AGSO

AUSTRALIAN GEOLOGICAL
SURVEY ORGANISATION

AUSTRALIAN PETROLEUM SYSTEMS

PAPUAN BASIN MODULE

VOLUME 1

BY

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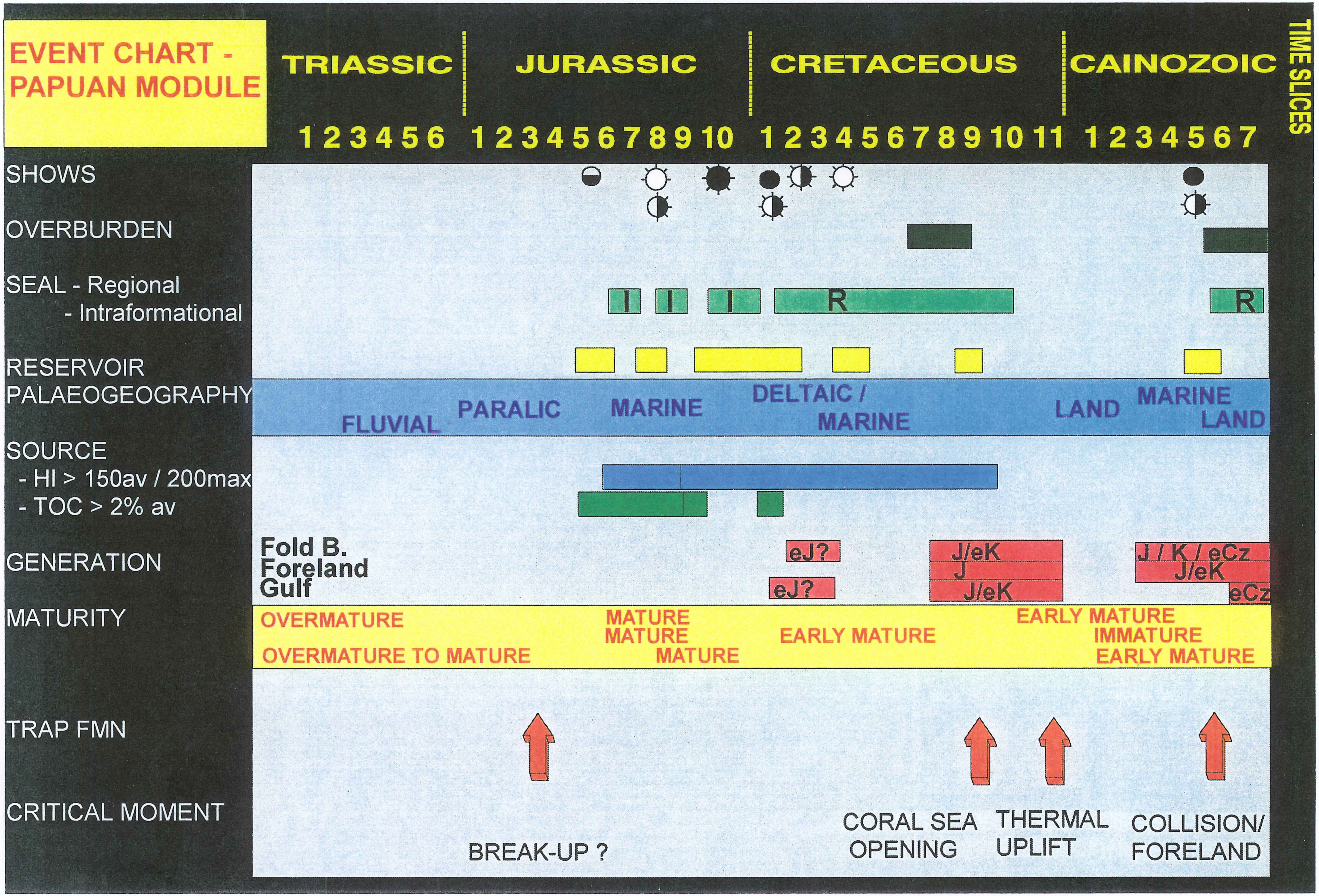
EVENT CHART - PAPUAN MODULE
TRIASSIC
JURASSIC
CRETACEOUS
CAINOZOIC
TIME SLICES
1 2 3 4 5 6
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10 11
1 2 3 4 5 6 7
SHOWS
OVERBURDEN
SEAL - Regional
- Intraformational
I
I
I
R
R
RESERVOIR
PALAEOGEOGRAPHY
FLUVIAL
PARALIC
MARINE
DELTAIC / MARINE
LAND
MARINE
LAND
SOURCE
- HI > 150av / 200max
- TOC > 2% av
GENERATION
Fold B.
Foreland
Gulf
eJ?
eJ?
J/eK
J
J/eK
J / K / eCz
J/eK
eCz
MATURITY
OVERMATURE
OVERMATURE TO MATURE
MATURE
MATURE
MATURE
EARLY MATURE
EARLY MATURE
IMMATURE
EARLY MATURE
TRAP FMN
CRITICAL MOMENT
BREAK-UP ?
CORAL SEA OPENING
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COLLISION/ FORELAND

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In preparation of the Papuan Basin Module, significant time and effort was contributed by the members of the Australian Petroleum Systems Group. Without the dedication of those involved, the project would have been less extensive and correspondingly certain products would not have been produced. Areas of responsibility were assigned to each member of the group, as listed below.

Steve Winn and John Wilmot, senior authors of the Papuan Basin Report, were responsible for the geological and geochemical interpretation, respectively. In conjunction with other members of the Petroleum Systems Group, John and Steve were involved in most aspects of the Project, ranging from data organisation of the STRATDAT and RESFACS databases to in-depth basin analysis and product generation.

John Bradshaw, manager/coordinator of the Australian Petroleum Systems Group, was largely involved with the organisation of geological and geophysical information for the project study, as well as, producing various data outputs from the STRATDAT and ORGCHEM database for analysis. John has provided valuable technical information and assistance throughout this project.

Clinton Foster, was mainly involved with the organisation of the STRATDAT database and contributed towards the analysis of the biostratigraphic data that were upgraded by Robin Helby, consultant biostratigrapher.

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INTRODUCTION

PURPOSE

The aim of the project is to analyse the palaeogeographic controls on source, seal, and reservoir distribution together with the structural and maturation history of the Papuan Basin. This study builds upon previous work and concepts developed in the AGSO-APIRA Palaeogeographic Maps and Phanerozoic History of Australia Projects. Analyses are based on information from 32 wells, up to 1500 km of seismic line data and published data. Results are presented as time slice data and interpretation maps, regional well log cross sections, graphical plots and summary tabulations. The analysis is largely restricted to the Mesozoic section; for palaeogeographic reconstructions of the Cainozoic refer to Carman (1993) and Struckmeyer et al. (1993).

DIGITAL DATA

A series of digital databases containing prospectivity data (porosity, permeability, and hydrocarbon shows - called RESFACS) and biostratigraphic data (palynology and palaeontology - called STRATDAT) have also been prepared. Below is an example of the data from the RESFACS database. This data was originally compiled from Excel (Windows) format, and hard copies are included in Appendices 4 to 6 in spreadsheet format.

WELL NAME	Depth m RT	Depth to m RT	Porosity Average	Porosity Minimum	Porosity Maximum	Source	Who
GOARI #1	2870	2880	15	5	18	LOG	ESSO
GOARI #1	3002	3009	13	5	15	LOG	ESSO

The STRATDAT database is in an ORACLE relational format, a hard copy of the data is shown in Appendix 2.

Both STRATDAT and RESFACS link to AGSO's Petroleum Exploration Database (PEDIN) by the use of the Unique Number (UNO).

TIME SLICE DEFINITION AND BOUNDARIES

Biostratigraphic schemes used in the study are:

(1) Integrated dinoflagellate and spore-pollen zonation of the Australian Mesozoic developed by Helby et al (1987),

(2) Foraminiferal zonation for the North West Shelf (Wright, 1977; Heath & Apthorpe, 1981, & 1984; Apthorpe, 1988)

(3) Foraminiferal zonation for the Cainozoic (Blow, 1969, & 1979; Berggren, 1969; Kennett & Srinivasan, 1983)

(4) Australian Phanerozoic Timescales Volume 1 - 10 (Shergold, 1989; Webby & Nicoll, 1989; Strusz, 1989; Young, 1989; Jones, 1989; Archbold & Dickins, 1989; Balme, 1989; Burger, 1989a & 1989b; Truswell et al, 1989).

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

The correlation, duration and absolute ages of the time slices were derived from previous projects after consultation with many biostratigraphers, industry sponsors and the State Geological Surveys.

In general, the time slice boundaries coincide with major changes in rates of sedimentation or changes in facies that are common to several basins. Some time slices are representative of geological events that have continent wide effects, for example, regional unconformities resulted from uplift and erosion. The selection criteria for the time slices are based on a broad correlation between key continent-wide geological events and major biostratigraphic zones.

There are some difficulties in selecting time slices that are applicable across Australia due to contrasting depositional and tectonic regimes and correlation problems with the biostratigraphy such as correlating the spore-pollen zonations in Eastern Australia with the dinoflagellate zones of Western Australia.

The products in both the Palaeogeographic Maps Project and the Phanerozoic History of Australia project were based on the same time slice framework. Thus the details presented in this study can immediately be related to more regional concepts and incorporated into the existing regional maps.

The following section outlines the time slice definition and boundaries summarised from the BMR Palaeogeographic Atlas of Australia, Volume 8 - Jurassic and Volume 9 - Cretaceous (Bradshaw & Yeung, 1993, Bradshaw et al, (in press)).

A total of ten time slices for the Jurassic and eleven for the Cretaceous have been recognised from the previous projects. The selection criteria for these time slices are illustrated in Figures 1 and 2 and defined below. An AGSO Phanerozoic Time Scale chart is provided in Enclosure 3, while Figures 3 and 4 illustrate a correlation drawn by Robin Helby between the Helby et al (1987) palynological scheme and those of Simon (Davey, 1987) and BP (Welsh, 1990). The Simon (Davey, 1987) and BP (Welsh, 1990) schemes are widely used by various companies currently working in PNG.

JURASSIC TIME SLICE 1: HETTANGIAN TO SINEMURIAN (213-200Ma)
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.

JURASSIC TIME SLICE 2: PLIENSBACHIAN TO EARLY TOARCIAN (200-19Ma) The base of Time Slice J2 corresponds to the *N. vallatus* datum of Price et al. (1985) in eastern Australia. It is marked by facies change in many basins and the commencement of deposition in others, eg on the northwest margin there was a facies change from marginal marine clastic sediments to shallow water limestone.

JURASSIC TIME SLICE 3: EARLY TO MIDDLE TOARCIAN (191-189Ma)
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, and corresponds to a high sea level episode.

JURASSIC TIME SLICE 4: LATE TOARCIAN TO EARLY BAJOCIAN (189-180Ma)
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 5: EARLY TO MIDDLE BAJOCIAN (180-177Ma)

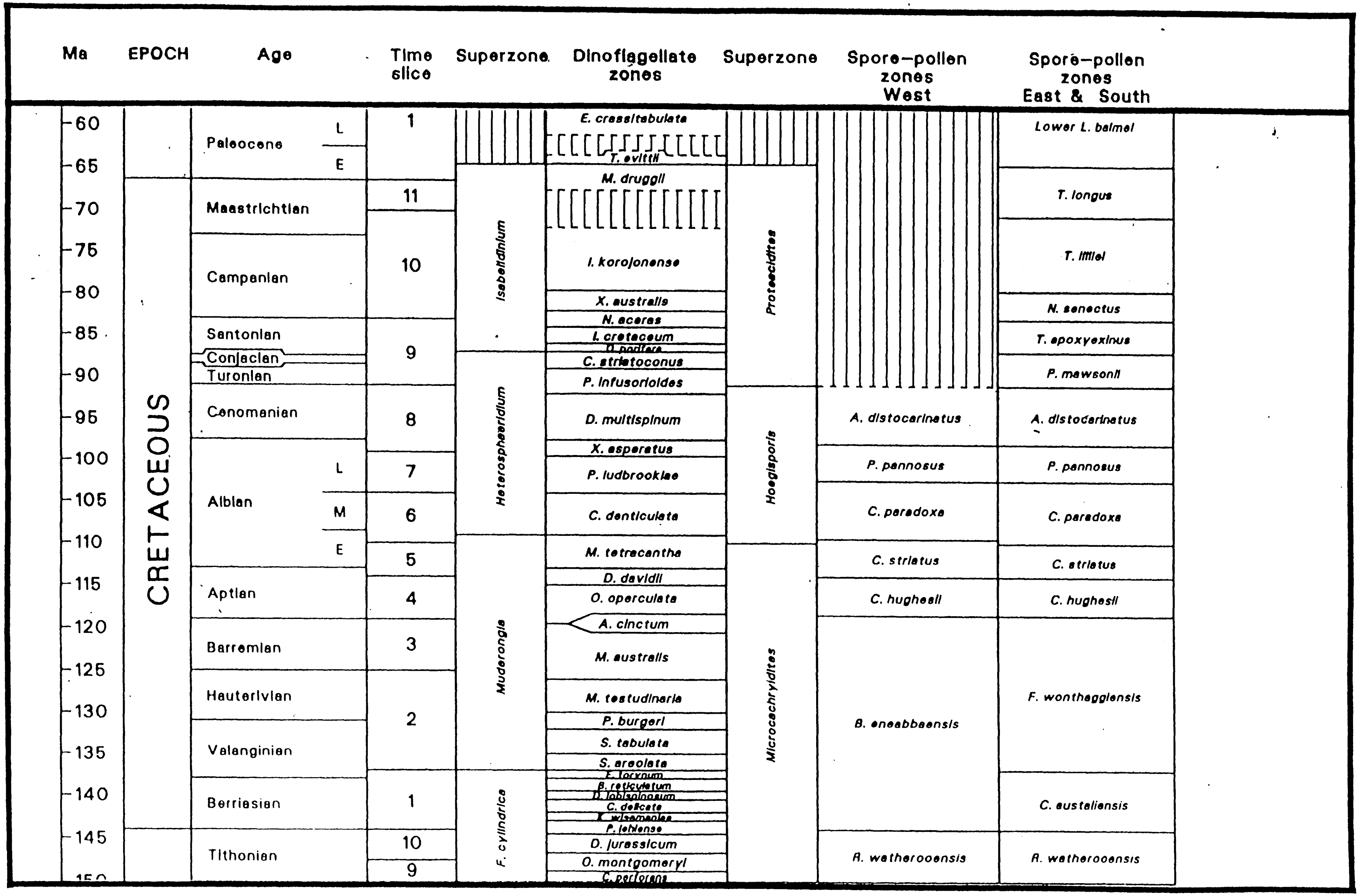


Figure 1 Cretaceous time slices versus fossil zonations

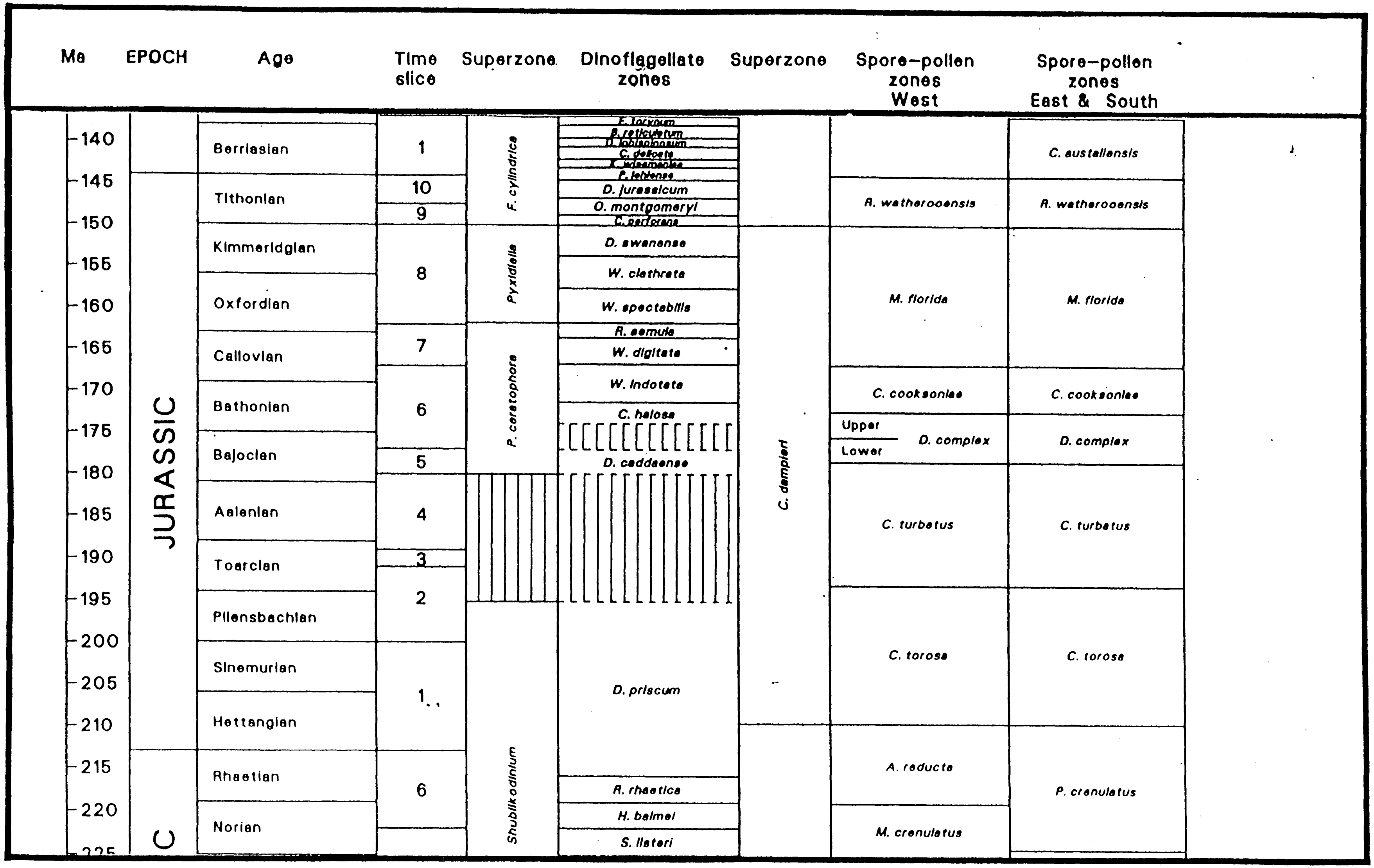


Figure 2 Jurassic time slices versus fossil zonations

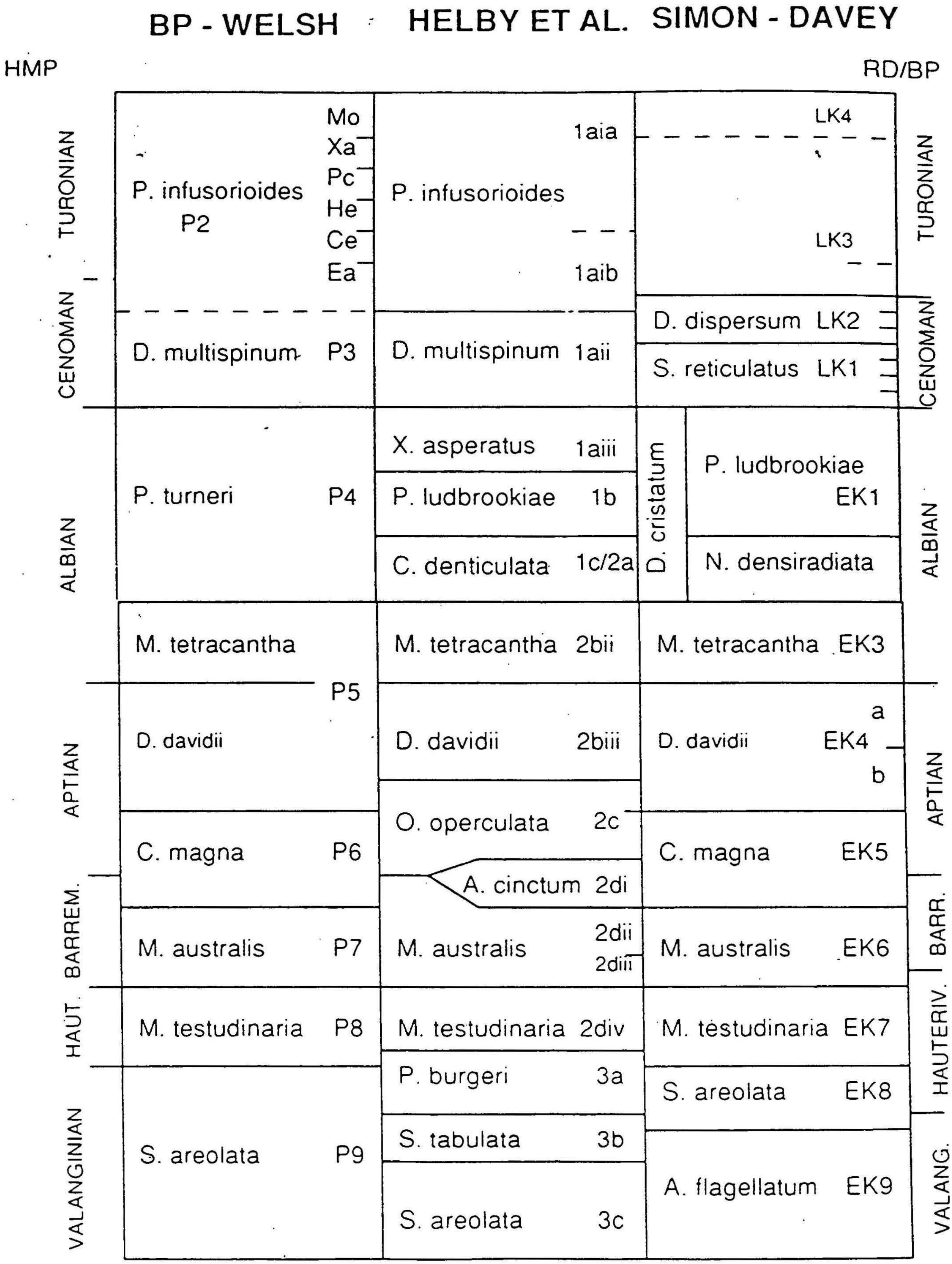


Figure 3 Correlation of the *P. infusorioides* to *S. areolata* biozones of Helby et al (1987) with the BP (Welsh, 1990) and Simon Petroleum (Davey, 1987) palynological zonations.

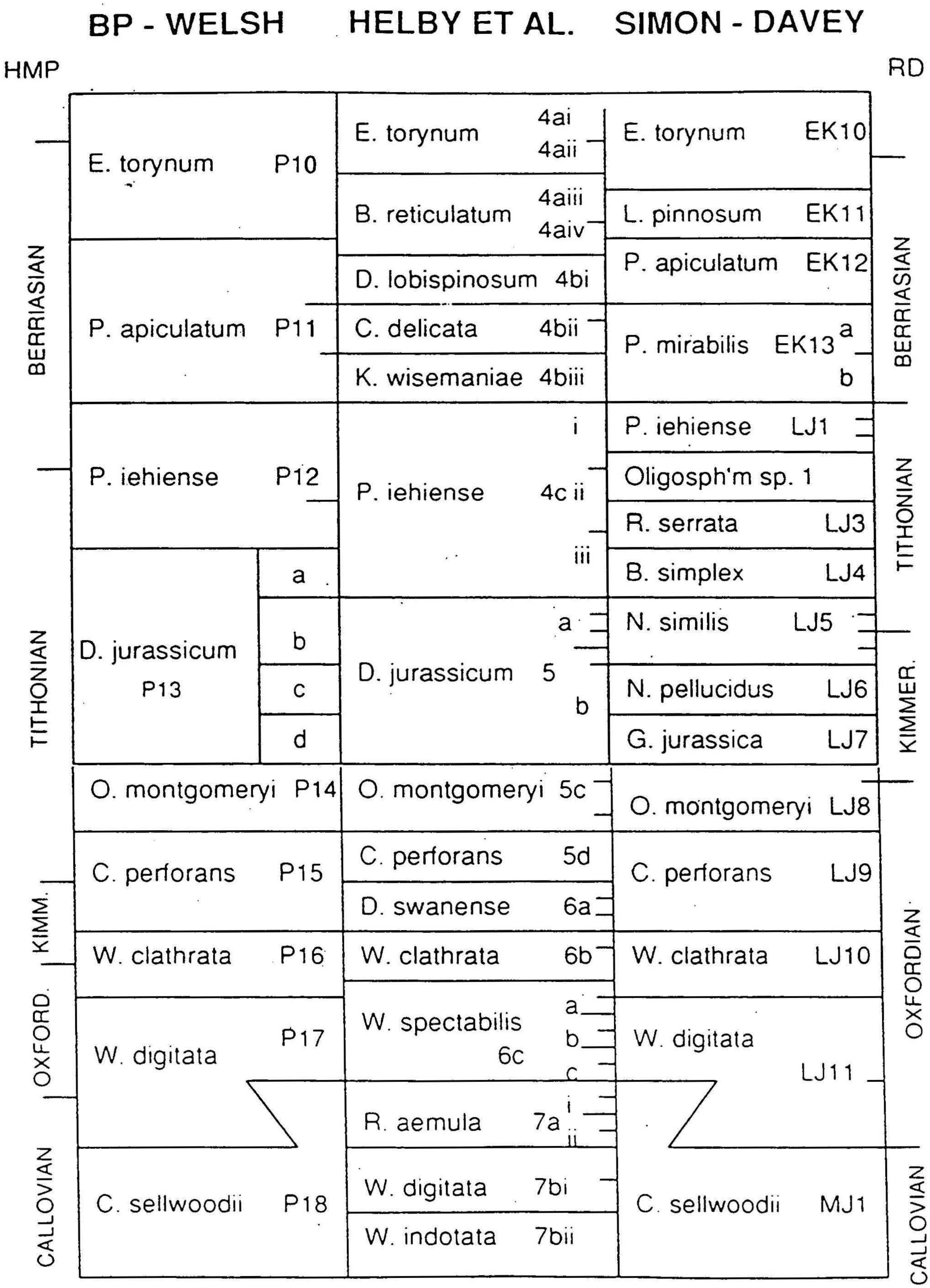


Figure 4 Correlation of the *E. torynum* to *W. indotata* biozones of Helby et al (1987) with the BP (Welsh, 1990) and Simon Petroleum (Davey, 1987) palynological zonations.

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 6: LATE BAJOCIAN TO EARLY CALLOVIAN (177-167Ma)
The base of Time Slice J6 equates with the top of the *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.

JURASSIC TIME SLICE 7: MID CALLOVIAN TO EARLY OXFORDIAN (167-162Ma)
The base of Time Slice J7 equates with the bases of the *M. florida* and *W. digitata* zones 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. It also coincides with the transition from Hutton Sandstone deposition to a lower energy shale prone Birkhead fluvio-lacustrine regime in eastern Australia.

JURASSIC TIME SLICE 8: EARLY OXFORDIAN TO KIMMERIDGIAN (162-150Ma)
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 and spore-pollen schemes (Fig. 2).

JURASSIC TIME SLICE 9: EARLY TITHONIAN (150-147.5Ma)
The base of Time Slice J9 is marked by a regional unconformity observed in the Papuan and Bonaparte basins. It 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. 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 higher energy sand sheet regime of the Adori Sandstone.

JURASSIC TIME SLICE 10: LATE TITHONIAN (147.5-144Ma)

The base of Time Slice J10 corresponds to the base of *D.jurassicum* dinoflagellate zone. The top of the time slice represents the Jurassic/Cretaceous boundary which 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.

CRETACEOUS TIME SLICE 1: BERRIASIAN TO EARLY VALANGINIAN (144-137Ma)
The base of Time Slice K1 is defined by the Jurassic/Cretaceous boundary, which is within the *P.iehiense* dinoflagellate zone and equates with the base of the *C. australianensis* spore-pollen zone.

CRETACEOUS TIME SLICE 2: VALANGINIAN TO HAUTERIVIAN (137-125Ma)
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. Biostratigraphically the base is defined by the *E.torynum / S. areolata* dinoflagellate and the *C. australianensis / F. wonthaggiensis* spore-pollen zone boundaries. 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.

CRETACEOUS TIME SLICE 3: BARREMIAN (125-119Ma)
This time slice is characterised by transgression of the sea into central and western Australia. There is no direct biostratigraphic correlation to the Barremian stage, but a working definition equivalent to the *M. australis* dinoflagellate zone.

CRETACEOUS TIME SLICE 4: APTIAN (119-114Ma)
Time Slice K4 records the peak marine transgression across the Australian continent. It is biostratigraphically defined by the dinoflagellate zones *A. cinctum, O. operculata* and *D. davidii*; and the *C. hughesii* spore-pollen zone. Time Slice K4 corresponds to changes in stratigraphy in many basins with the deposition of marine shales over sandstones in offshore locations. Time Slice K4 may be absent or represented by a condensed sequence.

CRETACEOUS TIME SLICE 5: EARLY ALBIAN (114-110Ma)
Time Slice K5 encompass a period of sea level retreat. It equates to the *C. striatus* spore-pollen zone and approximates the *M. tetracantha* dinoflagellate zone.

CRETACEOUS TIME SLICE 6: MIDDLE ALBIAN (110-104Ma)

Continued regression occurred 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.

CRETACEOUS TIME SLICE 7: LATE ALBIAN (104-99Ma)

Time Slice K7 represents a transgressive episode and corresponds to a global oceanic anoxic event. Biostratigraphically it approximates the *P. ludbrookiae* dinoflagellate zone.

CRETACEOUS TIME SLICE 8: LATE ALBIAN TO CENOMANIAN (99-91Ma)

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. It is biostratigraphically defined by the C2, C3a and C3b foram zones, approximates the *X. asperatus* and *D. multispinum* dinoflagellate zones and *A. distocarinatus* spore-pollen zone.

CRETACEOUS TIME SLICE 9: TURONIAN TO SANTONIAN (91-83Ma)

Carbonate sedimentation became dominate on the western margin during this time slice. It 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.

CRETACEOUS TIME SLICE 10: CAMPANIAN TO EARLY MAASTRICHTIAN (83-70 Ma)

Time Slice K10 corresponds to the commencement of sea floor spreading in the Tasman Sea. It is biostratigraphically defined by the C4 to C8 foram zones, the *N. senectus* and *T. lilliei* spore-pollen zones, and approximates the *N. aceras* to *I. korojonense* dinoflagellate zones.

CRETACEOUS TIME SLICE 11: 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 boundary represents the Mesozoic / Cainozoic boundary.

METHODOLOGY

Biostratigraphic data from Well Completion Reports and other published information were reviewed by consultant biostratigrapher Dr Robin Helby (palynology) and AGSO palaeontologists Dr George Chaproniere (palaeontology) and Dr Sami Shafik (nannofossil). The revised palynological and palaeontological data were further reviewed and documented into the STRATDAT database (Appendix 2) by Dr Clinton Foster.

Age/depth plots were constructed to provide quick-look interpretations of changes in sedimentation rates, condensed sections, unconformities and fault intersections. These plots also provide age estimates for depth intervals with poor biostratigraphic control. An example of an interpreted age/depth plot is shown in Figure 5 and a schematic diagram of age/depth plot interpretations in Figure 6. Age/depth plots for all the wells studied in the Papuan Module are provided in Appendix 3. Time slice boundaries are picked using all available biostratigraphic data correlated with wireline logs and age/depth plots. The time slice boundaries are further constrained by key sequence boundaries and major flooding surfaces interpreted from well log data.

Lithological descriptions from ditch cuttings, sidewall cores and conventional cores were used in conjunction with well log signatures to determine facies type and environments of deposition. Biostratigraphic data such as the diversity of fossil content, the relative abundance, and the ratio of spore-pollen to marine micro fossils provided additional information on the depositional environments.

Digital well log data were provided by the PNG Department of Minerals and Petroleum, with the exception of Wabuda 1 which was kindly contributed by CanadianOxy. However, more than 25% of the wells had no digital logs and were manually "scanned" and edited from paper copies. Five well log cross sections (Enclosures 4 to 8), datum on the top Mesozoic, were constructed to provide a regional coverage of the Papuan Basin. The sections display the gamma, or SP, and resistivity curves together with codes representing the various depositional environments and landform elements and any significant hydrocarbon shows. The definition of the environment and landform element codes is shown in Figure 7 and Table 1. A tabulation of these codes for each of the study wells is provided in Appendix 7, the palaeogeographic interpretation component of RESFACS, in Excel format.

Over 4000 km of seismic lines were selected for the Papuan Module (Figure 8). The emphasis of the seismic interpretation was on the resolution of specific geological problems,

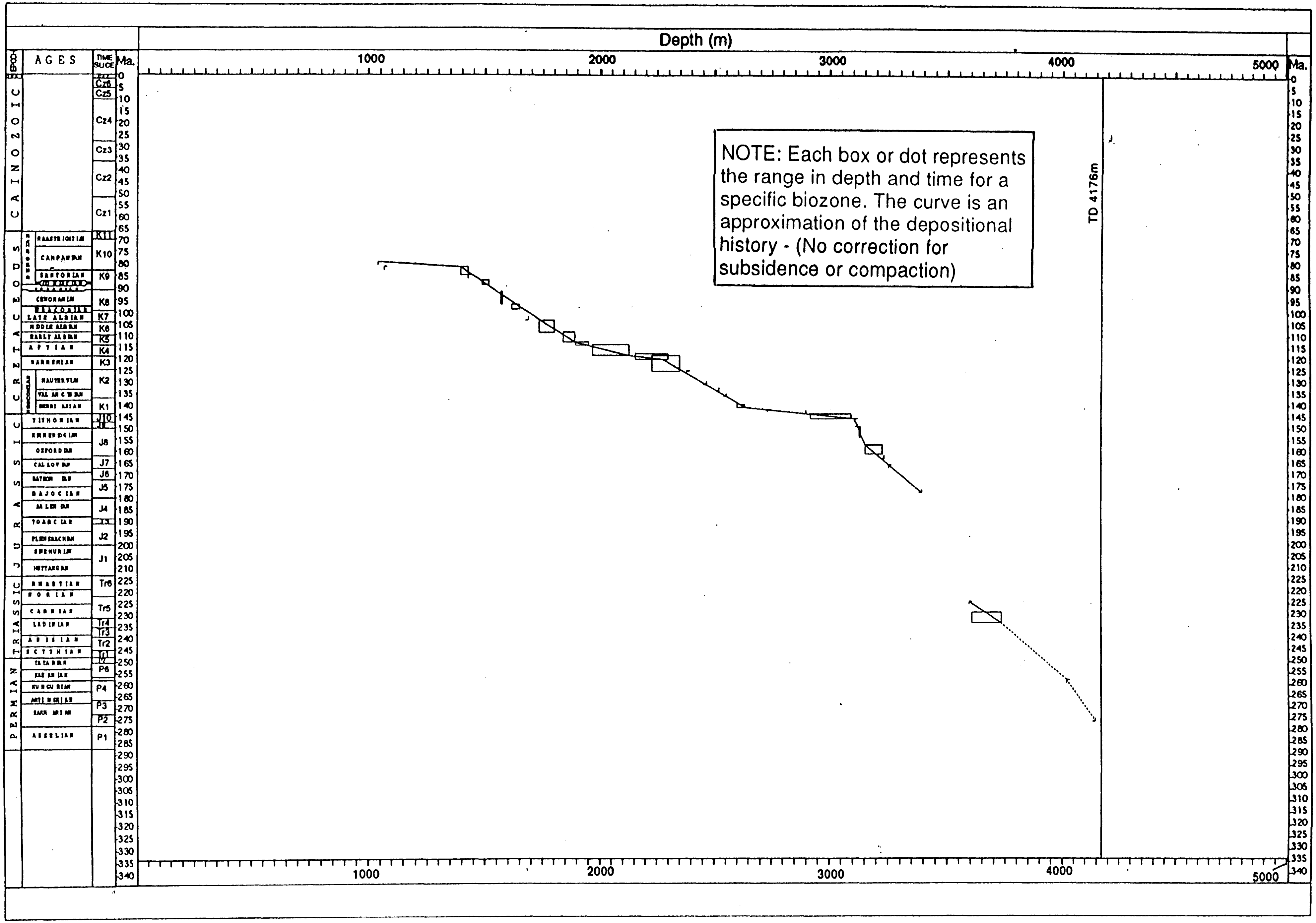


Figure 5 Example of an interpreted age/depth plot

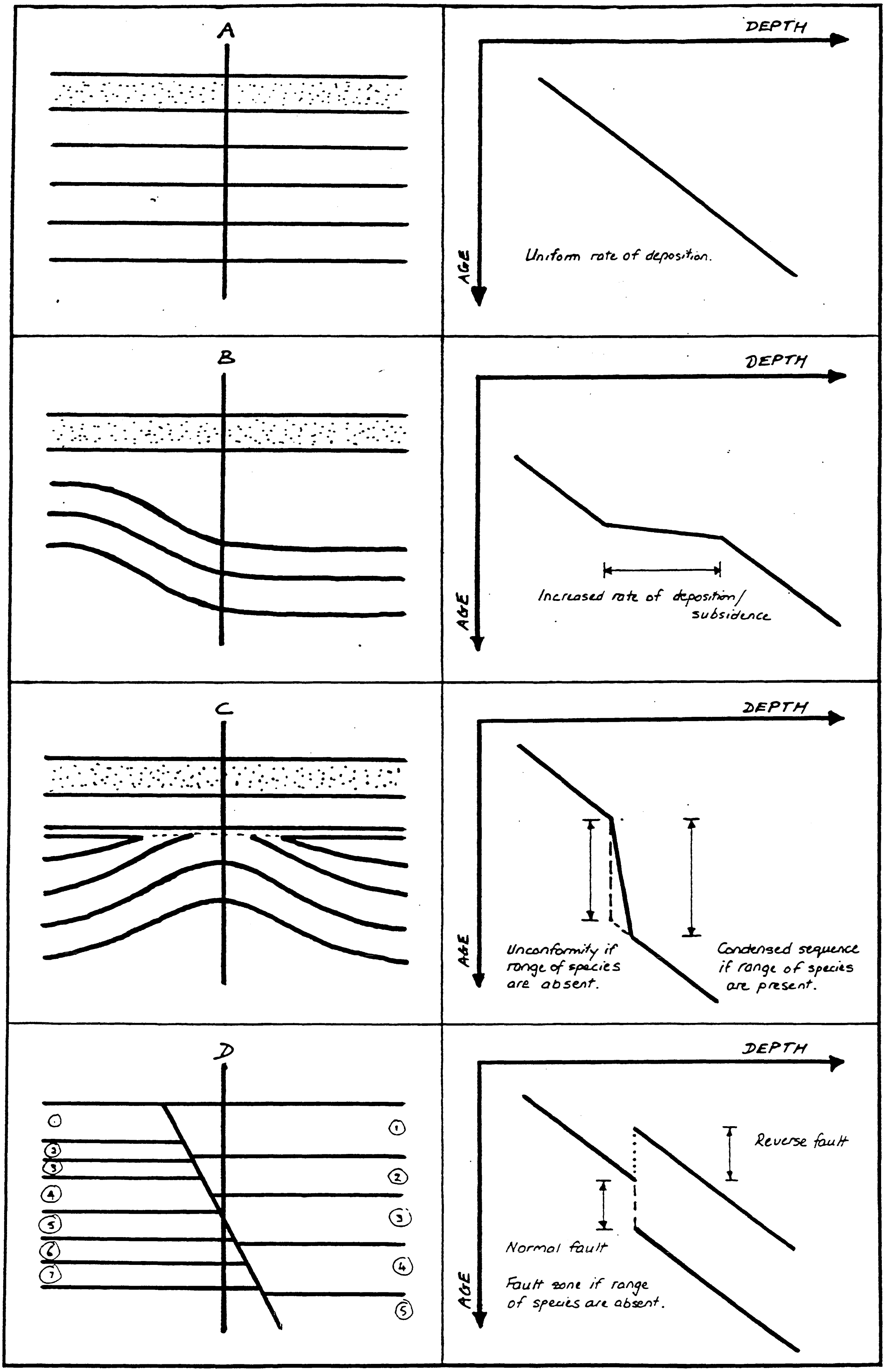
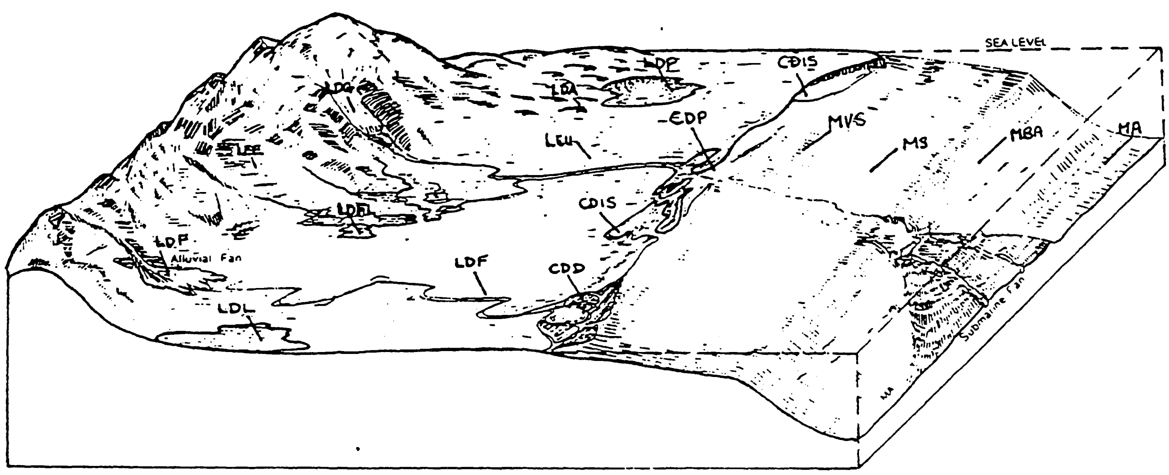


Figure 6 Schematic diagram of age/depth plot interpretations

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 Arburn 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 7 Schematic diagram showing classification of depositional environments (after; BMR Palaeogeography Group, 1990).

	ENVIRONMENT CODES				LANDFORM ELEMENT CODES			
	LEU	Unclassified						
	LEE	Erosional						
	LUD	Unclassified Depositional			V	Volcano		
					LF	Lava Field		
					VM	Volcanics 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		
LAND					LE	Levee		
					CS	Crevasse Splay		
					BS	Backswamp		
	LDL	Lacustrine			LD	Lacustrine Delta		
	LDFL	Fluvial-Lacustrine						
	LDP	Playa			SF	Salt Flat		
					MF	Mud Flat		
					P	Pond		
	LDA	Aeolian			D	Dune		
					S	Swale		
	LDG	Glacial						
	CDP	Paralic						
	CDIS	Intertidal / Supratidal			B	Beach		
					BR	Beach Ridge		
	CDD	Deltaic	CDDU	Upper Delta Plain	SMB	Stream Mouth Bar		
COASTAL			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				
	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
MARINE			MVS	Marine Very Shallow (0 - 20m)	R	Reef	RT	Reef Toe
							RF	Reef Front
							RB	Reef Back
	MBA	Bathyal to Abyssal (>200m)			CSH	Continental Shelf		
					CSL	Continental Slope		
					TF	Turbidite Fan	TFP	Turbidite Fan Proximal
							TFM	Turbidite Fan Mid
			MA	Abyssal			TFD	Turbidite Fan Distal
					AP	Abyssal Plain		

Table 1 Environment and Landform Element Codes.

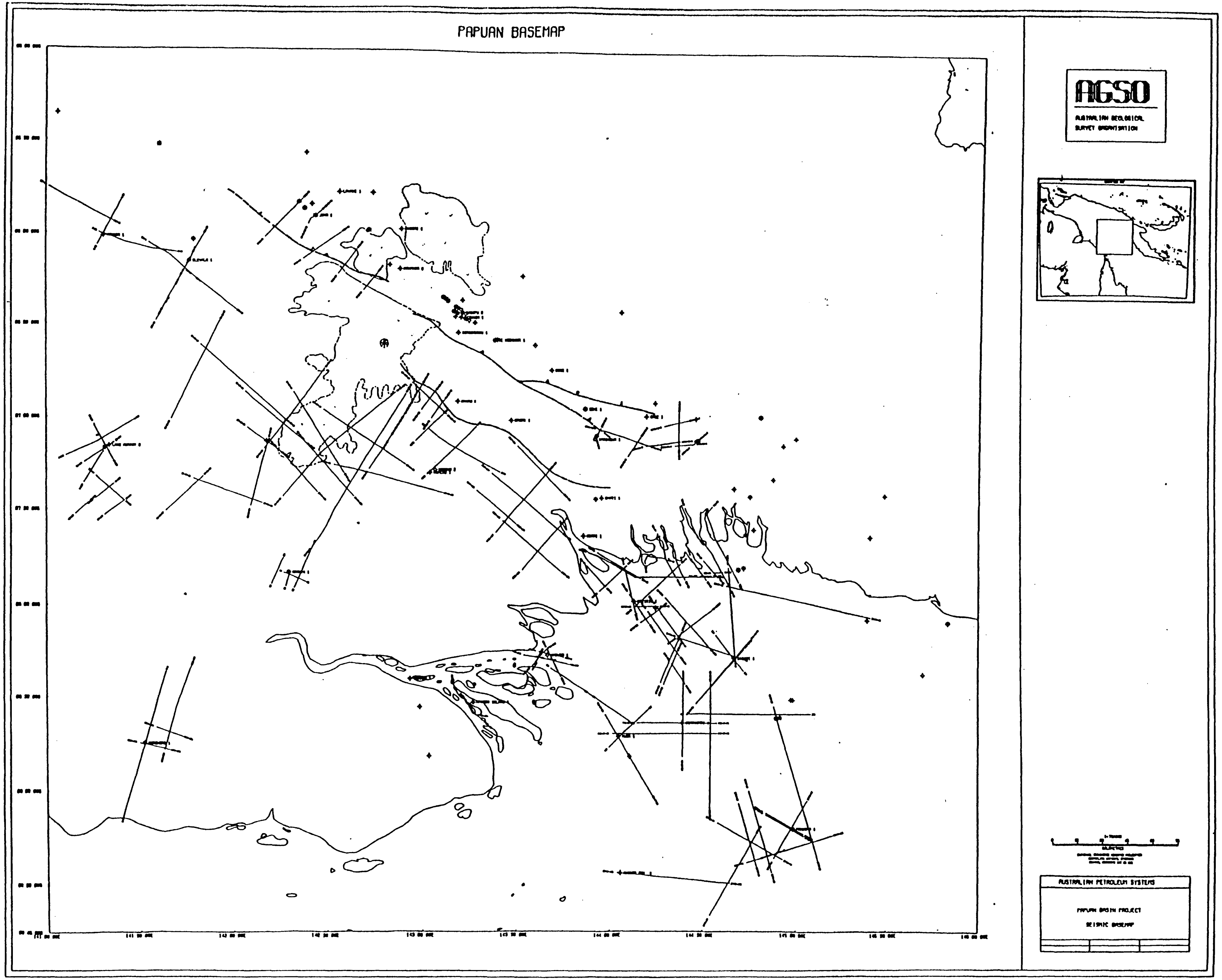


Figure 8 Seismic lines collected for the Papuan Module.

such as whether a well was drilled off the structure or adjacent to a major fault. In addition, the seismic data helped in the delineation and correlation of megasequences and provided estimates of depth to "basement" and thicknesses of sedimentary sections that were not intersected by any of the wells. A series of seismic profiles illustrating the various structural and stratigraphic styles within the Papuan Basin are presented by Pono (1990). Time versus depth relationships from various parts of the basin are shown in Appendix 18.

Palaeogeographic data and interpretive maps were constructed for each time slice. The J10 and K1 maps were further sub-divided using a sequence stratigraphy approach.

EXPLORATION HISTORY AND HYDROCARBON OCCURRENCES

Detailed reviews of the History of Exploration are presented by Rickwood (1990, 1992) and Pawih and Halstead (1993). The following paragraphs are extracts from these publications and briefly summarise the history of exploration.

The first report of hydrocarbons in Papua was made by two gold prospectors in 1911 in the lower Vailala River 60km northeast of Kerema on the Gulf of Papua coast. Following examinations by Evan R. Stanley, the first government geologist, and a Commonwealth of Australia petroleum geologist, drilling commenced at Upoia in the Vailala region in 1912 and resulted in the production of small amounts of light oil, 350 gallons at Upoia 7.

By the end of the First World War optimism was high for the potential for oil production from both Papua and the Mandated Territory of New Guinea, north-east New Guinea. Mapping was carried out by Anglo Persian geologists and twenty eight relatively shallow wells were drilled between 1921 and 1930. Few of these early wells failed to penetrate below the Upper Pliocene and with the exception of some short lived oil flows, in the vicinity of the Matapau oil seeps, results were generally disappointing.

In 1938 the Australasian Petroleum Company (A.P.C), a consortium of Anglo Iranian, Stanvac and Oil Search, was formed and commenced a detailed program of field work, photogeological, palaeontological, gravity, magnetic and experimental seismic surveys. During this period a great deal was learned about the petroleum geology of the country culminating with the drilling of the Kariava anticline some 70km up the Vailala River in March 1941.

Drilling at Kariava was halted in December 1941 when Japan declared war. World War II considerably subdued petroleum exploration with only six wells drilled between 1941 and 1950. Kariava reached a total depth of 12,621 feet in March 1948 without significant oil shows.

Significant discoveries were made in the 1950's with the first real oil discovery in the Papuan Basin at Puri in 1958 and the discovery of gas at Kuru, Barikewa, Bwata and Iehi. Puri 1 flowed 1600 barrels of oil per day (BOPD) from fractured Miocene carbonates, but the oil watered out during testing.

Exploration moved offshore into the Gulf of Papua in the 1960's and resulted in the discovery by Phillips Petroleum of gas with condensate in reefs of Miocene age in the Uramu and Pasca wells.

Prior to the seventies most exploration had been focussed on areas accessible from either the coast or major navigable rivers, or in the offshore portion of the basin. With the arrival of modern heavy lift Boeing Vertol helicopters in 1971, both Cecilia 1 and Mananda 1 were drilled in the Highlands. However, both these wells drilled through faults and failed to reach their objectives. Exploration drilling diminished during the 1970's due to a combination of the perceived gas prone nature of hydrocarbons in PNG and a period of administrative preparations that were being made prior to the granting of Independence in 1975.

However the oil price shock of the seventies kept exploration interest alive enough for the A.P.C consortium to drill Barikewa 2 in early 1982. The well encountered minor gas shows and fluorescence in the Late Jurassic to Early Cretaceous Toro sandstone and perhaps more importantly brought the 20,000 ft rated, helicopter transportable, Parker Rig 140 into PNG. The availability of Rig 140 together with the return to PNG of the Boeing Vertol helicopters made drilling targets within the mountainous Highlands accessible.

Niugini Gulf Oil utilising Rig 140 and the Boeing Vertol's drilled the successful Juha 1X gas/condensate discovery in 1983 and subsequently proved the existence of a gas field with Proved, Probable and Possible reserves of 1.5 TCF gas and 57 MMBC in the Toro reservoir. Meanwhile in the Gulf of Papua the blowout at Pasca A-3 demonstrated in spectacular fashion that wet gas was recoverable in the Papuan Basin from not just Mesozoic plays but also the Tertiary pinnacle reefs.

Up to 1985, the Papuan Basin had recorded eight non commercial gas fields varying in size and remoteness, and one discrete oil discovery which watered out during testing. In early 1986 the Toro sandstone was successfully tested at Iagifu 2X as PNG's first substantial and sustainable oil flow. The oil is a light sweet crude with a stocktank gravity of 45^{o} API.

Further oil discoveries were made by Niugini Gulf in the adjacent Hedinia, Usano and Agogo structures and with gas in the SE. Hedinia Anticline. Meanwhile, in the adjacent licence area BP and Oil Search discovered the Hides gas field in 1987. More recently, other structures to the northwest and southeast of the Iagifu/Hedinia field yielded significant quantities of gas at Angore and P'nyang (1990 for BP and Chevron respectively), and oil and gas at SE. Mananda (1991, Chevron), and SE. Gobe (1991, Command). In the Papuan Basin Foreland gas was discovered by Santos at Elevala and Ketu while offshore in the Gulf of Papua gas was produced from the Miocene Pandora reef complex by International Petroleum Limited in 1988 and 1992. Figures 9 and 10 summarise the major hydrocarbon occurrence's in the Papuan Basin.

The most recent discovery was made in January 1994 by Chevron and partners at Gobe 4X located on the main Gobe culmination approximately 15 kms northeast of the SE Gobe discovery. Gobe 4X encountered a 94m thick oil column within the lagifu sandstone and produced 2500 BOPD on initial testing from a structure with the potential to contain about 100 MMBO.

PNG's first oil production officially commenced on 27 June 1992, from the Kutubu development, and is currently averaging 130,000 BOPD.

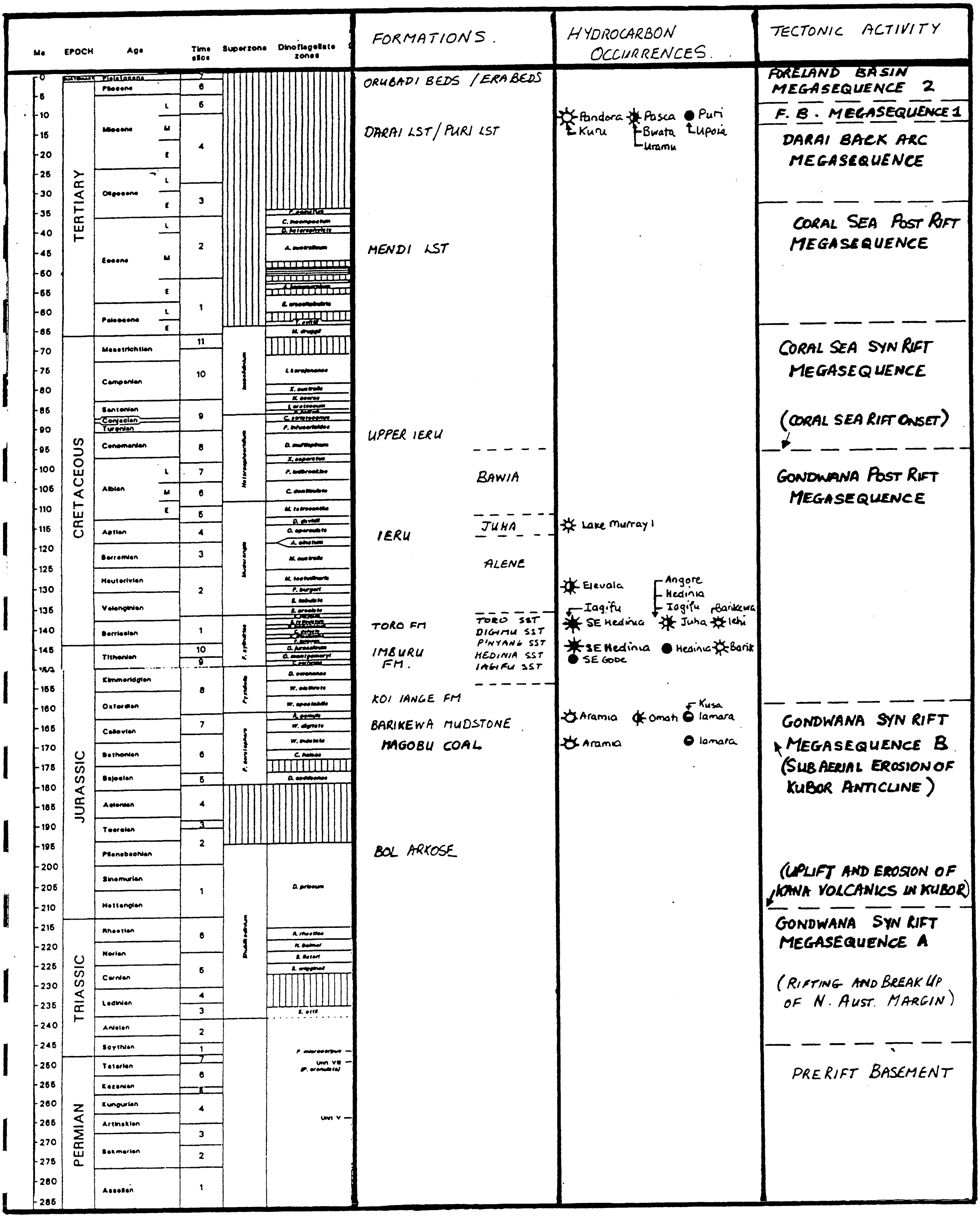


Figure 9 Formation names, major hydrocarbon occurrences and tectonic activity (after; Home et al, (1990) and Phelps and Denison, (1993)) plotted against the AGSO time scales versus fossil zonation chart.

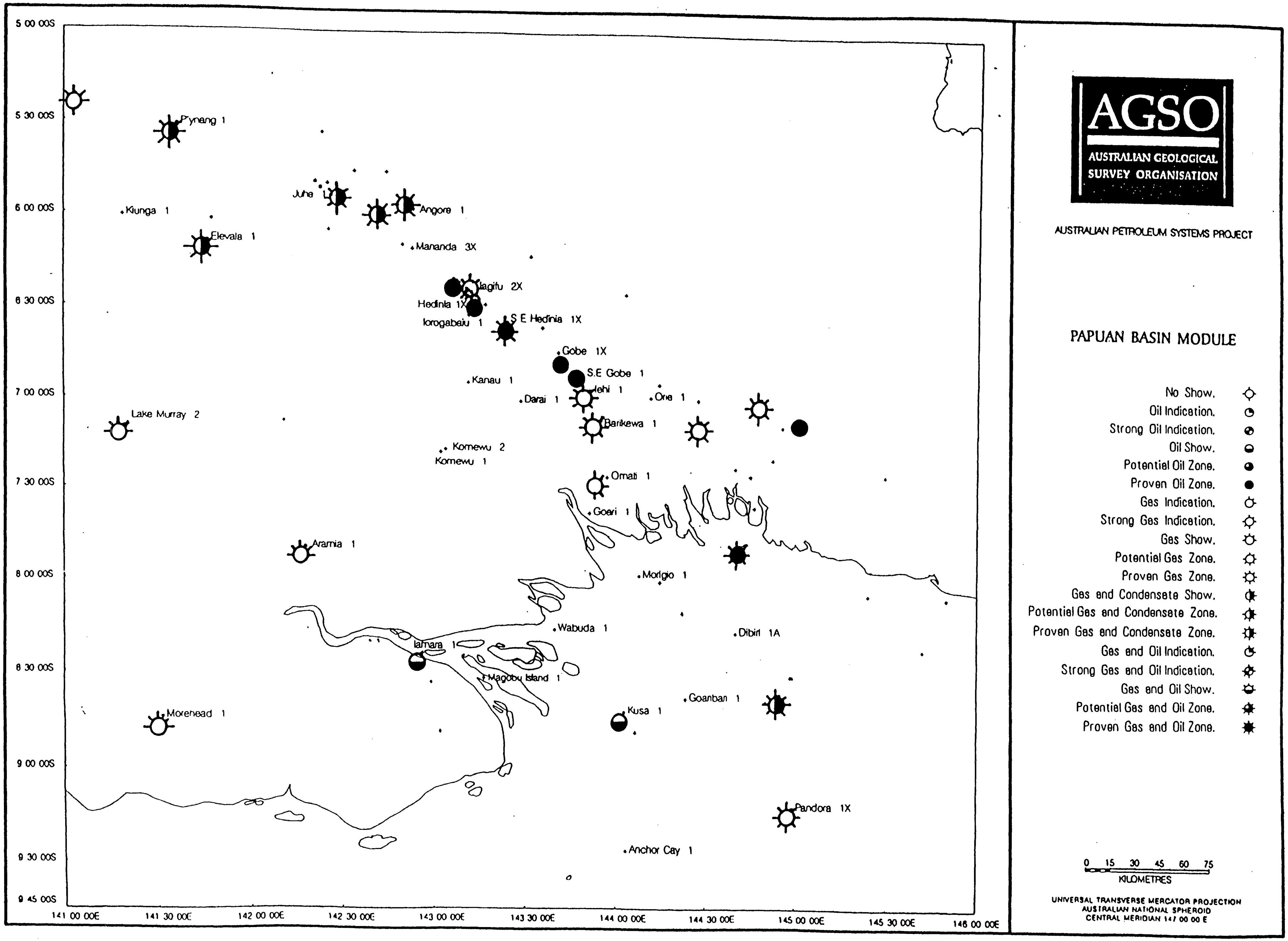


Figure 10 Location and nature of major hydrocarbon occurrences in the Papuan Basin. Named wells are those incorporated in to the AGSO study.

REGIONAL GEOLOGY

BASIN DEFINITION

The Papuan Basin is bounded on the north by the Lagaip/Bismarck Fault zones and by the Owen Stanley Metamorphics in the east. The Basin extends to the west into Irian Jaya and is bounded by the northern margin of the Frederick-Hendrick basement high. To the southwest, the Papuan Basin links with the Carpentaria Basin, and includes semi regional elements such as the Morehead Sub Basin and the Oriomo basement high. To the southeast, the Basin extends offshore into the Gulf of Papua and its boundary is broadly placed at the southeastern margin of the Pasca Ridge. A tectonic elements map covering the study area is shown in Figure 11 and at a larger scale in Enclosure 1 (in the plastic pocket at the back of the report). The present day plate tectonic setting of PNG is shown in Figure 12, and a schematic cross section across the basin is shown in Figure 13.

TECTONIC EVENTS AND REGIONAL STRATIGRAPHY

Figure 14 shows a Summary Stratigraphic Column for the Papuan Basin. A Time Space Correlation, illustrating regional unconformities and condensed sections, is shown in Figure 15 and at a larger scale in Enclosure 2.

Five schematic cross sections (Figures 16 to 20) show the total depths reached in each of the study wells and the corresponding thickness and age of strata penetrated. The age boundaries are based on recent biostratigraphic revision which are dependent on the availability of good biostratigraphic data such as range charts and species lists. As a consequence of inadequate sampling and/or drilling problems palaeontological data for the Cainozoic section in most wells is relatively poor in quality. Therefore the interpreted thicknesses for the Miocene, Oligocene and Eocene, as shown in Figures 16 to 20, are to be used only as a guide. Additional work is required to resolve some of the major inconsistencies in the interpretation, especially the implied thickening of Oligocene age rocks.

Tabulations of the relative thicknesses for each of the wells are provided in Tables 2 to 4. The schematic cross sections (Figures 16 to 20) show that relatively few wells in the Papuan Basin intersected sedimentary sections older than Jurassic. However in the Foreland, where the Mesozoic section is relatively thin, some wells reached economic basement.

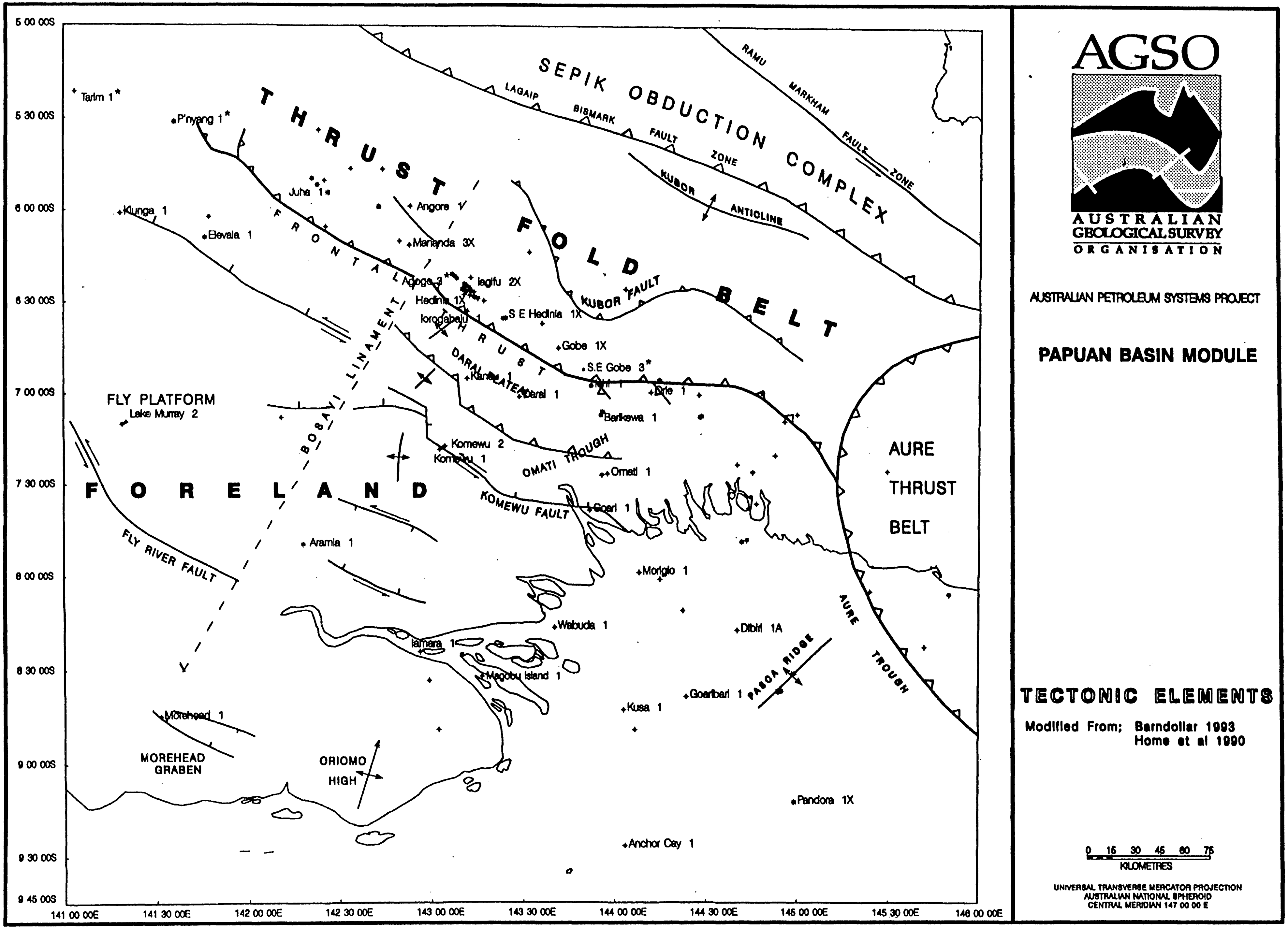


Figure 11 Papuan Basin Tectonic Elements Map (modified after; Home et al, (1990) and Barndollar, (1993)).

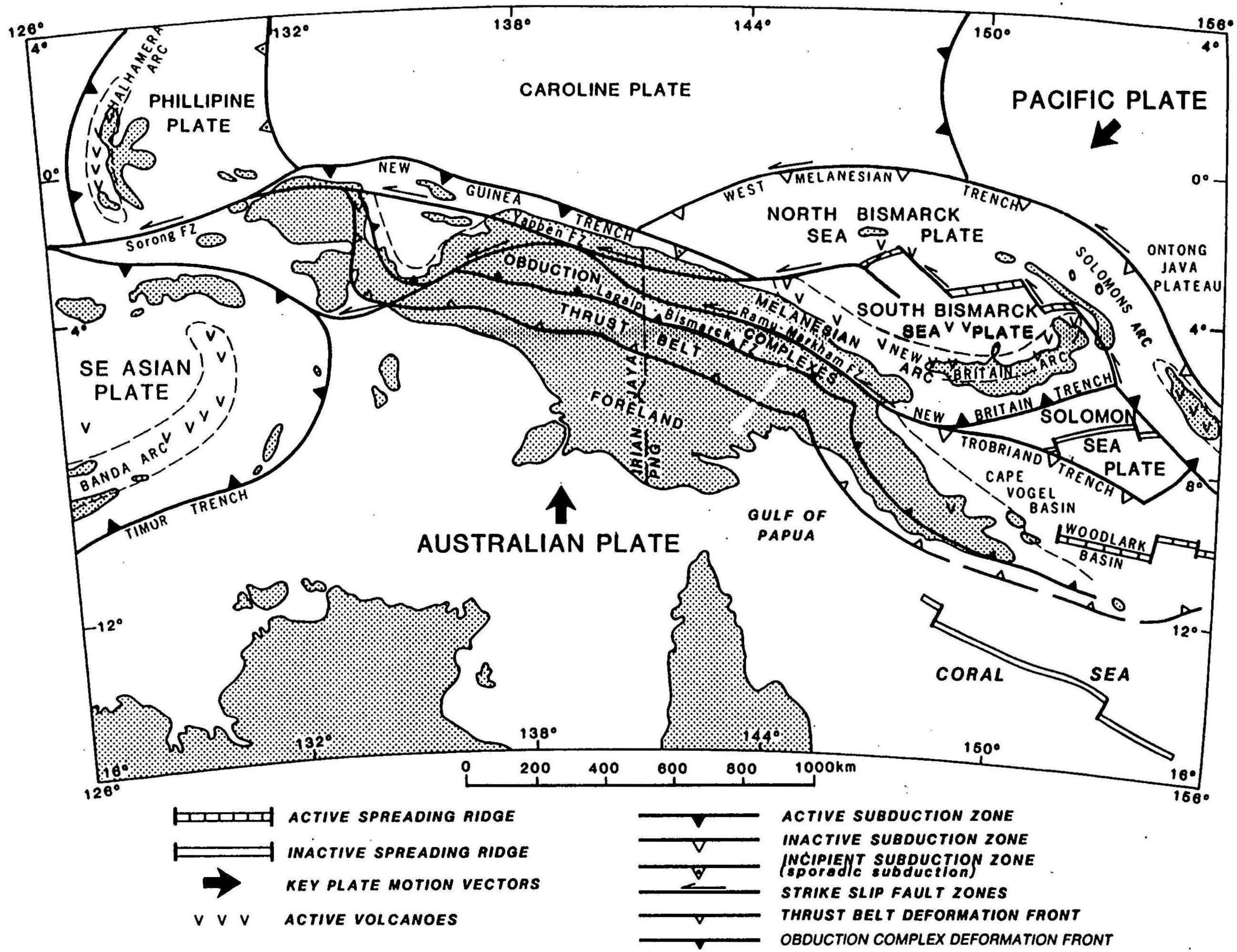
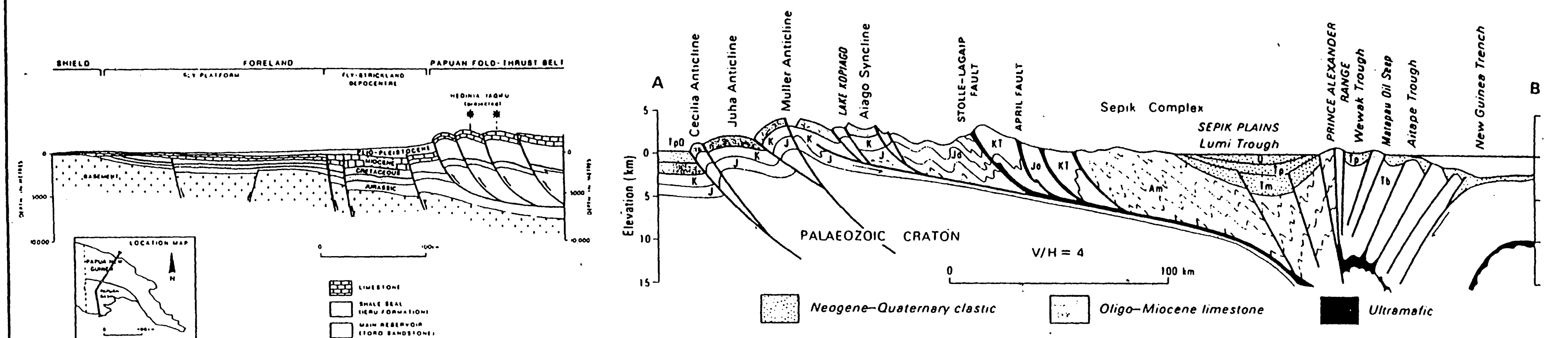


Figure 12 Present day Plate Tectonic Setting of Papua New Guinea (after Smith, 1990).

Figure 13 Schematic cross section from the southernmost Papuan Foreland to the Bismark Sea (after; Davies, (1990) and Osborne, (1990)).



Cross-section from Fly-Strickland plains to Bismarck Sea Am Ambunti Metamorphics; Jo Jurassic carbonaceous siltstone (Om, Maril); J Jurassic sediments; K Cretaceous sediments; KT Cretaceous-Eocene Salumei arc-trench sediments and volcanics, part metamorphosed; Tb Bliri pre-Miocene arc volcanics and intrusives; Tm, Tp, Q indicate Miocene Pliocene and Quaternary sediments respectively.

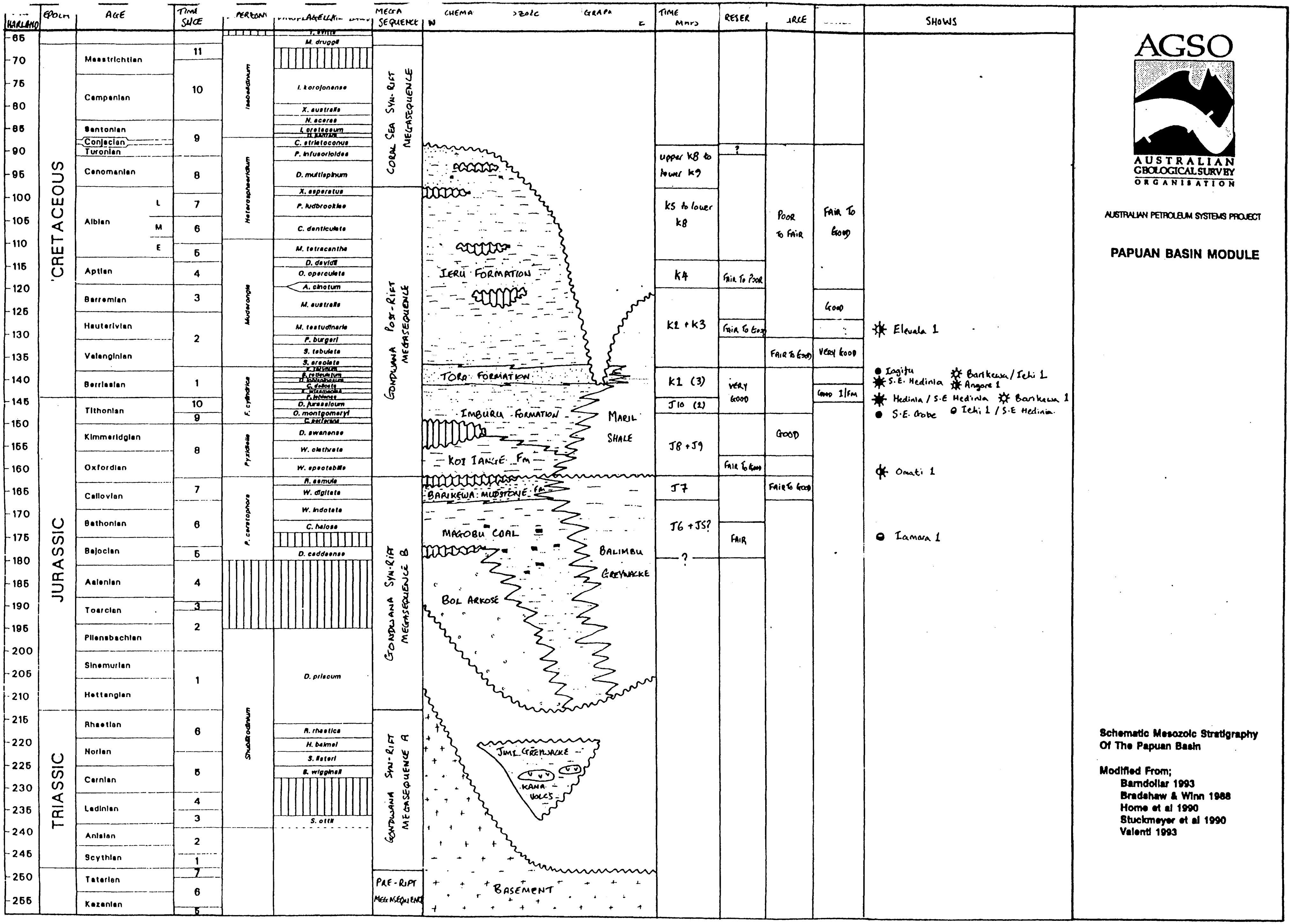


Figure 14 Schematic Mesozoic Stratigraphy of the Papuan Basin (after; Barndollar, (1993), Bradshaw and Winn, (1988), Home et al, (1990), Struckmeyer et al (1990) and Valenti (1993)).

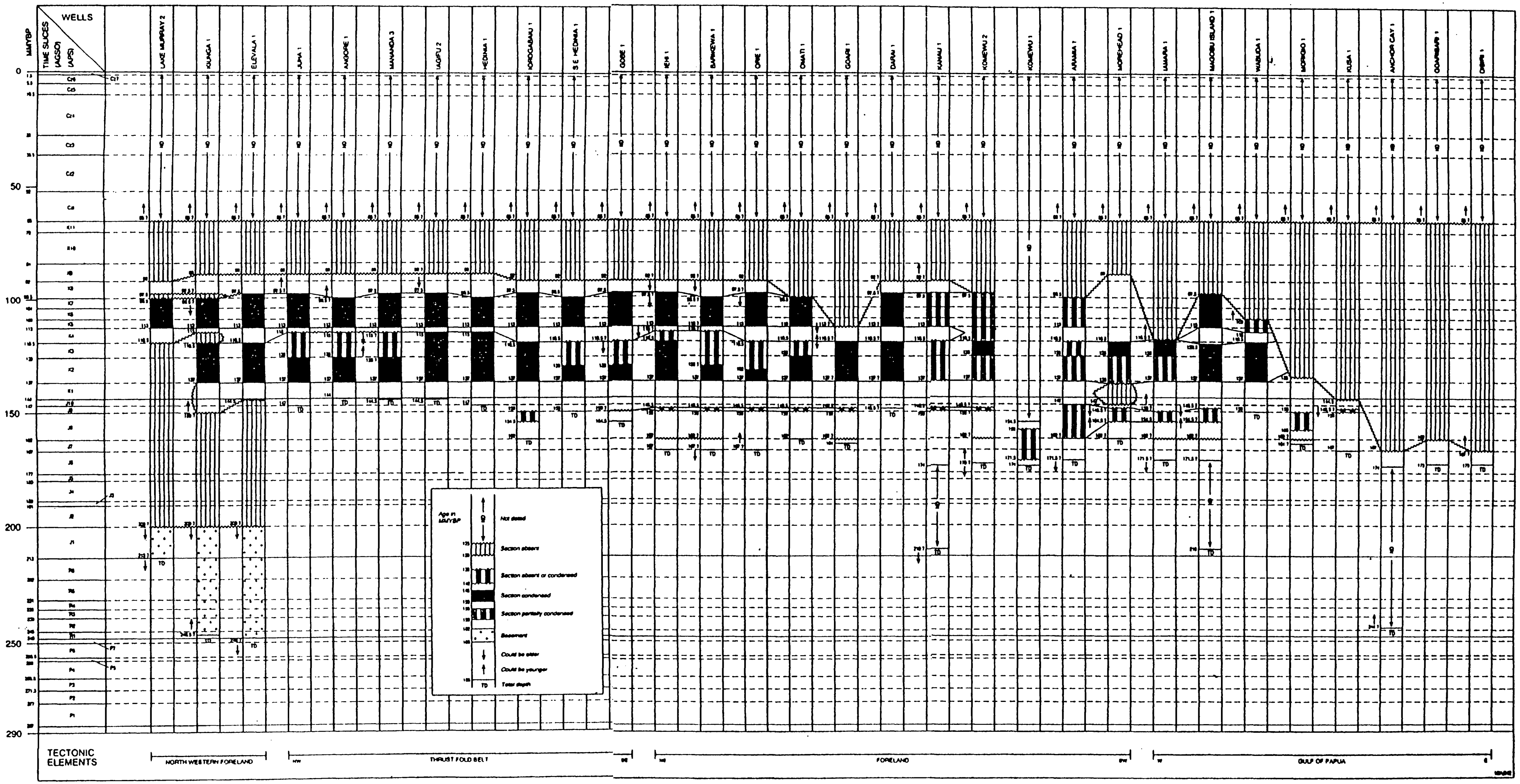


Figure 15 Papuan Basin Time Space Correlation Diagram.

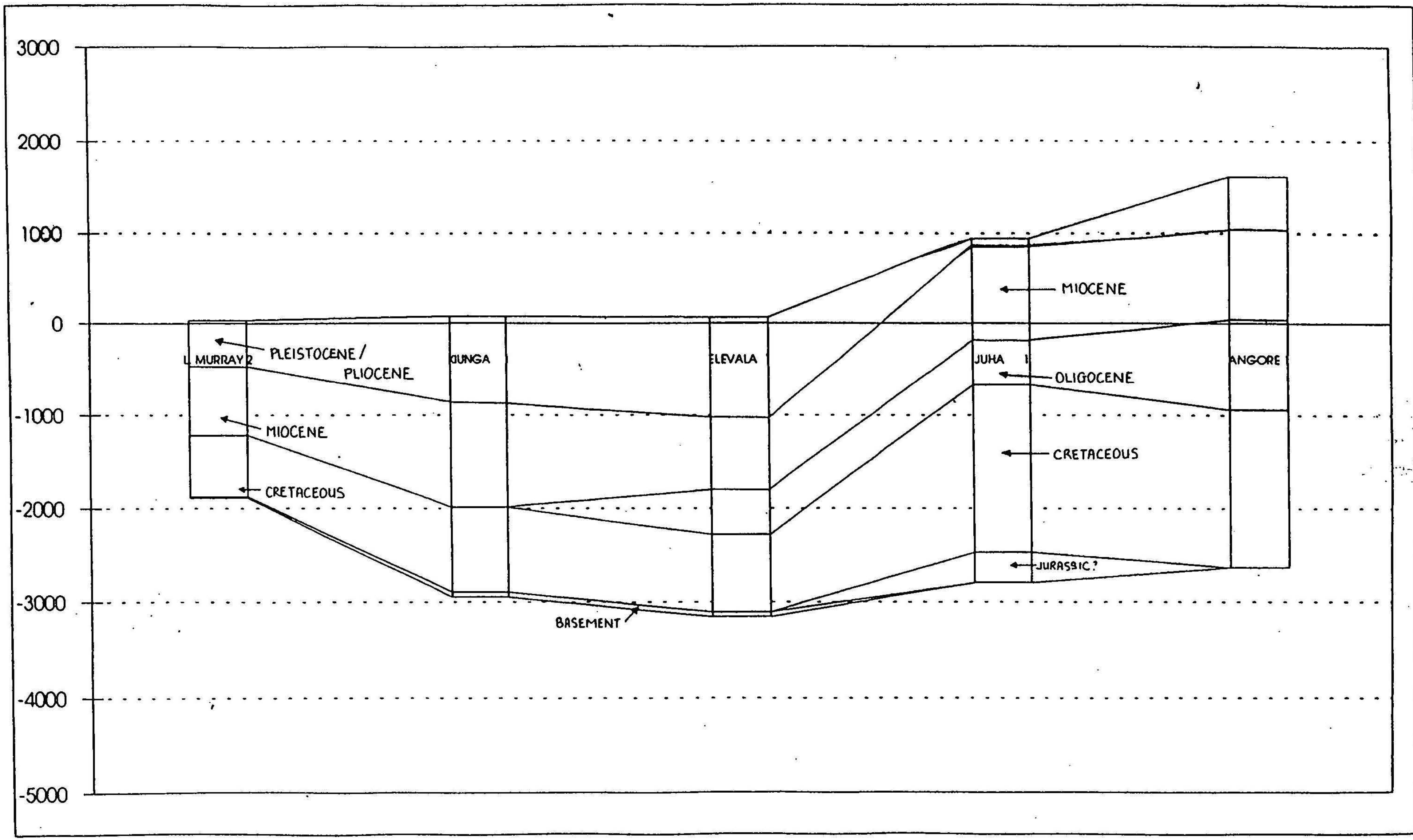


Figure 16 Papuan Basin Schematic Cross Section A-A' datum at Sea Level.

Figure 17 Papuan Basin Schematic Cross Section B-B' datum at Sea Level.

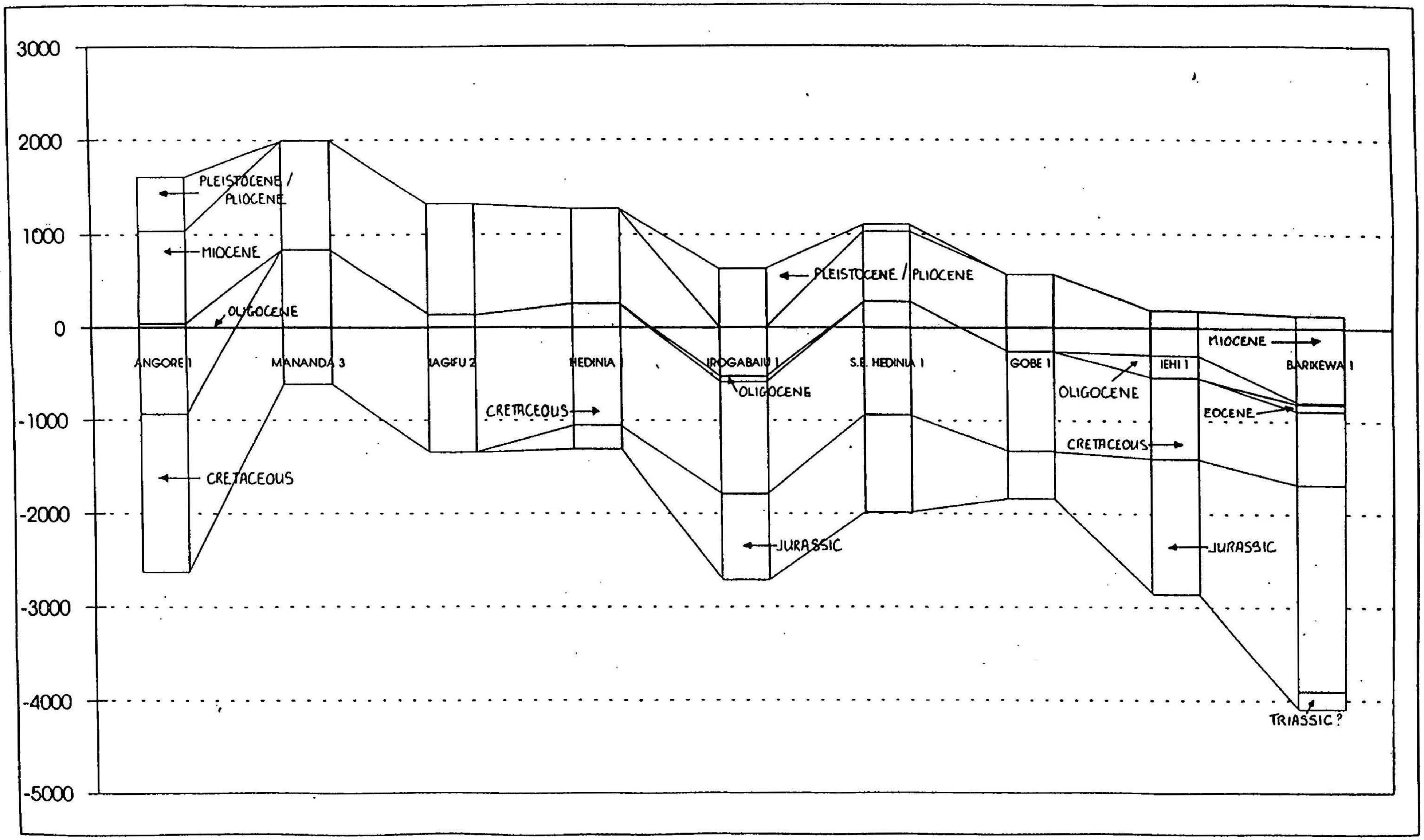
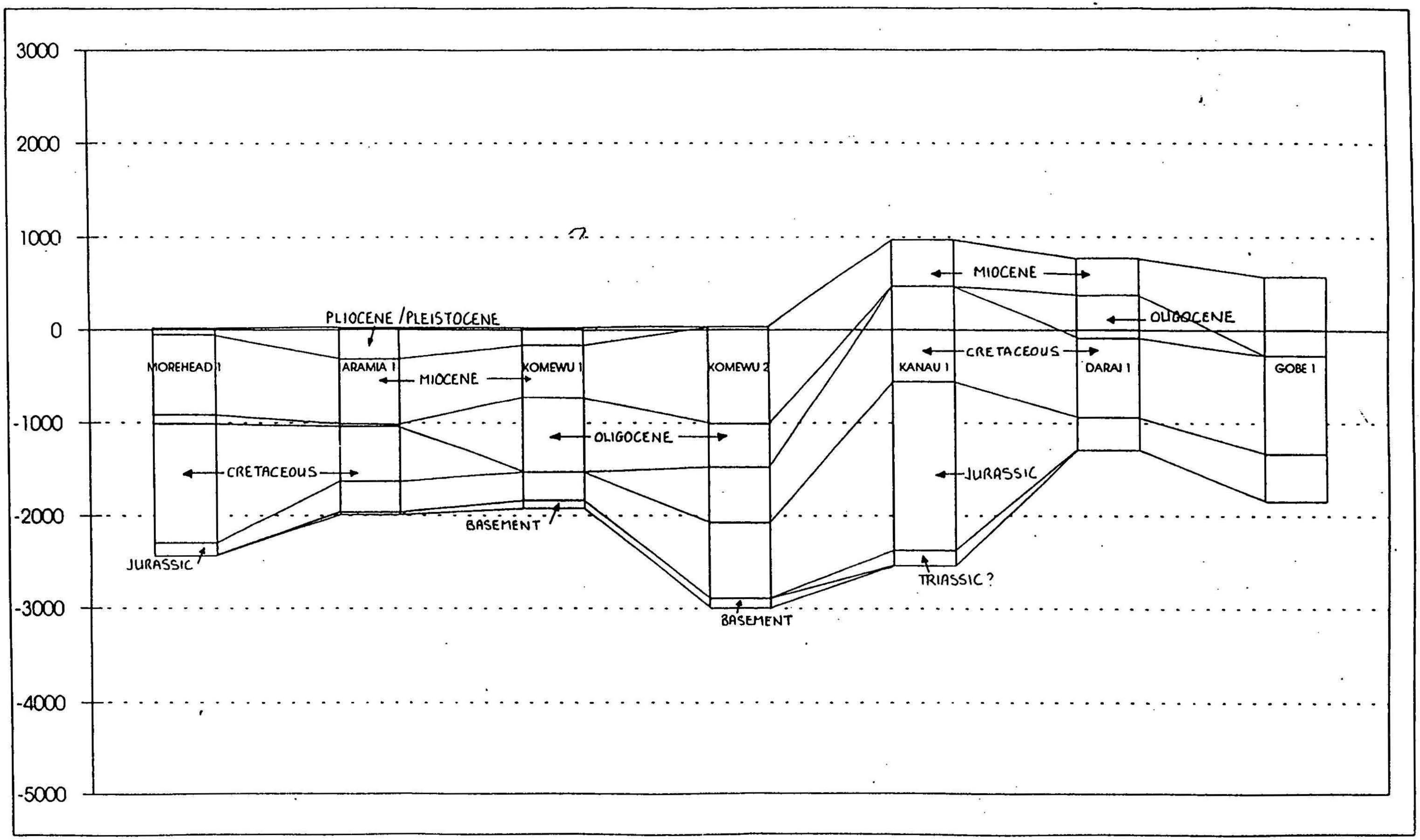


Figure 18 Papuan Basin Schematic Cross Section C-C' datum at Sea Level.



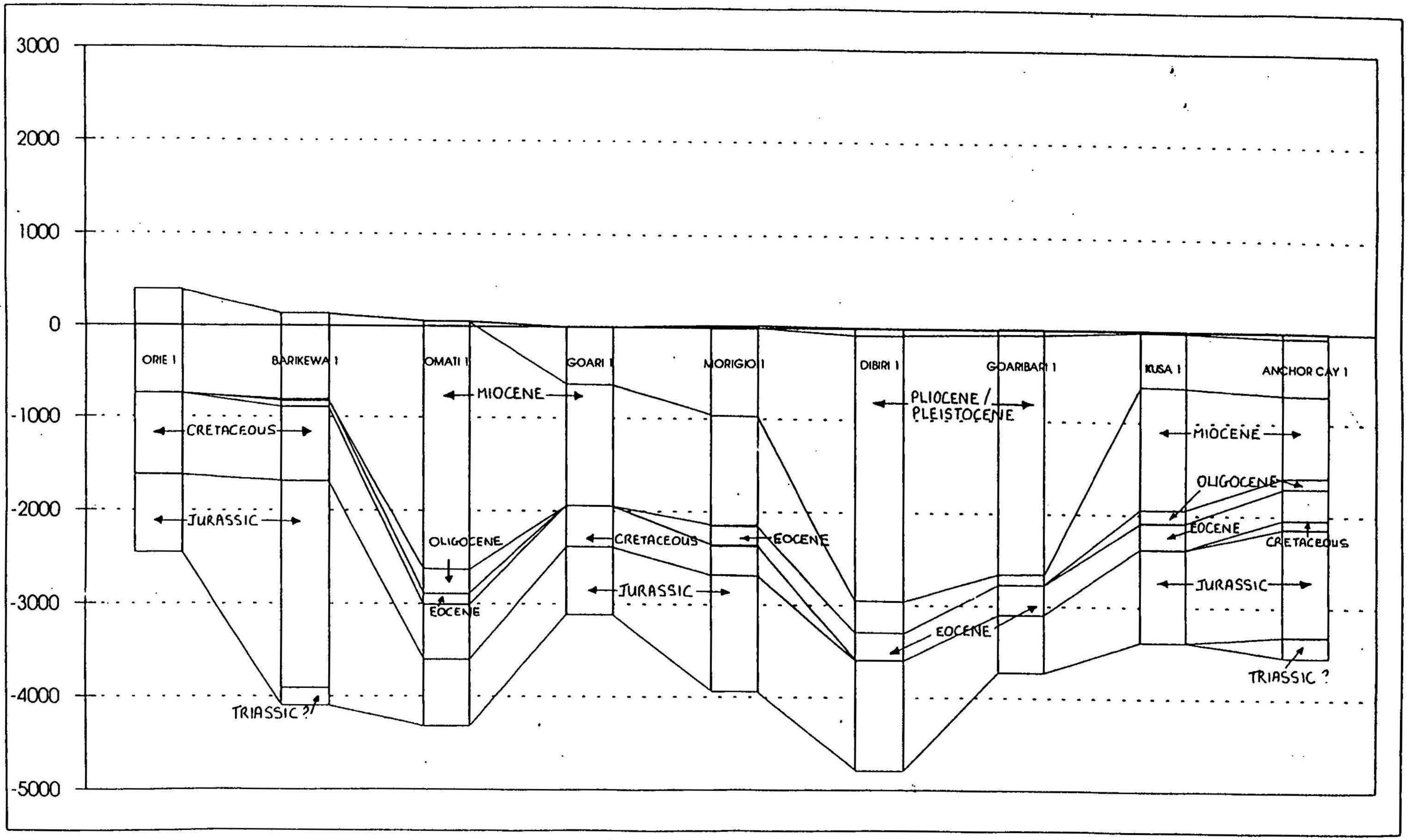


Figure 19 Papuan Basin Schematic Cross Section D-D' datum at Sea Level.

Figure 20 Papuan Basin Schematic Cross Section E-E' datum at Sea Level.

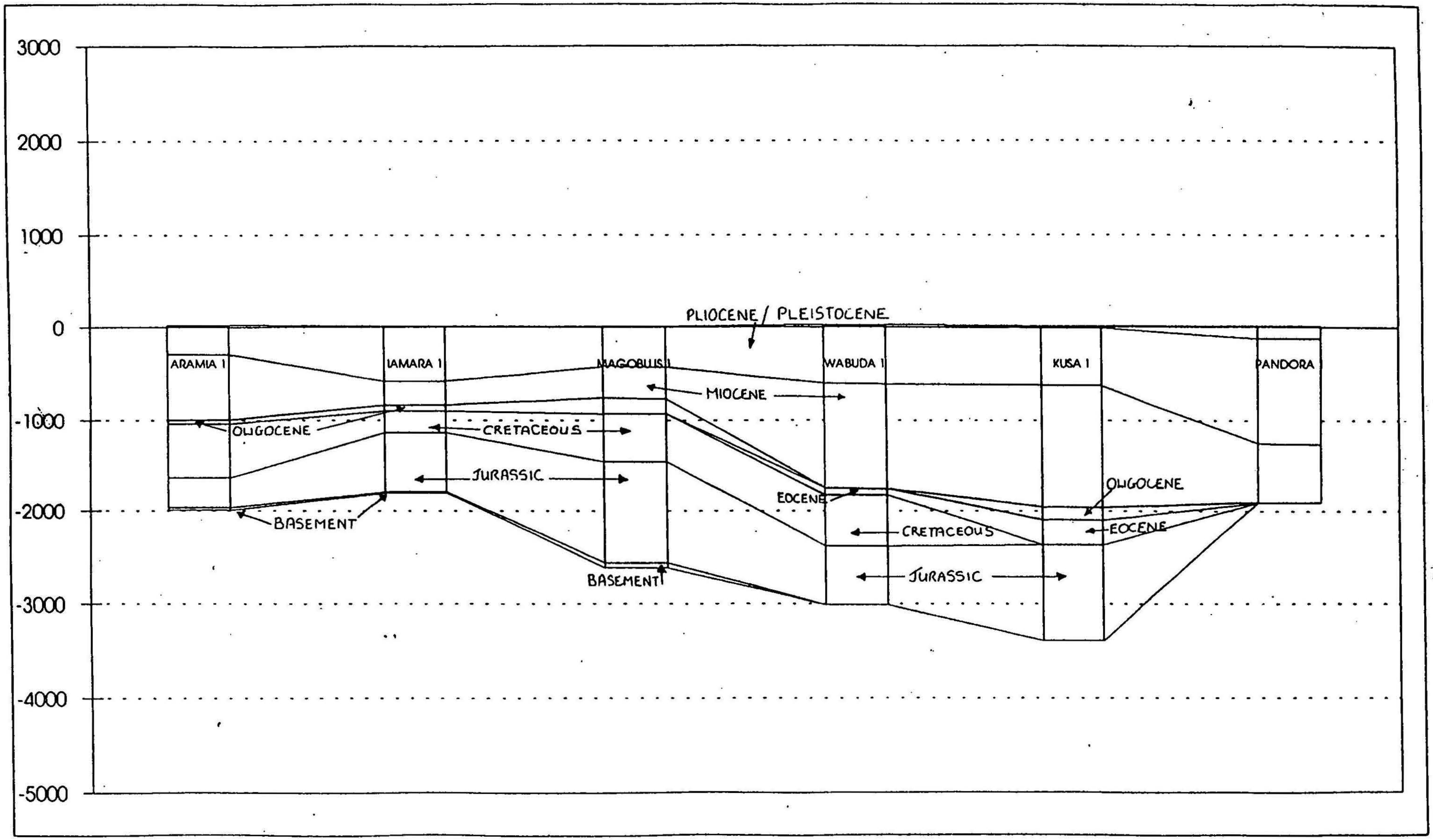


Table 2 Tabulation of the stratigraphic thickness encountered in wells located on sections A-A' and B-B'.

SECTION A - A' STRATIGRAPHIC THICKNESS									
WELLNAMES	LAKE MURRAY 2	KIUNGA 1	ELEVALA 1	JUHA 1	ANGORE 1				
KB ELEVATION	37	74	65	945	1610				
SEABED	-	-	-	-	-				
PLIO. / PLEIST.	505	940	1086	93	582				
MIOCENE	757	1125	784	1035	993				
OLIGOCENE	-	-	469	489	974				
EOCENE	-	-	-	-	-				
CRETACEOUS	653	907	836	1792	1690				
JURASSIC	-	-	-		-				
TRIASSIC	-	-	-	-	-				
BASEMENT	19	54	50	-	-				
TOTAL DEPTH	1934	3026	3225	3742	4239				
SECTION B - B' STRATIGRAPHIC THICKNESS									
WELLNAMES	ANGORE 1	MANANDA 3	IAGIFU 2	HEDINIA 1	IOROGOBAIU 1	SE HEDINIA 1	GOBE 1	IEHI 1	BARIKEWA 1
KB ELEVATION	1610	1997	1327	1275	632	1106	569	188	135
SEABED	-	-	-	-	-	-	-	-	-
PLIO. / PLEIST.	582	-	-	-	622	79	-	-	-
MIOCENE	993	1157	1192	1020	554	750	835	495	949
OLIGOCENE	974	-	-	-	54	-	-	237	11
EOCENE	-	-	-	-	-	-	-	-	69
CRETACEOUS	1690	1464	1490	1311	1196	1216	1065	866	792
JURASSIC	-	-	-	259	928	1049	511	1463	2413
TRIASSIC	-	-	-	-	-	-	-	-	-
BASEMENT	-	-	-	-	-	-	-	-	-
TOTAL DEPTH	4239	2621	2682	2590	3354	3094	2411	3061	4234

Table 3 Tabulation of the stratigraphic thickness encountered in wells located on sections C-C' and D-D'.

SECTION C - C' STRATIGRAPHIC THICKNESS									
WELLNAMES	MOREHEAD 1	ARAMIA 1	KOMEWU 1	KOMEWU 2	KANAU 1	DARAI 1	GOBE 1		
KB ELEVATION	20	24	27	38	967	769	569		
SEABED	-	-	-	-	-	-	-		
PLIO. / PLEIST.	76	324	182	-	-	-	-		
MIOCENE	868	716	564	1059	505	390	835		
OLIGOCENE	92	28	811	456	-	461	-		
EOCENE	-	-	-	-	-	-	-		
CRETACEOUS	1287	584	-	601	1014	859	1065		
JURASSIC	142	337	302	821	1830	358	511		
TRIASSIC	-	-	-	-	170	-	-		
BASEMENT	-	31	90	104	-	-	-		
TOTAL DEPTH	2465	2020	1949	3041	3519	2068	2411		
SECTION D - D' STRATIGRAPHIC THICKNESS									
WELLNAMES	ORIE 1	BARIKEWA 1	OMATI 1	GOARI 1	MORIGIO 1	DIBIRI 1	GOARIBARI 1	KUSA 1	ANCHOR CAY 1
KB ELEVATION	396	135	55	8	24	13	14	14	10
SEABED	-	-	-	-	31	70	69	28	63
PLIO. / PLEIST.	-	-	-	628	974	2964	2696	622	697
MIOCENE	1144	949	2684	1308	1181	345	113	1337	890
OLIGOCENE	-	11	258	-	-	-	-	138	115
EOCENE	-	69	126	-	221	301	310	290	350
CRETACEOUS	871	792	591	440	317	-	-	-	105
JURASSIC	835	2413	715	762	1266	1195	650	1020	1175
TRIASSIC	-	-	-	-	-	-	-	-	228
BASEMENT	-	-	-	-	-	-	-	-	-
TOTAL DEPTH	2850	4234	4374	3138	3990	4895	3838	3434	3623

Table 4 Tabulation of the stratigraphic thickness encountered in wells located on section E-E'.

SECTION E - E' STRATIGRAPHIC THICKNESS									
WELLNAMES	ARAMIA 1	IAMARA 1	MAGOBU IS 1	WABUDA 1	KUSA 1	PANDORA 1			
KB ELEVATION	24	11	9	25	14	16			
SEABED	-	-	-	31	28	139			
PLIO. / PLEIST.	324	585	430	606	622	1268			
MIOCENE	716	255	335	1146	1337	659			
OLIGOCENE	28	73	168	-	138	-			
EOCENE	-	-	8	73	290	-			
CRETACEOUS	584	234	521	564	-	-			
JURASSIC	337	650	1118	628	1020	-			
TRIASSIC	-	-	-	-	-	-			
BASEMENT	31	17	55	-	-	-			
TOTAL DEPTH	2020	1814	2634	3048	3434	2066			

Based on seismic data the Jurassic and older rocks thicken to the east and northeast of the basin. The Cretaceous section is absent due to erosion in the Gulf of Papua but thickens from the west to the east and northeast. Although a considerable amount of work is still required to fully delineate the Cainozoic a preliminary interpretation suggests that the Oligocene section is much thicker than previously recognised. Seismic data also indicates several significant unconformities of Oligocene to Mid-Miocene age.

Home et al (1990) identify eight megasequences in the sedimentary section of the western Papuan Basin. The 'pre-rift' basement is probably Palaeozoic metamorphics intruded by Permo-Triassic to Triassic-Jurassic granites and granodiorites (Davies, 1990). Basement outcrops to the north in the Strickland River and Kubor Anticline where it has been dated at 222+/-10 Ma (Page, 1976). Of the Foreland wells which intersect basement, the most recent is P'nyang 1 which reached total depth in granodiorite dated using K-Ar methods at 205 Ma +/-5m.y. (Valenti, 1993), the Earliest Jurassic of Harland et al (1982). These intrusives could be products of the latter stages of continental rifting as described by Pigram and Panggabean (1984) and Home et al (1990). Valenti (1993) notes the regional significance of this date constraining the maximum age for the post-breakup unconformity of Pigram and Panggabean (1984). The gross shape of the Papuan Basin "container" is illustrated by a depth to basement contour map shown in Figure 21.

The Triassic Kana Volcanics and Jimi Greywacke have a restricted areal distribution and unconformably overlying basement. These Triassic strata constitute the Gondwana Syn Rift Megasequence A of Home et al (1990). The Jimi Greywacke is probably in part the lateral equivalent to the Kana Volcanics and appears to be restricted in outcrop to the area north of the Kubor Anticline. The sequences are characterised by sub aerial and submarine volcanics and volcaniclastic sediments with rapid lateral thickness changes as a consequence of their syn-tectonic deposition. Triassic sediments were probably encountered in the hanging wall of the Darai Fault at Kanau 1, their absence from surrounding wells suggests that syn depositional extensional faulting occurred along the Darai Fault during the Triassic. Home et al (1990) use evidence from the Kubor area of pre-Jurassic uplift and erosion of the Triassic to differentiate the Gondwana Syn Rift A and B Megasequences.

The Gondwana Syn-Rift Megasequence B (Home et al, 1990) comprises the Lower to Middle Jurassic Bol Arkose which is restricted to local rift basins bounded by extensional faults. This sequence is penetrated in Kanau 1 and outcrops in the core of the Muller Anticline (Valenti, 1993). It comprises dominantly arkosic sandstones interpreted to be largely non-marine in origin and deposited in fluvial and alluvial fan environments. The

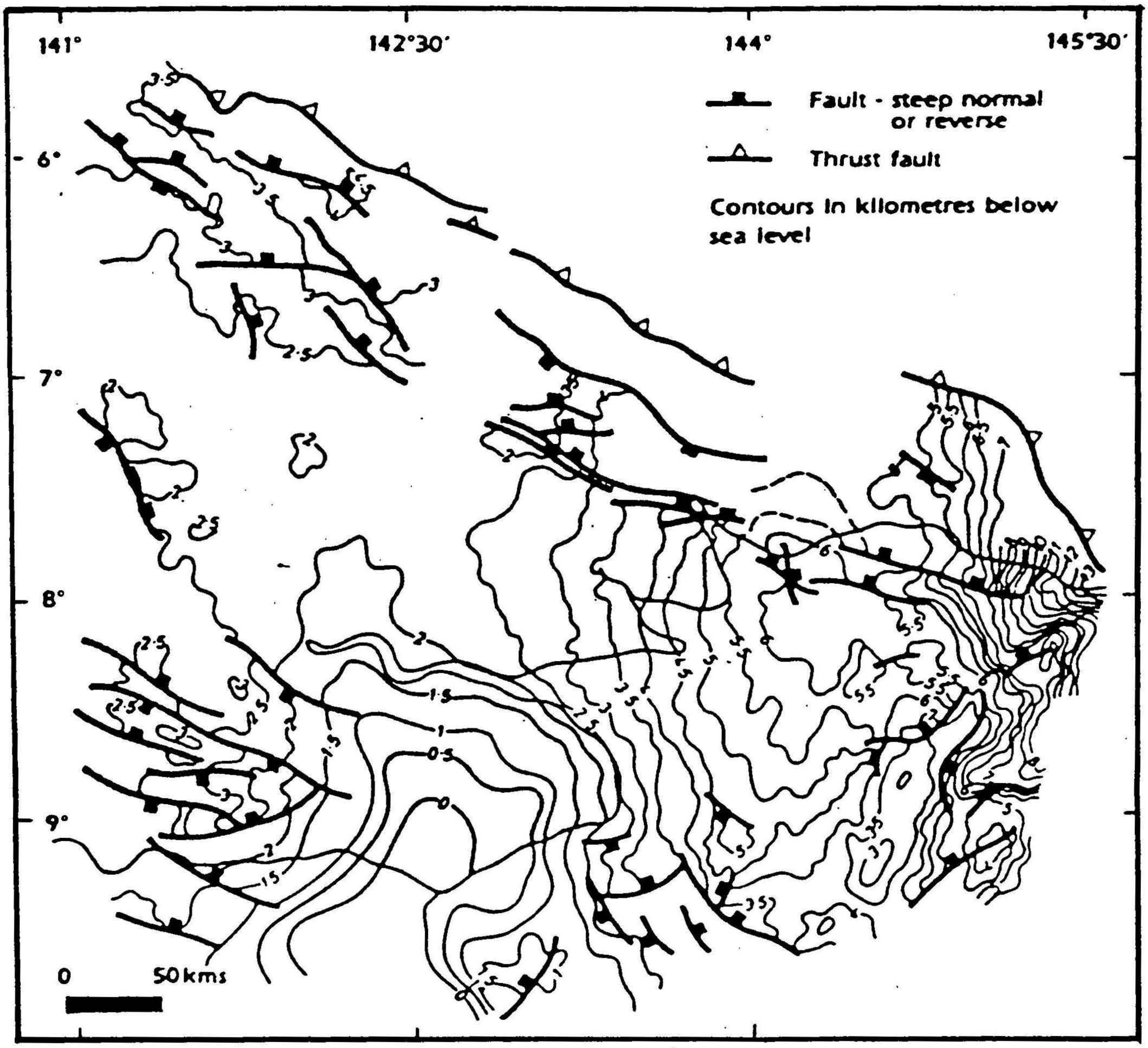


Figure 21 Basement depth contour map, contour interval is 500 metres (after; Pincher et al, 1986).

occurrence of ammonites and other indicators of marine influence are interpreted to indicate periodic marine incursions from an ocean lying to the north of the basin (Home et al, 1990).

The overlying Magobu Coal Formation is interpreted to be deltaic in origin and is widespread in the south and east of the Fly Platform. Home et al (1990) suggest it is the product of southeasterly flowing river systems coalescing to form a major deltaic plain approximately coincident with the present day coastline. To the north and east the Magobu Coal passes into the Balimbu Greywacke which is thought to be a shallow water deposit (Home et al, 1990). The absence of the Balimbu Greywacke from the Kubor Anticline, the northern Muller Anticline and over the Pasca Ridge suggests these areas were emergent and sheltered the Papuan Basin from truly open marine conditions during the Mid Jurassic.

The incursion of marine conditions over the Fly Platform during Time Slice J7 (Callovian) results in the retreat of the deltaic systems towards the south and the development of a thick monotonous mudstone sequence, the Barikewa Mudstone. This sequence represents the uppermost part of Home et al's (1990) Gondwana Syn Rift B Megasequence, it's upper limit has been interpreted by Home et al (1990) to represent the Breakup Unconformity. Maturity data indicates this boundary marks a significant change in the evolution of the basin with the J7 and older sequences demonstrating higher geothermal gradients than the overlying sequences. This implies that the J7 and older sequences may have either been buried to much deeper levels or that the section was exposed to a higher heat flow associated with basin rifting. However, the recognition of a minimum radiometrically derived break-up age of 155 Ma (Ludden, 1992), the Early Kimmeridgian of Harland et al (1982)(middle J8 time slice), at Ocean Drilling Program (ODP) Site 765 in the southeastern Argo Abyssal Plain clearly suggests that break-up in the Papuan Basin should occur earlier than that proposed by Home et al (1990).

During this Early to Mid Jurassic phase of deposition the major tectonic elements of the Papuan Basin, which were to control much of it's subsequent evolution, were established. The Fly Platform remained virtually unstructured except for the Morehead Sub Basin, to the north the NW-SE trending extensional faults had developed and the possibility exists that the Bosavi Lineament, a major transfer zone, transferred this extension northwards to the Juha-Muller Fault system (Home et al, 1990). This transfer zone is tentatively linked to the possible northwards extension of the Palaeozoic Tasman Line (Home et al, 1990) and marks the western limit of the Magobu Coal Formation.

The overlying Koi-Iange Formation marks the base of the Gondwana Post Rift Megasequence (Home et al, 1990). This megasequence is deposited as a transgressive wedge in response to thermal subsidence associated with sea floor spreading to the north and east of PNG (Pigram and Panggabean, 1984). It comprises a sequence of shallow marine siltstones, shales and sandstones.

Water depth is thought to gradually increase towards the north and east where the distal deep water equivalent to the Koi-Iange are the lower Maril Shale in the Kubor area and the Om Beds to the north of the Muller Anticline. Conformably overlying the Koi-Iange Formation are the open marine shales and siltstones of the Lower Imburu Formation. Valenti (1993) and Matzke et al (1992) suggest the Lower Imburu Formation contains the primary source interval for both the P'nyang hydrocarbons and the oil currently being produced at the Iagifu/Hedinia Field. The Upper Imburu Formation coarsens upwards into the Iagifu, Hedinia, P'nyang and Digimu sands (Denison & Anthony, 1990; Valenti, 1993). Each of these sands represent a minor regressive sequence deposited in an overall transgressive megasequence.

The Lower Cretaceous Toro Formation conformably overlies the Imburu Formation and represents the last and most significant regressive event within the Gondwana Post Rift Megasequence. It consists of sheet sands deposited in a shoreface environment on a low angle shelf and can be subdivided into three distinct lowstand packages separated by transgressive sequences. Sand deposition is terminated by a transgressive event at the top of Time Slice K1 which is responsible for the deposition of the overlying Lower Ieru Formation. The Lower Ieru Formation is dominantly an argillaceous unit with occasional sandstones and deposited in a predominantly low energy marine environment characterised by slow rates of deposition and condensed intervals (Figure 22).

The upper boundary of Home et al's (1990) Post Rift Megasequence is marked by a significant change in the rate of sedimentation (Figure 22) corresponding to a renewed extensional episode associated with rifting in the Coral Sea. This occurs at the base of the *D. multispinum* biozone (Helby et al, 1987) and forms the boundary between our lower and upper K8 time slice. Sedimentation during this Late Cretaceous interval (Cenomanian and younger) is referred to as the Coral Sea Syn-Rift Megasequence (Home et al, 1990) and consists of the upper part of the Ieru Formation and its distal equivalent the Chim Formation. Seismic evidence, to the north of the Kiunga area and in the area west of the Bosavi Lineament, clearly show extensive thickening of the Upper Ieru Formation across major faults. The base of this megasequence is locally erosive.

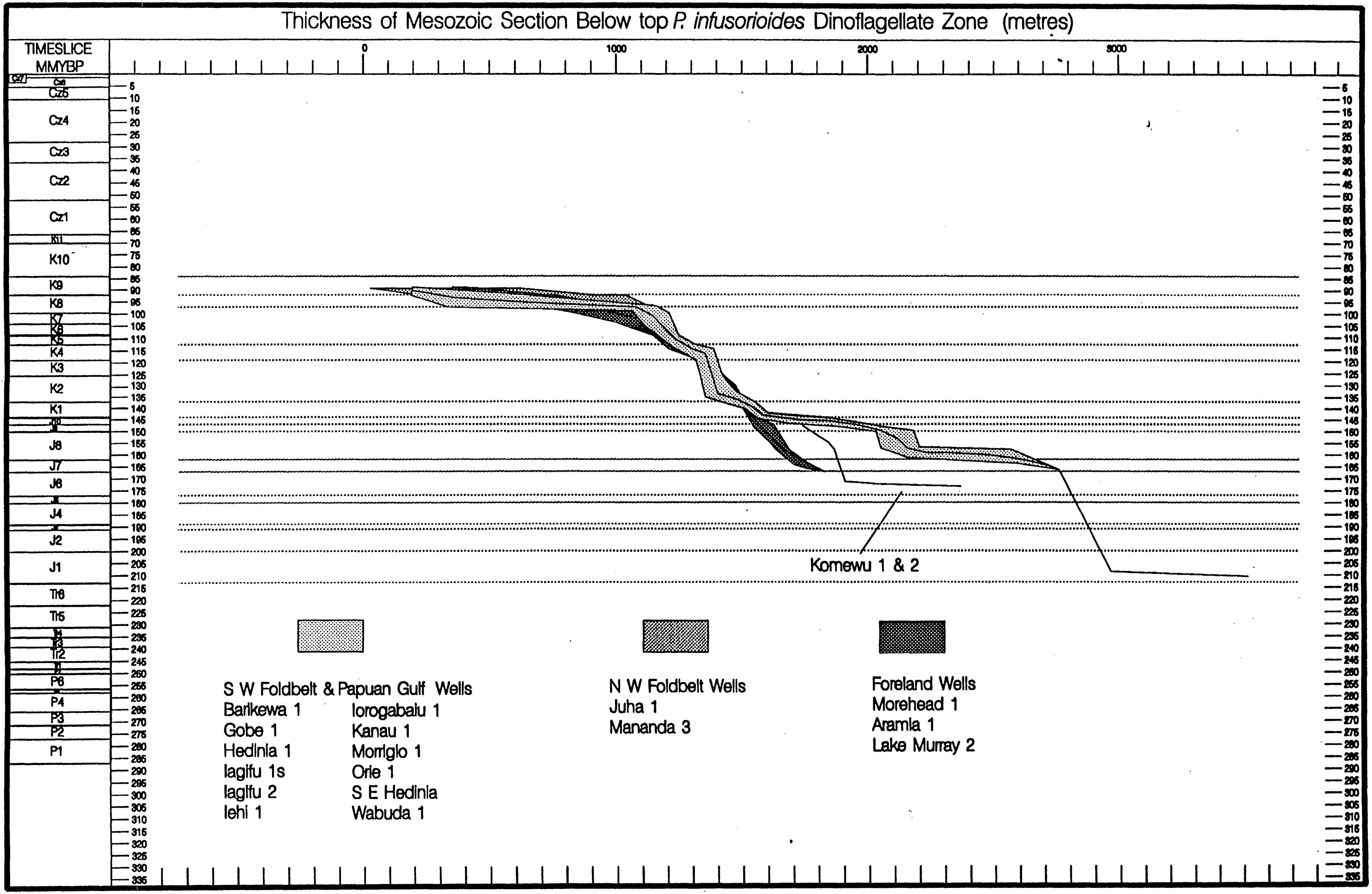


Figure 22 Cumulative Mesozoic Age Depth Plots for the Papuan Basin.

During the latest Cretaceous, a phase of regional thermal uplift and erosion resulted in the development of a major unconformity across the Papuan Basin. Most of the upper Ieru Formation was eroded and only a few wells in the northwestern portion of the basin intersect the remains of the underlying syn rift megasequence. Based on well log and seismic data, approximately 350m to 500m may have been eroded in the Fly Platform area, whereas in the southeastern part of the Papuan Basin, it has been documented that up to 2 km of sediments were removed as a result of the regional uplift. However, seismic data indicate that most of the erosion took place over prominent structural highs and that significantly thick syn rift deposits may be present in some of the intrabasinal lows, eg northeastern parts of Kiunga and the northern areas of Dibiri and Morigio.

Home et al (1990) identified the Coral Sea Post Rift Megasequence as comprising all sediments of Palaeocene and Eocene age. In the Gulf of Papua, sedimentation resumed by Eocene times but most of the onshore Papuan Basin remained emergent until Oligocene times.

An extensive carbonate platform developed over most of the Papuan Basin during the Late Oligocene to early Miocene. This depositional period is referred to as the Darai Back-Arc Megasequence (Home et al, 1990). Smith (1990) interpreted the renewed subsidence in the Papuan Basin to be associated with another phase of extensional faulting related to the back-arc extension.

The cessation of the Darai back-arc extension and the commencement of a regional compressional phase defines the Foreland Basin Megasequence 1 (Home et al, 1990). This structural change was probably associated with the late Early Miocene ophiolite obduction in northern PNG (Smith, 1990). However, during this period, carbonate deposition continued in most parts of the Papuan Basin, with some structural inversion occurring in the northwestern Foreland.

The second Foreland Basin Megasequence of Home et al (1990) is characterised by the initiation of clastic deposition during the latest Miocene and it's continuance up to the present day. The Plio-Pleistocene tectonics have significantly affected the geometry and stratigraphy of the Papuan Basin. In the Gulf of Papua, continued thermal subsidence and foreland loading has resulted in an accumulation of over ten kilometres of marine clastics. Compressional tectonics in the Papuan Fold Belt has resulted in the formation of large ramp anticlines, some of which involve basement, and is responsible for an estimated 100 kilometres of shortening (Hill, 1991; Hobson, 1986).

PALAEOGEOGRAPHIC RECONSTRUCTION

METHODOLOGY

Time slice data maps and palaeogeographic interpretation maps have been constructed for a series of time slices ranging in age from the Triassic to the Turonian. The J10 to K1 time slices have been subdivided using detailed sequence stratigraphy. Several time slices with either poor data control or limited environmental variation have been combined to make composite time slice maps.

Each time slice data map shows the location of the wells used in the study in bold type. Each of the study wells that intersect the time slice has a blocked in gamma ray, or SP, log profile at a vertical scale of 1:10,000 posted near the well location and the hydrocarbon indications shown by the well symbol. If the time slice is not penetrated or absent from a study well, or if insufficient biostratigraphic control exists to determine it's presence or absence a symbol is shown by the well location. Palaeogeographic data maps give a visual representation of the thickness variations and distribution of each time slice throughout the basin.

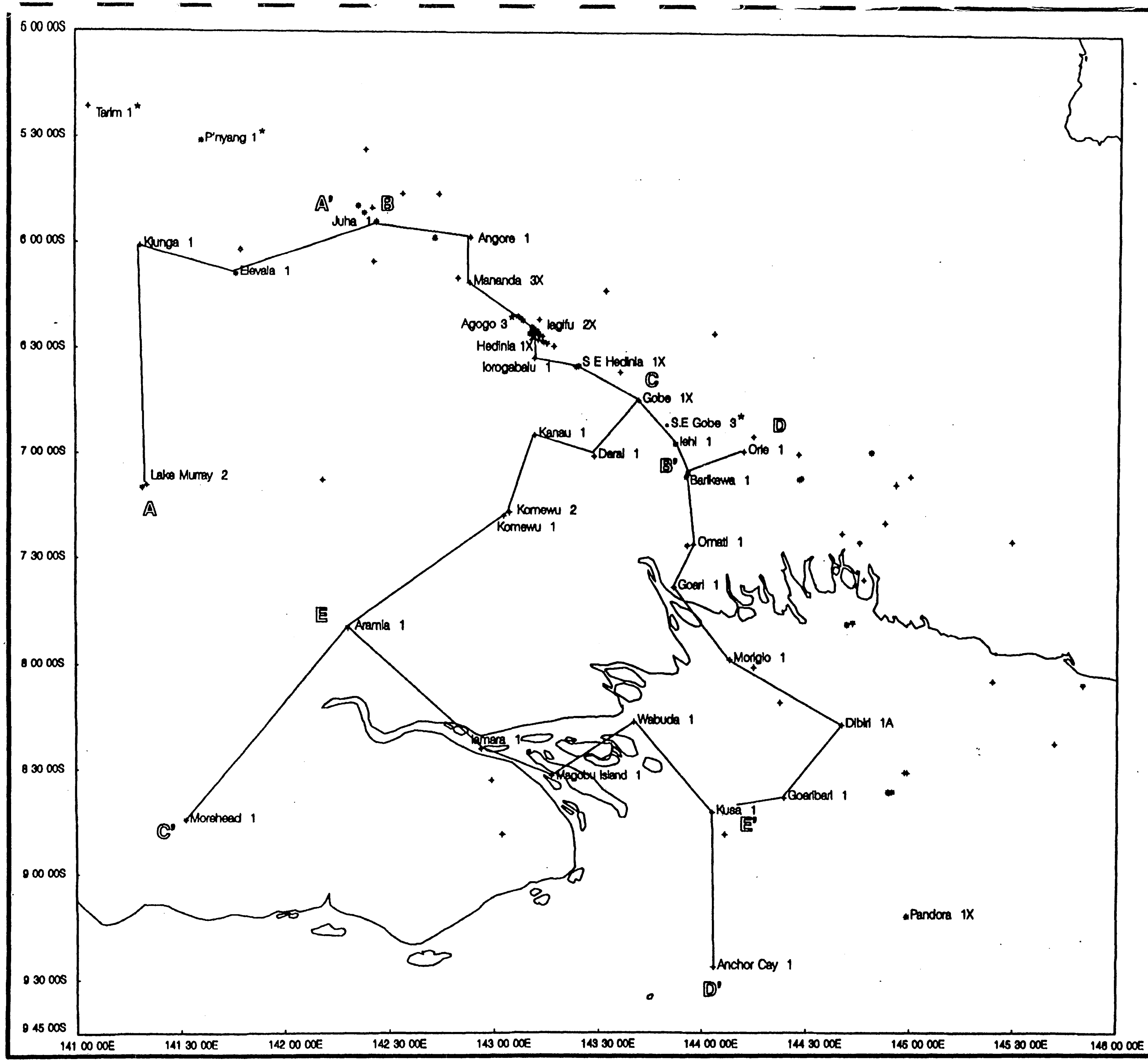
Palaeogeographic interpretation maps have been compiled for those time slices with sufficient information to allow such an interpretation. Detailed descriptions on the palaeogeographic interpretation and prospectivity of each time slice are provided in the following section.

A summary of the organic chemistry is provided for each time slice map. This data is a synthesis of AGSO's ORGCHEM database and data from open file geochemical and well completion reports. It is shown as time slice maps of Total Organic Carbon (TOC), Hydrogen Index (HI) and Vitrinite Reflectance (VR) in Appendix 9.

Figure 23 shows the orientation of the five well log cross sections. Each cross section shows detailed time slice correlations, time slice facies interpretations, regional unconformities/disconformities, flooding surfaces and condensed sections. Interpreted environments of deposition and landform elements are provided in the form of codes (Introductory Section Figure 7 and Table 1) on the well log cross sections. The well log cross sections, which correlate 30 wells, are provided in Enclosures 4 - 8 and should be referred to in conjunction with the palaeogeographic interpretation maps and accompanying notes.

PALAEOGEOGRAPHIC INTERPRETATIONS AND PROSPECTIVITY OF TIME SLICES

Figure 23 Location Map of the Papuan Basin Well Log Cross Sections.



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PAPUAN BASIN MODULE

0 15 30 45 60 75
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 147 00 00 E

TIME SLICE Tr1 to Tr6: Triassic (Figure 24)

SUMMARY : Texturally immature fluvial and alluvial fan deposition in localised, northwest to southeast trending, fault bound depocentres. Bulk of the Fly Platform is emergent and in several places intruded by Triassic granites. The Kana Group volcanics outcrop around the Kubor Anticline. Little reservoir or source potential and only minor oil indications.

PALAEOGEOGRAPHIC INTERPRETATION

To date Triassic rocks have only been penetrated in wells located in the Foreland and Gulf of Papua. However, Triassic strata do outcrop in the northernmost parts of the Papuan Basin on the flanks of the Kubor Anticline (Home et al, 1990 & Struckmeyer et al, 1990).

In the Foreland at Kanau 1 Triassic sediments, that are unlikely to be any older than the upper Early Triassic (Appendix 2), are penetrated in the hanging wall of the Darai Fault. These sediments comprise coarse grained arkosic sands with volcanic pebbles and occasional carbonaceous material and are interpreted to be deposited in a fluvial or alluvial fan environment. Similar sediments are absent from other wells in the area (eg. Komewu 2) and it is suggested by Home et al (1990) that syn-depositional extension occurred along the Darai Fault during the Triassic. The formation of this fault bounded northwest to southeast trending depocentre is thought to relate to the extensive rift system that propagated in an anticlockwise direction around the Australian Plate during this period (Home et al, 1990, Barndollar, 1993).

The Triassic rift deposits have limited areal distribution and elsewhere in the Foreland Triassic aged granitic and granodioritic basement rocks are intersected at Aramia 1 and P'nyang 1 (Page, 1976, Valenti, 1993). Basement is also penetrated at Kiunga 1 (rhyolite/granite), Elevala 1 (granite), Lake Murray 2 (quartz diorite), Komewu 2 (granite), Iamara 1(rhyo-dacite) and Magobu Island 1 (dacite) but unfortunately no reliable radiometric ages exist for any of these sections.

Struckmeyer et al (1990) interpret most of the Fly Platform to be emergent in the Middle Triassic and suggest most of the deposition is restricted to the northernmost part of the Papuan Basin. In the Late Triassic volcaniclastics, redbeds and volcanics of the Kana Group were deposited (Pigram et al, 1987). The Kana Group outcrops around the Kubor Anticline

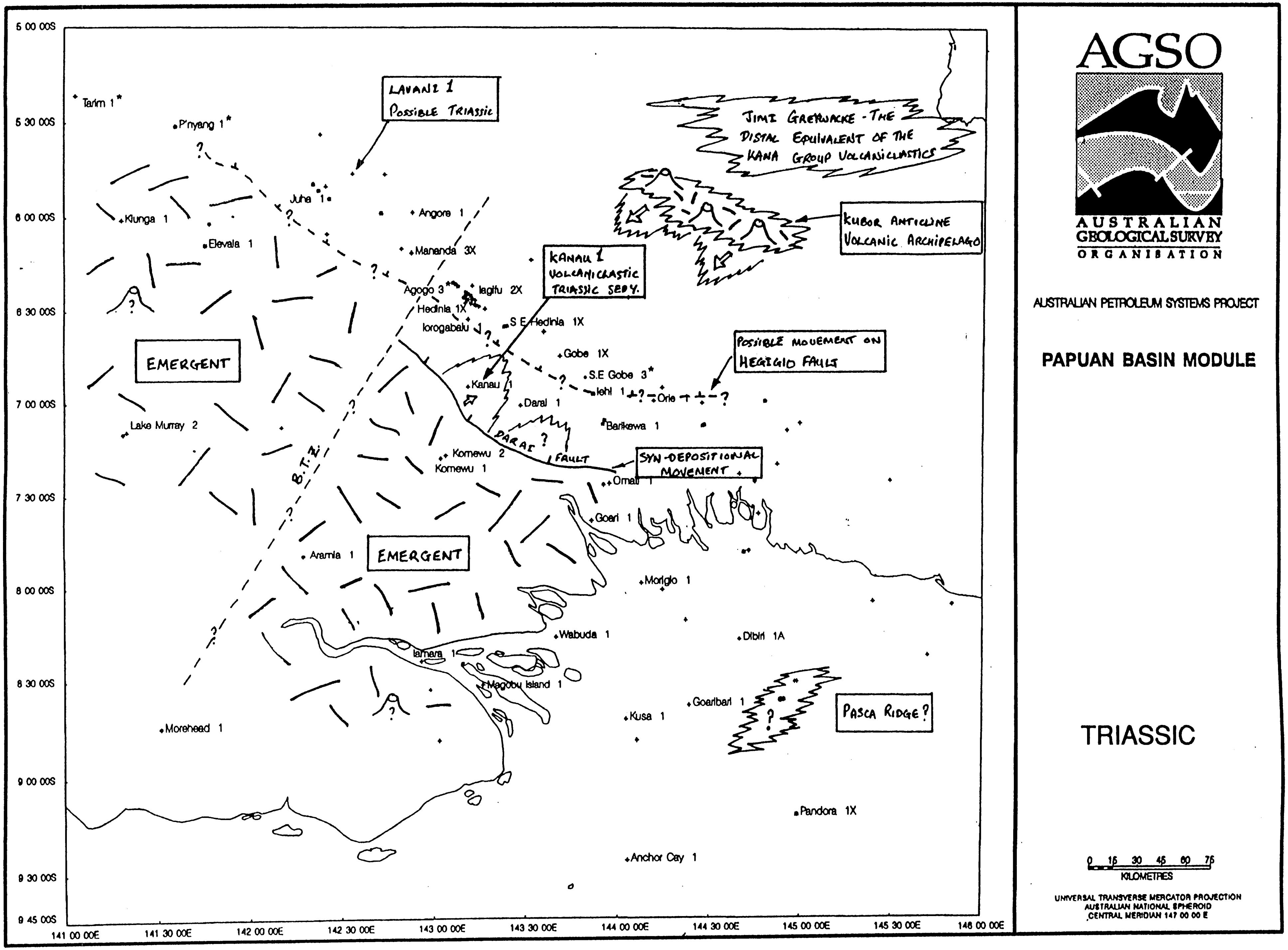


Figure 24 Palaeogeographic reconstruction for the Triassic.

and possibly constitute some of the undated basement sequences penetrated in the Foreland wells. Its distal equivalent, the Jimi Greywacke, is restricted to areas north of the Kubor Anticline (Home et al, 1990, Struckmeyer et al, 1990). The occurrence of both sub-aerial and submarine volcanics in the Kubor area suggests the existence of a volcanic archipelago in this area during the Middle and Upper Triassic (Home et al, 1990).

Triassic sediments with a maximum age of *Lower T. playfordii* were penetrated in the Gulf of Papua at Anchor Cay 1. No electric logs exist over this interval but the lithological descriptions, although sparse, indicate a sequence of coarse sands, conglomerates and volcanics which are interpreted to be part of the Kana Group.

PROSPECTIVITY

The texturally immature clastics in the volcanic dominated Kana Group offer little potential for reservoir development.

The sparse and somewhat limited geochemical data indicates this Triassic sequence also has little, if any, potential as a source interval. Median TOC values range from 1.34 to 2.58% and are interpreted to reflect the occurrence of coaly material within the Triassic sequence. There are only a few HI values, and all are very low. The VR measurements are sparse, mean values range from 0.77 to 1.09 and suggest the Triassic sequences are in the late peak oil generative stage.

Hydrocarbon shows within the Triassic sequence are restricted to minor oil indications from cuttings at Kanau 1.

TIME SLICE J1 to J4 : Early to Mid Jurassic; Hettangian to Earliest Bajocian (Figure 25)

SUMMARY : Fault bound rift basins in the northern Foreland are dominated by fluvial and alluvial fan deposition with occasional marine incursions, equivalent to the Bol Arkose. The Balimbu Greywacke is deposited further to the north of the Fold Belt while the southern Foreland is emergent. Potential development of minor source intervals but limited reservoir potential and no significant shows.

PALAEOGEOGRAPHIC INTERPRETATION

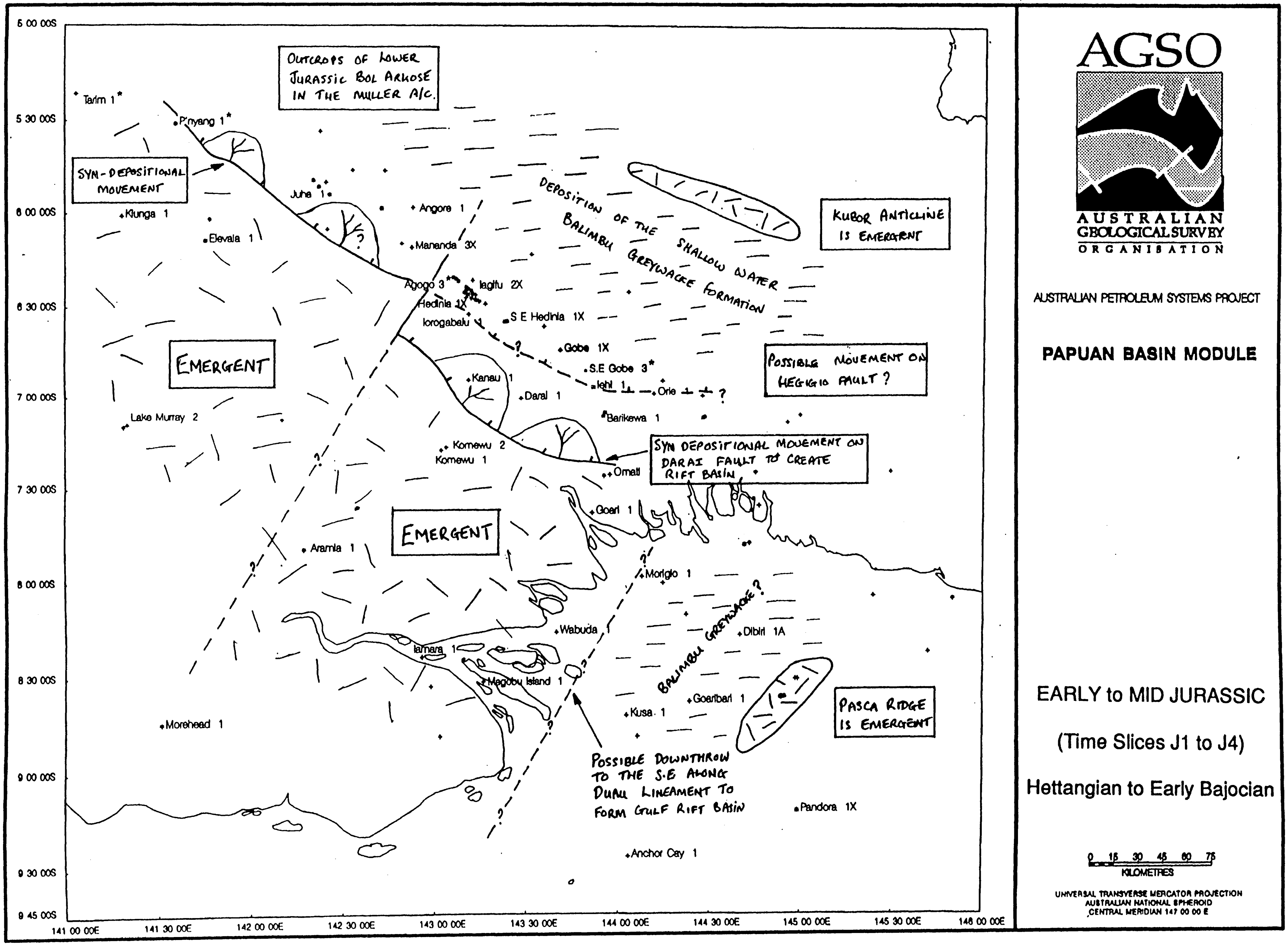


Figure 25 Palaeogeographic reconstruction for Time Slices J1 to J4.

Sediments from Time Slices J1 to J4 are interpreted to have been penetrated in two of the study wells, Kanau 1 and Anchor Cay 1. This interval, which is equivalent to the Bol Arkose of Home et al (1990), has very poor biostratigraphic control.

In Kanau 1 a sequence of fine to coarse grained arkosic sands with minor interbeds of siltstone and occasional carbonaceous material is penetrated. This J1 to J4 sequence is interpreted as a largely non marine fluvial and alluvial fan deposit with occasional periods of marine influence. The absence of similar sequences from other wells in the Foreland suggests that these Early to Middle Jurassic sediments could be restricted to local fault bounded rift basins.

A Lower to Middle Jurassic (time slices J1 to J6) sequence has been interpreted at Anchor Cay 1, in the Gulf of Papua, and comprises of a series of shales, volcaniclastics and arkosic sands thought to be deposited in a similar environment to that interpreted at Kanau 1.

The palaeogeographic interpretation for the northern Papuan Basin relies heavily on published information based on outcrop investigations. The Lower Jurassic Bol Arkose is known to outcrop to the north of the Foreland in the Muller Anticline but is absent 15 kms to the south in the P'nyang wells (Valenti, 1993). The absence of the Lower Jurassic from the P'nyang wells could be indicative that the Frontal Thrust (Figure 11) was an active extensional fault during this period with downthrow to the northeast. The extension may have been transferred to the Frontal Thrust from the Darai Fault via the Bosavi Transfer Zone (BTZ). These two northwest to southeast trending faults, which were subsequently inverted during the Pliocene compressional event (Hill, 1991), may have formed the southerly limit to the Lower Jurassic rift sediments leaving the remaining Foreland areas emergent.

The Balimbu Greywacke Formation, the distal equivalent of the Bol Arkose (Home et al, 1990), was deposited further to the north and consists of volcaniclastic sandstones, conglomerates, siltstones and mudstones deposited in shallow marine environments which deepened to the north (Pigram et al, 1987). Struckmeyer et al (1990) suggest that the presence of basic volcanics in this sequence gives a possible minimum age for ocean formation. The absence of the Balimbu Greywacke Formation from the Kubor Anticline, the northern part of the Muller anticline and over the Pasca Ridge has been interpreted by Home et al (1990) to indicate these areas were emergent during the Early Jurassic.

PROSPECTIVITY

The J1 to J4 sequence offers little potential for the development of any significant reservoir intervals and has no significant hydrocarbon shows.

Geochemical data, although somewhat sparse (Appendix 9), suggests the J1 to J4 sequence offers limited potential as a source interval. The median TOC values range from 1.12 to 1.49% with a maximum value of over 8% from a coaly sequence in Magobu Island 1. The HI values are generally low to moderate with a maximum of 271 in Magobu Island 1. The limited VR data ranges from 0.53 to 0.93 and indicates wells in the Gulf of Papua and northeastern Foreland are in the early to mid stage of peak oil generation (Tobin, 1991).

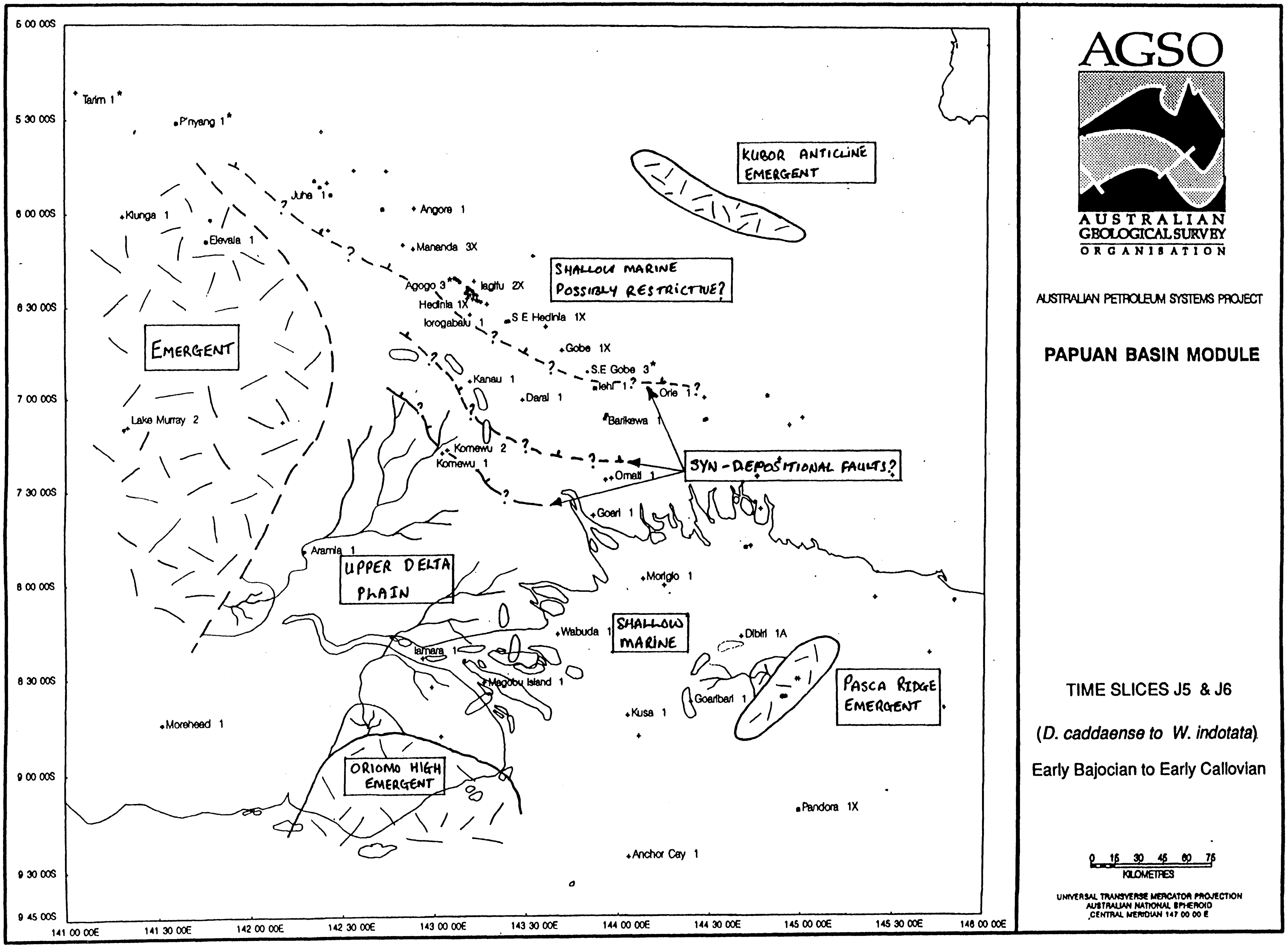
TIME SLICE J5 & J6 : Early Bajocian to Early Callovian (Figure 26, Enclosures 9 and 10)

SUMMARY : J5 sequences onlap basement in the southeastern Foreland. The J6 sequence is dominated by deltaic deposits in the southern Foreland which become increasingly marine to the north. The position of the palaeo shoreline may relate to a series of northwest to southeast trending syn-depositional extensional faults. Transgressive sequences develop in upper J6. Potential for; source intervals, reservoir (low permeability) and seal development. Oil extracted from cores at Iamara 1.

PALAEOGEOGRAPHIC INTERPRETATION

Time Slices J5 and J6, the Middle Jurassic, are penetrated by nine wells in the eastern Foreland (east of the BTZ) and the Gulf of Papua. Wells located to the west of the BTZ and south of P'nyang 1 are missing sediments of equivalent age, a function of the continued emergence of this area during Time Slices J5 and J6. The majority of the present Papuan Fold Belt, the eastern portion of the Foreland and the Gulf of Papua were transgressed during this Mid Jurassic interval. The northeastern and eastern margins of the basin, the Kubor Anticline and Pasca Ridge, are interpreted by Home et al (1990) to be relative highs during this period. Time Slices J5 and J6, the Early Bajocian to Early Callovian, are equivalent to the Magobu Coal Formation.

Figure 26 Palaeogeographic reconstruction for Time Slices J5 & J6.



Well log correlations between Aramia 1 and Magobu Island 1 (Enclosure 8) indicate the presence of an older J5 sequence onlaping basement in the eastern wells. The occurrence of this older sequence together with an observed thickening of the J5 and J6 section across the Fly Platform towards the east and northeast indicates that a transgression occurred from east to west and northeast to southwest.

A phase of sediment outbuilding into this newly formed accommodation space resulted in the development of upper delta plain deposits with arkosic sands, coals, channels and back swamps in the southwestern Foreland at Aramia 1 and Iamara 1. These coarse grained immature clastics are interpreted to be derived from land areas to the southwest. Further to the northeast at Kanau 1, coarsening upwards sands with glauconite and carbonaceous material are interpreted to be stream mouth bar deposits indicative of the transition to more paralic conditions in the northern Fly Platform. Thickness variations between Komewu 1 and 2 may be indicative of syn depositional faulting during Time Slices J5 and J6 and the possibility exists for the palaeo shoreline to be coincident with one such fault, the Darai Fault. More marine conditions are interpreted further to the north, in the Fold Belt, but to date have not been intersected in any exploration wells.

To the east of the Fly Platform, in the Gulf of Papua, a thick sequence of siltstones is penetrated in Dibiri 1 and interpreted to have been deposited in a quiet offshore marine environment by Partridge (1975). The development of similar marine siltstones with interbedded stream mouth bar sands at Goaribari 1 may be indicative of sediment input from the Pasca Ridge into this quiet offshore marine environment. Anchor Cay 1 intersects a poorly sampled sequence of shales, sands and granitic wash which is interpreted to be deposited in a marine environment with sediment input from the southwest, possibly the Oriomo High.

The upper portions of Time Slice J6, in Magobu Island 1, show an incoming of more marine conditions indicative of a gradual rise in relative sea level. Valenti (1993) reports a sequence of Middle Callovian to ?Late Bajocian sediments (Simon Petroleum's MJ1 - see Figure 4) in P'nyang 1 unconformably overlying basement. This sequence may be equivalent to our upper J6 time slice and possibly represents the earliest stages of transgression over the western portion of the Foreland.

PROSPECTIVITY

In the eastern Foreland, the J5 and lower J6, sand dominated sequences offer some potential for the development of significant reservoir packages. Spot porosities from wells in this location range from 12.0 to 33.9% (Appendix 4) and although permeabilities are often low (<10 mD), due to the texturally immature nature of these deltaic sands, Magobu Island 1 has spot permeabilities ranging up to 530 mD. The lateral continuity of sands, especially those in the southwestern Foreland, is uncertain and in several wells individual sands are relatively thin and interbedded with siltstones. However, potential does exist for the development of thicker and more extensive lowstand sands as are correlated between Iamara 1 and Magobu Island 1 (Enclosure 7).

Median TOC values range from 0.65 to 2.10%, a maximum values of 2.41% at Komewu 2 is associated with the development of upper delta plain coals. Maximum TOC values of 2.08% at Barikewa 1 and 6.23% at Dibiri 1 relate to the accumulation of carbonaceous material eroded from the Foreland delta plain and deposited in relatively low energy, possibly restrictive, marine environments. The HI values in the eastern Foreland are generally low, except for Komewu 2 where they reach a maximum of 223. Mean HI values in the eastern portion of the Gulf of Papua range from 84 to 160 and reach a maximum of 567 in Dibiri 1. The majority of mean VR values range from 0.45 to 0.77 and indicate that the J5 & J6 sequences are in the early to mid peak oil generative stage of Tobin (1991). However, Dibiri 1 has a mean VR value of 1.68 indicative of dry gas generation and the formation of overmature sequences, due to the impact of the Coral Sea opening.

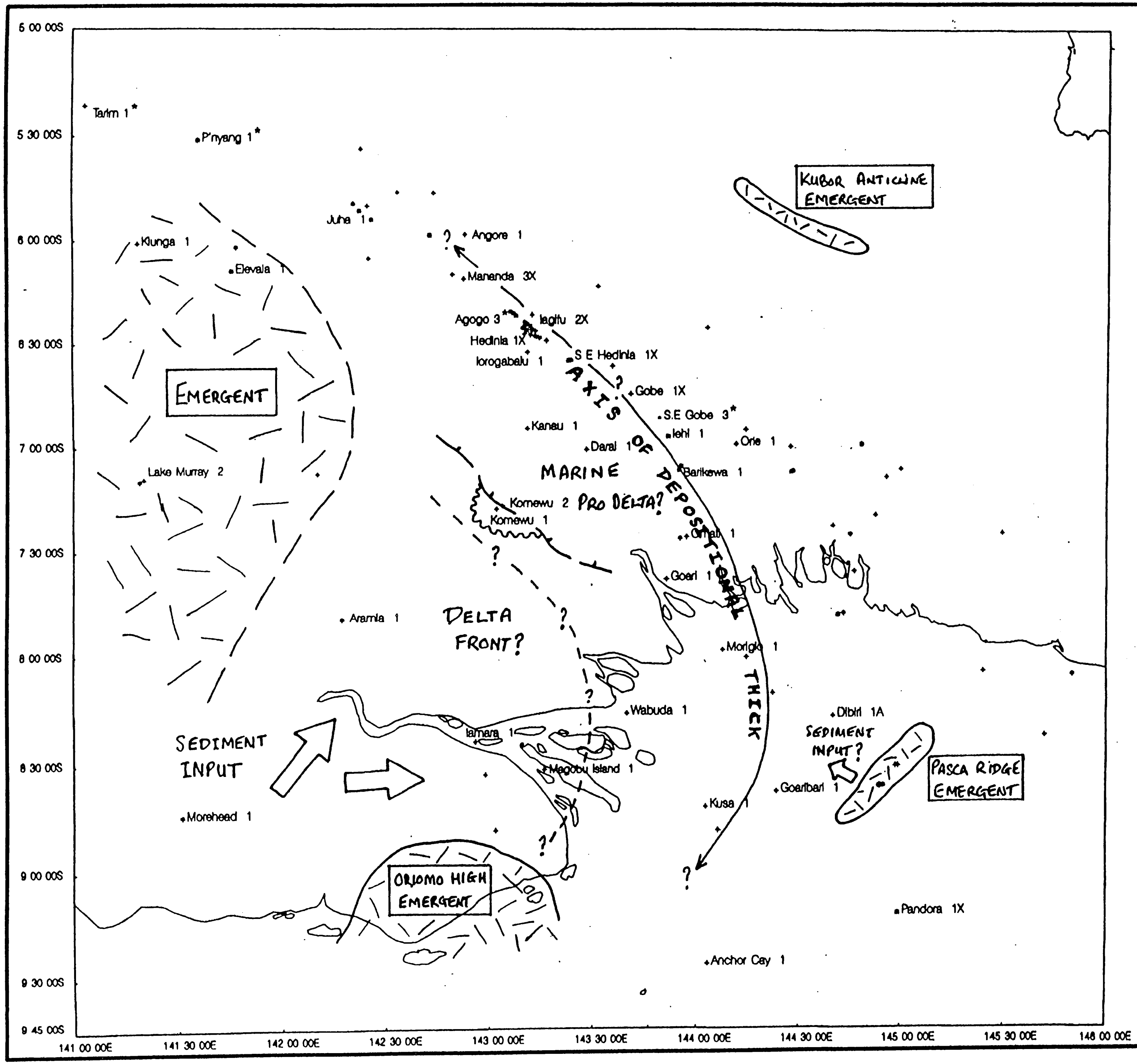
The most significant hydrocarbon indication occurs in Iamara 1 where oil was extracted from two cores within the J6 interval.

The transgressive nature of the upper portion of Time Slice J6 could provide a semi regional seal while the occurrence of interbedded siltstones within the sands offers some potential for the development of intraformational seals.

TIME SLICE J7 : Early Callovian to Early Oxfordian (Figure 27, Enclosures 11 and 12)

SUMMARY : Widespread development of low energy marine sequences, over 500 metres thick in several wells, due to a continued rise in relative sea level. Western Foreland is

Figure 27 Palaeogeographic reconstruction for Time Slice J7.



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PAPUAN BASIN MODULE

TIME SLICE J7

(*W. digitata to R. aemula*)

Early Callovian to Early Oxfordian

0 15 30 45 60 75

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
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CENTRAL MERIDIAN 147 00 00 E

emergent. Little if any potential for reservoir development, some source and excellent seal potential. Oil extracted from cores at Iamara 1.

PALAEOGEOGRAPHIC INTERPRETATION

A total of ten wells located in the eastern Foreland and Gulf of Papua intersect at least part of the sedimentary section covered by Time Slice J7. As in the underlying J5 to J6 interval, wells located to the west of the BTZ and south of P'nyang 1 are missing sediments of equivalent age due to this area's emergence. In the northern portion of the basin, control is limited to outcrop since none of the Fold Belt wells have been drilled deep enough to intersect sediments of this age.

This time slice is characterised by the widespread development of low energy mud dominated sequences deposited as a direct result of the continuation of a relative sea level rise, first noted within the upper portion of Time Slice J6. This mudstone and siltstone dominated sequence, with glauconite and traces of fossil fragments, has occasional lithic rich sandstones and carbonaceous material. It is interpreted to be deposited in a relatively low energy marine environment subjected to the periodic influx of immature terrestrially derived clastics.

The palaeogeographic data map (Enclosure 11) shows the thickness to increase from the southwest towards the east and northeast. The axis of the depositional thick, and presumed depositional low, is shown on Figure 27 (and Enclosure 12) and is thought to extend further to the northwest into the Kutubu Trough. The orientation of this axis is similar to the present day structural grain and may be indicative of extension along controlling faults during J7, to create the depositional thick, followed by reactivation and inversion during the Pliocene compressional phase.

The Pasca Ridge and Kubor Anticline are interpreted by Home et al (1990) to persist as relative highs during this period and shelter most of the basin from truly open marine conditions. The Pasca Ridge may be the source of immature lithic and feldspar rich sands seen in the J7 section at Goaribari 1.

The identification of sediments from Time slice J7 at Komewu 2 and their absence from Komewu 1 may be indicative of syn depositional extension along the Komewu Fault, with downthrow towards the northeast. Alternatively it could be a product of a post J7 erosive event at Komewu 1.

PROSPECTIVITY

Little if any potential exists for the development of a significant reservoir interval within the dominantly fine grained J7 sequence. However this sequence should make an excellent seal to any underlying J6 deltaic sands and may offer some potential as a source interval.

Time Slice J7 has median TOC values between 0.78 and 1.76% (with the exception of a coaly sample at Iamara 1) and a maximum value of 5.17% from a sequence with woody and carbonaceous material intersected at Kusa 1. The HI values are poor to fair with mean values ranging from 19 to 176 and a maximum value of 211 at Morigio 1. The mean VR values range from 0.39 to 0.77 and indicate the J7 sequences are in the early to the peak stage of oil generation as defined by Tobin (1991).

Oil is reported to be extracted from a core within the J7 sequence at Iamara 1 and to occur as a scum on fluids from a core at Kusa 1. In addition, fluorescence is reported from sidewall cores over the J7 interval at Morigio 1.

TIME SLICE J8 : Early Oxfordian to top Kimmeridgian (Figure 28, Enclosures 13 and 14)

SUMMARY : Equivalent to the Koi-lange and lower Imburu Formations. In the eastern Foreland lower J8 is characterised by sharp based, shallow marine lowstand sequences. Increasingly marine conditions are developed further to the north with relatively deep water deposition of the Om Beds and Lower Maril shale. Turbidites occur in the Gulf of Papua. Upper J8 is characterised by fining up transgressive sequences. Offers potential for; reservoir development in lowstand sands (low permeability), source intervals (particularly in the north) and seal formation. Omati 1 produced gas with minor condensate.

PALAEOGEOGRAPHIC INTERPRETATION

Sediments from Time Slice J8 are intersected by seventeen wells in the Gulf of Papua and the eastern portions (east of the BTZ) of the Papuan Fold Belt and Foreland. Wells to the west of the BTZ and south of P'nyang 1 lack sediments of equivalent age due to this areas continued emergence. Late Cretaceous uplift and erosion has resulted in the removal of the entire J8 and younger section in the eastern portions of the Gulf of Papua at Dibiri 1 and Goaribari 1. The lack of well control in the western Fold Belt (west of the BTZ) and northern

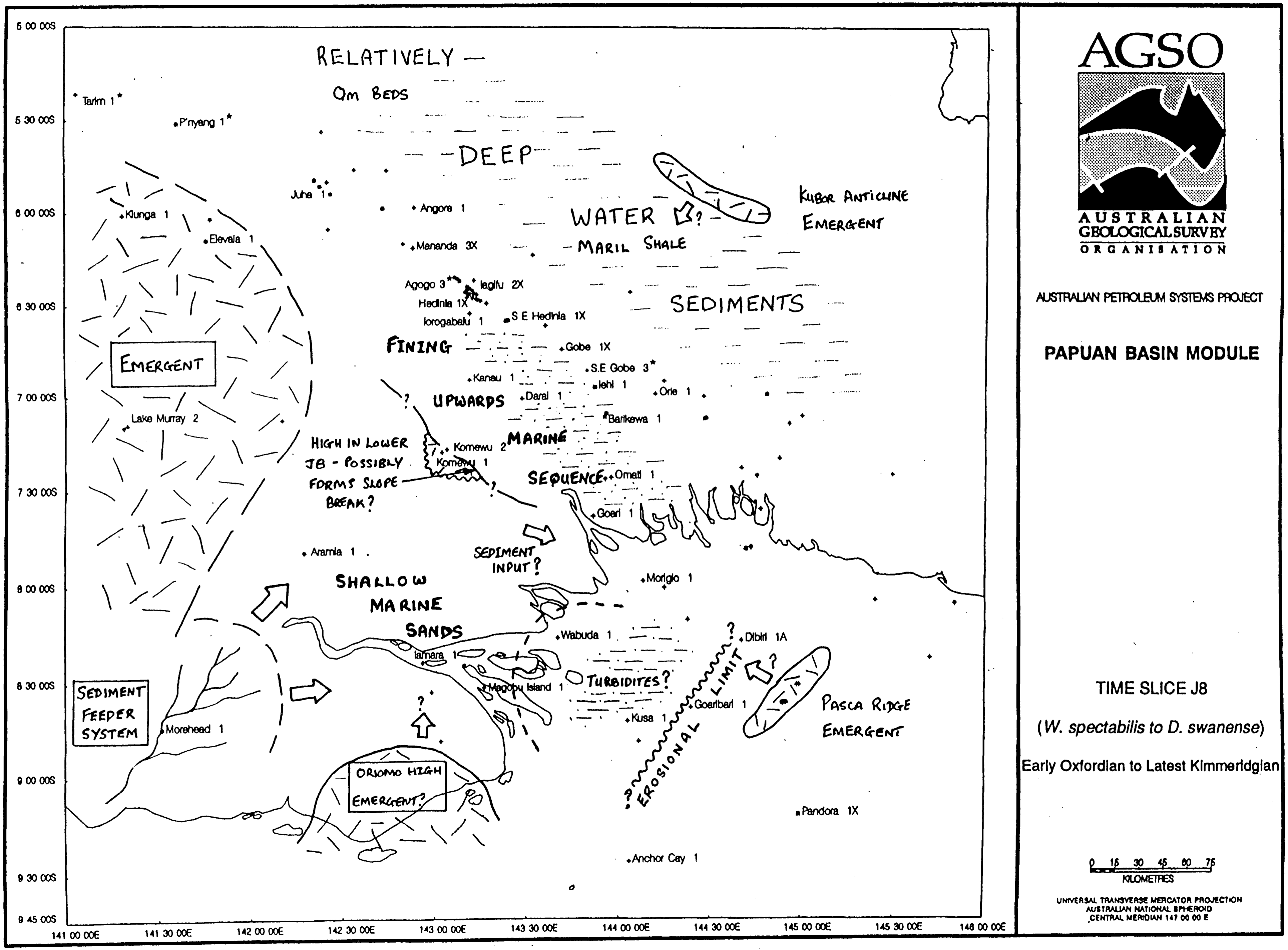


Figure 28 Palaeogeographic reconstruction for Time Slice J8.

portion of the basin, limits the palaeogeographic interpretation of these areas to published reports based on outcrop investigations. Sediments from Time Slice J8 are approximately equivalent to the Koi-lange and Lower Imburu Formations.

This time slice is characterised by the continuation of deposition in dominantly marine environments. The exception is Morehead 1 which penetrates a sequence of arkosic sands with specks of carbonaceous material interpreted to be deposited in a fluvial environment. The occurrence of fluvial deposits in the southwestern Foreland is indicative of a period of renewed sediment outbuilding, from emergent highs to the south. Further north, at Aramia 1, Iamara 1, Komewu 2, Iehi 1, Barikewa 1, Goari 1 and possibly Kanau 1, the base of Time Slice J8 is marked by a sharp based erosive lowstand sand sequence which cuts down into the underlying J7 sequence. These lowstand sands, with glauconite and shell fragments, are interpreted to be deposited in a shallow marine environment as channelised and coalescing bars. They are deposited in response to a relative lowering of base level at the J7/J8 boundary and an associated increase in sediment supply, as suggested by Morehead 1.

Faulting occurs within the J8 section penetrated at Iorogabaiu 1. However, the presence of the *W. spectabilis* palaeo zone in the hanging wall suggests the thrust plane is close to the base of Time Slice J8 and possibly the entire J8 section is intersected above the fault. The development of a sequence of lowstand shallow marine channel sands in the hanging wall section immediately overlying the interpreted thrust fault adds some support to this theory.

A transgression within the upper portion of Time Slice J8 is responsible for a fining upwards of the J8 section and the development of lower energy marine sequences as seen in Iehi 1, Barikewa 1, Goari 1, Aramia 1 and the hanging wall section of Iorogabaiu 1. This transgressive event is responsible for the inundation and renewal of sedimentation at Komewu 1, an emergent high during J7 and lower J8 times.

Throughout Time Slice J8 relatively deep water sediments were deposited to the north of the Muller Anticline, the Om beds, and in front of the Kubor Anticline, the lower Maril shale (Home et al, 1990).

In the Gulf of Papua a sequence of interbedded siltstones, claystones and very fine sandstones at Wabuda 1 exhibit rapid environmental changes and contain reworked Middle Jurassic material. This adds support for erosion at the base J8 lowstand sequence boundary and is interpreted by Morgan (1991) to indicate deposition of turbiditic type deposits at Wabuda 1. The development of dirty and relatively immature sands at Kusa 1 may also be a product of turbiditic deposition and offers some support for the continuation of sediment input from the Pasca Ridge during Time Slice J8.

Biostratigraphic data indicates the upper portion of Time Slice J8 is absent from Morigio 1, possibly a function of localised tectonics. The lower J8 sequence, as in the majority of other wells, consists of a shallow marine lowstand channel and / or bar sequence.

PROSPECTIVITY

The shallow marine lowstand channelised and coalescing bar sands offer some potential for the development of relatively widespread reservoir sequences within the lower portion of Time Slice J8. This lowstand sequence is up to 55 m thick and comprises individual sand packages that average approximately 10 to 15 m thick with porosities of between 8.3 % and 30 %. However, permeability readings are generally low and reach a maximum of 35.9 mD in a spot sample at Aramia 1.

Median TOC values from this portion of the regionally significant Imburu sequence range from 0.53 to 1.55%. A broad trend of increasing values towards the northeastern Foreland, Fold Belt and Gulf of Papua is observed, the maximum value of 3.09% is recorded from a marine sequence at Kusa 1. Mean HI values are low in the southern Foreland and western flank of the Gulf of Papua but increase towards the north and east where they range from 66 to 133 and reach a maximum value of 202 at Omati 1. The majority of mean VR values range from 0.42 to 0.69 and indicate that the J8 sequences are in the early to early peak oil generative stage as defined by Tobin (1991). However, the J8 sequence at Orie 1 has a mean VR of 0.91 and a maximum value of 1.09 indicating it is in the late peak oil stage of generation.

The deposition of finer grained sequences within the upper J8 transgressive sequence offers potential to seal the underlying sands.

A sand interval within Time Slice J8 was tested at Omati 1 and produced 10,000 cu ft of gas and 2 gallons of condensate over a 48 hour period. Several other wells have low level oil and gas indications within this time slice.

TIME SLICE J9 : Early Tithonian (Figure 29, Enclosures 15 and 16)

SUMMARY : Equivalent to the middle portion of the Imburu Formation. Continuation of the transgressive mega sequence from J8 is responsible for the development of widespread low energy marine sequences with minor clastic input from the southern Foreland. In the north deposition of the relatively deep water Om Beds and Maril Shale continued; while turbidites are interpreted as having been deposited in the Gulf of Papua. Forms an excellent regional seal and offers some potential as a source interval (particularly to the north). Minor hydrocarbon shows and indications.

PALAEOGEOGRAPHIC INTERPRETATION

Time Slice J9 is intersected by seventeen wells in the Fold Belt, Gulf of Papua and eastern portion of the Foreland. To the west of the BTZ and south of P'nyang 1 sediments from Time Slice J9 are absent due to this areas continued emergence. An episode of Late Cretaceous uplift and erosion has removed the entire J9 and younger section in the eastern portions of the Gulf of Papua at Anchor Cay 1, Dibiri 1 and Goaribari 1. Well control in the Fold Belt is limited to three, stratigraphically deep, wells; Juha 1, Iorogabaiu 1 and Gobe 1. A forty three metre thick section at Komewu 1, between the top of Time Slice J8 and the base of the Tertiary section, has no biostratigraphic control and could feasibly be part of Time Slice J9 and / or any other younger Jurassic or Cretaceous time slice. Sediments from Time Slice J9 are approximately equivalent to the Imburu Formation.

The transgressive event that started in the upper portion of Time Slice J8 continues in J9 and is responsible for the widespread development of a fining up sequence of calcareous mudstone and siltstone deposits. As in the underlying time slice, Morehead 1 is once again the exception to this. The deposition of arkosic sands at Morehead 1 is interpreted to be indicative of a fluvial depositional system feeding into the basin from further to the SW. The deposition of interdistributary bay type sequences at Aramia 1 may represent deltaic and/or estuarine conditions developing slightly to the northeast of Morehead 1 as a consequence of the sediment input from this feeder system.

Further to the north in the Foreland and Fold Belt this time slice is characterised by the deposition of relatively thin low energy marine siltstones and mudstones with occasional intervals of immature sandstones. In Goari 1 the upper portion of Time Slice J9 is marked by the development of a thin coarsening up stream mouth bar type sand with pyritised rootlets.

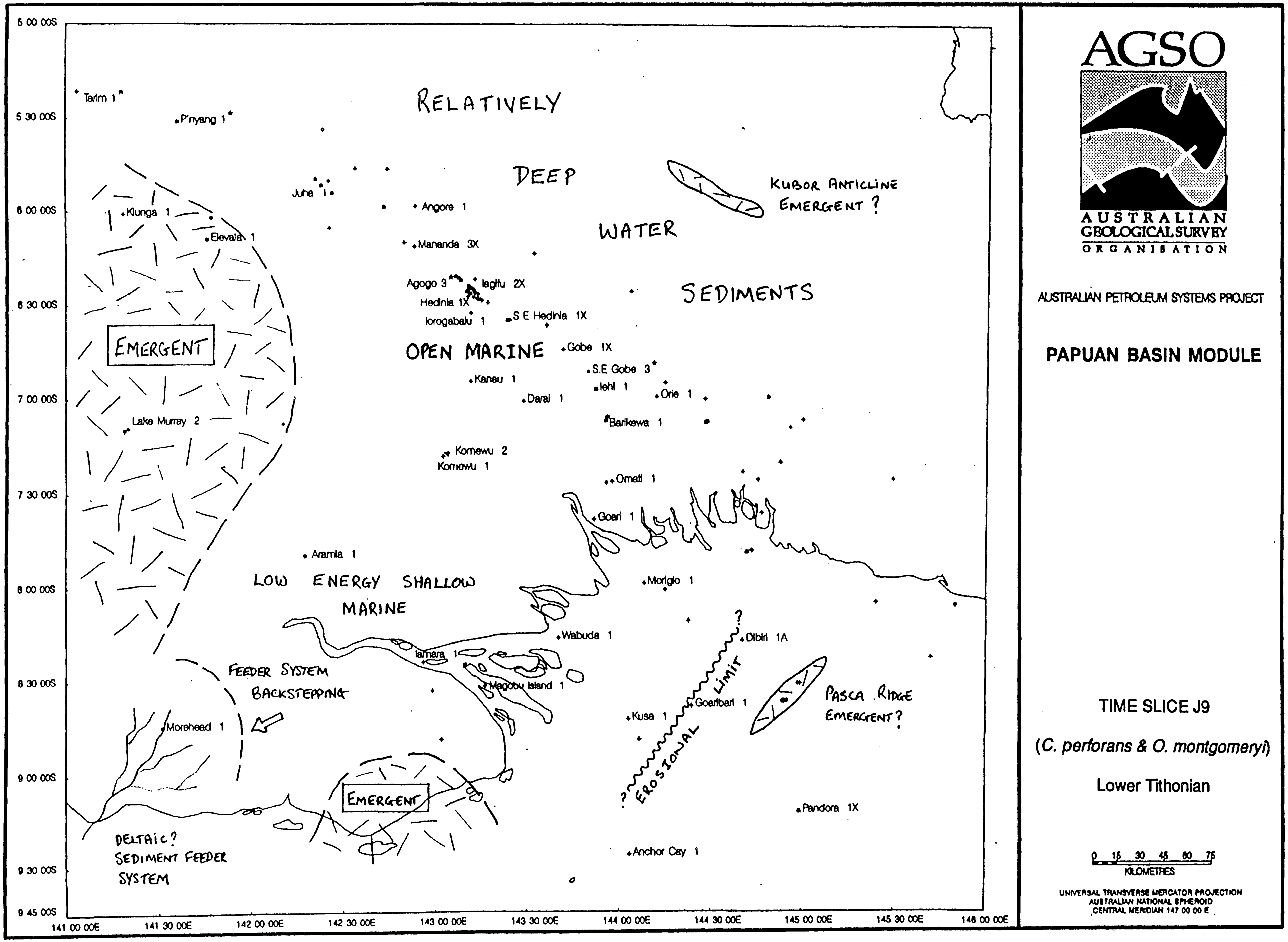


Figure 29 Palaeogeographic reconstruction for Time Slice J9.

Rootlets are indicative of shallow water conditions which are interpreted to be associated with the development of a low angle shelf over the Foreland during the Late Jurassic.

As in the previous time slice, Home et al (1990) interpret the deposition of relatively deep water sediments to the north of the Muller Anticline, the Om beds, and in front of the Kubor Anticline, the Maril shale.

In the Gulf of Papua the J9 section is much thicker than in the Foreland and rapid environmental changes in the sequence at Wabuda 1 have been interpreted by Morgan (1991) to be indicative of a turbidite style of deposition. These relatively thick sequences suggest a depositional low existed in the Gulf of Papua during the Early Tithonian (Time Slice J9) with sediment input from either the Foreland and / or the Pasca Ridge. The northeast to southwest trending Duau Lineament (Barndollar, 1993) may have exerted some control on this depositional low.

PROSPECTIVITY

The transgressive, dominantly fine grained, J9 sequences offer little if any potential for reservoir development. However the basin wide distribution of these sediments could provide a seal to any underlying sands and perhaps most importantly provides an excellent source interval for the overlying Late Jurassic and Early Cretaceous reservoir intervals.

Median TOC values range from 0.4 to 1.23% (except in Iamara 1 where a sequence with bitumen flecks is penetrated). It should be noted that although median TOC values are fairly well distributed throughout the basin they are, for the most part, based on low sample numbers. Mean HI ranges from 11 to 145 and increase to the north and east of the Foreland, a maximum value of 297 occurs in Iorogabaiu 1. The mean VR values in the eastern Foreland and the Gulf of Papua range from 0.39 to 0.59 and indicate the early to early peak stage of oil generation (Tobin, 1991). The mean VR values in the Fold Belt are generally higher, in the range from 0.55 to 0.98, and indicative of the peak oil generative stage.

A gas show is reported over the J9 interval in Juha 1 and oil indications occur at Omati 1 and Goari 1.

TIME SLICES J10 & K1: Late Tithonian to Earliest Valanginian (Figures 30 to 38, Enclosures 17 to 23)

Time slices J10 and K1 have been subdivided using a sequence stratigraphy approach. A series of flooding surfaces and sequence boundaries have been identified (Enclosures 4 to 8) and used to split this interval, into a series of systems tracts as shown in Figure 30. Figure 31 shows a comparison between the time slices generated in this module and the published sequence stratigraphic work of Home et al (1990), Welsh (1990), Varney and Brayshaw (1993) and Phelps and Denison (1993). The J10 palaeogeographic data map (Enclosure 17) has been used as a base for two interpretive maps over this interval (Enclosures 18 & 19, Figures 32 & 33), the Iagifu and Hedinia lowstand sands (Figure 30). In a similar fashion, the K1 palaeogeographic data map (Enclosure 20) has been used as a base for three interpretive "snap shot" maps within the K1 time slice (Enclosures 21, 22 & 23, Figures 34, 37 & 38), the Digimu, Toro C and Toro B/A lowstand sands (Figure 30).

SUMMARY : Equivalent to the upper Imburu and Toro Formations. Consists of at least seven lowstand sequences characterised by widespread deposition of relatively thick and texturally mature shallow marine sands. Major depocentres occur in the Fold Belt and the Gulf of Papua. The BTZ plays a significant role in controlling sediment distribution. Excellent reservoir sequences are developed and associated with important hydrocarbon discoveries at Iagifu 2, Hedinia 1, SE Gobe 1, Gobe 4, Iehi 1 and Barikewa 1. Transgressive sequences deposited between the lowstand sands are proven as intraformational seals.

TIME SLICE J10 PALAEOGEOGRAPHIC INTERPRETATION

Eighteen of the study wells intersect Time Slice J10. The absence of sediments from Time Slice J10 in the area to the west of the BTZ and south of P'nyang 1 is interpreted, as in the underlying time slices, to be a result of this areas continued emergence over this interval. Although well control is somewhat limited in the Foreland it is sufficient to suggest a thickening of the J10 section from Aramia 1 towards the east and northeast (Enclosure 17).

Lower J10

The lowermost portion of Time Slice J10 (*Lower D. jurassicum*) shows a gradational coarsening upwards associated with the development of a highstand systems tract. This highstand systems tract forms the lower portion of the Iagifu Member as defined by Denison & Anthony (1990). During this interval progradation occurred into accommodation space

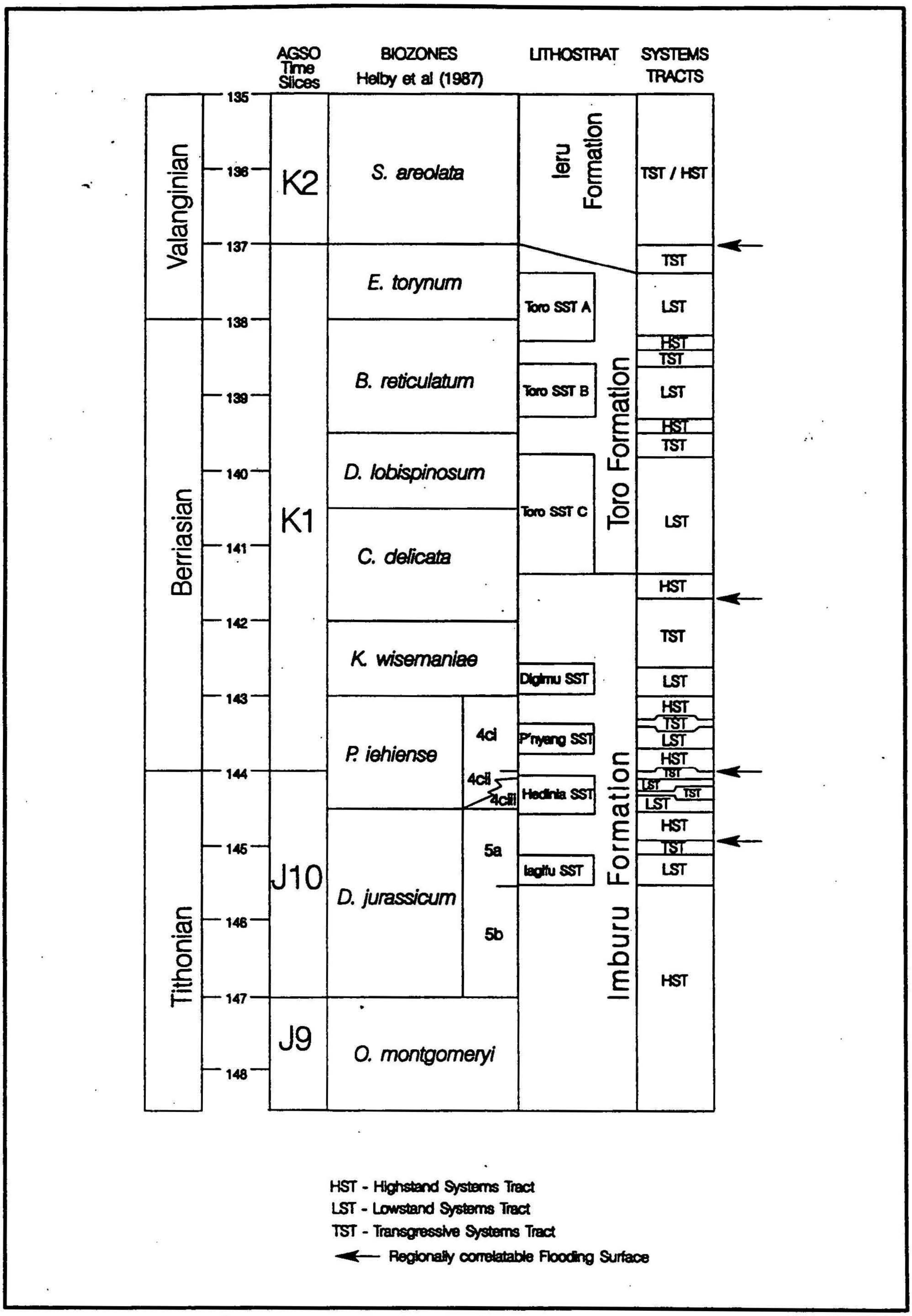


Figure 30 Summarised Stratigraphy over the J10 and K1 Reservoir Sequences

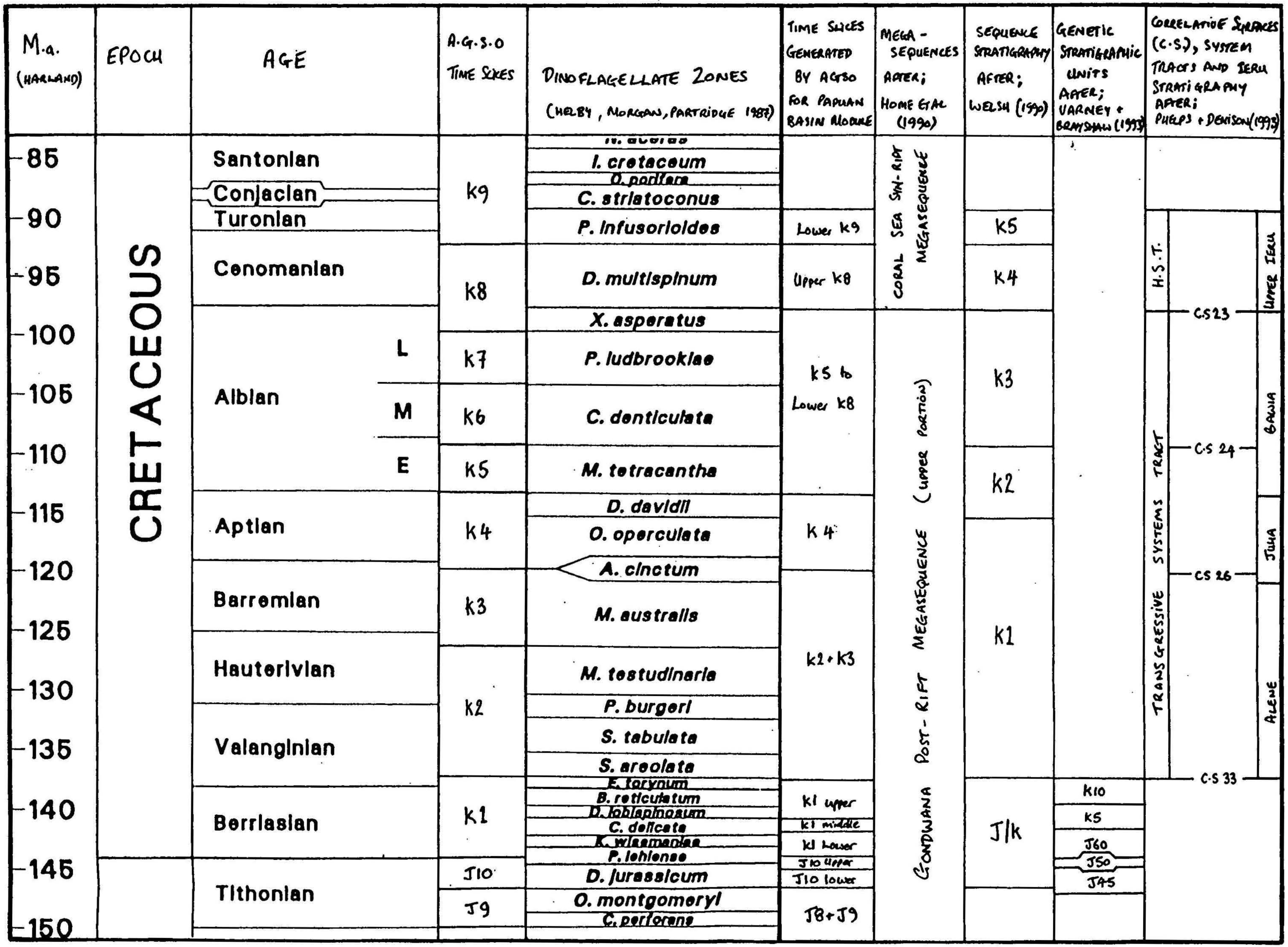


Figure 31 Comparison of the Time Slices generated in the Papuan Basin Module and published sequence stratigraphy work by; Home et al, (1990), Welsh, (1990), Varney & Brayshaw (1993) and Phelps & Denison (1993) over the Tithonian to Santonian interval.

created by the regional transgression which started during J8 and continued into upper J9. Varney & Brayshaw (1993), interpret this depositional system to comprises a progradational to aggradational, coarsening and cleaning up unit deposited in an upper shoreface overlying lower shoreface environment (good log examples are seen at Kusa 1 and in several Fold Belt wells). Sands deposited within this highstand consist of coalescing sand sheets and bars deposited as sea level falls (Varney & Brayshaw, 1993), the depocentre may have been located in proximity to a delivery system such as a delta and could be subsiding. Varney & Brayshaw (1993) note a decrease in the marine content of palynoflora from the base to top of this coarsening up unit and suggests assemblages may reflect the proximity of a sediment delivery system. Facies range from muddy bioturbated siltstones to fine grained well sorted sandstones. One possible interpretation is that the shelf was storm dominated, alternatively higher energy sedimentation may have resulted from longshore currents on a wave dominated shelf, or perhaps sedimentation may have occurred near an active delivery system such as a delta. The top of this systems tract is marked by an erosive sequence boundary formed during the lowermost *Upper D. jurassicum*. This sequence boundary defines the base of the lagifu lowstand sandstone.

The palaeogeographic interpretation constructed for the lagifu lowstand sands (Enclosure 18 & Figure 32) shows the development of a gentle shelf to the south of the present day Darai fault while to the north (between lorogabaiu 1 and lehi 1) and to the east (between Magobu Island 1 and Morigio 1) lay two sand rich depocentres.

The development of sharp based lowstand sands in the Fold Belt depocentre is concomitant with a lowering of base level and an associated rejuvenation of landward fluvial systems causing an increase in the rate of sediment supply and a downward shift of facies. In the Fold Belt the lagifu lowstand sands consists of a series of stacked, fining up, aggradational sharp based sands with scattered glauconite. The depositional thick is centred around Kanau 1 and interpreted to spread to the north and east as shown in Figure 32., where the lobate form of the isopachs suggests a fan deposit. Varney & Brayshaw (1993) suggest the lowstand sands may be either, storm reworking of very shallow marine upper shoreface or beach sediments with wave scouring causing abrupt erosive bases, or channels cutting through a series of bars and shoals as a result of lowered base level. Powis (1993) presented a sequence stratigraphic analysis of the lagifu Sandstone and concluded that the lowstand sands, in the SE Gobe field, were deposited in estuarine conditions.

Analysis of palynofloras (Varney & Brayshaw, 1993) indicates the lowstand sands are more terrestrially influenced than the underlying highstand deposits reflecting an increased

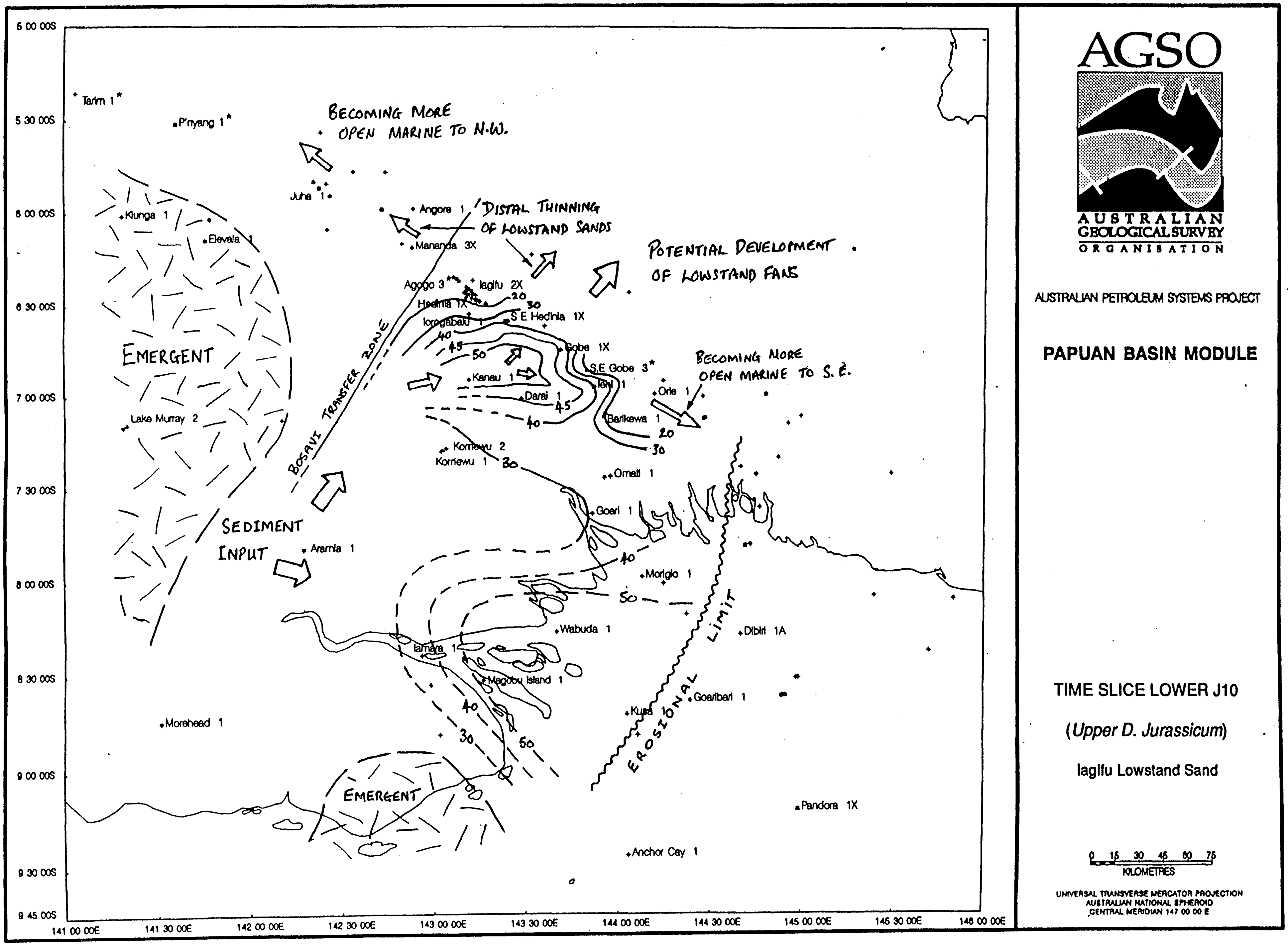


Figure 32 Palaeogeographic reconstruction for Time Slice lower J10, the Iagifu Lowstand sequence.

sediment input. Thin mudstones within this sequence yield extremely marginal marine assemblages possibly delivered into this environment via a deltaic feeder system located somewhere to the south in the Foreland.

North of the BTZ, in the P'nyang and Muller anticline areas, and south of Iehi 1 lowstand sands are not developed. However, equivalent samples do contain a high proportion of terrestrial palynomorphs indicating high volumes of terrestrial sediment were shedding into areas adjacent to the main depocentres during this time.

In the eastern depocentre the lowstand is represented by relatively thicker sequences characterised (with the exception of Morigio) by more erratic log curves which suggest the development of two lowstand sequences separated by a minor transgression. The deposition of less mature sands together with mudstone interbeds could be indicative of a relatively proximal sediment feeder system and / or the lack of marine reworking possibly relating to a steeper depositional profile. This would enable low energy offshore mud dominated sequences to be established between pulses of sand and the development of an apparent transgression.

Upper J10

A relative increase in sea level within the upper portion of *D. jurassicum* results in a transgression which marks the top of the Iagifu Member (Denison & Anthony, 1990). This interval shows an overall fining upwards but is comprised of several prograding parasequences. It culminates in the development of a flooding surface which is well developed throughout the basin and forms a good regional correlation surface (Figure 30).

A series of stacked progradational to aggradational, coarsening and cleaning up sands are deposited on top of the flooding surface which marks the top of the transgressive system overlying the Iagifu Member. These sands are deposited in a highstand system and represent the lowermost Hedinia Member as defined by Denison and Anthony (1990).

In the Fold Belt depocentre these highstand sands were deposited in a middle to lower shoreface environment and probably represent coalescing sand sheet bars which were deposited in response to a lowering of relative sea level and diminishing accommodation space. The highstand deposits are interpreted, in a similar fashion to Powis (1993), to be overlain by two lowstand sands (Figure 30) with some localised erosion at the sequence boundary, (see Darai 1 - Enclosure 6). It should be noted that Varney & Brayshaw (1993) present an alternative interpretation with the Hedinia sandstone being comprised of three or four highstand sequences.

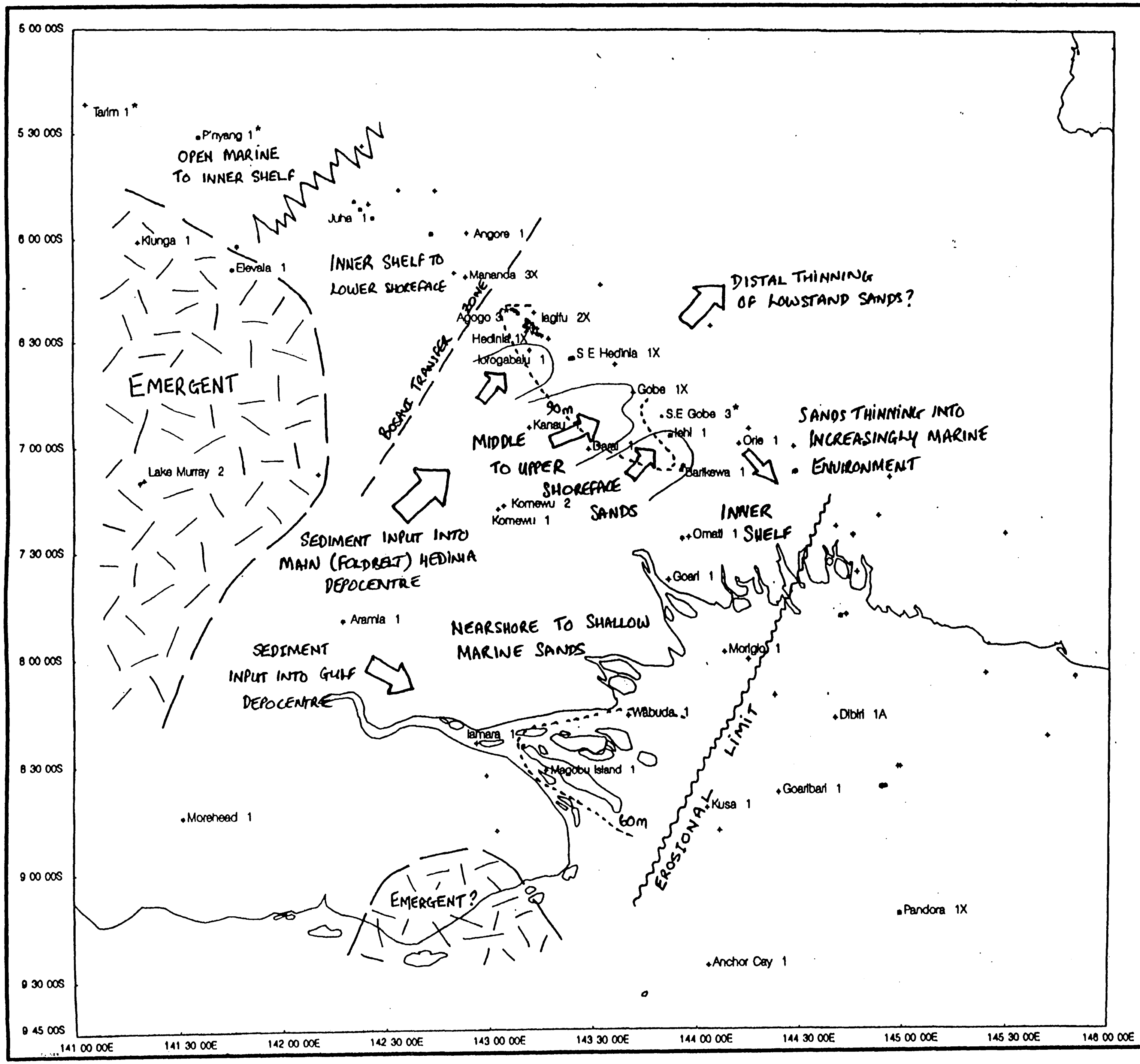
Figure 33 and Enclosure 19 show an interpretive palaeogeographic reconstruction for the Hedinia lowstand sands. Well control is somewhat limited in the Foreland but suggest the deposition of nearshore to shallow marine sands. The main lowstand depocentre lies to the northeast, in the Fold Belt, and is possibly separated from the Foreland by faults in the region of the present day Komewu Fault and / or the Frontal Thrust. In the Fold Belt the lowstand sands characteristically have a blocky log character and are interpreted as a series of channels and bars deposited in a middle to upper shoreface environment. The development of these lowstand sands is a result of the lowering of base level in the uppermost portion of *D. jurassicum* and the associated increased sediment supply causing a downward shift of facies.

Isopachs show the thickest sections of the lower Hedinia lowstand sequence occur around Kanau 1, Darai 1 and Gobe 1 in a similar fashion to that observed for the Iagifu lowstand. This may be indicative of the development of a major sediment feeder system proximal to this location during the lower Hedinia lowstand and Iagifu lowstand sequences. The erosive base of the lower Hedinia lowstand sequence in Darai 1 and Kanau 1 may offer some support for this interpretation and could be indicative of channel sands flowing to the northeast and feeding into the Fold Belt depocentre.

A second lowstand sequence in the upper Hedinia Member (Figure 30) results in another downward shift of facies in the Fold Belt depocentre and the establishment of widespread upper shoreface sands between Hedinia 1 and Barikewa 1. Isopach maps suggest the upper Hedinia lowstand has two depositional thicks, one centred around Iorogabaiu 1 and the other around Iehi 1 and Barikewa 1. The isopach maps also demonstrate that the underlying lower Hedinia lowstand thick, centred around Kanau 1, has become a relative thin during the deposition of the upper Hedinia lowstand. The migration of lowstand depocentres is thought to be related to variations in compaction rates and / or tectonic controls, such as the BTZ, causing a migration of the sediment feeder systems.

Well control in the northwestern Fold Belt, across the BTZ, is limited but does indicate the development of lower shoreface to more open marine shelfal environments (increasing to the northwest) with relatively minor sand deposition. The BTZ may act as a topographic control on sedimentation during the deposition of the Hedinia sands. It could be a high

Figure 33 Palaeogeographic reconstruction for Time Slice upper J10, the Hedinia Lowstand sequence.



AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

AUSTRALIAN PETROLEUM SYSTEMS PROJECT

PAPUAN BASIN MODULE

TIME SLICE UPPER J10

(*Lower P. iehiense*)

Hedinia Lowstand Sand

0 15 30 45 60 75

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 147 00 00 E

preventing the in flux of sands to the northwest and restricting them to the Fold Belt depocentre, or alternatively a low across which minor sands are transported.

To the southeast Orie 1, Barikewa 1 and Goari 1 are dominated by open marine to lower shoreface deposits during the lower Hedinia lowstand. A significant ocean ward shift of facies during the upper Hedinia lowstand is associated with the development of middle and upper shoreface bar sands in this area.

A second, less significant, Hedinia lowstand depocentre occurs in the Gulf of Papua and is dominated by less well developed sands characteristic of those deposited proximal to a relatively immature sediment feeder system with minor shoreface reworking.

TIME SLICE J10 - PROSPECTIVITY

Time Slice J10 is characterised by the widespread development of good reservoir sands, the Iagifu and Hedinia Sandstone Members (Denison and Anthony, 1990) of the Imburu Formation. The thickest and most mature sands, with average porosities of approximately 17 % and permeabilities up to 770 mD, occur in the present day Fold Belt to the southeast of the BTZ. The Iagifu Sandstone Member intersected in the SE Gobe field is reported by Surka (1993) to have net effective core porosities averaging 19 % and permeabilities up to 1.7 Darcies. Other prospective sands, although thinner and less mature, occur in the Foreland (Aramia 1; spot porosity 23.7 %, spot permeability 305 mD) and the Gulf of Papua (Morigio 1; max spot porosity 27 %, max spot permeability 900 mD).

Median TOC values range from 0.37 to 1.27%, with a maximum value of 2.13% in Juha 1. Further work is required to correlate the TOC data with the detailed sequence stratigraphy over Time Slice J10 to test any relationship between potential source intervals and the development of maximum flooding surfaces. The mean HI values are generally poor to fair with a maximum of 323 occurring in Juha 1. The mean VR data range from 0.41 to 0.88, the early to peak stage of oil generation of Tobin (1991). The most mature sequences occur in the Fold Belt with a maximum VR value of 0.91 at Juha 1.

Significant hydrocarbon discoveries have been made in the Iagifu Sandstone Member at the SE Gobe wells and more recently at Gobe 4X. SE Gobe 1 was drilled in March 1991 and discovered light oil, with characteristics very similar to the Kutubu crude (Surka, 1993). A maximum flow rate of 8907 BOPD is reported from SE Gobe 2 (Doran, 1993, Surka, 1993). In January 1994 Gobe 4X, drilled on the main Gobe Anticline culmination approximately 15 kms northeast of the SE Gobe field, discovered oil in the Iagifu Sandstone Member, initial testing is reported to have produced 2500 BOPD.

The Hedinia Sandstone Member also has several significant hydrocarbon shows. Production tests over the Hedinia Sandstone Member in both Hedinia 1 and SE Hedinia 1 proved the existence of gas and oil zones with 90 BOPD & 0.11 MMCFD of gas and 215 BOPD & 0.75 MMCFD gas respectively. Barikewa 1 has a proven gas zone within the upper Hedinia lowstand and a small amount of oil was extracted from this interval at Iehi 1.

The hydrocarbons accumulated within the J10 reservoir sequences are interpreted to be sourced from the underlying Middle to Late Jurassic interval (Earnshaw et al, 1993, Matzke, 1992 & Valenti, 1993). Both the Iagifu and Hedinia Sandstone Members are effectively sealed by overlying transgressive deposits.

TIME SLICE K1 PALAEOGEOGRAPHIC INTERPRETATION

Time Slice K1 is intersected by twenty four of the study wells and thickens to the east and northeast away from Morehead 1 (Enclosure 20). In the northwestern Foreland, at Elevala 1 and Kiunga 1, sediments from Time Slice K1 directly overly basement and are interpreted to be deposited as a consequence of the gradual transgression over this longstanding emergent block. The absence of equivalent aged sediments further to the south, at Lake Murray 2, indicates the continued emergence of this area as part of the Frederick-Hendrick High (Smith 1990). Sediments from Time Slice K1 are absent from the eastern Gulf of Papua, Anchor Kay 1, Kusa 1, Goaribari 1 and Dibiri 1, due to an episode of Late Cretaceous uplift and erosion, see Time Slice J9 interpretation.

Lower K1

A palaeogeographic interpretation map has not been constructed for the basal K1 time slice, the P'nyang sandstone (Figure 30), which to date has only been recorded in the P'nyang and Muller anticlines. It is interpreted by Varney & Brayshaw (1993) to be deposited as shoals and sandsheets in a middle to lower shoreface environment in close proximity to a clastic source. This sand has been given the status of new member and renamed as the Emuk Sand Member of the Imburu Formation by Valenti (1993). Valenti (1993) interprets the depositional environment as shallow marine barrier bar with the sandstone deposition as a tidal channel fill sand body or possibly an upper shoreface sand. Further to the southeast, in the Fold Belt, time equivalent units demonstrate an increased terrestrial component with some suggestion of minor lowstand sequences (ie Gobe 1). However these sequences lack the development of good reservoir intervals.

The Digimu Member Sandstone (Denison & Anthony, 1990) of the Imburu Formation has a relatively small and focussed depocentre located between the Agogo to Iagifu and Hedinia wells (Figure 34 & Enclosure 21). In this depocentre the Digimu lowstand sequences are characterised by an erosive based sequence of channelised coalescing bars and sheet sands which are interpreted to represent an upper to middle shoreface environment. Varney & Brayshaw (1993) note that mudstones developed within the lowstand yield assemblages indicative of very low energy conditions in an extremely marginal marine environment such as a mangrove or vegetated estuarine environment. It would seem that the lowstand sand deposition of the Digimu Member is a relatively brief regression, and associated increase in energy, in an overall low energy marginal marine environment.

Further to the southeast, around Gobe 1 and SE Gobe 1, the lowstand sands are less well developed and the sequence is interpreted to be deposited in a lower and middle shoreface environment. Deposits consistent with more open marine conditions are intersected at Omati 1 and interpreted to spread up to Kanau 1 in a northwesterly trending embayment (Figure 34). A relatively thin and possibly condensed sequence penetrated at Iorogabaiu 1 and SE Hedinia 1 may indicate the development of a localised high in this location during the Digimu Member deposition, *K. wisemaniae* biozone of Helby et al (1987).

To the northwest, across the BTZ, Varney & Brayshaw (1993) interpret the time equivalent sediments in the Mananda region as less marine than those located in the main Digimu depocentre. This is interpreted to indicate that the BTZ influenced sedimentation during this period by either generating a relative high area of preferential shoaling or by creating a depocentre in which sands were concentrated. Varney & Brayshaw (1993) report that further to the northwest, in the P'nyang and Muller anticlines, sediments become increasingly marine. They suggest the presence of a separate depositional province in this area may be related to a change in basin morphology, the expression of which had a controlling influence on sedimentation.

A second active sediment feeder system lies to the south of the Fold Belt and is associated with an easterly progradation of coarsening and cleaning upward sands in to the Gulf of Papua. A lowstand sand is penetrated in Magobu Island 1 but to the east of here the development of lowstand sands is less well defined, possibly a function of this areas relatively distal location and / or increased subsidence rate.

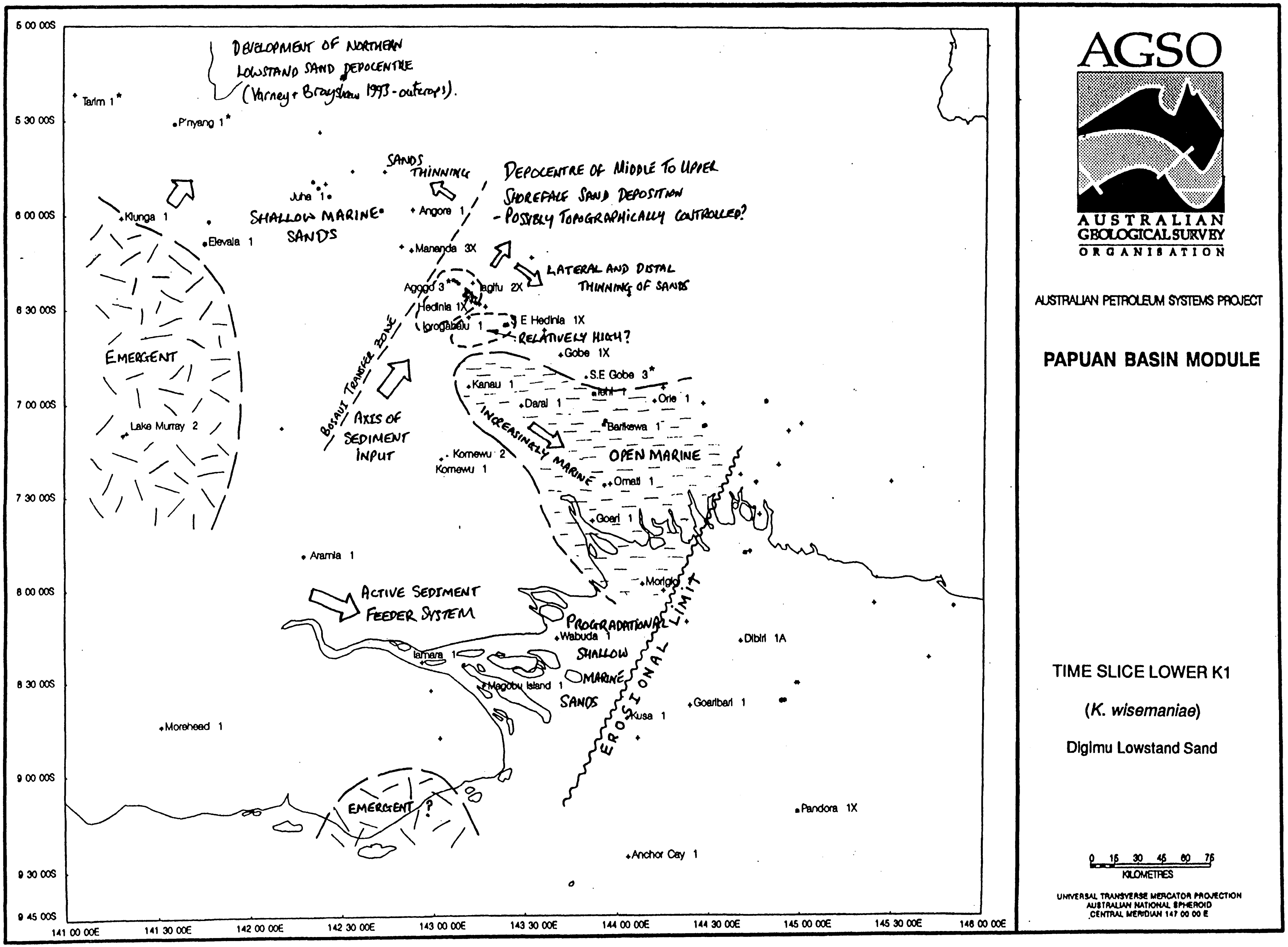


Figure 34 Palaeogeographic reconstruction for Time Slice lower K1, the Digimu Lowstand sequence.

A fining up transgressive sequence overlies the Digimu lowstand and culminates in the development of a basin wide correlatable maximum flooding surface in the lower portion of the *C. delicata* biozone (Helby et al, 1987) (Figure 30). The subsequent progradation of a highstand system into the accommodation space created by this transgressive system results in a gradual coarsening upwards sequence overlying the *C. delicata* maximum flooding surface. Sands deposited within this highstand consist of coalescing sand sheets and bars deposited as sea level falls (Varney & Brayshaw, 1993).

Middle K1

The top of the *C. delicata* highstand systems tract is truncated by an erosive sequence boundary within the upper portion of Helby et al's (1987) *C. delicata* biozone (Figure 30). This sequence boundary marks the base of the Toro Formation and is related to the basinward shift of facies due to a relative fall in base level and the establishment of a lowstand system. This lowstand event is not only identified in the Papuan Basin but also on the North West Shelf ; ie. the *C.delicata* sands in the Browse Basin.

The Toro Formation comprises three sand units, A, B and C in descending order, separated by intervals of bioturbated argillaceous sandstone, siltstone and claystone (Valenti, 1993). Although the individual sands are difficult to constrain biostratigraphically the Toro Formation is well defined with the top marked by the *E.torynum* flooding surface and base by the *C.delicata* sequence boundary (Figure 30). The three lowstand sands represent three abrupt basinward shifts with the middle sand locally downcutting far enough to remove the underlying highstand system and sometimes all of the Toro C lowstand sand. This results in the local preservation of only two of the three lowstand sands (ie. Gobe 1).

It is possible to further subdivide each of the "lowstand" sands into a series of smaller scale sand packages recognisable from electric log character (Figure 35). The possibility exists for each of these smaller scale packages to represent different phases of sedimentation which may relate to the migration of a sediment feeder system through time (K. Wulff pers com Nov 1993). In addition, sand packages towards the top of the interpreted lowstand sands may in fact represent deposits from a separate overlying transgressive systems tract. A more detailed subdivision was considered beyond the scope of this project but we do recognise that such an interpretation may well lead to the amendment of the interpretation presented here. It is recommended that dipmeters be used in conjunction with electric logs in any attempt to further subdivide the sequence. For reference, a dipmeter plot over the Toro Formation intersected in Agogo 1 is shown in Figure 36.

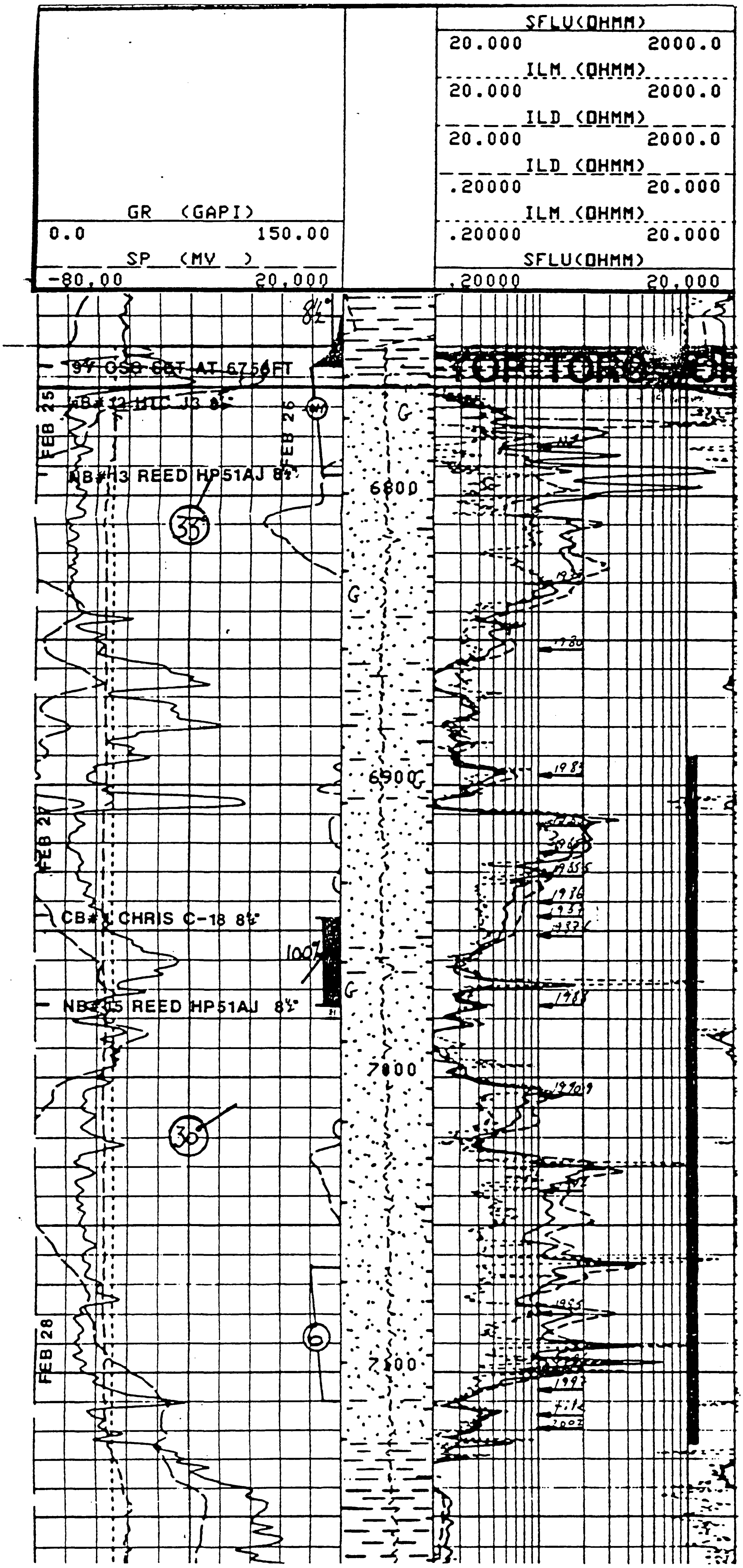


Figure 35 Electric Logs over the Toro Formation intersected by Hedinia 1

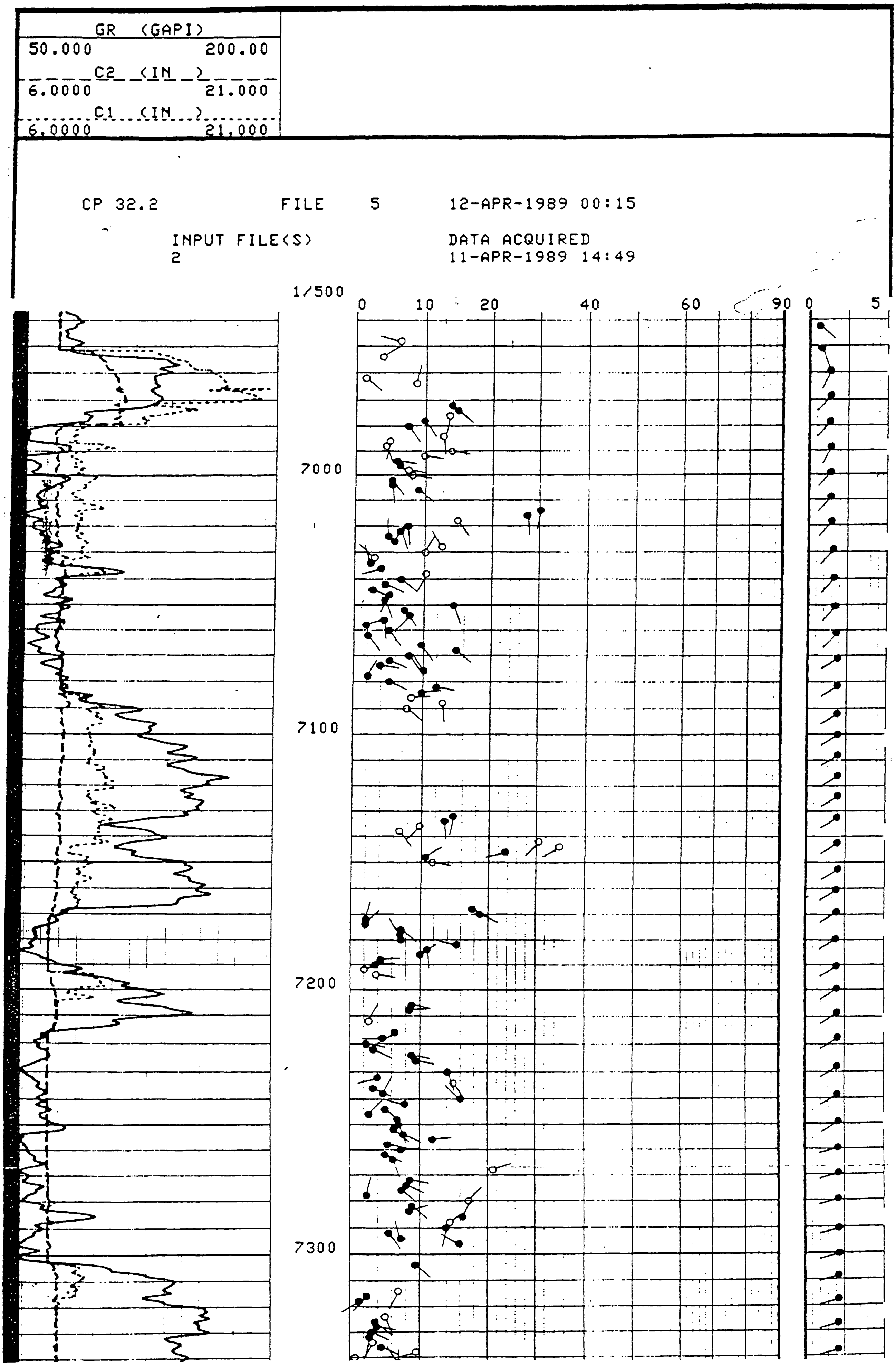
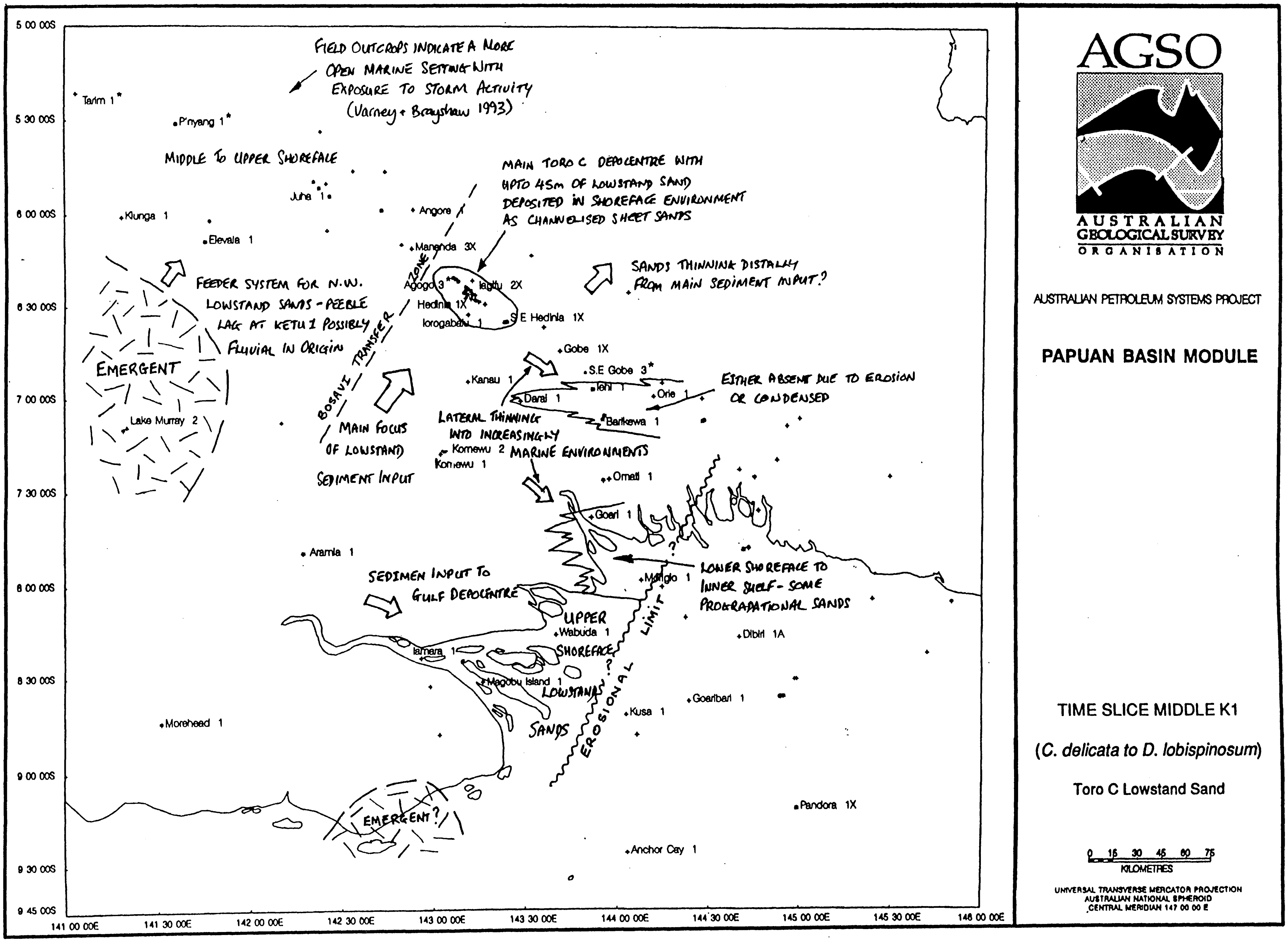


Figure 36 Dipmeter plot over the Toro Formation in Agogo 1.

Figure 37 Palaeogeographic reconstruction for Time Slice middle K1, the Toro C Lowstand sequence.



The following section details the palaeogeographic interpretations for the Toro C lowstand (Figure 37, Enclosure 22).

During the Toro C lowstand the main depocentre was located between Agogo 3 and SE Hedinia 1 (Figure 37, Enclosure 22). The depocentre is characterised by the development of up to 45 metres of fine to coarse sands which fine upwards, are physically structured with little evidence of bioturbation, have abundant glauconite and a blocky log response. They are interpreted to have been rapidly deposited in a high energy nearshore upper shoreface environment. Cores from this interval are totally devoid of palynomorphs (Varney and Brayshaw, 1993) and interpreted as channelised sheet sands. However, Powis (1993) suggests that the sands are at least in part estuarine in origin. The location of the Toro C lowstand depocentre is directly linked to the location of the main sediment feeder system, and may be related to the topographic control exerted by the BTZ.

Further to the southeast of the main depocentre, the Toro C lowstand sands thin and are absent from several wells due to erosion at the Toro B and Toro A lowstand sequence boundaries. This southeastern portion of the Fold Belt is interpreted to be relatively distal to the main point of sediment input and becomes increasingly marine towards the southeast.

A pebble lag has been identified by Varney and Brayshaw (1993) at the Toro C lowstand sequence boundary in Ketu 1 and interpreted to indicate possible exposure and fluvial erosion in this area. At Kiunga 1 and Elevala 1 immature thinly interbedded sandstones, mudstones and siltstones are interpreted to be indicative of deposition relatively proximal to a sediment feeder system. A fluvial to paralic environment is interpreted in this northwestern portion of the Foreland during the Toro C lowstand. Sediment is postulated to be derived from emergent areas to the southwest (ie. Lake Murray 2) and transported towards the north where more marine environments are established in the northwestern portion of the Fold Belt. P'nyang 1 and Juha 1 intersect middle to upper shoreface lowstand sands similar to those in wells to the southeast of the BTZ but somewhat thinner (10 -15m as opposed to 45m) and with assemblages more characteristic of open marine conditions (Varney and Brayshaw, 1993). Further to the northwest, in the Muller Anticline, outcrops indicate storm reworking of sediment equivalent in age to the Toro C lowstand (Varney and Brayshaw, 1993).

In the Gulf of Papua well developed upper shoreface Toro C lowstand bar and channel sands are intersected in Wabuda 1 and Magobu Island 1. These sands appear similar to those in the Fold Belt depocentre but are much thinner and interpreted to be the product of a sediment feeder system flowing to the east from the southern portion of the Foreland. Further to the northeast Goari 1 and Morigio 1 intersect a sequence of more distal lower shoreface sands interbedded with low energy inner shelf mudstones.

The top of the Toro C lowstand sequence is marked by a transgressive event within the upper portion of Helby et al's (1987) *D. lobispinosum* biozone (Figure 30). This transgression culminates in the formation of a flooding surface which separates the Toro C lowstand from the overlying Toro B and A lowstands. Overlying this flooding surface is a relatively thin highstand sequence consisting of progradational to aggradational, coarsening and cleaning upward sequences. This sequence is interpreted by Varney and Brayshaw (1993) to be deposited in an upper shoreface, overlying middle to lower shoreface environment as a series of sand sheets and bars under conditions of lowering relative sea level and diminishing accommodation space. The top of this highstand sequence is truncated by the sequence boundary which marks the base of the Toro B lowstand.

Upper K1

The Toro A and B lowstand sequences have been combined into a single palaeogeographic interpretation which is shown in Figure 38, Enclosure 23 and described in the following section.

In the southern Foreland, Morehead 1 intersects a sequence of coarse grained arkosic sandstones which are interpreted as fluvial deposits within a sediment feeder system. It is speculated that feeder systems are flowing towards the north and east across the Foreland into the main Fold Belt and Gulf of Papua depocentres. Further to the northeast of Morehead 1, the Toro Formation at Aramia 1 lacks sufficient biostratigraphic control to confidently subdivide the sequence but observed facies suggests the development of shallow marine, and possibly estuarine, environments during the Toro A to Toro B period.

At Magobu Island 1, Wabuda 1 and Goari 1, on the flank of the Gulf of Papua, the Toro B lowstand sequence consists of a series of progradational to aggradational shoreface deposits. Further to the east, at Morigio 1, more distal low energy shelfal deposits are found. The Toro A sequence is characterised by upper shoreface channel and bar sands with erosive bases. They are deposited in response to a fall in base level and an associated downward shift of facies.

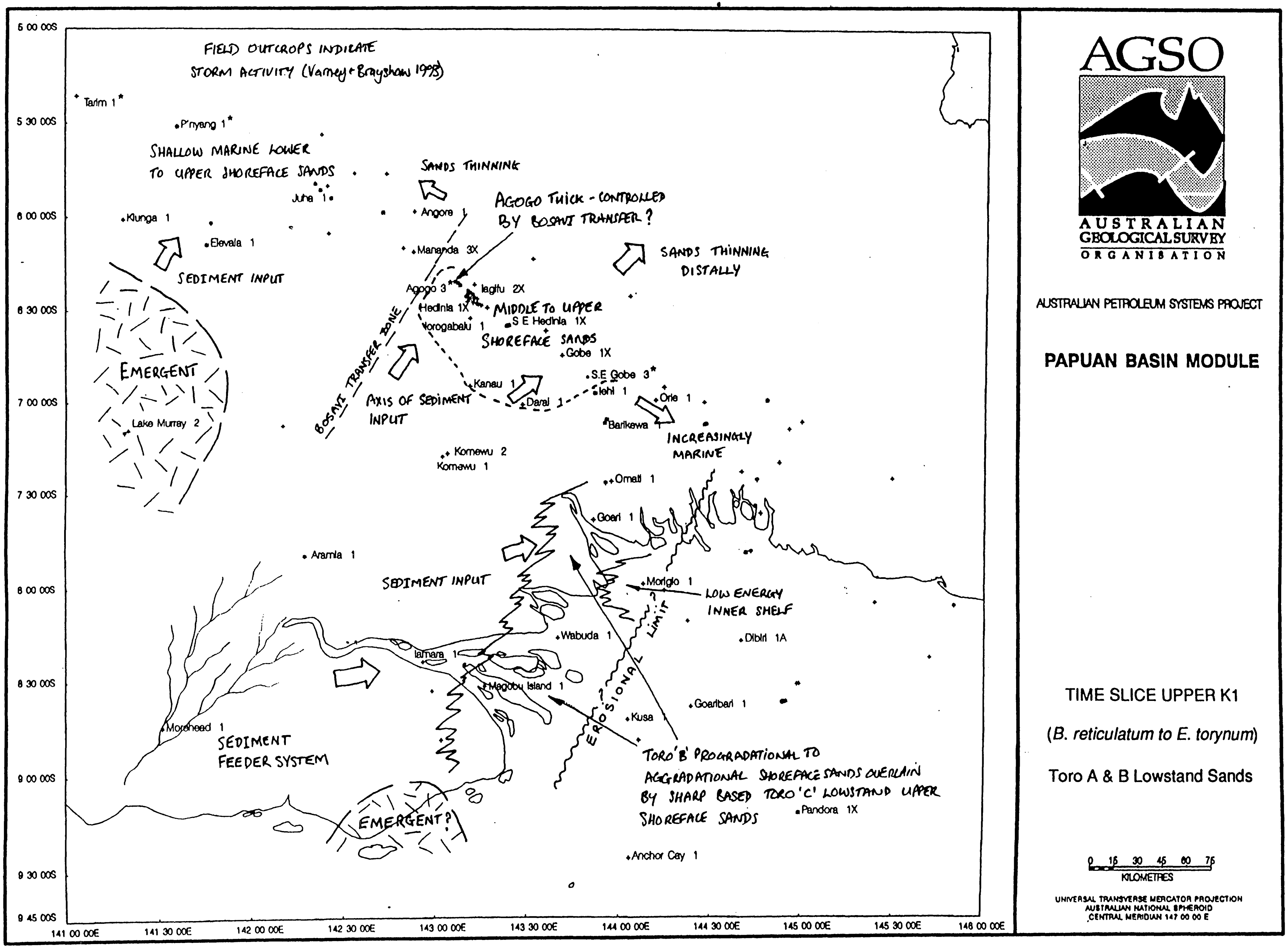


Figure 38 Palaeogeographic reconstruction for Time Slice upper K1, the Toro A & B Lowstand sequences.

The Toro B lowstand sequence is thickest within the Fold Belt depocentre to the east of the BTZ. The Toro B lowstand sands typically have a sharp erosive base, are dominantly composed of fine to coarse quartz grains, contain glauconite and have a blocky log character. As before, the BTZ is interpreted to have a topographic control on sediment distribution during the Toro B lowstand period.

The Toro C sequence is absent from Darai 1 and Gobe 1 due to erosion at the base of the Toro B lowstand sequence. This erosion together with the development of relatively thick Toro B lowstand sequences in these wells suggests this area was proximal to an axis of sediment input during the Toro B lowstand. It is possible that the axes of sediment input are migrating with time in response to variations in; relative sea level, compaction, subsidence, tectonic and topographic controls which effect the availability of accommodation space.

The Toro A lowstand sequence is well developed between Agogo 3 and the SE Gobe wells and characterised by aggradational upper to middle shoreface sands which on average are between 20 and 40 metres thick. However, Powis (1993) suggests an alternative interpretation with the lowstand sequences in the Gobe Anticline being, at least in part, estuarine in origin. The thickest Toro A sequences are intersected at Gobe 1 and Agogo 3 which penetrate 40 and 35 metres respectively. These thicker pods are interpreted to be related to the increased accommodation space at these localities and the proximity of an axis of sediment input. The development of a 30 metre thick section of Toro A lowstand sands in Kanau 1 is interpreted to indicate that the feeder system responsible for the Gobe 1 thick also passes close to Kanau 1. This interpretation offers potential for the development of good lowstand sands both to the southwest of Kanau 1 and northeast of Gobe 1. The depocentre at Agogo 3 is once again thought to relate to the topographic control exerted by the BTZ on sedimentation during this time.

Further to the southeast the Toro A lowstand remains as a significant sequence downcutting into both Toro B and C sequences at Iehi 1 and Barikewa 1. The Toro A sequence becomes thinner, less mature and more marine in nature towards the southeast.

To the northwest of the BTZ both Angore 1 and Mananda 1 have relatively thin Toro A lowstand sequences which are interpreted by Varney and Brayshaw (1993) to be deposited in marine conditions. The BTZ could be either a relative high which prevented the flow of sands towards the northwest or alternatively it may have been a low across which only minor sands were transported. Further to the northwest, outcrops in the Muller Anticline area indicate the development of another Fold Belt depocentre with up to 30 metres of sand deposited in a shallow marine progradational to aggradational shoreface environment (Varney & Brayshaw, 1993).

In the northwestern Foreland, Elevala 1 has relatively dirty middle shoreface sands which are interpreted to be deposited in close proximity to a sediment feeder system. Kiunga 1 penetrates a similar sequence but also intersects a significant Toro A lowstand sand which is interpreted as an upper shoreface barrier bar deposit. Paralic depositional environments are interpreted to be developed in the northwestern Foreland during the Toro A and B periods with possible sediment source areas lying to the south in emergent portions of the Frederick-Hendrick High. These north to northeasterly flowing sediment feeder systems are also thought to be the source for the time equivalent marine sequences developed in Varney and Brayshaw's (1993) Muller Anticline depocentre.

The top of the Toro A lowstand is marked by a transgressive sequence which culminates in the development of a flooding surface at the boundary between Helby et al's (1987) *E. torynum* and *S. areolata* biozones (Figure 30). This transgressive system marks the base of the Ieru Formation and results in the development of a flooding surface which is correlatable throughout the basin and equivalent to CS 33 of Phelps & Denison (1993) (Figure 31).

TIME SLICE K1 - PROSPECTIVITY

The K1 time slice is characterised by the widespread development of thick good quality clastic reservoir sequences, the Toro Formation and Digimu Member of the Imburu Formation. Packages of lowstand sand are on average approximately 10 to 20 metres in thickness and reach a maximum of 40 metres in the Toro A sequence at Gobe 1. Good porosities are reported from all wells which intersect this interval and average approximately 15 % with a maximum spot value of 33.5 % at Kanau 1. Fair to good permeabilities are reported throughout the Fold Belt and the Gulf of Papua (Appendix 5). The best permeabilities occur at Iagifu 2 and Hedinia 1 where spot values of 1070 and 1800 mD, respectively, are reported. At Aramia 1, in the Foreland, permeabilities are low as a consequence of the relatively immature nature of the sands in this area.

Median TOC values range from 0.16 to 1.30% and reach a maximum of 1.65% at Morigio 1. As in the previous time slice, further work is required to correlate the TOC data with the detailed sequence stratigraphy to test any relationship between potential source intervals and the development of maximum flooding surfaces. In the northwestern Foreland, Fold Belt and Gulf of Papua mean HI values are fair to good and reach a maximum of 644 in Angore

1. However, the mean HI values in the eastern Foreland are low. Mean VR values range from 0.40 to 0.79 and indicate the K1 sequences are in the early to mid peak stage of oil generation as defined by Tobin (1991). In general, the most thermally mature sequences are encountered in the Fold Belt.

Drilling at Iagifu 2 during early 1986 resulted in the first commercial oil discovery in the Papuan Basin within the K1 Toro Formation. Other significant hydrocarbon occurrences within the K1 time slice include, gas and condensate at Hedinia 1, SE Hedinia 1, Angore 1 and Juha 1 and gas at Iehi 1 and Barikewa 1. The discoveries at Iagifu and Hedinia are currently being produced as part of the Kutubu Field which produces approximately 130,000 BOPD. To date none of the wells drilled in either the Gulf of Papua or the southeastern portion of the Foreland have had any hydrocarbon shows from this interval.

As in the previous time slice, the hydrocarbons within the K1 reservoir interval are interpreted to be derived from the underlying Middle to Late Jurassic interval. The *E. torynum* transgressive sequence, at the base of the Ieru Formation, provides an excellent regional seal to the Toro Formation. Other transgressive deposits between the three Toro lowstands and overlying the Digimu lowstand also offer the potential to act as semi regional intraformational seals.

TIME SLICES K2 and K3 : Early Valanginian to top Barremian (Figure 39, Enclosures 24 & 25)

SUMMARY : Equivalent to the lowermost Ieru Formation. Rise in relative sea level at the base of K2 is associated with the development of condensed intervals in the Fold Belt (organic rich in places) and associated with greensands in the Foreland, the Alene sands. Transgression continues into K3 and results in demise of clastic supply to the basin. Offers potential for; significant reservoir development in the Foreland portion of the basin, limited source intervals in the Fold Belt and a good regional K3 seal. The basal K2 transgressive sequence seals the underlying Toro Formation. Gas condensate discovery at Elevala 1, oil show at Tarim 1 and gas show at Langia 1.

PALAEOGEOGRAPHICAL INTERPRETATION

Due to the condensed nature of the K2 and K3 time slices, particularly in the Fold Belt, they have been combined into one palaeogeographic interpretation (Figure 39, Enclosure 24).

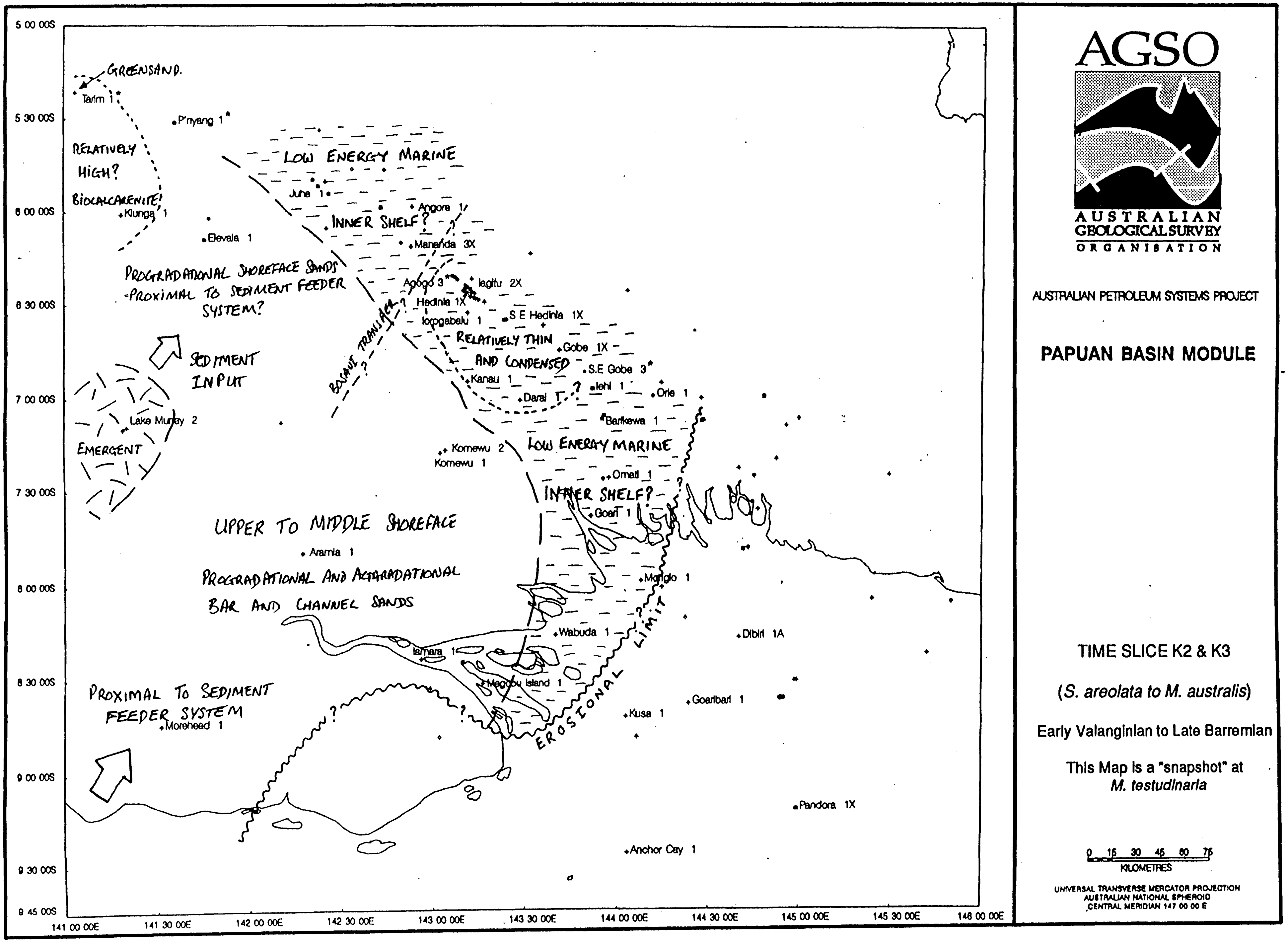


Figure 39 Palaeogeographic reconstruction for Time Slices K2 & K3.

The K2 and K3 time slices are equivalent to the lowermost portion of the Ieru Formation (Figure 31) and are intersected by twenty four of the study wells.

Available well control suggests subtle thickness variations exist between adjacent wells (Enclosure 23), the most noteworthy being a broad thinning towards the Gulf of Papua and the development of a relative thin to the southeast of the BTZ between Iagifu 2 and Gobe 1. An episode of Late Cretaceous uplift and erosion has removed the upper portions of time slices K2 / K3 from Morigio 1 and the entire K2 / K3 section from Anchor Cay 1, Kusa 1, Goaribari 1 and Dibiri 1.

The base of Time Slice K2 is characterised by the widespread development of a mudstone dominated transgressive sequence due to a relative sea level rise at the top of Helby et al's (1987) *E. torynum* biozone (Figure 30). This transgressive sequence is associated with the development of condensed intervals which in some wells include organic rich mudstones, ie. Elevala 1 (Fennessy, 1990). High concentrations of marine organic matter within condensed sections in the Fold Belt (Welsh, 1990) are coincident with areas that were major depocentres during the deposition of the J10 and K1 reservoir sequences. This may be indicative of the continued control of the BTZ on sedimentation in this area forming either a topographic high or depositional low. Alternatively it may relate to the development of palaeohighs in these locations due to differential compaction leading to sediment bypass and hence the formation of condensed sequences.

In the Foreland, a sequence of coarsening upward sands overly the lower K2 transgressive deposits and are interpreted to relate to a period of renewed sediment progradation. The development of two relatively thin sharp based sands within the upper portion of Time Slice K2, in the Foreland, is thought to be a result of two brief lowstand periods. These lowstand sequences occur in the *M. testudinaria* biozone of Helby et al (1987) and are equivalent to the Alene sands (Figure 31) of Phelps and Denison (1993). During this period a series of immature arkosic sands with occasional glauconite were deposited at Morehead 1 and are interpreted to indicate deposition in a paralic environment proximal to a sediment feeder system. More distal paralic depositional environments are interpreted at Iamara 1 and Magobu Island 1 where a sequence of fairly immature fine to occasionally coarse sands with glauconite and ostracods are intersected. Further to the north and west at Aramia 1, Komewu 2, Elevala 1, P'nyang 1 and Tarim 1, a more mature sequence of very fine to coarse grained, quartz dominated sands with frosted grains, occasional belemnite fragments and glauconite (occasionally abundant) are interpreted to be deposited as a series of bars and channels in a middle to upper shoreface environment.

The upper K2 sequence penetrated at Kiunga 1, in the northwestern Foreland, consists of biocalcarenites with belemnite and shell debris (O'Day, 1980). The absence of any upper K2 clastics from Kiunga 1 together with the deposition of a time equivalent carbonate sequence is interpreted to indicate the development of an area of sediment bypass, a palaeo high. Further to the north and east, in the Fold Belt and Gulf of Papua deposition continues to be dominated by low energy marine mudstone sequences with interbedded siltstones and occasional very fine sandstones with glauconite.

An increase in the relative sea level during Time Slice K3 is responsible for the final demise and "drowning" of clastic supply to the basin. This K3 transgressive system is responsible for the basin wide development of low energy marine mudstone dominated sequences. According to Welsh (1990) this sequence demonstrates an increase in distal shelf palynoflora upwards.

In the western Foreland, the lack of sediments from time slices K2 and K3 at Lake Murray 2 is interpreted to indicate the continued emergence of this area as part of the Frederick-Hendrick High.

PROSPECTIVITY

The K2 and K3 time slices are associated with the development of progradational and aggradational reservoir sequences within the Foreland portions of the basin. The total sand package averages between 30 and 40 metres thick, has measured porosities ranging from 4 to 20.9 % and permeabilities of up to 3200 mD (Aramia 1).

Median TOC values range from 0.50 to 1.20% and reach a maximum of 3.29% from a section with carbonaceous material intersected at Iamara 1. Condensed sections in the central portion of the Fold Belt are associated with higher than average TOC values. Fair to good mean HI values occur in the Fold Belt and northwestern Foreland, a maximum of 275 is recorded at Mananda 3. However, mean HI values in the eastern portion of the Foreland are low. Mean VR values range from 0.40 to 0.92 and indicate that the majority of the Foreland is in the early stage of oil generation as defined by Tobin (1991). In the Fold Belt and northwestern Foreland more thermally mature K2 and K3 sequences occur with maximum VR values of 0.92 and 0.83 recorded in Kiunga 1 and Juha 1.

Elevala 1, drilled in 1990, discovered gas and condensate in the upper K2 *M. testudinaria* sands, DST 1 flowed 11.9 MMCFD of gas and 634 BCPD over a 12 metre interval. Other significant hydrocarbon shows in this interval include a reported oil show at Tarim 1 (Bagby and Handley, 1990) and a report of gas from *M. testudinaria* sands at Langia 1 (Barndollar, 1993).

The condensed and sometimes organic rich lower K2 and K3 transgressive sequences may offer some potential for the development of local source intervals. The K3 sequence also provides an excellent seal to the upper K2 sands.

TIME SLICE K4 : Aptian (Figure 40, Enclosures 26 & 27)

SUMMARY : Characterised by a basin wide increase in sedimentation rates and the deposition of low energy marine sequences with some volcanic material and occasional shallow marine sands. The K4 sequence represents the first sediments deposited over basement at Lake Murray 2. Limited potential for the development of either reservoir or source intervals and only minor hydrocarbon indications.

PALAEOGEOGRAPHIC INTERPRETATION

Time Slice K4 is penetrated by twenty two of the study wells in the Fold Belt, Foreland and western margin of the Gulf of Papua. A phase of Late Cretaceous uplift is responsible for the erosion of the entire K4 and younger sequence from Morigio 1, Dibiri 1, Goaribari 1, Kusa 1, Anchor Cay 1 and Iamara 1 and the truncation of the K4 sequence at Goari 1. The K4 sequence penetrated in Lake Murray 2 represent the first sediments deposited on a previously emergent quartz diorite basement high.

The K4 time slice is characterised by the deposition of a fairly uniform thickness of low energy marine mudstones and siltstones with occasional fine grained sandstones, glauconite, detrital coal, volcanogenic material and shell fragments. A characteristic marine assemblage has been recognised over this interval by Welsh (1990). Comparatively thin K4 sequences in Kiunga 1 and Komewu 2 are interpreted to be a consequence of sediment bypass around palaeo highs.

A basin wide increase in the rate of sedimentation occurs within Time Slice K4. This is well demonstrated on Figure 22 and interpreted to be a function of a rejuvenation in sediment

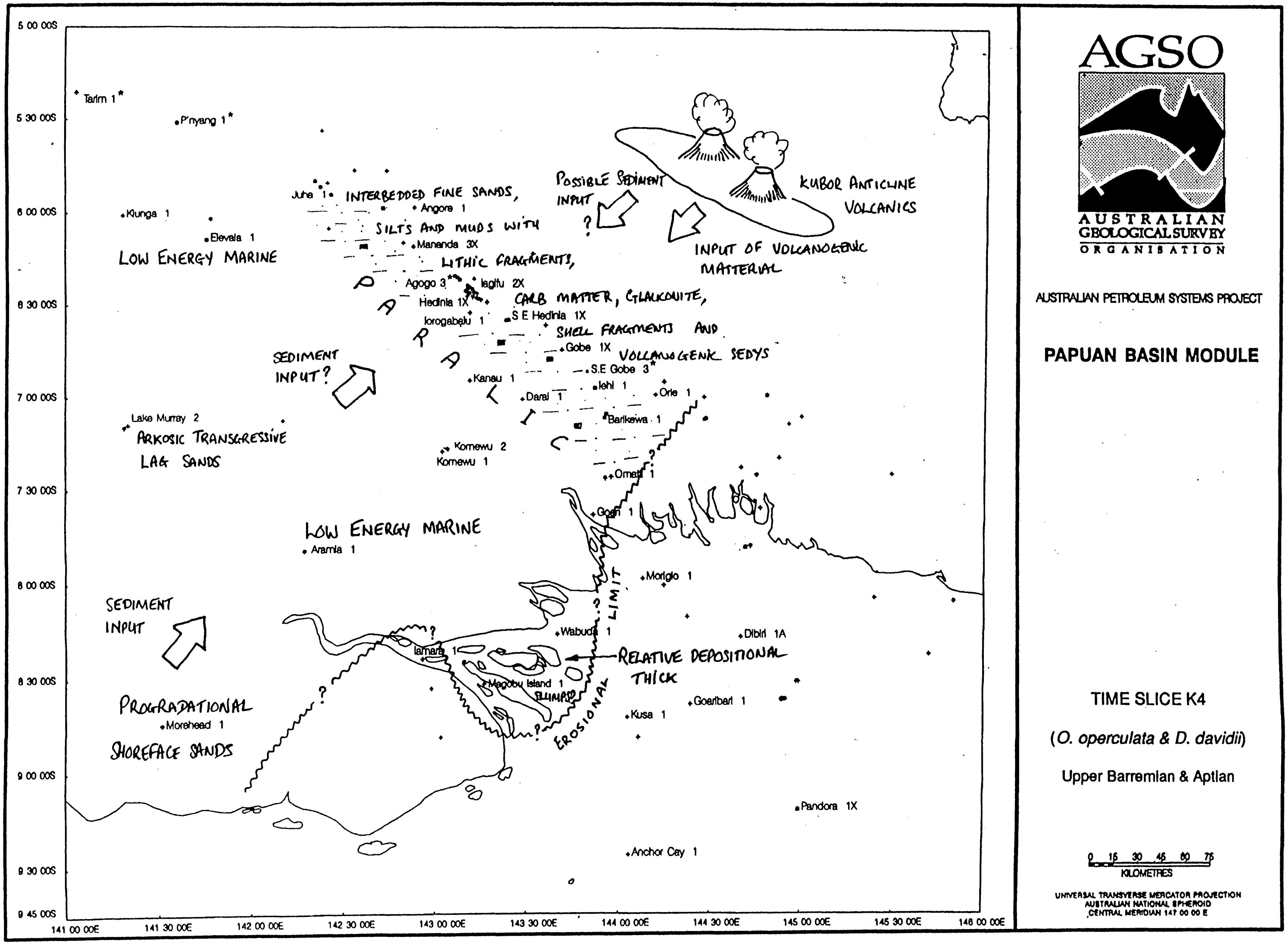


Figure 40 Palaeogeographic reconstruction for Time Slice K4.

source areas due to a relative fall in base level. This fall in base level also results in the formation of a sequence boundary at the base of Time Slice K4 and an increase in the proportion of immature sands within this time slice.

Occasionally more mature sands are developed; ie. Morehead 1 intersects a sequence of quartz rich sands with frosted grains and minor glauconite which are interpreted as offshore bar deposits, and Omati 1 penetrates a sharp based very fine glauconitic sand possibly deposited as a lowstand fan sequence. Volcanic fragments within the K4 sands at Omati 1 are interpreted by Welsh (1990) to be related to the Kondaku Tuff which outcrops further to the east of the study area. This implies that at least some of the K4 sediment was derived from this area. In addition, Home et al (1990) and Struckmeyer et al (1990) note the development of a northerly volcanic province around the Kubor Anticline and suggest this area could also contribute sediments to the Papuan Basin during Time Slice K4. The Kubor Anticline volcanic province may also have some potential as a source of the immature sediments with lithic fragments and carbonaceous material which were deposited in the Fold Belt during this time slice. This volcanic activity could be a significant driving force causing uplift of sediment source areas and an associated fall in base level during Time Slice K4.

On the western margin of the Gulf of Papua, slumping has been described from cores within the K4 sequence at Magobu Island 1 (Hocking et al, 1971). The occurrence of slumping together with slightly thicker than average sequences at both Magobu Island 1 and Wabuda 1 may be indicative of the development of a depocentre in this location during Time Slice K4. Phelps and Denison (1993) suggest thickness variations within the Lower Ieru Formation may relate to the availability of accommodation space as well as sediment input and dispersal patterns.

The occurrence of a K4 sequence at Lake Murray 2, a long standing palaeo high, suggests that the fall in base level during Time Slice K4 is a relatively minor event within a transgressive megasequence. The base of the onlapping K4 sequence intersected at Lake Murray 2 is marked by a basal transgressive lag deposit consisting of arkosic sands. The transgressive lag deposit grades into a poorly sorted, fine to coarse grained sandstone with occasional glauconite which is indicative of the gradual establishment of more marine conditions.

PROSPECTIVITY

Several potential reservoir sands are deposited within Time Slice K4. However, their lack of regional continuity and relative textural immaturity, when compared to the J10 and K1 reservoir sequences, downgrades them as potential targets.

The transgressive lag deposits intersected at Lake Murray 2 have a measured log porosity of up to 23 % and are predicted to extend as a diachronous unit both to the northeast and southwest. Gas at Lake Murray 1 is indicative of hydrocarbon migration into this area. However, the potential development of thick reservoir sequences with good permeability, amongst this dominantly immature sequence, is thought to be somewhat limited.

Good to fair log and core porosities are measured over relatively thin intervals at Orie 1, Komewu 2, Omati 1 and Morehead 1. Permeabilities however, are somewhat limited and only reach a maximum spot value of 7.7 mD at Morehead 1.

Median TOC values range from 0.36 to 0.97% and reach a maximum of 1.78% at Magobu Island 1. To the northwest of the BTZ mean HI values range from 106 to 172 and reach a maximum of 320 at Angore 1. However, HI values in the southeastern portion of the Fold Belt and Foreland are low and only reach a maximum of 89 at Magobu Island 1. The mean values of VR range from 0.39 to 0.85, the early to middle peak stage of oil generation as defined by Tobin (1991), and indicate an increase in thermal maturity towards the northeast.

The finer grained sequences within Time Slice K4 offer some potential to form good intraformational seals.

Hydrocarbon shows are restricted to an oil indication at Juha 1 and gas indications at SE Hedinia 1 and Magobu Island 1.

TIME SLICES K5 to LOWER K8 : Albian (Figure 41, Enclosures 28 & 29)

SUMMARY : Equivalent to the upper portion of the Lower Ieru Formation. Characterised by condensed mudstone sequences deposited in outer shelf to upper slope environments. Offers limited potential as a source interval, is unlikely to contain any significant reservoir sequences and has only minor hydrocarbon indications.

PALAEOGEOGRAPHIC INTERPRETATION

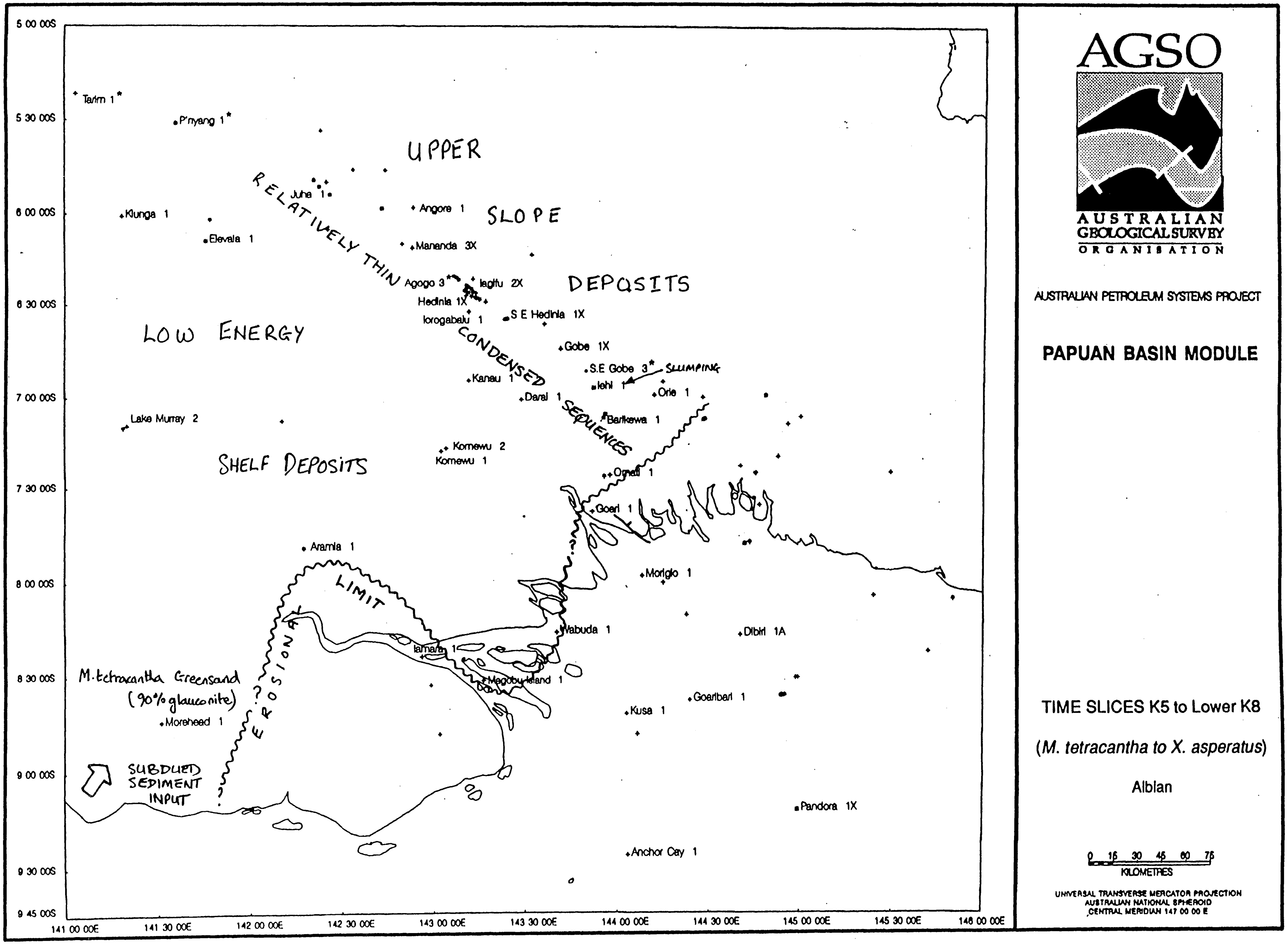


Figure 41 Palaeogeographic reconstruction for Time Slices K5 to lower K8.

As a consequence of the condensed nature and similar lithologies encountered in time slices K5 to lower K8, *M. tetracantha* to *X. asperatus* biozones of Helby et al (1987), they have been amalgamated into one composite palaeogeographical interpretation (Figure 41 and Enclosure 29). This interval, equivalent to the uppermost portion of Welsh's (1990) K2 sequence and the entire K3 sequence, is penetrated at least partially in twenty two of the study wells (Enclosure 28).

The K5 to lower K8 time slices are characterised by a monotonous, often calcareous, mudstone sequence which according to Welsh (1990) includes the richest and most diverse foraminiferal and nannofossil assemblages encountered in the Cretaceous of the Papuan Basin. This sequence is interpreted to be deposited in an outer shelf to upper slope environment. A shelf / slope break has been interpreted by Welsh (1990) to probably occur along a northwest to southeast line through Hides 1, just east of Iagifu and through Barikewa 1. Slumping has been identified from cores over this interval at Iehi 1 (Gay & Brown, 1961) and add support to Welsh's (1990) interpretation for the position of the shelf / slope break.

The *M. tetracantha* biozone (Time Slice K5) is often absent (Welsh 1990). The base of this interval has been identified by Phelps and Denison (1993) as a correlatable surface, CS 24, associated with an estimated time break of approximately 6 to 8 My. and marking a change from middle neritic to outer neritic / upper bathyal environments. This interval also corresponds to a sharp decrease in the rate of sedimentation (Figure 22) and is interpreted to relate to an increase in the relative sea level at the top of Time Slice K4, top *D. davidii* biozone, causing a condensing of the *M. tetracantha* biozone. Hence, the common absence of the *M. tetracantha* biozone is interpreted to be a consequence of its absence from samples due to its condensed nature as opposed to its removal by erosion at a sequence boundary as suggested by Welsh (1990). The occurrence of *M. tetracantha* greensands with up to 90 % glauconite at Morehead 1 and Komewu 2 is good evidence to support a K5 period of condensed sedimentation due to transgression and associated sediment starvation.

The top of this K5 to lower K8 condensed interval is marked by a gamma ray log anomaly equivalent to CS23 (Figure 31) of Phelps and Denison (1993).

PROSPECTIVITY

The K5 to lower K8 transgressive sequence offers limited potential for significant reservoir development. The texturally immature sands are generally in the order of 5 metres thick and have unknown lateral continuity. Measured spot porosities range from 11.8 to 25.6 % and permeabilities average 0.1 to 2 mD, an isolated sample at Omati 1 has a spot permeability of 194 mD.

Median TOC values range from 0.37 to 0.90% and reach a maximum of 1.10% at Morehead 1. Mean HI values are low, except for Angore 1 which has a value of 160. Mean VR values range from 0.38 to 0.95 and indicate the K5 to lower K8 sequences are in the early to peak stage of oil generation as defined by Tobin (1991).

The mudstone dominated sequences within this interval act as an excellent seal to any underlying sands.

Hydrocarbon shows are relatively minor with reported oil indications at Juha 1 and Barikewa 1 and gas indications at SE Hedinia 1 and Magobu Island 1.

TIME SLICE UPPER K8 : Cenomanian (Figure 42, Enclosures 30 & 31)

SUMMARY : The base of this time slice is equivalent to the base of the Coral Sea Syn-Rift Megasequence. It is characterised by a rapid increase in sedimentation rates and dominated by lithologically varied nearshore and shallow marine sequences. Sand dominated sequences in the northwestern Fold Belt and southern Foreland offer some reservoir potential. Minor hydrocarbon indications.

PALAEOGEOGRAPHICAL INTERPRETATION

The upper K8 time slice is defined by the *D. multispinum* biozone of Helby et al (1987) and intersected, at least partially, by seventeen of the study wells in the Fold Belt and western Foreland. The common truncation of the upper portions of this time slice together with its complete absence from the Gulf of Papua and the eastern Foreland (Enclosure 30) is related to a period of Late Cretaceous uplift and erosion.

The base of the upper K8 time slice is marked by a well defined sequence boundary which marks the end of the Lower Ieru Formation (time slices K2 to lower K8) passive margin style of deposition. This boundary is identified by Home et al (1990) as the base of the Coral Sea Syn-Rift megasequence and interpreted to relate to the initiation of rifting in the Coral Sea. The rejuvenation of the hinterland during this period of rifting resulted in increased

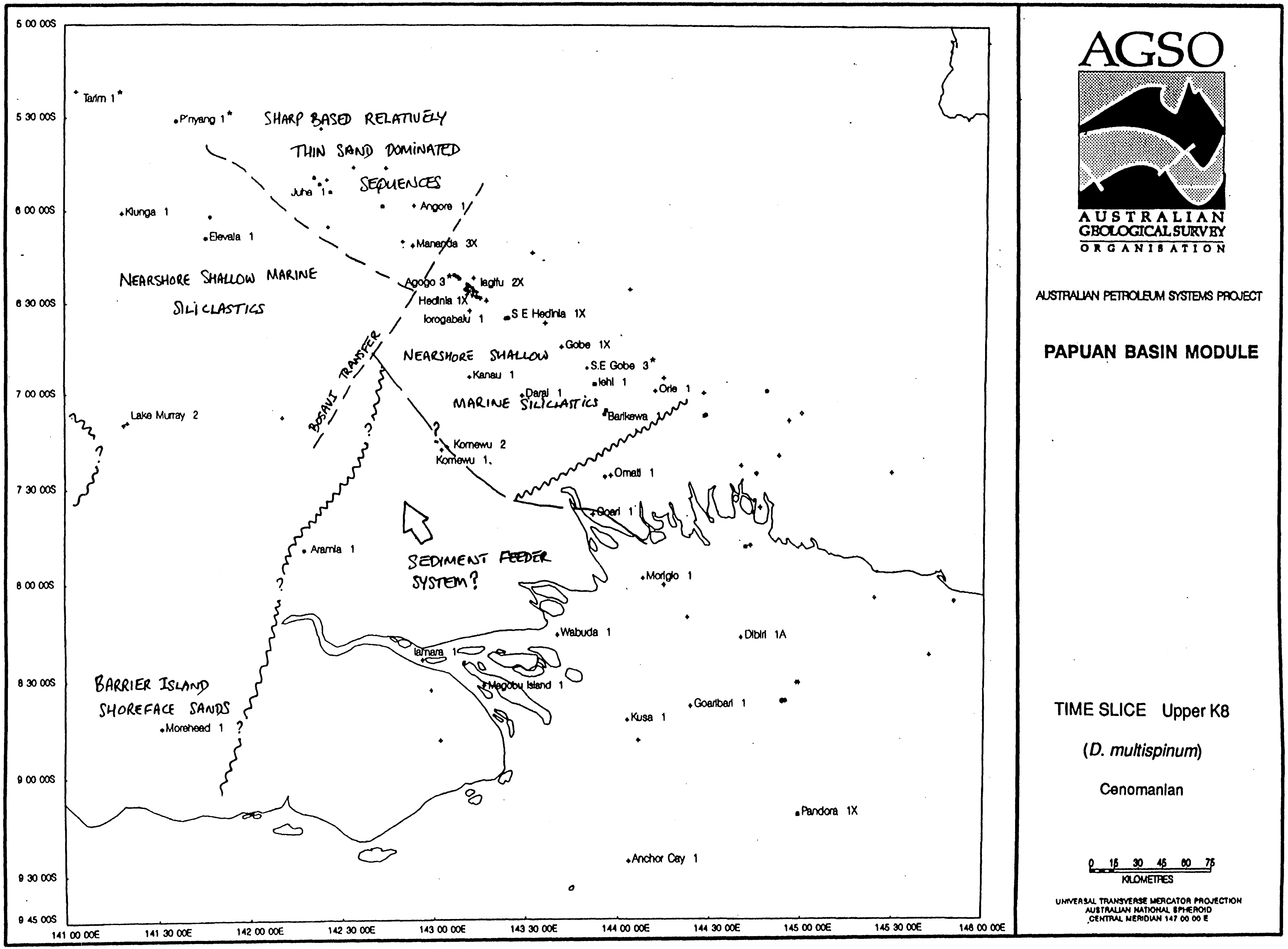


Figure 42 Palaeogeographic reconstruction for Time Slice upper K8.

sedimentation rates as shown on Figure 22. This megasequence boundary and the associated increase in depositional rates are reflected biostratigraphically with a change from thin biozones with rapid vertical change to thick biozones and slow change (Welsh, 1990, Phelps & Denison, 1993). Welsh (1990) notes that forams demonstrate a transition to restricted nearshore marine environments within the upper K8 time slice and suggests a fall in base level occurred at the end of the Lower Ieru Formation. A regional unconformity could be expected at such a megasequence boundary but a definite hiatus can only be recognised in a small number of wells (Welsh, 1990). These minor, yet significant unconformities, probably represent localised extensional faults and erosion of fault blocks prior to deposition of the upper K8 sequence. The occurrence of reworked K5 to lower K8 palynomorphs testifies to this erosion. Due to poor chronostratigraphic control and sparse well coverage the magnitude, or in some areas the presence, of this hiatus cannot be measured.

In the Fold Belt, to the southeast of the BTZ, and in the western Foreland the upper K8 time slice is characterised by the development of thick and lithologically varied nearshore shallow marine shelf siliclastics with lithic fragments, glauconite and carbonaceous material. Slumping recognised by Gay & Brown (1961) in cores from the upper K8 time slice at Iehi 1 may be indicative of movement downslope towards more distal lower energy sequences such as those penetrated at Orie 1.

To the northwest of the BTZ Mananda 1, Angore 1 and Juha 1 have much thinner upper K8 sequences which are characterised by sharp based very fine to medium grained quartz rich sandstones with glauconite, occasional lithic fragments and some clay clasts at Juha 1. The restriction of these deposits to the northwestern portion of the Fold Belt suggests this area was separated from the rest of the basin by structural or topographic barriers located at the BTZ and the present day Frontal thrust. The increased maturity of these sediments may indicate this area was a relative high during upper K8 and prone to winnowing or alternatively it may be a function of sediment input and dispersal patterns which relate to structural controls and availability of accommodation space. Sediment input could have been from either a northerly source area or one to the south and possibly controlled by the BTZ.

Morehead 1, in the southern Foreland, intersects a high energy nearshore sand dominated sequence comprising sharp based sand packages with frosted grains, cross stratification, pebbles, carbonaceous layers and belemnites. This sequence is interpreted to be deposited in a nearshore barrier island environment proximal to a sediment feeder system.

Phelps & Denison (1993) interpret the occurrence of mono specific dinocyst populations at the top of biozones over this interval to be indicative of a high stress environment.

PROSPECTIVITY

Porosity and permeability measurements within the upper K8 time slice, although sparse, suggest that a sequence of barrier island deposits intersected at Morehead 1 offers the best potential for reservoir development over this interval. Morehead 1 has average core porosities between 21.2 and 33.3 % over a 500 metre interval while spot permeabilities over the same interval are normally less than 1 mD but up to 115.6 mD. No porosity or permeability data is available for the sand dominated sequence intersected in the northwestern Fold Belt.

Median TOC values range from 0.39 to 0.86% and reach a maximum of 1.68% at Barikewa 1. Mean HI values are generally low but do reach a maximum of 170 and 132 at Elevala 1 and Angore 1. The mean VR values range from 0.39 to 0.76 and indicate the upper K8 sequences are in the early to middle peak oil generative stage as defined by Tobin (1991). The VR data also indicate increased thermal maturity in the Fold Belt and at Kiunga 1.

Hydrocarbon occurrences within the upper K8 time slice are relatively minor and restricted to an oil indication at Juha 1 and gas indications at Elevala 1 and Kiunga 1.

TIME SLICE K9 : Turonian to Santonian (Figure 43, Enclosures 32 & 33)

SUMMARY : K9 represents the youngest Cretaceous sequence, equivalent to the Upper Ieru Formation. Characterised by thick and lithologically varied nearshore shallow marine sequences with limited areal distribution due to a period of late Cretaceous erosion. Sands at Morehead 1 and in the northwestern portion of the basin may have some reservoir potential. Oil staining reported at Tarim 1.

PALAEOGEOGRAPHIC INTERPRETATION

Sediments from Time Slice K9 are only intersected in eight of the study wells which, with the exception of Morehead 1, lie in the northwest portion of the basin (Enclosure 32). The upper portion of Time Slice K9 (*C. striatoconus* to *I. cretaceum*) is absent throughout the Papuan Basin due to an episode of Late Cretaceous uplift and erosion which is also responsible for

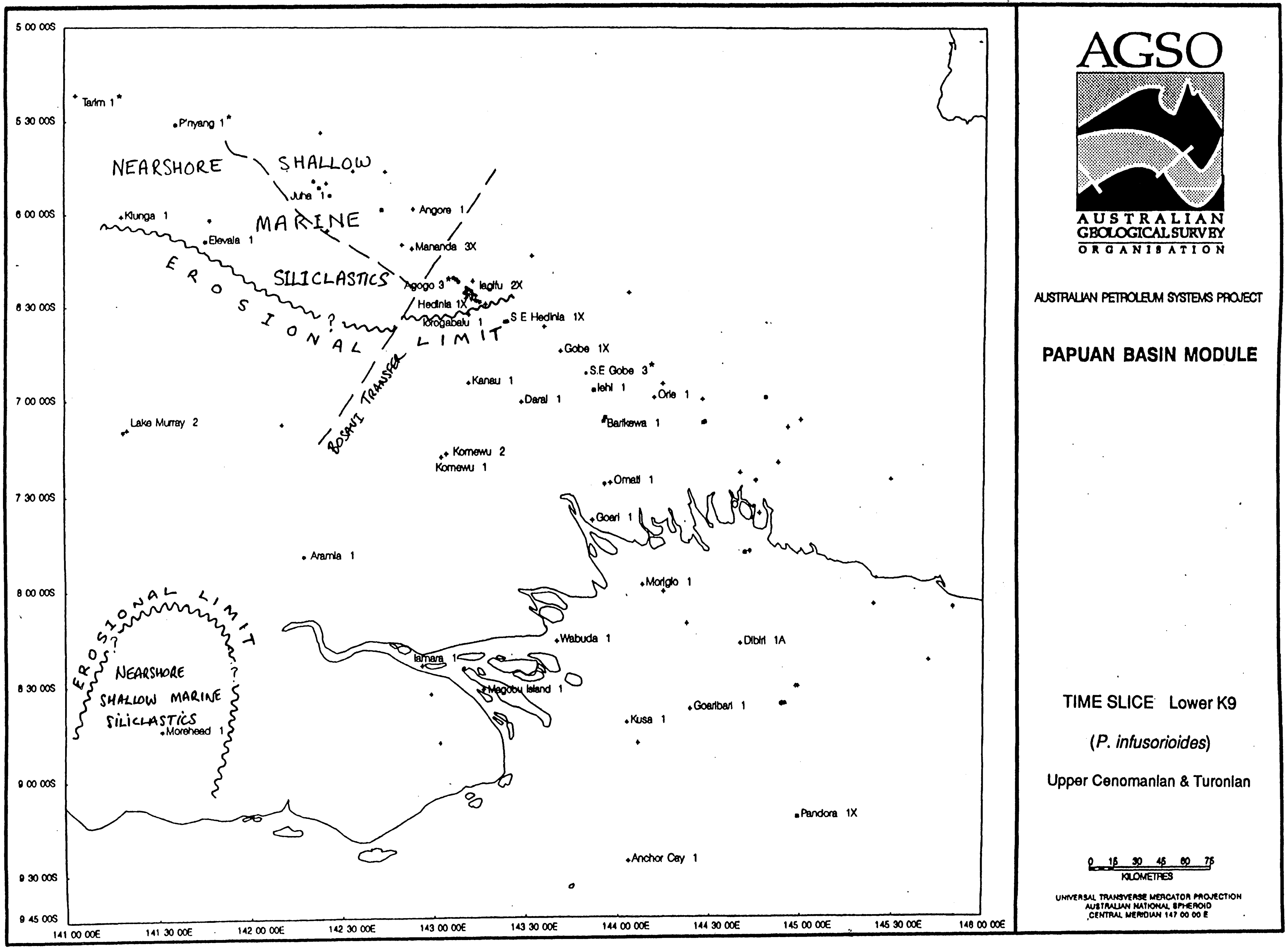


Figure 43 Palaeogeographic reconstruction for Time Slice K9.

the removal of the lower K9 (*P. infusorioides*) and older sequences from many wells. As a consequence of this major erosive episode the K9 sequence represents the youngest Cretaceous section intersected to date from drilling in the Papuan Basin. Home et al (1990) suggest the Late Cretaceous erosive event is a consequence of thermal uplift prior to the initiation of sea-floor spreading in the Coral Sea during the Paleocene.

Lithologically this time slice resembles the underlying upper K8 interval and is characterised by the continued deposition of generally thick and lithologically varied nearshore shallow marine shelf siliclastics with lithic fragments, glauconite and carbonaceous material. Welsh (1990) notes that assemblages indicate variable marine palaeoenvironmental conditions.

This time slice has been interpreted by Home et al (1990) to be part of the Coral Sea Syn-Rift Megasequence. However, Welsh (1990) recognises an unconformity at the base of the K9 sequence in the Juha area together with the presence of reworked upper K8 palynomorphs in the K9 sequence and a palaeoenvironmental change at this boundary. This evidence suggest that Time Slice K9 is part of the same megasequence as the upper K8 time slice but separated from it by a sequence boundary.

In the northwestern portion of the Fold Belt, northwest of the BTZ and north of the Frontal thrust, the K9 sequence is substantially thicker (1011m in Juha 1) than that intersected elsewhere in the basin. This is thought to be a function of the magnitude of the erosion at the base Tertiary unconformity increasing to the south and east away from the BTZ and Frontal thrust, such that Tertiary overlies the upper K8 at Iorogabaiu 1, K4 at Goari 1 and J10 at Kusa 1. There is insufficient control to determine if the observed variation in thickness of the K9 sequence could also relate to primary depositional thickness variations.

A sequence of sands with poor biostratigraphic control directly underlie the Tertiary section in Juha 1 (40 m), Tarim 1 (30 m) and Kiunga 1(10 m). This sharp based unconsolidated sequence is dominantly medium grained, moderately sorted and contains shell fragments, occasional frosted quartz grains and glauconite. It is interpreted as a moderate to high energy shallow marine deposit which may be related to either the Campanian Pale Sandstone of Carman (1987, Boult & Carman 1993), the Maastrichtian sands in the North West Shelf or possibly a transgressive lag deposit on the base Tertiary unconformity.

The preservation of Time Slice K9 at Morehead 1 indicates that the Morehead Sub-Basin remained as a relative low during the Late Cretaceous erosive phase.

PROSPECTIVITY

The best potential for reservoir development within Time Slice K9 is likely to be the 10 to 40 metre thick sand which is intersected in the uppermost Cretaceous section immediately beneath the Tertiary unconformity at Juha 1, Tarim 1 and Kiunga 1. Unfortunately porosity data over the K9 interval is limited to two spot samples from Morehead 1 which gave values of 31.3 and 25.6 %. No permeability data exists within Time Slice K9.

Median TOC values range from 0.41 to 0.99% and reach a maximum of 42.2% in a mudstone dominated sequence with occasional carbonaceous material penetrated by Angore 1. Mean HI values are generally fair to good and reach a maximum of 891 in Angore 1, 308 in Mananda 3 and 315 in Elevala 1. The mean VR values range from 0.27 to 0.7 and indicate the K9 sequence is in the early to mid peak stage of oil generation as defined by Tobin (1991).

Oil indications are noted from the K9 sequence at Juha 1 and Kiunga 1 while Bagby & Handley (1990) report rare oil staining and fluorescence at Tarim 1.

GEOCHEMISTRY ANALYSES

This geochemical summary is based on data from open file Well Completion and geochemical reports. A series of more specific notes summarising the detailed findings of these reports has been compiled into Appendix 10. Graphical plots of vitrinite reflectance's, Tmax values, TOC's, HI's, S1+ S2, and HI vs OI for individual wells are provided in Appendices 11 to 16.

Figures 44 to 49 show the relative stratigraphic and structural positions of the major oil and gas accumulations intersected by the study wells. The definition of the hydrocarbon show symbols is given in Figure 9 and Appendix 6 provides a detailed listing of the hydrocarbon occurrences in the study wells. Most of the hydrocarbon discoveries have been made in the Late Jurassic to Early Cretaceous interval (oil, condensate and gas) and in the Miocene section (gas and oil). The Late Jurassic to Early Cretaceous section ranges from 2000 m to 4000 m below the rotary table.

Geochemically, the oils of the Papuan Basin are similar to those of the North West Shelf, indicating an origin from Jurassic sediments containing mixed marine algal and terrestrial higher plant material (Murray et al., 1993). A characteristic feature of these oils is a high proportion of dia- and neohopanes; and the fingerprints given in Murray et al. (1993) for South East Gobe 1 and South East Hedinia 1 are typical. The relative extent of marine and terrestrial influence, as indicated by biomarkers, varies from well to well. Analyses of Jurassic sediments in Wabuda 1, Omati 1, Juha 1 and many other wells show that the Jurassic section matches reasonably well in biomarker and isotopic composition with the oils. The hydrocarbons are generally considered to have been sourced from the Middle to Late Jurassic intervals (J5 to J9 time slices). However, biomarker analysis has shown the presence of a Tertiary deltaic source in the mobile belt (Murray et al., 1993); and several of the Fold Belt oils also contain traces of Tertiary biomarkers, indicating minor co-sourcing or contamination with foreign material. There have been several phases of generation, and hydrocarbons were re-migrated during thrusting in Pliocene to Recent (Earnshaw et al., 1993). Geochemical analyses can help resolve some of this complex history as shown in Figure 50.

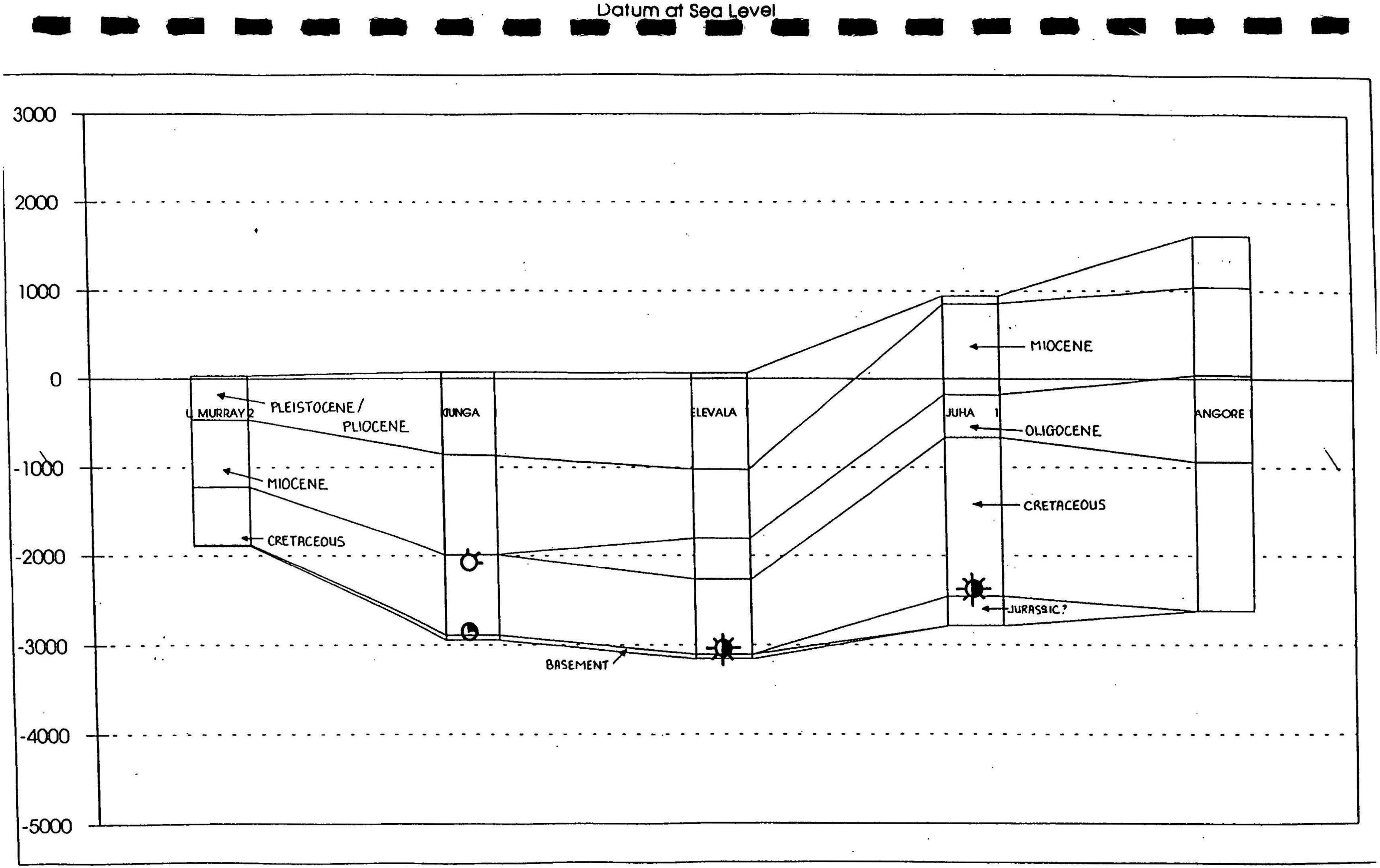


Figure 44 Papuan Basin Schematic Cross Section A-A' datum at Sea Level annotated with hydrocarbon occurrences.

Cross Section B-B'
Datum at Sea Level

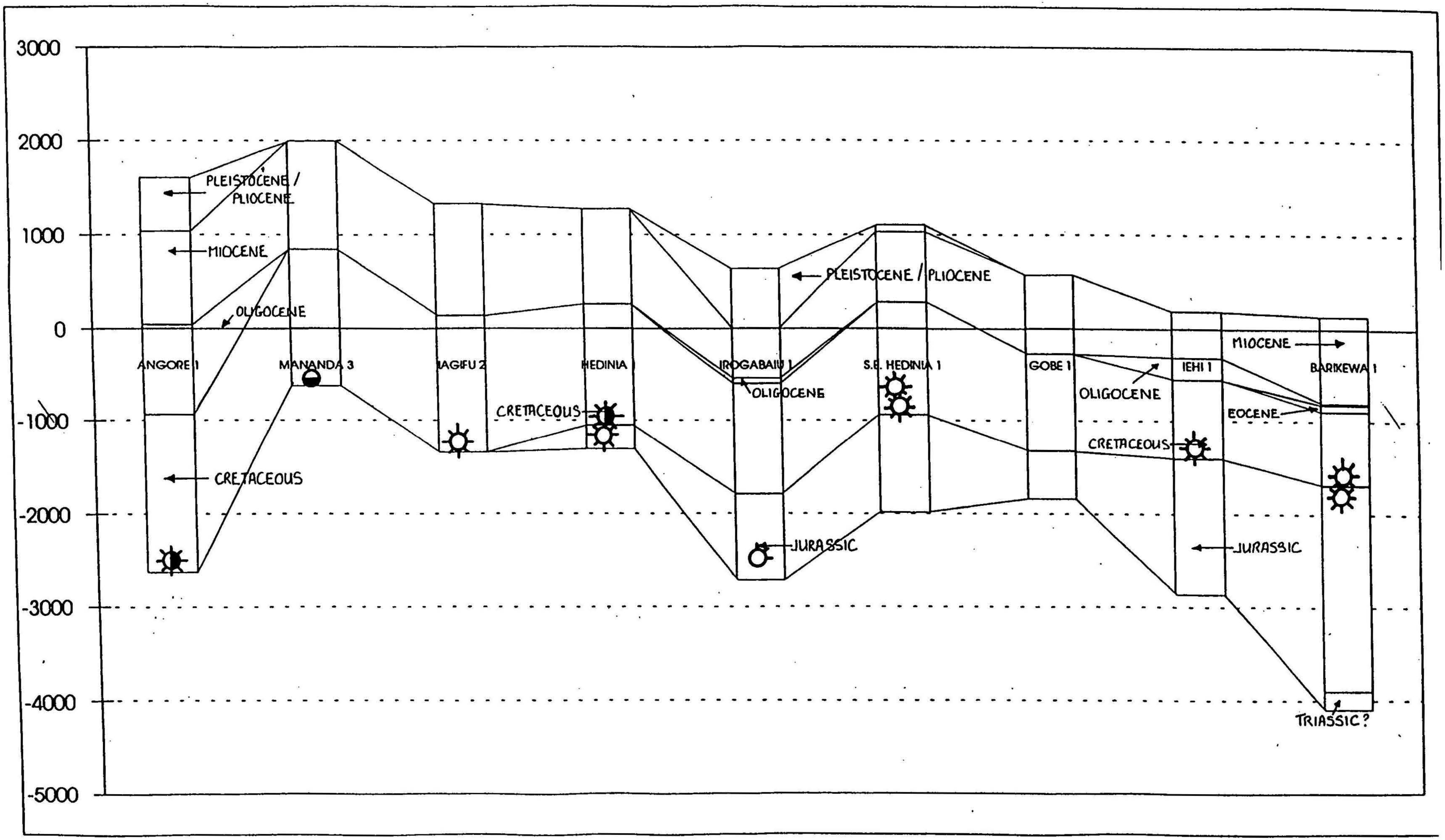


Figure 45 Papuan Basin Schematic Cross Section B-B' datum at Sea Level. annotated with hydrocarbon occurrences.

Dat[redacted]at S[redacted]evel

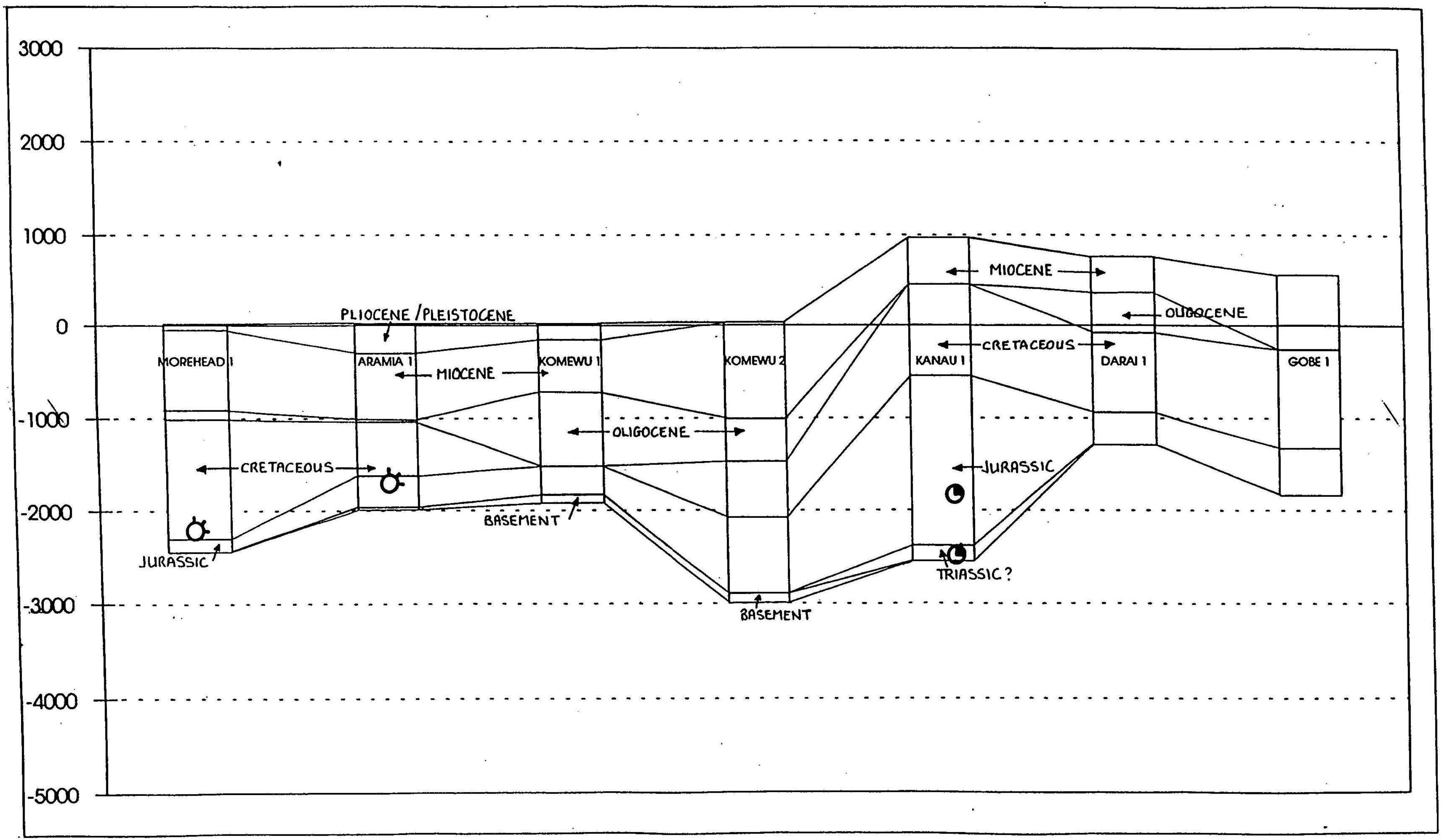


Figure 46 Papuan Basin Schematic Cross Section C-C' datum at Sea Level. annotated with hydrocarbon occurrences.

Cross Section D-D'
Datum at Sea Level

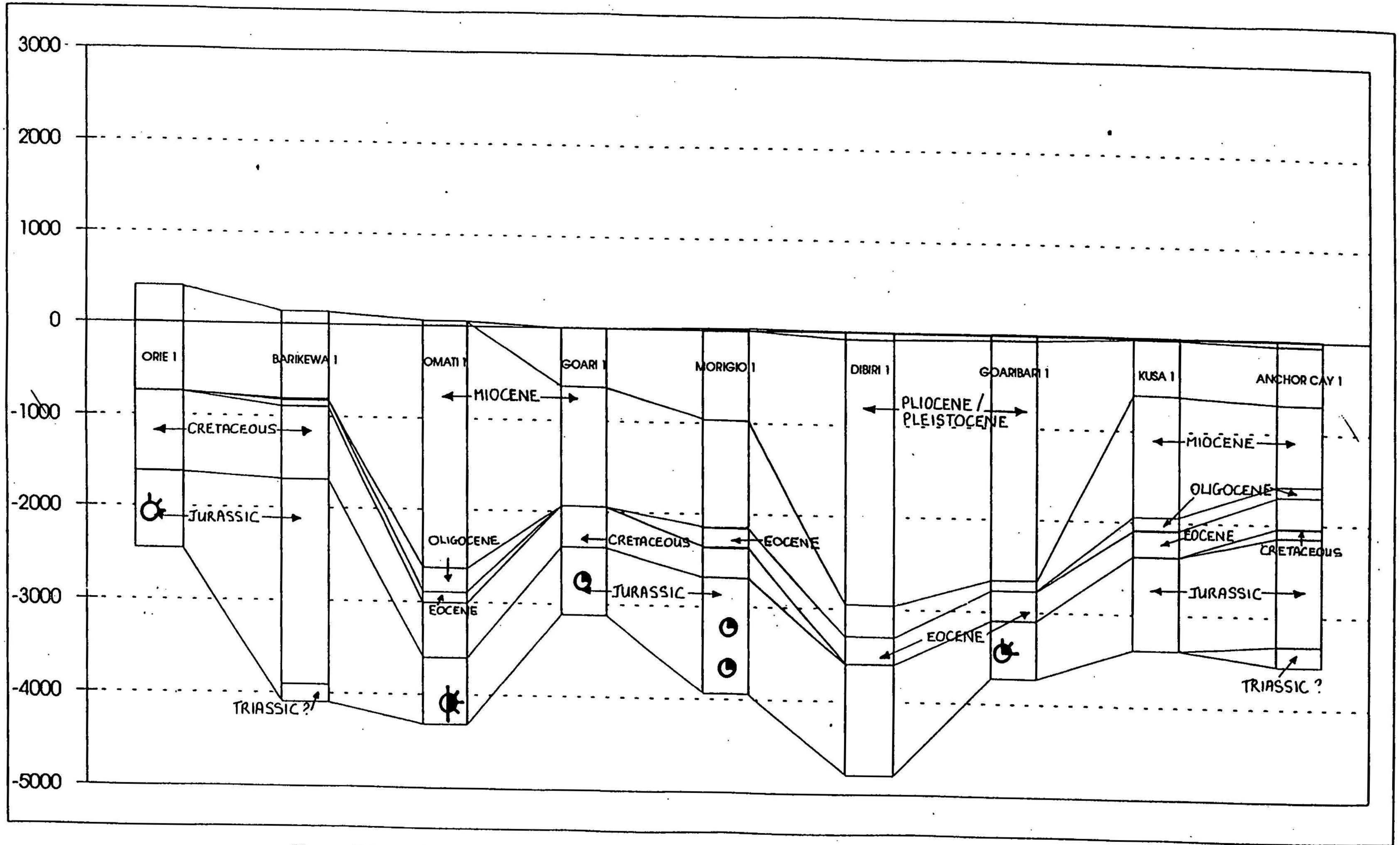


Figure 47 Papuan Basin Schematic Cross Section D-D' datum at Sea Level.
annotated [redacted]

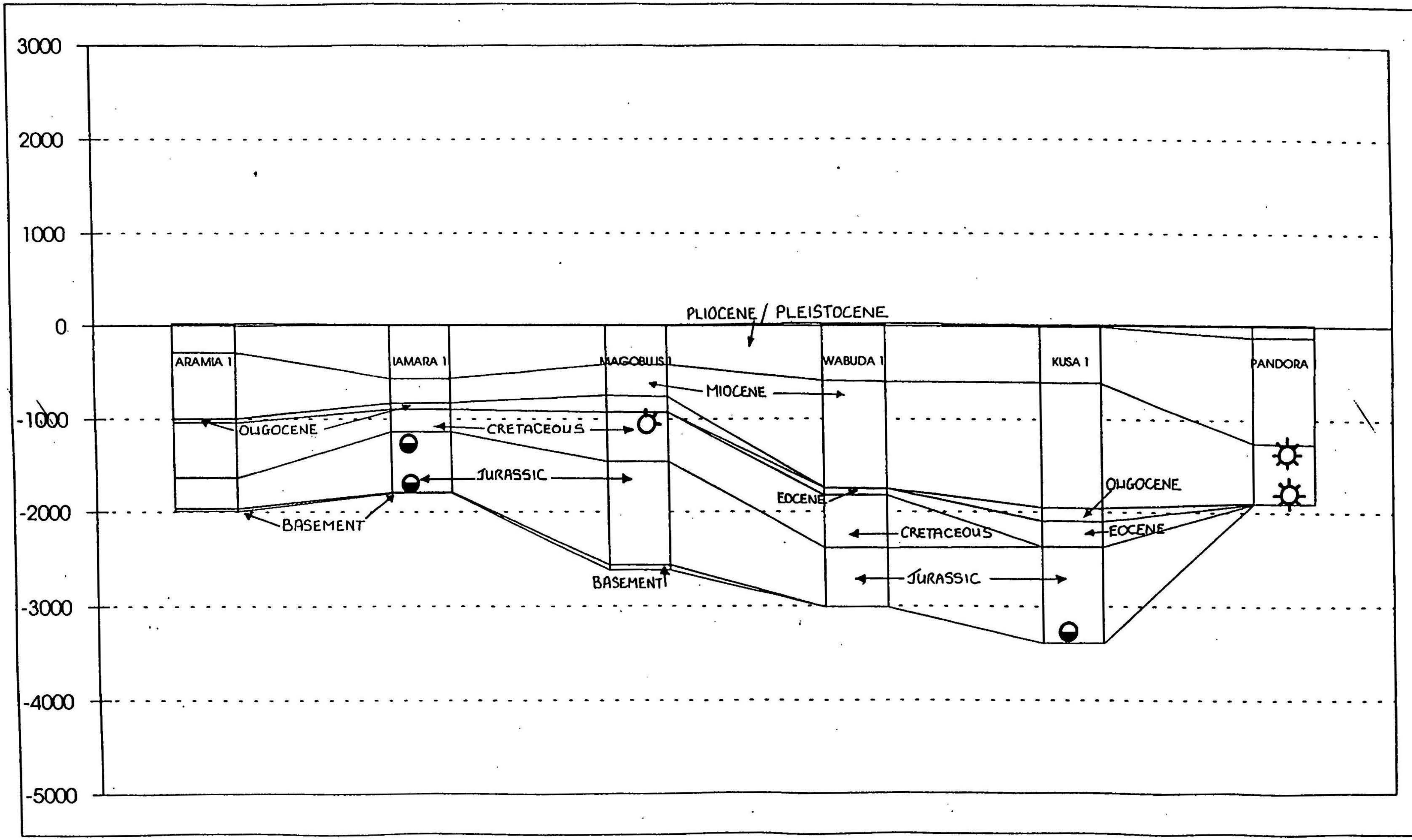


Figure 48 Papuan Basin Schematic Cross Section E-E' datum at Sea Level. annotated with hydrocarbon occurrences.

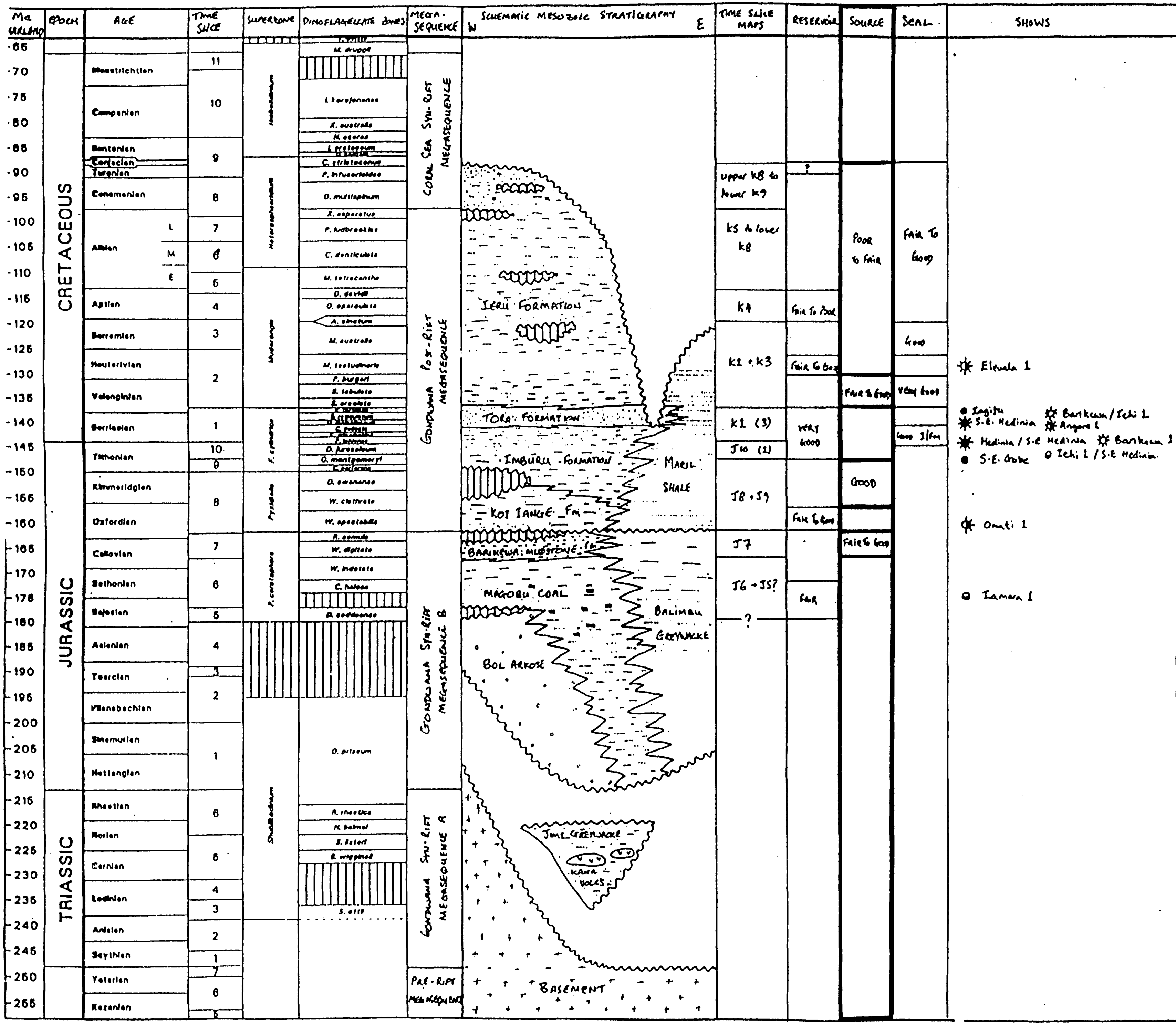


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FIGURE 49.
STRATIGRAPHIC AND LITHOLOGIC INFORMATION ON SOURCE ROCKS.

Schematic Mesozoic Stratigraphy Of The Papuan Basin

Modified From;
Barndollar 1993
Bradshaw & Winn 1988
Home et al 1990
Stuckmeyer et al 1990
Valenti 1993

GEOLOGICAL INPUT	ORGANIC GEOCHEMICAL INPUT
Stratigraphic and lithologic information	Identification of source rocks
Spatial relationship between source rocks and hydrocarbons	Oil source rock correlation
Palaeogeography and facies diagram	Regional extent of source rock and organic facies
Subsidence and geothermal gradients	Maturation stages of source rocks
Distribution of reservoir beds, faults and unconformities	Migration pathways in the basin
Subsidence and timing of trap formation	Timing of oil and gas generation, expulsion, migration and accumulation.

Figure 50 Geological and organic geochemical inputs to the assessment of petroleum potential.

MATURATION

Vitrinite reflectance (Ro) is a guide to the level of maturation of sediments. The following list, derived from Robertson Research (Jeffery, 1989) compares vitrinite reflectance values to their interpreted hydrocarbon generation phases:

Ro (0.5% - 1.2%)	window for oil generation
Ro (1.0%)	peak wet gas generation
Ro (2.0%)	limit of wet gas generation
Ro (1.5%)	peak dry gas generation
Ro (3.0% - 4.0%)	limit of dry gas generation

Figure 51 is a composite graphical plot subdivided into three columns. Each column contains several line graphs of vitrinite reflectance values versus depth. The three columns represent data from wells located in three different structural areas: the Gulf of Papua, the Foreland and the Fold Belt.

In the majority of wells vitrinite reflectance values range between 0.5% and 0.6% at a depth of 3000 m below the surface. This implies that the sedimentary sections at that level are just within the early mature oil window and shallower sections are considered to be within the immature phase.

Most of the hydrocarbons found to date are mainly light oils (> 42^{o} API) and condensates associated with large amounts of gas. The prevalence of gas and light oil can be the result of advanced maturity, the presence of mainly gas prone source material or from the displacement processes which favour phase separation. Since the source is of mixed marine and terrestrial character (classically type II/III) it is expected to be gas-prone, even at moderate maturity. However, source type and secondary processes being equal, more gas is expected where the source rock has a vitrinite reflectance above 1.0. From the limited data shown in Figure 51, only a few wells showed maturity levels that indicate late mature oil and peak wet gas threshold (usually 1.0% Ro). The 1% Ro level generally occurred at a depth range of 3800 m to 4000 m below the surface.

Dibiri 1, in the Gulf of Papua, shows a significant displacement in vitrinite values at approximately 3800 m where the values exceeded 1% Ro. This 'displacement' indicates that there is an unconformity at that depth. The higher maturity values below the unconformity

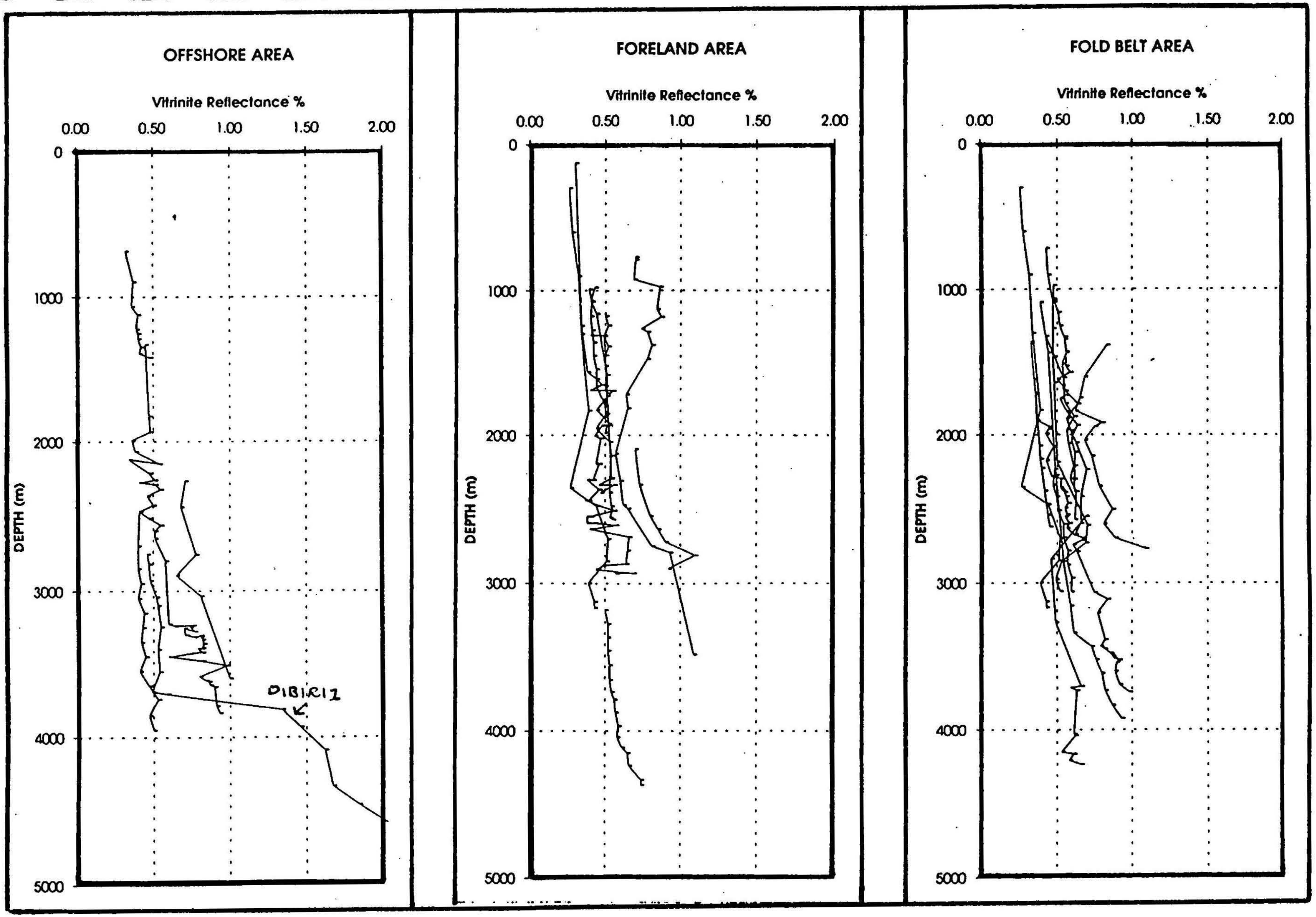

Figure 51 Vitrinite reflectance profiles for the study wells in the Offshore, Foreland and Fold Belt areas.

suggest that it was deeply buried prior to uplift and erosion. The data suggest that as much as 1500 m of Jurassic section has been removed at that level. The data also show a shift in gradient suggesting the sedimentary section below the unconformity was subjected to a slightly higher heatflow. These are all effects related to the opening of the Coral Sea in the Paleocene.

Appendix 9 maps vitrinite reflectance by time slice for the study wells. Apart from the expected increase in maturation with stratigraphic age, there is a consistent pattern of lower Ro values in Foreland and higher values in the Fold Belt.

Figure 52 shows the range of maturity levels across the Papuan Basin for the combined J8/J9 time slice. In the Gulf of Papua, geochemical data is sparse but the overall trend indicates very low maturity levels. At present day, the interval appears to have just reached the oil window. In the Fold Belt, the map shows a range in maturity levels from early maturity in Barikewa 1 to post mature in Juha 1. Both of these wells discovered significant volumes of gas, however, this dataset suggests that the gas in Barikewa 1 must have been sourced from deeper levels in the surrounding area.

Figure 53 shows the maturity levels over a broad interval from the J7 time slice and older. In the Gulf of Papua and the Fold Belt, the maturity levels are considered high enough to mature most source types beyond the wet gas phase and into the dry gas phase.

SOURCE ROCK ASSESSMENT

Source rock quality in terms of overall richness and oil/gas proneness is determined largely by the relative content of marine, as against humic terrestrial material, and hence position in relation to the palaeocoastline. Figure 54 maps source rock type for the combined J8/J9 time slice interval. Type III source rocks are dominant in the Gulf of Papua and a mixed Type II/III source rock is located in the present day Fold Belt area. This pattern is reflected in the palaeogeography (Figs 28 & 29), where a gradient existed from shallow marine environments in the Gulf of Papua to deeper marine environments in the Fold Belt. The interpreted palaeogeography suggests that Type II source rocks would have been deposited in the north east, beyond the well control, in deeper water. Our current knowledge of source rock character, although sparse, suggests that the Fold Belt may be more oil prone than the Foreland.

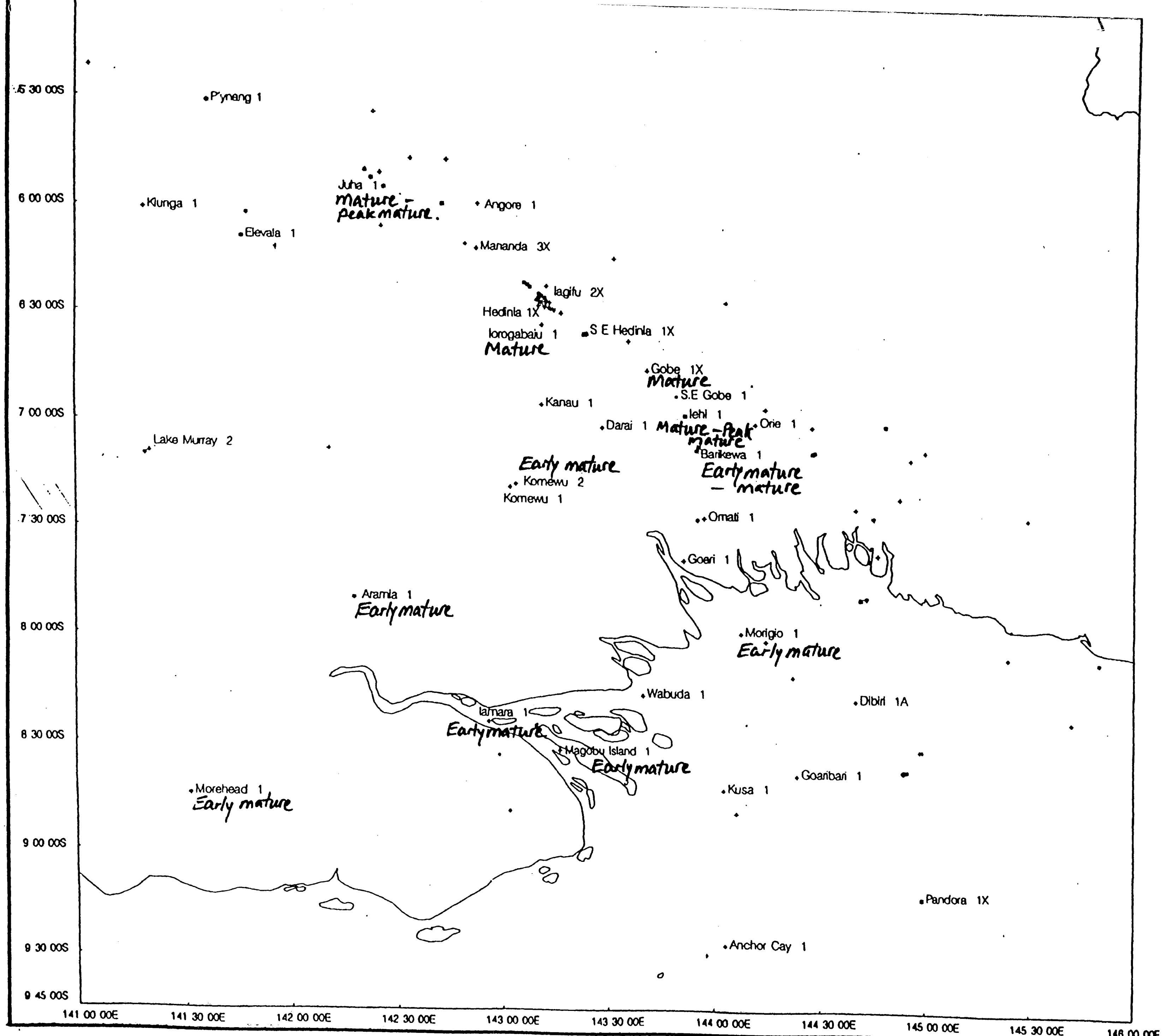

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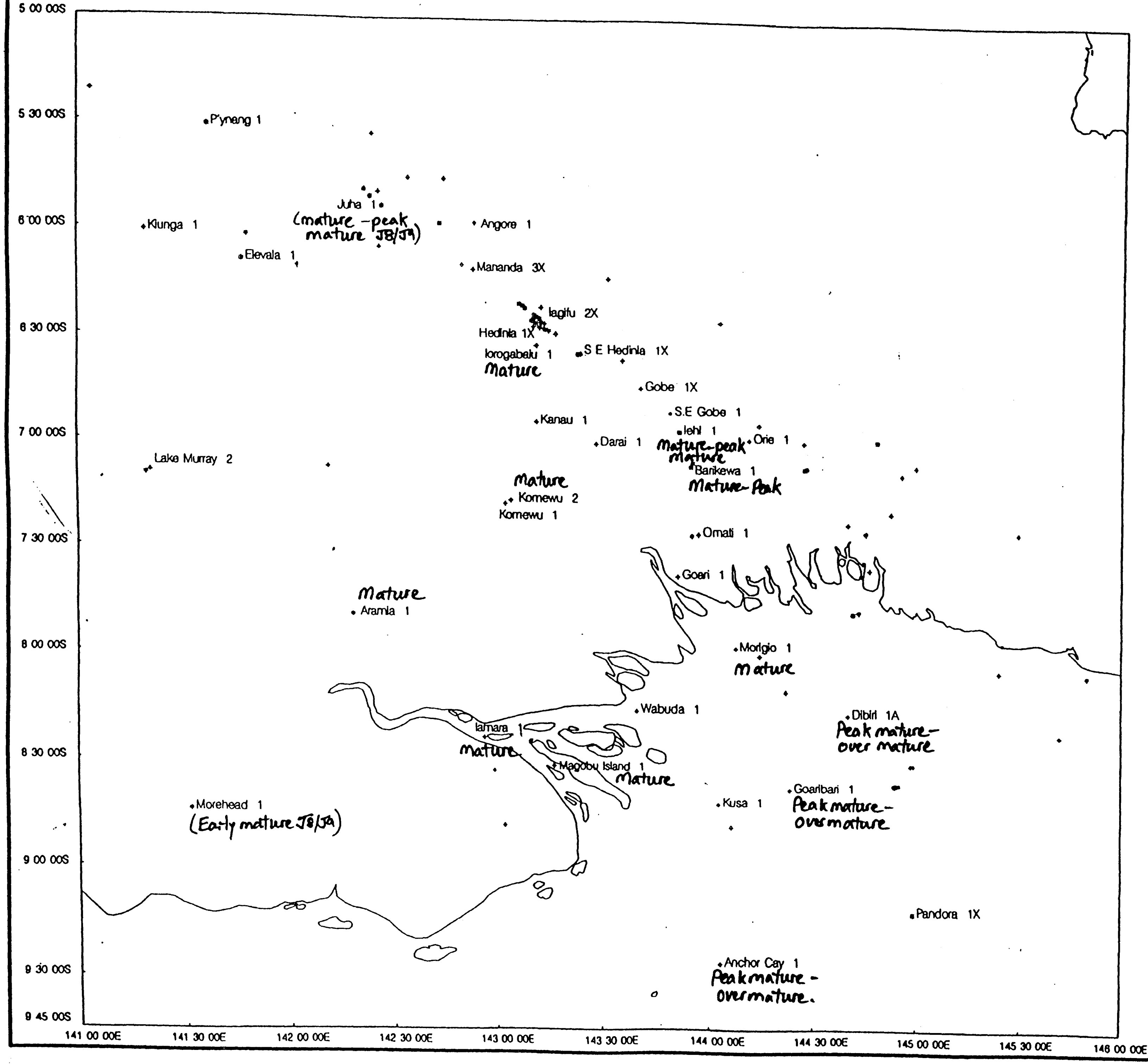
FIGURE 52.
TIME SLICES J8/J9
THERMAL MATURITY.



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PAPUAN BASIN MODULE

FIGURE 53.

TIME SLICES J7 AND OLDER

THERMAL MATURITY

0 15 30 45 60 75

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 147 00 00 E

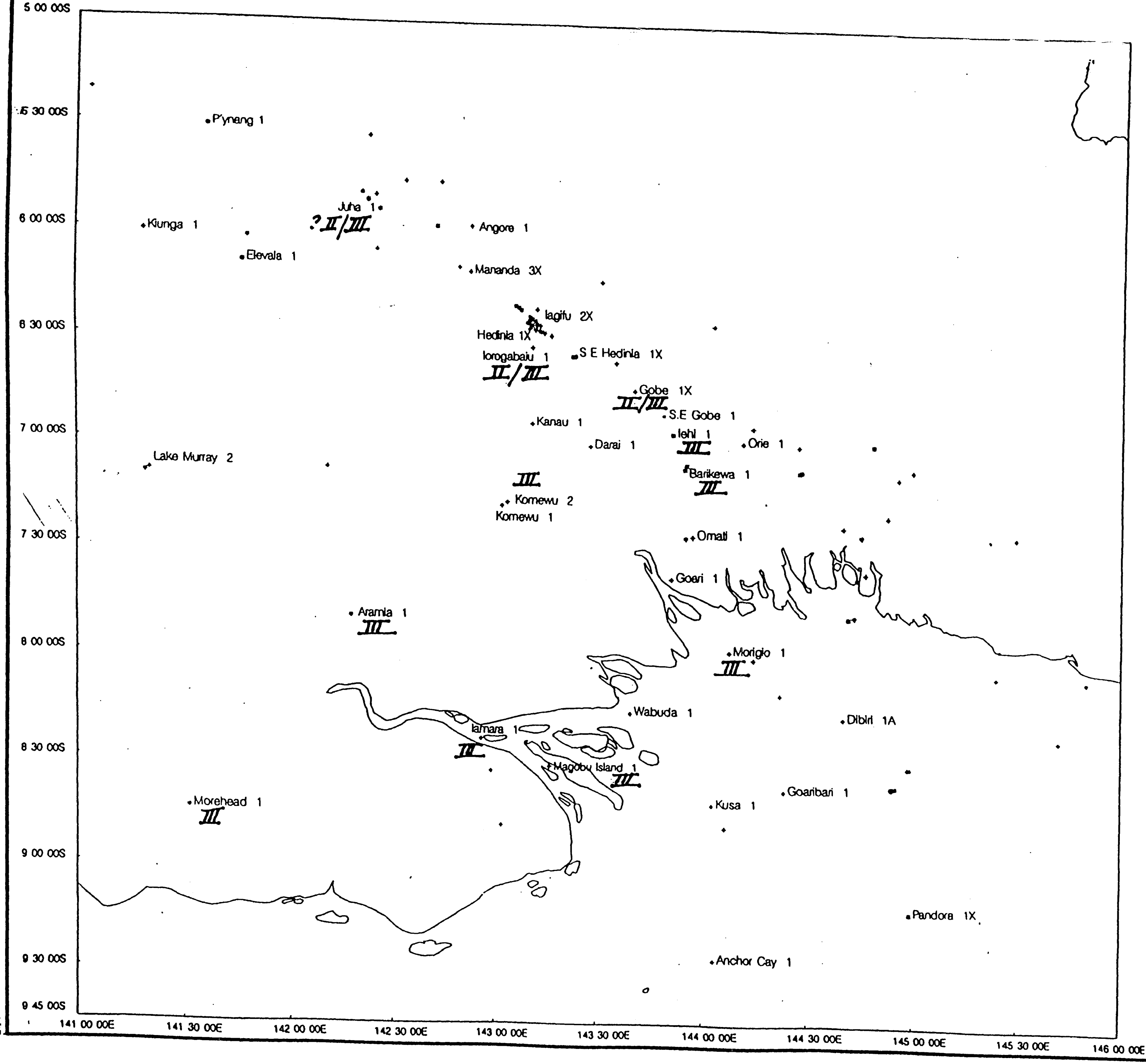

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FIGURE 54.

TIME SLICES J8/J9

SOURCE ROCK TYPE

0 15 30 45 60 75

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 147 00 00 E

However it should be remembered that hydrogen richness, expressed as HI, is the primary control on hydrocarbon generation and that hydrogen rich source rocks can be fully terrestrial in nature (e.g. Gippsland Basin, Ardjuna Basin, Taranaki Basin).

Total organic carbon content (TOC) and hydrogen index (HI) provide measures of source rock quality, and are mapped by time slice in Appendix 9. Fair to good source rocks have TOCs greater than 1% and average HIs above 150. Using this criteria intervals of source rock quality occur in the Cretaceous and Jurassic with some of the best potential in time slices J7, J8 and J9.

There is a correlation between lower energy marine environments and good source rock quality. For the combined time slice J5/6, TOCs are generally above 1%, but HIs are low in the upper delta plain sediments of the Foreland (Fig. 26). Source quality HI values only occur at Dibiri 1 in shallow marine sediments. The delta front and prodelta environments of time slice J7 (Fig. 27) have TOCs around 1 to 1.5% and the higher HI values are in the more marine environments in the east of the basin. A similar pattern occurs in Time Slice J8; and in J9, though TOC values are generally lower. The lobe of sand building into the basin, centred on Kanau 1 in time slice lower J10 (Fig. 32) had the effect of diluting the accumulating organic matter in the sediments, if the average TOC values in Kanau 1 (0.47%) and Komewu 2 (1.27%) are compared.

Source rock type, quality and maturation level all need to be considered to assess the hydrocarbon potential of an interval. Figure 55 is a geochemical composite log showing a combination of graphs presented in Appendices 11 to 16 for four wells. The vitrinite reflectance and Tmax profiles provide a visual estimate of the maturity levels at the well location. The Total Organic Content and oil generating potential (S1+S2) profiles provide an estimate of the source richness and the remaining potential yield. The Hydrogen Index profile provides a guide to the source type and when compared with the other curves, its relative maturity level.

The wells plotted in Figure 55 are representative of the Fold Belt, Foreland and Gulf of Papua. In Juha 1 in the north west of the Fold Belt, the Cretaceous and Jurassic section are in the oil window, but the source quality is poor, save for a narrow interval in time slice J10. Barikewa 1 is a Foreland well with the top of the oil window in the Upper Jurassic and fair to good source quality throughout the Jurassic, though gas prone. Komewu 2, another Foreland wells has similar maturation levels and TOC values to Barikewa 1, but with better

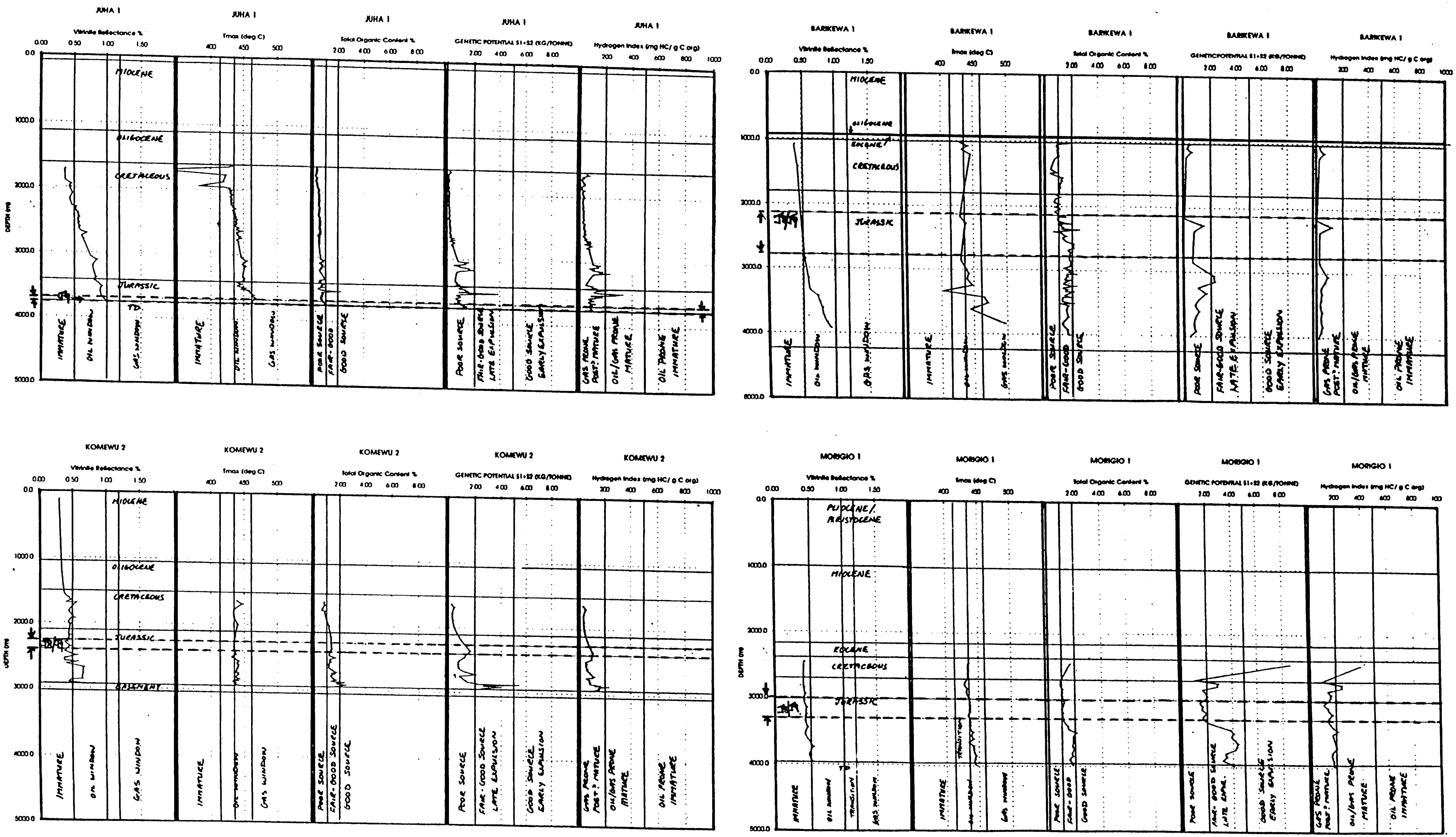


Figure 55 Profiles of vitrinite reflectance, Tmax, TOC, genetic potential and HI for Juha 1, Barikewa 1, Komewu 2 and Morigio 1.

source quality in the Middle Jurassic towards the base of the well. Morigio 1 in the Gulf of Papua only nudges into the oil window but has good source quality in the Jurassic section.

SOURCE ROCK AGE

Maturation values and oil and source rock geochemistry are all consistent with the major source of the hydrocarbons in the Papuan Basin being Jurassic sediments containing mixed marine and terrestrial organic matter. However, there are persistent and enigmatic reports of Tertiary biomarkers in oils which otherwise have the standard Jurassic source character. Angiosperm biomarkers (oleananes, bicadinanes and triterpanes) in seep oils in the New Guinea Mobile Belt; and from shallow seabed cores from Wabuda 1, in the mouth of the Fly River Estuary (Murray et al., 1993), point to the existence of a mature Cainozoic source. There are also reports of oleanane in some Fold Belt oils, including Hides 1 (Appendix 10; Pecten Nuigini, 1991), Omati 1, Puri 1A and Uramu 1A (Murray et al., 1993) which suggests some co-sourcing from the Tertiary.

Oil has been recovered from Miocene carbonates in Puri 1A, from a sub-thrust footwall location (La Rue, 1993). The geochemical signature of the oil is not consistent with a carbonate source rock. Though containing angiosperm biomarkers, it appears very similar to the typical Jurassic-sourced oils of the Fold Belt, with perhaps evidence of more marine-influence (Andrew Murray, unpublished). Puri 1A is located at the eastern end of the Fold Belt, where the depositional environments were more strongly marine throughout the Late Jurassic.

Gas has been discovered in Miocene reef reservoirs in the Gulf of Papua at Pasca (wet gas) and Pandora (immature, biogenic dry gas) and is believed to have been sourced from Cainozoic sediments (Durkee, 1990).

BURIAL AND THERMAL GEOHISTORY

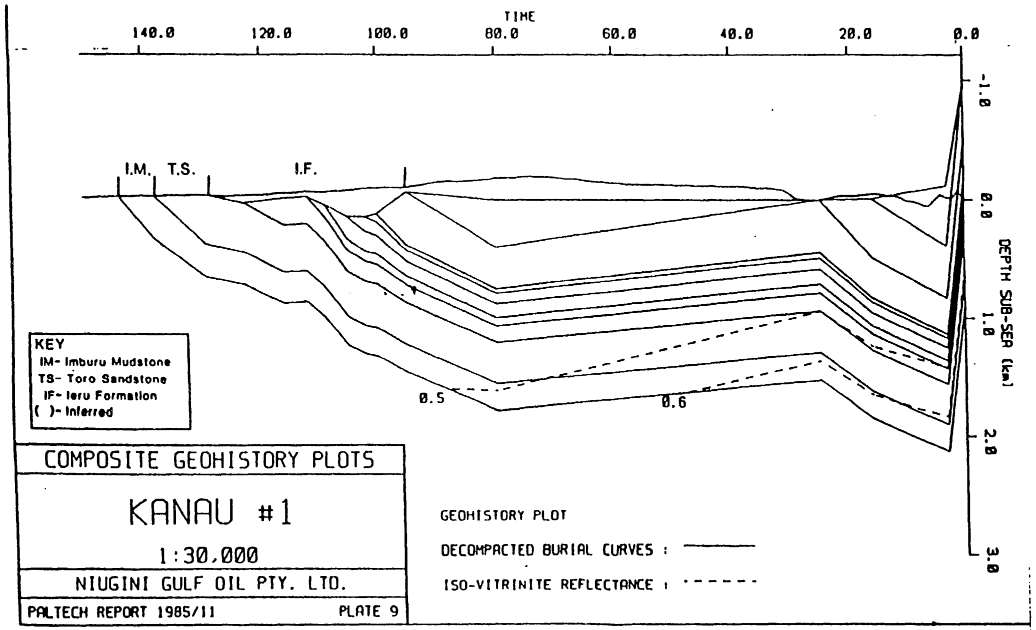
Several different types of generation and maturation models have been suggested by various authors. Most of the models indicate hydrocarbon generation from the Jurassic source rocks to have initiated in the Late Cretaceous. The timing of hydrocarbon generation is variable across the basin, primarily due to the level of maturation of the source rocks. Most authors suggest that there was a second phase of hydrocarbon generation which occurred in the Miocene and the Pliocene. Other authors suggest there was only one phase of hydrocarbon generation and expulsion. Earnshaw et al (1993) suggest from their study of fluid inclusion and cementation history that the petroleum charge took place during the Late Tertiary and Quaternary.

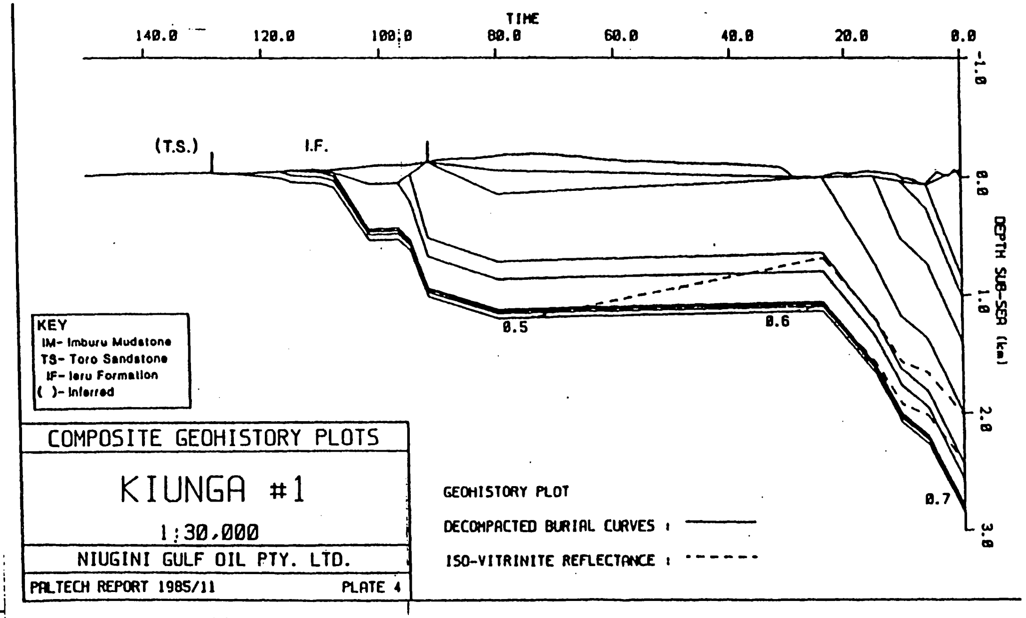
Figure 56 is a composite of geohistory plots of four wells produced by Paltech. These examples were selected to provide a good cross section sample of the basin. Most of the plots indicate the onset of the hydrocarbon generation in the Late Cretaceous.

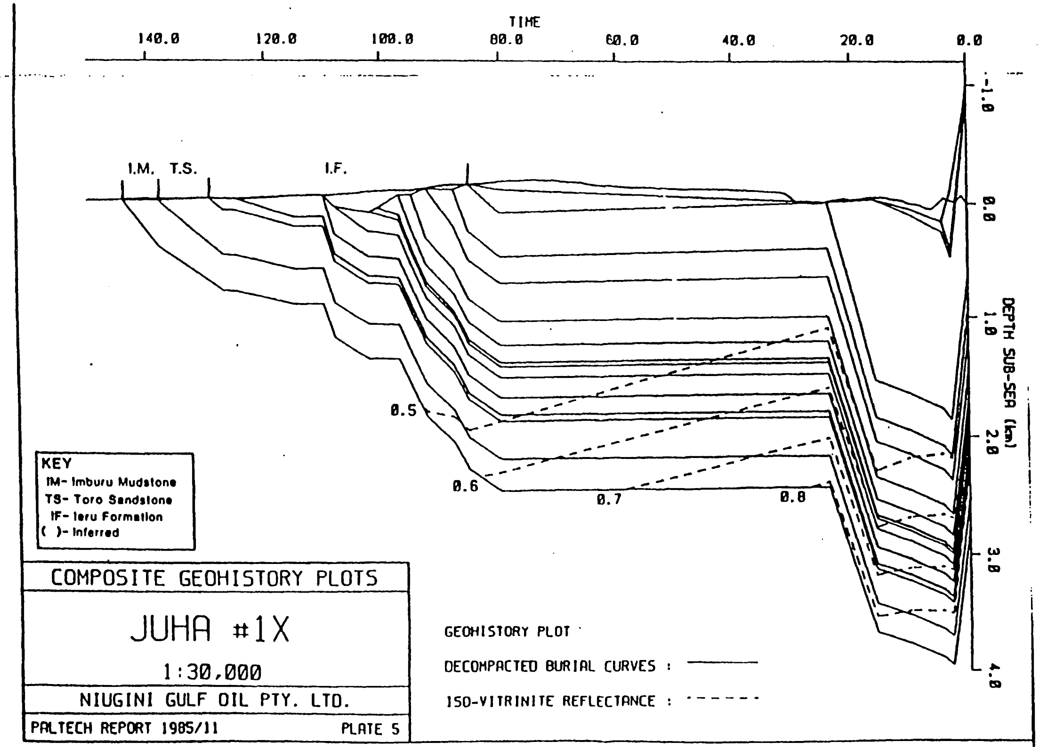
The following section lists some of the subsidence and thermal history details that were included in the modelling:

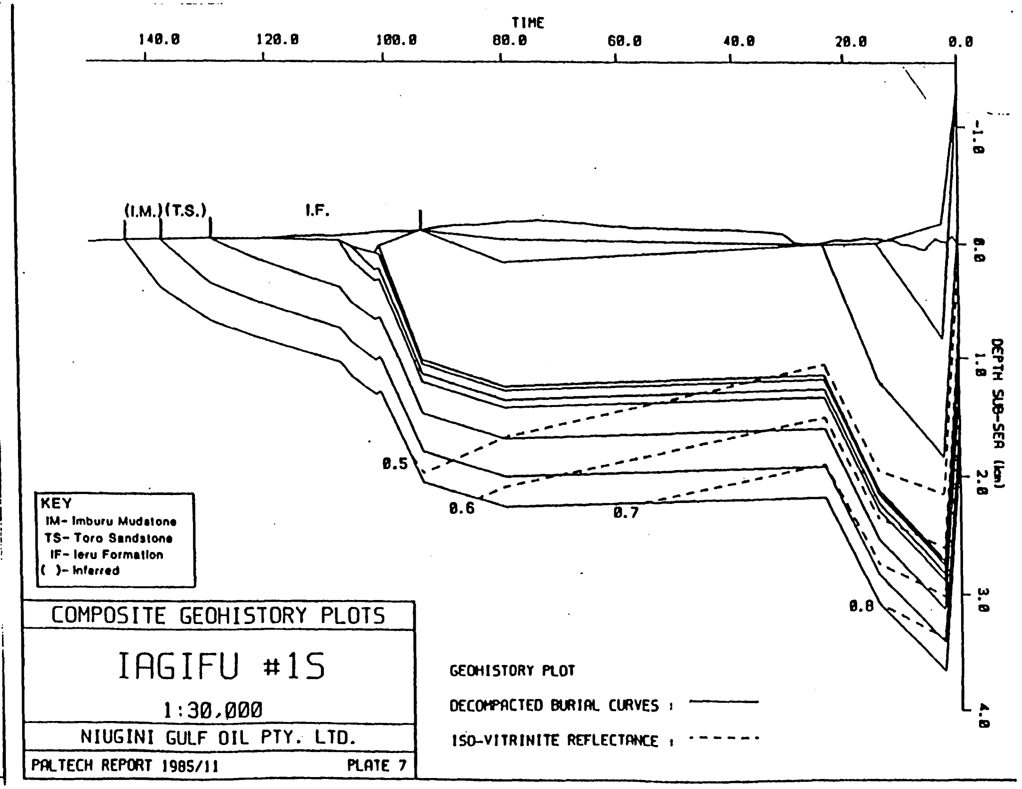
Barikewa 1
Basement modelled at 5000 m below surface and age of sediment immediately above basement modelled at 190 my. Rapid subsidence (Mid Jurassic-early Cretaceous) with two hiatuses at 143-140 my and 130-125 my. Slow subsidence during early Cretaceous but an increase in subsidence rates during Albian. Late Cretaceous uplift and erosion - about 1000 m. Slow subsidence during Eocene to Early Oligocene, followed by rapid late Oligocene-early Miocene subsidence. Plio-Pleistocene uplift and erosion - 500 m.

Predicted maturation curve indicates:
* Aramia Mudstone is immature
* Imburu Mudstone is currently Ro=0.67 to 0.8 and is mature during the last 20 my. Dry gas in Toro Sst is believed to be sourced by the underlying Imburu.
* Barikewa Mudstone is currently Ro=1.0 to 1.3 and is mature prior to late Cretaceous /early Tertiary uplift.


TIME
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
I.M.
T.S.
I.F.
0.5
0.6
-1.0
0.0
1.0
2.0
3.0
DEPTH SUB-SEA (km)
KEY
IM- Imburu Mudstone
TS- Toro Sandstone
IF- Ieru Formation
( )- Inferred
COMPOSITE GEOHISTORY PLOTS
KANAU #1
1:30,000
NIUGINI GULF OIL PTY. LTD.
PALTECH REPORT 1985/11
PLATE 9
GEOHISTORY PLOT
DECOMPACTED BURIAL CURVES :
ISO-VITRINITE REFLECTANCE :


TIME
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
(T.S.)
I.F.
0.5
0.6
0.7
-1.0
0.0
1.0
2.0
3.0
DEPTH SUB-SEA (km)
KEY
IM- Imburu Mudstone
TS- Toro Sandstone
IF- Ieru Formation
( )- Inferred
COMPOSITE GEOHISTORY PLOTS
KIUNGA #1
1:30,000
NIUGINI GULF OIL PTY. LTD.
PALTECH REPORT 1985/11
PLATE 4
GEOHISTORY PLOT
DECOMPACTED BURIAL CURVES :
ISO-VITRINITE REFLECTANCE :


TIME
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
I.M.
T.S.
I.F.
0.5
0.6
0.7
0.8
-1.0
0.0
1.0
2.0
3.0
4.0
DEPTH SUB-SEA (km)
KEY
IM- Imburu Mudstone
TS- Toro Sandstone
IF- Ieru Formation
( )- Inferred
COMPOSITE GEOHISTORY PLOTS
JUHA #1X
1:30,000
NIUGINI GULF OIL PTY. LTD.
PALTECH REPORT 1985/11
PLATE 5
GEOHISTORY PLOT
DECOMPACTED BURIAL CURVES :
ISO-VITRINITE REFLECTANCE :


TIME
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
(I.M.)
(T.S.)
I.F.
0.5
0.6
0.7
0.8
-1.0
0.0
1.0
2.0
3.0
4.0
DEPTH SUB-SEA (km)
KEY
IM- Imburu Mudstone
TS- Toro Sandstone
IF- Ieru Formation
( )- Inferred
COMPOSITE GEOHISTORY PLOTS
IAGIFU #1S
1:30,000
NIUGINI GULF OIL PTY. LTD.
PALTECH REPORT 1985/11
PLATE 7
GEOHISTORY PLOT
DECOMPACTED BURIAL CURVES :
ISO-VITRINITE REFLECTANCE :

Kanau 1

Late Cretaceous uplift and erosion - 500 m

Plio-Pleistocene uplift and erosion - 250 m

Observed Ro's are very high for the upper part of the well, compared to the Ro values for the lower part of the well, may be due to the thermal effects of Mt Bosavi, a Quaternary volcano.

* Imburu Mudstone is marginally mature
* Barikewa Mudstone is currently 0.72<Ro<0.8 and is mature since 60? my.
* Magobu Coal Equivalent mature since pre-Tertiary times

Kiunga 1

Late Cretaceous uplift and erosion - 250 m

Rapid subsidence commenced in late Oligocene and continued to recent.

Well has a thick upper carbonaceous sequence (low thermal conductivity - 1.0) and a quartzite basement (very high thermal conductivity) Computed curve poor match.

However, the predicted maturation profile indicates that the Toro Sst was mature between 45-35 my

Komewu 2

Late Cretaceous uplift and erosion - 250 m

Report does not mention Plio-Pleistocene uplift.

Computed maturation profile indicates basal section of well is, at most, marginally mature.

Attempts were made to re-model the geohistory of several areas. However, due to time constraints only one geohistory model, for Kiunga 1, was produced. Figure 57 is a geohistory plot of Kiunga 1. The plot has considerably more detail than the plot for Kiunga 1 shown in Figure 56. Both plots show that the initial onset of hydrocarbon generation occurred in the Late Cretaceous. However, the isoreflectance in both plots do not concur with the real vitrinite data from the well. At the base of Kiunga 1, vitrinite reflectance values were observed to be about 0.9% whereas both plots showed a value of 0.7%. This is probably due to the heatflow profile used in the model as shown in Figure 58. For a simple test of the model, only a constant heatflow profile was used. The effect on the calculated vitrinite reflectance versus the observed values are shown in Figure 59. A much higher heatflow anomaly is required to match the calculated curve with the measured vitrinite data.

Based on geological evidence, three major heat 'pulses' were experienced in the Papuan Basin. The first heat pulse relates to the Triassic and Early-Mid Jurassic syn-rift phase, the

Harland Age Scale.

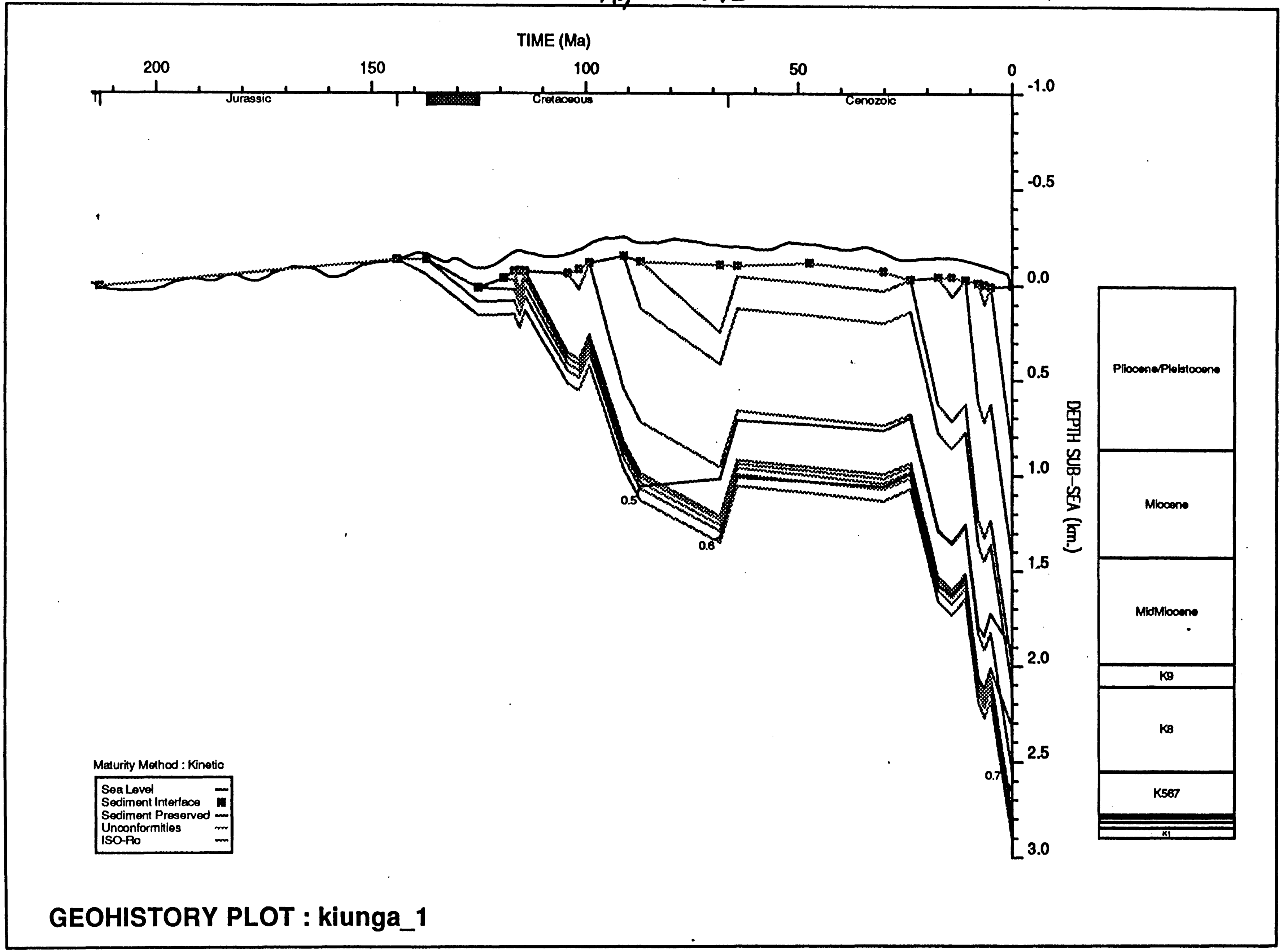


Figure 57 Geohistory plot for Kiunga 1

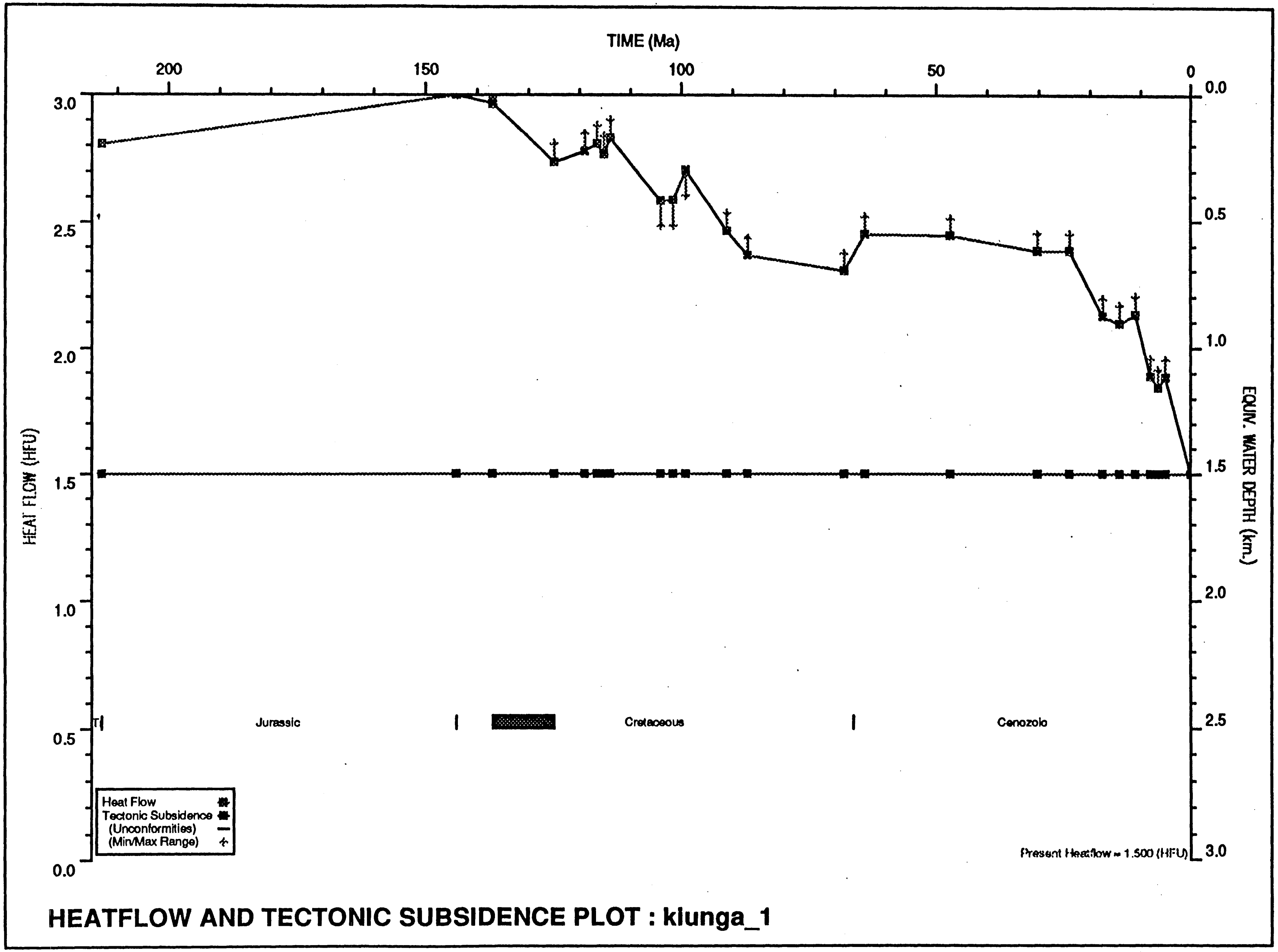


Figure 58 Heatflow and tectonic subsidence plot for Kiunga 1

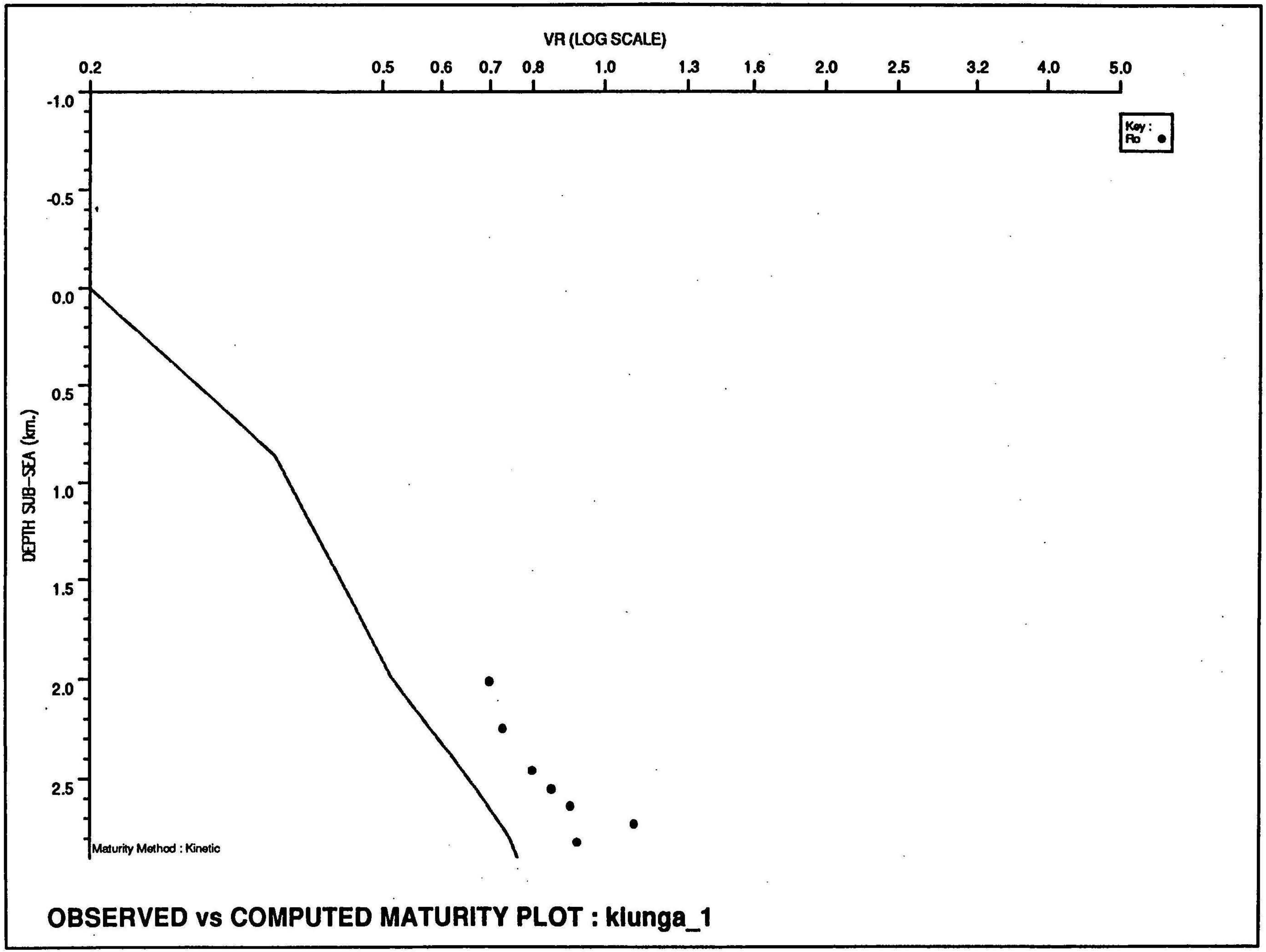


Figure 59 Observed/computed maturity plot for Kiunga 1

second during the Coral Sea syn-rift phase and the third pulse relates to the change from a passive margin to an active margin during the Tertiary. It is reasonable to expect that the higher heatflow will change the isoreflectance profile either shifting to the left of the time scale and/or up on the depth scale to include a much thicker section within the oil window.

Very few geohistory modelling packages exist that can handle the complexities associated with a thrust system. However, several synthetic examples have been generated by various authors such as Lerche (1990). Figure 60 is a composite of plots showing the thermal recovery time scale of a block overthrust on an underlying block. The following section was extracted from Lerche (1990) and refers to Figure 60.

'In the first set of examples a 1000 m thick block is overlaid instantaneously. The thermal gradient in both the underlying sediments and the overthrust block is set at 4°C/100m. For the overthrust block the surface temperature is set at 10°C. For the underlying block we vary the surface temperature so that at the moment of overthrusting, we can vary the temperature difference between the base of the overthrust block (temperature 50°C at the time of overthrust) and the top of the underlying sediments. After ovethrusting, the combined thermal system of two blocks tends to equilibrium and heads toward a final thermal gradient of 4°C/100m. For a thermal diffusivity of 0.01 sq cm/s (typical of sedimentary materials) shows that somewhere in the region of 1 MY after overthrusting, the thermal anomalies are negligible. Thus the recovery is rapid on a geological time scale. Increasing the thickness of the overthrust block to 2000m, but keeping all other parameters constant, the thermal anomalies are again removed in 1 to 10 MY after overthrusting. Even for an overthrust block of 4000m thickness, the time scale to reach thermal equilibrium is still of the order of 1 to 10 MY, although converging toward the 10 MY range. Therefore, overthrust blocks less than 2000-3000m in thickness, the cool down time is rapid (of the order of 1 MY) on a geologic time scale.'

In the Papuan Thrust Belt, overthrust blocks are commonly 2000-3000 m in thickness (as illustrated in Figures 61 & 62) and thrusting occurred in the last 1 to 5 MY.
From the synthetic models, the maturation levels of the underlying sediments would be approaching the equilibrium gradient of 4°C/100 m. This implies that some of the source rich intervals of the Ieru Formation and the basal Toro Sandstone sequences would be matured for peak hydrocarbon generation.

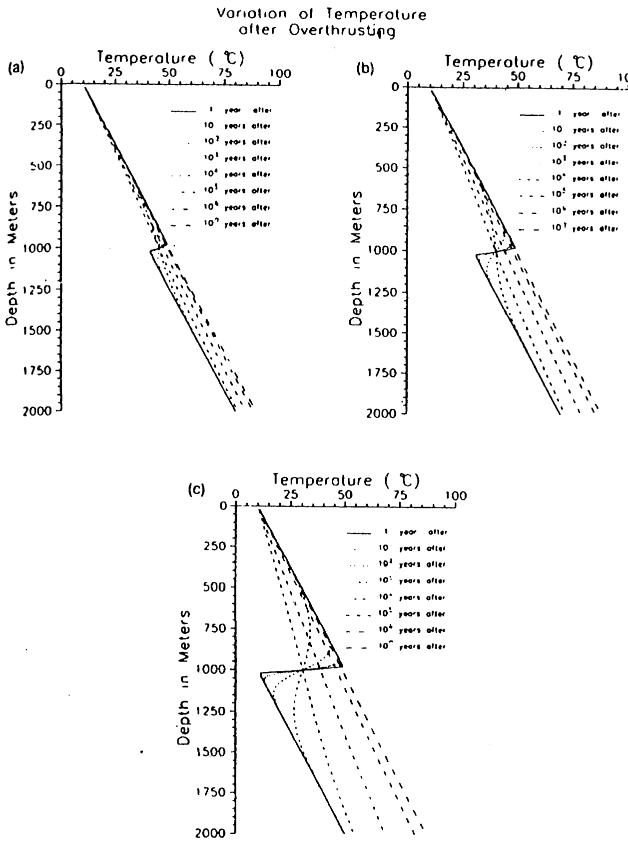


FIGURE 1 Temperature recovery curve with time after overthrusting of a 1000-m thick block for three different surface temperatures of the underlying block at the moment of overthrusting.

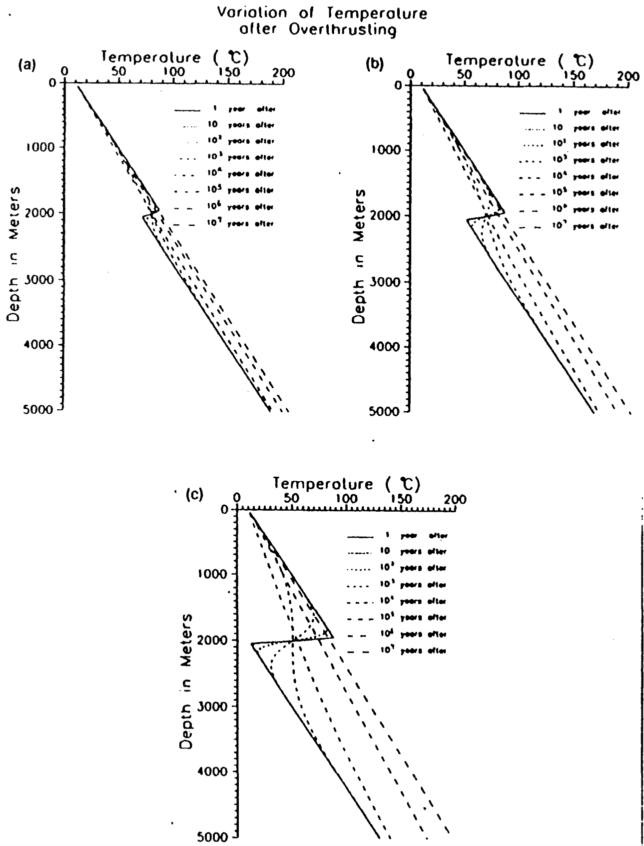


FIGURE 2 As for Fig. 1 but with the overthrust block thickness increased to 2000 m.

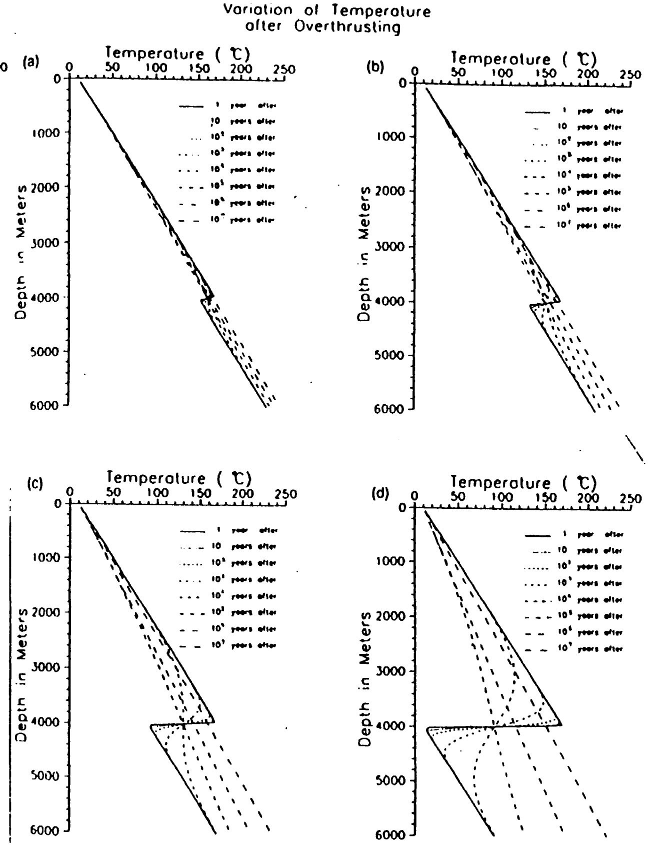


FIGURE 3 As for Fig. 1 but with the overthrust block thickness increased to 4000 m.

Figure 60 **Temperature recovery curves with time after overthrusting from Lerche (1990).**

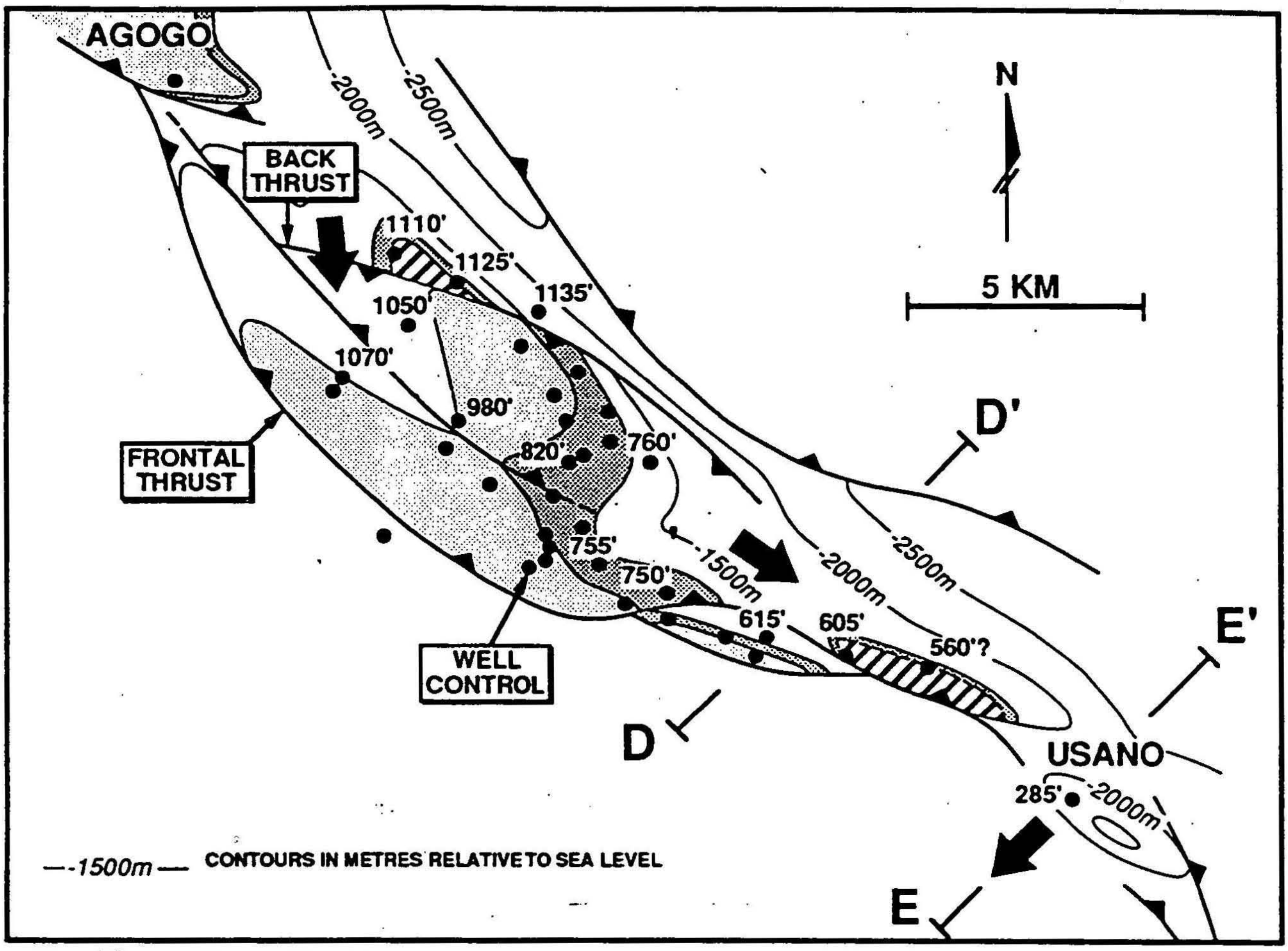


Figure 61 Top Toro structure contours (metres relative to sea level) from Eisenberg (1993).

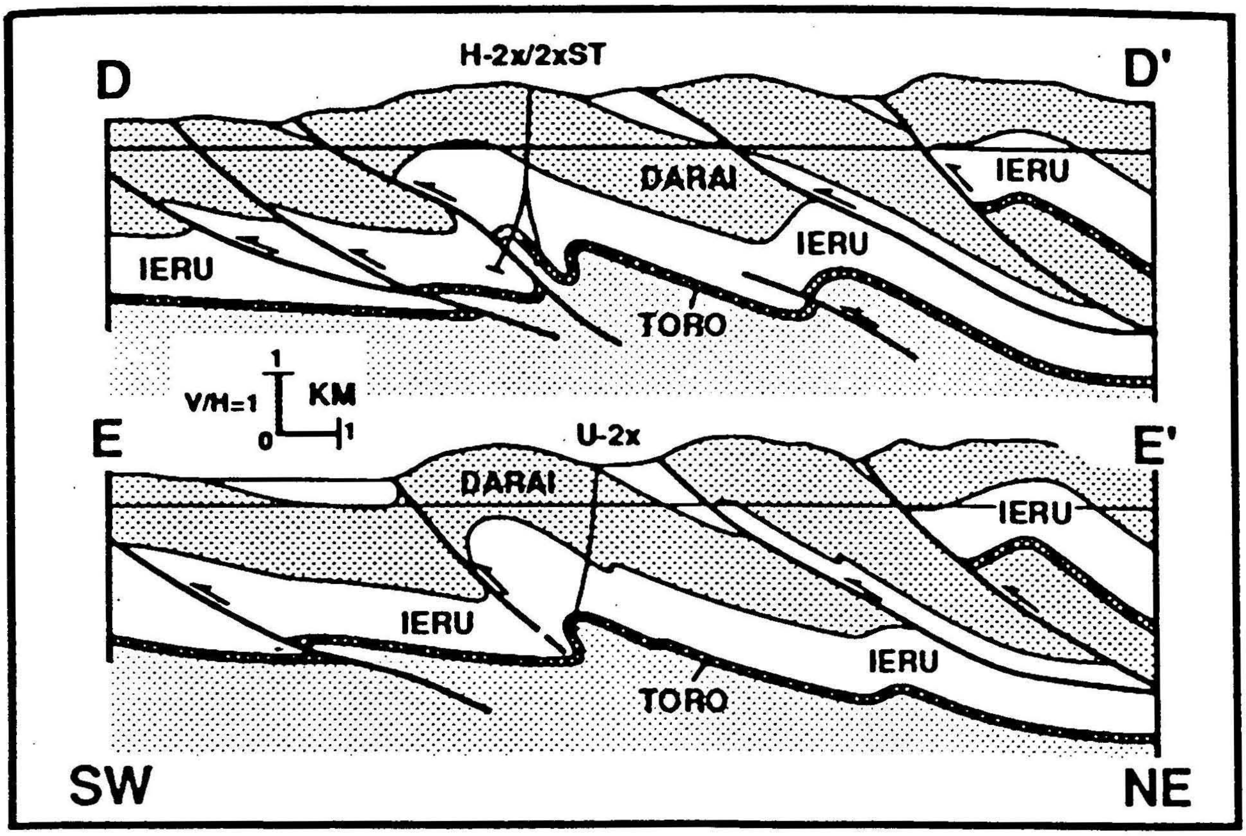


Figure 62 Schematic cross-section through Fold Belt from Eisenberg (1993). See Figure 61 for location of sections.

PETROLEUM SYSTEMS AND PLAY ANALYSIS

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 two of these occur in the Papuan Basin -- the Westralian and the Capricorn supersystems -- separated by a major regional unconformity in the Late Cretaceous. Both supersystems have operated successfully as indicated by the major hydrocarbon discoveries in each.

A model of the relationships between the components of the supersystems (Fig. 63) was proposed at the beginning of the study. Proven reservoir, seal and source facies are indicated in upper case; and potential reservoirs, seals and sources in lower case. Figure 64 was constructed at the completion of the study and plots against time the key events in the evolution of the petroleum systems in the Papuan Basin. The deposition of source, reservoir and seal facies; and of the overburden required for maturation, is shown, along with the

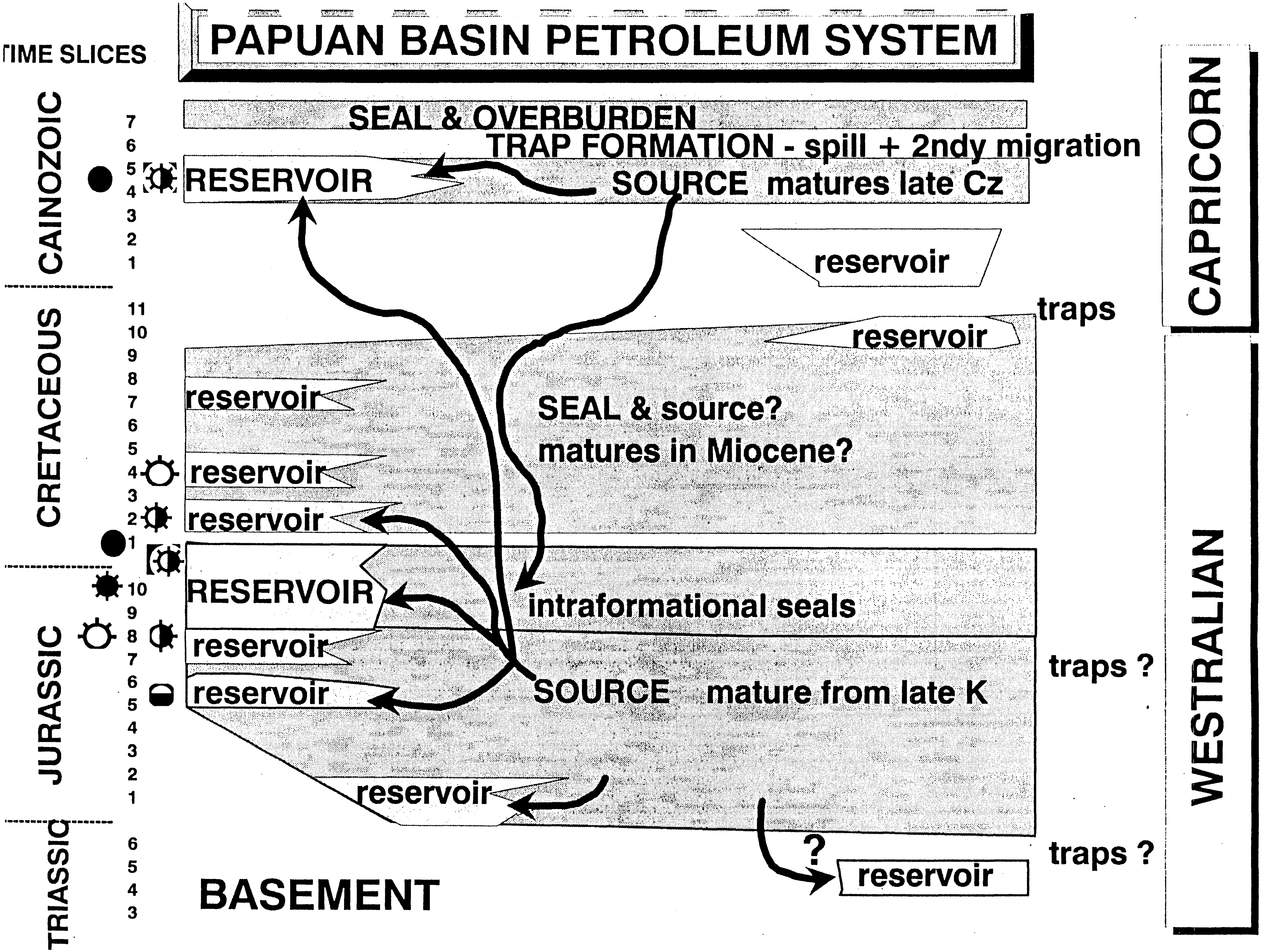


Figure 63 Model of Papuan Basin petroleum systems

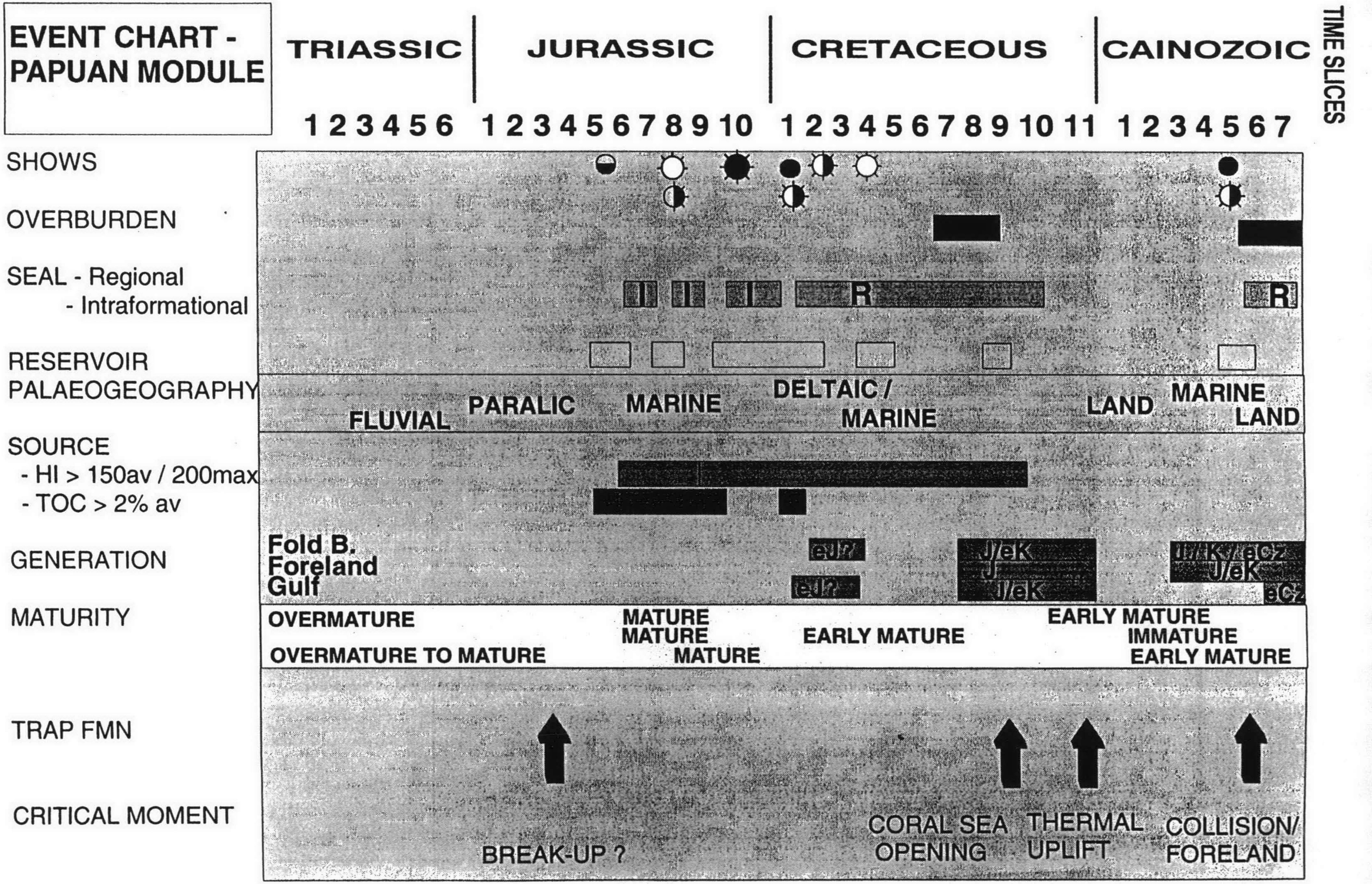


Figure 64 Event chart for the Papuan Basin module

timing of maturation, hydrocarbon generation and trap formation. The palaeogeographic and structural history is also charted.

There is no evidence of active Palaeozoic petroleum systems in the Papuan Basin; and little to indicate that there is any hydrocarbon potential in the pre-Mesozoic. Most of the basin is underlain by Palaeozoic metamorphics and Late Palaeozoic to Early Mesozoic intrusives that can be considered an extension of the Tasman Fold Belt of eastern Australia (a mineral not a petroleum province). To the west, parts of the basin are underlain by the undeformed Palaeozoic sediments of the Arafura Basin (Bradshaw et al., 1990) which may have some limited potential; though the intersection of 'meta-quartzite and meta-dolomite' in Mata 1 in the Morehead Sub-basin is not encouraging.

WESTRALIAN SUPERSYSTEM

The Westralian Supersystem links together basins, from the Exmouth Plateau 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 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 produced a palaeogeography 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 (Struckmeyer et al., 1993).

In the Papuan Basin, the Westralian Supersystem ranges in age from the Triassic to the Turonian. There is negligible reservoir potential in the scattered occurrences of Triassic volcaniclastic sediments. Early Jurassic sedimentation (time slices J1 to J4) was similarly restricted to the deposition of texturally immature sequences in localised fault bounded rift basins. These possible reservoir units are represented in Figure 63 and the potential of sourcing from the Middle and Upper Jurassic is indicated by arrows. However, the study results suggest that this was an overly optimistic part of the model, given the reservoir quality and the lack of hydrocarbon indications. In contrast, major gas, condensate and oil fields occur on the North West Shelf in Upper Triassic and Lower Jurassic sequences. Good quality reservoir sands and the coaly source facies for the giant gas and condensate accumulations were deposited in widespread fluvio-deltaic environments.

A relative sea level rise in the Early Bajocian (time slice J5) transgressed the previously emergent eastern Foreland and resulted in the widespread development of deltaic depositional environments. These deltaic sequences form the oldest prospective reservoir sands in the Foreland and are associated with an oil show at Iamara 1 (Fig. 64). They are sealed by upper J6 and J7 transgressive sequences. The upper J6 and J7 transgressive sequences are overlain by lower time slice J8 sharp based lowstand sands which produced gas with minor condensate at Omati 1 (Fig. 64). Renewed transgression in the upper portion of time slice J8 and J9 seals the lowstand sands and forms the regionally important Imburu Formation source interval. Geochemical analysis supports the initial model, in that most of the oil recovered from Jurassic, Cretaceous and Cainozoic reservoirs has been of one family consistent with a Jurassic source (Fig. 63). Other parts of the Westralian Supersystem also have source rocks in time slices J8 and J9; and Late Jurassic fan sands are important hydrocarbon reservoirs in the Dampier Sub-basin.

Excellent reservoir sands occur within time slice J10 and K1, the Upper Imburu and Toro Formations, and are associated with major hydrocarbon discoveries in the Fold Belt and the gas discoveries at Iehi 1 and Barikewa 1. Minor transgressive sequences within the J10 and K1 interval form intraformational seals for the lowstand sands. Time slice K2 marks the base of the transgressive lower Ieru Formation and forms a good regional seal for the upper Toro Formation sands. The J8 to J10 Imburu Formation is the likely source. To date, this has been the most common and successful Westralian Supersystem play in the Papuan Basin; and the same hydrocarbon habitat is seen in other parts of the supersystem, in particular the oil discoveries in the Damper and Barrow sub-basins.

A period of sediment outbuilding within the upper K2 time slice is responsible for the deposition of sands in the Foreland, the Alene sands, which form a significant Cretaceous play in the Foreland. They are associated with a gas condensate discovery at Elevala 1 and oil shows at Tarim 1 (Fig 63). The K2 sands are sealed by the overlying K3 to lower K8 transgressive deposits of the lower Ieru Formation.

Another reservoir interval is flagged by the gas occurrence at Lake Murray 1 in K4 offshore bar sands. These sands are quartzose and have good porosity, but in general the sands deposited in time slice K4 lack regional continuity and have poor permeability due to texturally immaturity and the input of volcanic detritus.

The upper Ieru Formation (upper K8 and K9 time slices) is characterised by high sedimentation rates, and the deposition of potential reservoir sequences in the northwestern portion of the basin. The time slice K8 and K9 sands require an extremely tortuous migration path if they are to receive a hydrocarbon charge from the Late Jurassic source interval; and to date only minor hydrocarbon indications have been reported. However, Late Cretaceous reservoirs are viable in other parts of the Westralian Supersystem, as shown by the oil discovery at Puffin in the Vulcan Sub-basin. In this case, migration is via a fault conduit from the Jurassic source rocks through the regional Cretaceous seal; and the complications of overthrusting and secondary migration are absent.

CAPRICORN SUPERSYSTEM

The Capricorn Supersystem is separated from the Westralian Supersystem by the major Late Cretaceous unconformity related to the opening of the Coral Sea. It is a distinct petroleum system with its own major hydrocarbon discoveries, indigenous mature source rocks, and a characteristically tropical caste to its facies. The proven reservoirs are Miocene carbonates which contain oil at Puri IA and gas in reef traps at Pandora and Pasca. Other reservoirs include Pliocene sands that flowed gas at Tovala 1, and potentially, the late Cretaceous Pale Sandstone (Carman, 1993) and reefs in the early Cainozoic Mendi Group carbonates. A series of marine shales, marls, and volcaniclastics are potential seal facies.

The presence of angiosperm biomarkers in various oils in the basin (Murray et al., 1993) shows that there is a mature, deltaic source rock in the supersystem. There is also the potential for other source rock types such as marine carbonate back reef facies; and possibly lacustrine oil shales as occurs in another part of the supersystem, in the coastal basins of Queensland (Bradshaw, 1993). As previously discussed, the geochemical signature of the oil in Puri 1A is consistent with a Jurassic source as indicated by the arrow on Figure 63 linking the Westralian and Capricorn supersystems. Angiosperm biomarkers in some Fold Belt oils suggests that a similar arrow is required in the opposite direction.

TIMING OF GENERATION AND TRAP FORMATION

Figure 64 plots the timing of overburden deposition, hydrocarbon generation and trap formation. The model illustrated here suggests that there may have been some early generation from early Jurassic source rocks in the early Cretaceous in the Fold Belt and Foreland as a result of sediment loading (Figs 22 & 64). A major episode of generation from Jurassic source rocks throughout the basin occurred in the Late Cretaceous (Barndollar, 1993; Earnshaw et al., 1993) in response to the deposition of thick Coral Sea syn-rift sediments (see Fig. 22). The uplift and erosion associated with the opening of the Coral Sea stopped hydrocarbon generation in the Latest Cretaceous/early Tertiary (Fig. 64; Earnshaw et al., 1993). Foreland loading in the Miocene and overthrusting in the Pliocene provided the overburden for another major phase of generation in the late Cainozoic (Earnshaw et al., 1993) from Jurassic, Cretaceous and early Cainozoic source rocks (Fig. 64).

Hydrocarbons generated in the early Cretaceous may have been trapped in fault block structures formed during Gondwanan rifting dúring the late Triassic and early Jurassic. Other possible traps formed in the Jurassic were combination structural/stratigraphic traps related to fans on the downside of syn-depositional faults such as the Komewu Fault. Deposition of the Early Cretaceous regional seal largely post-dated this first phase of generation, though it is likely that adequate intraformational seals were in place. These trap types have the best chance of preservation in the Foreland.

Formation of extensional fault block traps coincided with the major phase of generation and migration in the Late Cretaceous related to Coral Sea rifting (Fig. 64). This structuring was probably controlled by the pre-existing fault fabric and may have enhanced some of the earlier formed traps. The regional seal of the Cretaceous shales was now in place and the volume of hydrocarbons expelled was greater than in the proposed episode of early Cretaceous generation. The uplift and erosion in the latest Cretaceous and early Tertiary would have destroyed many of these traps, especially in the Gulf region where kilometres of sediment were stripped off.

Late Cainozoic thrusting created new traps and destroyed pre-existing traps. This period of trap formation coincided with the last major phase of hydrocarbon generation. The fluid inclusion work of Earnshaw et al. (1993) shows that the large anticlinal fields of the Fold Belt received their hydrocarbon charge in the Pliocene to Recent and that some of these hydrocarbons were re-migrated from accumulations trapped in the Cretaceous. The Cainozoic source rocks of the Capircorn Supersystem were matured and generated at this time; and with the spill of hydrocarbons from pre-existing traps there was the potential for Fold Belt accumulations to contain both Jurassic and Cainozoic derived oils, as indicated by their geochemical signatures (Murray et al., 1993). Another trap type formed in the Cainozoic is the stratigraphic traps of the Miocene reefs in the Capricorn Supersystem.

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