DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1978/33

EXPLANATORY NOTES TO ACCOMPANY STRATIGRAPHIC COLUMNS - CARNARVON BASIN, AUSTRALIA

by

V.L. Passmore

Record 1978/33

EXPLANATORY NOTES TO ACCOMPANY STRATIGRAPHIC COLUMNS - CARNARVON BASIN, AUSTRALIA

by

V.L. Passmore

CONTENTS

Introduction

The Carnarvon Basin lies along the central western coast of Australia and occupies an area of 110 000 km2 onshore and 190 000 km2 offshore. It is an elongate downwarp, 1000 km long and 300 km wide, marginal to the Australian craton. The Carnarvon Basin is separated from the Canning Basin to the north by the North Turtle Arch, and from part of the Perth Basin to the south by several structural features, including the Northhampton Block, Hardabut Fault, and the Ajana Ridge (Fig. 1). Along the eastern boundary, where the basin limits are best defined, basin sediments either onlap or are in faulted contact with Precambrian rocks of the Pilbara, Gascoyne, and Yilgarn Blocks. The western limit is an arbitrary boundary formed by bathymetric features: the Exmouth Plateau, Cuvier Abyssal Plain, and the Wallaby Saddle.

Until late in the Palaeozoic, sediments were deposited in an intracratonic basin, which developed by gentle downwarping during a period of tectonic stability. Subsequent basin evolution has been related in plate tectonics terms to the events which led to the break up of eastern Gondwanaland and resulted in the Carnarvon Basin becoming one of a series of basins along the Australian continental margin.

The Carnarvon Basin is structurally complex and is divided into several provinces by faults and geophysically defined ridges and highs (Fig. 1). Over 15 000 m of Late Ordovician-Silurian to Holocene basin sediments unconformably overlie sedimentary, metamorphic, and igneous Precambrian basement rocks. Pre-Permian rocks are known only in the southern Carnarvon Basin (Fig. 3), where they crop out and were reached in wells. In the northern Carnarvon Basin, wells have not penetrated below the Permian, but did encounter the thickest and most complete sequence of Mesozoic rocks in the basin (Fig. 4). The Cainozoic sequence is known from both the northern and southern parts of the basin, but is probably best documented from the many wells drilled in the north.

Substantial quantities of gas have been discovered in the northern offshore part of the basin, and oil has been found both onshore and offshore. Barrow Island oil field is currently the only field in production. Production from the large gas reserves, the largest in Australia, is expected to commence in the next decade.

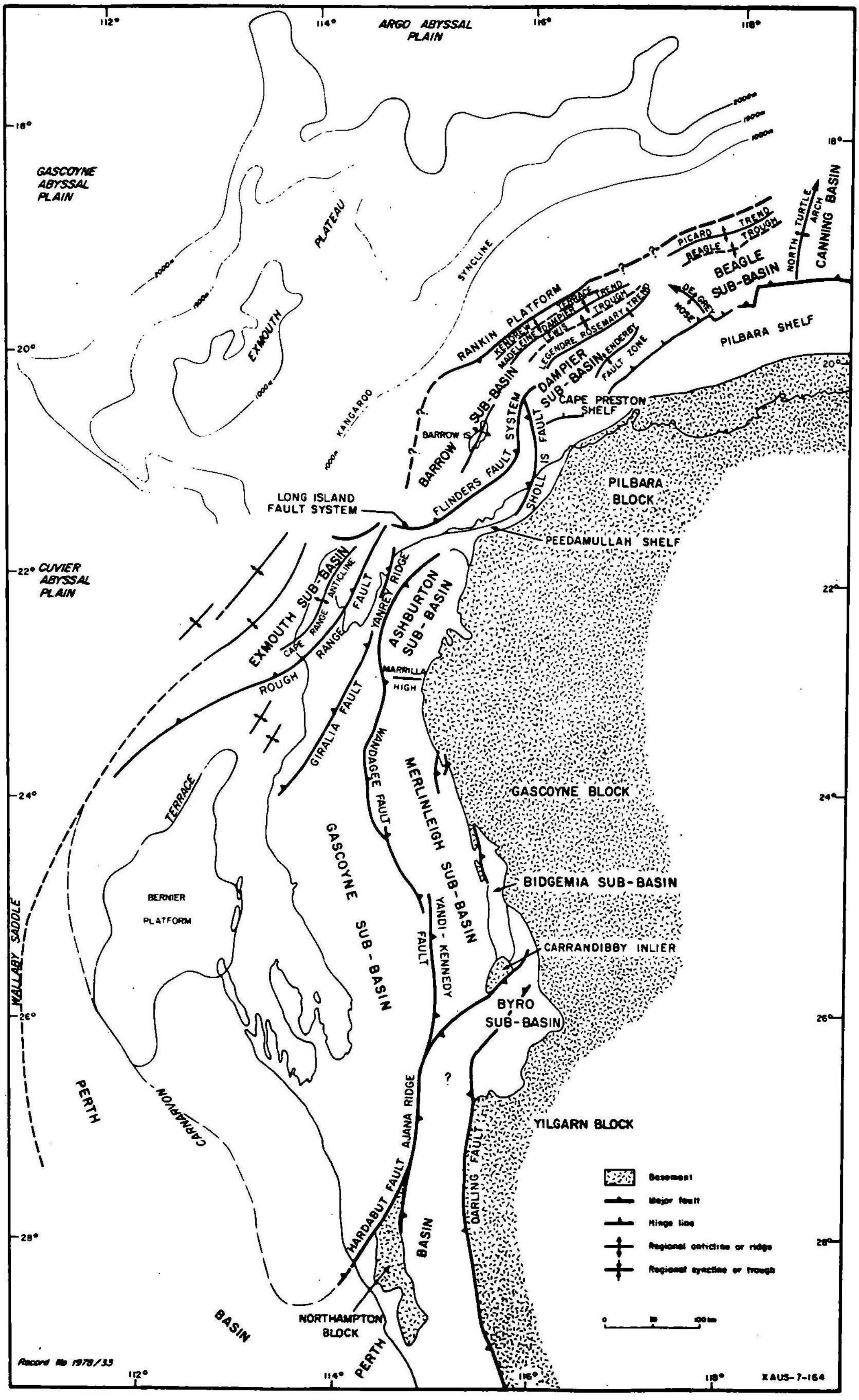


Fig. 1 Carnarvon Basin tectonic elements
(after WAPET & BOC interpretations)

Data Compilation

Most of the wells used on the cross sections (Figs. Au 1a to 1e) are sited offshore in the northern part of the Carnarvon Basin where well density is greatest, owing to the hydrocarbon discoveries in the Dampier and Barrow Sub-basins. The stratigraphy is largely based on company interpretation from well completion reports (Table 1). Mesozoic and Cainozoic unconformities and disconformities shown represent faunal breaks determined from company micropalaeontological reports; the older unconformities are from regional geological relationships.

The stratigraphy of the Carnarvon Basin is shown in the generalized stratigraphic table (Fig. 2). Some formation names which are informal or only in local use have been omitted from the stratigraphic table, although they appear on the cross-sections. Because the stratigraphic table covers the whole of the Carnarvon Basin, some formations on the table were not encountered in the representative wells used for the cross-sections. The term Barrow Formation (Playford & others, 1975) which conforms with the Australian Code of Stratigraphic Nomenclature is used instead of the informal, but more familiar, company term, Barrow Group.

The references used to compile these notes are listed in the selected bibliography.

Regional Tectonic Evolution

The Phanerozoic tectonic evolution of the western margin of Australia can be related to two separate phases: a speculative, early to middle Palaeozoic phase in which the Tethys Sea is postulated to have developed as Gondwanaland separated from Eurasia; and a better known latest Palaeozoic to Mesozoic phase which has been related, in terms of plate tectonic theory, to the separation of the "Indian" and Australian parts of Gondwanaland, the pattern of development being similar to that of the "Atlantic type" margin model.

The inception of the Tethys Sea was marked locally, at the northern end of the present western margin, by Early Cambrian volcanism and the development of a northwest-trending aulacogene which became the site of earliest deposition (Bonaparte Gulf Basin) in the Middle Cambrian, when shallow marine conditions were established in a postulated arm of the Tethys Sea. Subsequent

AGE		UNIT	ENVIRONMENT	HYDROCARBON
QUAT.	PLEISTOCENE	UNNAMED / EXMOUTH SANDSTONE	MARINE	
TERTIARY	PLIOCENE	TREALLA LIMESTONE		
	MIOCENE	CAPE RANGE GROUP		
	OLIGOCENE	GIRALIA CALCARENITE		
	EOCENE			
	PALEOCENE	CARDABIA GROUP		
CRETACEOUS	LATE	MIRIA MARL TOOLONGA CALCILUTITE		
	EARLY	WINNING GROUP: GEARLE SILTSTONE, WINDALIA RADIOLARITE, MUDERONG SHALE BIRDRONG SANDSTONE		● ☼
		WOGATTI SANDSTONE / BARROW FORMATION	DELTAIC TO FLUVIAL	● ☼
JURASSIC	LATE MIDDLE EARLY	LEARMONTH FM / LEGENDRE FM / Dupuy Member, DINGO CLAYSTONE	MARGINAL TO NON-MARINE / MARINE TO "DELTAIC"	● ☼
TRIASSIC	LATE MIDDLE	MUNGAROO FORMATION	FLUVIAL TO MARGINAL MARINE	● ☼
	EARLY	LOCKER SHALE	MARINE TO MARGINAL MARINE	
PERMIAN	LATE	UNNAMED	MARINE AND MARGINAL MARINE	
	EARLY	KENNEDY GROUP BYRO GROUP WOORAMEL GROUP		
		CALLYTHARRA FORMATION	MARINE	
		LYONS GROUP	GLACIAL MARINE TO LACUSTRINE	
CARB.	EARLY	YINDAGINDY FORMATION WILLIAMBURY FORMATION	"DELTAIC" TO MARINE	
		MOOGOOREE LIMESTONE	MARINE	
DEVONIAN	LATE	WILLARADDIE FORMATION	NEAR SHORE MARINE	
		MUNABIA SANDSTONE	SHELF TO MARINE	
	MIDDLE	GNEUDNA FORMATION		
	EARLY	NANNYARRA GREYWACKE	CONTINENTAL	
SILURIAN	LATE	DIRK HARTOG FORMATION	SHELF	
	EARLY	TUMBLAGOODA SANDSTONE	CONTINENTAL	
ORD.				
pЄ				

BMR File No. XAUS-7-162

Record No 1978/33

Fig.2 Generalised Stratigraphy of the Carnarvon Basin (after Playford & Others, 1975; & Thomas & Smith, 1974)

TABLE 1. WELLS USED IN CROSS-SECTIONS

COMPANY WELL NAME	YEAR	T.D. (m)	SUB-BASIN
BOC OF AUSTRALIA LTD			
Dampier 1	1968/69	4142	Dampier
Madeleine 1	1969	4428	Dampier
Enderby 1	1970	2149	Dampier
Legendre 2	1970	3618	Dampier
De Grey 1	1971	2088	Pilbara Shelf
North Rankin 1	1971	3534	Dampier
Rankin 1	1971	4111	Dampier
Angel 1	1971/72	3411	Dampier
Hauy 1	1972	825	Pilbara Shelf
Sable 1	1972	3972	Beagle
Cossigny 1	1972/73	3203	Beagle
Picard 1	1972/73	4216	Beagle
Rosemary 1	1972/73	3909	Dampier
Ronsard 1	1973	2848	Beagle
Lambert 1	1973/74	3700	Dampier
Depuch 1	1974	4300	Beagle
WEST AUSTRALIAN PETROLEUM PTY LTD			
Cape Cuvier 1	1955	457	Gascoyne
Dirk Hartog 17B	1957	1523	Gascoyne
Quail 1	1963/64	3581	Merlinleigh
Paterson 1	1964	2286	Exmouth
Kennedy Range 1	1966/67	2227	Merlinleigh
Flag 1	1969/70	3797	Barrow
East Marilla 1	1972	638	Ashburton
Barrow Deep 1	1972/73	4650	Barrow
North Tryal Rocks 1	1972/73	3658	Barrow
West Tryal Rocks 1	1972/73	3866	Barrow
CONTINENTAL OIL COMPANY OF AUSTRALIA LTD			
Yaringa 1	1966	2288	Gascoyne
GENOA OIL N.L.			
Pendock ID 1	1969	2501	Gascoyne
HEMATITE PETROLEUM PTY LTD			
Cane River 1	1971	694	Peedamullah Shelf
OCEANIA PETROLEUM PTY LTD			
Kalbarri 1	1973	1540	Gascoyne
Tamala 1	1973	1225	Gascoyne

epeirogenic movements progressively initiated intracratonic basins from north to south along the site of the present west coast of Australia, south of this aulacogene. An arm of the Tethys Sea gradually transgressed southward inundating all except the most southerly of these basins, but did not reach the Carnarvon Basin until the Late Silurian. Renewed movement in the Middle Palaeozoic created northwest-trending rifts within some of the northerly basins.

The Late Palaeozoic to Mesozoic phase of activity consisted of continental rifting movements that eventually led to the complete break-up of eastern Gondwanaland. It began with major tensional movement in the Late Palaeozoic that produced a trough parallel to the present coastline. This trough was superimposed on the Palaeozoic intracratonic basins, and was apparently open to the Tethys Sea. The accumulation of thick sediments in the trough was locally interrupted by tensional movements, in the late Permian, Late Triassic, and Early and Middle Jurassic, that produced structural trends generally at right angles to those formed earlier in the Palaeozoic. In the Carnarvon Basin most movements occurred in the Jurassic. Within the complex continental margin development a series of parallel aborted rifts formed east of the main rift in which separation later took place, along a spreading ridge located west of the Exmouth Plateau. Seafloor spreading commenced in the northwest in the late Middle Jurassic and reached the southwest in the Early Cretaceous.

As the plates drifted apart in the Cretaceous a marine transgression affected the area east of the rift, inundating the now peripheral basins and eventually submerging the horst blocks. This newly developed part of the Indian Ocean passed through a juvenile ocean phase, characterized by clastic sedimentation that lasted into the Late Cretaceous. In the Senonian, a change to dominantly carbonate deposition, that began in the north and progressed southward, marked the beginning of the present mature ocean phase.

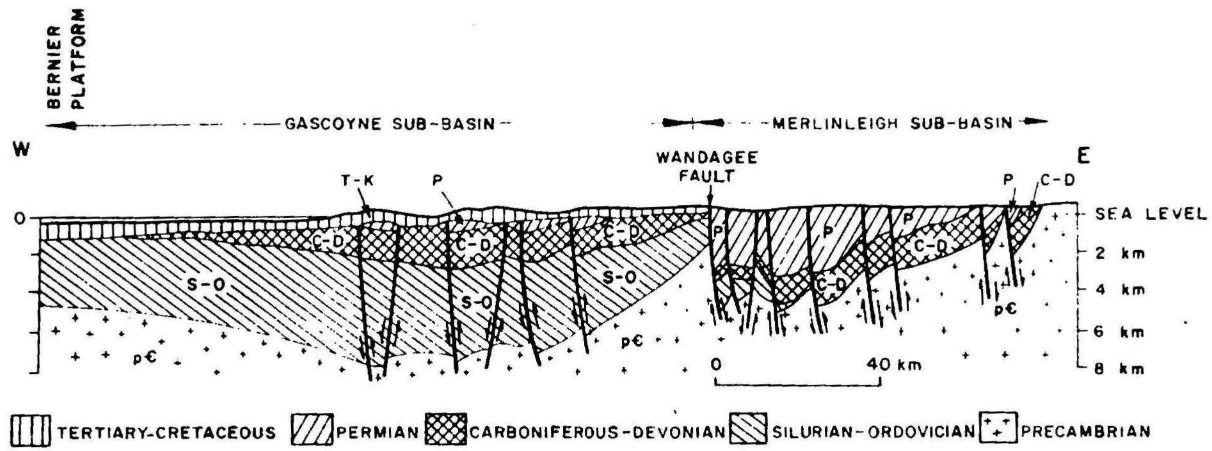
Basin Evolution

Uplift of the Precambrian craton in the Ordovician initiated the embryo Carnarvon Basin, a downwarp lying northwest of the craton, and provided the sediment source for the oldest rocks in the basin, the fluviatile Tumblagooda Sandstone. The rising eastern margin continued to supply clastic sediment throughout the Silurian, although by Late Silurian it was reduced to low relief. The carbonates of the Dirk Hartog Formation imply a connection with the Tethys Sea by the Late Silurian, and the evaporites of the same formation provide evidence of the basin's proximity to sub-equatorial latitudes in the Early Palaeozoic.

Renewed subsidence in the Early Devonian is indicated by a basal conglomeratic unit, the Nannyarra Greywacke. Clastic detritus was again derived from an uplifted eastern margin. This margin, however, lay farther to the east than it did during the Silurian, so that the basal conglomerate was deposited on Precambrian rocks of the older basin margin. The overlying Devonian to Early Carboniferous sequence of carbonate and clastic sediments was laid down in a shallow marine environment that developed in the Middle Devonian, when connection with the Tethys Sea to the north was established. This period was essentially one of quiescence, with only minor tectonic activity indicated by local unconformities and coarse clastic sediments along the eastern margin of the basin. Gentle upwarping in the eastern part of the basin in the Late Carboniferous created a highland from which much of the Carboniferous and Devonian sequence was subsequently removed, the area being the main provenance for the Late Palaeozoic sediments. Progressively deeper erosion southward suggests that the southeastern part of the basin probably remained emergent until the early Permian. Climatic conditions were cold and moist at this time, reflecting the shift in Australia's position from the sub-equatorial latitudes in the Early Palaeozoic to sub-Antarctic latitudes in the Late Palaeozoic.

Glaciers developed during the Early Permian on the rejuvenated eastern craton and flowed westward into a trough that occupied the present onshore Carnarvon Basin. Marine fossils associated with the tillites indicate that at least part of the Lyons Group was marine, and glacial erratics deposited at this time may have been ice rafted. Widespread and uniform shallow marine sedimentation in the Artinskian implies a return to tectonic stability in the Early Permian.

The southern Carnarvon Basin (Fig. 3) ceased to be an active area of deposition in the Late Permian when the sea regressed northward; there is no evidence of renewed subsidence in this area until the Cretaceous. Arching of the Bernier Platform probably severed the remaining Palaeozoic connection with the Perth Basin to the south. In the northern Carnarvon Basin sedimentation recommenced. There are some local unconformities, which suggests a hiatus between the Upper and Lower Permian rocks. The establishment of a



Record No 1978/33

AUS 1/644

Fig. 3 Structural cross-section southern Carnarvon Basin (after Thomas & Smith, 1974) northern trough, in which the thick Permo-Triassic sediments accumulated, is probably related to initial rifting in the basin. Tectonic activity is indicated at this time by Late Permian volcanics in Enderby 1 (Dampier Sub-basin) and local unconformities between Upper and Lower Permian rocks. Sedimentation continued uninterrupted into the Early Jurassic with a shift from a marine environment of deposition to a dominantly fluvial-deltaic one in the mid-Triassic. Upper Triassic fluvial-deltaic sands later became the main reservoir for gas accumulations on the Rankin Platform.

The most activephase of tectonism occurred during the Jurassic. It began with the sinking of the western margin of the Carnarvon Basin in the Early Jurassic, and reached a climax during the period of pull-apart movement that commenced at the end of the Middle Jurassic. This phase of tectonism initiated a major rift valley west of the Exmouth Plateau along which the Australian and Indian plates separated and also initiated extensive block-faulting in the Carnarvon Basin. Along some of the faults the throw is in the order of 3000 m. While the northern sub-basins were being faulted and downwarped, the southern Carnarvon Basin was uplifted, block-faulted, and eroded. It was in this period of tectonism that most of the basin's present complex horst and graben infrastructure (Fig. 1) was established.

During the Jurassic active subsidence in the northern Carnarvon Basin resulted in deposition of a thick sequence of the deltaic to marine Dingo Claystone and equivalents which in some areas are over 5000 m thick. Over the Rankin Trend Jurassic sediments are thin to absent, implying uplift and/or erosion in this area.

The final rupture, or dispersal phase, of eastern Gondwanaland in the Early Cretaceous was marked by foundering of the Exmouth Plateau area and the Cuvier Abyssal Plain to the west of the Carnarvon Basin. Within the basin this event is indicated only by the establishment of widespread marine conditions, shown by the clastic deltaic to fluvial sediments of the Barrow Group being succeeded by the marine Winning Group. These clastic sediments were laid down over an uneven block-faulted surface - the breakup unconformity (Fig. 4), and as a result of later differential compaction were draped over the higher palaeotopographic features; on the Rankin Trend they form a seal for the major gas traps.

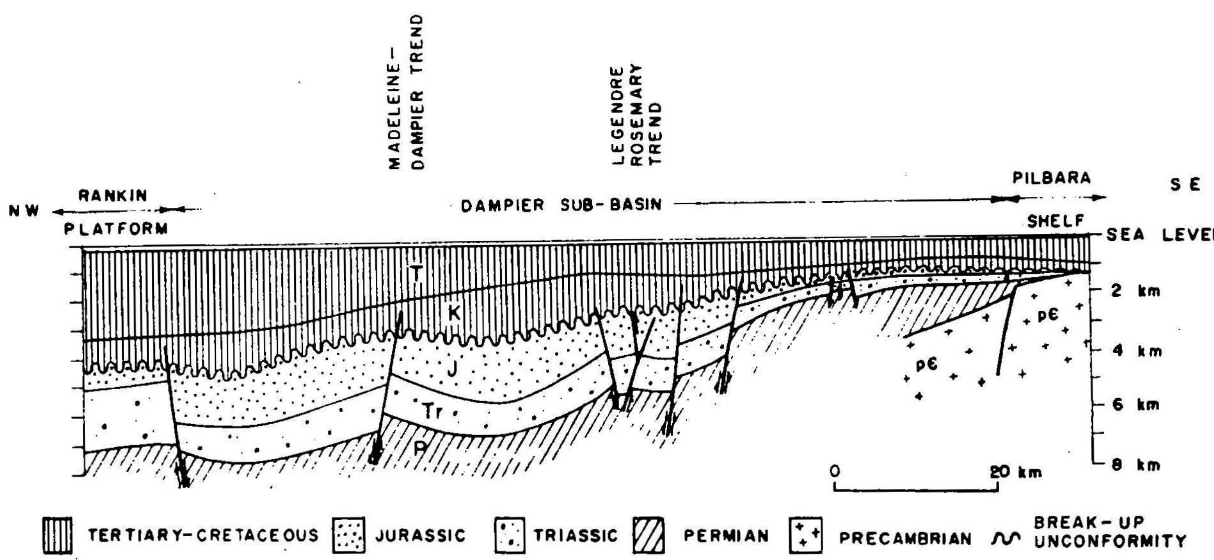
The Late Cretaceous and Cainozoic was generally a period of tectonic stability; however some faults show evidence of movement in the Late Cretaceous, and the development of an anticlinal fold belt, a series of surface anticlines in the Gascoyne, Barrow, and Exmouth sub-basins, is related to later tectonic activity in the Late Tertiary. Many of the anticlines are small features that were formed in the Miocene by reverse movement on some of the older normal faults. Fault movement up to 300 m caused thrusting and arching of the Cretaceous and Tertiary sediments, which have surface expression as asymmetrical anticlines. The larger anticlines, such as the Cape Range and Barrow Island Anticlines, which are the dominant structural features in the Exmouth and Barrow Sub-basins respectively, are broad simple structures, consisting of gently folded Cretaceous and Tertiary rocks. Although growth of these structures occurred mainly during the Miocene, in the Barrow Island Anticline there is also evidence of earlier intermittent structural growth. Whether the anticlinal fold belt developed as a result of compressional forces or is due to isostatic adjustment is unclear. The Tertiary tectonism is a similar age, and thus couldbe related to adjustments of the continent margin during collision of the Australian Plate with the Indonesian Arc in the Late Cainozoic.

Gradual sagging of the continental margin since the Late Cretaceous has allowed the build up of a prograding wedge of shelf sediments, although parts of the Exmouth Plateau remained high into the Tertiary. During the Senonian (Late Cretaceous) there was a marked change in sedimentation, when a mainly terrigenous deposition gave way to a carbonate regime. This change may have been related to the start of thermohaline circulation in the widening Indian Ocean in the Late Cretaceous, and the accompanying recycling of nutrients increased production of organic carbonate material. Carbonate sedimentation continued to predominate through the Cainozoic. The accumulation of a vast carbonate platform was the major depositional feature of the Cainozoic.

Resources

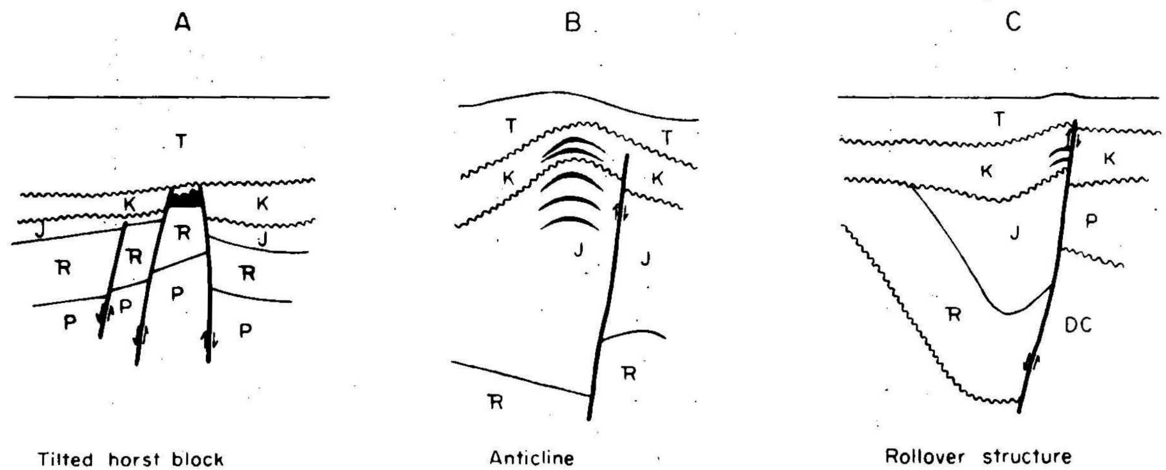
Hydrocarbons

Large gas/condensate reserves and small, but significant, oil reserves have been proven offshore in the northern Carnarvon Basin. Most of the major discoveries are in the Dampier Sub-basin, mainly along the Rankin Platform. Onshore on Barrow Island in the Barrow Sub-basin, the Barrow Island oil field has been producing for over ten years, and non-commercial quantities of petroleum are known in the Exmouth Sub-basin.



Record No 1978/33 AUS 1/645

Fig. 4 Structural cross-section northern Carnarvon Basin (after Leslie & others, 1976)



Record No 1978/33 BMR File No. XAUS-7-163

Fig. 5 Hydrocarbon traps in the Carnarvon Basin (after Leslie and others, 1976)

Hydrocarbon reservoirs occur at two major stratigraphic levels: in sands of the Mungaroo Formation at the top of the Late Triassic fluvial-deltaic sequence, and above the Late Jurassic break-up unconformity, in deltaic and marine sediments, the most important of which is the Early Cretaceous Windalia Sandstone Member of the Muderong Shale (Fig. 2). Jurassic shales, and Cretaceous siltstones and shales act as both seal and major source rocks; Triassic shales are also considered to have source rock potential.

The hydrocarbon traps are predominantly structural. Figure 5A is typical of the Rankin Platform traps, in which complexly faulted tilted horst blocks of Triassic rocks are draped and sealed by Cretaceous marine beds. The Jurassic Dingo Claystone in the adjacent troughs is probably the main source rock. Hydrocarbon traps present in the Tertiary anticlinal fold belt are shown in Figures 5B and 5C. Figure 5B is an example of the larger Tertiary anticlinal closures found in the Exmouth and Barrow Sub-basins, and from which the Barrow Island hydrocarbons are produced. The Barrow Island Anticline contains several reservoirs, the most productive of which are in the Winning Group. The rollover or dip reversal structures (Fig. 5C) are fault dependent traps in the small Tertiary anticlines adjacent to major basin faults. The only discovery from this type of trap has been a non-commercial discovery in the Exmouth Sub-basin. The hydrocarbons were in the Early Cretaceous Birdrong Sandstone, and the seal and source rocks were also in the Winning Group.

Much of the hydrocarbon migration post-dates Tertiary tectonism, although some hydrocarbon movement in the area of the Rankin Platform may have begun as early as the Late Cretaceous, while offshore migration may still be occurring as continued sedimentation provides a sufficient depth of burial to initiate generation and possible migration.

The arrival of West Australial Petroleum Pty Ltd (WAPET) onto the explorationscene in 1952, which ushered in the era of modern exploration techniques in the search for hydrocarbons in the basin, was the effective start of hydrocarbon exploration in the Carnarvon Basin. Prior to 1952 most exploration was limited to reconnaissance mapping. Oil Search Ltd carried out the first systematic mapping between 1932 and 1934; this led to the drilling of a shallow dry hole in the Byro Sub-basin in the mid 1930s. From 1952 to 1965 WAPET was the only company engaged in exploration drilling in the basin, although some geophysical work was conducted by other organisations. WAPET's first well, Rough Range 1, which tested a Tertiary anticline in the Exmouth Sub-basin in 1953, was an oil discovery. Although follow-up drilling proved the pool to be sub-economic, the well was important because it was Australia's first oil discovery and provided a stimulus to exploration, not only in the Carnarvon Basin, but Australia-wide. Because of the Rough Range 1 discovery, exploration was concentrated on the Tertiary anticlinal fold belt. A lack of further discoveries led to a decline in exploration activity in the late 1950s and early 1960s. In 1964 WAPET drilled Barrow Island 1 to test the Barrow Island Anticline, and made its second oil discovery. Subsequent drilling proved this field commercial, and it came into production in 1967. After the discovery of oil at Barrow Island WAPET concentrated its exploration efforts in the northern part of the basin, but farmed out leases in the southern Carnarvon Basin, where several dry holes were put down by various companies in the late 1960s.

Attention turned to the offshore part of the basin in the 1960s. BOC of Australia Ltd (BOC), which commenced exploration in the basin during this period, drilled the first offshore well in 1968. This well, Legendre 1, was an oil discovery, which although it proved to be sub-economic, gave the impetus to offshore drilling that led to the discovery of Australia's major gas fields. The first gas discovery which still ranks as the largest in Australia, was BOC's North Rankin 1, drilled on the Rankin Platform in 1971. In contrast to the rest of the basin, the ratio of discoveries to wells drilled in the Dampier Sub-basin has been very high, with the greatest success rate being achieved on the Rankin Platform.

Exploration drilling reached a peak in 1972, but has declined steadily since; however, recently there have been signs of increased activity. Two hundred and thirteen exploration wells have been drilled to date, plus an additional 520 wells on Barrow Island; 320 of the latter are oil producers, the rest being service wells and dry holes.

The only producing field is the Barrow Island oil field in the Barrow Sub-basin. Cumulative production since 1967 exceeds 140 billion barrels of oil. 98% of this oil comes from the Windalia Sandstone and has a gravity of 36° - 38° API. Although mainly an oil producer, the field also produces minor amounts of condensate, LPG, and natural gas from the Late Jurassic-Early Cretaceous sandstone reservoirs in the Barrow Formation and Dupuy Member of the Dingo Claystone (Fig. 2). Barrow Island field is now partly under secondary recovery and average production has fallen from a maximum 49 830 BOPD in 1970, to the present (1977) rate of 33 000 BOPD.

Estimated recoverable gas reserves for the Carnarvon basin are in the region of 14 TCF. None of the gas fields are in commercial production, but feasibility studies on their development are in progress.

The basin's hydrocarbon potential is still good, particularly for further gas discoveries. The potential for large oil discoveries is limited, but smaller pools are a possibility. On the continental shelf and onshore most of the obvious structures have been drilled, and further exploration will have to be directed to the more subtle structures and stratigraphic traps. The deep-water parts of the basin on the continental slope are still virgin territory in terms of drilling. The potential is high in this area, but so are the drilling costs.

Evaporite Minerals

Present day geography of the basin favours the exploitation of evaporite minerals, which has been carried on sincethe late 1960s, chiefly at Shark Bay, Dampier, and Lake MacLeod. The basin supplies 75% of Australia's total salt production, all of which is produced by solar evaporation. The operation at Lake MacLeod is the second largest solar salt mining operation in the world. In 1975, the basin produced 2.86 million tonnes of salt, mainly from Dampier and Lake MacLeod. Between 1973 and 1975 10 000 tonnes of potassium in the form of langbeinite was also extracted from the Lake MacLeod brines, but in 1975, this part of the operation was suspended. Gypsum is mined from several isolated barred basins at the head of relict inlets in the Shark Bay area, which in 1975 produced over 49 000 tonnes of gypsum. Bedded lake and dunal deposits of gypsum are also present in the Lake MacLeod area. Reserves are estimated to be large, but production has not yet begun.

Selected Bibliography

BEDDOES, L.R. JR., 1973 - OIL AND GAS FIELDS OF AUSTRALIA, PAPUA NEW GUINEA AND NEW ZEALAND. Tracers Petroleum and Mining Publication, Sydney.

BRANSON, J.C., 1978 - Evolution of sedimentary basins from Mesozoic times in Australia's continental slope and shelf. Tectonophysics, 48, 389-412.

BMR, 1977 - Bureau of Mineral Resources, Australia, Australian Mineral Industry Review, 1975.

BMR, 1978 - Bureau of Mineral Resources, Australia, Petroleum Newsletter, 70.

CONDON, M.A., 1965, 1967, 1968 - The geology of the Carnarvon Basin, Western Australia. Part I: Pre-Permian stratigraphy. Part II: Permian stratigraphy. Part III: Post-Permian stratigraphy; structure; economic geology. Bureau of Mineral Resources, Australia, Bulletin 77.

CRANK, K., 1973 - Geology of Barrow Island oil field. The APEA Journal, 13(1), 49-57.

CROWELL, J.C., & FRAKES, L.A., 1971 - Late Palaeozoic glaciation of Australia. Journal of the Geological Society of Australia, 17(2), 115-155.

EMBLETON, B.J.J., 1973 - The palaeolatitude of Australia through Phanerozoic time. Journal of the Geological Society of Australia, 19(4), 475-482.

EXON, N.F., & WILLCOX, J.B., 1978 - The geology and petroleum potential of the Exmouth Plateau area off Western Australia. AAPG Bulletin 62(1), 40-72.

KAYE, P., EDMOND, G.M., & CHALLINOR, A., 1972 - The Rankin Trend, northwest shelf, Western Australia. The APEA Journal, 12(1), 3-8.

KNIGHT, C.L. (Editor), 1976 - Economic geology of Australia and Papua New Guinea, 4 - Industrial minerals. Australasian Institute of Mining and Metallurgy, Monograph 8.

LESLIE, R.B., EVANS, H.J., & KNIGHT, C.L. (Editors), 1976 - Economic geology of Australia and Papua New Guinea, 3 - Petroleum. Australasian Institute of Mining and Metallurgy, Monograph 7.

OZIMIC, S., 1970 - Bibliography of the Carnarvon Basin, Western Australia (to 31-12-69). Bureau of Mineral Resources, Australia, Record 1970/71 (unpublished).

PLAYFORD, P.E., 1975 - Petroleum in Western Australia: a review of exploration, production, and future prospects. The APEA Journal, 15(2), 72-79.

PLAYFORD, P.E., COPE, A.E., LOW, C.H., & LOWRY, D.C., 1975 -Phanerozoic. In Geology of Western Australia. Geological Survey of Western Australia, Memoir 2, 269-318.

POWELL, D.E., 1976 - The geological evolution and hydrocarbon potential of the continental margin off northwest Australia. The APEA Journal, 16(1), 12-23.

POWELL, T.G., & McKIRDY, D.M., 1973 - Crude oil correlations in the Perth and Carnarvon Basins. Bureau of Mineral Resources, Australia, Record 1972/142 (unpublished).

QUILTY, P.C., 1974 - Tertiary stratigraphy of Western Australia. Journal of the Geological Society of Australia, 21(3), 301-18.

QUILTY, P.G., 1975 - Late Jurassic to Recent geology of the western margin of Australia. In VEEVERS, J.J. (Editor) - Deep sea drilling in Australian waters. Challenger Symposium, Sydney.

ROBERTSON, C.S., CRONK, D.K., LOCKWOOD, K.L., & MAYNE, S.J., in preparation - A review of petroleum exploration and prospects in the Carnarvon Basin. Bureau of Mineral Resources, Australia, Record (unpublished).

SYMONDS, P.A., & CAMERON, P.J., 1977 - The structure and stratigraphy of the Carnarvon Terrace and Wallaby Plateau. The APEA Journal, 17(1), 30-41.

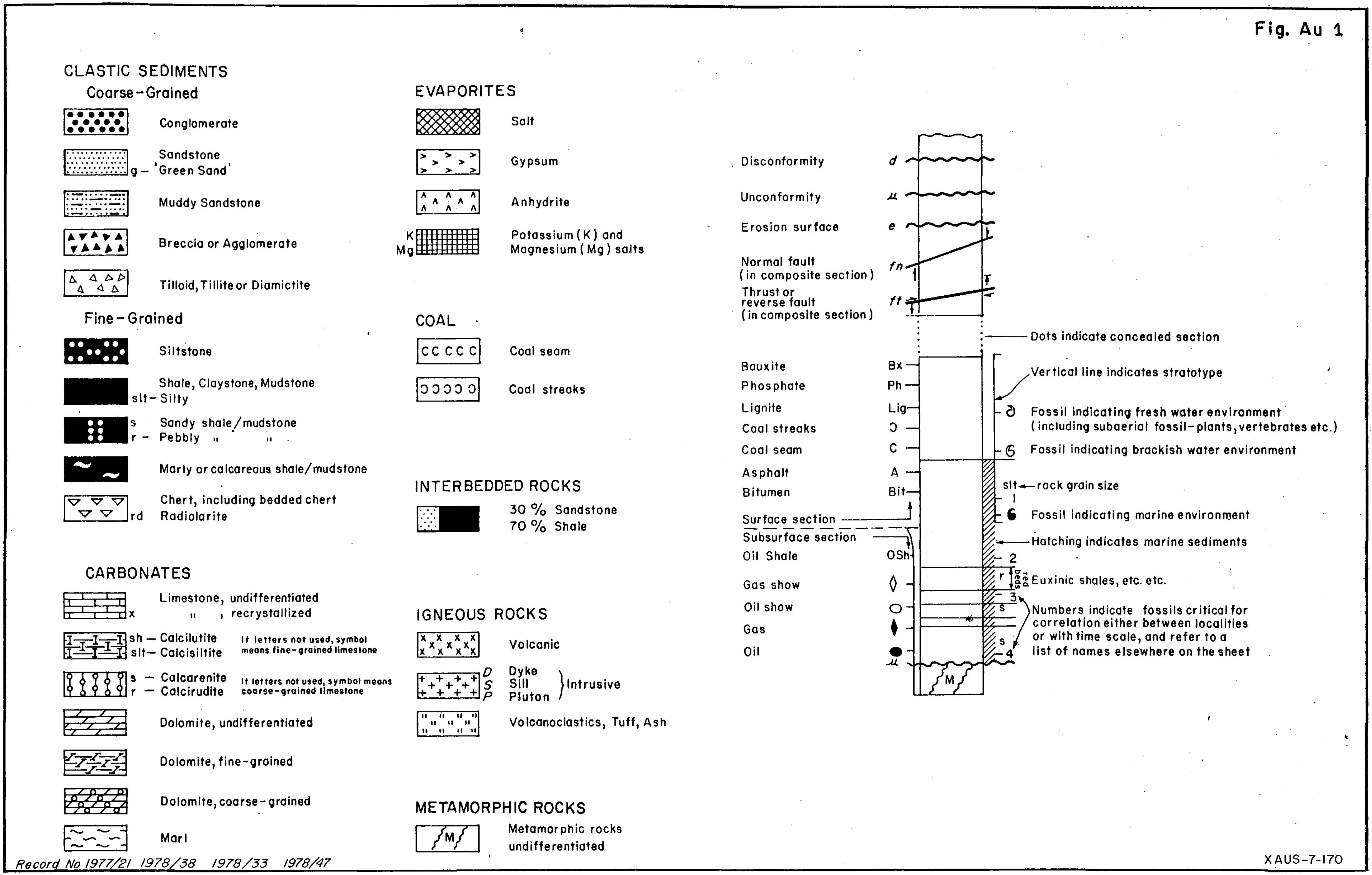
THOMAS, B.M., & SMITH, D.N., 1974 - A summary of thepetroleum geology of the Carnarvon Basin. The APEA Journal, 14(1), 66-76.

VEEVERS, J.J., 1971 - Phanerozoic history of Western Australia related to continental drift. Journal of the Geological Society of Australia, 18(2), 87-96.

VEEVERS, J.J., & JOHNSTONE, M.H., 1974 - Comparative stratigraphy and structure of the western Australian margin and the adjacent deep ocean floor. In VEEVERS, J.J., HEIRTLER, J.R., and others. Initial report of the Deep Sea Drilling Project, 27, 571-585. U.S. Government Printing Office, Washington.

VEEVERS, J.J., & McELHINNY, M.W., 1976 - The separation of Australia from other continents. Earth-Science Reviews, 12(2/3), 139-159.

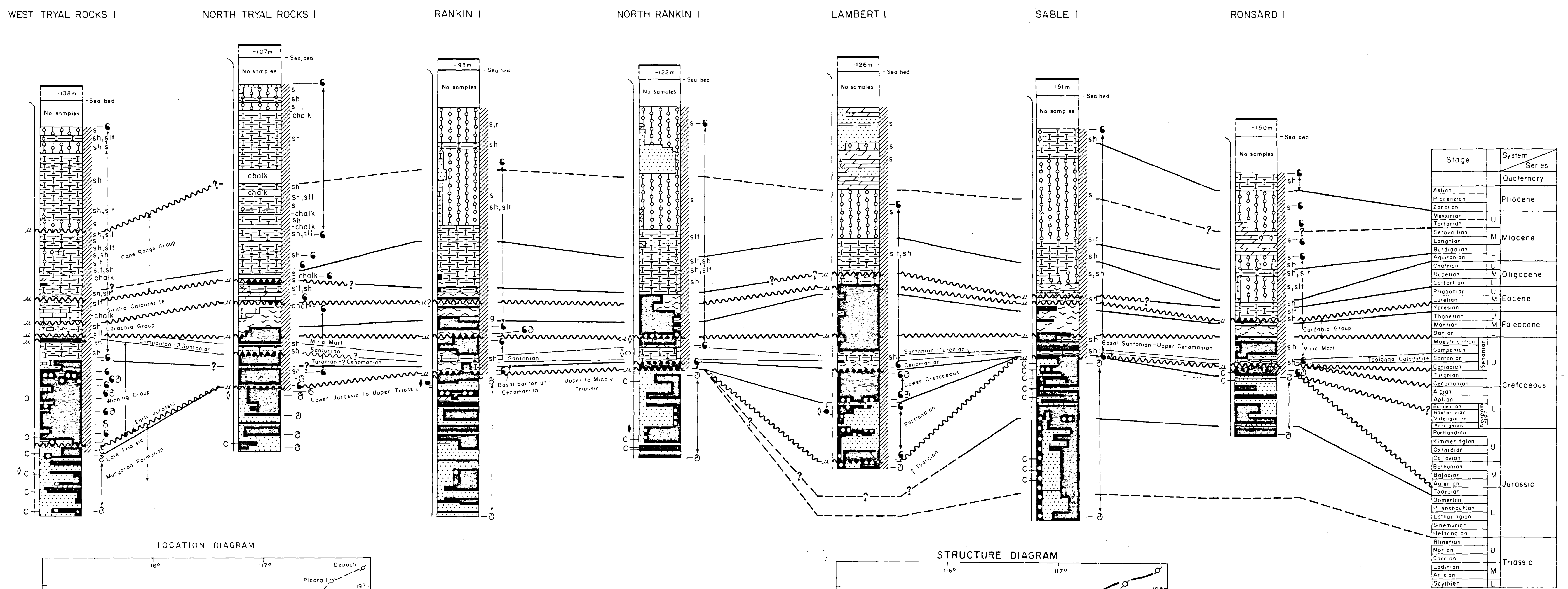
WHITWORTH, R., 1969 - Marine geophysical survey of the northwest Continental Shelf, 1968. Bureau of Mineral Resources, Australia, Record 1969/99 (unpublished).



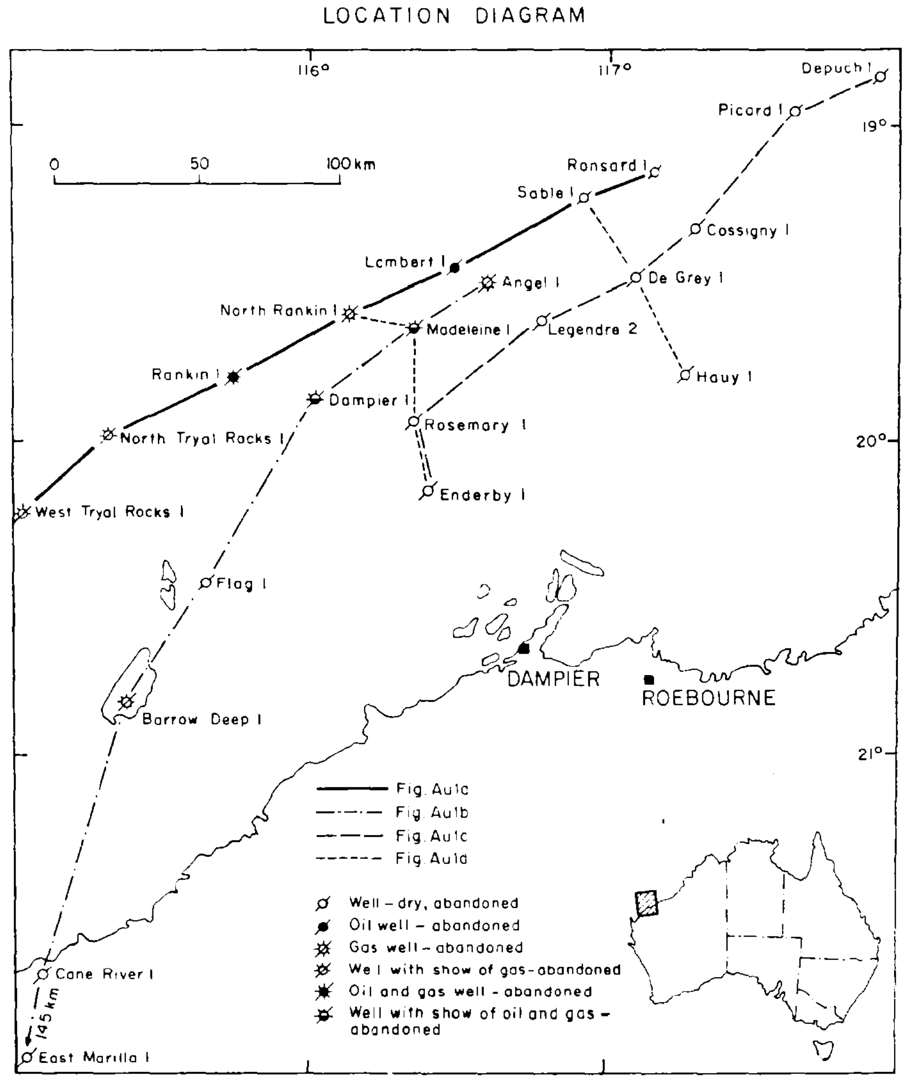
Standard legend for stratigraphic columns

CARNARVON BASIN : WESTERN AUSTRALIA

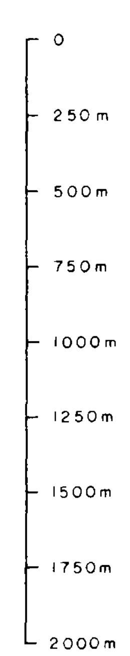
ESCAP ATLAS OF STRATIGRAPHY (IGCP PROJECT No.32)



LOCATION DIAGRAM

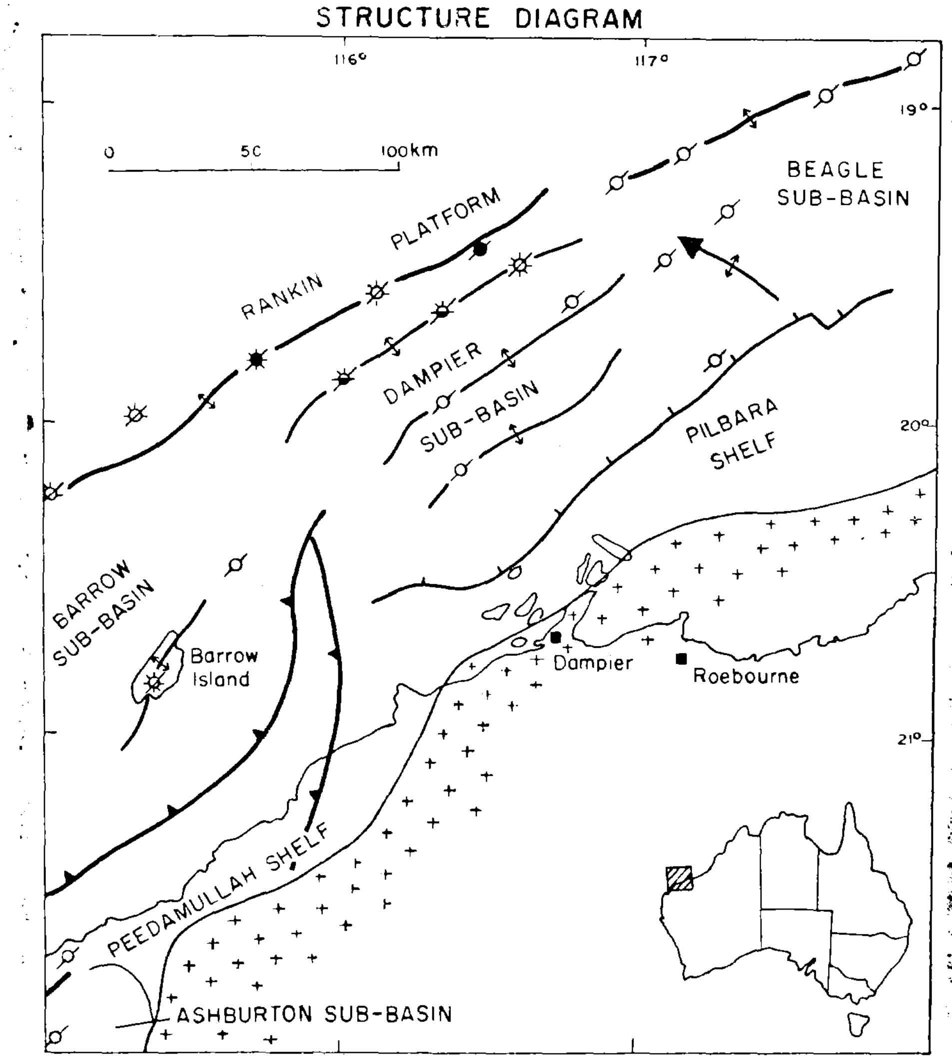


● Oil discovery
♦ Gas discovery



Vertical Scale
1:25000

STRUCTURE DIAGRAM

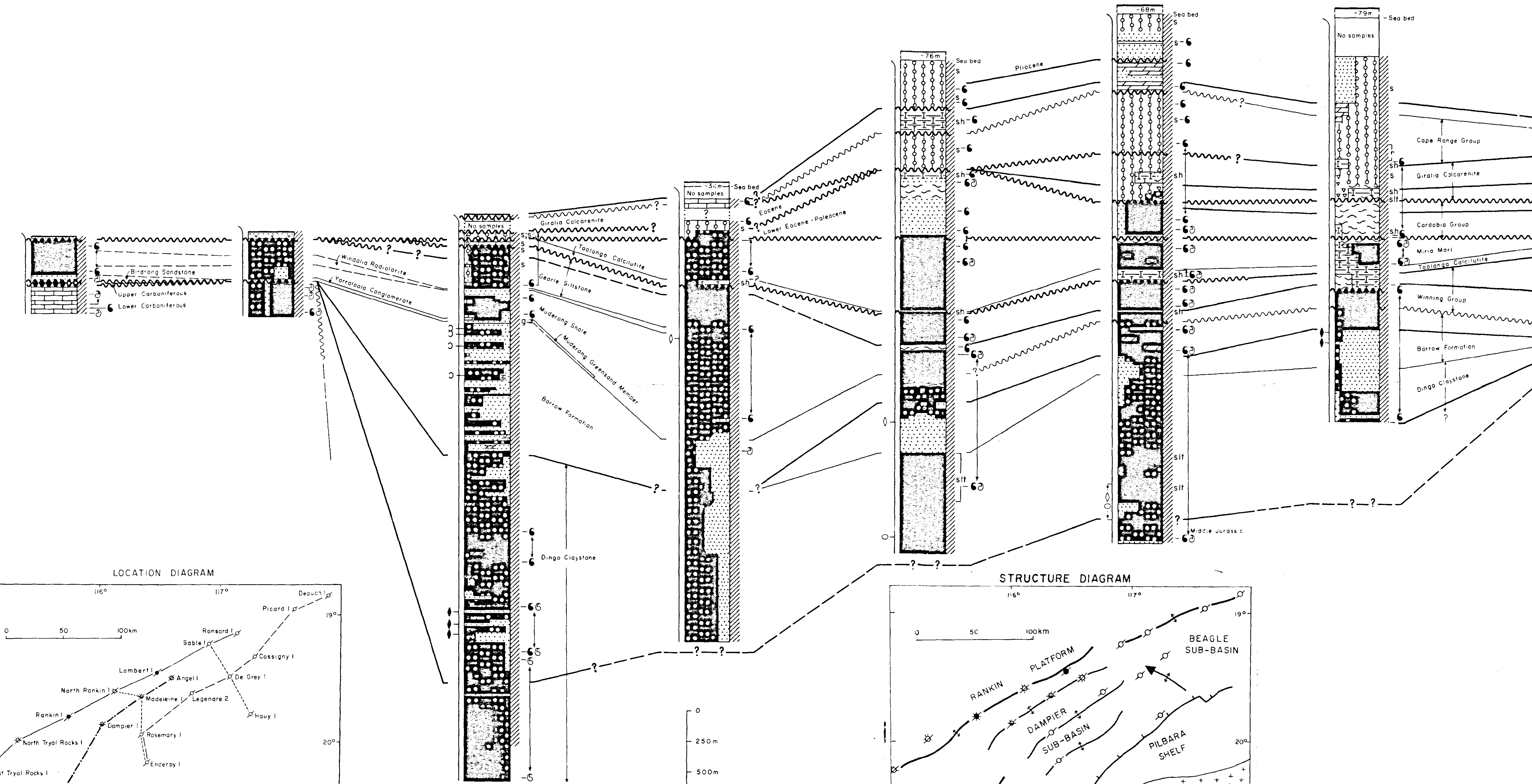


Geological data compiled by A. Mond
Palaeontological data compiled by V.L. Passmore, D.J. Belford
Drawn by B.J. Pashley, N. Kozin
Acknowledgment: West Australian Petroleum Pty Ltd and BOCAL Pty Ltd for permission to use company data

AUSTRALIA Au 1a Carnarvon Basin

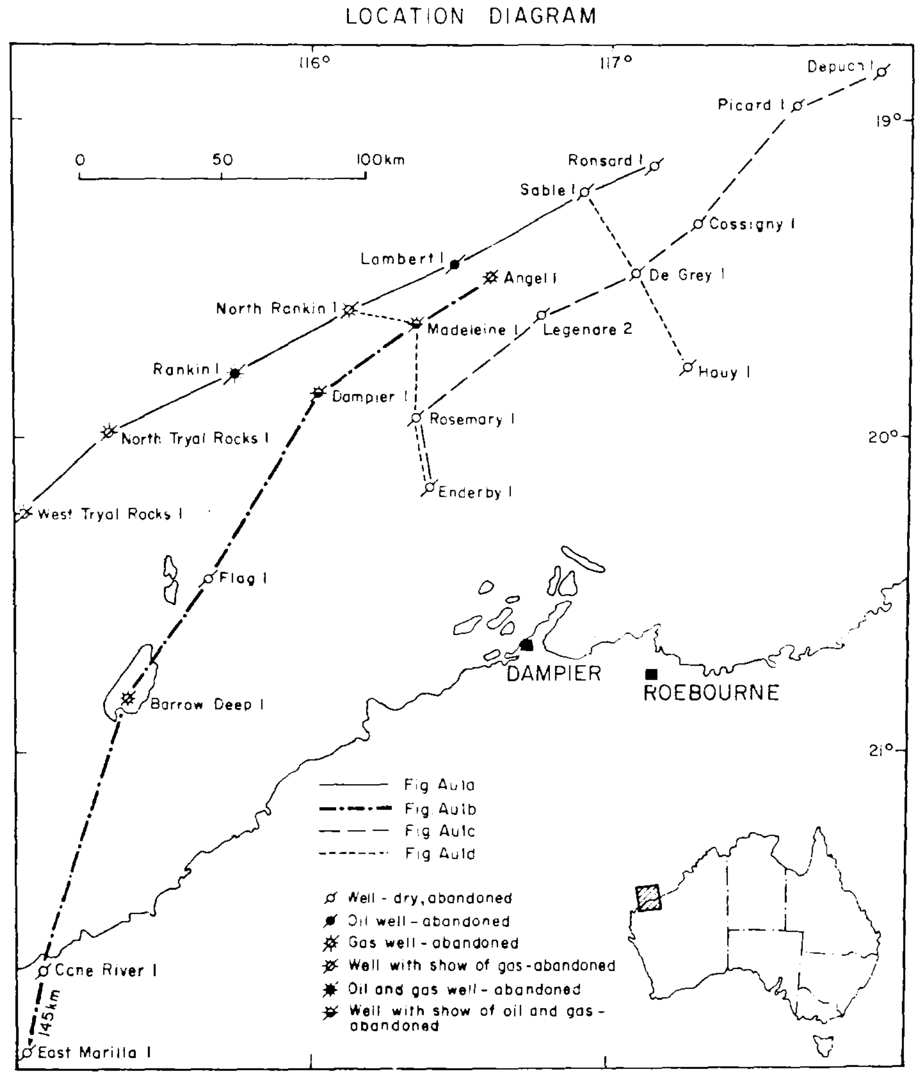
CARNARVON BASIN : WESTERN AUSTRALIA

ESCAP ATLAS OF STRATIGRAPHY (IGCP PROJECT No.32)

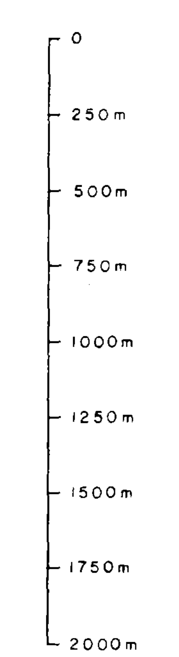


Stage		System / Series
		Quaternary
Astian		Pliocene
Piacenzian		
Zanclian		
Messinian	U	Miocene
Tortonian		
Seravallian	M	
Langhian		
Burdigalian	L	
Aquitanian		
Chattian	U	Oligocene
Rupelian	M	
Lattorfian	L	
Priabonian	U	Eocene
Lutetian	M	
Ypresian	L	
Thanetian	U	Paleocene
Montian	M	
Danian	L	
Maestrichtian (Senonian)	U	Cretaceous
Campanian (Senonian)		
Santonian (Senonian)		
Coniacian (Senonian)		
Turonian		
Cenomanian		
Albian	L	
Aptian		
Barremian (Neocomian)		
Hauterivian (Neocomian)		
Valanginian (Neocomian)		
Berriasian (Neocomian)		
Portlandian	U	Jurassic
Kimmeridgian		
Oxfordian		
Callovian		
Bathonian	M	
Bajocian		
Aalenian		
Toarcian	L	
Domerian		
Pliensbachian		
Lotharingian		
Sinemurian		
Hettangian		
Rhaetian	U	Triassic
Norian		
Carnian		
Ladinian	M	
Anisian		
Scythian	L	
Tatarian	U	Permian
Kazanian		
"Ufimian"		
Kungurian	L	
Artinskian		
Sakmarian		
Asselian		
Orenburgian	U	Carboniferous
Gzhelian		
Moscovian		
Bashkirian		
Namurian		
Visean	L	
Tournaisian		

LOCATION DIAGRAM

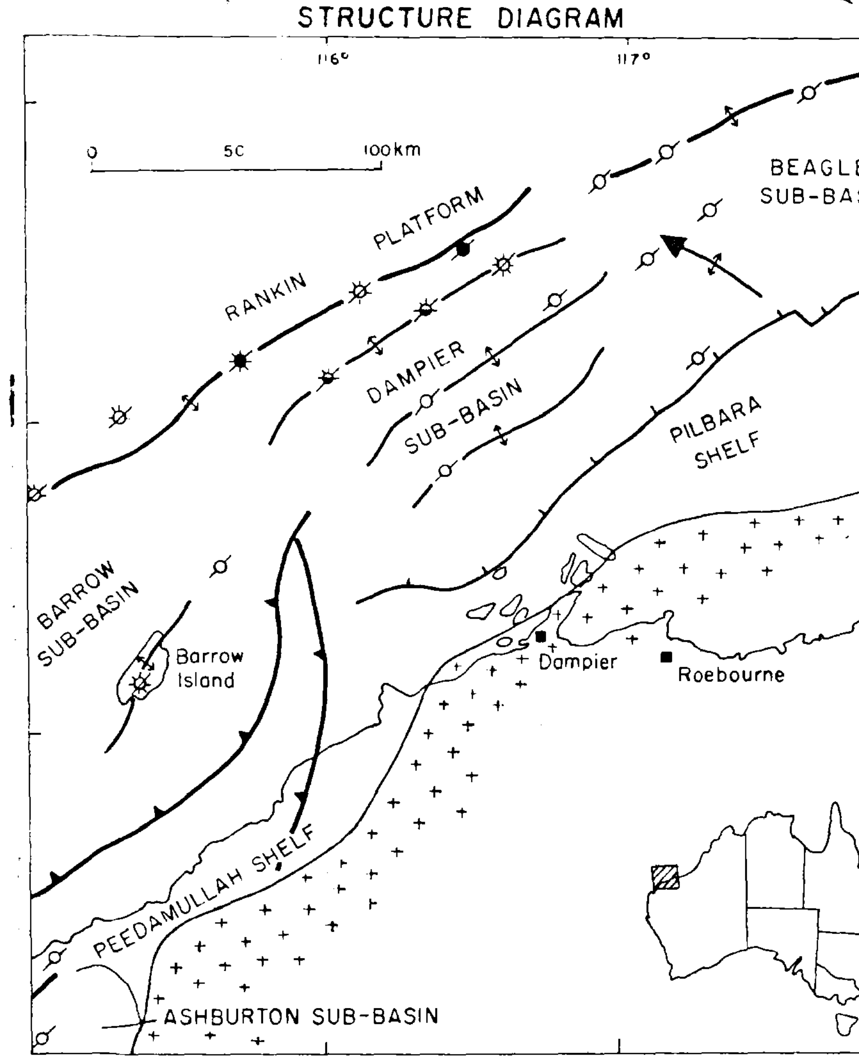


Gas discovery



Vertical Scale 1:25 000

STRUCTURE DIAGRAM

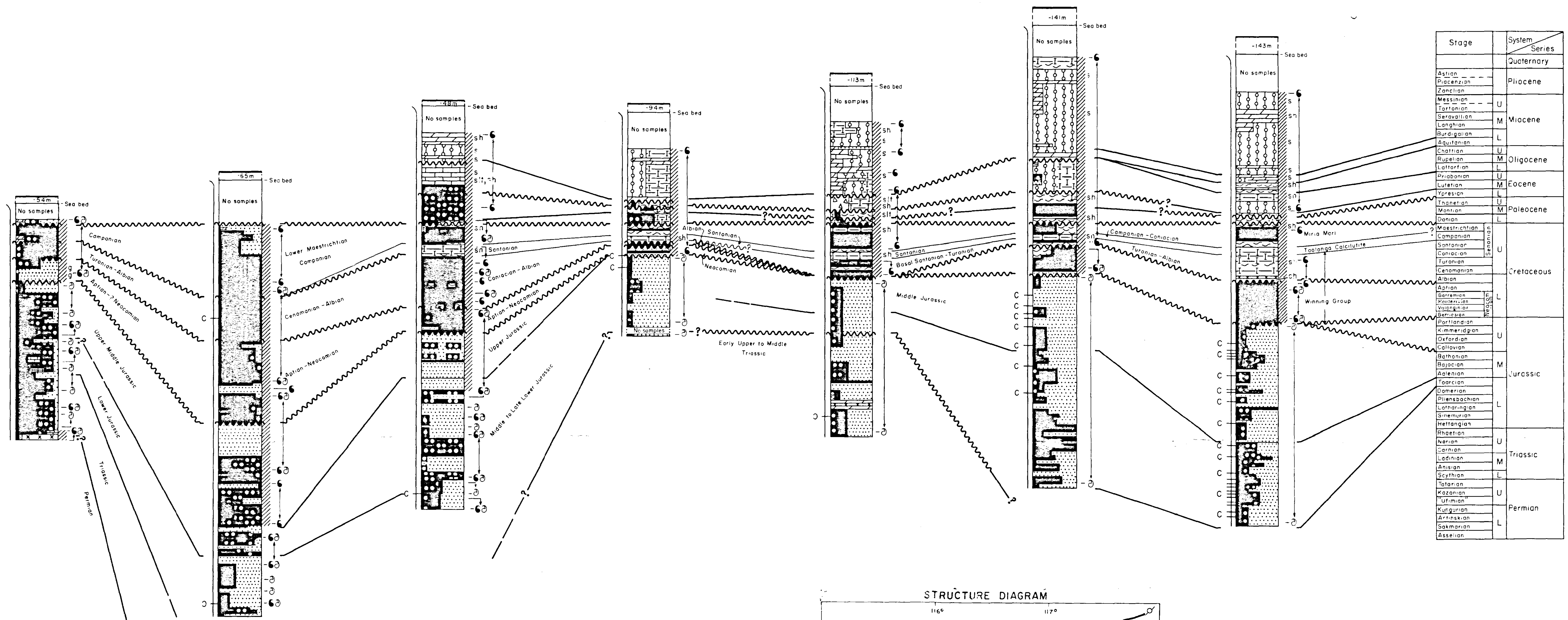


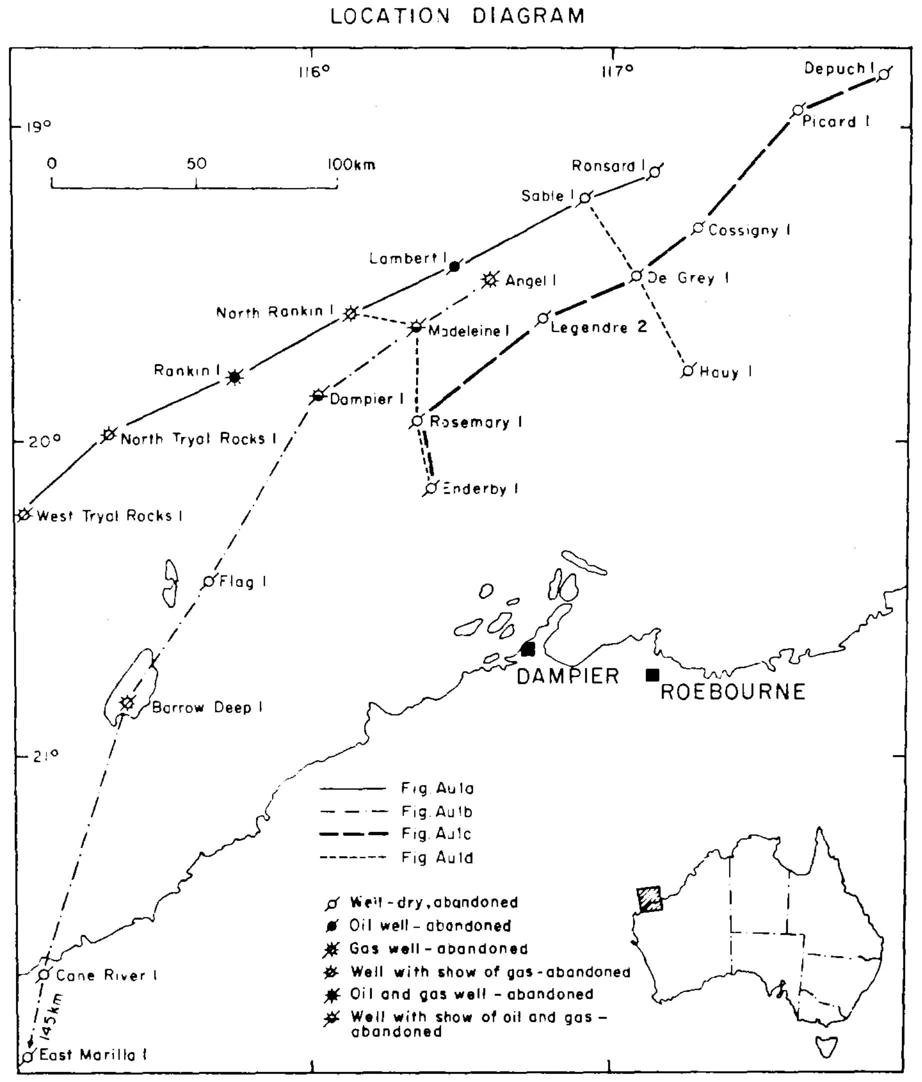
Geological data compiled by A Mond
Palaeontological data compiled by V.L Passmore, D.J Belford
Drawn by B.J Pashley, N Kozin
Acknowledgment: West Australian Petroleum Pty Ltd and BOCAL Pty Ltd for permission to use company data

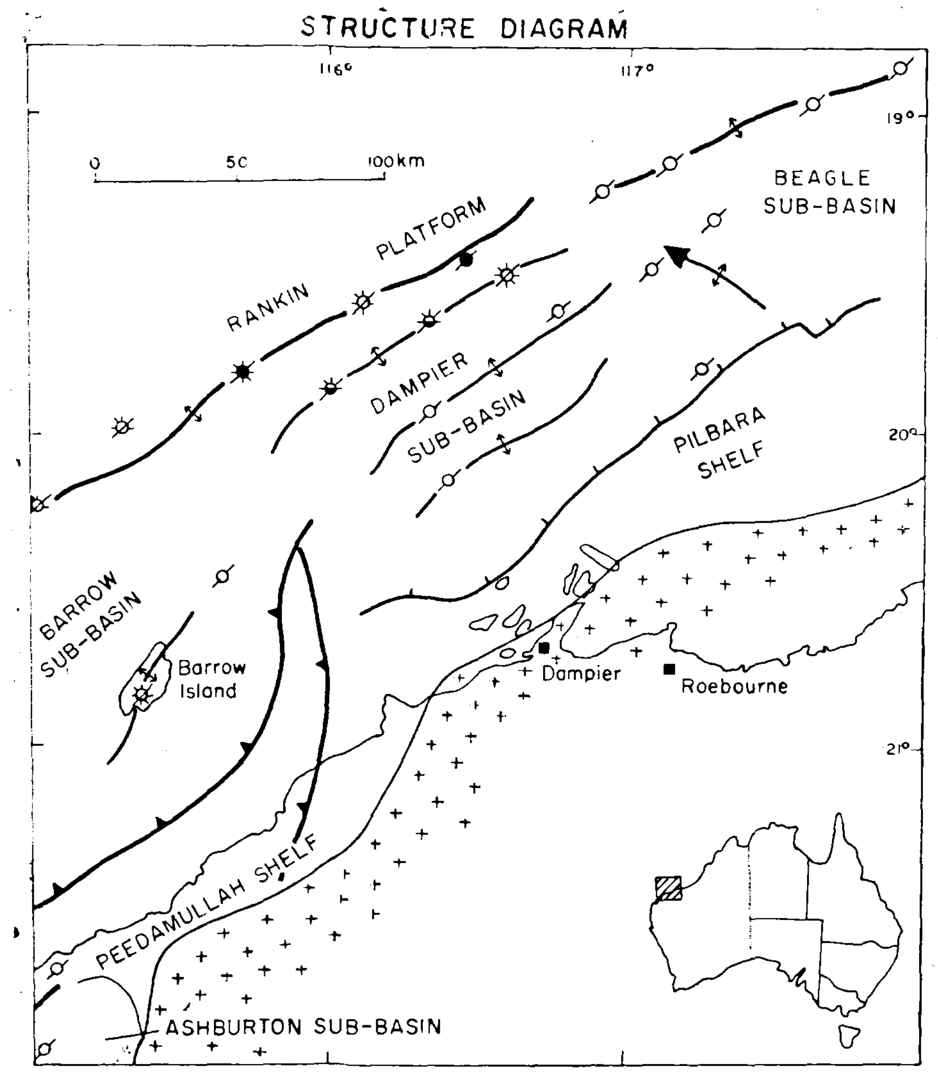
AUSTRALIA Au 1b Carnarvon Basin

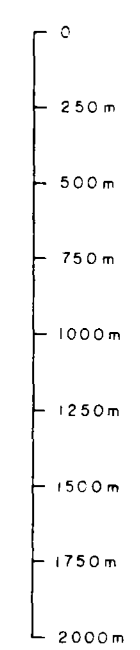
CARNARVON BASIN : WESTERN AUSTRALIA

ESCAP ATLAS OF STRATIGRAPHY (IGCP PROJECT No.32)









Vertical Scale
1:25000

Geological data compiled by A. Mond
Palaeontological data compiled by V.L. Passmore, D.J. Belford
Drawn by B.J. Pashley, N. Kozin

Acknowledgment: West Australian Petroleum Pty. Ltd and BOCAL Pty Ltd for permission to use company data

AUSTRALIA Au 1c Carnarvon Basin

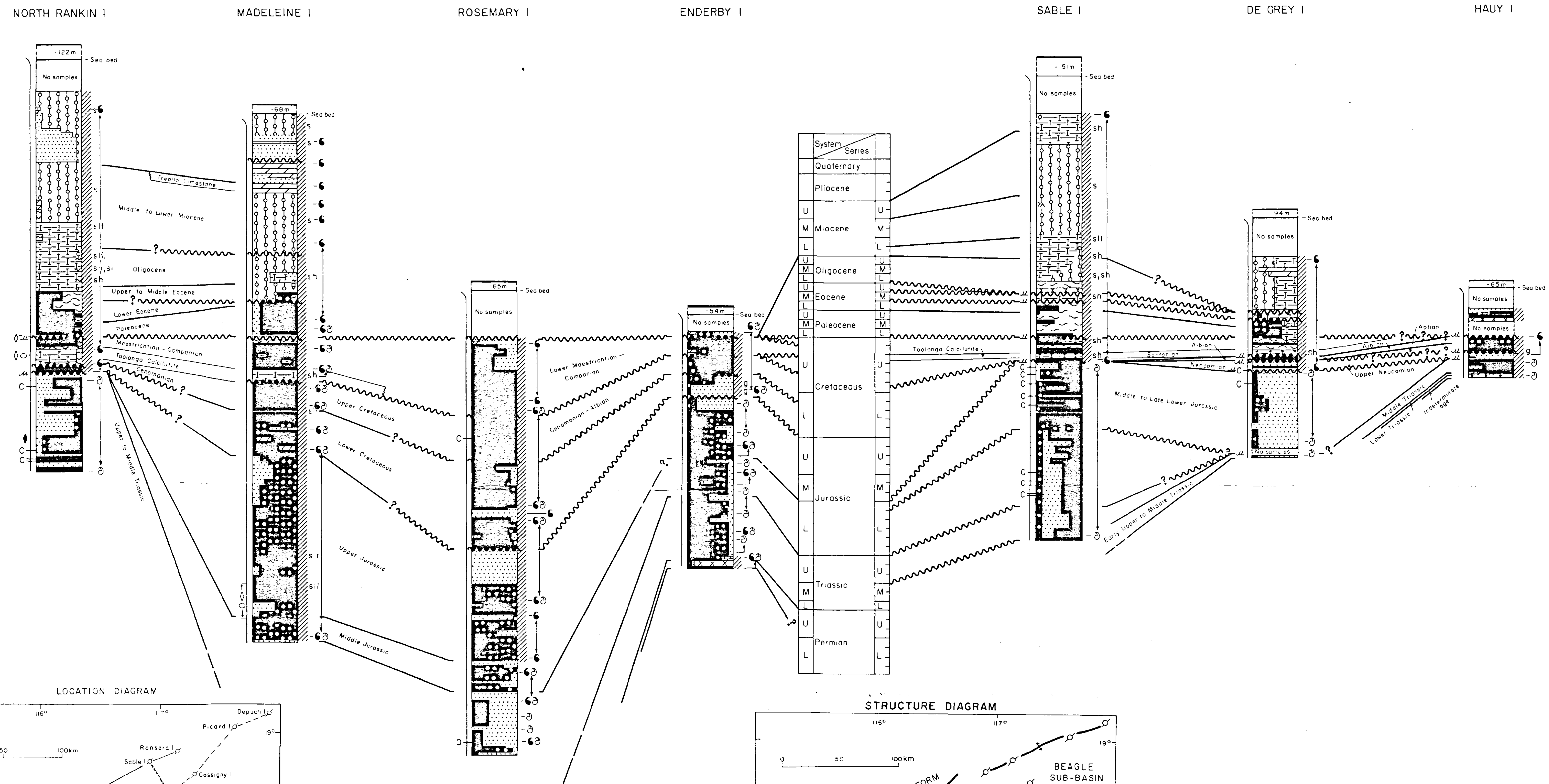
(Plate 9) 1978/47
(Au 1c) 1978/33
Record No 1977/21

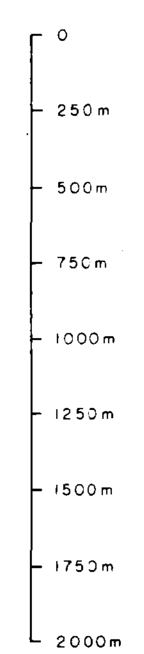
BMR File No XAUS-7-66

Fig. Au Id

CARNARVON BASIN : WESTERN AUSTRALIA

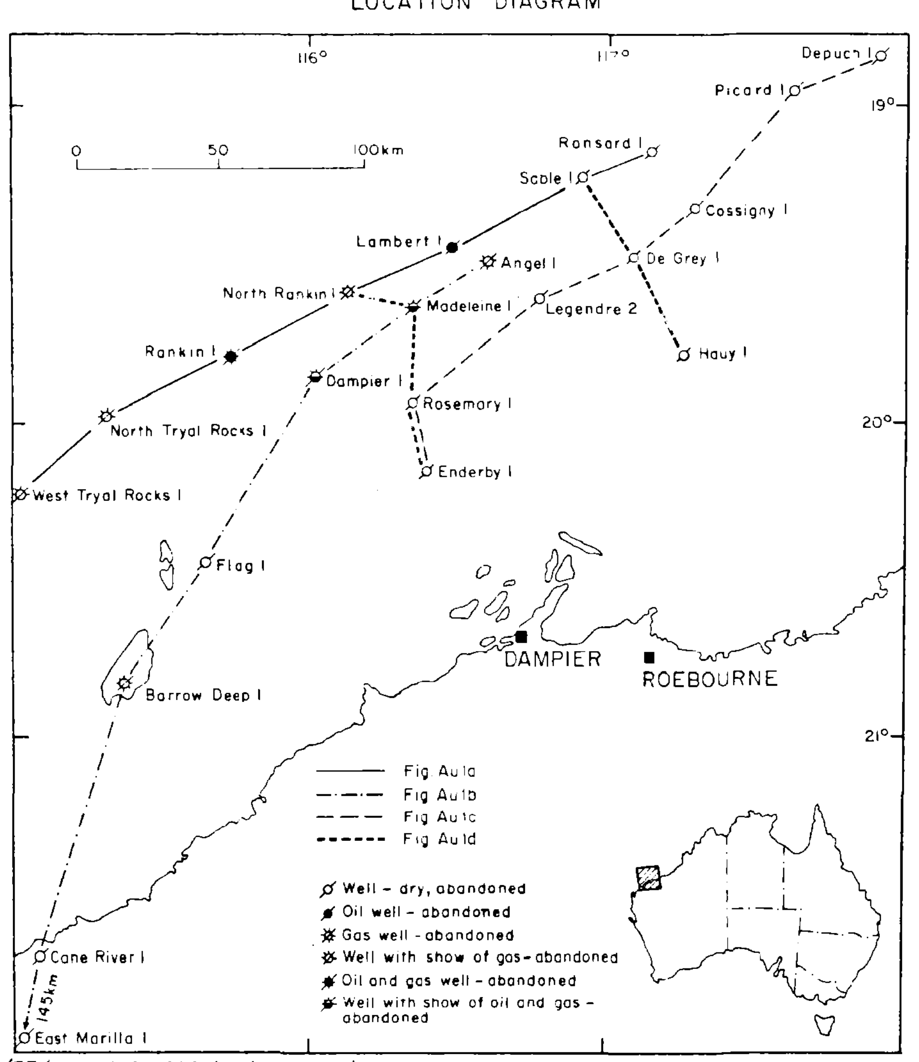
ESCAP ATLAS OF STRATIGRAPHY (IGCP PROJECT No.32)





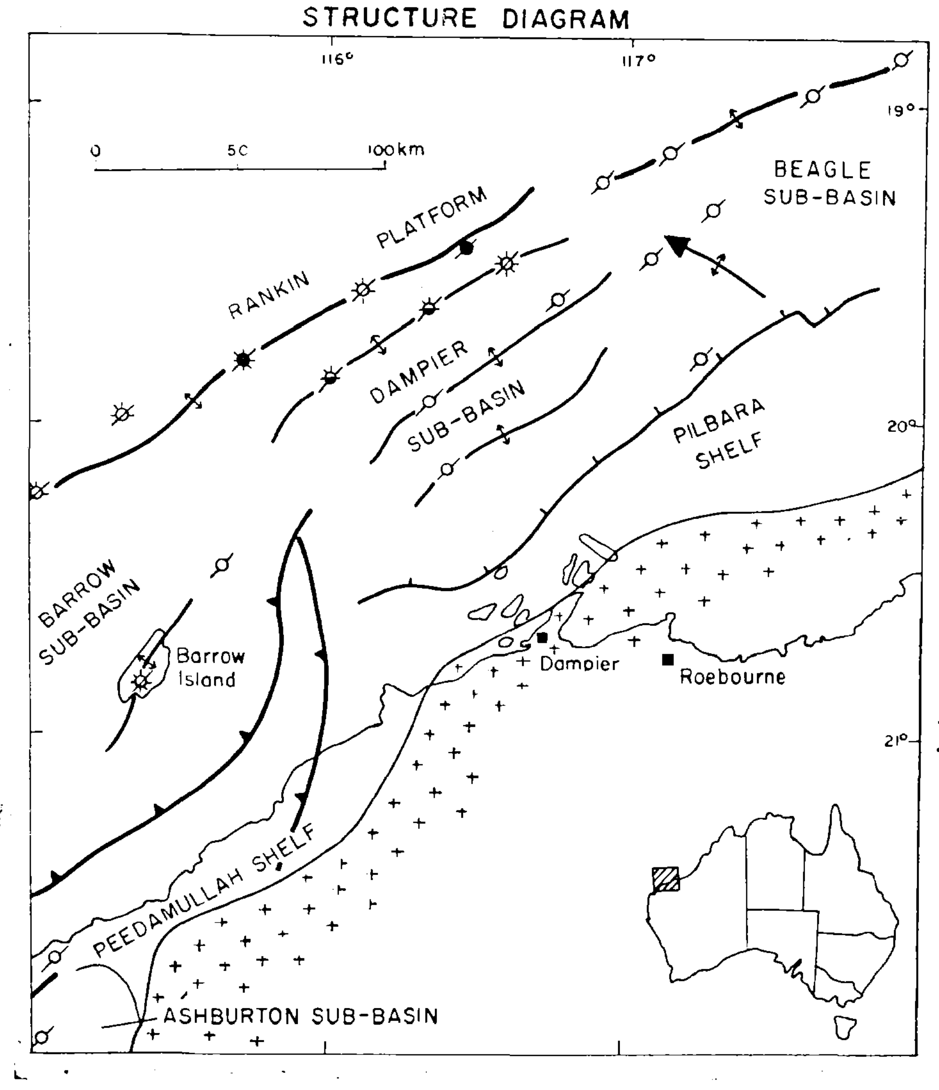
Vertical Scale
1 25000

LOCATION DIAGRAM



Gas discovery

STRUCTURE DIAGRAM



Geological data compiled by A Mond
Palaeontological data compiled by V.L Passmore, D.J Belford
Drawn by B.J Pashley, N Kozin

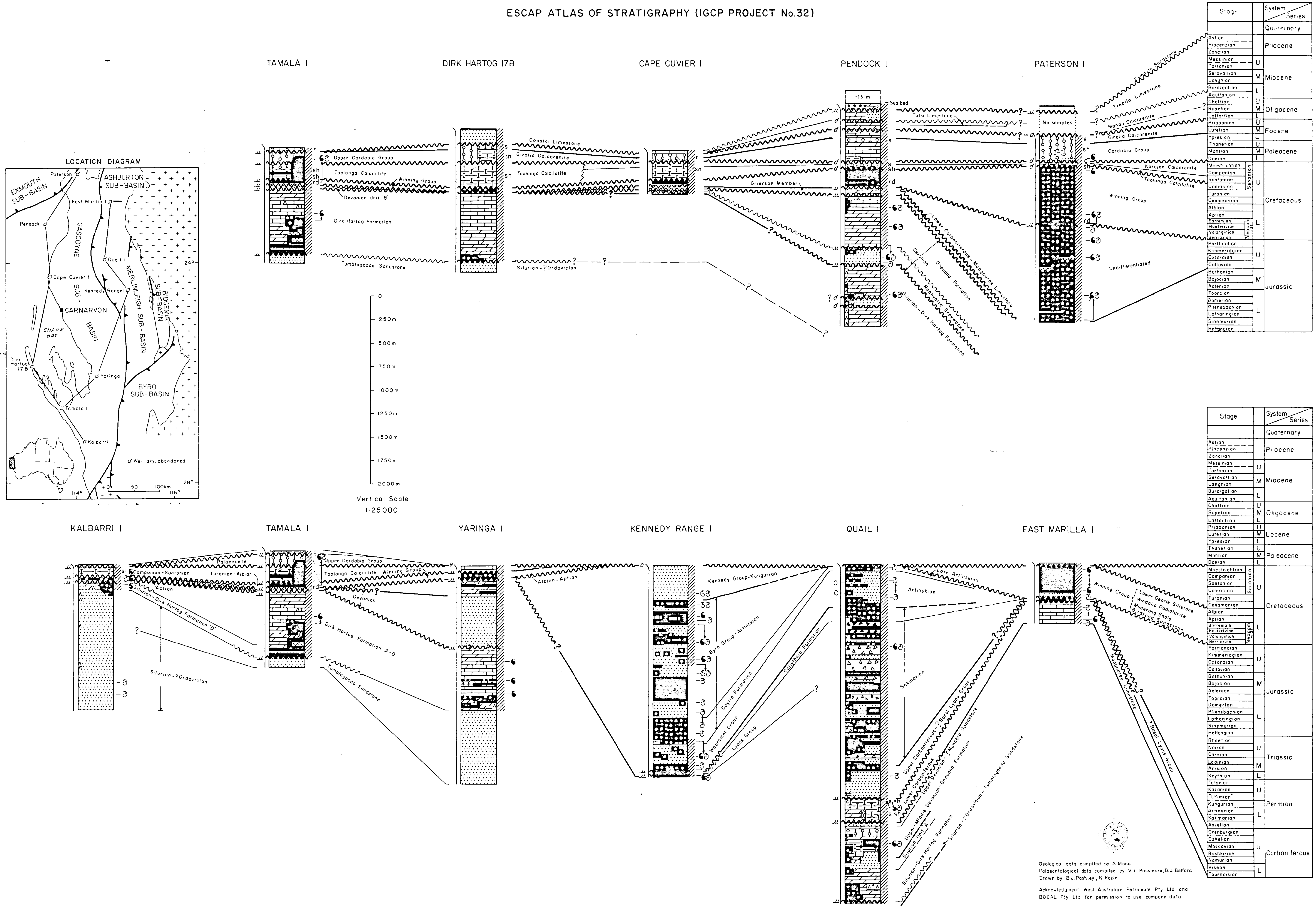
Acknowledgment: West Australian Petroleum Pty Ltd and BOCAL Pty Ltd for permission to use company data

AUSTRALIA Au Id Carnarvon Basin

Fig. Au le

CARNARVON BASIN : WESTERN AUSTRALIA

ESCAP ATLAS OF STRATIGRAPHY (IGCP PROJECT No.32)



AUSTRALIA Au le Carnarvon Basin

Record No.1977/21 & 1978/33 (Au le) & 1978/47 (Plate II)

BMR File No. XAUS-7-68