oil show in a sand above the Locker Shale, which was too thin to warrant testing. This show suggests that the Locker Shale may indeed be an oil source here. The Perth Basin is the only place in the Gondwanan Super System where a proven oil source exists in the earliest Triassic, and is in sediments of marine facies.

Porosity measurements, from cores, were variable and were commonly in the 15-20% range in Long Island 1, and mostly below 10% in Flinders Shoal 1, with readings up to a maximum of 15.9%. Recorded log porosity for Mermaid 1 were largely between 24% and 38%. These variations had a strong correlation with depth of burial, with the top of the Flinders Shoal 1 interval at 2140m, and intervals in other wells being shallower.

Permeability measurements were only recorded for Long Island 1 and the spot readings from core fall into two groups: those of effectively zero permeability and those with >100mD; with a middle category of 2 to 5mD being lightly represented. The highest value was 431mD in the core with the oil show in Time Slice TR4. Two other readings of 110.3 and 101.1mD were measured from this 0.5m interval.

Long Island 1 is the southernmost of the study wells which intersected this time slice and the show within Time Slice TR4 may imply that better source rock character exists in this area, or better migration from the depocentre exists in this area.

Prospectivity: GOOD-SOME OIL PRONE SOURCE VARIES FROM MARGINALLY MATURE TO MATURE, WITI RESERVOIRS ABOVE AND BELOW

Expect fair to good oil source potential in the Permian Kennedy Group and Triassic Locker Shale and fair potential in the Mungaroo Formation downdip of Candace 1, assuming lateral continuity into deeper areas. The possible reason for failure in these wells is that the Flinders Fault System forms a barrier to migration from the deeper, more prospective source west at deeper targets. Wandoo 1 and Stagg 1 demonstrate that hydrocarbons are capable of migration eastward across basin bounding faults to the west and local source rocks are immature-therefore look to the west at deeper target.

Flinders Shoal 1 does not have good sands over this interval despite the occasional high porosity/permeability stringer, but any good porosity at this level would be prospective.

In Mermaid 1, migration across the Sholl Island Fault System and into Triassic and Late Permian sands of the Mermaid area is proposed to have occurred during the Late Jurassic, Cretaceous and Early Tertiary times. The Cretaceous seal is the Muderong Shale lying directly on pre-unconformity section.-- the presence of a basal granitic wash overlying basement, if areally extensive, would have allowed leakage to the surface of any hydrocarbons from the Permian sandstone to the south and south east, and from the Triassic sandstone to the east, a thief zone.

Traps and Plays:

Kopsen and McGann (1985, pp157) noted canyons of probable Late Permian age, which could be seen in seismic but their exact age is conjectural. The Kybra 1 play was based upon numerous factors, including an updip seal against Locker Shale having filled these canyons.

As the coastline transgressed, a basal transgressive sand may have filled the canyons, before burial by the quiescent Locker Shale unit. The canyons themselves may therefore be targets, as well as speculated fans at debouchments from them. They have not been penetrated by the drill, but may be attractive targets, if Kybra's failure implies that the canyons are sand filled.

The shoreward limit of the basal transgressive sand with its overlying, sealing (and possibly sourcing) Locker Shale may provide attractive targets, but it seems that the main potential in this area is west of the Flinders Fault System. This involves a considerably deeper test than has hitherto been attempted for these targets. Porosity, however, appears to be depth dependent, and would therefore imply a maximum to target depths, and mitigate the prospectivity of deeper plays.

Finally, there may be an attractive play where there is effective reservoir development in, say, the offshore bars of the growing fluvial prograding deltaic system. Indeed, the best show in this interval appears in Long Island 1, which reaches total depth in Time Slice TR3 after penetrating 170m of prodelta Locker Shale. In this well where a thin leg of oil is identified at the top of the first sand package overlying the Locker Shale. The reservoirs and seals at this level maybe quite prospective but prove to be somewhat elusive.

TIME SLICE TR5:

MIDDLE TRIASSIC: Carnian to Early Norian (231.0 to 222.0 MA). SEE ENCLOSURES 18 & 19.

Petroleum System: Westralian

The pragmatic boundary between the Gondwanan and the Westralian Systems is the top of the regional seal, the Locker Shale (Bradshaw, 1993). In this area the top of the Locker Shale is diachronous, ranging from Time Slice Tr2 to Tr5 in places. A suitable place to put the break between the Gondwanan and Westralian Supersystems is at the Time Slice Tr4/Tr5 boundary which corresponds with a significant regional unconformity and shortly precedes the maximal distribution of the Mungaroo Formation.

The Westralian system is described by M. Bradshaw (1993, pp48) as..."Middle Triassic to Cainozoic in age....The tectonic regime (included)... extension and eventual break-up and seafloor spreading in the Late Jurassic to Early Cretaceous. Reservoirs for giant gas fields...and significant oil fields...include Late Triassic to Middle Jurassic fluvial to deltaic sandstones....(D)eposition of the (Jurassic) source rock (was) in marine anoxic conditions with the contribution of a significant amount of terrestrial organic matter... The Westralian system has thick regional shales so that there is the potential for faults to seal: thus trap types include horst blocks, tilted fault blocks, faulted anticlines as well as simple anticlines." For a fuller description of this system see the above paper.

Formation Synonyms:

Mungaroo Formation, G, H, I & J (See Bint and Helby 1988, p593 for a discussion of Woodside letter codes) and Locker Shale.

Regional Definition of Time Slice:(see Enclosure 3).

Upper S. speciosus and Lower M. crenulatus.

Detailed definitions of the Triassic Time Slices are not yet available. Enclosure 3 summarises the spore-pollen, dinoflagellate and foraminiferal zones and related time slice boundaries. Recent work by Nicoll and Foster (1994) revises the position of the *S. speciosus/ M. crenulatus* spore-pollen boundary upwards from the base of the Norian to well within the stage, where it approximates the Time Slice Tr5/Tr6 boundary. For the purposes of this study the boundary is taken as it appears in Enclosure 3.

Palæontology:(see Enclosure 2)

Of the nine wells in this study which intersected Time Slice Tr5, all four on the Rankin Trend or in the Exmouth Sub-basin reached total depth within the time slice, as did Leatherback 1 and Dailey 1. Age control is quite coarse given that neither boundary is defined by a spore-pollen zone boundary.

Dampier Sub-basin Summary:

Eleven wells intersected sections of Time Slice TR5 age. All but Cossigny 1 were drilled on the Rankin Trend, eight of these reached total depth within this time slice. A delta system occupied the area, with fluvial fining upward point bar sequences and coarsening upward delta distributary channels. Sediments comprise interbedded sandstones, siltstones, shales and coals. Deposition occurred on a lower delta plain with minor marginal marine to estuarine conditions prevailing episodically. Although rated as having fair to good prospectivity, this time slice is not generally the productive interval of the Triassic along the Rankin Trend. It is normally too far below the main Cretaceous seal to be within the hydrocarbon column in most structures. However, it could be prospective elsewhere on the Rankin Platform and Kangaroo Synclinal area. TOC and HI values indicate good source quality associated with the lower delta plain facies. The vitrinite reflectance data on the Rankin Trend suggest that this interval is in the early to peak stages of oil generation. Most wells have no shows, but Dockrell 1 has gas reserves, and Montague 1 has gas condensate reserves. Good primary porosity and permeability are characteristics of the blocky sandstone facies.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

Diastrophism in the Canning Basin to the east continued, with erosion of these and other uplands believed to be the major provenance for the Late Triassic sediments of the North West Shelf. (BMR Palæogeographic Group, 1990)

Local

This depocentre continued to be depressed as a simple sag basin with flexuring only along the margins- most faulting along the Candace Terrace is interpreted to be either pre or post-Triassic (of Time Slice J2 age and later).

Lithology:

Parry and Smith (1988, pp140) describe the Mungaroo Formation as 'a thick and remarkably widespread sequence of mainly fluvial and deltaic sandstones and shales'. As is characteristic of fluvio-deltaic sedimentation, the occurrence and ratio of sandstone, siltstone and shale is highly variable. In Dailey 1, this time slice consists of intervals which are dominantly 90% siltstone, slightly carbonaceous, with minor argillaceous or sandy beds. These may be interbedded with slightly sandier or occasional sandstone intervals. On the other hand, Bluebell 1 has over 50% of the entire interval as sandstone. Central Gorgon 1 is a typical intersection consisting of a thick siltstone, shale and claystone intervals with thin fine-medium grained sandstone, and indications of some minor marine influence. The Time Slice Tr5 interval in Central Gorgon 1 also includes two point bar sands greater than 30m thick which reservoir the gas pay. Both Leatherback 1 and Zeewulf 1 have sandy sections.

Thickness Variations: (see Enclosure 18).

The thickest intersection of Time Slice Tr5 was 958m at Central Gorgon 1, even though the well reached total depth within the time slice, reflecting high rates of sedimentation at the delta front (see Appendix 2 and Enclosure 19). In the southeast, Dailey 1 also reached total depth in this interval after penetrating 491m of sediments, whereas Long Island 1 had a full intersection at 396m. Hermite 1 confirms thinner section adjacent to and up on the Candace Terrace with a full intersection of only 240m. This would imply a zero edge to the near southeast, except for the valleys of the fluvial systems.

Palæodepositional Environments:(see Enclosure 19).

Fluvial environments predominate and landform features include point bars, backswamps, and channels. However, the youngest section of Time Slice Tr5 in Zeewulf 1 and Central Gorgon 1 has distributary channels, stream mouth bars, and interdistributary bay sediments, indicating a marginal marine environment. The Dailey 1 well completion report interprets low-relief fluvio-lacustrine and shallow marine (inter-distributary bays) environments for the Time Slice Tr5 interval, whereas this study finds no compelling evidence for a marine environment at this location. A fluvial environment on the upper delta plain is the preferred interpretation, consistent with the surrounding wells (Enclosure 19).

Palæogeography:(see Enclosure 19)

The Time Slice Tr5 section indicates a fluvial environment, with meandering rivers predominating in the southeast and extending as far west as the Exmouth Sub-basin and Rankin Platform region. All wells show very similar depositional environments, with the exception that the northwestern wells (Central Gorgon 1 and Zeewulf 1 in particular). These show evidence of marine inundation and sediment reworking associated with high energy coastal environments, especially near the top of the interval. The fluvial sediments prograded into a rising sea level and lobe switching may have allowed transgression in local areas. With massive sediment influx into relatively deep water environments, there was the potential for unstable sediment loads to intermittently flow to the base of slope.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).

The mean TOC ranges from 0.5% to 7.1%, with a maximum value of 39% in Bowers 1, whereas the maximum value from the three module wells is 1.6%. The mean HI values range from 85 to 117 with a maximum of 139 in Bowers 1. The mean S2 values range from 1.79 to 6.18 with a maximum of 34.8 in Bowers 1, but with a module well maximum of only 1.89 in Flinders Shoal 1. These data indicate fair to poor source potential on the Peedamullah Shelf, becoming very good near the Hilda-Alpha Arch, and gas prone. The vitrinite reflectance data suggest that the Peedamullah Shelf sediments are in the early gas generative phase, but around the Hilda-Alpha Arch they are in the peak generative window. The higher TOC values of Bowers 1 would correspond to coaly backswamp or paralic environments.

Well completion reports supplement these data as follows:

In Zeewulf 1, the entire well is immature with only the bottom 100m reaching the very early stage of maturity, but the Triassic has an average TOC of 2.2% and the potential to source both liquid and gaseous hydrocarbons if buried deeper. Therefore the thermally overmature gas/condensate reservoir in Time Slice Tr6 sands migrated into the trap from much deeper in the section. Similarly, the potential to source both oil and gas is seen in Dailey 1 and Zeepaard 1.

Dailey 1 had three Mungaroo samples containing greater than 10% TOC. One sample of 13.69% TOC had 40% oil prone kerogen.

Zeepaard 1 has good TOCs; and VR data below the Triassic-Jurassic unconformity suggests a heating event and subsequent erosion from the top of the horst. A major break in the VR profile occurs above the Triassic, at 3981m, with the underlying section being late to over mature. A major phase of coalification occurred in Late Triassic and possibly Earliest Jurassic, with these high temperatures decaying prior to the deposition of the remaining Jurassic. This probably indicates maturation, generation and hence a loss of hydrocarbons prior to the establishment of a seal. This break in reflectance profile is also seen in Resolution 1and Investigator 1.

In Central Gorgon 1, the whole section from the top(3630m) to 4400m is mature, becoming over-mature deeper than this, and has all fair to good TOC, but is hydrogen poor, and therefore gas prone source (except for an interval from 4350 to 4400m which is poor as regards TOC). The Bluebell 1 interval is gas/condensate prone. Leatherback 1 has a very good oil show in Time Slice Tr6. The origin of this oil is speculative, and may have been sourced from any of a number of intervals within the Triassic or Jurassic.

It is notable that oil prone kerogen is reported in a number of wells, despite the predominance of gas in Triassic discoveries to date.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

Central Gorgon 1 has an indicated net gas pay of 25m over the interval 4012-4072m, which, in the gargantuan proportions of that field was disappointing. This is mainly due to the lack of, or poor development of sands above this zone in the section immediately under the seal. Minor sands above this interval are largely water wet and therefore isolated from the source. It tested at 1059MCM/day gas with 14.3 kl/day condensate and 7.6kl/day water.

Hermite 1 has a strong gas indication (a possible gas zone -it was a 2 metres thick with water saturation of approximately 60%), and with an associated minor oil indication. Zeepaard 1 contains a clean gas sand at 4007.5- 4016.5m and thinner or dirtier gas sands at 4161-4163.5 and possibly 4103-4108.5m - the gas is almost all thermogenic methane.

Data from Zeepaard 1 within the intervals sampled showed that porosity generally ranged from 10-20% with an average of approximately 15%. Higher porosity were recorded in Long Island 1 with a range of 11-32%, and a mean of ~22%. In the lower section of Central Gorgon 1, the limited permeability data varied from 0.0 to 11mD and averaged 0.3mD (similar to Bluebell 1 data); whereas in the reservoir section it varied from 0.4mD to >2 Darcies, with an average of 100mD. Long Island 1 revealed very variable results of 0-366mD, with a low average except for one 3 metre section which averaged approximately 20mD. There are generally better quality reservoir sands in distal areas such as the Rankin Platform and Exmouth Plateau, probably due to reworking at the delta front (see Enclosure 19).

Prospectivity: GOOD TO VERY GOOD.

In the prograding fluvio-deltaic environment organic rich fine-grained sediments were deposited and then overlaid with fluvial and reworked sands. Any interval which can claim a gas/condensate field the size of Gorgon must be viewed as highly prospective. It appears that the wells in the west intersected this section at maturity meaning that lookalike plays are promising, but very little apart from gas is in prospect for deeper targets. By contrast immaturity is the problem in the southeastern wells so deeper targets may still be of interest there. The main feature of this interval is its prospectivity for gas and also probably for oil if timing of generation and entrapment under later seals is right.

Traps and Plays:

Bluebell 1 and to a lesser extent Central Gorgon 1 demonstrate the importance of finding porosity adjacent to the overlying seal. Commonly in the Flinders Fault Zone wells, the absence of hydrocarbons was partly attributed to their inability to migrate across faults. Study of the hydrocarbon drainage directions around Zeewulf 1 (see Figure 7) shows that very little if any hydrocarbons would drain to it. Given the generative nature of most of this section significant potential should exist in the first trap out of depocentres. This interval may be a target in structural plays, especially flanking the Exmouth Sub-basin, but also on the Rankin Platform and Exmouth Plateau.

TIME SLICE TR6:

LATE TRIASSIC: Late Norian to Rhaetian (222.0 to 213.0 Ma). SEE ENCLOSURES 20 & 21

Petroleum System: Westralian

For a description of this System, see the Time Slice TR5 section

Formation Synonyms:
Mungaroo Formation, Brigadier Formation, D, E and F. (See Bint and Helby 1988, p593 for a discussion of Woodside letter codes), Muiron Siltstone and Murat Siltstone.

Regional Definition of Time Slice:(see Enclosure 3)
Time Slice Tr6 is biostratigraphically defined by the Lower *A. reducta* and upper *M. crenulatus* spore pollen zones. Detailed definitions of the Triassic Time Slices are not yet available. Enclosure 3 summarizes the spore-pollen, dinoflagellate and foraminiferal zones and related Time Slice boundaries.

Palæontology:(see Enclosure 2)
This time slice was intersected by ten of the study wells, three of which reached total depth within the interval. Three of these wells are on the Rankin Trend or its southern equivalent flanking the western edge of the Exmouth Sub-basin, five are associated with the margin flanking Long Island Fault Zone, whilst Jurabi 1 is in the Long Island Transfer Zone and Griffin 1 is on the Hilda-Alpha Arch (see Enclosure 1). There is everywhere continuous deposition from Time Slice Tr5, but the upper boundary is erosional in five wells. This appears to most likely be the result of an hiatus which occurred, at the earliest, at the Time Slice J1/J2 boundary. Biostratigraphic control continues to be poor because time slice boundaries do not correspond with spore-pollen zone boundaries. It is not until Time Slice J5 (middle Jurassic) where dinoflagellate zonation becomes more definitive, that certainty of time slice zonation considerably improves.

Dampier Sub-basin Summary:
Sedimentation is dominantly claystone with interbedded sandstones and minor siltstone.
Deltaic deposition on a near shore to shallow shelf environment is indicated.
Fining upward fluvial point bar sequences are recognised at the base of the interval. The overall interval is interpreted as a major transgressive sequence.
The North Rankin area is characterised by more fluvial deposits. A zone of shallow marine or paralic deposition fringed this lobe. Offshore bars, tidal channel and beach deposits are probable.
Rankin Trend VR data suggest this interval is in the peak stages of generation, with TOCs and HI's indicating good oil prone source, but because this area has been thoroughly tested, future success is limited unless deeper reservoirs are pursued.
Porosity and permeability are poor to very good. Two major gas condensate accumulations occur in North Rankin 3 and Goodwyn 2, as well as a proven oil and minor condensate accumulation at Eaglehawk and numerous gas or condensate or oil indications occur elsewhere.

Tectonics:(see Enclosure 1 & Figure 2)
Regional
In the Canning Basin erosion probably persisted, with substantial volumes of sediment continuing to be supplied. The rate of sediment supply possibly waned towards the end of this time slice, allowing marine inundation.

Local
There are several possible explanations for the generally thinner interval seen here than in Time Slice Tr5 (apart from erosion). These include lower subsidence rates, eustatic sea level fluctuations, sediment bypass into areas further west and diminished erosional rates from the main sediment source. The evidence points to there being sufficient basinal accommodation to exclude sediment bypass and therefore sediment supply was probably reduced.

Lithology:
The top of this interval, where present, consists predominantly of siltstone which persists into Time Slice J1. This lithological unit is described in the well completion report for Jurabi 1 and Dailey 1. It is termed the Muiron Siltstone, and partially equates with the Murat Siltstone, defined by Hocking (1992,

pp28). The onset of Muiron Siltstone deposition was in *A. reducta* time whereas the Murat Siltstone is defined as beginning no earlier than mid-*C. torosa* time.

The majority of sediment is interbedded sandstone, siltstone and claystone, with common coal intervals (Mungaroo Formation). Sandstones are generally clean, very pale grey to mid grey or cream, fine to medium to coarse grained, well sorted and have sharp lower contacts, with either sharp or fining-upwards upper contacts. They are generally firm to hard, subfissile to fissile with some sandstones being friable, well rounded (distally) to subangular to angular.

The finer grained rocks are generally mid to dark grey and black, with minor brown to red-brown, orange and yellow to very pale grey horizons present in the upper part of the formation. In places, the typical overbank deposits are described as sandy and clayey siltstone which is most commonly finely laminated, mainly dark grey, carbonaceous and pyritic. Pyrite is a minor component, with varying amounts of carbonaceous matter.

Hermite 1, however, records the Mungaroo Formation as dominantly medium to very coarse grained sandstone, in parts conglomeratic, containing chert fragments and thin interbedded siltstones which are oxidised to red-brown, yellow and pale grey-green colours.

Thickness Variations:(see Enclosure 20)

The thickest intersection in this time slice is 635m at Dailey 1, whilst those most proximal to the Flinders Fault System (Hermite 1, Flinders Shoal 1 and Long Island 1) have thicknesses of 100-200m. Flinders Shoal 1 and Long Island 1, like Griffin 1, Zeewulf 1 and Resolution 1 have an unconformity as their upper boundary.

Palæodepositional Environments:(see Enclosure 21)

The sea transgressed across the study area during this time slice, with fluvial and/or deltaic environments (such as interdistributary bays, distributary channels and backswamps) yielding to shoreface and marine environments. For example, beach deposits interpreted in Dailey 1 are overlain by shelfal siltstones. This reworking of sediments provides typically good reservoirs. Large tracts of paralic and tidal environments would also be expected under these circumstances.

Palæogeography:(see Enclosure 21)

Marine inundation over a very large peneplain produced a complex shifting mosaic of marine, paralic and fluvial environments. There were periods of local regression and resumption of fluvial deposition, but marine environments finally prevailed.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)

The mean TOC ranges from 0.8% to 7.6%, with a maximum of 36% in Bowers 1. This considerably distorts the module well data which report mean values up to 1.5%, with a maximum of 2.4% in Zeewulf 1. The mean HI values range from 22 to 142 with a maximum of 155 in Flinders Shoal 1. The mean S2 values range from 0.19 to 1.91 with a maximum of 2.39 in Zeewulf 1. These data suggest that the sediments have fair to good organic matter content which is gas prone, and are poorly generative. This interval is in the peak gas generative phase around Bowers 1 and in the early generative gas or peak generative oil phase in other areas. The higher TOC values correspond to lower delta plain environments

The well completion reports add the following information for this time slice:

The Mungaroo Formation in this interval has an average TOC of approximately 2% in Dailey 1 and Zeewulf 1. Zeewulf 1 section is immature with marginal maturity only becoming evident within 100m of the total depth. The overmature gas/condensate trapped here has therefore migrated from much deeper in the section. Griffin 1 has only fair to moderate potential for dry or wet gas/condensate, but it goes from marginally mature to peak oil generation in this intersection, however the oil cracking temperature would only be 100-200m deeper than total depth. Jurabi 1 has poor to fair source potential for gas or oil (but more gas prone) and is mature, approaching over-maturity at the bottom of the well. Resolution 1 has an interval relatively rich in TOC with an average value of 2.53%, contains less oil-prone organic matter, but would be expected to source both gas and oil. The Triassic was coalified early and there is a major thermal index discontinuity below the Early Jurassic unconformity suggesting that greater than 500m of Triassic and Early Jurassic was removed.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5)

A proven oil accumulation with minor gas occurs at Leatherback 1 - it flowed at 1799 BOPD oil (41.8 API) and 0.222 MMSCFD through a 1m perforation interval and 56/64" choke. A gas/condensate accumulation, largely methane, is interpreted in Zeewulf 1- it has low gas saturation, with low porosity and probably low permeability.

Strong gas indications occur at Jurabi 1 and Resolution 1, which also has oil indications. There is a lesser gas indication at Flinders Shoal 1 and a minor oil indication at Bluebell 1.

Reservoir quality sands are noted in Leatherback 1(ave porosity~ 24%, and spot permeabilities commonly >2 Darcies) and Dailey 1(10-25%, ave ~18%) in particular, with Flinders Shoal 1 also noting good porosity (14-26%, ave ~19%) near the top of this interval. Jurabi 1 however has a tight section with porosities of 3-7% due to compaction and pressure solution. This has negative implications for the deeper parts of the Exmouth Sub-basin.

Resolution 1 has reservoir quality sandstones, but the lack of significant hydrocarbons in the structure is attributed in the well completion report, to overpressuring in the Mungaroo Formation, which was transmitted from the Dingo Claystone prior to thermal maturation of the source rocks, retarding hydrocarbon migration into the structure.

Resolution 1's location also affords very little Jurassic drainage into its structure, and Zeewulf 1 is poorly located for either Jurassic or Triassic drainage (see Figure 7)

Prospectivity: GOOD TO VERY GOOD.

This section houses major gas and gas/condensate reserves in the Dampier Sub-basin. Also it has a very significant oil discovery in Leatherback 1 but local thermal maturity would preclude significantly deeper tests in this area. The only reason for a less major gas accumulation in this time slice at Central Gorgon is due to the lack of juxtaposed porosity with the seal at that location, and Bluebell's lack of porosity proximal to seal can similarly explain the failure to discover pay. Available seismic in the Leatherback 1/Jurabi 1 area could not allow a definitive interpretation on the source of drainage into the Leatherback 1 structure.

Traps and Plays:

Triassic and Jurassic apparent dip studies indicate that the south-east margin of the Exmouth Sub-basin (such as near Griffin 1)has substantial potential for trapping migrating hydrocarbons. However, hydrocarbons become overly mature near Griffin's total depth and shallower targets closer to the structurally complex Leatherback - Jurabi area may be more attractive but more elusive. Deeper structures on the Zeepaard Terrace which are overlain by substantial thicknesses of Late Jurassic may have some potential.

Time Slice TR6 could be a target in structural plays in the Kangaroo Syncline area where the section is mature and has potential source, reservoir and seal facies.

JURASSIC TIME SLICES

TIME SLICE J1:

EARLY JURASSIC: Hettangian to Sinemurian:(213.0 to 200.0 MA) SEE ENCLOSURES 22 & 23.

Petroleum System: Westralian

The general significance of the this interval on the Westralian Petroleum System is poorly understood.

Formation Synonyms:

Dingo Claystone, Brigadier Beds, North Rankin Beds, North Rankin Formation, D & C (See Bint and Helby 1988, p593 for a discussion of Woodside letter codes). Murat Siltstone (Hocking, 1992) approximately equates with the Muiron Siltstone as described in Jurabi 1 and Dailey 1, Mungaroo Formation, Lower Learmonth Formation.

Regional Definition of Time Slice:(see Enclosure 3)

Time Slice J1 is biostratigraphically defined by the Middle *D. priscum,* Lower *C. torosa* and Upper *A. reducta* spore pollen zones. The Jurassic/Triassic boundary is not marked biostratigraphically. It occurs within the *A. reducta* and *P. crenulatus* spore-pollen zones, and the *D. priscum* dinoflagellate zone. The upper boundary of this time slice is within the *C. torosa* spore-pollen zone and the *D. priscum* dinoflagellate zone.

Palæontology:(see Enclosure 2)

Only five of the study wells intersected this time slice, three of which have a regional unconformity forming their upper boundary. The only two wells which have continuous deposition into Time Slice J2 are Jurabi 1 and Leatherback 1, both of which are located in the Long Island Transfer Zone, which came into existence at the end of this time slice.

Dampier Sub-basin Summary:

A decrease in depositional rate occurred during Time Slice J1 as compared to the underlying Triassic. On the Enderby Terrace the base of Time Slice J1 is a significant unconformity where it onlaps the eroded Triassic. On the Rankin Trend most of the Jurassic has been eroded but in several wells significant sections of Time Slice J1 remain. In these wells the top of Time Slice J1 is an erosional unconformity. In the Lewis Trough the Jurassic is probably conformable on the Triassic. The dominant lithology is dark grey to medium grey, olive grey to brown, silty calcareous claystone that grades occasionally into micaceous shale. Stacked delta lobes, as seen around Saturn 1, are characteristic of fluvial dominated delta systems where both wave and tidal influences are minor. The limited data suggest a very broad division of deltaic coastal sedimentation to the east and shallow marine shelf sedimentation to the west. A source area from the northeast is possible. The transgressive sequence seen in the Late Triassic time slices culminates in onlap of the previously exposed Enderby Terrace.

Although this is a significant time slice because of its major reserves, it is viewed as having only fair to poor prospectivity because all major plays on the Rankin Trend have been drilled and in the Lewis Trough it is probably too deep to be a viable target. On the Enderby Terrace the basal transgressive sand could prove a viable target but requires the migration of hydrocarbons from the Lewis Trough to be prospective.

Vitrinite reflectance data suggest that this interval is in the early stage of oil generation on the Enderby Terrace and the early peak stages of oil generation in the Kangaroo Syncline and Rankin Platform area. Major gas condensate accumulations occur along the Rankin Trend sealed by the overlying Early Cretaceous.

Tectonics:(see Enclosure 1 & Figure 2)

Regional

This time immediately preceded the onset in the Argo-land area of the Northern Exmouth Plateau, and formation of the Exmouth, Barrow and Dampier sub-basins. This tectonism occurs at the end of this time slice and so for a fuller discussion of this phase see Time Slice J2.

Local

Drowning of the fluvial Mungaroo Formation sediments continued within the study area. This was possibly caused by one or both of the following:

1) Fluvial influx was diverted from this area. OR

2) Compressive forces which generate the discrete depocentres are initiated causing gentle regional buckling, and in the lows, marine influx.

Lithology:

Hocking (1988, pp106) described this interval as having grey siltstone and lesser shale, claystone and fine sandstone. However at Bluebell 1, the dominant lithology for this Time Slice is described as claystone with occasional intergradational siltstone. The claystone is light olive-grey to brown grey, grading to very calcareous claystone which is very light grey to yellow-grey. At Jurabi 1, what is informally called the Muiron Siltstone in the well completion report, and equates with the Murat Siltstone (see Time Slice Tr6, Lithology), is described as a quartz siltstone with lesser black carbonaceous shale and minor sandstone. Hermite 1 has a similar lithology to Hocking's description in the latter half of this time slice, but the lower half is dominantly sandstone. It is described as pale to dark grey, soft to hard, fine, medium and coarse grained, variably cemented with calcite, with trace limestone and pyrite.

Thickness Variations: (see Enclosure 22)

Time Slice J1 is absent due to erosion or nondeposition in 10 of the study wells. Further, it was not penetrated in another 14 of the study wells being deeper if present than their total depths. Jurabi 1 has the thickest preserved section of this time slice (230m), similar to the maximum preserved thickness encountered in the Dampier Sub-basin. In both areas the thickest sections are found in wells near the basin margins. If structural development of the sub-basins was not initiated until the end of this time slice, then similar thicknesses may be anticipated in the depocentres.

An unconformity defines the top of this interval in wells proximal to those which have absent section, however Jurabi 1 and Leatherback 1 have continuous deposition into Time Slice J2. In Leatherback 1 the unconformity is within Time Slice J2, and Jurabi 1 has a correlative log anomaly which equates to the lithological boundary between underlying 'Muiron Siltstone' and overlying Dingo Claystone. Thus the youngest sediment preserved under the unconformity is J2 in age, implying that the major tectonism occurred within Time Slice J2, not at the Time Slice J1/J2 boundary. Our previous studies in the Dampier Sub-basin implied a time more within Time Slice J1 because they were the youngest sediments seen under the unconformity.

Palæodepositional Environments:(see Enclosure 23)

At the commencement of Time Slice J1 inner shelf environments were established at Jurabi 1 and Dailey 1, shoreface environments had encroached to Leatherback 1 and lower delta plain environments persisted at Hermite 1. Stream mouth bar and delta front conditions are interpreted for the Time Slice J1 interval in Bluebell 1. It was the only well not displaying evidence of marine environments by the close of Time Slice J1, which may be explained by its vicinity to one of the rarer fluvial systems of this time, or by erosion of its younger marine section.

Palæogeography:(see Enclosure 23)

Fluvial environments persisted from the Triassic into the earliest Jurassic. The Jurassic transgression commenced earlier on the west and later on the eastern margin, as the river systems were progressively drowned. As the time slice progressed, silty and sandy influx lessened, resulting in widespread shale deposition within a possibly deepening marine environment over most of the northern Carnarvon Basin.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)

The mean TOC values range from 0.9% to 6.8% with a maximum of 36% at Bowers 1. The mean HI values range from 30 to 103 with a maximum of 108 at Hermite 1. The mean S2 values range from 0.53 to 1.74 with a maximum of 1.99 in Hermite 1. That is, this interval generally has good levels of TOC which are gas prone and have poor generative potential. The vitrinite reflectance data suggest that this interval is in the early to early peak stages of gas generation,.

The well completion reports largely concur with these data stating that:

In Dailey 1, the average TOC for the Muiron Siltstone is 1.6% and although VR data indicate that current maturity onset is within this Time Slice, significant hydrocarbon generation could not be expected here, but in deeper, more mature and good oil-sourcing section off-structure. Jurabi 1 is assessed as having poor to fair source potential for gas and oil, (but is more gas prone) and is very mature in Time Slice J1, approaching overmaturity at the bottom of the hole(in Time Slice Tr6).

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5)

Hermite 1 has a minor gas and a minor oil show in this time slice. Minor oil shows were seen in Bluebell 1 and Strickland 1 whereas Jurabi 1 had a minor gas show. All other wells intersecting this time slice had no significant shows. None of the wells in this study had any significant reservoir quality potential at this level except Hermite 1.

Prospectivity: FAIR TO GOOD

This Time Slice contains large accumulations of gas and gas/condensate on the Rankin Trend where it overlies the Late Triassic as reservoir. The only place where prospective reservoir is encountered in this study is in Hermite 1. This nearshore/shoreface setting may be sought along the margin from this well and in downthrown blocks in the Flinders Fault System, where porosity may be enhanced by lesser carbonate cementation. Fluvial sediments may also be present, although their occurrence would be less predictable.

Traps and Plays:

Geochemical studies demonstrate a favourable source and maturity conjunction off-structure but proximal to Dailey 1. They also give a lead to the range of target depths via the Jurabi 1 intersection (3055-3285m) approaching overmaturity. However, they also indicate that this time slice is poorly generative.

The complex Flinders Fault Zone may yield favourable targets given that it may contain reservoirs which overlay prospective Triassic source, and may be sourced and sealed by Dingo Claystone. Given the poor amount of well data for this time slice, a number of possibilities are still available. There may be reservoirs of this age in the terraced blocks adjacent to the Triassic highs seen flanking the Exmouth and western Barrow sub-basins.

If Hermite 1 failed due to inadequate or breached overlying seal, then the southeast Barrow Sub-basin margin plays, including the fault and pinchout plays, are seriously downgraded; but if it is due to unrecognised structural complexity or barriers to migration, then the potential remains.

TIME SLICE J2:

EARLY TO MIDDLE JURASSIC: Pliensbachian to Early Toaracian (200.0 to 191.0 MA). SEE ENCLOSURES 24 & 25

Petroleum System: Westralian System

This is the time where a new tectonic regime was emplaced within this region, where the dominantly fluvial Mungaroo Formation and shallow shelf Murat Siltstone gave way to the marine Dingo Claystone. Time Slice J2 may mark a subdivison within the Westralian Supersystem. Time Slice J1 reservoirs are found on the Rankin Trend, reservoiring gas and condensate, they represent the top unit of a petroleum system being sourced within the late Triassic.

Formation Synonyms:

Lower Dingo Claystone, Murat Siltstone, Muiron Siltstone (informal name used in the well completion reports of Dailey 1 and Jurabi 1 - with an earliest occurrence predating that of the Murat Siltstone) Athol Formation (Hocking.1992) The rationale for the Murat Siltstone being overlain by the Athol Formation is that, though they are lithologically similar, one would hereby distinguish between deposition before and after what is called by some (Barber, 1982 and Kopsen and McGann, 1985) the rift onset unconformity. The Athol Formation is sometimes called the Middle Dingo Claystone.

Regional Definition of Time Slice:(see Enclosure 3).

Time Slice J2 is biostratigraphically defined by *upper D. priscum, Upper C. torosa to Lower C. turbatus.* Time Slice J2 corresponds to the *N. vallatus* datum. Marked by facies change in many basins and commencement of deposition in others, eg on the northwest margin there was a facies change from marginal marine clastic sediments to shallow water limestone.

Palæontology:(see Enclosure 2)

This time slice has well intersection in only two of the study wells, with all of the rest being either absent through erosion/nondeposition, or too deep for the drill. The two which yielded section are within the Long Island Transfer Zone, and only Jurabi 1 is not eroded at all. Leatherback 1 has an unconformity forming its upper boundary.

Dampier Sub-basin Summary:

Six wells penetrated Time Slice J2. Age control is poor to very poor over this interval as both *Upper D. priscum* and *Upper C. torosa* also extend into Time Slice J1. Dark grey to medium grey, olive grey to brown silty calcareous claystone or occasionally micaceous shale, is the dominant lithology, with claystone and minor argillaceous siltstone. This time slice is rated as having fair to poor prospectivity since there have been no discoveries within this time slice, and the Lewis Trough is probably too deep to be a viable target. The vitrinite reflectance data suggest the southern Enderby Terrace is in the early stage of oil generation and the northern Enderby Terrace is in the initial stage of peak oil generation. In the Dampier Sub-basin the Dingo Claystone is an established source rock. A 10 -15m thick sandstone and oolitic limestone with fair porosity and encased in seal and potential source facies was intersected in Gandara 1.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

The base of this time slice is referred to by some workers as the rift-onset unconformity, however the evidence from Jurabi 1 and Leatherback 1 would suggest that the event is best dated within Time Slice J2, in lowermost *C. turbatus*. Furthermore, it marks the onset of what Etheridge and O'Brien (1994, pp907), and Stagg and Colwell (in press) have proposed was a compressional event associated with the Fitzroy Movement. As a prelude to this episode, initiating in the Palæozoic, the Exmouth Plateau region underwent "a major episode of lower crustal thinning that lasted from the Permo-Carboniferous to the

Jurassic. During this phase, almost the entire crust below a mid-crustal discontinuity was removed "(Stagg & Colwell, in press).

Marine then fluvial-deltaic deposition occurred across this region in much of the Triassic as the area uniformly subsided.

It is beyond the scope of this document to deal in detail with the tectonism occurring on the Northern and Western margins of the Exmouth Plateau, but evidence suggests that there was a regional northwest-southeast compressive event which was the genesis of the discrete depocentres of the Lewis Trough and the Barrow-Exmouth Sub-basins. (This tectonism may be alternatively explained as a southwest-northeast tensional event.)

In the Early Jurassic compression, a long wavelength anticline formed across the Exmouth Plateau/ Rankin Platform area and where this thinner crust met resistance against the much thicker continental lithosphere of the Pilbara Block, there was locally an intense, short wavelength syncline with associated flanking anticlines which formed the Exmouth-Barrow and Dampier Sub-basins into depocentres. These flanking anticlines were the sites of subsequent erosion and deposition into the narrow troughs which in turn led to unloading and loading adjustments, and accentuated these features during the remainder of the Early Jurassic. The strain ellipsoid in Figure 2 indicates the prevailing stress field, and the crustal deformation resulting from it. This offers an explanation for the folding orientation and the strike-slip extension on the Long Island Transfer Zone.

If one equates the northwest-southeast compression as an southwest-northeast extension, this then better explains events as effects of the Greater India Rift onset. After this initial tensional episode, the main source of tension moved to the northern and western margin of the Exmouth Plateau where Argoland was undergoing preliminary tectonism. This therefore implies that the region underwent tensional strain in an southwest-northeast orientation precipitating basin forming synclines and WNW-ESE transfer faults, possibly followed soon after by another tensional strain from the NNW which caused transtensional faulting on the south-eastern margins of each of these developing sub-basins.

The strong coincidence of the western margins of the Exmouth and the northern Barrow Sub-basins being on trend with each other suggests that they were part of the same feature.

Associated with the initial tectonic activity was an amount of local extension on the Rough Range Fault, Learmonth Fault, Bundegi Fault and accommodating that movement, the Cape Range and Long Island Transfer Faults. To the north there was possible reactivation of the Sholl Island Fault.

Local

Within this transtensional regime, accelerated subsidence exaggerated faulting along the basin margins, defining the central troughs of the sub-basins. In the Exmouth Sub-basin, there was subsidence adjacent to the Rough Range and Bundegi Faults. The Rosemary and Flinders Fault Systems became active or reactivated and possibly also the Rankin Trend faults - this enhanced subsidence in the Barrow and Dampier depocentres. Faulting here has a transtensional appearance with steep normal faults and little bedding rotation, indeed, little extension in evidence.

Lithology:

Siltstone was the dominant lithology, with minor claystone, sandstone and dolomite interbeds. The siltstone is described in Leatherback1 as 'light green grey to medium to dark grey with rare glauconite grading to light to medium brown grey with depth, dominantly soft and moderately dispersive, occasionally slightly sticky, very argillaceous, non- to slightly calcareous at the base to moderately calcareous in the top of this time slice, with occasional pyrite, sparry calcite and micro-mica.'

The Jurabi 1 well completion report describes the lithology in this time slice as Muiron Siltstone which is quartz siltstone with lesser black carbonaceous shale.

Thickness Variations:(see Enclosure 24)

Jurabi 1 has the thicker intersection of this time slice (138m), and Leatherback 1, which has an unconformity as its upper boundary, has a 49m section. J2 sediments are absent from erosion or nondeposition in all basin margin wells, and were not penetrated in all deeper basinal wells of the study, where they may be of substantial thickness.

Palæodepositional Environments:(see Enclosure 25)

The extremely limited well control here indicates an inner shelf environment around Leatherback 1 and similarly in Jurabi 1, inner shelf to lagoonal environments are interpreted. More generally, the depositional environment is regarded as being of outer shelf to slope bathymetry. In the southern Exmouth Sub-basin, the deposition of prograding deltaic or alluvial fan complex was abruptly terminated by transgressive marine flooding during this time. Accelerating basin subsidence through this time slice caused claystones to come to dominate siltstones as the eastern basin margin sagged. Seismic evidence suggests that the Rosemary Fault System was active at this time, with significant thicknesses of Early Jurassic sedimentation interpreted.

Palæogeography:(see Enclosure 25)

This was a phase of relatively high sea-level compared with Time Slice J1, with shallow shelf conditions and extensive inshore tidal and paralic environments interpreted. A rapid rate of subsidence caused initially deepening water, with sediment starvation causing a limestone to develop in the depocentre (Hocking, 1992, pp42). Sedimentation thereafter kept pace with or outstripped subsidence during this time slice.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).

The mean TOC ranges from 0.8% to 2.6%, with a maximum of 12% in Hampton 1. The mean HI values range from 68 to 158 with a maximum of 188 in Hampton 1. The mean S2 values range from 1.18 to 3.3 with a maximum of 20.4 in Hampton 1. That is, good TOC levels exist for this time slice, which is nevertheless gas prone and has generally poor generative potential with the exception of Hampton 1 which has very good TOC and very good generative potential.The sparse vitrinite reflectance data suggest that the southern area around West Tryal Rocks 1 is in the early peak of the gas generative range according to Tobin (1991, pp146), whilst Hampton 1 on the Enderby Terrace is at the earliest generative stage. Time Slice J2 is much shallower in Leatherback 1 than Jurabi 1.Well completion reports show that extrapolation from BHT would imply this interval to be marginally mature to mature and therefore deeper targets off-structure would be attractive from a maturity perspective. Jurabi 1 has poor to fair source potential mainly for gas and is mature to very mature.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

Jurabi 1 has minor oil shows, whereas Leatherback 1 had a minor dry gas show. A minor oil indication which occurs in Strickland 1 may be indicative of migration into that area. In Jurabi 1, the Muiron Siltstone is recognised as a good seal.

Prospectivity: POOR

The minimal direct evidence from these two wells implies a lack of reservoir as a significant problem for this time slice. Hocking (1992, pp42) has interpreted a fining upwards basal sandstone as a transgressive, coastal sand prism above a ravinement surface. This time slice does not have any discoveries within it and it seems to be broadly of low generative potential, but it is a seal facies.

Traps and Plays:

The most likely occurrence of significant porosity in this time slice is on the shelfal areas where this section is generally not preserved, or adjacent to and on the downthrown blocks and terraces of the major basin margin faults. Good source intervals of the Triassic underlie this interval, and the Dingo Claystone as a good source and seal overlies it. At Jurabi 1 this interval approaches overmaturity, so deeper plays would not be prospective for oil. The window for prospectivity therefore appears quite narrowly confined to significant depths in the basin margin fault systems, where buried to an optimal depth, and within the Long Island Transfer Zone.

TIME SLICE J3-6:

MIDDLE JURASSIC: Late Toarcian, Aalenian, Bajocian, Bathonian and Early Callovian (191.0 to 167.0 MA) SEE ENCLOSURES 26 & 27.

Time Slices J3, J4, J5 and J6 have been compiled into one map for reasons detailed below but which include poor palynological resolution, sparse well coverage for any individual time slice and a similar palæodepositional environment across the time slices.

Petroleum System: Westralian

The general significance of the this interval on the Westralian Petroleum System is poorly understood.

Formation Synonyms:

Legendre Formation, Dingo Claystone, Upper Learmonth Formation, Athol Formation, Judy Member.

Regional Definition of Time Slice:(see Enclosure 3)

- JURASSIC TIME SLICE J3: EARLY TO MIDDLE TOARCIAN (191.0 - 189.0 Ma)

Time Slice J3 is marked by a distinct change in lithology and depositional environment in the Surat and other eastern basins. It corresponds to the appearance of *Applanopsis spp*, and is marked by the development of ironstone oolite beds within the Evergreen Formation and its equivalents.

- JURASSIC TIME SLICE J4: LATE TOARCIAN TO EARLY BAJOCIAN (189.0 - 180.0 Ma).

Time Slice J4 corresponds to the commencement of deposition of the Hutton Sandstone in the Eromanga and Surat basins, the Algebuckina Sandstone in the Poolowanna Trough, the Cattamarra Coal Measures in the Perth Basin, and the expansion of deposition in the Papuan Basin. Biostratigraphically it is loosely defined as occurring within the lower part of the *C. turbatus* zone.

- JURASSIC TIME SLICE J5: EARLY TO MIDDLE BAJOCIAN (180.0 - 177.0 Ma)

Time Slice J5 is marked by a marine transgression in the Perth Basin. It is biostratigraphically defined by the *D. caddaense* dinoflagellate zone. Ammonites contained within sediments of Time Slice J5 in the Perth Basin allow direct correlation with the European stages.

- JURASSIC TIME SLICE J6: LATE BAJOCIAN TO EARLY CALLOVIAN (177.0 - 167.0 Ma) The base of Time Slice J6 equates with the top of *D. caddaense* dinoflagellate zone. Stratigraphically, the base of the time slice coincides with the end of the Cadda transgression in the Perth Basin and the top of the time slice equates to the regional "Callovian Unconformity" seen in several basins on the North West Shelf.

The spore pollen zones for the different time slices are listed on the left and the dinoflagellate zones on the right.

Time Slice J6: *D. complex & C. cooksoniae. . . . . W. indotata &C. halosa.*
Time Slice J5: *C. turbatus. . . . .D. caddaense.*
Time Slice J4: *C. turbatus.*
Time Slice J3: *C. turbatus.*

Palæontology:(see Enclosure 2)

Of the six wells in this study which intersected this combined interval, only one well, Jurabi 1 intersected Time Slices J3-J5. Two wells reached total depth within Time Slice J6, and the other three wells recorded Time Slice J6 directly overlying an unconformity, under which were sediments of Time Slice J2 or J1.

Dampier Sub-basin Summary:

This composite time slice is penetrated in a total of thirteen wells. Palynological control is fair over this interval. The top is normally easily identified as a major basin wide unconformity (the Main Unconformity), that is identifiable everywhere except in some wells in the central Lewis Trough where deposition into Time Slice J7 was probably continuous. Time Slice J6 was identified in eight wells. The upper Time Slice J6 marks the boundary of the commencement of the major tectonic episode which, among other features formed the Kendrew Terrace. Five lithologies dominate the composite time slice, dark claystone, dark siltstone, fine grained sandstone, coal and limestone. The interpreted depositional environments include fluvial, to deltaic, near shore and shallow marine shelf. Delta distributary channels, beaches and offshore bars are interpreted. The overall pattern is of a low to moderate energy system. The trend throughout this interval is a continuation of the transgressive phase of previous time slices up till the middle or end of Time Slice J5. In Time Slice J6, the environment of deposition was deltaic in the eastern half of the area, offshore shallow marine in the western area, with a marine regression continuing slowly until the onset of major tectonism. The prospectivity of this interval is fair because good mature source rocks are present, however stratigraphic trapping situations, though likely to be numerous, are difficult to predict. This interval is generally in the initial to middle peak stages of oil generation. There are gas and oil indications in numerous wells, but in only one well, Angel 2, are there strong oil and gas indications. There is a strong possibility that reservoir quality sands could be stratigraphically isolated between early Jurassic seal rocks (potential source rocks) and overlying Cretaceous seals. Traps in this reservoir could be structural, isolated fault blocks or stratigraphic pinchout. Hydrocarbons could also enter via faults from deeper mature source.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

In Time Slices J3 to J5, the western Exmouth and Rankin plateaux probably remained high in response to the development of the Argoland rift, and possibly created a source of sediment from the west. There is no incontrovertible evidence for this proposition, but significant volumes of sediment were deposited in the depocentres, and this time was one of non-deposition or subsequent erosion on the high blocks of the plateaux. There may also be preserved condensed intervals in the localised lows.

Local

Coevally with the rift margin development, were the subsiding depocentres of the Dampier, Exmouth and Barrow sub-basins. Malcolm et al (1991, pp168) identified significant block rotation related to oblique-slip movement in the Exmouth Sub-basin. They saw this tear movement on features such as the Bundegi Fault creating terraces and thereby extending the boundary of the Exmouth Sub-basin eastwards. In Time Slice J6 subsidence continued, as did the Argoland rift development. Associated transtensional faulting intensified along the margins of the Barrow, Dampier and Exmouth Sub-basins.

Lithology:

There are still few control points for this time slice group because it is mostly absent on the flanks of the depocentre and too deep for the drill in most basinal areas. Emma 1 and Barrow Deep 1 being the only basinal wells to reach this interval, both reach total depth within Time Slice J6. Hermite 1, Dailey 1 and Leatherback 1 each have no obvious unconformity at the top of Time Slice J6, but sedimentation rates and facies types appear to be affected at and above the Time Slice J6/J7 boundary. Jurabi 1 is the only well in this study which has continuous deposition throughout the group of Time Slices J3-6

Siltstone and then claystone continued to dominate deposition (Athol Formation) in the Barrow and northern Exmouth sub-basins as subsidence on the Flinders and Rosemary Fault Systems persisted episodically. By the onset of Time Slices J5 and then J6, fine-grained deposition continued in the Barrow Sub-basin as before, but with mixed-lithology turbidite flows (the Judy Member and other lesser sandy units) becoming significant.

The Judy Member is described by Hocking (1992, pp30) as "marginally sandier than immediately overlying and underlying units, based on its spikey gamma-ray character and cuttings descriptions, and it is interpreted as a mixed siltstone-sandstone mass-flow deposit, possibly a detached fan from a point source", or it may be described as a slump.

Jurabi 1 had continuous sedimentation throughout this period and it is described as dominated by shale grading into claystone and argillaceous siltstone with traces of limestone, dolomite and sandstone. The shale/claystone is light grey to dark grey to grey brown, micaceous, pyritic, slightly to very calcareous with variable amounts of carbonaceous matter.

Mixed sand, shale and clay deposition occurred locally near the basin margin, as in Dailey 1 and Leatherback 1 during Time Slice J6. Hermite 1 has the sandiest facies, described as dominantly sandy siltstone grading to fine-grained silty sandstone. The more basinal Barrow Deep and Emma wells were dominated by shale and claystone with some siltstone.

Time Slice J3-6 deposition consisted in part of sediments as old as Time Slice Tr5 re-eroded from the elevated flanks of the depocentres.

Thickness Variations:(see Enclosure 26)

Wells on the Enderby Terrace have the thickest intersections of this time slice group, but that is largely due to their comparative shallowness allowing a more complete drill penetration than, say, in Barrow Deep 1. It should also be noted that the three Enderby Terrace wells have a much more complete section than in this study, implying a deeper position on the margin at that time.

All wells in this study have an unconformity bounding this time slice group at the top (Emma1, Barrow Deep 1, the Enderby Terrace wells) or the base (Hermite 1, Dailey1, Leatherback1), with the exception of Jurabi 1 which has a full section. Both Emma 1 and Barrow Deep 1 reach total depth within Time Slice J6 so it is unknown as to whether they have a basal unconformity, it is considered unlikely within the depocentre.

It is curious that four of the wells around the margin of the Barrow Sub-basin are not capped by an unconformity, whereas the two wells towards the depositional axis are truncated. This is probably the result of fault movement at this time.

Palæodepositional Environments:(see Enclosure 27).

The only well within this study which has Time Slice J3-J5 intersection is Jurabi 1. Middle and outer shelf environments are interpreted there for this interval. Other authors (Hocking, 1992, pp43) have mentioned the onset of a regressive phase in Time Slice J5 and for all of Time Slice J6, however we interpret low energy, deep water environments in Barrow Deep 1 and Emma 1- these may actually be low energy but shallowing, restricted circulation environments.

Towards the end of Time Slice J6 environments were locally deep (low energy) in the Barrow Sub-basin and Lewis Trough area. The facies at Hermite 1 is much sandier than typical Dingo Claystone, and therefore possibly nearshore, or given its position on the downthrown margin, more likely a slump or mixed lithology turbidite. Other slump, fan and mixed-lithology turbidite flows similar to the Judy Member may be expected emanating from that margin. Reservoir lithologies would be resricted to winnowed siltstone to silty fine grained sandstone, as the slumps and fans would mainly consist of fine-grained, earlier Jurassic sediments.

Palæogeography:(see Enclosure 27)

Initially there may have been a sandy coast of barrier bars and lagoons, with some possible riverborne outbuilding where supplies of sediment were greatest. Time Slice J3 represents the peak of the sea-level rise where shelf conditions prevailed, and were generally low energy and of restricted circulation. Water depths in the depocentres would have fluctuated significantly during this time, but the lack of well information from this study on these time slices precludes any further detailed discussion.

At the end of Time Slice J6, with uplift widespread, circulation would have been very restricted.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).

The mean TOC values range from 0.9% to 2.1% with a maximum of 4.7% at Enderby 1. The mean HI values range from 68 to 139 with a maximum of 287 at West Muiron 2. The mean S2 values range from 1.18 to 2.59 with a maximum of 22.9 in Hampton 1. TOC content is therefore generally good, with fair to good potential to generate primarily gas but around West Muiron 2, primarily oil. The vitrinite reflectance data suggest this interval is variably in the early or peak stages of oil generation, or the early stages of gas generation. The well completion report for Emma 1 shows very good TOC content in these time slices ranging from 2.07-3.48%, and described as the best source rock interval in this well by far.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).
Of the nine wells intersecting this time slice group (six from this study and three from the Dampier module), only three had shows of any significance. Minor oil shows were seen in Jurabi 1 and Strickland 1 whereas Barrow Deep 1 had a minor gas show. All other wells intersecting this time slice had no significant shows. In Jurabi 1 the Dingo Claystone is noted as a particularly good seal.

Prospectivity: FAIR
Mature source rocks and the potential for these and younger sediments to form effective seals, the limiting factor on prospectivity is reservoir quality sediments. Sandy deposition around the faulted margins again offers the best opportunity for finding porosity within these time slices.

Traps and Plays:
The most likely play areas would be proximal to the evolving escarpment or a fluvial influx point. As in the Dampier Sub-basin, stratigraphic traps with a structural component are the likely trap style.This would make targets very difficult to predict and therefore risky.

TIME SLICE J7:

MIDDLE JURASSIC: Middle Callovian to Early Oxfordian (167.0 to 162.0 MA).SEE ENCLOSURES 28 & 29.

Petroleum System: Westralian
This is part of a major source rock interval with significant turbidite sand reservoir potential, but mostly deeply buried.

Formation Synonyms:
Dingo Claystone, Calypso Formation (Hocking defines this as the fine-grained sedimentary rocks which were deposited between the onset and the completion of the Callovian- Oxfordian rifting episode, its time range being from the base of *W. digitata* to *W.spectabilis*), and the Emma Member is a sandy interval at the base of the Calypso Formation in the eastern Barrow and Dampier Sub-basins.

Regional Definition of Time Slice:(see Enclosure 3).
Time Slice J7 is defined by dinoflagellate zones *W. digitata* and *R. aemula* and spore pollen zone lowermost *M.florida*. The base of Time Slice J7 equates with the bases of the *M. florida* spore-pollen zone and the *W. digitata* dinoflagellate zone. It incorporates the *R.aemula* zone, and the top is defined by the base of the dinoflagellate zone *W. spectabilis*. It also represents an episode of uplift and erosion, prior to the commencement of sea floor spreading on the North West Shelf; and coincides with the transition from Hutton Sandstone deposition to a lower energy shale prone Birkhead Formation fluvio-lacustrine regime in eastern Australia.

Palæontology:(see Enclosure 2)
This time slice was intersected by nine of the study wells, three of which reached total depth within the time slice. It is absent due to erosion or nondeposition in eleven wells, and it was not penetrated in another nine of the study wells. Age control was fair in the well penetrations. An unconformity at the

beginning of this time slice was only noted in the two most basinal wells. An hiatus at the end of this time slice only in the Bambra 2, Flag 1 and Emma 1 area indicates local tectonic activity.

Dampier Sub-basin Summary:

Time Slice J7 is a syntectonic deposit entirely limited to the Lewis Trough/Kendrew Terrace depocentre. There seems to be an asymmetry to the trough and the thickest section appears to occur adjacent to the Rosemary Fault System. It appears that the Madeleine Trend came into existence at this time, resulting in non deposition and erosion onto this feature.

The dominant lithology is olive grey to olive black to brown black highly silty claystone with a trace of mica and pyrite. This is gradational into, and interbedded with, olive grey argillaceous siltstone with lesser quartz sandstones which have only a trace of intergranular porosity, and with calcite and dolomite cement.

It is assumed that much of the erosion of the Lower Jurassic on the flanks of the Rankin Trend occurred at this time leading to the development of the Rankin Escarpment.

The prospectivity of Time Slice J7 is considered poor, mainly due to poor porosity and permeability. This interval is in the initial stage of peak oil generation, and is believed to be a major source rock interval. Play potential in this unit is significantly reduced because reservoir quality is very poor.

Tectonics:(see Enclosure 1 & Figure 2).

There is an area of shallow Triassic to the north-west of the Exmouth Sub-basin depocentre (which is relevant to this discussion). It may be divided into two areas, the Exmouth Platform, and to its southeast, the Zeepaard Terrace which is informally named and defined below (see Figure 2):

Zeepaard Terrace- an area of complex Triassic faulting, overlain by a veneer of Late Jurassic sediments which thins to be absent to the northwest as successive Triassic fault blocks step up. The southeastern margin of this feature is formed by the northwestern edge of the Exmouth Sub-basin depocentre, a sharply defined linear feature which trends SW-NE and can be described as the line of inflexion where the steeply dipping (to the SE) top Triassic(or top Earliest Jurassic) unconformity becomes markedly less steeply dipping, and it is most clearly identified on seismic diagram 110/12, sp 1850 (Figure 12).

The width of the Zeepaard Terrace is approximately 15-20 kilometres such that the northwestern margin of this feature is sub-parallel to the southeastern margin, and is defined by the SE edge of the shallowest Triassic block proximal to the depocentre. This would largely coincide with the northwestern extent of contiguous Jurassic deposition which therefore defines the limit of the Exmouth Sub-basin.

The southwestern margin of this feature is defined by the Long Island Transfer Fault Zone, beyond which the terrace does not appear to exist, and to the northeast, deposition of Late Jurassic appears to have thinned to be absent in the area immediately west of the Gorgon field. Evidence of a negative flower structure, related to the genesis of the Zeepaard Terrace, is seen on seismic diagram 101R/07 (Figure 10). Zeepaard 1 and Resolution1 are on the Zeepaard Terrace.

Regional

Through all or most of Time Slice J7, the transtensional regime re-ignited distal rifting and, according to Kopsen and McGann (1985, pp159), caused possibly as much as 1 to 2 kilometres of uplift along the major platforms. This is the time of the Argoland break-up, and the first oceanic crust is generated there by the end of this time slice. Not only does this event occur on the northern margin of the Exmouth Platform, but there is also tectonic activity on the western and southern boundaries along the rifting margin of Greater India's eventual Time Slice K1 break-up. The transtensional nature of this tectonism caused different areas to simultaneously be undergoing extension or compression. Within the Barrow and Dampier (and probably the Exmouth) depocentres, there was an hiatus at the start of Time Slice J7, followed by extensive subsidence and deposition. Tectonic activity was locally variable, with the Long Island Transfer Zone to the south having suffered no hiatus, and the Flag-Bambra-Emma area of the Barrow Sub-basin becoming erosional also at the end of this time slice.

Local

The Alpha-Hilda Arch and the Rankin Platform were uplifted, and fault movement on the Madeleine Trend further restricted circulation within the basin. At this time it appears that the Zeepaard Terrace was formed, as the northwestern margin of the then Early Jurassic Exmouth depocentre came under transtension, and the margin was complexly faulted and stepped towards the sub-basin axis. Specific timing for this event is imprecise (early or late Time Slice J7) because well information from Resolution 1, which is sited on a high block, commences in Time Slice J8. Similarities between this terrace and the Kendrew Terrace are sufficiently strong for one to be confident that information on the genesis of one would be relevant to the understanding of the other. Consideration of depositional rates may point to the dynamics of the local tectonism (see also the Age/Depth Plots- Appendix 2) . For instance, depositional rates in Jurabi 1, which had been quite constant throughout the period of Time Slice J2 to J6, doubled in Time Slice J7. Hermite 1 similarly doubled its depositional rates from Time Slice J6 to J7; whereas in the depocentre, Barrow Deep 1 increased depositional rates by probably more than fourfold- this after an unconformity early in the time slice. Bambra 1 and Koolinda 1 corroborated this subsidence rate with very high depositional rates for this time slice. Malcolm et al (1991, pp170) describe this as a time of major extension in the Exmouth Sub-basin, with accelerated basin subsidence exemplified by renewed movement, with large fault throws, on the Bundegi Tear Fault. The area north of the Cape Range Transfer Fault subsided and deposition resumed there at this time.

Lithology:

Commonly, as in Bambra 2, the interval was described as claystone grading to siltstone with minor sandstone. The claystone is dark brown grey to grey black, hard to very hard and indurated. Mica is a common diagenetic accessory. The claystone grades to siltstone in part and, rarely, to very fine sandstone. More centrally in the sub-basin, the Barrow Deep 1 lithology is described as shale, medium to dark grey and brownish grey, firm, subfissile, occasionally blocky and dolomitic, silty in part, grading to very argillaceous, with siltstone, sandy in part and trace pyritic, with minor claystone, light grey, soft and silty and with traces of dolomite, limestone, sandstone and sand. Below a fault bisecting this interval in Hermite 1, the lithology is dominantly sandy siltstone (much sandier than typical Dingo Claystone) grading to fine grained silty sandstone. Above this fault the interval is finer grained. A good sand in Emma 1, at the base of this interval, is interpreted as a turbidite fan. Other fans could be expected adjacent to the basin margin. Generally, it is a period of predominantly fine-grained deposition, primarily due to provenance. Overlying the fan complexes are massive, soft, dispersive olive grey claystones (basinal marine shales).

Thickness Variations: (see Enclosures 28)

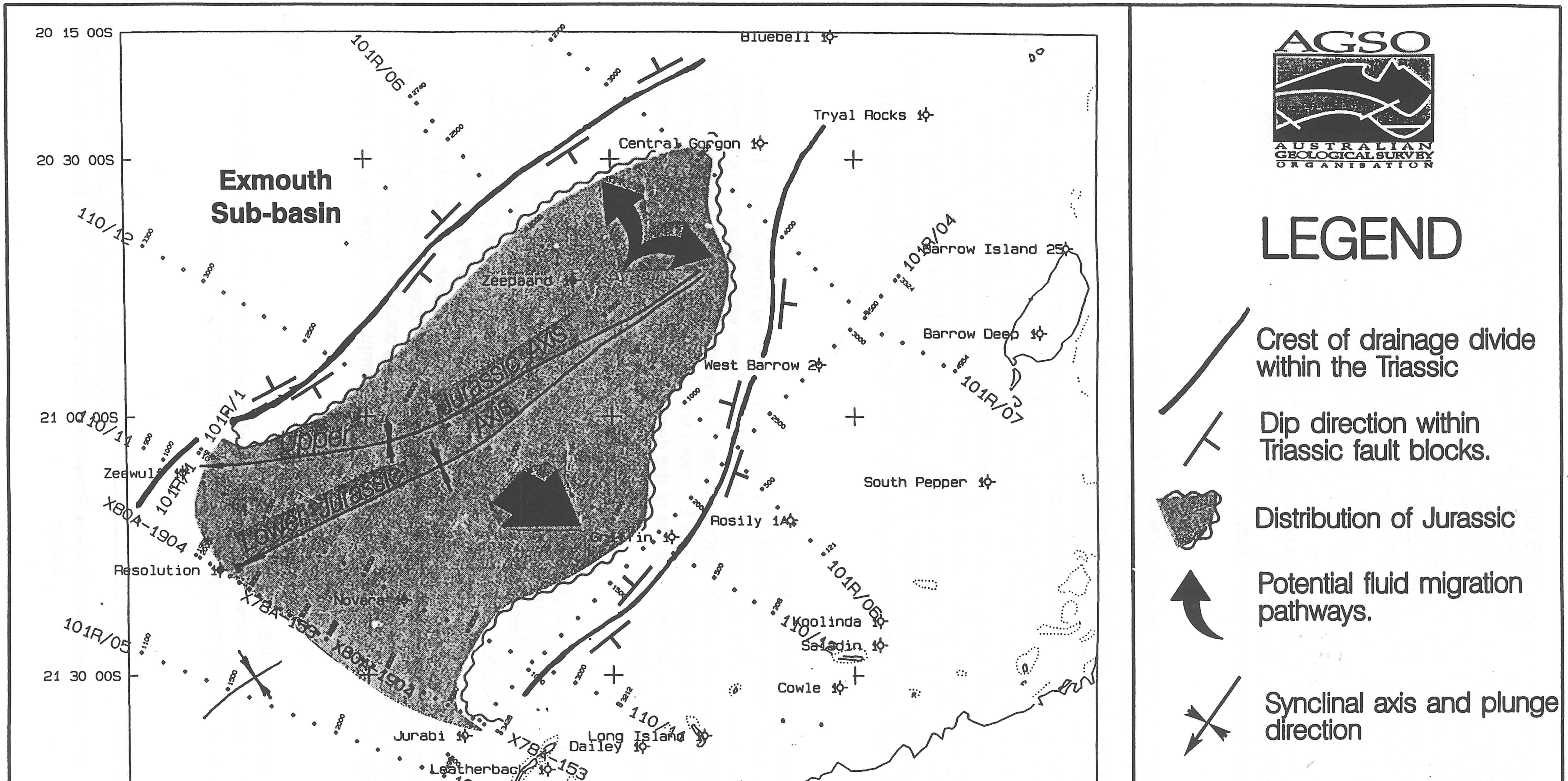
Bambra 2 has the thickest section (791 m) of the nine wells intersecting Time Slice J7. It reached total depth in this time slice, and therefore is at least 791m thick. Of those wells which did not penetrate to this time slice, all except Novara 1 in the Exmouth Sub-basin, were in the Barrow Sub-basin, and all were targeted at the Cretaceous or top Jurassic. The Exmouth and the Barrow Sub-basins underwent a brief hiatus everywhere except perhaps near the axes of the depocentres, followed by rapid subsidence and high sedimentation rates in these lows.

Palæodepositional Environments:(see Enclosures 29)

Circulation within the basin was further restricted by the uplift of the Alpha-Hilda Arch and the Rankin Trend, and fault movement on the Madeleine Trend. The basin margins were erosional, reworking mainly earlier Jurassic sediments. Sandy and mixed-lithology turbiditic intercalations (some could be described as slumps) are common proximal to the margins and rarer more remotely. Emma 1 is described as having good sands deposited from submarine fans in deeper water, overlain by middle shelf argillaceous sediments. The Exmouth Sub-basin also became a restricted circulation, low energy depocentre with deep marine clays prevailing. Some marginal slumping could be expected. Similarly, deposits in the Dampier Sub-basin represent distal sedimentation, slumping and flows from the edge of deltas.

Palæogeography:(see Enclosure 29)

An erosional regime prevailed over most of the platforms of the study area at this time, so that deposition occurred only into the rapidly subsiding Barrow and Exmouth depocentres.



Exmouth Sub-basin

Triassic & Jurassic Source Drainage and Seismic Line Location Map.

Figure 7

Water depth rapidly increased as subsidence accelerated and sediments slumped off the faulted margins and accumulated. Large influxs of finer grained sediments failed to fill the low energy, restricted depocentres.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).
The mean TOC values range from 1.2% to 1.6% with a maximum of 2.2% at Jurabi 1. The mean HI values range from 63 to 171 with a maximum of 225 at Emma 1. The mean S2 values range from 1.07 to 2.45 with a maximum of 4.01 in Emma 1. These data indicate an interval with good TOC content which has fair to poor generative potential to generate primarily gas, but with some oil in the north of the study area. The sparse vitrinite reflectance data suggest that this interval is in the pre-generative stage (immature) in the north and in the early stages of gas generation in the south..

The well completion reports provide complementary information and suggest that the interval may be more oil prone than indicated above. In Barrow Deep 1, this time slice is described as overly mature, and in Bambra 2 and Koolinda 1, it is mature to overmature. Jurabi 1 is marginally mature and this time slice is immature at Emma 1 and Dailey 1. TOC data reveal averages for the following wells of :1-2% at Emma 1, 1.73% at Dailey 1, 2.24% at Jurabi 1 (with 40-70% oil prone kerogen).

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).
Bambra 2 had strong gas and oil indications, Barrow Deep 1 had strong gas indications and a minor oil indication, and Koolinda 1 had a strong gas indication only. Minor gas shows were seen in Flag 1 and in Emma 1, which also had a minor oil show. There were only three other wells intersecting this time slice and they had no significant shows. Average porosities were derived for intervals within the following wells: Bambra 2 (5.5%), Emma 1 (10%) and Hermite 1 (18%). Measured permeabilities for this time slice were all effectively zero permeability except for a 1 metre interval within Hermite 1 which ranged 3.7-58mD. This time slice had fairly widespread claystone,siltstone and shale deposition throughout, with only a few exceptions, those being some tight sands near the top of this interval in Barrow Deep 1, and a zone near the base of this interval in Hermite 1 and Emma 1. This is the Emma Member and has been described by Hocking (1992, pp33) as an intermittent silty turbidite and in the well completion report for Emma 1 as shaly tight sands, having an average core porosity and permeability as above.

Prospectivity:
Detached, Mutti (1985) Type I, basin floor fan sands, potentially exist in the study area, but have not been identified seismically or intersected by wells due to excessive depths of burial. The deeper intersections of this time slice are bordering upon overmaturity which sets a limit on effective target depths. The depocentre is narrow and has very constricted circulation, consistent with the geochemical evidence of good source rock quality. Again within the Dingo Claystone, good porosity/permeability is the elusive key.

Traps and Plays:
Very sandy deposits from eroded fault blocks present a play down dip from Triassic structures. However, they would need to be detached in order to trap hydrocarbons, given the risk of leakage across to the upthrown fault blocks into the porous Triassic. If it is not sealed, hydrocarbons would leak into Triassic sediments and accumulate in high blocks and against dip reversals in blocks flanking the depocentre (see Figure 7). The turbidite cum slump deposits lack suitable reservoir properties, but there may be narrow, preserved shoreline deposits perched upon the margins which could provide adequate porosity/permeability characteristics.

TIME SLICE J8:

LATE JURASSIC: Early Oxfordian to Kimmeridgian: (162.0 to 150.0 MA). SEE ENCLOSURES 30 & 31

Petroleum System: Westralian.

This is the major source rock interval of the Westralian Petroleum System. It has significant turbidite sand reservoir potential.

Formation Synonyms:

Dingo Claystone, Biggada Formation Equivalent, Eliasson Formation, Lauchie Member (a shale interval within the Eliasson Fm), Angel Formation (may extend to the base of *D.swanense* (Hocking, 1992, pp36))

Regional Definition of Time Slice:(see Enclosure 3).

Time Slice J8 is biostratigraphically defined by dinoflagellate zones *D. swanense, W. clathrata, W. spectabilis*. Time Slice J8 encompasses the time of maximum transgression in the Jurassic. The top boundary coincides with an unconformity on the North West Shelf, the Papuan and Laura Basins. It also coincides with a facies change in many other basins. Biostratigraphically, the base of the time slice equates to the base of the *W. spectabilis* dinoflagellate zone and the top corresponds to major zonation boundaries in both dinoflagellate (top *D. swanense)* and spore-pollen (top *M.florida)* schemes.

Palæontology:(see Enclosure 2)

Thirteen of the study wells intersected this time slice. The thickest intersection of this time slice occurs in Barrow Deep 1, which has 1322m. Although high depositional rates are implied, this actually implies a drop in subsidence rate in the Barrow Deep 1 and Hermite 1 areas when compared to Time Slice J7, because of Time Slice J8's longer duration. The Barrow Deep 1 rate may be explained as anomalous if this was due to the incipient development of the Barrow Anticline. Jurabi 1 thickness implies accelerating subsidence in the Long Island Transfer Zone, though data are very incomplete, and are further complicated by hiatuses bordering this time slice. Deposition recommences here after a lengthy hiatus in Resolution 1 and Flinders Shoal 1, whereas the Flag 1, Bambra 2 and Emma 1 area endured only a brief hiatus, and all of the wells flanking the SE margin of the Barrow Sub-basin have an unconformity at the top of this time slice.

Dampier Sub-basin Summary:

Deposition is restricted to the Lewis Trough, the thickest section being near the trough axis. Deep basin deposition is dark grey-black, poorly fissile, moderately well compacted shale with varying amounts of quartz silt. The environment is marine, though circulation may have been restricted at times.The uplifted Rankin Trend acted as a dam to sediment which was sourced dominantly from the east. In early Time Slice J8 sources of relatively clean sand developed. The sands appear to be mass flow deposits that fed into the sub-basin from point sources on its margins. The finer material that accumulated in the sub-basin has no apparent preferential source location. Prospectivity here is judged as fair to good because this is a major source rock interval particularly in the deeper Lewis Trough, and there is potential for good reservoir quality sands. The vitrinite reflectance data suggest this interval is in the peak stages of oil generation in the Lewis Trough. The mass flow sands of the Legendre area have been unsuccessfully tested at this level, but intraformational clay seals exist and so stacked traps are possible, if closure exists at these levels.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

Complex tectonic activity continued to be experienced, albeit at lesser intensity, in the Late Jurassic because this area was impacted by the maturing stages of Argoland break-up, and the pre-breakup phase of the rift to the southwest.

Local

Although various authors nominate this period as the time of maximum subsidence, depositional rates at selected wells imply that various of the tectonic elements were behaving differently at this time. Jurabi 1's high depositional rate came to an abrupt finish at the end of Time Slice J8- implying an end to subsidence within the southeastern Long Island Transfer Zone.

The previously high depositional rate (N.B. these rates are undecompacted) in Barrow Deep 1 slowed during this time slice and continued to approximately halve in rate for each time slice within the remaining Jurassic (see also Appendix 2).

The area around Bambra 2 had constant depositional rates throughout Time Slices J8-J10, and is probably more representative of the majority of the Barrow Sub-basin (Withnell 1 in the southern Dampier Sub-basin had similar depositional rates).

Koolinda 1 also appears to have had stable depositional rates through this time with the exception of a brief hiatus on the Time Slice J8/J9 boundary. Elsewhere along this margin, (Hermite 1, Emma 1 and Leatherback 1) there are very low Time Slice J8 depositional rates and no preserved sediment from Time Slices J9 and J10, implying exposure either during Time Slice J8, or at its end, as indicated by Koolinda 1.

The majority of mid to late Jurassic basin architecture therefore appears to have been constructed during Time Slice J7 and this time slice is more involved with its aftermath, where terraced fault blocks or transfer faults resolve strain and settle further, and where loading and unloading of individual fault blocks may add impetus to these adjustments.

Lithology:

The base of this time slice is, in some of the Barrow Sub-basin, an unconformity coinciding with the conclusion of Argoland break-up. Associated with this, slightly sandier section is seen in a number of wells in the earliest part of this time slice. In Bambra 2, a sequence of argillaceous siltstones with thinly interbedded argillaceous sandstones sits on the Time Slice J7/J8 unconformity.

In the Barrow Sub-basin, a stacked series of sandy, detached basin-floor fans (Biggada Formation) were deposited in the central part. The Biggada Formation consists for the most part of massive, clean, quartz sandstone, medium to very coarse grained, sometimes granular, containing accessory jasper and minor calcite and siderite cement (McClure et al, 1988, pp382).

The middle of the three sandy reservoirs in Barrow Deep 1, is described in the well completion report as: "Mostly sand; medium to very coarse and loose, with minor thin interbeds of siltstone grading to shale, and sandstone, very fine to medium." Overlying this, and for the majority of this time slice, is the Dingo Claystone which is described by Parry and Smith (1988, pp136) as "massive, medium to dark grey silty claystone which for the most part lacks bedding as a result of rapid deposition."

Hermite 1 has a sandy interval at the top of this time slice, on top of which is an unconformity. This has been called by some, the base of the Dupuy Sandstone (Flag 1, Hermite 1 well completion reports). If so, it is older here in the NE of the Barrow Sub-basin than elsewhere. A preferred interpretation, given its *W. spectabilis* age is as a poorly developed Biggada Sandstone equivalent.

Thickness Variations:(see Enclosure 30)

The maximum isopach implies early Time Slice J8 faulting on the Madeleine Trend and later (end J8) faulting on the Rankin Trend, which precipitated such large depositional rates as seen in Withnell1 for Time Slice J9. Zeewulf 1 has 5m of sediments dated at Time Slice J8, but this interval is seen as probably a palæosol, or possibly eroded Time Slice J8 section which is redeposited here when deposition resumed in this area in the early Cretaceous.

Palæodepositional Environments:(see Enclosure 31)

Depositional sequences in the eastern Barrow Sub-basin, whether of tectonic or eustatic origin, consist primarily of lowstand systems tracts (Wulff, 1992, pp104). In the depocentral axis, deep water environments persisted for the remainder of the Jurassic (and during much of the Neocomian) phase of the supercycle.

A stacked series of sandy, detached basin-floor fans were deposited in the central part of the sub-basin. These constitute the Biggada Formation as seen in Barrow Deep 1. Other similar sand bodies may be expected in this setting elsewhere within the Barrow Sub-basin and possibly within the Exmouth Sub-basin as well as continental slope and dirtier turbiditic fan deposits.

Rich marine microfloras and widespread glauconite support moderate to deep marine depositional environment interpretations. Rapid subsidence and/or high rates of sedimentation occurred in this increasingly restricted environment.

The top of this time slice in the northeast quadrant of the Barrow Sub-basin, specifically the Campbell 1, Flag 1, Bambra 2 and Hermite 1 area, is interpreted as a prodelta environment ahead of a retreating coastline.

Palæogeography:(see Enclosure 31)

This was a time of maximum transgression with deep water in the troughs, but the uplifted eastern basin margin restricted the landward shift of the coastline. The areas of significant transgression at this time were the Kendrew and Zeepaard Terraces.

Sediment was sourced dominantly from the east. The uplifted Rankin Platform margin (Rankin Trend) acted as a dam to this source. The Rankin Trend flank of the sub-basin may also have sourced material by slumping, as may have the flanks of the Exmouth Sub-basin.

The Rankin and Exmouth platform areas may have been partially emergent or possibly shallow marine. These areas do not appear to be a major source of sediment supply, although the sands were possibly reworked from this area. Sandy mass flow deposition is possible from these flanks into the depocentres.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).

The mean TOC values range from 0.5% to 2.3% with a maximum of 6.4% at Flag 1. The mean HI values range from 73 to 186 with a maximum of 294 at Flinders Shoal 1. The mean S2 values range from 1.22 to 4.1 with a maximum of 5.96 in West Muiron 2. The large volumes of sediment deposited in this time slice have TOCs which are good to very good, and they are classed as having fair to good generative potential for both oil and gas. The vitrinite reflectance data suggest this interval is in the early and peak stages of oil generation and in the early stages of gas generation.

Restricted circulation enhanced the deposition of organic rich rocks to make Time Slice J8 an excellent source interval. It has a strongly marine character with rich marine microfloras and widespread glauconite.

Well completion reports agree with this favorable assessment, stating that high TOCs prevail in this time slice in wells such as Bambra 2, where this is seen as the source of the Flag Sandstone occurrence, and Withnell 1 which is currently generating oil. Time Slice J8 is also well placed within the basin maturation profile in that it is classed as early mature to mature in most places where it is intersected, including in Resolution 1 in the Exmouth Sub-basin - this reflects the Exmouth Sub-basin's comparable depositional history.

The exceptions to this level of maturity are seen in Dailey 1 and Emma 1, where the section is immature, but is expected to reach the maturity window nearby off-structure. In Barrow Deep 1, the base of this time slice approaches late maturity, so this would indicate that the majority of this section is well placed to be generative, with only the deepest parts of the depocentre being overmature.

The Exmouth Sub-basin has a more complex maturity profile given that Triassic sediments at total depth in Zeewulf 1 are immature at 3500m, whereas those at total depth (4200m) in Zeepaard 1 are late to overmature. Therefore the Zeewulf 1-Novara 1 area would have substantial Jurassic within the oil window whereas further to the north in the Zeepaard 1 -Minden 1 area, virtually all of the Jurassic section, and certainly into the Time Slice J8 would be expected to be overly mature.

The kerogen is almost unanimously described as good to excellent oil source with the exception of Bambra 2, which reports it as gas/condensate prone, and Barrow Deep 1 which contains a gas/condensate field seen as sourced from the enclosing sediments. This may be a result of overmaturity rather than source type.

This is the best oil source rock interval because the depositional rate possibly slowed compared with the previous time slice, and local tectonism further restricted circulation, which enhanced anoxia.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

This time slice has a proven gas/condensate zone in Barrow Deep 1 and strong gas indications in Bambra 2, as well as Resolution 1, which has an associated oil show. Koolinda 1 and Withnell 1 display strong oil indications with minor associated gas, whereas Dailey 1 and Flag 1 have minor gas and oil indications and Jurabi 1 has minor oil indications.

This is the time of the Dingo Claystone proper and is variously described as the best source rock in this region, and as an excellent seal.

In Barrow Deep 1, at the base of this time slice, there are three major porous and permeable sand bodies known as the 10,600ft, 10,900ft and the 11,250ft sands (at 3242-3254m, 3329-3363m and 3424-3500m respectively). These have significant accumulations (8.46×10^9 m^3 - McClure et al, 1988, pp378) of high pressure gas and gas condensate, with a total of 24.7m (81ft) of gas pay intersected, and the deeper two sands containing gas-water contacts.

This section is best summarised as currently generating source, mostly oil prone, with good reservoirs being rare and the claystone commonly acting as a seal.

Porosity data indicates an average figure for each of the three Biggada Formation sands in Barrow Deep 1 to be 20%,18% and 16% in descending order, and Flinders Shoal 1 has at least a 6m interval averaging over 20%. Flag 1 records more variable (5-26%), but lower average porosities at approximately 12%.

Permeability data are scarce, and therefore not representative, but show promising potential for this interval, with averages in brackets: Barrow Deep 1 (20mD), Flag 1 (3-366mD, mean ~50mD), Flinders Shoal 1 (8mD)

Prospectivity: GOOD

In a similar vein to the Dampier Sub-basin, this interval has major source characteristics and good sealing capabilities. Barrow Deep 1 has shown it capable of containing good reservoirs and it is largely within the oil generative window. The problem with this interval, in common with previous time slices, is the predictability of reservoir quality sands, and the possibility of there being traps in settings where good reservoir is likely to occur.

Traps and Plays:

Isolated sands deeper than Barrow Deep 1 would be overmature, making basin margin targets more prospective for oil. The most attractive possibility would be in reservoirs proximal to the margins of either depocentre, either trapped by intraformational seals possibly associated with facies changes, or by juxtaposition against local tectonic elements around the margins. These are difficult to map and high risk due to the largely stratigraphic component of trapping.

TIME SLICE J9:

LATE JURASSIC: Early Tithonian:(150.0 to 147.5 MA). SEE ENCLOSURES 32 & 33.

Petroleum System: Westralian.

This is one of the main source rock intervals of the Westralian Petroleum system. The combination of rapid sedimentation and local restricted marine circulation leading to anoxia has resulted in a massive accumulation of fair, to locally good, source rock. This source rock is mainly condensate to light oil prone. It is thought to be the source of the majority of hydrocarbons in the Jurassic, Cretaceous and Tertiary reservoirs in the Barrow Sub-basin. Overpressuring within this section is a major drilling problem in the area.

Formation Synonyms:
Dingo Claystone, Dupuy Sandstone Member, Dupuy Formation and Angel Formation.

Regional Definition of Time Slice:(see Enclosure 3).
Time Slice J9 is defined biostratigraphically by the *C. perforans* and *O. montgomeryi* dinoflagellate zones and is within the lower part of the *R. watherooensis* spore pollen zone. The Time Slice J9 - J10 boundary occurs within the *O. montgomeryi* zone. Time Slice J9 represents a phase of relative regression on the North West Shelf that corresponded to a shift in the Eromanga Basin from low energy Birkhead deposition to the higher energy sandsheet regime of the Adori Sandstone. The base is marked by a regional unconformity that is also observed in the Papuan and Bonaparte basins.

Palæontology:(see Enclosure 2)
Nine wells intersected Time Slice J9. Two of these wells, Barrow Island 25 and Tryal Rocks 1, reached total depth within the time slice, and so their lower boundaries are undefined. Age control on the upper boundary is fair, as it does not correspond to a dinoflagellate zone boundary, but close sampling was routinely undertaken over this interval.

Dampier Sub-basin Summary:
Deposition is restricted to the Lewis Trough. A basal unconformity or hiatus exists in wells adjacent to the Rosemary Fault System and the northern Lewis Trough. This time slice is characterised by the initiation of mass flow deposition into the deep water, partially anoxic, Lewis Trough. In the trough dark shale dominates the sedimentation with varying amounts of quartz silt. Mass flow sands are seen in wells immediately adjacent to the sub-basin's edge. The vitrinite reflectance data suggest this interval is oil generative. Prospectivity is judged to be fair to poor because, although this is a major source rock interval, none of the good reservoir quality sands are sealed. The mass flow sands have been unsuccessfully tested in several places at this level, however intraformational clay seals exist, so traps are possible.

Tectonics:(see Enclosure 1 & Figure 2).
Regional
The region continued to be tectonically active as the rift between the western and southern margin of the Exmouth Plateau and Greater India developed. This resulted in renewed uplift, subsidence and the (re)commencement of movement on the Long Island and Cape Range Transfer Zones.

Local
A regional unconformity occurs at the beginning of Time Slice J9 and substantial uplift is interpreted along the eastern margin of the Barrow depocentre where Time Slices J9 and J10 are absent. Withnell 1 in the southern Dampier Sub-basin experienced an extremely high depositional rate related to major movement on the Madeleine Fault. Growth of the Barrow Anticline resulted in decreasing depositional rates over the feature and consequent channelling of sediment in a north-northwesterly direction around the feature (Wulff, 1992, pp117). Significant uplift along the Long Island and Cape Range Fracture Zones commenced in this time slice as deposition in Jurabi 1 came to a standstill and the Leatherback 1 site became erosional. At Resolution 1 adjacent to this uplifted zone sedimentation rates increased. None of the wells in the depocentres record an unconformity at the upper Time Slice J9 boundary.

Lithology:
Deep basin sedimentation is dark claystone and shale. Interbedded with this are the chaotic slump turbidites and mass flow deposits grouped as the Dupuy Sandstone Member. This is variously described as a siltstone, or mainly sandstone, or as a sandstone with interbedded siltstone and claystone.
In Tryal Rocks 1 it is described as a medium to dark brown siltstone, occasionally light grey-brown, firm, blocky, variably sandy, glauconitic, pyritic and micaceous, with lesser sandstone, off-white, pale grey, light brown, friable to firm, very fine to medium grained with common scattered subangular to

subrounded, coarse to very coarse grains, non to very silty and argillaceous, and with minor claystone/shale.

In Barrow Deep 1 it is described as mainly sandstone, white to brown, very fine to fine, occasionally coarse, silty and argillaceous in part, with silica, dolomite and calcite cements, glauconitic in part, with rare red jasper and minor interbeds of siltstone, claystone, dolomite, lignite and siderite.

In Bambra 2 it is described as a sandstone with interbedded siltstone and claystone. The sandstone is typically very fine to medium grained and poorly to moderately sorted. Moderately abundant siderite, pyrite, silica and kaolinite choke available pore space, resulting in low effective porosity. The interbedded siltstone is medium to dark grey, blocky to subfissile, slightly to moderately calcareous and grades to a sticky claystone.

Time Slice J9 is generally sandier in the Barrow Sub-basin adjacent to the eastern basin margin, and a similar pattern is speculated to occur in the Exmouth Sub-basin.

Thickness Variations:(see Enclosure 32)

The thickest intersection occurs in Barrow Island 25 (+430m) which reached total depth within this time slice. The Barrow Anticline is a growth feature at this time so thicker section is expected off this structure, particularly in the Lowendal Syncline. The basin margins were erosional during this time slice.

The Exmouth Sub-basin is a substantial Jurassic depocentre (see the seismic interpretations of Figures 8 to12). Only Novara 1 drilled within this area, but it terminated in the Cretaceous with overpressuring problems.

Palæodepositional Environments:(see Enclosure 33).

Deposition was confined to the Barrow and Exmouth Sub-basins. These were fairly rapidly subsiding, moderately deep water (200-500m estimated), restricted marine shale basins that were probably partially anoxic at times. Tectonism initiated erosion around the margins. This fed sandier (compared to the previous time slice) mass flow deposits into these basins from sources adjacent to the active margins. Slope fan, basin floor fans and detached fan systems have been recognised.

Palæogeography:(see Enclosure 33).

Time Slice J9 is characterised by episodic turbiditic deposition into two subsiding, partially anoxic, basins. Uplift of the eastern margin of the Barrow Sub-basin caused canyon incision into, and sediment bypass of the shelf areas. Rapid turbiditic deposition and fan development was associated with times of movement on the margin faults or other tectonic activity (see Wulff, 1992, pp117 -118 for additional details). A slope fan and basin floor fan system was supplied from a silty and muddy source; its lateral extent indicates that it is the product of a multiple feeder system or even a slope apron system. (also see Hocking 1992, pp37). Basinward of the Flinders Fault System, mounds have been interpreted as slope fan channel-levee systems. These are downlapped by overlying prograding outer shelf to slope sediments. Isolated basin floor fan sands occur in the Barrow Sub-basin possibly related to maximum sea level falls. In the Exmouth Sub-basin, the palæodepositional environment at Resolution 1 is initially a low energy deepwater site of claystone accumulation, that becomes a site of turbiditic fan and slump deposits shed from the uplifting Long Island and Cape Range Fracture Zone to the south.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).

The mean TOC values range from 0.9% to 2.3% with a maximum of 4.6% at Withnell 1. The mean HI values range from 35 to 185 with a maximum of 465 at Withnell 1. The mean S2 values range from 0.52 to 3.73 with a maximum of 15.8 in Withnell 1. The TOC content is considered fair to good. As a source it is variably gas and/or oil prone, particularly oil prone around Withnell 1. Generative potential is fair, ranging to good at West Muiron 2 and very good at Withnell 1. The sparse vitrinite reflectance data suggest that this interval is in the peak stages of generation around Withnell 1, and the early stages of oil generation or very early stages of gas generation around West Muiron 2.

The fine grained basin claystone has the best source rock potential. This is a consequence of rapid deposition, restricted circulation and poor oxygenation of bottom waters in the basin areas. The more marginal, coarser sediments are poorer source rocks.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

A strong gas and oil indication occurs in Koolinda 1 and minor gas and oil indications in Barrow Deep 1 and Tryal Rocks 1. A strong gas indication occurs in Bambra 2, and there are minor oil indications in Flag 1, Resolution 1 and Withnell 1.

Reservoir quality is patchy. Bambra 2 has 8% average porosity and is tight; Koolinda 1 has good porosity but very low permeability; Flag 1 has marginal pay zones within thin sandy to shaly interbeds. The very limited porosity data show Flag 1 has porosities mainly 5 to15%; Barrow Deep 1 range 20 to 28% and Koolinda 1 range 16 to 24%. The even more limited permeability data from Flag 1 are <0.5mD except for one value of 23mD; Barrow Deep 1 has only three values which vary from 0.8 to 40mD; a 7 metre interval in Flinders Shoal 1 averaged 8mD.

Prospectivity: FAIR TO POOR

This is a major source rock interval, particularly distally to the margins and the developing Barrow Anticline but reservoir intervals in trap configurations are not common and good permeability appears rare. The good reservoir quality sands at the base of the fault bounded eastern flank of the Barrow Sub-basin are not prospective due to lack of top seal. Any hydrocarbons entering these reservoirs can be expected to migrate upward into the overlying sandy beds.

By analogy to the Barrow Sub-basin, fluvial input into the Exmouth Sub-basin would have been sourced from the east or southeast depositing reservoir quality sediments adjacent to the eastern margin.

Traps and Plays:

Intraformational traps within the turbidite and mass flow sands are possible. A number of isolated possible detached sand bodies were identified on seismic in the Lewis Trough (see the Dampier Module) and similar potential reservoirs should exist here.

A large complex negative flower structure exists in the southern Exmouth Sub-basin within the Late Jurassic and several structural trap types could be associated with it (see Figure 8). These potential plays are in water depths of less than 500m and drain a large area, but structuring is complex, reservoir parameters uncertain and the targets underlie a substantial thickness of overpressured Cretaceous. The faults in this complex may be a conduit for hydrocarbons migrating from older Jurassic source into shallower reservoirs on the upraised flanks. These reservoirs may be younger Jurassic or older Triassic (see Figure 7).

TIME SLICE J10:

LATE JURASSIC: Late Tithonian:(147.5 to 144.0 MA):SEE ENCLOSURES 34 AND 35.

Petroleum System: Westralian.

This is a major source rock in this petroleum system and is currently generative.

Formation Synonyms:

Dingo Claystone, Dupuy Sandstone Member and Dupuy Formation.

Regional Definition of Time Slice:(see Enclosure 3).

Time Slice J10 is biostratigraphically defined by the lower *P. iehiense, D. jurassicum* and upper *O. montgomeryi* dinoflagellate zones. The base of Time Slice J10 is found within the *O. montgomeryi* dinoflagellate zone. The top of the time slice represents the Jurassic/Cretaceous boundary that lies within the *P. iehiense* dinoflagellate zone. The first appearance of *C. australiensis* pollen is used as the biostratigraphic definition of the base Cretaceous in Australia. Time Slice J10 also represents a transgressive phase following the regression of Time Slice J9.

Palæontology:(see Enclosure 2)

Fourteen wells intersected this time slice and two of these reached total depth within it. Age control is fair, for although the time slice boundaries do not correspond with species boundaries, each species zone is of relatively short duration and the wells are generally well sampled over this interval. The upper boundary of this time slice is a regional unconformity that is evident in all of the wells except Resolution 1.

Dampier Sub-basin Summary:

The Lewis Trough and Kendrew Terrace wells appear to have complete sections with evidence of a minor hiatus occurring at the top in a few of the wells. In contrast, the wells adjacent to the Rosemary Fault System all appear to have part, or all, of the *P. iehiense* zone missing. The time slice is characterised by mass flow deposition into the deep water narrow fault bounded Dampier Sub-basin. The basin appears to have been anoxic at different times. In a number of the basin wells the section shows a well defined coarsening upward trend. This reflects episodic mass grain flow depositional lobe deposits. Entrenched valleys or submarine canyons are feeders for these depositional lobes. Sands entered from mainly point source locations from both flanks of the trough. Background sedimentation was mainly organic rich shales. The implication is that the reservoir sandstones are likely to be adjacent to mature source rocks, and wherever sealed should contain hydrocarbons. This time slice is highly prospective but most of the low risk structural closures at the top of these sands have already been drilled. The vitrinite reflectance data suggest this interval is in the early stages of oil generation, with source rock of fair, but not good, quality. Numerous oil, and gas condensate deposits are reservoired in this time slice which is regionally sealed by the overlying Cretaceous claystones. Lambert is a major oil accumulation, Angel is a major gas condensate field, and Wanaea and Cossack are major oil fields within this time slice (Bint 1991).

Tectonics:(see Enclosure 1 & Figure 2).

Regional

The tectonic style of Time Slice J9 continues into Time Slice J10 intensifing towards the onset of the second, Greater India, break-up phase in earliest Time Slice K1 (Malcolm et al, 1991, pp173). Volcanic activity commenced in the rift zone west of the Exmouth Plateau with resultant widespread volcanic ash falls across the Barrow, Exmouth and Dampier Sub-basins.

Local

Time Slice J10 is characterised by continued active tectonism. Tectonism had major effects in the Exmouth Sub-basin and resulted in the reactivation of basin margin faults. Uplift occured on the Peedamullah Shelf and on fault blocks along the eastern shelf margin. Growth occurred on the Barrow Anticline which restricted mass flow deposits to the Lowendal Syncline (Wulff, 1992, pp119).

At the end of Time Slice J10, marking the onset of the second breakup phase, a tectonically induced brief, but regional unconformity occurs, except in Resolution 1. A major new sediment provenance in the south becomes active.

The erosional unconformity at the top of this time slice is interpreted as being related to the uplift that occurred south of the Long Island Transfer Fault.

Lithology:

Mass flow sandstone units tens of metres thick are interbedded with thinner claystones and sandy claystones (Dupuy Sandstone Member). Correlation indicates that the sandstones form lenses up to tens of square kilometres in area, which overlap and stack to form regional sheet sands. Three lithotypes constitute this unit; fine grained homogeneous sandstones, bioturbated sandstone to claystone and matrix supported conglomerates. The sandstones occur in units less than 5 metres thick, but they are often stacked and produce reservoirs up to 50m thick. The bioturbated sediments range from reservoir quality sandstones to non-reservoir claystone, and all have been thoroughly reworked, whilst the conglomerates are interbedded with the first two lithofacies (see Tait,1985, pp283).

Thickness Variations:(see Enclosure 34)

The thickest intersection occurs in Saladin 1 (+399m) which reached total depth within the time slice. Thickness variations in this time slice can be ascribed to two factors; proximity to the sediment source on the southeast margin and the extent of erosion at the end of the Jurassic, with the former being the main determinant. The section thins over the Barrow Anticline due to syndepositional growth on this feature and possibly post depositional erosion.

Palæodepositional Environments:(see Enclosure 35)

The palæodepositional environments are similar to those in Time Slice J9. More distal basin floor areas, such as at Zeepaard 1, have fine grained abyssal plain claystones or occasionally slightly more silty pulses associated with distal fan deposition. Turbidites occur in the central area and on the eastern flanks of the Barrow Sub-basin debris flows and submarine turbidite fans occur.

Palæogeography:(see Enclosure 35)

Fine grained shales were deposited in both the Barrow and Exmouth Sub-basins, and shaly chaotic slumps and submarine turbidites were deposited immediately adjacent to the margins. This area still has restricted circulation, although less so than in Time Slice J9. Canyon incision occured into the eastern shelf area associated with ancestral rivers that flowed from the Pilbara Shield and Hamersley Ranges. Submarine fans are associated with the canyons. However some areas along the basin margin were bypassed or became sites marginal to the main fan systems, as feeder systems for the fan complexes shifted. Time Slice J10 sediments onlapped the Zeepaard Terrace, the Rankin Trend and some blocks of the Flinders Fault System. Mass-flow deposition (Dupuy Sandstone Member) commonly stopped at the top of *D. jurassicum.* Volcanic ash falls, probably from sources to the west, may have been deposited in this time slice. A widespread hiatus occurred at the end of this time slice.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6).

The mean TOC values range from 0.6% to 3.7% with a maximum of 21% at West Tryal Rocks 1. The mean HI values range from 95 to 184 with a maximum of 234 at West Tryal Rocks 1. The mean S2 values range from 0.86 to 9.94 with a maximum of 40.5 in West Tryal Rocks 1. TOC content is good, but generally gas prone, except at West Tryal Rocks 1 which also has some potential for oil. Generative potential is poor in the south, ranging to fair to good in the north. The vitrinite reflectance data suggest that this interval is in the peak stage of oil generation and in the earliest to early peak stage of gas generation. As with the earlier Jurassic time slices maturity depends upon the depth of burial and this is strongly controlled by location within this tectonically active setting.

Zeepaard 1 has good oil sourcing potential from the deep marine clays of the basin floor; Bambra 2 yielded high TOC values from a similar setting but is gas/condensate prone and unlikely to be a major oil source.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

South Pepper 1 has a total 5m proven gas zone, with a trace of oil. The reservoir is a very fine grained tight sandstone with interbedded sandy claystone. It has an average porosity of 12.5%. Koolinda 1 has strong gas and oil indications; Barrow Deep 1, Tryal Rocks 1 and Zeepaard 1 have minor gas and oil indications; Flag 1, Jurabi 1 and Resolution 1 have minor oil indications, whilst Central Gorgon 1 has a minor gas indication.

Good reservoirs are rare in this time slice. Commonly porosity is poor to good; Saladin 1 average porosity over a 6m interval is ~22%; Koolinda 1 average porosity ~19%. Regionally the permeability is very low, but Flag 1 has one spot permeabilty measurement of 75mD and Campbell 2 encountered good sands in this time slice but no porosity/ permeability data are available (see the well completion report).

Prospectivity: PROSPECTIVE CLOSE TO THE SOUTHEAST MARGIN OF THE BARROW SUB-BASIN WHERE POROSITY AND PERMEABILITY HAVE BEEN PRESERVED, AND ON MIGRATION PATHWAY, BUT ALWAYS HIGH RISK DUE TO LACK OF CERTAIN SEAL.

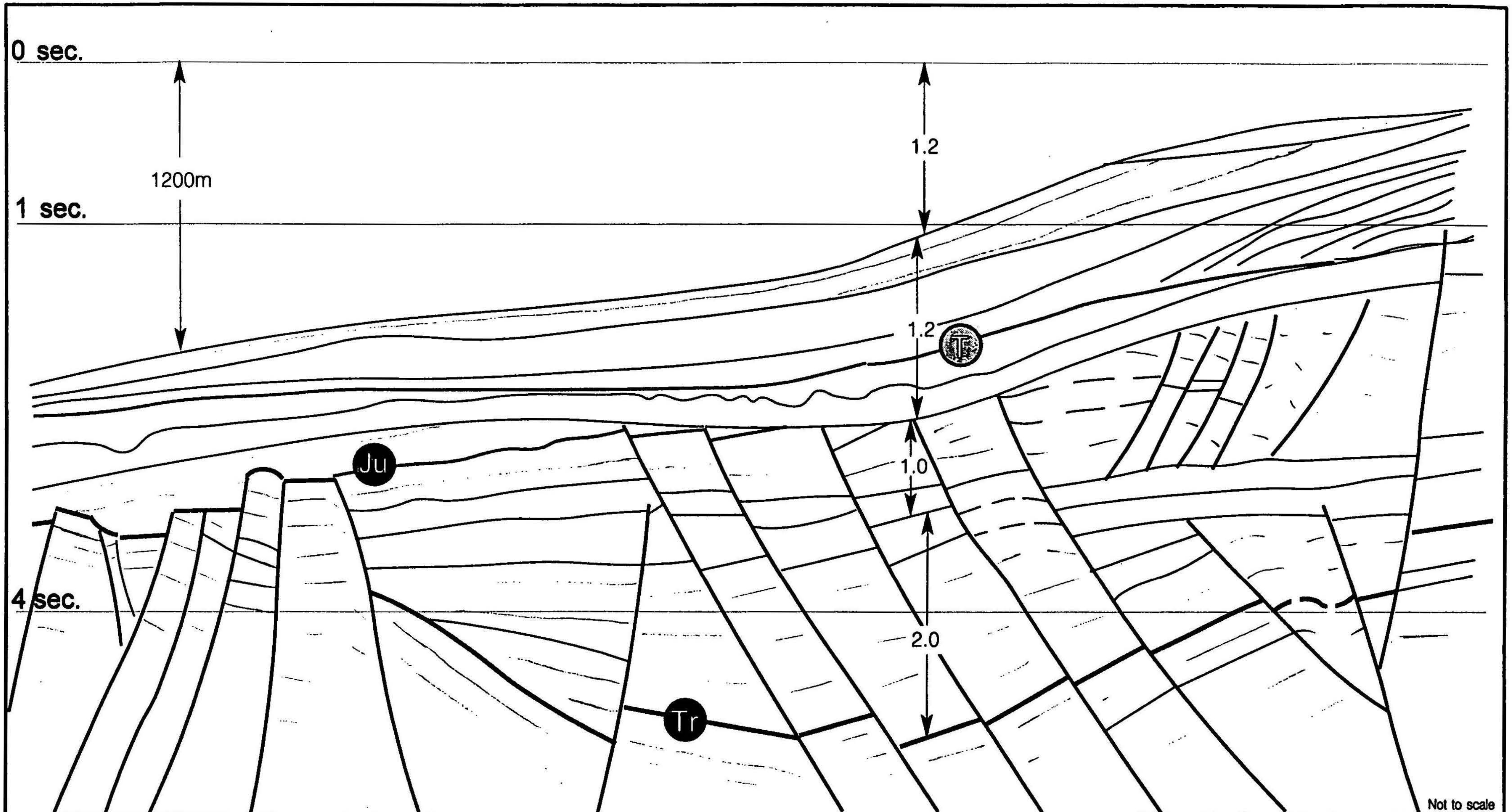
Source is not a major risk factor. The Late Jurassic is a good to excellent source rock that is currently generative in the Barrow Sub-basin, and most likely in the Exmouth Sub-basin as well. The lack of permeability is the major risk in the distal (central basin area) mass flow sands where porosity is lowest as well. Seal, lateral and/or vertical is the main risk on the proximal portions of the mass flow sands adjacent to the basin margins.

Traps and Plays:

Very good porosities but with variable permeabilities, are found in the submarine fans sourced from the Peedamullah Shelf. Any traps within these fans would constitute targets. The complex faulting of the east margin of the Barrow Sub-basin makes mapping of top structure difficult and there is always an element of lateral fault seal risk. Intrafan shale drapes could create traps if appropriate structuring were present at this level. Lowest risk might be in detached fans. The Barrow Anticline was a growth feature during Time Slice J10 and deflected mass flow sands around it. Therefore the eastern flank of this feature provides a site for stratigraphic pinchout traps.

Similar possibilities exist in the Exmouth Sub-basin where mass flows from the south may be deposited into deep water with dominantly fine-grained deposition and low circulation rates that could provide similar source rock quality to that in the adjacent Barrow Sub-basin. Mass flow sands that provide reservoir are predicted for the Exmouth Sub-basin but the lack of Jurassic well information means that play types are more speculative.

In South Pepper 1, the Dupuy Sandstone Member was penetrated outside its mapped closure. The well did not penetrate the entire sand sequence but did encounter oil higher in the section, suggesting that updip potential exists (see WCR).



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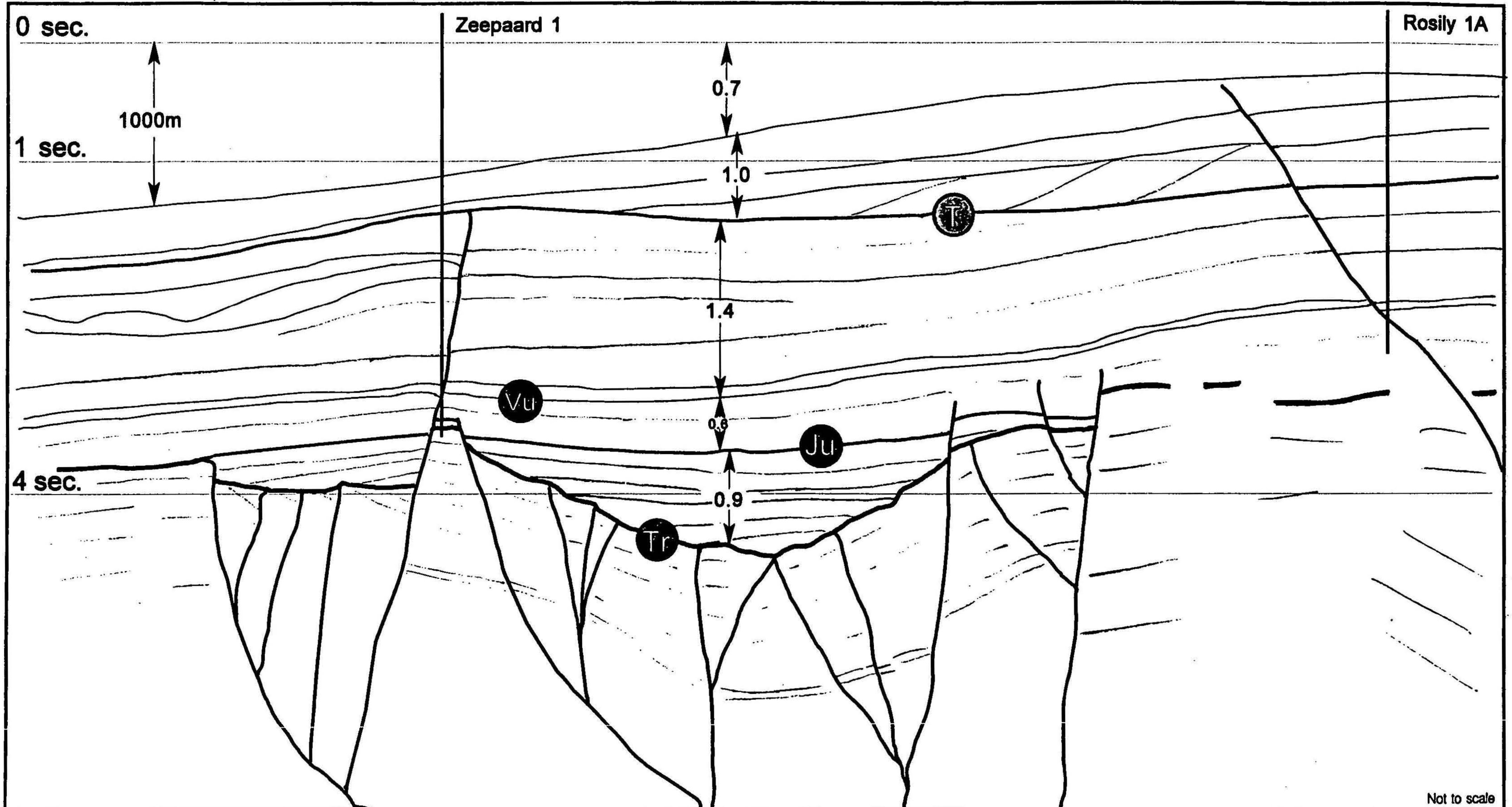
Diagrammatic Interpretation Seismic Line 101R/05

Australian Petroleum Systems Project 1994: EXMOUTH-BARROW SUB-BASINS MODULE

Figure 8



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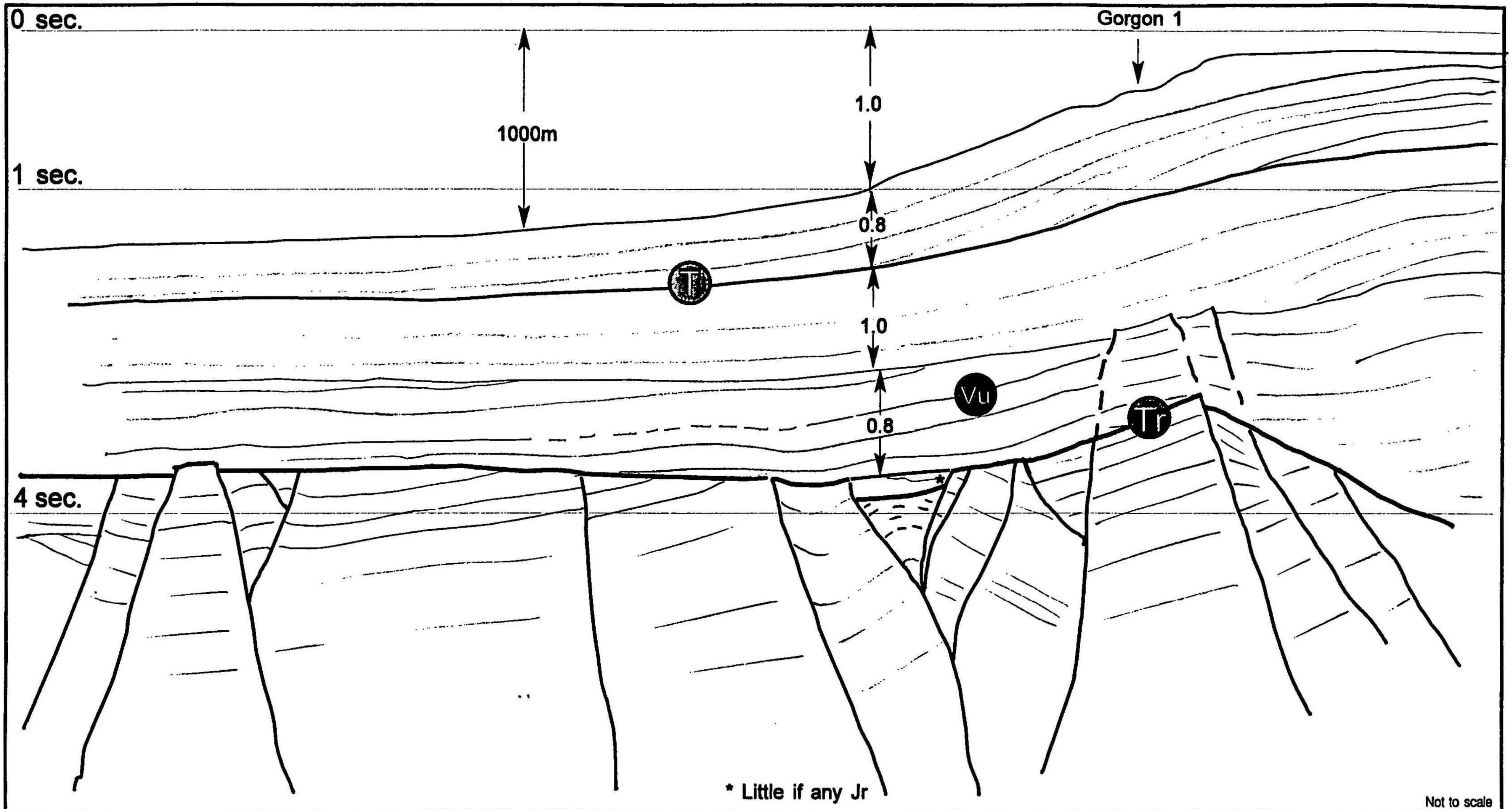
Diagrammatic Interpretation Seismic Line 101R/06

Australian Petroleum Systems Project 1994: EXMOUTH-BARROW SUB-BASINS MODULE

Figure 9



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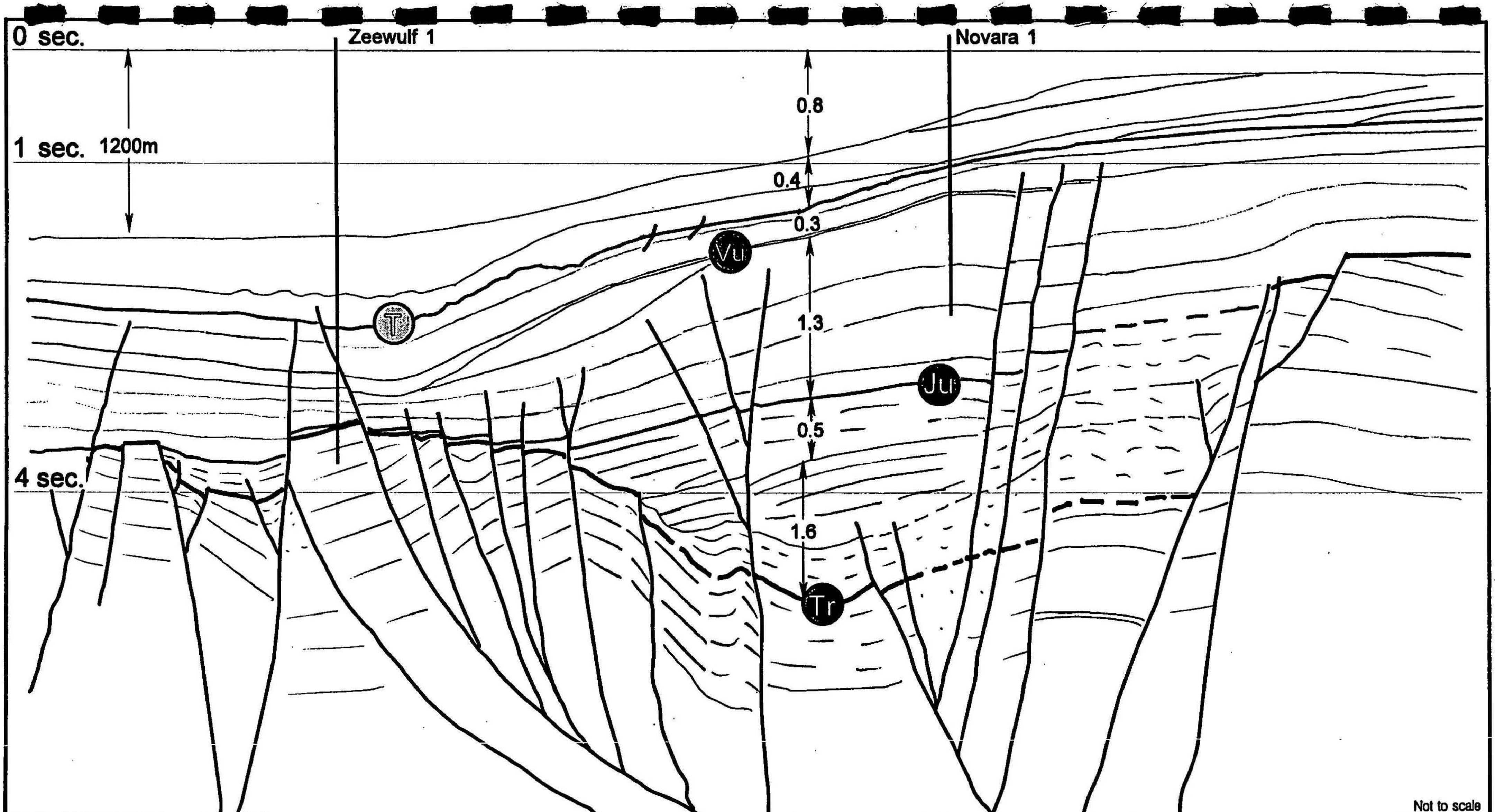
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Diagrammatic Interpretation Seismic Line 101R/07

Figure 10

Australian Petroleum Systems Project 1994: EXMOUTH-BARROW SUB-BASINS MODULE



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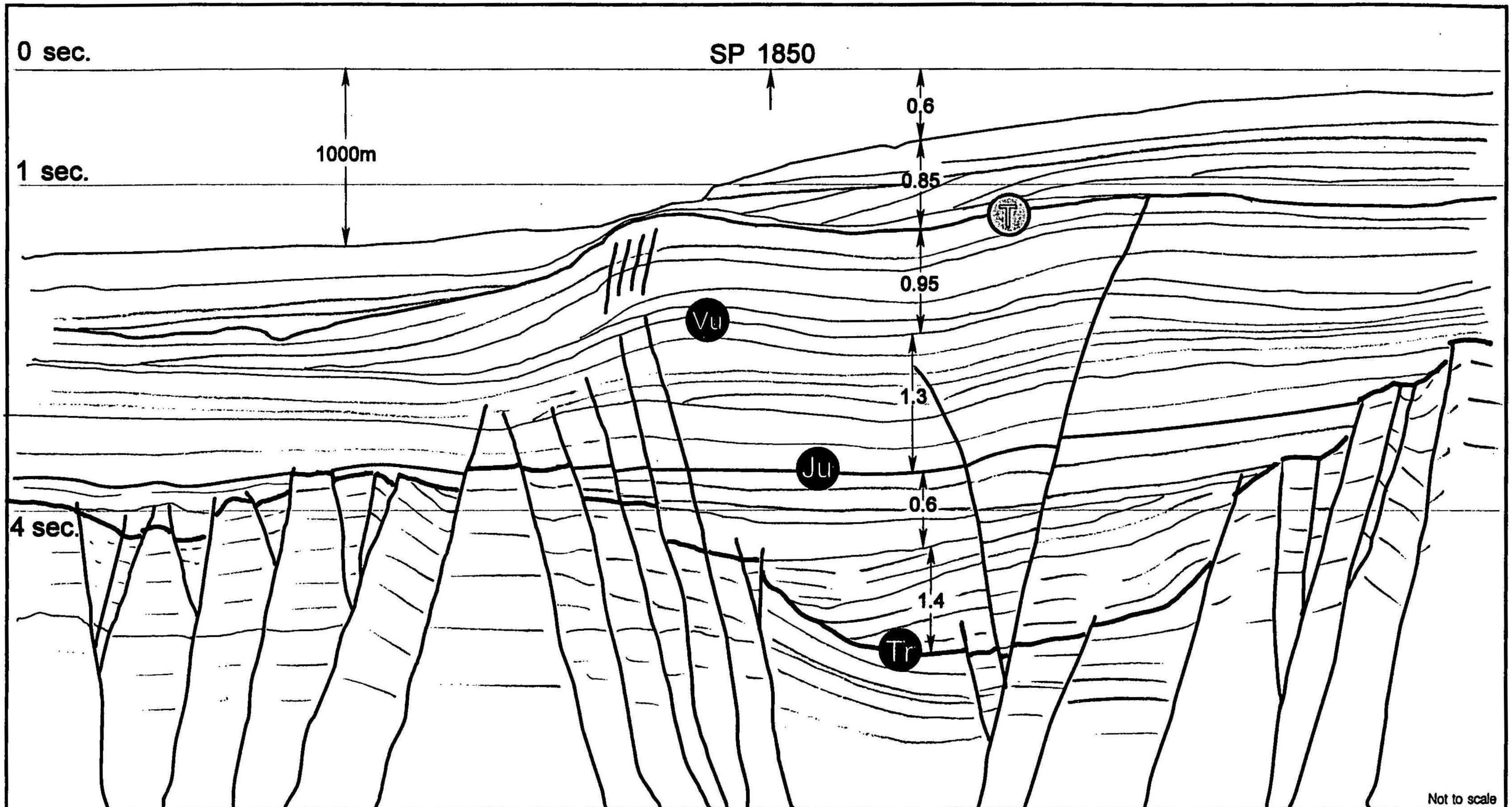
Diagrammatic Interpretation Seismic Line 110/11

Australian Petroleum Systems Project 1994: EXMOUTH-BARROW SUB-BASINS MODULE

Figure 11



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Diagrammatic Interpretation Seismic Line 110/12

Figure 12

CRETACEOUS TIME SLICES

TIME SLICE K1:

EARLY CRETACEOUS: NEOCOMIAN: BERRIASIAN TO EARLY VALANGINIAN: (144.0 to 137.0 MA): SEE ENCLOSURES 36 & 37.

Petroleum System: Westralian.

Very restricted marine circulation in the southern Barrow Sub-basin during the latest Jurassic and earliest Time Slice K1 infers marine anoxic conditions existed. Good oil prone source rocks should exist in the southern Barrow Sub-basin, beneath the Barrow Group.

Formation Synonyms:

Barrow Group equivalent, Barrow Megasequence, Lower Barrow Group, Barrow Unit D, Barrow Unit C, Barrow Unit B, Barrow Unit A, Dupuy Formation, Malouet Formation, Flacourt Formation, Forestier Claystone, Airlie Member and Flag Sandstone. Minor equivalents are Wogatti Sandstone, Yarraloola Conglomerate and Nanutarra Formation.

Regional Definition of Time Slice:(see Enclosure 3).

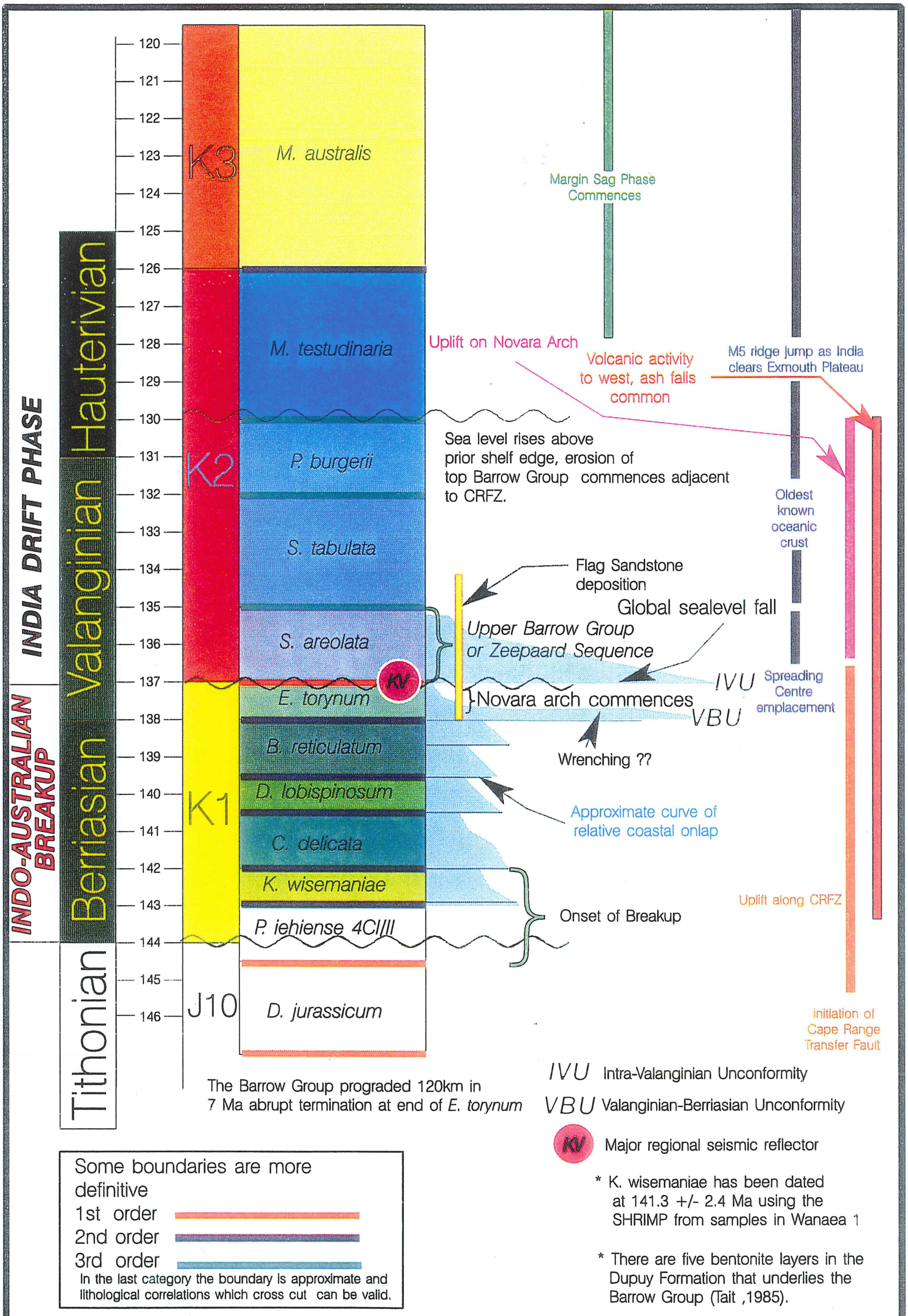
The Time Slice is defined by dinoflagellate zones *E. torynum, B. reticulatum, D. lobispinosum, C. delicata, K. wisemaniae* and *P. iehiense*. The base of Time Slice K1 is defined as the Jurassic/Cretaceous boundary. This is within the *P. iehiense* dinoflagellate zone and at the base of the *C. australiensis* spore-pollen zone. The top is defined as the top of the *E. torynum* dinoflagellate zone and the *C. australiensis / F. wonthaggiensis* spore-pollen boundary. The top of Time Slice K1 represents a major unconformity on the western margin of the Australian continent and may correspond to a major sea level fall.

Palæontology:(see Enclosure 2).

This time slice was intersected in twenty wells. The age control is poor to fair. On the basis of the available data, there is evidence for a regional hiatus at the base of Time Slice K1. This varies between wells but as a minimum includes the upper *P. iehiense* and lower *K. wisemaniae* zone. The top of the time slice is also thought to be a hiatus although it is less well defined.

Dampier Sub-basin Summary:

Time Slice K1 is bounded by a significant unconformity on both upper and lower surfaces. There are altered volcanic ash beds (montmorillonitic bentonite layers that cause major wash outs) at the base of Time Slice K1 *(K. wisemaniae)*, in Wanaea 1 (Bint 1991, p28). They are dated at 141 ± 2.4 Ma.. The pre-Barrow Group bentonites discussed in Tait (1985) are possibly older, but are currently interpreted to indicate that Time Slice J10 style of deposition continued into the base of Time Slice K1. Along the Rosemary Fault System the *P. iehiense* zone is absent suggesting possible fault movement at this time. The Rankin Trend and De Grey areas were positive features at the commencement of Time Slice K1 deposition. The Rankin Trend shows progressive onlap and burial from the south by the distal deposits of the prograding complex in the Barrow - Exmouth areas. By *C. delicata* time most of the Rankin Trend was onlapped. Significant Time Slice K1 deposition is confined to the Lewis Trough and Kendrew Terrace.



AGSO

Time Slice K1 to K3 Event Summary

Figure 13

Tectonics:(see Enclosure 1 & Figure 2).

Regional

Time Slice K1 defines the ***second syn-rift phase*** of final breakup and separation of India from Australia. The base of the Time Slice is coincident with the onset of breakup and the top is thought to mark the completion of breakup, though this may be slightly younger.

The major events which impacted on the area are;

(a) Movement on the Cape Range Transfer Fault and associated Long Island Transfer Zone. Breakup proceeded by relative westward movement of the Indian continent along the Cape Range Transfer Fault. To the south of this zone the land was uplifted and provided a source for the prograding complex which infilled the rapidly subsiding Barrow and Exmouth Basins to the north. The uplift is possibly related to the emplacement of basic dykes, at depth, adjacent to the Cape Range Fracture zone.

(b) Syndepositional faulting occurred during the deposition of the prograding complex. Towards the end of the time slice wrenching and uplift occurred including movement on the Barrow Island anticline and Novara arch. The hiatus at the base of Time Slice K1 may be coincident with fault block rotation on the Exmouth Plateau (Barber 1982).

(c) Pronounced volcanic activity occurred throughout the time slice. The main volcanic sources appear to have been to the west of the Exmouth Plateau, in the rift valley area present at the time. Sources to the south in the vicinity of the Cape Range Transfer Fault may also have existed.

(d) Commencement of drift, and associated emplacement of a spreading centre at the very end of Time Slice K1.

Local

The Time Slice K1 tectonism is a result of regional tectonic events summarised above.

Lithology:

Sandstones, siltstones and claystones dominate the section sourced from the Gascoyne Sub-basin area. Pebbly conglomeratic sandstones, glauconitic sandstones and carbonaceous material are secondary lithologies. In general the mass flow sandstones and slope claystones dominate the section. This is a result of the dominance of progradation over aggradation in the complex. The overall sequence tends to display coarsening upward cycles, with internal fining upward cycles within the mass flow deposits. These commence as fine to medium grained erosive based sandstones that become glauconitic (distal mass flow), to coarser grained varieties that show massive fluid escape features (proximal mass flow). The claystones become siltier and more carbonaceous up the section. The sandstones of the uppermost sections, although mineralogically similar to the deeper units, show bedding features of fluvial, or coastal environments. They also tend to be more argillaceous and contain scattered plant fragments.

Deposits fed from the Pilbara Province are generally fine grained homogeneous sandstones to fine grained argillaceous sandstones and claystones. Bioturbation is common. Indications of large scale slump structures and storm generated turbidites are seen (see Thompson et al 1990).

Thickness Variations:(see Enclosure 36)

A maximum thickness of 1463m was encountered in Novara 1 which reached total depth within this Time Slice. The zero edge to the south is tectonically controlled by the Long Island Transfer Fault. Two depocentres are evident, one centred roughly on the Barrow and the other on the Exmouth Sub-basin. They are separated by the Alpha Hilda Arch-Rankin Trend. The isopachs thin to the north and reflect a pattern which implies a dominant source area to the south of Novara, probably the Gascoyne Sub-Basin.

Palæodepositional Environments:(see Enclosure 37)

The wedge of sediment that prograded north has been variously termed the Barrow Delta, a delta complex or a clastic wedge or prograding complex. The term used here is prograding complex. At least six sequence stratigraphic intervals have been identified within this prograding complex. They loosely correlate with the identified dinoflagellate zones except that two sequences may be defined within the *B. reticulatum* zone (Thompson et al 1990). The major tectonism characteristic of this Time Slice makes correlation of the local section with global sealevel curves a highly contentious exercise (as above).

Within this prograding complex numerous palæodepositional environments have been recognised, or inferred. These include

- **Sub aerial delta**: fluvial channels, point bars, overbank, delta distributary channels and alluvial fans
- **Coastal plain**: beach, fluvial, delta plain and lower delta and estuarine and tidal environments.
- **Slope and Rise**: various style of turbidites, submarine fans and slumps are particularly common on the subaqueous slope of the northerly advancing prograding complex.
- **Basin Floor**: fans and turbidites tend to accumulate at the base of slope of advancing prograding complex and basinal shales accumulated distal to this front in the deepest water.

It appears characteristic of this succession that only a narrow zone that might be classified as a shelf environment existed. There is also subjective evidence that the marine energy increased throughout the K1 interval so that the younger coastal environments tend to be more wave and tidally dominated and the older section more fluvially dominated.

Palæogeography:(see Enclosure 37)

Two major sources of sediment were active during Time Slice K1.

The main source area was to the south of Novara 1, probably the Gascoyne Sub Basin. The enormous volume of sediment deposited implies major uplift in this area. Whether one or several drainage areas fed the prograding wedge is unclear but it does appear that the Alpha-Hilda Arch provided a major divide that deflected the bulk of the sediments away from the Barrow Sub-basin, at least in the earliest part of Time Slice K1. It is speculated that the deflection was related to the Long Island Transfer Fault. Water depths to the basin floor have been estimated at between 200m and 500m(Jones and Wonders 1992) and there is no reason to suspect depths much greater than this existed. The rate of sedimentation far exceeded the capacity of the basin to redistribute it and the shoreline advanced northward 120 km in approximately seven million years. It is unclear from the current work whether this source was ever a direct contributor to the coarser sediments of the Barrow Sub-basin. What is clear is that the detailed aspects of the growth of the clastic wedge are quite complex.

A second sandier source was from the Pilbara Craton via the Peedamullah Shelf. This fed exclusively into the Barrow Sub-Basin across the Flinders Fault Zone. The Fault Zone was active throughout Time Slice K1 and sourced reworked earlier Mesozoic and late Permian sediments along the eastern boundary of the Barrow Sub-basin. In latest Time Slice K1 a relative sea level fall occurred that is thought to have resulted in shelf incision and commencement of a major deep water sandy Mutti type I (Mutti 1985) fan - the Flag Sandstone.

During the earliest stages of Time Slice K1 sedimentation in the Barrow Sub-basin area was essentially a continuation of Time Slice J10 style with submarine fans and slumps of the Flinders Fault System occurring. The prograding complex is interpreted to have been restricted to the Exmouth Sub-basin. Later in Time Slice K1 the prograding complex sourced from the Gascoyne Basin area overtopped the Alpha-Hilda Arch and the Barrow Sub-basin became a secondary locus for deposition from this source.

A subsidiary source of sediment is volcaniclastically derived ash falls that have subsequently been altered to bentonitic layers. A well defined source(s) for this component of the sedimentation is not established but the areas of the Wallaby, Wombat, Joey Rises and the developing mid oceanic spreading centres all could be potential source areas (Thurow & von Rad 1992, Figure 2 p92). It is speculated that the bentonitic ash layers were deposited episodically by westerly directed high level winds. Their importance is obvious. If identified and accurately dated they offer a potentially more reliable method for stratigraphic subdivision of this section than that currently available.

The primary source of sediments appears to have been abruptly terminated at the end of Time Slice K1 (Arditto, 1993, p151 and Thurow & von Rad 1992, Figure 4, p96), though previous work implied a slightly younger date, within Time Slice K2, for this event. The termination of the sediment supply is interpreted to be coincident with and a consequence of breakup.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)
The mean TOC ranges from 0.3% to 3.9% with a maximum of 8% in Flag 1. The mean HI values range from 38 to 382 with a maximum of 398 in Griffin 1. The mean S2 values range from 0.18 to 6.14 with a maximum of 77.9 in West Tryal Rocks 1. The vitrinite reflectance data suggests the sediments are mature in the deep basin and immature to marginally mature on the basin flanks. The higher TOC values correspond to the slope and basin shale environments.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).
Sixteen of the wells have significant shows. Major accumulations of hydrocarbons occur in Campbell 2, South Pepper 1 and Griffin 1. Porosity measurements are highly variable and range from 30% to 25% at depths of 1500m. The majority of the data is in the range 12 to 25%. Porosities of 15% are preserved at depths of 3500m. Permeability measurements are highly variable, but good to excellent permeability can be anticipated for any of the sandstone facies that were initially mineralogically mature and/or of coarser grain size, irrespective of burial depth.

Prospectivity: HIGHLY PROSPECTIVE, MODERATE TO HIGH RISK, OIL & GAS CONDENSATE PRONE SOURCED INTERNALLY AND FROM UPPER JURASSIC J6 TO J10.
The interpreted restricted circulation in the Barrow Sub-basin during the latest Jurassic and earliest Time Slice K1 implies a potential for good oil prone source rocks to exist, especially in the southern Barrow Sub-basin, beneath the prograding complex. (see the preceding sections). The deepest wells here, Rosily 1A and West Barrow 2 only penetrated to the *D. lobispinosum* zone meaning that the source potential immediately beneath the prograding complex has not been evaluated.
Good source rock quality is also established for the slope shaley facies within the sediments of the K1 prograding complex and these sediments are currently mature. Good reservoir quality exists within the sandy fans sourced from the Pilbara province and variable though generally good quality reservoirs exist in submarine slope and basins fans sourced from the Gascoyne province.

Traps and Plays:
Most wells have not drilled Time Slice K1 as a direct target, rather the top Barrow Group is mapped and the target is sands sealed beneath the regional Muderong Shale seal. As a general rule any hydrocarbons trapped in the upper Time Slice K1 tend to be a result of this seal. Structural targets at the top Barrow Group- eg Griffin 1 and South Pepper, are sealed by the overlying Muderong Shale. These targets are normally not specifically aimed at Time Slice K1 sediments. Time Slice K1 becomes reservoir in those situations were the oil leg, generally reservoired in Time Slice K2 or K3 sediments is sufficiently long to extend into Time Slice K1.
Time Slice K1 can be a structural target in its own right. South Pepper 1 was drilled on a closure mapped at the top Barrow Group and was successful at this level. It also encountered a 3m oil leg in sands in the shaley lower Time Slice K1. The oil is thought to be sourced from the underlying Jurassic claystone. At this level the well is probably significantly outside the upper closure (see Williams & Poynton 1985 Fig 8). The oil is either a stratigraphic trap but a separate deeper structural culmination is apparently possible. Structural prospects, sealed by intra Time Slice K1 shale obviously exist but need to be mapped at the target level.
Fault closure of lower Time Slice K1 against Late Jurassic is an additional potential variation on the four way dip closed structure. The Upper Jurassic is generally shaly, overpressured and a potential

source rock. Fault seal risk is lowest under these conditions. No examples of this type of trap have been observed.

The sandy fans of the area are well established reservoirs on structural targets within the Flag area. The distal pinchout area towards Withnell 1 warrants attention as there is potential for dip reversal across the Cape Preston Arch. Reservoir quality is anticipated to be reduced in the area due to anticipated finer grain size. However the sandy fan margins interfinger with thick basinal shales and small fault offsets could easily compartmentalise the reservoir.

Isolated detached fans are a possibility and indications of their existence is seen as mounding on seismic lines that cross the axis of the basin.

Stratigraphic traps within submarine fans, particularly within the lower slope and base of slope environments are considered the most prospective of the subtle traps. They immediately overlie or are interbedded with currently mature potential source rock. Grain size, porosity and permeability, are likely to be maximised at this location on the fans. West Barrow 2 was drilled on this concept, however post drill evaluation tends to suggest that closure was absent. This highlights the difficulty of mapping out these plays using seismic.

TIME SLICE K2:

EARLY CRETACEOUS: NEOCOMIAN: EARLY VALANGINIAN TO EARLY HAUTERIVIAN: (137.0 TO 126.0 MA):SEE ENCLOSURES 38 & 39.

Petroleum System: Westralian.

Time Slice K2 is an important reservoir sequence in the Barrow Sub-basin, although the dominant factor is the overlying Time Slice K3 regional seal.

Formation Synonyms:

Winning Group, Barrow Group Equivalent, Barrow Unit A(?), Barrow Unit B(?), Muderong Shale, Mardie Greensand (Flores and Tunney Members), Birdrong Sandstone, Upper Barrow Group, Zeepaard Sequence. Minor equivalents are Yarraloola Conglomerate and Nanutarra Formation.

Regional Definition of Time Slice:(see Enclosure 3)

Biostratigraphically the base is defined by the *E. torynum / S. areolata* dinoflagellate zone boundary and the *C. australiensis / F. wonthaggiensis* spore-pollen boundary. It covers the *M. testudinaria, P. burgeri, S. tabulata* and *S. areolata* dinoflagellate zones. It equates to the M10 magnetic anomaly and to the start of a major phase of sea floor spreading along the western margin in the Perth, Cuvier and Gascoyne Abyssal Plains. The base of Time Slice K2 represents a major unconformity in many basins, particularly on the western margin of the Australian continent. It also corresponds to a major sea level fall on the Haq et al (1987) chart.

Palæontology:(see Enclosure 2)

Generally the palynology control is poor to very poor over this interval. Time Slice K2 is interpreted as present in a total of twenty four wells. It is absent from five wells at the southern end of the area. Time Slice K2 is probably bounded by a significant hiatus on the lower surface, that defines a basin wide sequence boundary. This boundary is not necessarily clearly defined by the current biostratigraphy but can be inferred from most seismic sections with well control. (see Figure 13, seismic horizon KV).

On the basis of generally poor age control in critical study wells, and its high prospectivity, this section is the one most in need of resampling and reinterpretation. Because of the poor age control the K1-K2 boundary is the mostly likely to change significantly in the future.

Dampier Sub-basin Summary:

Maximum preserved thickness occurs in Withnell 1(150 m) and thins towards the northeast end of the Lewis Trough. The Rankin Trend was a submarine topographic high progressively onlapped during Time Slice K2. Basinal deposition is dark claystone. The claystone's quartz and glauconite content increases towards the east and northeast. In Wanaea 1 there is an increase to 10-25% quartz silt or very fine grained quartz sand in the claystone. On the Enderby Terrace greensands dominate becoming more quartzose to the north. Porosity in the greensands ranges from nil to approximately 25%. The greensands developed in situ on a shallow, moderate to low energy, marine middle to outer shelf environment and clays were deposited offshore in deeper water on the shelf edge and continental slope. The pattern of facies suggests a minor clastic quartz source to the east or northeast of De Grey 1. Occasional storm action deposited limestone and dolomite layers in deeper water adjacent to the shelf or these may be in situ deposits. Talisman and Wandoo Fields are productive from this Time Slice. A pattern of better source quality to the south in the vicinity of Withnell 1 and Rosemary 1 is apparent.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

The early drift phase of Greater India from Australia and the beginnings of the Gascoyne and Cuvier Abyssal Plains occurs in Time Slice K2. Initial movement of the Indian Plate away from Australia was along the Cape Range Fracture Zone. The oldest known oceanic crust adjacent to the Exmouth Plateau is M10 age (late *S. tabulata*), however it is probable that older crust exists beneath the Tertiary section immediately adjacent to the continent ocean boundary. The inference from biostratigraphic and stratigraphic considerations is that breakup occurred at Time Slice K1/K2 boundary (top *E. torynum*). India did not clear the Exmouth Plateau until magnetic reversal anomaly M5 (mid *M. testudinaria*), which is also coincident with a ridge jump. Following this event the area entered a continental margin sag phase. Time Slice K2 is characterised by a continuous reduction in clastic input. This time slice also marks the commencement of a major transgression following the separation of Greater India from Australia (Veevers, 1988), and the commencement of margin sag.

Local

Basin inversion occurred near Novara 1 during latest Time Slice K1 and earliest Time Slice K2 resulting in the northeast - southwest trending Novara Arch. Uplift on the Novara Arch could have commenced as early as *D. lobispinosum*, but the most likely timing is at the end of Time Slice K1, in late *E. torynum*. This event appears to be coincident with the termination of the sediment supply from the Gascoyne Sub-basin area that fed the Time Slice K1 prograding complex.

Lithology:

Several facies groups are present within this Time Slice. For detailed descriptions see Thompson et al (1990).

<u>Sandstones</u>

- Thin calcite cemented sandy conglomerate in Flinders Shoal 1- distal Yarraloola Conglomerate
- Glauconitic conglomerates with jasper (sourced from Pilbara area)- shoreface
- Bioturbated greensands - lower shore face, tempestites and grain flows.
- Quartzose medium to fine grained sandstones- shoreface and submarine turbidites.
- Laminated fine to medium grained quartz sandstones and claystone - tidal.
- Coarse to very coarse grained cross bedded quartz sandstones - channel and bar, beach, upper shoreface and tidal- a massive variety occurs as a submarine fan.

Siderite, skeletal fragments and carbonised wood fragments are minor constituents in some of the sandstones.

Claystone and siltstone occur throughout the section as overbank deposits, prodelta and slope deposits and tend to be carbonaceous. Grey calcareous bioturbated claystone to shale is the basin floor facies.

Thickness Variations:(see Enclosure 38)

Basin inversion resulted in the Novara Arch developing near Novara 1. As a consequence Time Slice K2 is absence at Novara 1, which was the sight of maximum deposition in the preceding Time Slice K1. The arch divides the area into two depocentres the major one centred on the Barrow Sub-basin. Maximum interpreted thickness occurs in Tryal Rocks 1 (539m). A north northwest axis through Tryal Rocks 1 and Bambra 2 defines the main Time Slice K2 depocentre. A minor secondary depocentre occurs in the vicinity of South Pepper 1 and Flinders Shoal 1. Time Slice K2 deposits overstep Time Slice K1 deposits on the Candace Terrace and Peedamullah Shelf.

Palæodepositional Environments:(see Enclosure 39)

The major source of sediment that produced the Time Slice K1 prograding complex was abruptly terminated at or near the end of Time Slice K1. The lower most section of Time Slice K2 is a continuation of sedimentation style similar to that of Time Slice K1, and is variously known as the Upper Barrow Group or Zeepaard Sequence (Arditto 1993). It is possible that this sequence is sourced from the uplifted Novara Arch. The base of Time Slice K2 is coincident with a major sea level fall. Sea level falls in the vicinity of the K1-K2 boundary are proposed variously for the base of *E. torynum*, *S. areolata* and *S. tabulata* but the issue is not clarified by the module data set. It appears certain that at least one significant sea level fall did occur within this interval. This is based on the dating of the Flag Sandstone. This facies is best explained as a low stand canyon fed fan system. The rise following the fall is extremely rapid but it is thought that the lower Time Slice K2 built out a predominantly wave dominated delta sequence because the sediment supply exceeded the rate of sea level rise. Supply to the Flag Sandstone continued throughout the earliest stage of this rise. Following these earliest events Time Slice K2 is characterised by a marked reduction in sandy clastic sedimentation.

The remainder of Time Slice K2 is characterised by a transgression. A tidal delta plain sequence developed on the eastern margin of the Barrow Sub-basin where a source of minor sand still existed. Tidal channels and lower shore face sediments are recognised and fluvial braided sedimentation is speculated for the immediate hinterland. The last sands of the Flag Sandstone are deposited. In the Exmouth Sub Basin area the area of the clastic wedge was above sea level and probably not a site of active deposition.

By middle to late Time Slice K2 the sea level had risen above the edge of the prograding complex. Rapid transgression of the shoreface across the top of the prograding complex occurred. A source for coarser grained clastic was available for reworking and a typical fining upward transgressive sequence can be interpreted in many of the wells. An idealised section consists of

(i) a basal fluvial channel *-Birdrong Sandstone (and (ii) & (iii) below)*
(ii) overlain by proximal estuary deposits -tidal flat mud and fine channel sands
(iii) that is overlain by lower shore face- silty sands
(iv) glauconitic middle to inner shelf sandy silts. - *Mardie Greensand*
(v) dark outer shelf and slope claystone- *Muderong Shale*

Arditto (1993) argues that the group of transitional facies, the Birdrong Sandstone, is always Time Slice K2 in age, bound on the top by the Intra-Hauterivian Unconformity, and is therefore essentially not diachronous. Arditto (1993) interprets this Birdrong Sandstone as a last phase of delta building or reworking of the prograding complex. However most workers consider the Birdrong Sandstone to be a basal, partially reworked facies associated with the shore zone of a transgressive sequence (Hocking et al,1988, pp209).

Palæogeography:(see Enclosure 39)

Two source provinces existed in early Time Slice K2, a sandy Pilbara Province source area and the Novara Arch - Gascoyne Sub-basin source area. The main fluvial system is interpreted to have flowed north and east, sourced mainly from the Novara Arch, reworking earlier sediment, and building a fluvial dominated deltaic system that prograded northward against a rising sea level. The delta progradation probably ceased when the arch, basically uncompacted sediment, was rapidly reduced to sea level at the end of *S. areolata* time. A higher energy wave dominated environment is interpreted on the western margin of the Novara Arch. A strongly tidal environment existed in the general area of the junction of the

Long Island and Flinders Island Fault Zone. The sea level fall in *E. torynum* time resulted in canyon incision at the shelf edge. The canyon guided sandy sediment, sourced mainly from the Pilbara Province onto the basin floor at the break of slope. Episodic turbidity currents, that flowed down the canyon, deposited large sandy submarine fans over a broad area in front of the slope. The most distal deposits may have reached as far north as Withnell 1 but in general the lobes terminated within 20 km of Campbell 2. These deposits constitute the Flag Sandstone. A wave dominated coastal environment is likely to have existed along the western margin of the Pilbara area.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)

The mean TOC ranges from 0.2% to 2.3% with a maximum of 3.3% in Flag 1. The mean HI values range from 50 to 222 with a maximum of 403 in Bambra 2. The mean values of S2 range from 0.33 to 4.81 with a maximum of 7.54 in Flag 1. Parts of the section in the central Barrow Basin are mature for oil, the remaining sections appear to be marginally mature to immature. There is an apparent correlation between the slope and basin shale environments and the best source rock quality.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

Shows occur in eighteen of the wells. Major discoveries of oil and gas/condensate occur in Griffin 1, Cowle 1, Saladin 1, South Pepper, and Bambra 2. Porosity measurements range from 40% to 0%. Most of the available data is from depths between 800-1200m depth but porosity to 10% is preserved at 3500m. Permeability to 26 Darcies have been measured (probably friable but 10 to 15 Darcies is common) and exceptionally good permeability of several darcies are found in the cleaner sandstone facies at the maximum burial depths of Time Slice K2.

Prospectivity: GOOD BUT MOST MAJOR STRUCTURES ALREADY DRILLED:

The transgressive system initiated in lower Time Slice K2, the Birdrong Sandstone (transitional coastal facies), the Mardie Greensand (outer starved shelf) and Muderong Shale (outer shelf upper slope shales) form a highly significant sequence set. The Muderong Shale is a regional seal that reaches its acme in Time Slice K4, and the underlying units form reservoirs of varying quality across the basin. This regional seal is above the level of currently mature source and any traps associated with it are considered significant.

Traps and Plays:

All successful structural traps within Time Slice K2 are dependant on the Muderong Shale as a seal. The structural targets can be divided into two groups. Those structures drilled on top of the prograding complex have reservoirs within the uppermost sandstones of the prograding complex or reservoirs within the transgressive units that overlies the prograding complex or a combination of both. The reservoir quality within the overlying transgressive unit is generally more reliable than reservoir within the underlying prograding complex. The other major structural play is the massive Mutti Type I (Mutti, 1985) submarine sandstone (the Flag Sandstone) found in front of the prograding complex.

Although there are numerous opportunities for stratigraphic traps to be found within the prograding complex of Time Slice K2, mapping these out, and more particularly mapping a reliable internal seal is probably beyond the resolution of the current seismic. Such plays require the integration of all the well data in the area, good biostratigraphic control and stratigraphic subdivision to sequence stratigraphic level. Stratigraphic traps within the Mutti Type II submarine fans on the lower slope and on the base of slope are considered the most prospective of the subtle traps at present. They immediately overlie or are interbedded with potential source rock and grain size is likely to be maximised at this location on the fans.

TIME SLICE K3:

MIDDLE CRETACEOUS: NEOCOMIAN: BARREMIAN: (126.0 to 119.0 MA): SEE ENCLOSURES 40 & 41.

Petroleum System: Westralian.

Time Slice K3 provides the first regional seal over the area of the Exmouth and Barrow Sub-basins. This seal places a maximum age on the timing of hydrocarbon accumulation in Central Gorgon and Bluebell areas. The basal transgressive sandstone sequence is a major oil reservoir and oil migration pathway in the Barrow and Dampier Sub-basins eg Wandoo and Griffin 1. It is a major aquifer in the Barrow Sub-basin. This aquifer has allowed the introduction of microbes that has resulted in the biodegradation of hydrocarbons at least 60 km into the basin. Hydrocarbons are sourced from deeper mature Jurassic, and migration into the Time Slice K3 reservoirs appears to be related to the timing of faulting that opened pathways to the source rocks.

Formation Synonyms:

Winning Group, Birdrong Sandstone, Mardie Greensand, Muderong Shale, Strickland Member and Nanutarra Formation (see Hocking and van der Graaff (1977) for discussion of this onshore equivalent).

Regional Definition of Time Slice:(see Enclosure 3)

The working definition is that this time slice is equivalent to the *M. australis* dinoflagellate zone. The time slice is characterised by a major transgression of the sea into central and western Australia.

Palæontology:(see Enclosure 2)

M. australis and lower *A. cinctum*. This time slice is probably present in all of the wells. In Kybra 1, Hermite 1, Candace 1 and Saladin 1 poor age control means that the time slice top has been extrapolated from adjacent wells that have adequate age control. In the deeper distal areas the earliest part of Time Slice K3 is condensed, eg West Barrow 2 and Barrow Island 25.

In many of the wells there is lithological evidence of a hiatus at the base of Time Slice K3, though rarely is the palynology adequate to definitively establish the hiatus.

Dampier Sub-basin Summary:

Regionally the area has entered a continental margin sag phase. The Rankin Trend was onlapped by a thin, or condensed section during Time Slice K3. Basin and slope deposition is a dark coloured glauconitic claystone that has traces of glauconite, pyrite, minor quartz silt and up to 20% mica. Greensands developed in situ on a moderate to low energy, outer marine shelf. Cleaner sandstones were deposited in the area of Enderby 1 and Hampton 1. Occasional storm action deposited thin sandstones and silty layers in deeper water adjacent to the shelf. On the Enderby Terrace greensands and glauconitic, dominantly coarse grained, sandstones dominate. Glauconite contents higher than 30% (up to 60%) are greensands. These sands are interbedded with argillaceous glauconitic siltstone or fine sandstones and medium dark grey glauconitic claystone. The interpreted shoreline location is a long way east of the map area.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

The area has entered a continental margin sag phase as the adjacent ocean floor cooled and commenced to submerge to abyssal depth. Volcanic activity has ceased to affect the area and this is a period of general tectonic quiescence. The hinge line for the margin sag appears to have been the Flinders Island Fault Zone.

Local

No major local tectonic events are recognised, although activity on the Flinders Island Fault Zone and adjacent Lowendal fault is indicated. (Howell, 1988).

Lithology:
Where present the basal transgressive quartzose sandstone *(Birdrong Sandstone)* is generally medium grained, moderately well sorted, becoming coarser to rarely conglomeratic towards the east and south. The sandstone is occasionally glauconitic. It grades upward into, or is overlain by a greensands facies (*Mardie Greensand*). This facies grades into a silty claystone to claystone sequence. The claystones are generally dark coloured, with traces of glauconite, pyrite and minor quartz silt. Cleaner sandstones were possibly deposited in the area of the Robe River Embayment *(Nanutarra Formation)*.

Thickness Variations: (see Enclosure 40)
The greatest interpreted thickness of sediment occurs in Tryal Rocks 1, (466m) and a depocentre that reflects compaction, mainly in the underlying Time Slice K2 sediments, is defined loosely by a triangle of Rosily 1A, Campbell 2 and Tryal Rocks 1. Deposits thin to the north west of Zeepaard 1 and Bluebell 1.

Palæodepositional Environments:(see Enclosure 41)
Continental margin sag is coincident with a regional rise in sea level. A fining upward transgressive sequence can be interpreted in many of the wells that are south of the shelf break in the underlying Time Slice K2 prograding complex. The interpretation of this study, though not conclusive, is that Time Slice K3 is a diachronous system; being a continuation of the regional transgression that commenced in late Time Slice K2. The overall transgression may have been punctuated by brief stillstands or regressions. Time Slice K2 section gives a more detailed description of the alternative interpretations for this sequence.
An extreme reduction in coarse grained clastic input is characteristic of this time slice. However a source for coarser clastics was available for reworking from the underlying prograding complex.

An idealised section consists of
- (i) a basal fluvial channel -*Birdrong Sandstone, Nanutarra Formation (and (ii) & (iii) below).*
- (ii) overlain by proximal estuary deposits - tidal flat muds and fine channel sands.
- (iii) that is overlain by lower shore face - silty sands.
- (iv) glauconitic middle to inner shelf sandy silts - *Mardie Greensand and Windalia Sandstone Member*
- (v) dark outer shelf and slope claystone - *Muderong Shale.*

This last facies constitutes the dominant deposits of Time Slice K3. Other facies predicted to occur are storm reworked deposits on the shelf and possible submarine turbidites. Slope grain flow deposits could exist in the vicinity of Rosily 1A where a shelf edge inflection may have existed.

Palæogeography:(see Enclosure 41)
The shoreline is believed to have been east of the present day shoreline. Only minor fluvial input is interpreted which is limited mainly to the valleys of the fluvial systems adjacent to a narrow band of coastal deposits. The starved shelf has glauconitic sands that gradually become finer and argillaceous towards the shelf edge and slope. The palæosubmarine topography is thought likely to reflect compaction within the underlying Time Slice K2 sediments. The general trend of the coastline is beginning to approximate the present day northeast to southwest strike.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)
The mean TOC values range from 0.8% to 2.6% with a maximum of 3.3% at West Tryal Rocks 1. The mean HI values range from 77 to 226 with a maximum 233 in Griffin 1. The mean S2 values range from 0.68 to 4.97 with a maximum 4.97 in Tryal Rocks 1. The vitrinite reflectance data suggests the section is in the early stage of oil generation on the eastern and southern areas of the basin and in the

peak stage of oil generation in Tryal Rocks to West Barrow area. The deeper water slope and outer shelf environment provide the best source rock facies.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

Shows are recorded in fifteen of the study wells, with major oil legs in Novara 1 and Griffin 1. There are a series of minor to good shows in the wells flanking the southern and eastern margin of the Barrow Sub-basin. Towards the basin margins biodegradation of the oil has occurred. This is related to freshwater influx that probably occurred during sea level falls in the late Cainozoic. Measured porosity ranges from 5 to 40%, with preserved porosity of 20% recorded at 2500m. Most of the coarser grained sediments are unconsolidated to friable and good permeability is common.

Prospectivity: HIGHLY PROSPECTIVE FOR TRAPS ALONG MIGRATION PATHWAYS FROM DEEPER SOURCE BUT BIODEGRADATION PRONOUNCED EAST OF FLINDERS FAULT ZONE.

The mixed greensand and quartz sandstone facies is highly prospective. Wandoo Field (200 million barrels in place) is believed to produce from this interval, but to be sourced from the Jurassic of the Lewis Trough. Porosity are fair to good with many sands being unconsolidated. Permeability is probably high due to the general lack of consolidation. The Robe River Embayment area has a relict biodegraded oil column reservoired within, Mardie Greensand, Birdrong Sandstone, Nanutarra Formation and Yarraloola Conglomerate facies that are probably Time Slice K3 age. Thomas (1978) suggests this oil was partially hydrodynamically trapped in a 4 degree basinward dipping homocline. This situation ceased when the Yarraloola Conglomerate was breached by erosion. The oil is similar, although biodegraded, to that found at Barrow Island, and shown to be Jurassic sourced. The Robe River accumulation establishes that long migration pathways are possible.

Traps and Plays:

Time Slice K3 is a major reservoir for hydrocarbons, mostly oil and some condensate.

Traps are mapped at the base Muderong Shale (regional seal) reflector. The targets are reservoirs in the Mardie Greensand, Birdrong Sandstone and Nanutarra Formation immediately beneath this seal. However, in discovery wells the hydrocarbon column often extends into the underlying Time Slice.

Traps include

- simple four way dip closure - drape compaction features or folds eg Wandoo.
- rollover fault plays - structuring occurred at Time Slice K9 and latest Tertiary.
- reverse fault plays - were the basal sands are upthrown and sealed against the overlying Muderong Shale, this type of play may occur along the Flinders Fault Zone, and may require significant closure to allow for potential thief zone effects at the top of the Mardie Greensand.
- Stratigraphic plays, though possible, are not favoured by this depositional system. Pinchout of the basal sands onto pre-existing topographic highs is the most likely style of stratigraphic trap.

TIME SLICE K4:

MIDDLE CRETACEOUS: APTIAN (119.0 to 114.0 MA): SEE ENCLOSURES 42 & 43.

Petroleum System: Westralian.

Significant as the maximum transgressive phase for the regional seal facies. Reserves in Barrow Island occur within this Time Slice, but the reservoir is thought to be unprospective in offshore areas due to low productivity; a result mainly of poor permeability rather than poor porosity.

Formation Synonyms:
Winning Group, Muderong Shale, Mardie Greensand, Windalia Sand Member, Windalia Radiolarite (Albian Limestone).

Regional Definition of Time Slice:(see Enclosure 3)
Time Slice K4 records the peak of a marine transgression across the Australian continent. It is biostratigraphically defined by the dinoflagellate zones upper *A. cinctum*, *O. operculata* and *D. davidii*, and the *C. hughesii* spore-pollen zone. Time Slice K4 corresponds to a change in stratigraphy in many basins with the deposition of marine shales over sandstones in offshore basins.

Palæontology:(see Enclosure 2)
Time Slice K4 is interpreted to be present in twenty five of the wells. It is absent, or possibly extremely condensed, in the most offshore wells - Novara 1, Resolution 1, Zeepaard 1 and Zeewulf 1. Age control across this section is generally very poor. The top of Time Slice K4 represents a regional disconformity due to sediment starvation.

Dampier Sub-basin Summary:
The marine transgression that commenced in Time Slice K2 reaches a peak during Time Slice K4. This time slice is interpreted to represent the marine slope or outer shelf deposits of a major marine transgression on a sediment starved margin. Marine dark coloured silty claystone, firm to soft and plastic dominate deposition. The uppermost section is also characterised by radiolarian rich limestone. The top of Time Slice K4 is a major disconformity due to extreme sediment starvation. There is a depocentre centred on Rosemary 1 (282m). In Dampier 1 minor very fine grained thin sandstones are present.

Tectonics:(see Enclosure 1 & Figure 2).
Regional
This is a time of regional tectonic quiescence
Local
Activity on the Lowendal fault is recognised by Howell (1988).

Lithology:
A rare basal quartzose sandstone that is occasionally glauconitic occurs. If present it grades upward into, or is overlain by, a greensands facies (*Mardie Greensand*). This facies in turn grades into a silty claystone to claystone sequence. The claystone are generally grey coloured, with traces of glauconite, pyrite and minor quartz silt. This is the same transgressive sequence seen in Time Slice K3.
Radiolarite rich layers are recognised throughout Time Slice K4. They are thought to be due to an increased input of silica from deep weathering in the hinterland and exceptionally low clastic input. In most cases the radiolaria are replaced by white clay matrix, in a silty, glauconitic, foraminiferal calcilutite.
A thin fine grained yellow sandstone occurs at probably two levels within the shaly facies (Muderong Shale). This is probably a storm reworked layer formed during a halt in sea level rise. It is found over the Barrow Island area, which was thought to be a submarine topographic high at the time.

Thickness Variations:(see Enclosure 42)
A maximum thickness of 299m occurs in Flinders Shoal 1. The edge of significant deposition is slightly to the west of the Rankin Alpha Hilda Arch trend. This depocentre roughly coincides with the inner eastern Barrow Sub-basin. Thin areas occur over the Barrow Anticline, Lowendal Fault and Rosily 1A areas.

Palæodepositional Environments:(see Enclosure 43).

Two sequence stratigraphic intervals are recognised within Time Slice K4. The top of each is defined by a sandy layer (Windalia Sandstone), that is interpreted to be a result of winnowing occurring over submarine topographic highs eg. Barrow Island. The time slice has identical depositional environments to Time Slice K3. Glauconite is not as abundant though still common.

Palæogeography:(see Enclosure 43)

This Time Slice records the interval of maximum flooding associated with the transgression initiated in Time Slice K2. As a consequence, the shelf area received little clastic sediment and the upper surface of Time Slice K4 is recognised as a regional disconformity due to sediment starvation. However there are potential areas of shelf sands thought to be storm reworked deposits.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)

The mean TOC values range from 0.8% to 2.5% with a maximum of 3.1% at Dailey 1. There is a trend towards higher TOC to the south that equates loosely with a middle shelf environment. This pattern of better TOC values to the south is seen in the overlying Time Slice K5-7. The mean HI values range from 57 to 251 with a maximum of 414 at Griffin 1. The S2 values range from 0.61 to 3.38 with a maximum of 8.2 occurring in Griffin 1. The vitrinite reflectance data suggest this interval is in the earliest stages of oil generation in the deeper areas becoming immature towards the shallow areas. The best source rock occurs along the outer shelf to upper slope environments.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

There are shows in eight of the wells. A major oil field occurs in this time slice on Barrow Island. Low productivity makes the field economical only because of the onshore location and shallow depths to target. Most of the porosity data is from a core in Barrow Deep 1 over a narrow depth range at approximately 630m where measured porosity range from 12 to 34%. Permeability data are limited to South Pepper 1 and Long Island 1, where the maximum measured is 9 mD and most values are less than 5 mD.

Prospectivity: VERY POOR DUE TO POOR RESERVOIR PRODUCTIVITY AND SOURCE/MIGRATION RISKS.

This is a major seal facies and is therefore non prospective. Its significance lies in it sealing the underlying sandstones of Time Slice K3 but it may also constitute a thief zone where low productivity section overlies productive Time Slice K3 section. This Time Slice is a major reservoir in the Barrow Anticline but the special conditions at that field are not repeated elsewhere.

Traps and Plays:

Subtle traps in reworked sands in this dominantly shale facies are possible. These traps would require fault migration pathways to permit hydrocarbon charging.

TIME SLICE K5-7:

MIDDLE CRETACEOUS: ALBIAN: (114.0 to 99.0 MA): SEE ENCLOSURES 44 & 45.

Petroleum System: Westralian.

This Time Slice marks the onset and development of a significant thickness of regional seal, and thermal blanketing and burial of the Jurassic source rocks.

Formation Synonyms:

Winning Group, Windalia Radiolarite, Dailey Siltstone Member, Lower Gearle Siltstone, Haycock Marl and Alinga Formation.

Regional Definition of Time Slices:(see Enclosure 3).

- TIME SLICE K5: EARLY ALBIAN (114.0 - 110.0 MA).

Time Slice K5 encompasses a period of sea level retreat. It equates to the *C. striatus* spore-pollen zone and approximates the *M. tetracantha* dinoflagellate zone.

- TIME SLICE K6: MIDDLE ALBIAN (110.0 -104.0 MA).

Regression continued during Time Slice K6. The base of the time slice equates to the base of *C. paradoxa* spore-pollen zone and the top equates to the top of *C. denticulata* dinoflagellate zone.

- TIME SLICE K7: LATE ALBIAN (104.0 - 99.0 MA).

Time Slice K7 is a transgressive episode, as well as a global oceanic anoxic event. Biostratigraphically it approximates the *P. ludbrookiae* dinoflagellate zone.

Palæontology:(see Enclosure 2)

Age control is patchy to poor at best. The combined Time Slice 5 to 7 is present in twenty three of the wells. It is possibly present in the remaining six but is unidentified due to poor age control. Age control is inadequate in several of the wells where the time slice is interpreted, but the time slice has been extrapolated on lithological grounds to these wells, because fair or good control exists in nearby adjacent wells.

Time Slice K5 is absent or very condensed in the north towards the Dampier Sub-Basin. It is identified in wells to the south of Campbell 2, but appears to be absent over the Barrow Island area implying that this area was a topographic high during this time.

Time Slice K6 is present in most wells and where marked as absent this is due to non deposition or a highly condensed section.

Time Slice K7 is present in all wells with adequate age control, it represents the return to significant sedimentation rates following maximum sediment starvation at the end of Time Slice K4.

Dampier Sub-basin Summary:

The base of this combined time slice is a major disconformity associated with clastic sediment starvation of the shelf as a consequence of maximum transgression at end of Time Slice K4. Deposition recommenced on an extremely starved shelf after significant continental margin sag began. Subsequent sedimentation is dominated by marine calcilutites, marls and radiolarites. Time Slice K6 is the first interval to show the influence of significant carbonate sedimentation in the outer shelf to slope environments. Time Slice K6 is dominated by glauconitic sandstone sedimentation on the Enderby Terrace. These quartzose sandstones are up to 40m thick, with up to 30% glauconite, and trace to very good intergranular porosity. In Lewis 1A the sandstones are much thinner. Landward of these sandstones the sediments appear to become silty. There are no significant shows and no good source rock potential recognised. Better source rock quality is found in the south in the vicinity of Withnell 1 and Rosemary 1, but the section is immature and lean.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

Regionally the drifting Indian Sub-continent effectively cleared Australia and continental margin sag commenced along the entire western margin of the Australian continent.

Local

No significant local faulting or folding is recognised. Time Slice K5 appears to onlap the Barrow Island area. The area may therefore have been a local high due to differential compaction over a buried anticlinal feature or due to slight growth of the anticline, or a combination of both.

Lithology:

Radiolarite rich layers are recognised throughout Time Slice K5. They are thought to be due to an increased input of silica from deep weathering in the hinterland and exceptionally low clastic input. The overlying section of Time Slices K6 and K7 are mainly slightly calcareous very silty medium to dark grey claystone to clayey siltstone; claystone becomes dominant seaward and calcilutite and marl occurs towards the Dampier Sub-basin and seaward. Benthonic foraminifera are abundant in the marly facies.

Thickness Variations:(see Enclosure 44).

Time Slice K5 is absent or condensed to the north of Campbell 2 and apparently not developed over the Barrow Island area. Time Slice K6 appears to be absent along the submerged rim of the southern Rankin Tend. Time Slice K7 is present in all the wells were an interpretation could be carried. Maximum thickness occurs in Emma 1(460m), where age control is very poor.

Palæodepositional Environments:(see Enclosure 45).

Middle to outer shelf, slope and base of slope environments are recognised. The shoreline position is very poorly constrained but is thought likely to be parallel to the present coastline but some distance inland. The lack of abundant planktonic foraminifera in the sediments of this interval implies restricted oceanic circulation.

Palæogeography:(see Enclosure 45).

Open marine starved shelf and slope deposition associated with margin sag. Significant sedimentation did not occur until Time Slice K7 when India finally cleared Australia and significant margin sag commenced. The shelf edge at this time trended approximately parallel to the current orientation. Sand input shoreward of the recognised shelf area is possible but has not been clearly recognised.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)

The mean TOC values range from 0.8% to 2.5% with a maximum of 3.9% in Dailey 1. The mean HI values range from 40 to 126 with a maximum of 218 in Serrurier 1. The mean S2 values range from 0.77 to 2.40 with a maximum of 5.69 in Serrurier 1. There is a definite trend towards better source rock quality towards the south, in the vicinity of Dailey 1 and Leatherback 1. The deeper sections with the poorest quality source rock are mature but the area of the better source rock is immature to marginally mature.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

Minor shows have been encountered in this combined Time Slice, mainly minor gas indications in Tryal Rocks 1, Long Island 1 and Flag 1 and a minor oil indication in Novara 1. There is no porosity or permeability data for these time slices.

Prospectivity: VERY POOR AS THIS IS A MAJOR SEAL FACIES

This section does not appear to have any reservoir potential though there is a possibility of storm reworked deposits on the shelf area that could be of reservoir quality. There would need to be a fault migration pathway into these reservoirs to charge them.

Traps and Plays:

Potential sands on the shelf area could form pinchout and fault plays, sourced by faults from the deeper Jurassic. The remaining areas are non prospective.

TIME SLICE K8:

LATE ALBIAN TO CENOMANIAN (99.0 - 92.0 MA): SEE ENCLOSURES 46 & 47.

Petroleum System: Westralian.

Potential good source rock quality at base of slope environment, that may in places be marginally mature.

Formation Synonyms:

Gearle Siltstone, Lower Gearle Siltstone, Haycock Marl and Turonian Spike.

Regional Definition of Time Slice:(see Enclosure 3).

This time slice is biostratigraphically defined by the C2, C3a and C3b foram zones, approximates the *D. multispinum* & upper *X. asperatus* dinoflagellate zone and *A. distocarinatus* spore-pollen zone. During this time slice the sea retreated from the centre of the continent, but there is a rise in relative sea level on the western margin.

Palæontology:(see Enclosure 2).

Age control ranges from non existent to exceptionally good. Time Slice K8 is recognised in sixteen of the study wells. Of these four are interpreted on lithological grounds from adjacent wells, being Leatherback 1, Griffin 1, Central Gorgon 1 and Saladin 1, where age control is poor. Good age control suggests the section is absent in Bluebell 1 due to erosion. Time Slice K8 is probably present in the remaining wells with poor age control, but could be thin or absent on the Peedamullah Shelf. In the group of six most southern wells from Resolution 1 in the west to Long Island 1 in the east the upper most section of Time Slice K8 is absent due to removal in Time Slice K9

Dampier Sub-basin Summary:

Deposition is on an open oceanic continental shelf starved of clastic sediments. It is the first interval to show the influence of major carbonate sedimentation to the exclusion of almost any clastic sediments. The basal *X. asperatus* zone is missing from the Madeleine Trend, and also from Legendre 1. The top is marked by the Turonian spike. This spike is the log response to a layer of carbonaceous claystone deposited during a period of oceanic anoxia (pers. comm. A. Partridge) at the top of foram zone C3b. In several wells there is a hint of a second spike at the C2/C3a boundary. Sedimentation is dominated by marine calcilutites and marls and minor radiolarites. Most of the rocks contain traces of forams and *Inoceramus sp.* fragments. Time Slice K8 sediments overlap the boundaries of the Time Slice K5-K7, and form a seal facies on the Time Slice K6 sandstones in De Grey 1 and Cossigny 1. There is a continuation of relative sea level rise caused mostly by margin sag. The coastline is thought to be a long way to the east of the area. This is a major regional seal facies.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

India commences its northward drift at approximately this time. A continental sag margin occurs along the western margin of Australia.

Local

No general tectonic activity occurs within this time slice.

Lithology:

The section is dominantly a slightly calcareous very silty medium to dark grey claystone to clayey siltstone, the siltstone content appears to be dominant along the depositional axis, discussed below, and the claystone dominates away from this trend. Of interest is loose, fine to coarse, well rounded frosted quartz sand grains contained within the siltstone at Zeepaard 1. Radiolarite zones are mentioned in several well completion reports. Carbonate nodule horizons on Barrow Island act as reservoirs. These horizons are a result of weathering events.

Thickness Variations:(see Enclosure 46)
The maximum interpreted thickness occurs in West Barrow 2 (340m). A depositional axis appears to run west north west through West Barrow 2 and Zeepaard 1 but the interpretation is complicated by erosional truncation of the southern and eastern edges of the Time Slice.

Palæodepositional Environments:(see Enclosure 47)
This is a difficult time slice to interpret. Outer shelf and slope environments are apparent but it is difficult on the current data to be certain of boundaries. The distribution of the depositional axis and the existence of coarse quartz in Zeepaard 1 may imply a delta front to the east in the vicinity of the Robe River Embayment. An alternative source area could be south of Leatherback 1. The quartz would require transport via storm, turbidity currents or winds to explain the deep water occurrence. Very restricted marine to open marine conditions prevailed. Low oxygen to anoxic conditions prevailed episodically throughout the time slice.

Palæogeography:(see Enclosure 47)
A continental sag margin restricted marine environment is interpreted with a speculated clastic source area to the east in the vicinity of the Robe River Embayment.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)
The mean TOC values range from 0.2% to 2.1% with a maximum of 2.7% in Serrurier 1. The mean HI values range from 15 to 210 with a maximum of 210 in Central Gorgon 1. The S2 values range from 0.19 to 5.01 with a maximum of 5.01 in Central Gorgon 1. The vitrinite reflectance suggests the section is immature to marginally mature. The best source rock quality is inferred to be related to the base of slope environment and the anoxic conditions inferred at this depth.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).
Only a minor gas show is recorded in Long Island 1 and lost circulation occurred in the adjacent well Dailey 1. There is no porosity or permeability data for this Time Slice.

Prospectivity: QUESTIONABLE PROSPECTIVITY: POSSIBLE RESERVOIRS, AND POTENTIAL SOURCE:
There is no reservoir facies recognised in this time slice. However the coarse frosted quartz grains in Zeepaard 1 suggest a remote possibility that reservoir sands could exist in the vicinity. Hydrocarbons would need to migrate into these speculated reservoirs from deeper mature source rocks or from marginally mature Time Slice K8 source rocks.

Traps and Plays:
No traps are recognised for this unit though speculative traps are discussed above.

TIME SLICE K9:

LATE CENOMANIAN, TURONIAN, CONIACIAN AND LATE SANTONIAN (92.0 - 84.0 MA): SEE ENCLOSURES 48 & 49.

Petroleum System: Westralian.

Fault movement provides first vertical migration pathway for mature Jurassic and older source rocks into Cretaceous traps, formed or present at this time.

Formation Synonyms:

Upper Gearle Siltstone, Gearle Siltstone, Toolonga Calcilutite, Haycock Marl, Windalia Sandstone Member and Alinga Formation.

Regional Definition of Time Slice:(see Enclosure 3).

The time slice is biostratigraphically defined by the C4 to C8 foram zones, the *C. triplex* and *T. pachyexinus* spore-pollen zones, and approximates the *P. infusorioides* to *I. cretaceum* dinoflagellate zones. Carbonate sedimentation became dominant on the western margin during this time slice.

Palæontology: (see Enclosure 2)

Time Slice K9 is interpreted to be present in ten of the wells. In some of the wells poor age control, (eg Griffin 1), means that the section has been extrapolated from adjacent wells on lithological rather than biostratigraphic criteria. In 17 of the wells poor age control limits the interpretation of this time slice. However Time Slice K9 appears to be absent from most of the wells on the basin flanks, possibly due to a combination of nondeposition and erosion. It may in fact be absent from Central Gorgon 1 though this is unclear on present biostratigraphy.

Dampier Sub-basin Summary:

Deposition occurred on an open marine continental shelf and slope in an environment starved of clastics, and becomes totally dominated by carbonate offshore. The southeastern margin of the Lewis Trough forms a hinge line that divides the upper continental slope and outer shelf edge deposits from the deeper water base of slope deposits. The shore line is a long way to the east, but a minor finger of outer to middle shelf edge sands may exist in the vicinity of Rosemary 1. Parts of Time Slice K9 appears to be present in all wells except those on the Enderby Terrace, where it may be absent due to erosion. Middle Time Slice K9 is absent in most wells. The main depocentre is the Lewis Trough. Calcilutite, calcareous claystone and marl are the dominant lithologies. The calcilutite forms the uppermost section and calcareous claystones and marls are the older deposits. Glauconite traces are common inshore and foraminiferal and *Inoceramus sp.* fragments are also common. Very fine grained thin sandstone beds and arenaceous claystones occur in Rosemary 1

Tectonics:(see Enclosure 1 & Figure 2).

Regional

Subduction may have commenced in the Timor Trough area (Howell, 1988). Along the south margins separation of Antarctica from Australia commenced. (Veevers et al, 1991, p 379)

Local

Time Slice K9 is a time of tectonic activity, possibly as a result of right lateral wrenching along the basin margins. It is also the time of reactivation of the Lowendal Fault (Howell 1988) and South Pepper Faults (William & Poynton, 1985). These fault movements are significant for trap formation, but more importantly they seem to be coincident with the first migration phase of hydrocarbons sourced from the deeper Jurassic. The movement formed the Intra Gearle Hiatus that divides the upper and lower Gearle Siltstones.

Lithology:

The section is dominantly a dark grey to grey calcareous marl to calcareous claystone that becomes increasingly silty with depth. Glauconite, arenaceous foraminifera and *Inoceramus sp.* fragments are locally common. Radiolarites are abundant in the north. In the vicinity of Koolinda 1 minor sandstones and limestones are recognised.

Thickness Variations:(see Enclosure 48)

The maximum thickness (278m) occurs in Zeepaard 1. The section is apparently absent in many of the southern wells due to erosion subsequent to tectonic activity. It also appears to be thinner over a northwest to southeast axis through Barrow Island. The depositional axis through Zeepaard 1 and West Barrow 2, as first seen in Time Slice K8, is still present.

Palæodepositional Environments:(see Enclosures 49)

Open marine continental shelf and slope environments are interpreted..

Palæogeography:(see Enclosure 49)

A continental sag margin marine environment is interpreted with a speculated clastic source area to the east in the vicinity of the Robe River Embayment. The southern area was uplifted and eroded and activity on the South Pepper and Lowendal Fault occurred.

Geochemistry (TOC, HI and VR):(see Appendix 6)

The mean TOC ranges from 0.4% to 1.6% with a maximum of 2.4% in Central Gorgon 1 and Griffin 1. The mean HI values range from 27 to 227 with a maximum of 300 at Griffin 1. Mean S2 values range from 0.5 to 4.59 with a maximum of 7.23 at Griffin 1. The vitrinite reflectance data indicate the section is immature.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

There are no shows in this time slice. In Bambra 2 and Koolinda 1 the section was drilled under conditions of lost circulation. The actual lost circulation zone is thought to be higher in the well than Time Slice K9. There are however known oil shows in this section over Barrow Island. There is no porosity data for this time slice.

Prospectivity: POOR BUT SOME POTENTIAL FOR RESERVOIRS TO BE DEVELOPED:

The prospectivity of Time Slice K9 is considered poor, because good reservoir facies appear to be absent. The intra Time Slice K9 tectonic event raises a possibility of local reservoir being developed in response to a short lived relative sea level fall.

Traps and Plays:

None recognised.

TIME SLICE K10: (with notes on TIME SLICE K11)

LATE SANTONIAN & CAMPANIAN TO EARLY MAASTRICHTIAN (84.0 - 70.0 MA): SEE ENCLOSURES 50 & 51.

Petroleum System: Westralian.

Structuring that commenced in Time Slice K9 continued intermittently in Time Slice K10.

Formation Synonyms:

Withnell Formation, Korojon Calcarenite, Toolonga Calcilutite, Miria Marl, Miria Formation.

Regional Definition of Time Slice:(see Enclosure 3).

Time Slice K10 is biostratigraphically defined by the C9 to C11 foram zones, the *N. senectus* and *T. lilliei* spore-pollen zones, and approximates the *N. aceras* to *I. korojonense* dinoflagellate zones. The top of the time slice is marked with breaks in both the foram and dinoflagellate zones. It corresponds to the commencement of sea floor spreading in the Tasman Sea.

TIME SLICE K11: MIDDLE TO LATE MAASTRICHTIAN (70 - 65 MA)

Time Slice K11 is biostratigraphically defined by the C12 and C13 foram zones, the *M. druggii* dinoflagellate zone and the *T. longus* spore-pollen zone. Its top represents the Mesozoic / Cainozoic boundary.

Palæontology:(see Enclosure 2)

Time Slice K10 is interpreted to be present in fifteen of the wells. It is probably present in most of the remaining wells but is unrecognised due to poor age control. The top Cretaceous is marked by a regional unconformity in the Barrow Exmouth Sub-basin. This unconformity has partially or completely removed significant amounts of Time Slice K10. The section is interpreted as absent in Bluebell 1 and possibly absent in Flag 1. It could also be absent in Central Gorgon 1 as age control in this well is only fair. Time Slice K11 is found in a few of the deeper wells, Tryal Rocks 1, Novara 1, Zeewulf 1 and Zeepaard 1, as well as Griffin 1 but poor age control means that this is the practical limit of palynologically based subdivisions and Time Slice K11 could be much more widespread, as condensed section, than the raw data might imply.

Dampier Sub-basin Summary:

Deposition is open oceanic continental shelf and slope carbonates on a clastic starved continental sag margin. Shelf sands occur near Rosemary 1. Time Slice K10 was penetrated in all wells except those on the Enderby Terrace. There is a regional disconformity event at the base of the time slice that may range from middle Time Slice K9 to lower Time Slice K10. The depocentre for this time slice is the Lewis Trough to the southwest of Rosemary North 1. The sequence is marl offshore, interbedded with calcareous claystone inshore. On the southern Enderby Terrace quartz sandstone deposition occurs. In the southwest basal calcilutite occurs. The marl is commonly light greenish grey and slightly glauconitic. The claystone is most commonly dark olive grey and calcareous. Calcilutite is medium grey green, greenish white. The marls claystones and calcilutites are generally very soft but more deeply buried sections are moderately hard. Pyrite, glauconite and foraminifera are common and *Inoceramus sp.* fragments are abundant. In Rosemary 1 very fine to medium grained argillaceous glauconitic sandstones occur. Similar though less abundant sandstones occur in Lewis 1A and Legendre 1. Minor oil shows are interpreted as leakage from the underlying accumulations. This is a major seal facies. Fine grained sandstones in the vicinity of Rosemary 1 may have reservoir potential to the east on the assumption that they might become coarser, thicker and cleaner in this direction.

Tectonics:(see Enclosure 1 & Figure 2).
Regional
Subduction is occurring in the Timor Trough area.
Local
This time slice appears to be missing from Flag 1, probably due to tectonic activity on the Lowendal fault. Uplift along the Alpha - Hilda arch may have occurred.

Lithology:
The section is dominantly a light grey calcareous marl to calcareous claystone that occasionally has a basal glauconitic siltstone present. Glauconite, arenaceous foraminifera, rarer radiolarite layers are locally common and *Inoceramus sp.* fragments are common throughout.

Thickness Variations:(see Enclosure 50)
The thickest section occurs in Barrow Deep 1 (344m). Two depocentres can be interpreted one centred on the Dampier Barrow Sub-basins and the other on the Exmouth Sub-basin. The apparent thinning between these two depocentre suggests that uplift may have occurred along the southern Rankin - Alpha Hilda Arch throughout this time slice.

Palæodepositional Environments:(see Enclosure 51)
Open marine continental shelf and slope environments are interpreted.

Palæogeography:(see Enclosure 51)
This is a fully open oceanic circulation system, clastic starved, continental sag margin, with shelf slope and basin environments recognised. The continental margin is oriented approximately parallel to present coastline. Carbonate deposition dominates, the interior continent being peneplained and clastic deposits of any sort absent.

Geochemistry (TOC, HI, S2 and VR):(see Appendix 6)
Mean TOC values range from 0.2% to 0.7% with a maximum of 0.7% in Zeepaard 1. There is no vitrinite reflectance data. There is one HI measurement of 22 from Outtrim 1 and an S2 value of 0.11 from the same well. There are no indications that this is a potential source rock interval from this data.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).
Very minor gas shows are found in the deeper wells Tryal Rocks 1 & Withnell 1, perhaps best explained as biogenetic methane. In Barrow Deep 1 a minor oil indication is probably related to vertical migration from deeper accumulations. There is no porosity data for this time slice.

Prospectivity: CONSIDERED POOR AS NO RESERVOIR FACIES ARE OBVIOUS.
There are no indications of source rock potential nor are there any indications of potential significant reservoir development.

Traps and Plays:
None recognised.

TERTIARY TIME SLICES Cz7 to Cz1:

CAINOZOIC: PALEOCENE TO RECENT: (65.0 to 0. 0 MA): SEE ENCLOSURE 52.

Petroleum System: Westralian.

The Cainozoic is a significant part of the Westralian system. It is the time of major hydrocarbon generation and migration from the Westralian source rocks.

The thick carbonate wedge has buried the upper Jurassic source, and perhaps acted as a thermal blank. These two qualities partially control the timing and maturation of the late Jurassic. The Cainozoic is also a potential reservoir facies but needs to be sourced from Early Cretaceous or older source rocks via faults.

The dominant event is the late Miocene tectonics that caused reactivation of many of the faults and growth on several features including the Barrow Anticline. This event may also be correlated with a second phase of significant oil migration from deeper sources into shallower reservoirs. The Cainozoic is also a time of significant margin sag due to sediment loading. Tilting of earlier accumulations may have progressively spilt oil from them.

Formation Synonyms:

Lambert Formation, Dockrell Formation, Wilcox Formation, Walcott Formation, Giralia Calcarenite, Cardabia Calcarenite, Mandu Limestone, Trealia Limestone, Bare Formation and Delambre Formation, Cape Range Group.

Regional Definition of Time Slice:(see Enclosure 3)

TIME SLICE Cz1: TERTIARY: Paleocene to Early Eocene. (65.0 to 50.5 MA).

Biostratigraphically defined by foraminiferal Zones *T1* to middle *T10*. *T6* is generally considered to be absent and a time of submarine disconformity on the North West Shelf.(Apthorpe 1988). The top is defined as the top of *P9* planktonic foraminiferal zone. Cessation of rifting along the eastern margin, restricted marine conditions along the southern and western margin, widespread carbonaceous sedimentation.

TIME SLICE Cz2: TERTIARY: Middle to Late Eocene (50.5 to 38.0 MA).

Biostratigraphically defined by foraminiferal Zones *P10* to *P17* and *T10* to *T14*. The top is defined as the middle of *P17* planktonic foraminiferal zone. Increased Australian/Antarctic spreading rate, major transgression along southern and western margin, widespread carbonaceous sedimentation.

TIME SLICE Cz3: TERTIARY: Early Oligocene (38.0 to 32.8 MA).

Biostratigraphically defined by foraminiferal Zones *P17* to *P21* and *T15* to *T17*. The top is defined as the boundary between *P21a* and *P21b* planktonic foraminiferal zones. There is an apparent paucity of continental deposition except in the southeast, induration phenomena, widespread submarine erosion and/or non-deposition, ice development in Antarctica, strengthening of circum-Antarctic current.

TIME SLICE Cz4: TERTIARY: Late Oligocene to Late Middle Miocene (32.8 to 10.43 MA).

Biostratigraphically defined by foraminiferal Zones *P21* and *P22* and *T17* to *T20* and nannofossil zones *N4* to *N14*. The top is defined as the middle of nannofossil zone *N14*. Resumption of continental deposition, highest Tertiary sea level, widespread carbonate deposition, reef development in northern Australia, collision with New Guinea (New Guinea Orogen).

TIME SLICE Cz5: TERTIARY: Late Miocene (10.43 to 4.79 MA).

Biostratigraphically defined by nannofossil zones *N14* to *N17*. The top is defined as the top of nannofossil zone *N17*. Continent wide regression, induration features on land.

TIME SLICE Cz6: TERTIARY: Pliocene (4.79 to 2.0 MA).
Biostratigraphically defined by nannofossil zones *N18* to *N21*. The top is defined as the top of nannofossil zone *N21*. Transgressive period, widespread sedimentation, collision with Banda Arc, Antarctic glaciation.

TIME SLICE Cz7: QUATERNARY: Pleistocene (2.0 to 0.0 MA).
Biostratigraphically defined by nannofossil zones *N22* and *N23*. The top is defined as 10 ky. Major sea level and climatic fluctuations, development of modern Great Barrier Reef, development of continental dune fields.

Palæontology:(see Enclosure 2)

The palæontological control over this interval is exceptionally poor. Because of this no detailed biostratigraphic subdivision of the Cainozoic was deemed worthwhile. The available public domain data set requires major upgrading before an interpretation is justified.

Dampier Sub-basin Summary:

At most times the palæowater depths are thought to reflect in broad terms the modern shelf trends. However relative sea level falls appear to have occurred at the start and at the end of Time Slice Cz1. In the middle, at palynological zone *T7*, there is a submarine unconformity possibly caused by reorganisation of oceanic currents (Apthorpe 1988). The base of the Cainozoic is an unconformity except in the south where sedimentation was continuous. Deposition commenced later in the north and progressive onlap of the palæohighs occurred. The upper surface of Time Slice Cz1 is an unconformity probably due to erosion. Basal initial sedimentation consists of well-sorted, good to poor porosity, glauconitic sandstones with up to 60% quartz deposited on the outer shelf. It is interpreted that the greensands could form a belt generally paralleling the palæobathymetry. Fine to very fine silty quartzose sandstone in places grades into glauconitic sandstone are interpreted as inner continental shelf deposits. Following on the sea level rise an open marine carbonate dominated continental shelf to slope environment developed. A simple zonation of inner to outer shelf is seen paralleling the present coastline, finer grained sediments were deposited further offshore. Claystone, marl and calcilutite are the dominant lithologies. Foraminifera, skeletal fragments, pyrite and glauconitic siltstone and *Inoceramus sp.* are common within these lithologies. Minor clastic input occurs in the southeast of the Enderby Terrace. The sequence is essentially a seal facies with reservoirs where glauconitic sands of sufficient thickness accumulate. It would be necessary to migrate hydrocarbons into these reservoirs from underlying source rocks via faults. Time Slice Cz2

In the wells on the Enderby Terrace Time Slice Cz2 may be absent due to erosion. The base of Time Slice Cz2 is a significant unconformity in many wells. There is a regional time break, either erosional or non depositional, centred on the *T12* zone. The top of Time Slice Cz2 is an unconformity surface. Deposition was on an open marine clastic starved, carbonate dominated shelf. There are basal light grey glauconitic calcareous quartzose fine to medium grained marine sandstones with indications of good to fair porosity. The pre *T12* hiatus sediment package has inner shelf deposits of coarser grained material, dominated by calcarenites, siltstones and sandstones. A clastic source area is centred on Legendre. Further offshore the clastic input is reduced and minor quartz silts and clay minerals are mixed with dominant marls and calcilutites. The post *T12* hiatus package has similar zonation to the above except for a notable reduction in clastic input but an abundance of chert. The actual hiatus surface may have been exposed to silicification processes or winnowing that could have concentrated the chert. Three depositional episodes can be distinguished. A basal marine transgressive sand deposit, followed by two episodes of marine continental shelf progradation on a clastic starved continental shelf. In five wells, Dampier 1, Madeleine 1, Walcott 1, Wanaea 1 and Lewis 1 there are sandstones with indications of good to fair porosity. Reservoir facies are possible where glauconitic sandstones or calcarenites of sufficient thickness accumulate. It would also be necessary to migrate hydrocarbons into these reservoirs from underlying source rocks. Faults provide the only obvious mechanism for this.

Tectonics:(see Enclosure 1 & Figure 2).

Regional

Cainozoic tectonics are dominated by the collision and subduction of the Australia Plate with the South East Asian Plate in the area of Indonesia, Timor and New Guinea. The regional stresses have been transmitted through the Australian Plate with varied local responses. Climatically Australia drifted northward into temperate and tropical waters. The middle Oligocene Time Slice Cz3 marks a change from moderate rates of shelf progradation to fairly rapid progradation. It is thought to reflect the intraplate reorganisation in the Indian Ocean.

Local

The dominant event is the late Miocene tectonics that caused reactivation of many of the faults and growth on several features including the Barrow Anticline and reverse movement on the South Pepper Fault (Williams & Poynton 1985). This event may also be correlated with a second phase of significant oil migration from deeper sources into shallower reservoirs. The Cainozoic is also a time of significant margin sag due to sediment loading. Tilting of earlier accumulations may have progressively spilt oil from them.

Lithology:

Lithological information tends to be patchy as the Cainozoic section is commonly a zone of lost circulation (seventeen of the wells).

Carbonate deposition dominates the entire western margin. At any point the tendency is towards coarsening upward sequences of marl to calcarenites recording the prograding nature of the shelf. As a general observation it appears more quartzose sandy units are reported in the Barrow area and well cemented dolomites and calcarenites are frequently encountered in wells drilled inshore of the current shelf break. Ocean ward of the shelf edge calcilutites, marls and chalks appear more common, these being the predominant slope and basin facies of the carbonate progrades.

Thickness Variations: (see Enclosure 52)

Where no top to the Cretaceous could be established from the available biostratigraphy the tops in the well completion reports were used. This allowed the compilation of a basic isopach map for the Cainozoic. The map shows a depositional axis through Bluebell 1 that parallels the present coastline and a local thinning over Barrow Island. The maximum sediment thickness occurs in Bluebell 1 (2099m).

Palæodepositional Environments:

Open marine continental shelf and slope environments are interpreted.

Palæogeography:

Because of insufficient biostratigraphic control no interpretation was attempted.

Geochemistry (TOC, HI, S2 and VR):

There is no available geochemical data for the Cainozoic section.

Shows/Porosity/Permeability:(see Appendices 3, 4 & 5).

There is no porosity or permeability data for the Cainozoic. Common lost circulation problems establish that adequate porosity and permeability exist, presumably as primary porosity in calcarenites or perhaps as secondary porosity in carbonates exposed to fresh water.

Prospectivity: GOOD POTENTIAL FOR SUBTLE TRAPS FED VIA FAULTS FROM MATURE DEEPER SOURCE.

Maitland 1, a well in the Barrow Island area, flowed 7.9 MMCFPD of gas condensate from Palæocene sandstones. The only viable source would appear to be the deeper mature Jurassic source rocks. This discovery establishes that migration pathways into the Cainozoic do exist. The shallower Cainozoic section has increased risk of seal failure.

Traps and Plays:

Stratigraphic traps and combined traps dominants exploration within the Cainozoic carbonates. Exploration needs to focus on periods of sea level fall and the reworking of glauconitic and carbonate sands that might occur at such time, either as strandlines or if sea level fall is sufficient as incised shelf edge channels and associated slope turbidites. The older Time Slices Cz1 and Cz2 have significant amounts of quartz and siltstone detritus associated with them.

PETROLEUM SYSTEMS

INTRODUCTION

A petroleum system as defined by Magoon & Dow (1991) is a mature source rock and all its generated hydrocarbon accumulations. The system includes all the play elements – source, reservoir, seal, trap, overburden (required for maturation), and migration pathways – and the actual processes and linkages involved, from source to trap and including the preservation of the accumulation. The system operates successfully and hydrocarbons are accumulated when all the crucial elements are present and occur in the correct order.

The petroleum system concept can be applied to Australia at a number of different scales. At the continent-wide scale, Bradshaw (1993) established a framework that linked together basins of similar age, facies, structural history and hydrocarbon potential into petroleum systems, now more correctly termed supersystems. These groupings are much broader in scope than the original Magoon & Dow (1991) definition in that they extend through many basins, encompass a family of similar source rocks rather than a single pod, and include numerous individual petroleum systems.

The supersystems provide generalised models of how an individual petroleum system may operate at the basin-scale, but detailed analysis is necessary to 'test' the model. The key elements of reservoir, seal, source and trap need to be mapped and the processes of generation, migration, accumulation and preservation considered. Successful operation of the system in one basin points to prospective intervals in less well explored parts of the supersystem, and the insights gained can be used predictively.

Six petroleum supersystems are recognised in the Australian Phanerozoic (Bradshaw, 1993) and three of these occur in the Barrow-Exmouth module area – the Westralian, Gondwanan and Larapintine supersystems. All the major hydrocarbon discoveries are within the Mesozoic Westralian Supersystem, some hydrocarbon shows occur within the Gondwanan Supersystem and some petroleum potential can be speculated about in the Larapintine interval.

A model of the relationships between the components of the supersystems in the Candace Terrace area (Figure 14) was proposed prior to the study. Proven reservoir, seal and source facies are indicated in upper case; and potential reservoirs, seals and sources in lower case.

LARAPINTINE SUPERSYSTEM

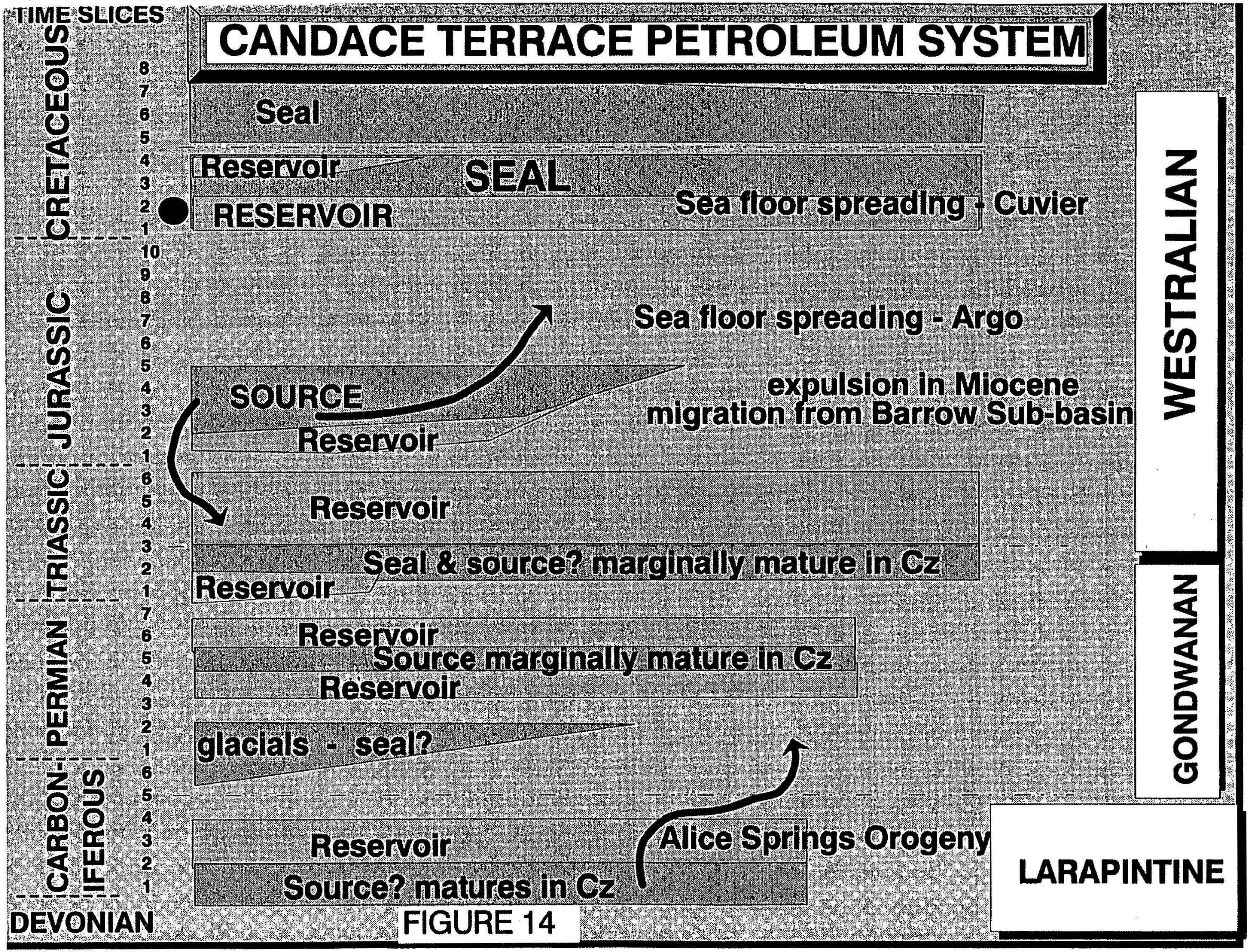
The Larapintine Supersystem is characterised by lower Palæozoic marine facies, including carbonates, evaporites and several intervals of organic rich marine rocks (Bradshaw, 1993), deposited during a tropical regime between the glacially influenced epochs of the late Precambrian and the Permo-Carboniferous. The key episodes of source rock deposition were the result of marine transgression in the Middle Cambrian, Early Ordovician and Late Devonian/Early Carboniferous.

There is the possibility of Ordovician source rocks, beneath the Peedamullah Shelf. They may be coeval with the proven oil source rocks in the successful Larapintine petroleum systems in the Amadeus and Canning basins. On the Candace Terrace, the Moogooree Limestone (Fig 3) is a potential Early Carboniferous source rock; and the Quail Formation is a possible reservoir facies. Reefal facies intersected at Pendock 1, south of the study area, recall the successful Late Devonian petroleum system of the Canning Basin.

The boundary between the Larapintine and Gondwanan supersystems is marked by a period of continent-wide tectonism in the Carboniferous coinciding with the peak of the Alice Springs Orgeny (Fig 14). In the few basins (Fitzroy Trough and Petrel Sub-basin), where significant thicknesses of petroliferous sediments were deposited during the Mid Carboniferous, a separate petroleum system is now recognised as transitional between the Larapintine and Gondwanan regimes (Bradshaw et al., 1994).

GONDWANAN SUPERSYSTEM

The Gondwanan Supersystem includes those sequences dominated by the late Carboniferous/early Permian Gondwanan glaciation. In comparison with the Larapintine Supersystem, terrestrial environments are better represented and the facies are predominantly clastic. Proven source facies tend to be gas prone, terrestrial organic facies such as the coals and carbonaceous shales in the basins of eastern Australia. Marine shales with a significant terrestrial component are the dominant source rocks on the western margin.



CANDACE TERRACE PETROLEUM SYSTEM
TIME SLICES
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBON-IFEROUS
DEVONIAN
Seal
Reservoir
SEAL
RESERVOIR
Sea floor spreading - Cuvier
Sea floor spreading - Argo
SOURCE
expulsion in Miocene
migration from Barrow Sub-basin
Reservoir
Reservoir
Seal & source? marginally mature in Cz
Reservoir
Reservoir
Source marginally mature in Cz
Reservoir
glacials - seal?
Reservoir
Alice Springs Orogeny
Source? matures in Cz
WESTRALIAN
GONDWANAN
LARAPINTINE

FIGURE 14

There are potential Permian source rocks on the Candace Terrace, that are similar to other marine Permian organic rich shales in the Canning and Bonaparte basins. These facies are in part related to post-glacial marine flooding. However, despite the occurrence of TOCs in excess of 5% and oil prone kerogen, this interval has not proved to be a successful part of the Gondwanan Supersystem on the western margin (Bradshaw et al., 1994).

The Early Triassic Locker Shale is distributed throughout the study area. It is an equivalent of the Kockatea Shale, a proven oil and gas source in the Perth Basin, and an effective seal over late Permian and early Triassic reservoirs. The source characteristics of the Early Triassic marine shales are inferior to the Permian shales, but the successful Gondwanan petroleum system is in this interval where there is a coincidence of reservoir, seal and trap (Bradshaw, 1994). In the study area there were gas and oil indications from the Permian (Flinders Shoal 1, Kybra 1) and Early to Middle Triassic (Flinders Shoal 1, Kybra 1, Hermite 1) (see enclosures 15 & 17).

The pragmatic boundary between the Westralian and Gondwanan supersystems is the top of the Locker Shale, which is diachronous. In this study, the boundary is taken as being within the Tr3 to Tr4 interval. The sandy Mungaroo facies are reservoir and gas prone source units in the overlying Westralian Supersystem.

WESTRALIAN SUPERSYSTEM

The Westralian Supersystem links together basins, from the Exmouth Sub-basin to the Papuan Basin, which share a history of extension and eventual break-up and sea floor spreading in the Late Jurassic to Early Cretaceous. They have a similar stratigraphy of Triassic to Cretaceous reservoirs, Jurassic marine oil source rocks, Cretaceous regional seal and a thermal blanket of Tertiary carbonates. The focus of the basin modules studied to date in the AGSO-APIRA Australian Petroleum Systems Project (Browse, Dampier, Barrow-Exmouth and Papuan) has been the prolific Westralian Supersystem.

The oils from the entire Westralian Supersystem are very similar geochemically, indicating deposition of the source rock in marine anoxic conditions, with the input of a significant amount of terrestrial organic matter (Murray et al., 1993). Tectonism related to continental break-up in the Late Jurassic, produced a palæogeography of restricted, deep-marine troughs bordered by emergent highland areas, ideal for the deposition of such source rocks. The marine environments of Australia's northern margin were partially barred from the Tethyan ocean by the continental fragments of Argo Land, and pieces of eastern Indonesia (Bradshaw et al., 1994).

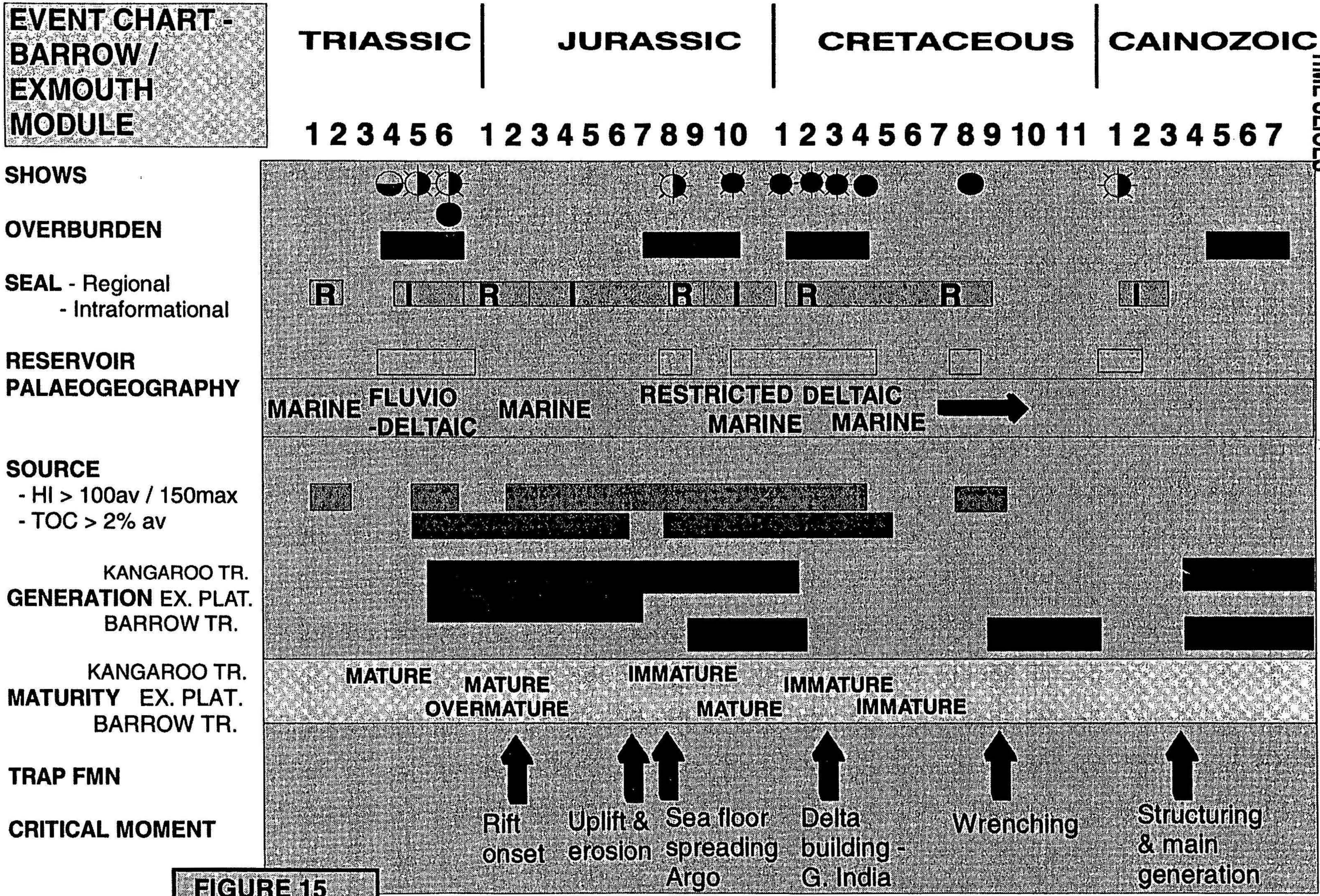
Another source interval in the Westralian Supersystem is the Late Triassic fluvio-deltaic sequences that have sourced the giant gas and condensate fields of the North West Shelf (Woodside Offshore Petroleum, 1988). The unconformity within Time Slice J2 (Figure 3), provides a convenient place to subdivide the Westralian Supersystem into two petroleum systems, both of which operate successfully in the study area and have distinctly different source rock facies.

Figure 15 plots against time the key events in the evolution of the Barrow-Exmouth petroleum systems during the Mesozoic. The deposition of source, reservoir and seal facies; and of the overburden required for maturation, is shown, along with the timing of maturation, hydrocarbon generation (Barber, 1988) and trap formation. The palæogeographic and structural history is also charted.

Major gas and condensate fields are reservoired in TR5 and TR6 (Central Gorgon 1, Zeepaard 1, Zeewulf 1) in sandy fluvial to deltaic facies. They are sourced from Late Triassic coaly sediments and in most cases, sealed by Cretaceous shales. Thus migration of hydrocarbons into these traps must be post the implacement of this regional seal. Earlier generated hydrocarbons that may have included significant volumes of oil have leaked from the system. The oil discovery in Tr6 in Leatherback 1 is particularly important in this context. It is oil rather than gas condensate and is sealed by Latest Triassic and Early Jurassic shales (Tr6/J1/J2 - Murat Siltstone). It demonstrates a regional seal facies in the interval (Fig 15) and suggests that the Triassic is a viable oil source.

The Middle Jurassic (J3 to J6) interval is a source and seal facies with no reservoir development. The tectonism associated with the Argoland break-up in Time Slice J7 produced rapid sedimentation as shown in Figure 15 by the plot of overburden. There are strong gas and oil indications in the study wells (Barrow Deep 1 & Bambra 2).

A producible gas and condensate zone occurs in Barrow Deep 1 in Time Slice J8, which is also an excellent oil source rock interval and a proven seal facies. Reservoir facies are provided by the fan deposits of the Biggada Formation. This gas accumulation has previously been attributed to the Callovian, Time Slice J7 (Woodside Offshore Petroleum, 1988, Figure 4 from Kopsen & McGann, 1985; Bradshaw & Yeung, 1992); but the dating revised for this study firmly places the 3200 - 3400 m gas



EVENT CHART - BARROW / EXMOUTH MODULE
TRIASSIC
JURASSIC
CRETACEOUS
CAINOZOIC
TIME SLICES
1 2 3 4 5 6
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10 11
1 2 3 4 5 6 7
SHOWS
OVERBURDEN
SEAL - Regional
- Intraformational
R
I
RESERVOIR
PALAEOGEOGRAPHY
MARINE
FLUVIO -DELTAIC
MARINE
RESTRICTED MARINE
DELTAIC MARINE
SOURCE
- HI > 100av / 150max
- TOC > 2% av
KANGAROO TR.
GENERATION EX. PLAT.
BARROW TR.
KANGAROO TR.
MATURITY EX. PLAT.
BARROW TR.
MATURE
MATURE
OVERMATURE
IMMATURE
MATURE
IMMATURE
IMMATURE
TRAP FMN
CRITICAL MOMENT
Rift onset
Uplift & erosion
Sea floor spreading Argo
Delta building - G. India
Wrenching
Structuring & main generation

FIGURE 15

sands at the base of J8 in the *W. spectabilis* zone and Oxfordian in age. This confusion may have been caused by an unconformity at the top of J7 in this area (Bambra 2, Flag 1) being taken as the "Main Unconformity, MU" which elsewhere is at the base of J7 and Callovian in age (see cross-section E - E').

Source rock quality facies continue into J9 and J10 (Figure 15). A gas accumulation at South Pepper 1 and an oil pool on Barrow Island (McClure et al., 1988) occur in Time Slice J10, reservoired in the Dupy Sandstone Member.

In the Early Cretaceous the impact of the Greater India break-up produced the outbuilding of the Barrow deltas, the first widespread and good quality reservoir facies deposited in the area since the Late Triassic. Major oil and gas accumulations are reservoired in Time Slice K1 sands. In Time Slice K2 transgression commenced that reached a peak in K4. The regional seal of the Muderong shale was deposited and oil and gas reservoirs occur in the basal transgressive sands of K2 and K3 age.

The major oil pool on Barrow Island is in Time Slice K4. The deposition of source quality facies continues from the Jurassic into the Early Cretaceous, but the level of maturation limits the area of effective source rock to the basin centre. Wrench tectonic activity in Time Slice K9 formed traps and coincided with the first phase of migration of hydrocarbons for the main Jurassic source intervals.

A minor oil pool on Barrow Island occurs in a zone of septarian nodules of K8 age (McClure et al., 1988). The Maitland gas and condensate discovery in Paleocene sands shows that there is leakage of hydrocarbons up through the regional seal and that in some places the Cainozoic marls can be effective seals. Cainozoic structuring and loading of the shelf were critical events in the development of the petroleum system, resulting in a major phase of hydrocarbon generation and trapping (Figure 15).

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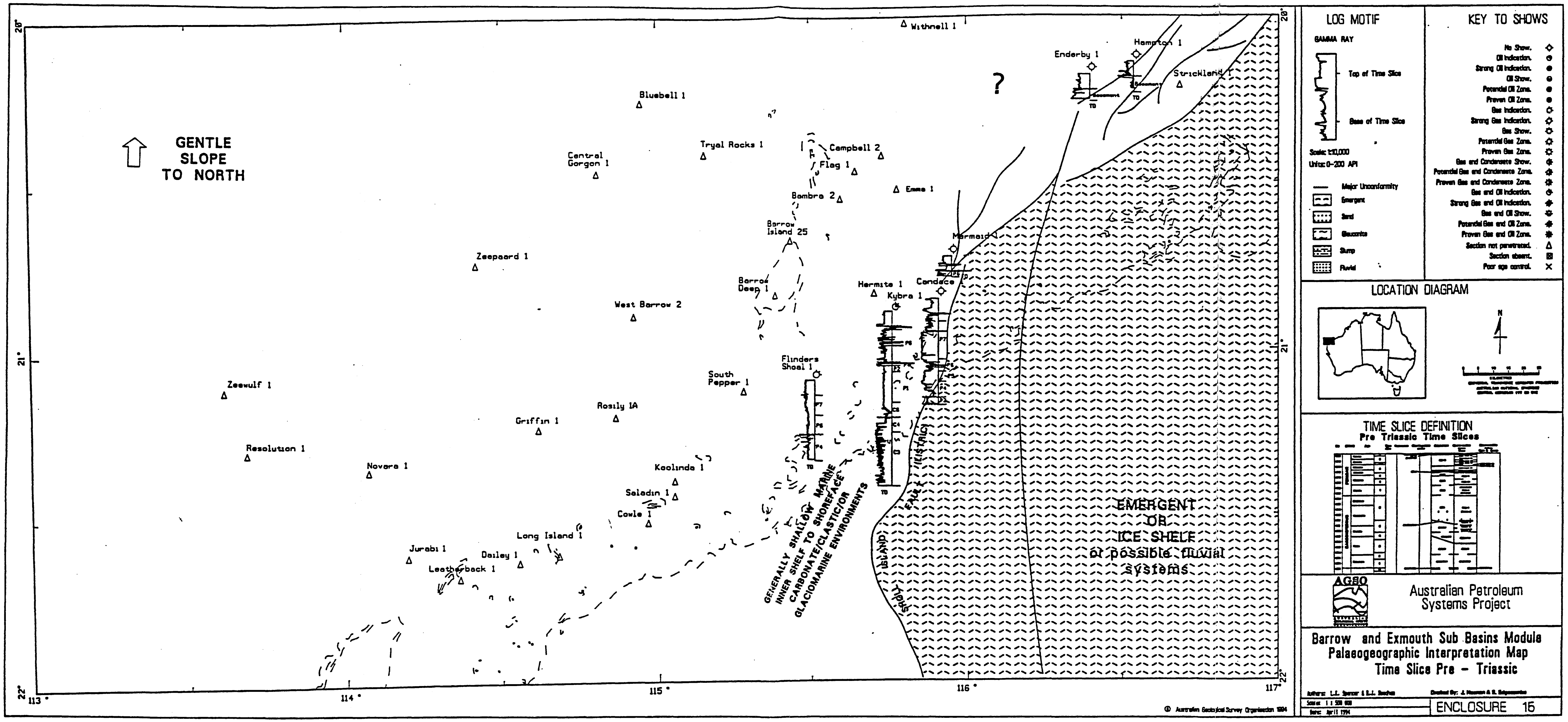
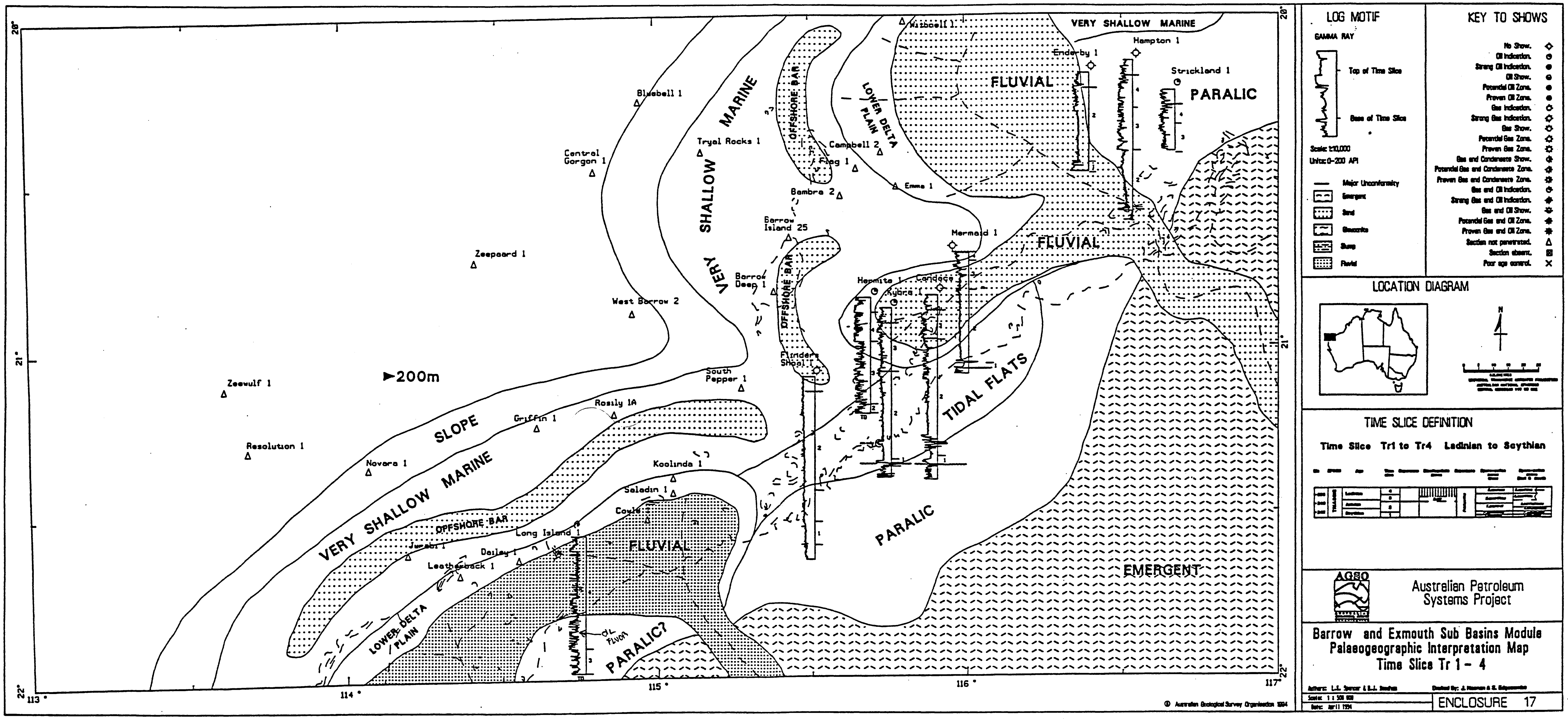
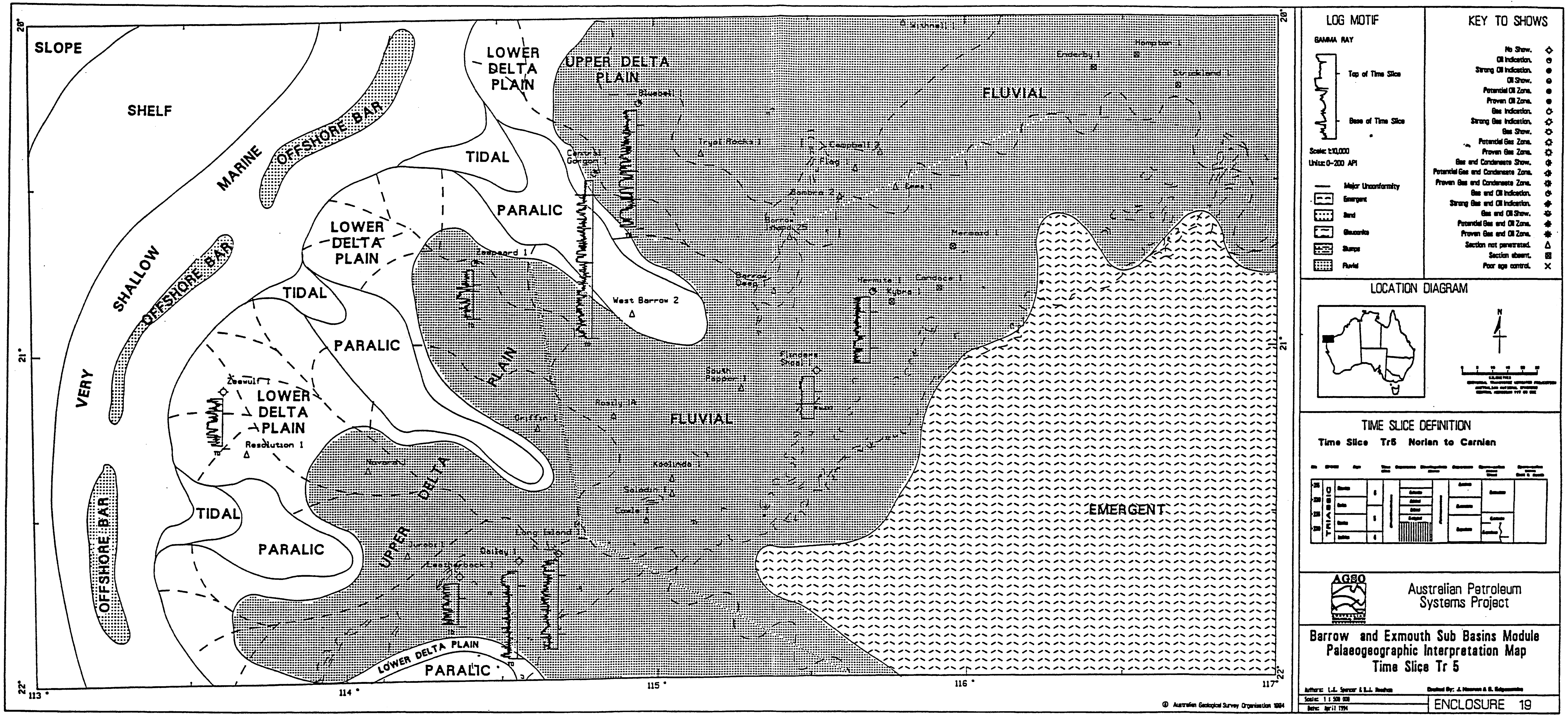
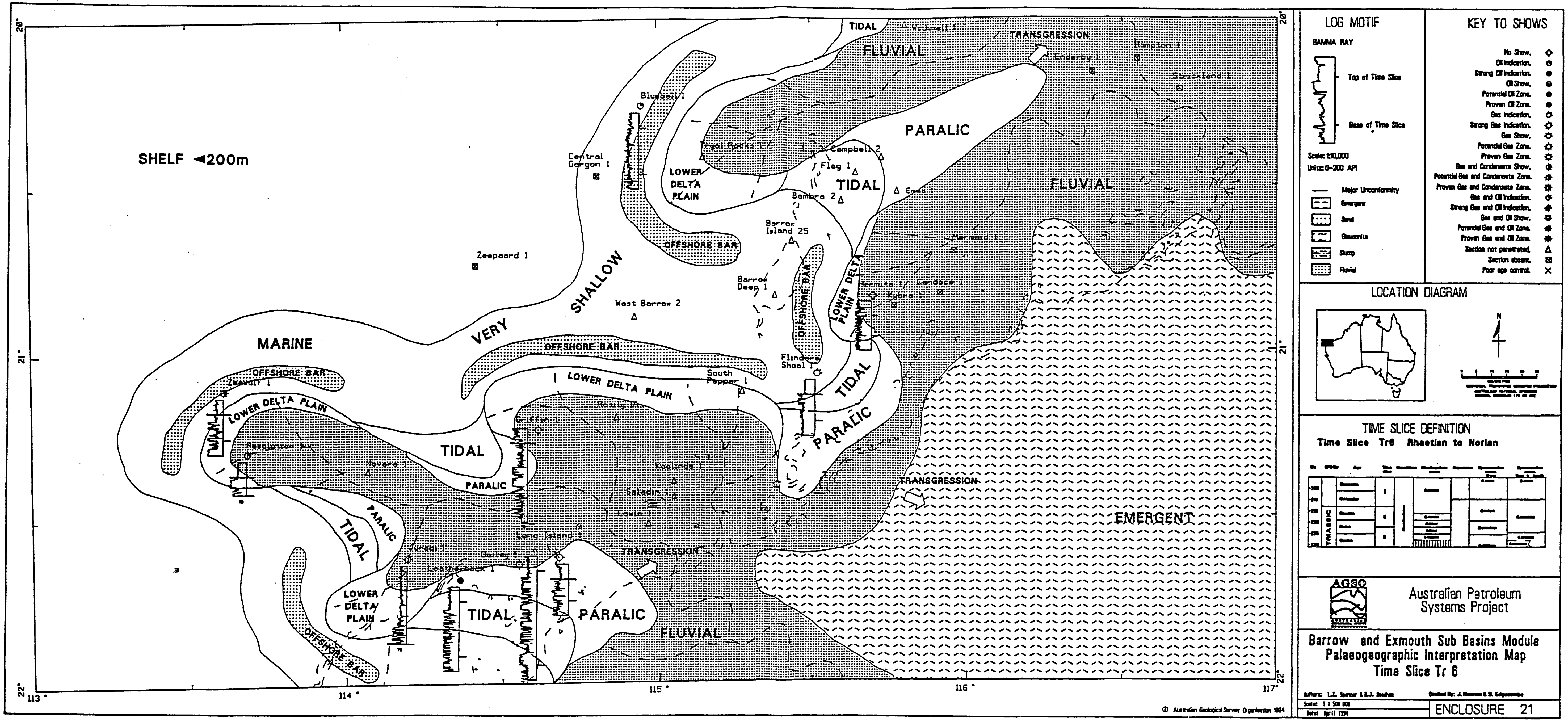
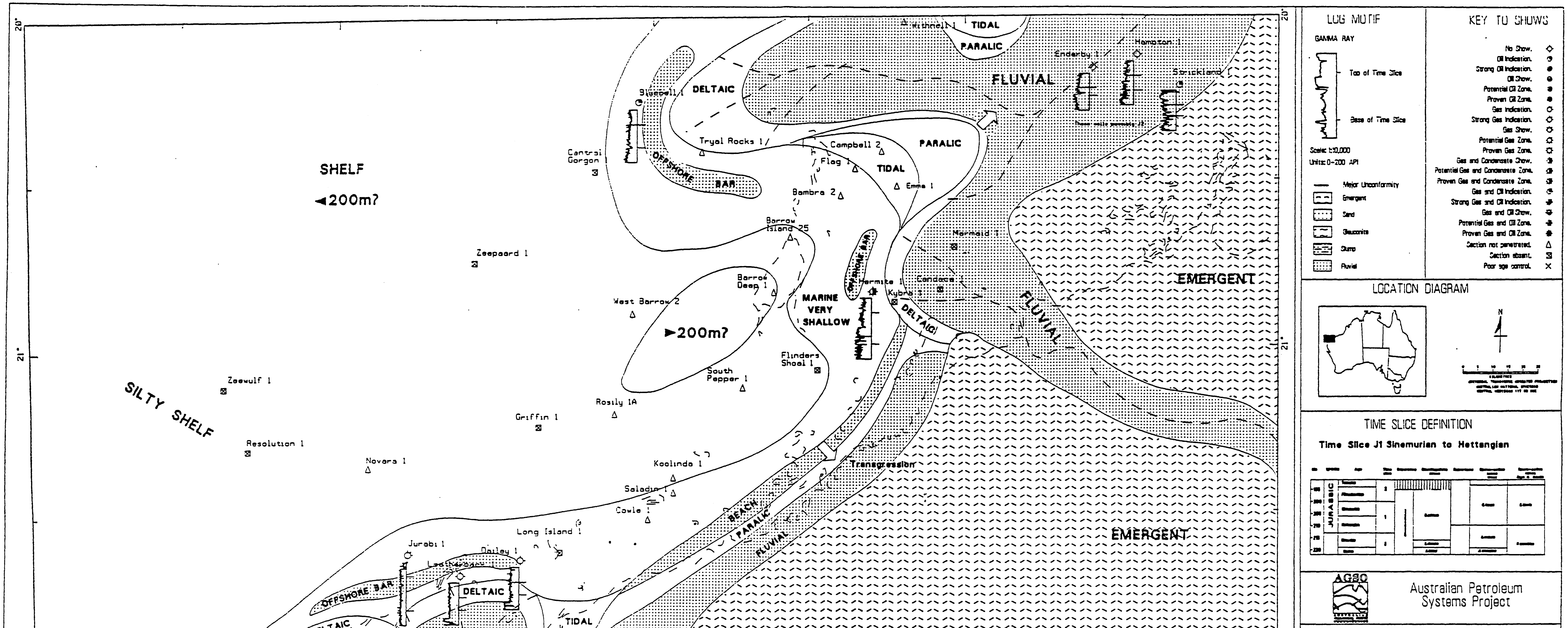

GENTLE SLOPE TO NORTH
?
Withnell 1
Enderby 1
Hampton 1
Strickland 1
Bluebell 1
Tryal Rocks 1
Campbell 2
Flag 1
Central Gorgon 1
Bambra 2
Emma 1
Barrow Island 25
Mermaid
Zeepaard 1
Barrow Deep 1
Hermite 1
Candace
Kybra 1
West Barrow 2
Flinders Shoal 1
South Pepper 1
Zeewulf 1
Rosily 1A
Griffin 1
Resolution 1
Novara 1
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Jurabi 1
Dailey 1
Leatherback 1
GENERALLY SHALLOW MARINE INNER SHELF TO SHOREFACE CARBONATE/CLASTIC/OR GLACIOMARINE ENVIRONMENTS
ISLAND FAULT (ISTAC)
ISLAND HIGH
EMERGENT OR ICE SHELF or possible fluvial systems
20°
21°
22°
113°
114°
115°
116°
117°
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Emergent
Sand
Glauconite
Slump
Fluvial
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Pre Triassic Time Slices
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice Pre – Triassic
ENCLOSURE 15



VERY SHALLOW MARINE
FLUVIAL
PARALIC
FLUVIAL
OFFSHORE BAR
LOWER DELTA PLAIN
VERY SHALLOW MARINE
OFFSHORE BAR
TIDAL FLATS
PARALIC
EMERGENT
SLOPE
VERY SHALLOW MARINE
OFFSHORE BAR
FLUVIAL
LOWER DELTA PLAIN
PARALIC?
►200m
Bluebell 1
Central Gorgon 1
Tryal Rocks 1
Campbell 2
Flag 1
Bambra 2
Emma 1
Barrow Island 25
Barrow Deep 1
Zeepaard 1
West Barrow 2
Flinders Shoal 1
Hermite 1
Kybra 1
Candace
Mermaid 1
Enderby 1
Hampton 1
Strickland 1
Zeewulf 1
Resolution 1
South Pepper 1
Rosily 1A
Griffin 1
Novara 1
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Jurabi 1
Dailey 1
Leatherback 1
113°
114°
115°
116°
117°
20°
21°
22°
© Australian Geological Survey Organisation 1994
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Emergent
Sand
Glauconite
Slump
Fluvial
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice Tr1 to Tr4 Ladinian to Scythian
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice Tr 1 - 4
ENCLOSURE 17


SLOPE
SHELF
VERY SHALLOW MARINE
OFFSHORE BAR
OFFSHORE BAR
OFFSHORE BAR
LOWER DELTA PLAIN
UPPER DELTA PLAIN
TIDAL
PARALIC
LOWER DELTA PLAIN
TIDAL
PARALIC
LOWER DELTA PLAIN
TIDAL
PARALIC
UPPER DELTA PLAIN
FLUVIAL
FLUVIAL
EMERGENT
LOWER DELTA PLAIN
PARALIC
Bluebell
Central Gorgon 1
Tryal Rocks 1
Campbell 2
Flag 1
Bambra 2
Barrow Island
West Barrow 2
Barrow Deep
Hermite 1
Candace 1
Kybra 1
Mermaid 1
Emma 1
Enderby 1
Hampton 1
Strickland 1
Withnell 1
Zeepaard 1
Zeewulf 1
Resolution 1
Flinders Shoal 1
South Pepper 1
Rosily 1A
Griffin 1
Novara 1
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Jurabi 1
Oalkey 1
Leatherback 1
113°
114°
115°
116°
117°
20°
21°
22°
© Australian Geological Survey Organisation 1994
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Emergent
Sand
Glauconite
Slumps
Fluvial
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice Tr5 Norian to Carnian
TRIASSIC
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice Tr 5
Scale: 1 : 500 000
Date: April 1994
ENCLOSURE 19


SHELF ◄200m
MARINE
VERY SHALLOW
OFFSHORE BAR
LOWER DELTA PLAIN
TIDAL
PARALIC
FLUVIAL
EMERGENT
TRANSGRESSION
Bluebell 1
Central Gorgon 1
Zeepaard 1
West Barrow 2
Campbell 2
Flag 1
Bambra 2
Barrow Island 25
Barrow Deep 1
Flinders Shoal 1
South Pepper 1
Zeewulf 1
Resolution 1
Griffin 1
Novara 1
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Leatherback 1
Enderby 1
Hampton 1
Strickland 1
Mermaid 1
Candace 1
Hermite 1
Kybra 1
Emma 1
113°
114°
115°
116°
117°
20°
21°
22°
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Emergent
Sand
Glauconite
Slump
Fluvial
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
TIME SLICE DEFINITION
Time Slice Tr6 Rhaetian to Norian
TRIASSIC
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice Tr 6
ENCLOSURE 21
© Australian Geological Survey Organisation 1994



Australian Petroleum Systems Project

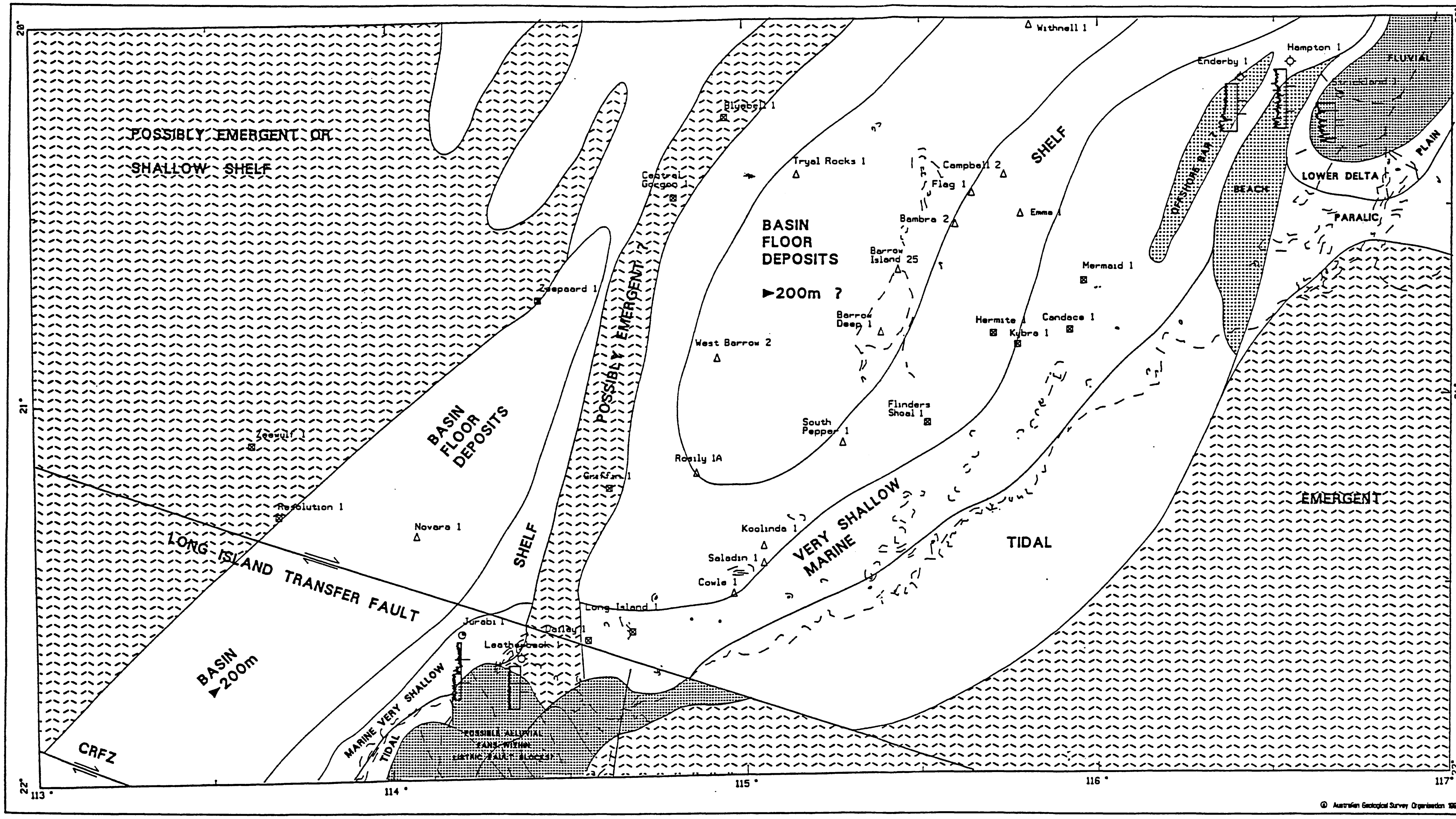
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice J1

Authors: L.E. Spencer & S.J. Reecher

Scale: 1 : 500 000

Date: April 1994

ENCLOSURE 23



LOG MOTIF

GAMMA RAY

Top of Time Slice

Base of Time Slice

Scale: 1:10,000
Units: 0-200 API

Major Unconformity
Emergent
Sand
Glauconite
Slump
Fluvial

KEY TO SHOWS

No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.

LOCATION DIAGRAM

TIME SLICE DEFINITION

Time Slice J2 Toarcian to Pliensbachian

JURASSIC

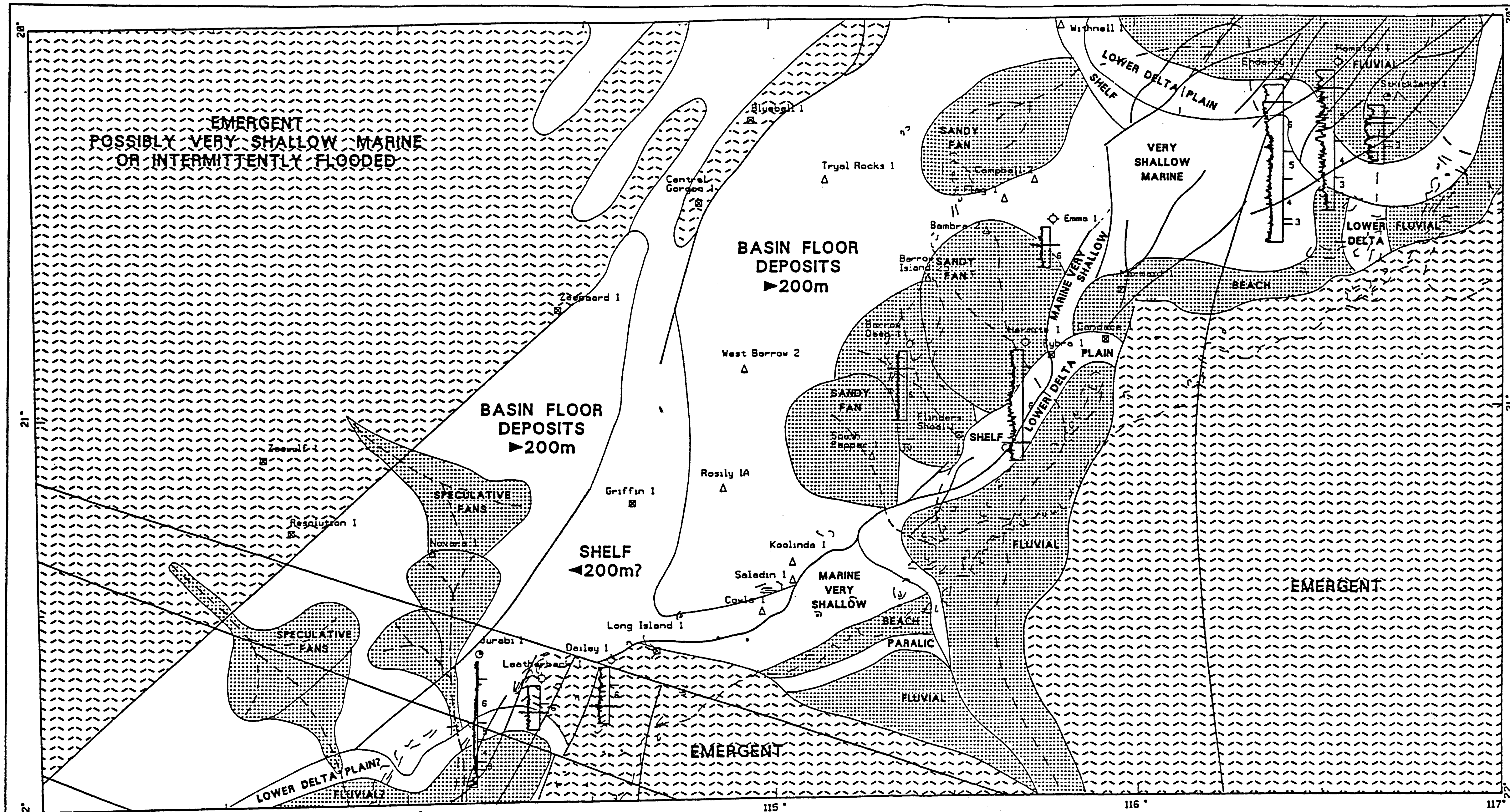
AGSO

Australian Petroleum Systems Project

Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice J2

Authors: L.E. Spencer & B.J. Beeches
Drafted By: J. Mossman & B. Golgowski
Scale: 1 : 500 000
Issue: April 1994

ENCLOSURE 26



LOG MOTIF

GAMMA RAY

Top of Time Slice

Base of Time Slice

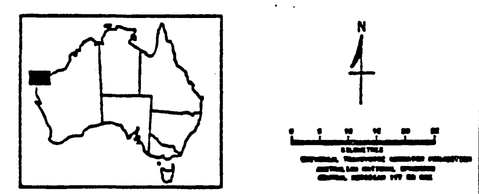
Scale: 1:10,000
Units: 0-200 API

- Major Unconformity
- Emergent
- Sand
- Glauconite
- Slumps
- Fluvial

KEY TO SHOWS

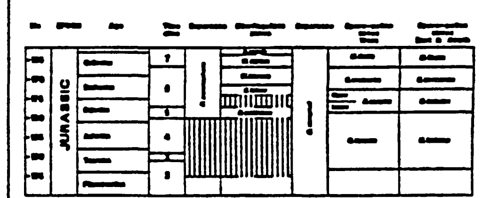
- No Show. ◇
- Oil Indication.
- Strong Oil Indication.
- Oil Show.
- Potential Oil Zone.
- Proven Oil Zone.
- Gas Indication.
- Strong Gas Indication.
- Gas Show.
- Potential Gas Zone.
- Proven Gas Zone.
- Gas and Condensate Show.
- Potential Gas and Condensate Zone.
- Proven Gas and Condensate Zone.
- Gas and Oil Indication.
- Strong Gas and Oil Indication.
- Gas and Oil Show.
- Potential Gas and Oil Zone.
- Proven Gas and Oil Zone.
- Section not penetrated. △
- Section absent. ⊠
- Poor age control. ✕

LOCATION DIAGRAM



TIME SLICE DEFINITIONS

Time Slice J3 to J6 Callovian to Toarcian



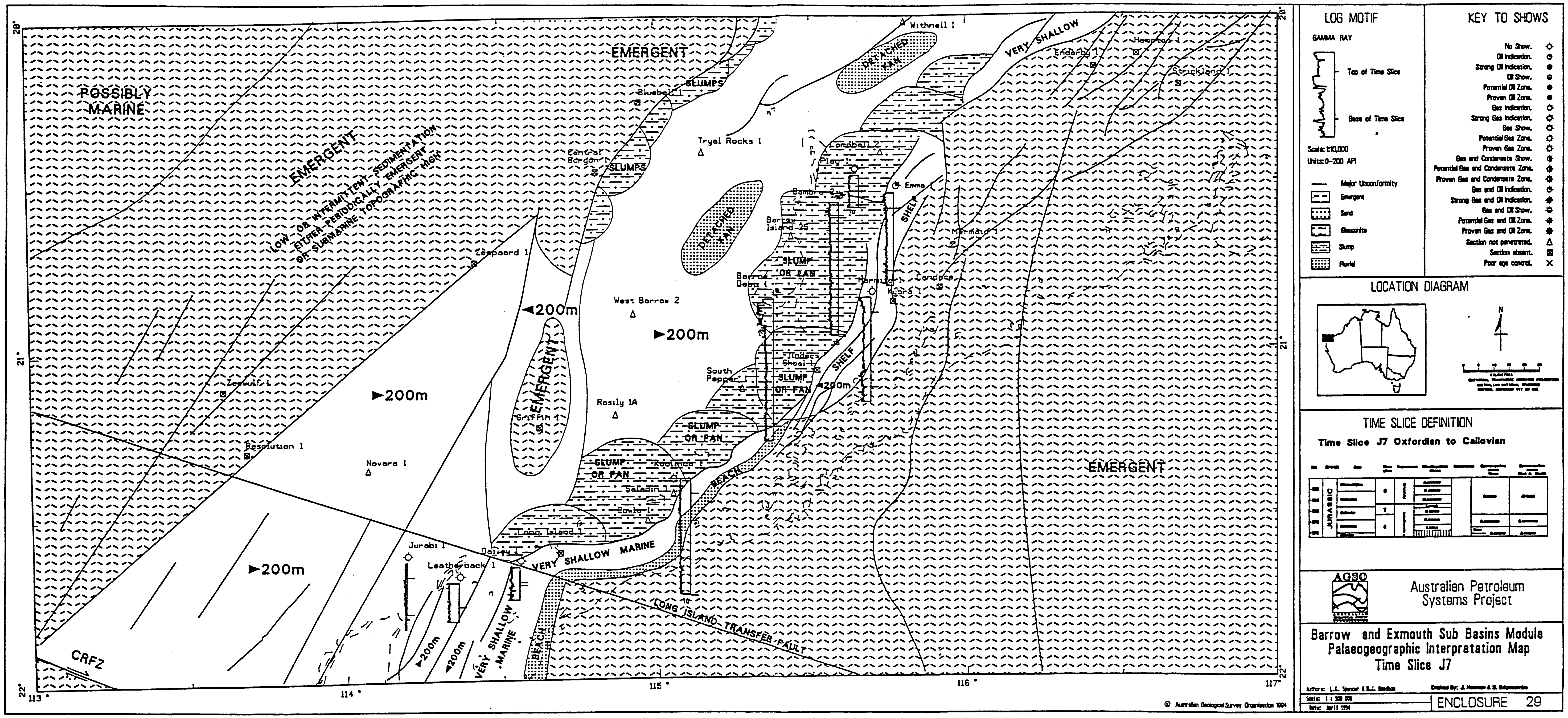
AGSO

Australian Petroleum Systems Project

Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice J3 to J6

Scale: 1:500 000
Date: April 1994

ENCLOSURE 27



POSSIBLY MARINE
EMERGENT
LOW OR INTERMITTENT SEDIMENTATION EITHER PERIODICALLY EMERGENT OR SUBMARINE TOPOGRAPHIC HIGH
EMERGENT
SLUMPS
SLUMPS
DETACHED FAN
DETACHED FAN
VERY SHALLOW
SHELF
SLUMP OR FAN
SLUMP OR FAN
SLUMP OR FAN
SLUMP OR FAN
SHELF
BEACH
VERY SHALLOW MARINE
VERY SHALLOW MARINE
BEACH
LONG ISLAND TRANSFER FAULT
CRFZ
◄200m
►200m
►200m
►200m
◄200m
◄200m
►200m
◄200m
EMERGENT
EMERGENT
Withnell 1
Enderby 1
Hampton 1
Strickland 1
Bluebell 1
Central Bargon
Tryal Rocks 1
Campbell 2
Flag 1
Emma
Bambra 2
Barrow Island 2S
Mermaid 1
Zeepaard 1
West Barrow 2
Barrow Deep 1
Candace
Kybra 1
Rosily 1A
South Pepper
Rodacs Shoal 1
Zeewulf 1
Griffin 1
Resolution 1
Novara 1
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Jurabi 1
Dolley 1
Leatherback 1
20°
21°
22°
113°
114°
115°
116°
117°
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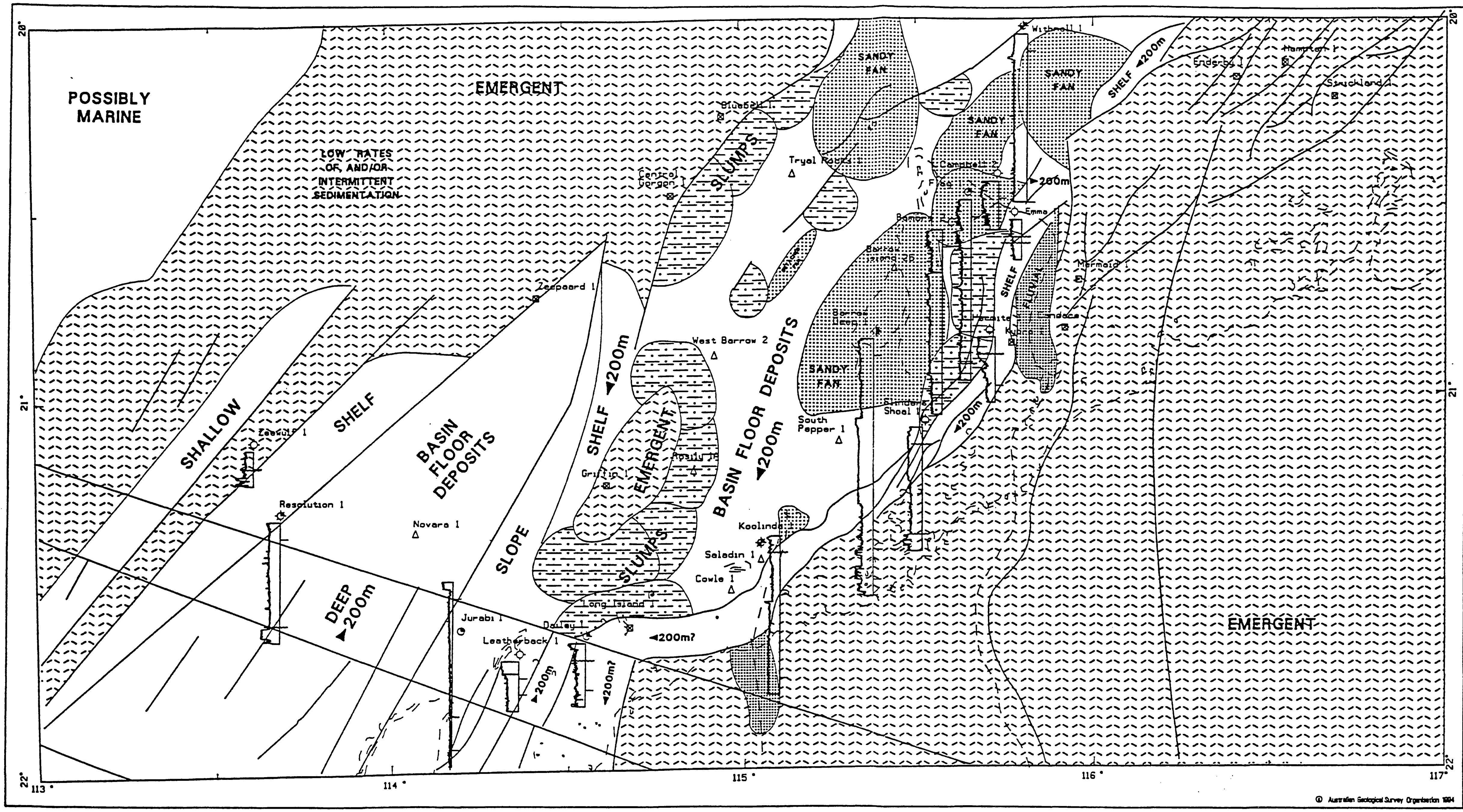
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Emergent
Sand
Glauconite
Slump
Fluvial
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice J7 Oxfordian to Callovian
JURASSIC
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice J7
Authors: L.E. Spencer & B.J. Beechas
Scale: 1:500 000
Date: April 1994
ENCLOSURE 29



LOG MOTIF

GAMMA RAY

Top of Time Slice

Base of Time Slice

Scale: 1:10,000
Units: 0-200 API

- Major Unconformity
- Emergent
- Sand
- Glauconite
- Slump
- Fluvial

KEY TO SHOWS

- No Show.
- Oil Indication.
- Strong Oil Indication.
- Oil Show.
- Potential Oil Zone.
- Proven Oil Zone.
- Gas Indication.
- Strong Gas Indication.
- Gas Show.
- Potential Gas Zone.
- Proven Gas Zone.
- Gas and Condensate Show.
- Potential Gas and Condensate Zone.
- Proven Gas and Condensate Zone.
- Gas and Oil Indication.
- Strong Gas and Oil Indication.
- Gas and Oil Show.
- Potential Gas and Oil Zone.
- Proven Gas and Oil Zone.
- Section not penetrated. △
- Section absent. ⊠
- Poor age control. ×

LOCATION DIAGRAM

TIME SLICE DEFINITION

Time Slice J8 Kimmerdgian to Oxfordian

AGSO

Australian Petroleum Systems Project

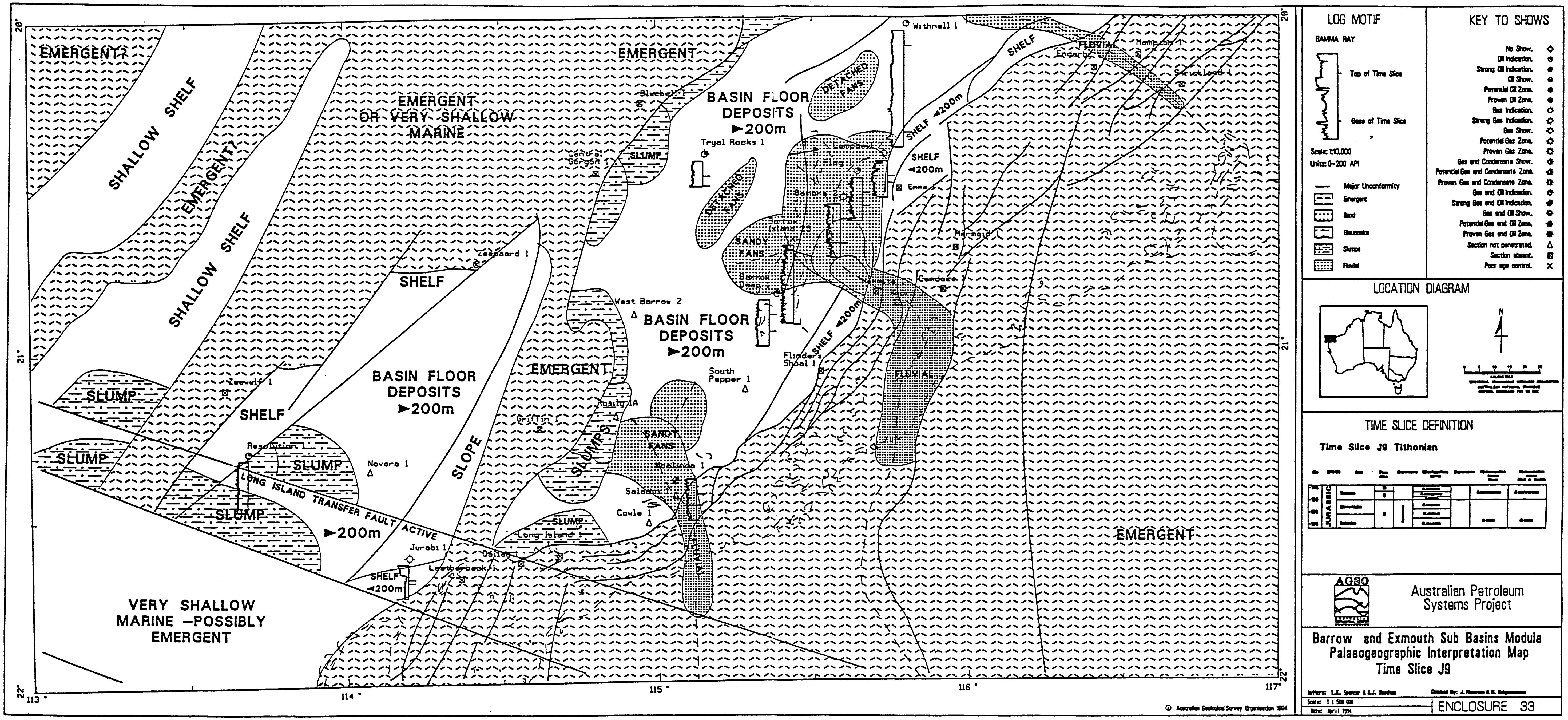
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice J8

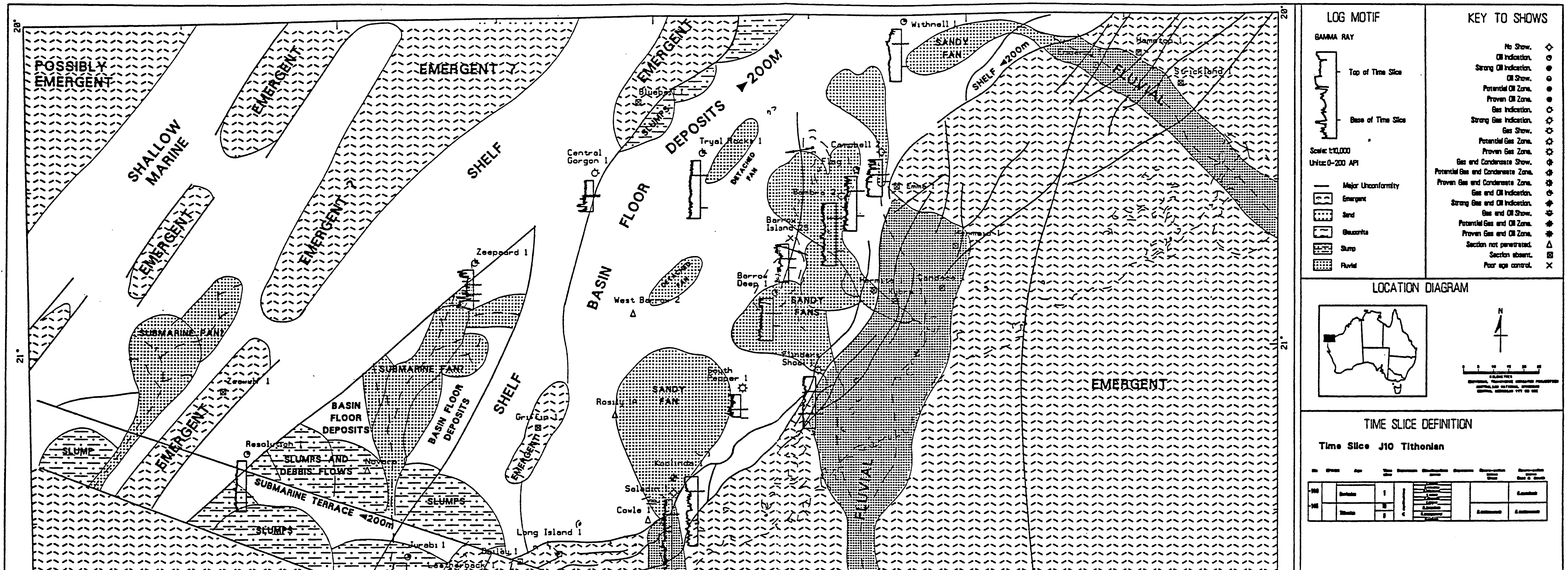
Authors: L.E. Spencer & B.J. Bradshaw

Scale: 1 : 500 000

Date: April 1994

ENCLOSURE 31


EMERGENT?
SHALLOW SHELF
EMERGENT?
SHALLOW SHELF
EMERGENT OR VERY SHALLOW MARINE
EMERGENT
BASIN FLOOR DEPOSITS ►200m
DETACHED FANS
SHELF
SHELF ◄200m
FLUVIAL
Withnell 1
Enderby 1
Hampton 1
Strickland 1
Bluebell 1
Tryal Rocks 1
Central Gorgon 1
SLUMP
Emma 1
Barrow Island 25
SANDY FANS
Barrow Deep 1
Mermaid 1
Cardabia 1
Zeepaard 1
West Barrow 2
BASIN FLOOR DEPOSITS ►200m
SHELF
Flinders Shoal 1
South Pepper 1
Zeewulf 1
SLUMP
SHELF
BASIN FLOOR DEPOSITS ►200m
EMERGENT
Rosily 1A
Griffin 1
SLUMPS
SANDY FANS
Resolution 1
Novara 1
SLOPE
Saladin 1
Cowle 1
LONG ISLAND TRANSFER FAULT ACTIVE
►200m
Jurabi 1
Long Island 1
Leatherback 1
SHELF ◄200m
VERY SHALLOW MARINE –POSSIBLY EMERGENT
EMERGENT
20°
21°
22°
113°
114°
115°
116°
117°
© Australian Geological Survey Organisation 1994
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Emergent
Sand
Glauconite
Slumps
Fluvial
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice J9 Tithonian
JURASSIC
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice J9
ENCLOSURE 33



AGSO

Australian Petroleum Systems Project

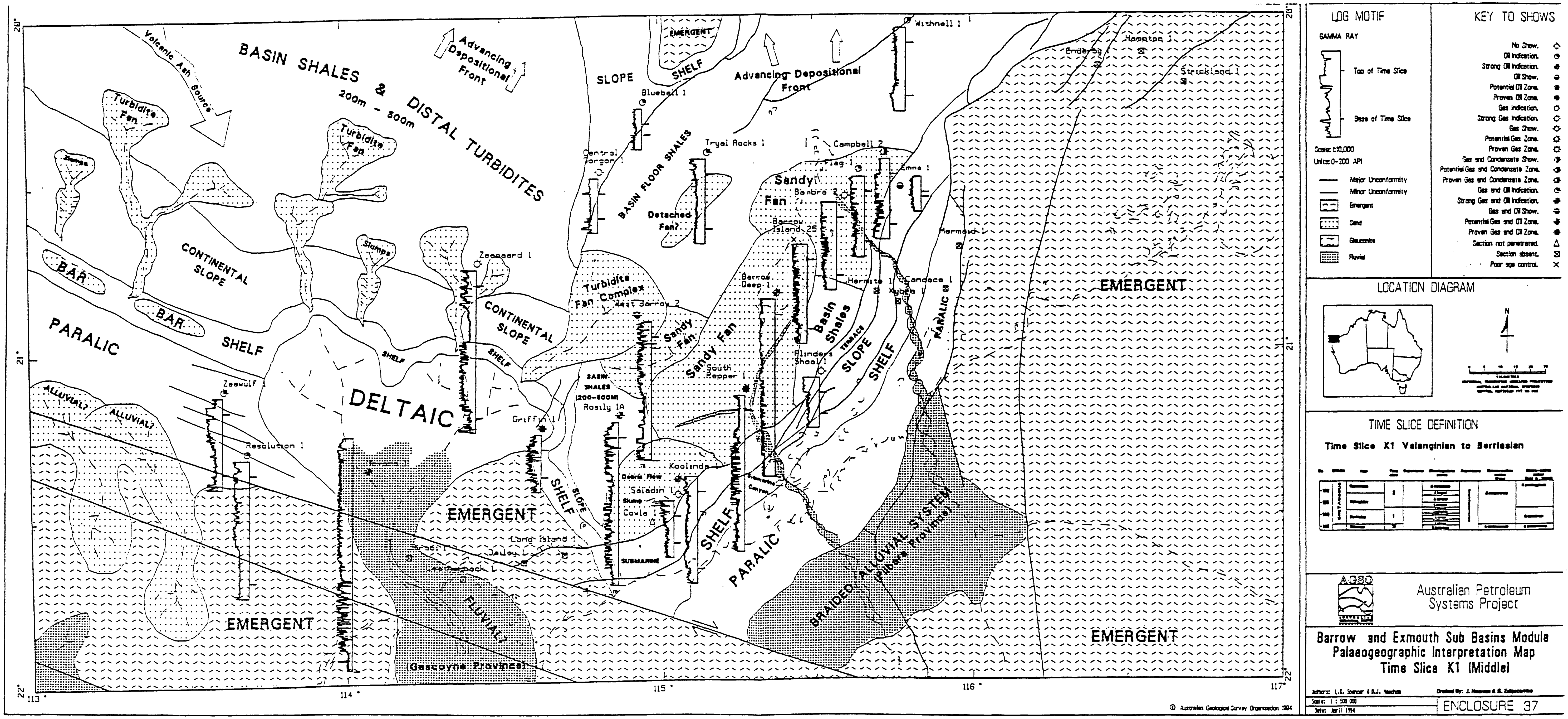
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice J10

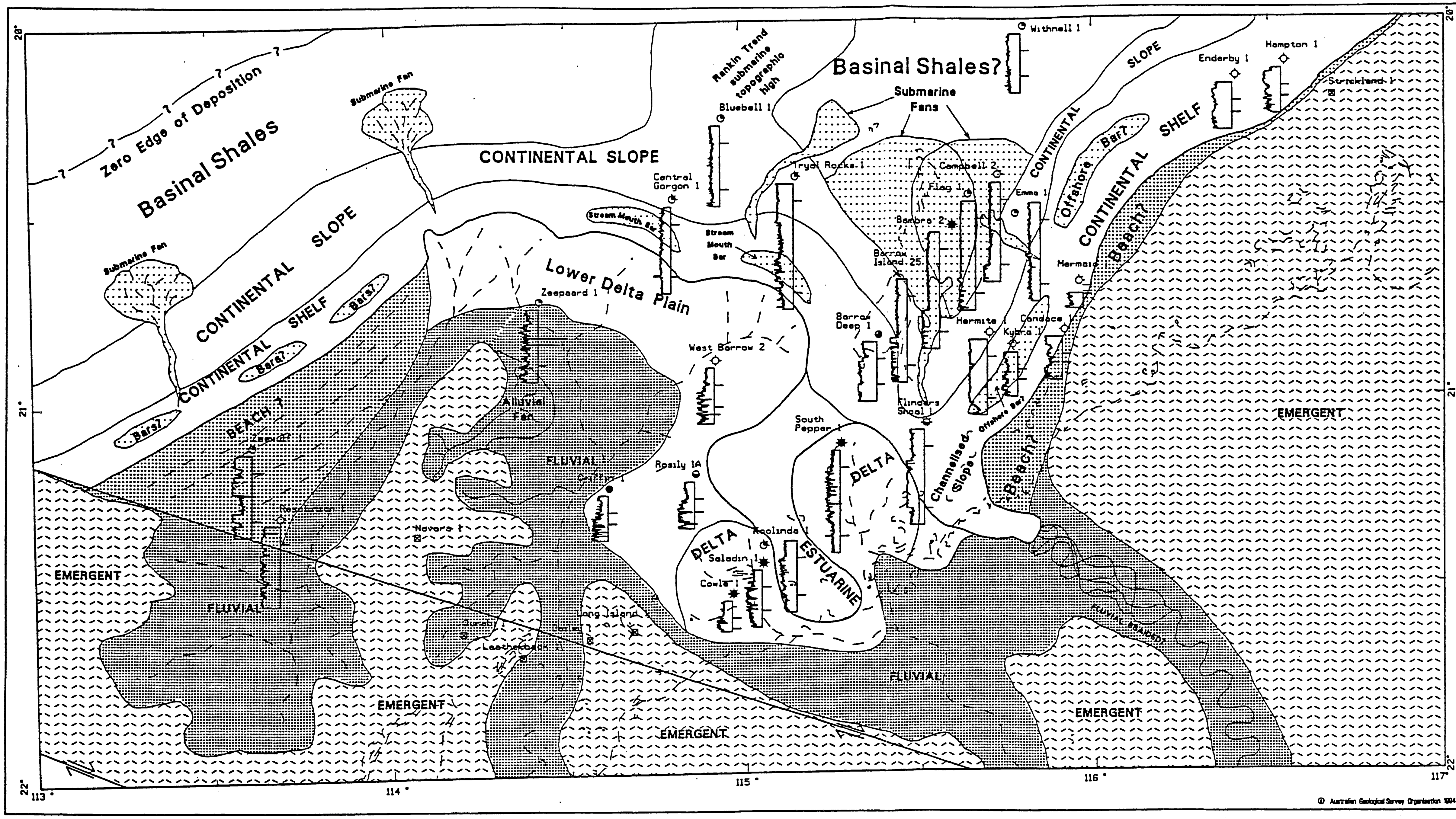
Authors: L.L. Spencer & B.J. Beecham

Scale: 1 : 500 000

Date: April 1994

ENCLOSURE 35


BASIN SHALES & DISTAL TURBIDITES
200m - 500m
Volcanic Ash Source
Advancing Depositional Front
Turbidite Fan
Slumps
CONTINENTAL SLOPE
BAR
PARALIC
SHELF
DELTAIC
ALLUVIAL?
EMERGENT
FLUVIAL?
(Gascoyne Province)
SLOPE
SHELF
BASIN FLOOR SHALES
Detached Fan?
Sandy Fan
Turbidite Fan Complex
BASIN SHALES (200-500M)
Debris Flow
Slump
SUBMARINE
Canyon
Basin Shales
TERRACE
BRAIDED ALLUVIAL SYSTEM (Pilbara Province)
Withnell 1
Bluebell 1
Central Gorgon 1
Tryal Rocks 1
Campbell 2
Flag 1
Emma 1
Bambra 2
Barrow Island 25
Barrow Deep 1
Hermite 1
Candace 1
Kybra 1
Hermes 1
Flinders Shoal 1
South Pepper 1
Zeepaard 1
West Barrow 2
Rosily 1A
Griffin 1
Zeewulf 1
Resolution 1
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Dailey 1
Enderby 1
Hampton 1
Strickland 1
Mermaid 1
20°
21°
22°
113°
114°
115°
116°
117°
© Australian Geological Survey Organisation 1994
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Minor Unconformity
Emergent
Sand
Glauconite
Fluvial
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice K1 Valanginian to Berriasian
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice K1 (Middle)
Authors: L.I. Spencer & B.J. Needham
Scale: 1 : 500 000
Date: April 1994
ENCLOSURE 37



LOG MOTIF

GAMMA RAY

- Top of Time Slice
- Base of Time Slice

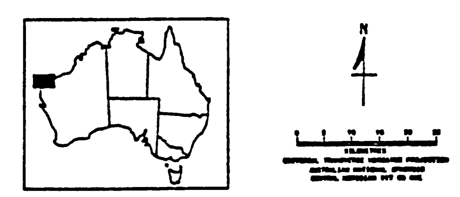
Scale: 1:10,000
Units: 0-200 API

- Major Unconformity
- Minor Unconformity
- Emergent
- Sand
- Glauconite
- Fluvial

KEY TO SHOWS

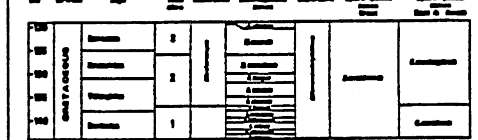
- No Show.
- Oil Indication.
- Strong Oil Indication.
- Oil Show.
- Potential Oil Zone.
- Proven Oil Zone.
- Gas Indication.
- Strong Gas Indication.
- Gas Show.
- Potential Gas Zone.
- Proven Gas Zone.
- Gas and Condensate Show.
- Potential Gas and Condensate Zone.
- Proven Gas and Condensate Zone.
- Gas and Oil Indication.
- Strong Gas and Oil Indication.
- Gas and Oil Show.
- Potential Gas and Oil Zone.
- Proven Gas and Oil Zone.
- Section not penetrated.
- Section absent.
- Poor age control.

LOCATION DIAGRAM



TIME SLICE DEFINITION

Time Slice K2 Hauterivian to Valanginian



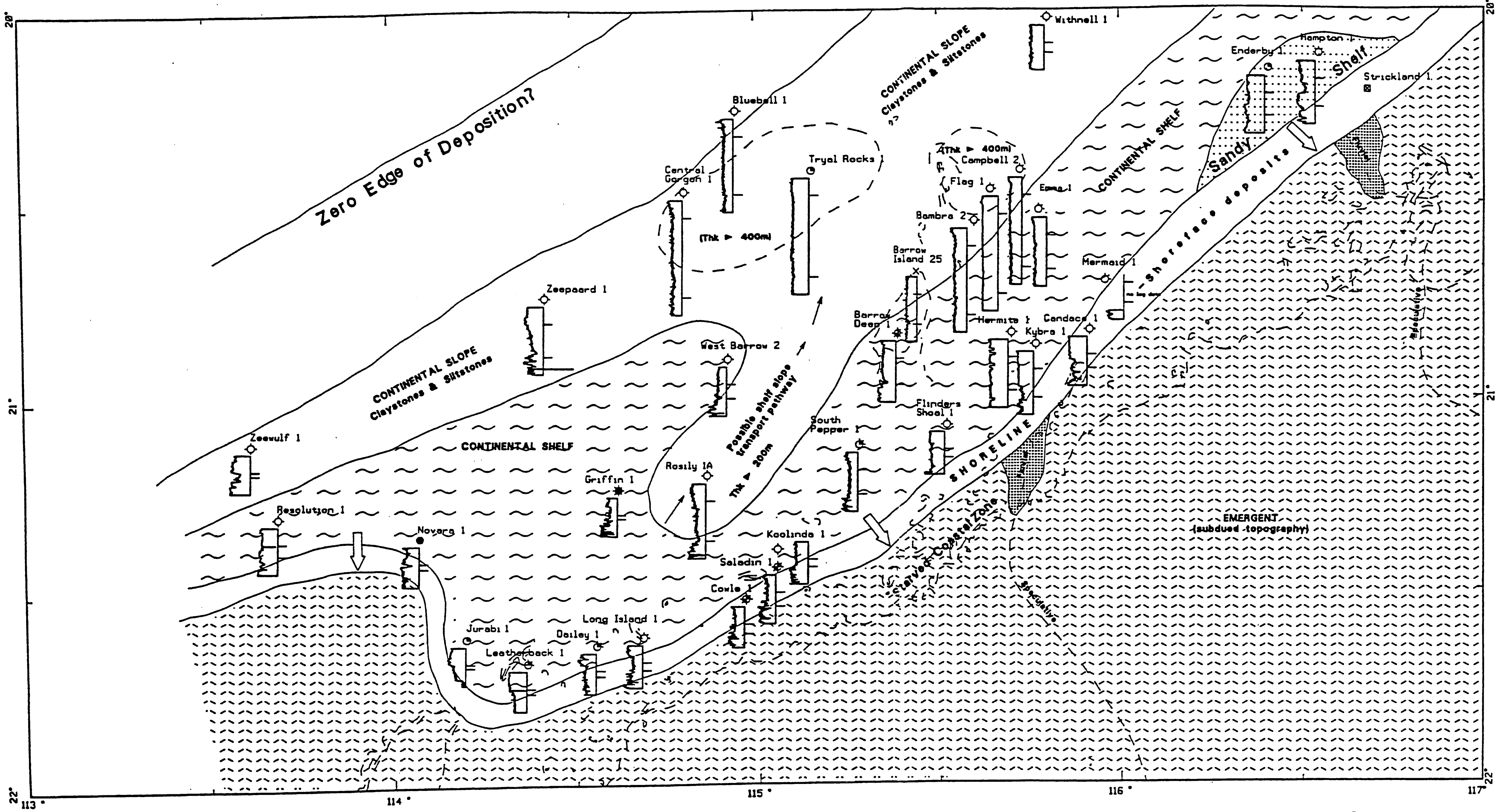
Australian Petroleum Systems Project

Barrow and Exmouth Sub Basins Module Palaeogeographic Interpretation Map Time Slice Early K2

Authors: L.L. Spencer & B.J. Beecham

Scale: 1 : 500 000
Date: April 1994

ENCLOSURE 39



LOG MOTIF

GAMMA RAY

Top of Time Slice

Base of Time Slice

Scale: 1:10,000

Units: 0-200 API

Major Unconformity

Minor Unconformity

Emergent

Sand

Glauconite

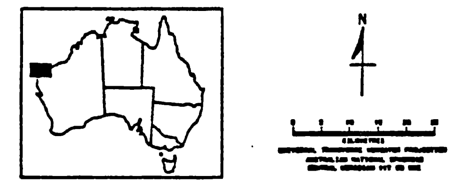
Fluvial

Dominant Direction of Transportation

KEY TO SHOWS

No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.

LOCATION DIAGRAM



TIME SLICE DEFINITION

Time Slice K3 Barremian to Hauterivian

AGSO

Australian Petroleum Systems Project

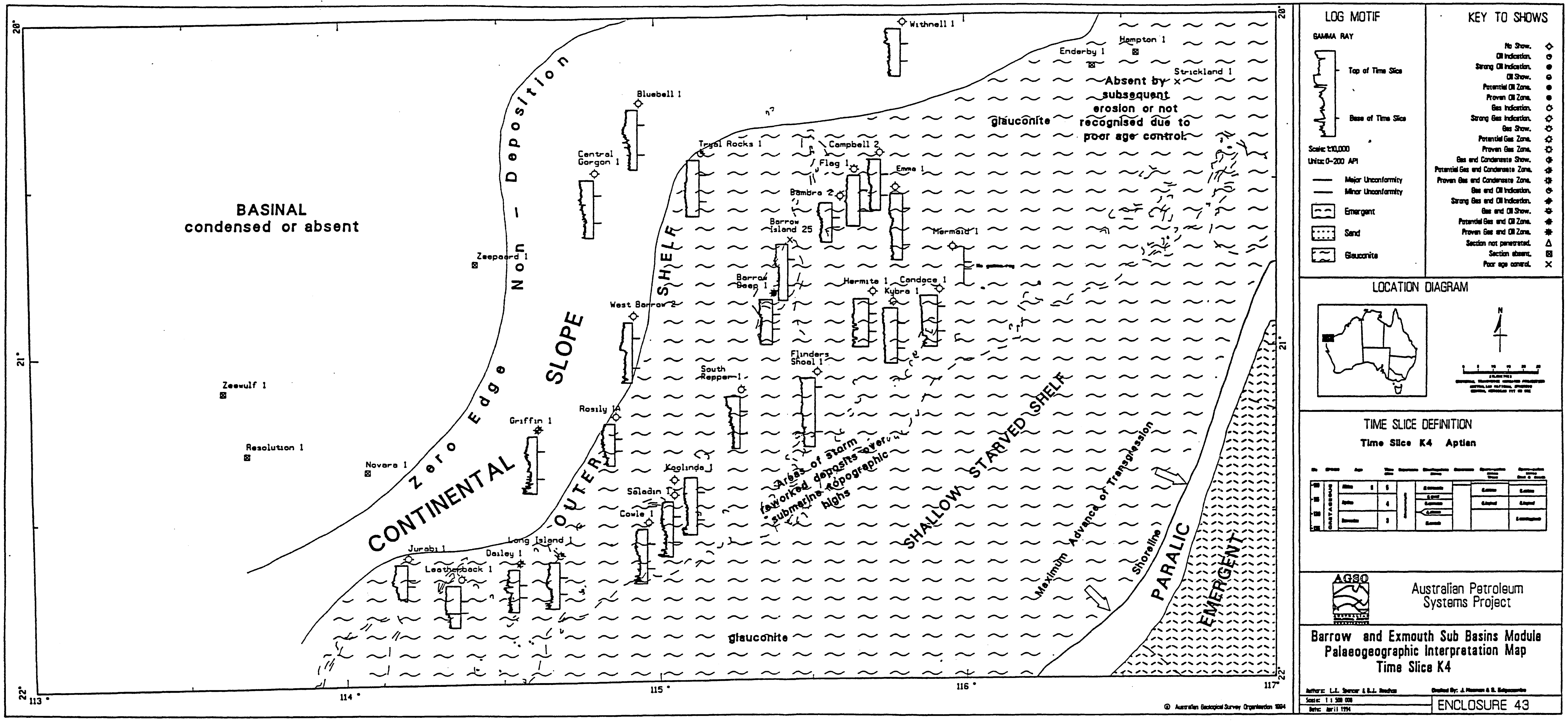
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice K3

Authors: L.L. Spencer & B.J. Beecham

Scale: 1:1 500 000

Date: April 1994

ENCLOSURE 41



BASINAL
condensed or absent
Zero Edge - Non - Deposition
CONTINENTAL SLOPE
OUTER SHELF
SHALLOW STARVED SHELF
Areas of storm reworked deposits over submarine topographic highs
Absent by subsequent erosion or not recognised due to poor age control.
glauconite
glauconite
Maximum Advance of Transgression
Shoreline
PARALIC
EMERGENT
Withnell 1
Enderby 1
Hampton 1
Strickland 1
Bluebell 1
Central Gorgon 1
Tryal Rocks 1
Campbell 2
Flag 1
Emma 1
Bambra 2
Barrow Island 25
Mermaid 1
Zeepaard 1
Barrow Deep 1
Hermite 1
Candace 1
Kybra 1
West Barrow 2
Flinders Shoal 1
South Pepper 1
Zeewulf 1
Rosily 1A
Griffin 1
Resolution 1
Novara 1
Koolinda 1
Saladin 1
Cowle 1
Jurabi 1
Long Island 1
Dailey 1
Leatherback 1
113°
114°
115°
116°
117°
20°
21°
22°
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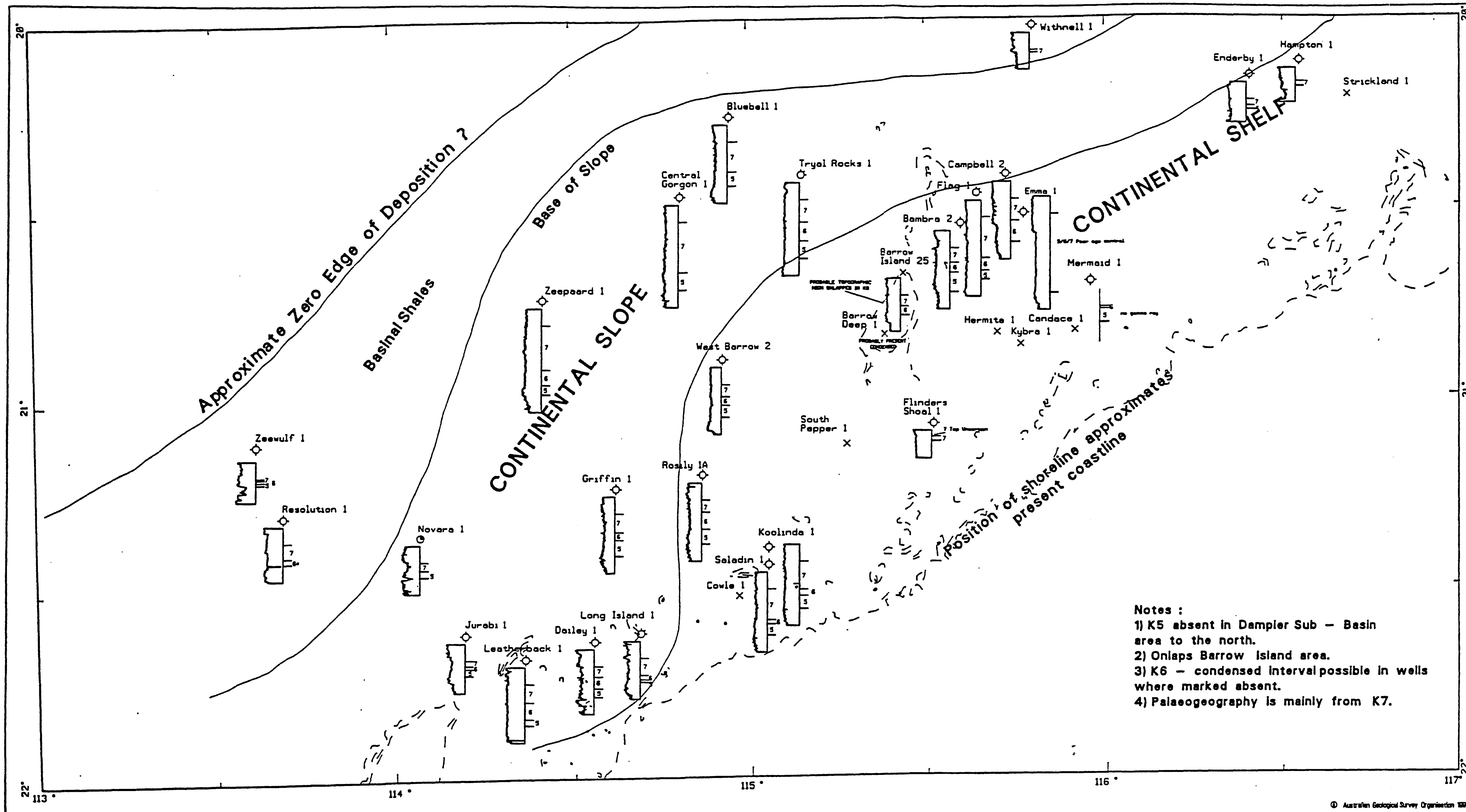
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale 1:10,000
Units 0-200 API
Major Unconformity
Minor Unconformity
Emergent
Sand
Glauconite
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice K4 Aptian
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice K4
Authors: L.E. Spencer & R.J. Brooks
Scale: 1:500 000
Date: April 1994
ENCLOSURE 43



LOG MOTIF

GAMMA RAY

Top of Time Slice

Base of Time Slice

Scale: 1:10,000

Units: 0-200 API

Major Unconformity

Minor Unconformity

KEY TO SHOWS

No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.

LOCATION DIAGRAM

TIME SLICE DEFINITIONS

Time Slice K5 – K7 Albian

AGSO

Australian Petroleum Systems Project

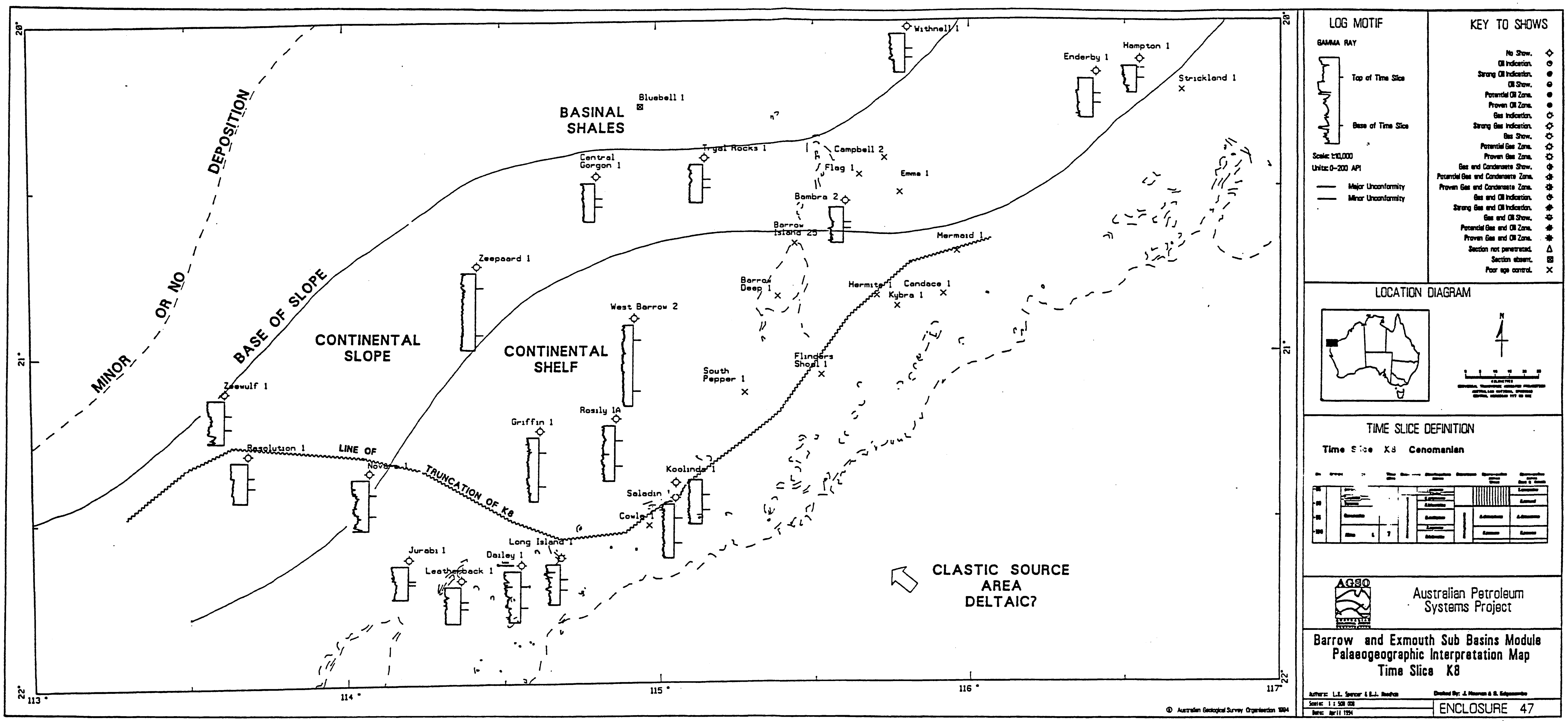
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice K5-K7

Authors: L.E. Spencer & B.J. Bradshaw

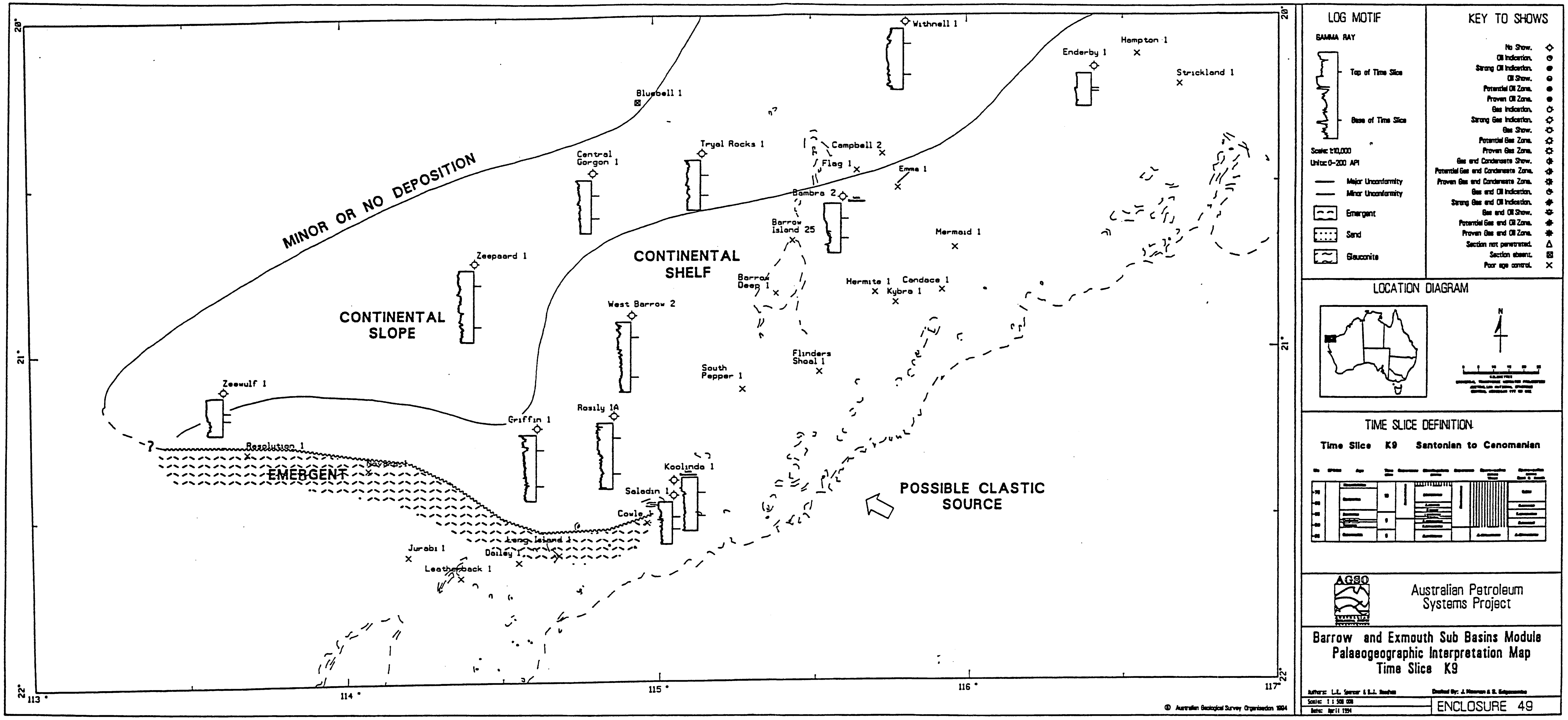
Scale: 1 : 500 000

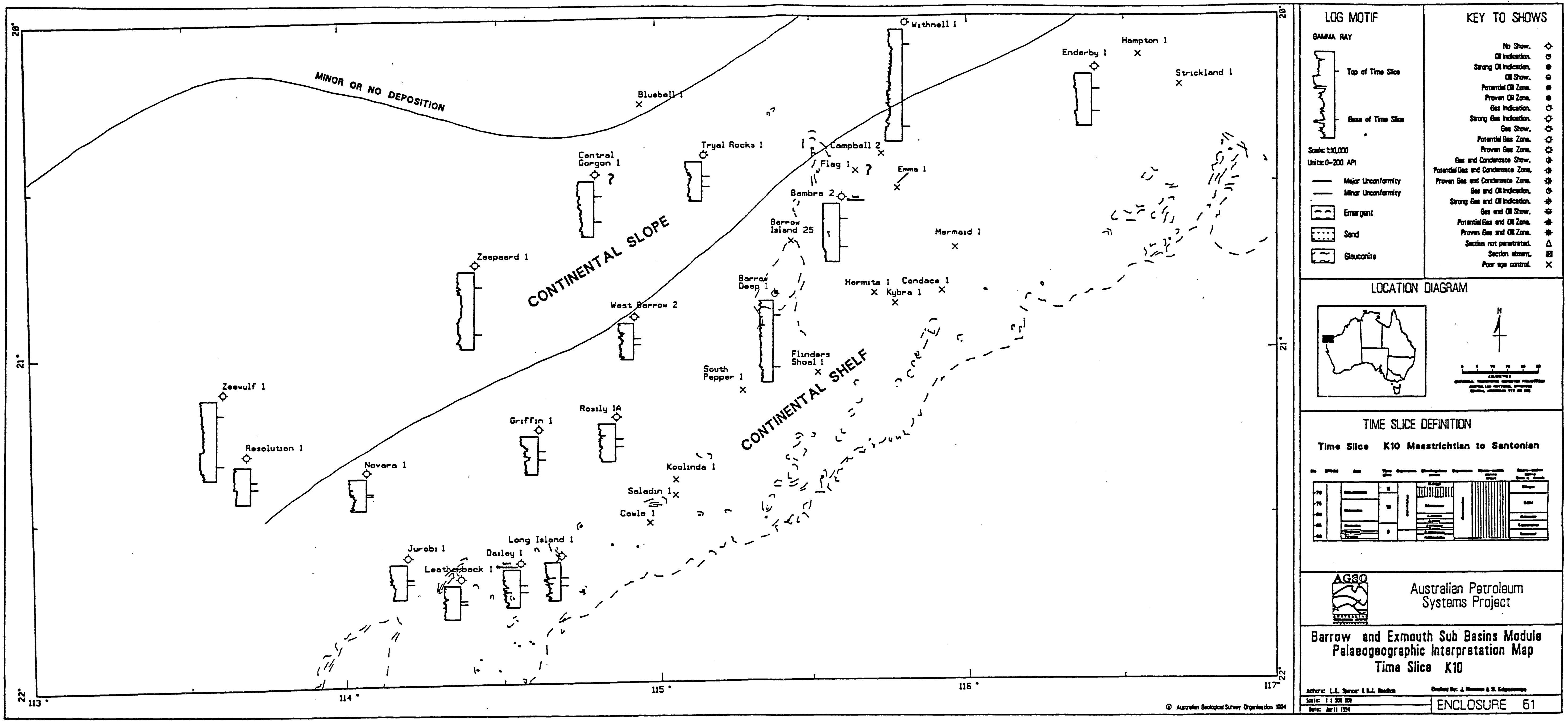
Date: April 1994

ENCLOSURE 45

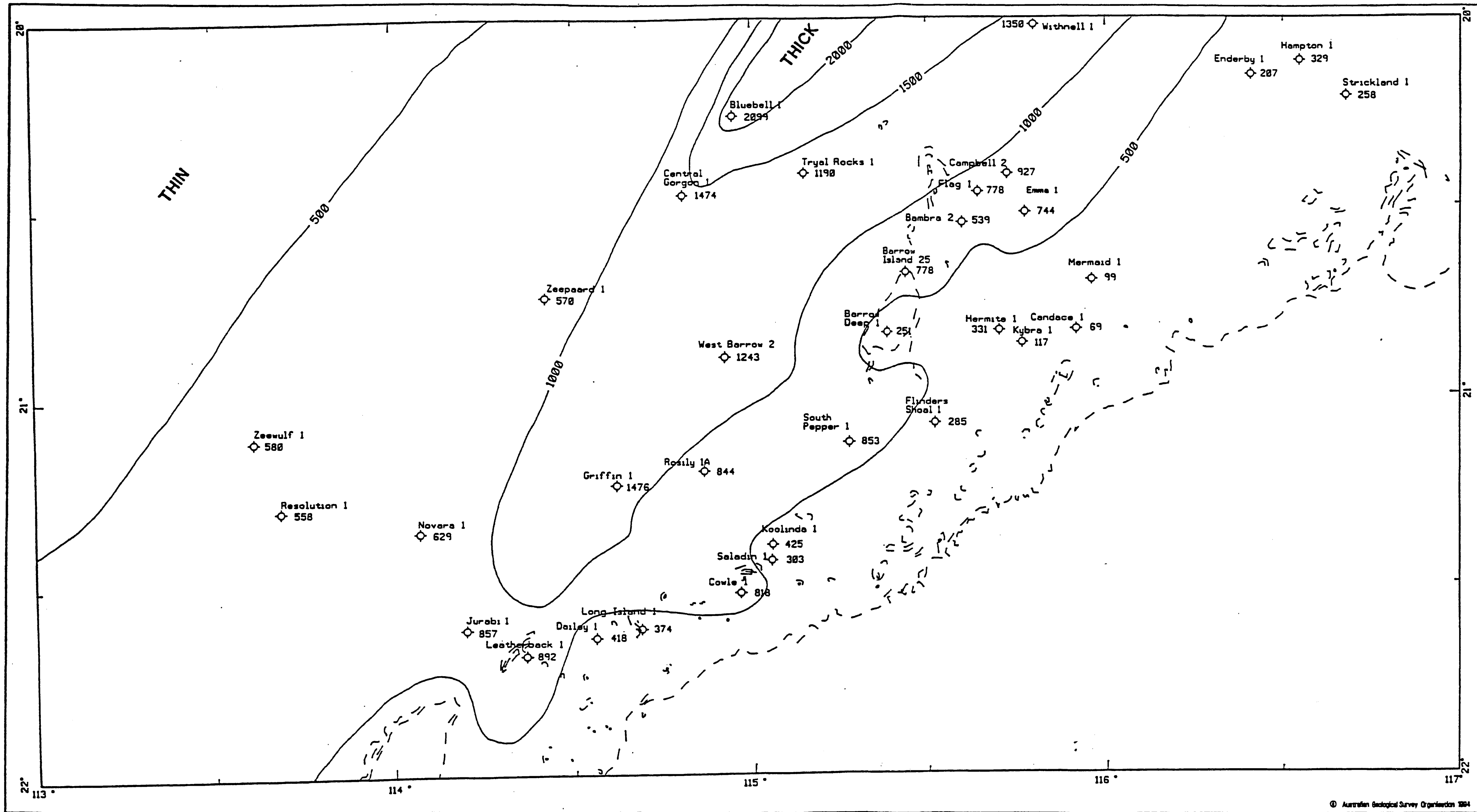


20°
21°
22°
113°
114°
115°
116°
117°
MINOR OR NO DEPOSITION
BASE OF SLOPE
BASINAL SHALES
CONTINENTAL SLOPE
CONTINENTAL SHELF
LINE OF TRUNCATION OF K8
CLASTIC SOURCE AREA DELTAIC?
Withnell 1
Enderby 1
Hampton 1
Strickland 1
Bluebell 1
Tryal Rocks 1
Campbell 2
Flag 1
Emma 1
Central Gorgon 1
Bambra 2
Barrow Island 25
Mermaid 1
Zeepaard 1
Barrow Deep 1
Hermite 1
Candace 1
Kybra 1
West Barrow 2
Flinders Shoal 1
South Pepper 1
Zeewulf 1
Rosily 1A
Griffin 1
Resolution 1
Novara 1
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Jurabi 1
Dailey 1
Leatherback 1
© Australian Geological Survey Organisation 1994
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Minor Unconformity
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice K8 Cenomanian
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice K8
ENCLOSURE 47
Date: April 1994


MINOR OR NO DEPOSITION
CONTINENTAL SLOPE
CONTINENTAL SHELF
EMERGENT
POSSIBLE CLASTIC SOURCE
Withnell 1
Hampton 1
Enderby 1
Strickland 1
Bluebell 1
Tryal Rocks 1
Central Gorgon 1
Campbell 2
Flag 1
Emma 1
Bambra 2
Barrow Island 25
Mermaid 1
Zeepaard 1
Barrow Deep 1
Hermite 1
Candace 1
Kybra 1
West Barrow 2
Flinders Shoal 1
South Pepper 1
Zeewulf 1
Resolution 1
Griffin 1
Rosily 1A
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Jurabi 1
Dailey 1
Leatherback 1
113°
114°
115°
116°
117°
20°
21°
22°
© Australian Geological Survey Organisation 1994
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Minor Unconformity
Emergent
Sand
Glauconite
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice K9 Santonian to Cenomanian
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice K9
ENCLOSURE 49

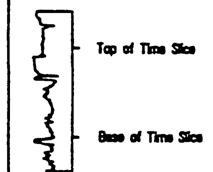


MINOR OR NO DEPOSITION
CONTINENTAL SLOPE
CONTINENTAL SHELF
Withnell 1
Enderby 1
Hampton 1
Strickland 1
Bluebell 1
Central Gorgon 1
Tryal Rocks 1
Campbell 2
Flag 1
Emma 1
Bambra 2
Barrow Island 25
Mermaid 1
Zeepaard 1
Barrow Deep 1
Hermite 1
Candace 1
Kybra 1
West Barrow 2
Flinders Shoal 1
South Pepper 1
Zeewulf 1
Resolution 1
Novara 1
Griffin 1
Rosily 1A
Koolinda 1
Saladin 1
Cowle 1
Long Island 1
Jurabi 1
Dailey 1
Leatherback 1
113°
114°
115°
116°
117°
20°
21°
22°
© Australian Geological Survey Organisation 1994
LOG MOTIF
GAMMA RAY
Top of Time Slice
Base of Time Slice
Scale: 1:10,000
Units: 0-200 API
Major Unconformity
Minor Unconformity
Emergent
Sand
Glauconite
KEY TO SHOWS
No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.
LOCATION DIAGRAM
N
TIME SLICE DEFINITION
Time Slice K10 Maastrichtian to Santonian
AGSO
Australian Petroleum Systems Project
Barrow and Exmouth Sub Basins Module
Palaeogeographic Interpretation Map
Time Slice K10
Authors: L.L. Spencer & B.L. Bradley
Scale: 1:1 500 000
Date: April 1994
ENCLOSURE 61



LOG MOTIF

GAMMA RAY

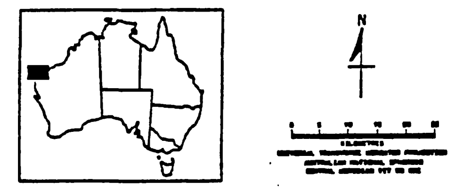


Scale 1:10,000
Units 0-200 API

KEY TO SHOWS

No Show.
Oil Indication.
Strong Oil Indication.
Oil Show.
Potential Oil Zone.
Proven Oil Zone.
Gas Indication.
Strong Gas Indication.
Gas Show.
Potential Gas Zone.
Proven Gas Zone.
Gas and Condensate Show.
Potential Gas and Condensate Zone.
Proven Gas and Condensate Zone.
Gas and Oil Indication.
Strong Gas and Oil Indication.
Gas and Oil Show.
Potential Gas and Oil Zone.
Proven Gas and Oil Zone.
Section not penetrated.
Section absent.
Poor age control.

LOCATION DIAGRAM



AGSO

Australian Petroleum Systems Project

Barrow and Exmouth Sub Basins Module
Simplified Isopach Map
Time Slice Cz1-7

Scale: 1:500 000
Date: April 1994

ENCLOSURE 52