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West Australian
Petroleum
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PERTH BASIN

HYDROCARBON GENERATION ANALYSIS - PERTH BASIN (ONSHORE)

VLAMING SUB-BASIN, ABROLHOS SUB-BASIN

G.J. DEMAISON
1972

PERTH BASIN

HYDROCARBON GENERATION ANALYSIS

PERTH BASIN (ONSHORE)

VLAMING SUB-BASIN

ABROLHOS SUB-BASIN

by

G.J. DEMAISON

West Australian Petroleum Pty. Limited

1972

PERTH BASIN

STRATIGRAPHY

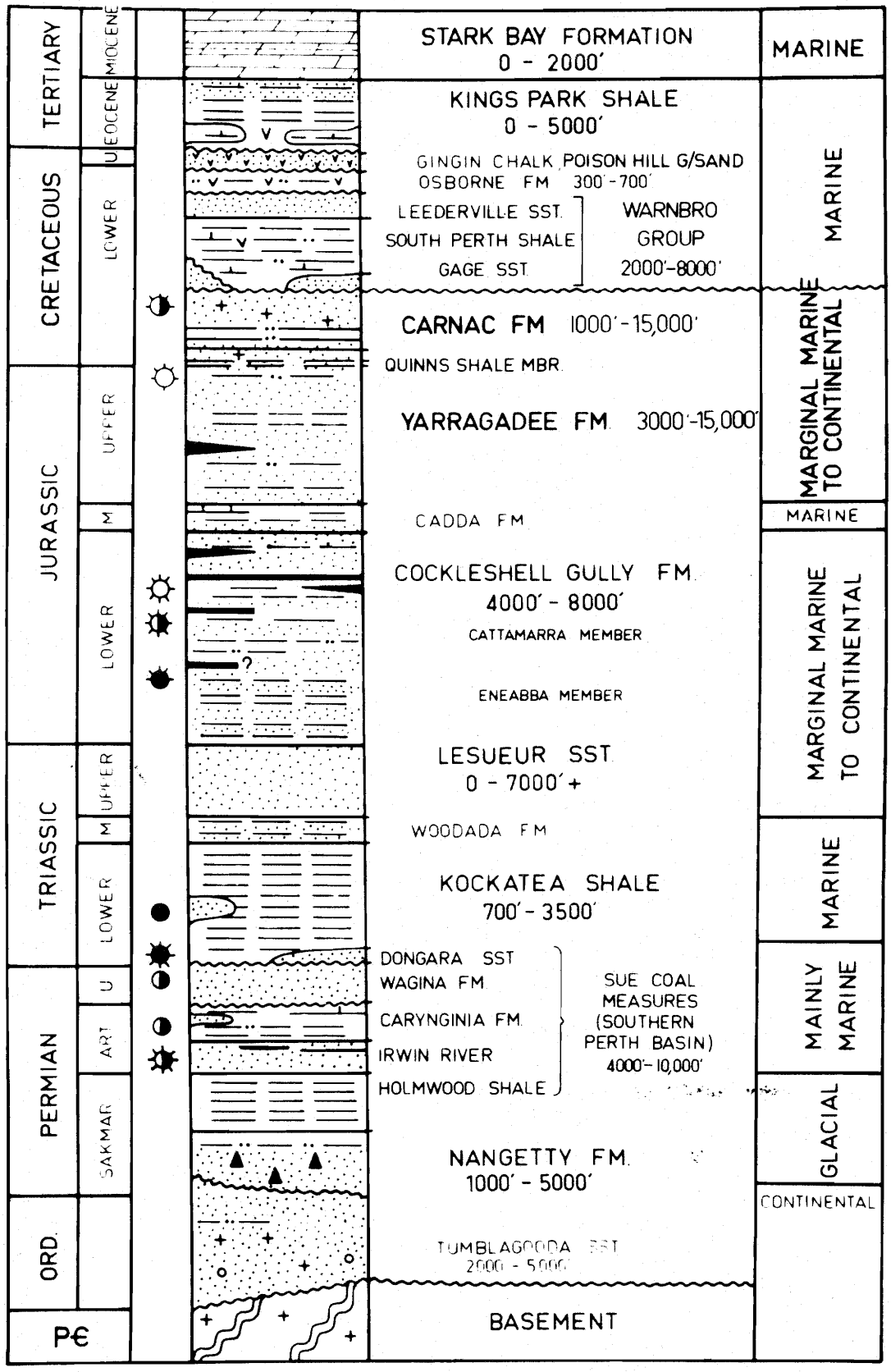
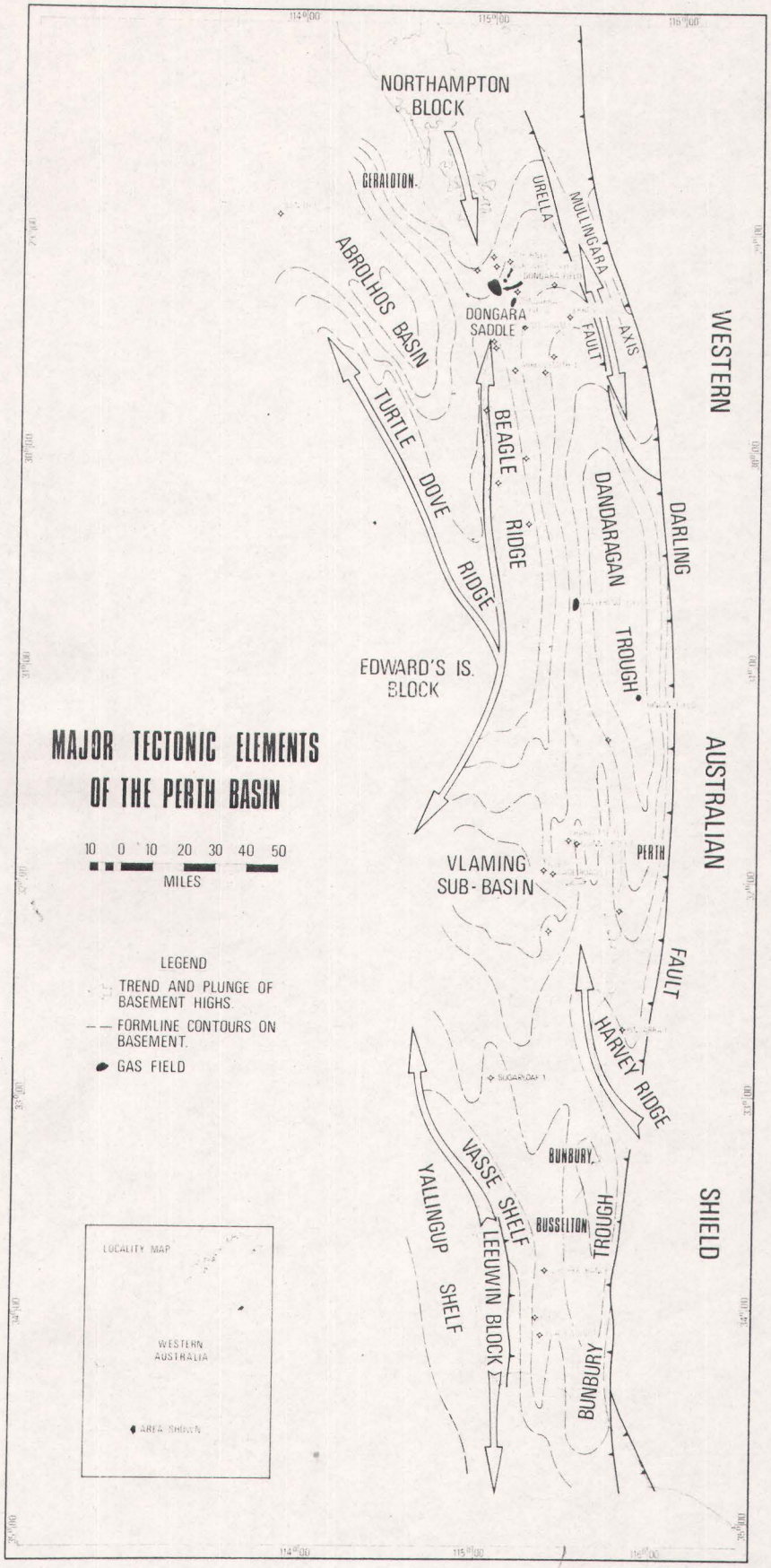


PLATE 1



A - 18,768 G.R. PEARSON 7.1.1972 PLATE 2

PERTH BASIN

HYDROCARBON-GENERATION ANALYSIS OF THE VLAMING SUB-BASIN

by

G.J. Demaison

West Australian Petroleum Pty. Ltd.

August, 1972

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1. SUMMARY AND CONCLUSIONS

1.1 The hydrocarbon potential of the Vlaming Sub-basin is closely conditioned by the presence of a major angular and erosional unconformity which separates:

- A pre-unconformity section of Upper Jurassic sands (Yarragadee) topped by a Lower Neocomian paralic sand and shale sequence. The Lower Neocomian section is a time equivalent of the Barrow Group of the Carnarvon Basin.

- From: A post-unconformity section ranging from Upper Neocomian through Aptian (Warnbro Group). The Warnbro Group is capped in turn by thin, and to a degree disconformable, Upper Cretaceous and Tertiary sediments. The Warnbro Group is a time equivalent of the Winning Group of the Carnarvon Basin.

The above described unconformity relates to the major unconformity which separates the Muderong from the Barrow Group and older rocks in the Carnarvon Basin. In more general terms, this unconformity marks a major break in the geological history of the western edge of Australia and a change from rift controlled deposition in inland seas to open oceanic shelf conditions.

1.2 For the Vlaming Sub-Basin Proper

1.2.1 Pre-Unconformity Section:

The Upper Jurassic is a thick flood plain sand unit (Yarragadee) practically devoid of source characteristics, but offering good reservoir potential down to the top of the Brown Zone.

The Lower Neocomian, a thick (over 15,000 ft.) sand and shale unit, includes two moderately to strongly mature effective generative sequences for natural gas and paraffinic oil: the Carnac Formation and the Quinns Shale.

The "5700 Ft." oil in Gage Roads No. 1 is a mature, high pour point, paraffin base crude which is entrapped below the unconformity and was generated within the base of the Carnac Formation. The presence of non-commercial gas saturation below the Quinns Shale (Lower Neocomian-Jurassic boundary) in Gage Roads 1 further documents the concept of significant hydrocarbon generation within the pre-unconformity section.

The Carnac Formation and Quinns Shale are in advanced stages of maturity (Brown to Black) in the Bathurst Syncline, to the west of Roe, and it is likely that large quantities of hydrocarbons have been generated and expelled from these strata.

Primary migration from the Carnac and Quinns Shale, in the Bathurst Syncline, began in Upper Cretaceous time with perhaps peaking in early Tertiary time.

1.2.2 Post-Unconformity Section:

The marine South Perth Shale is a slightly mature, marginally effective generative sequence for oil and gas. The South Perth Shale caps a post-unconformity basal sand: the Gage Sandstone. The Gage Sandstone is shaly at its base and acts as a barrier rather than a collector over the unconformity surface.

The thin oil column in the Gage Sandstone of Gage Roads 2 is unrelated to the "5700 Ft." oil in Gage Roads 1 and to the Carnac Formation. Rather, there is evidence that the source of this particular ~~oil~~ is the South Perth Shale.

Although the South Perth Shale is a good potential source rock, it has never reached sufficient thermal maturity over a large enough area to generate and expel large quantities of hydrocarbons.

Primary migration from the South Perth Shale began at the end of Tertiary time and is probably still taking place to day. ~~It~~ is unlikely that the peak of primary migration has yet been reached anywhere in the Bathurst Syncline for this particular source unit, thus explaining a pattern of only weak free hydrocarbon shows in the Gage Sandstone.

1.3 For the Offshore Ridge Marking the Western Boundary of the Vlaming Sub-basin

1.3.1 Pre-Unconformity Section:

The nature of this section, on the ridge itself, is highly conjectural and could range from Upper Jurassic down to Precambrian basement. It could provide suitable reservoirs (particularly the Upper Jurassic and Upper Triassic sands) for hydrocarbons generated from the draping post-unconformity section and from the flanking Lower Neocomian (Carnac Formation).

1.3.2 Post-Unconformity Section:

The Warnbro Group could be entirely shaly (the Leederville Sandstone being a near shore facies) and could, together with a shaly Upper Cretaceous section, provide an effective cap on the offshore ridge.

1.4 The concepts presented above lead to the following conclusions:

1.4.1 Petroleum, in economic quantities, must be sought in traps and reservoirs which have collected hydrocarbons from the Carnac Formation during Late Cretaceous and Tertiary time.

1.4.2 Closures critical to entrapment must be sought at the Neocomian unconformity itself.

The most favorable zone of hydrocarbon entrapment rims the Brown Zone around the Bathurst Syncline.

This belt includes:

- Part of the offshore ridge which, at least in dip sections, shows a striking resemblance with the Rankin Trend generative and entrapment model, except for the fact that the Tertiaries are much thinner.

- The Challenger, Salmon and Bovard prospects with, farther away from the generative area, the Hawley Shoals prospect.

1.4.3 Two key questions cannot at this time find an answer yet, their elucidation would be of critical assistance into a final assessment of the Vlaming Sub-basin.

A - Is the shaly interval at the base of Gage Sandstone Formation a widespread permeability barrier sealing the unconformity over and around the Bathurst Syncline?

B - Does the upper part of the Warnbro Group (Osborne or Leederville) provide a shaly cap wherever the South Perth Shale is absent by non-deposition (Salmon, offshore ridge)?

If the answer is yes, on both counts, then:

- Drainage difficulties to charge the Gage Sandstone with South Perth Shale hydrocarbons at Challenger or Bovard are irrelevant, as, anyhow, the bulk of hydrocarbon movements took place below the unconformity.

- The fact that the South Perth Shale is absent on Salmon does not detract to its effectiveness as a trap for pre-unconformity hydrocarbons. The peak of hydrocarbon migration occurred, in any case, after the deposition of Leederville equivalent or Osborne Formation shales which sealed the breach left by the South Perth Shale.

- Pre-unconformity reservoirs on the offshore ridge were properly capped by Leederville equivalent or Osborne Formation shales prior to time of migration from the Bathurst Syncline.

If the answer to the above two questions is no, then the whole Vlaming Sub-basin is a hydraulic sieve and its potential for retention of large hydrocarbon accumulations can only be very low.

ROE Nº 1 R.T. 99' I.E.S. | GAGE ROADS Nº 2 R.T. 99' I.E.S. | GAGE ROADS Nº 1 R.T. 70·4' I.E.S. | CHARLOTTE Nº 1 R.T. 99' I.E.S. | QUINNS ROCK Nº 1 R.T. 79' I.E.S.

DATUM SEA LEVEL — 3·5 miles — 1 mile — 11 miles — 3·5 miles — DATUM SEA LEVEL

UNNAMED CARBONATES (MIOCENE)

UNNAMED SANDSTONE (OLIGOCENE - MIOCENE)

OSBORNE FM 1769'

LEEDERVILLE SST 1260'

LEEDERVILLE SST 1475'

(SANDSTONE UNIT)

LEEDERVILLE SST 1880'

LEEDERVILLE SST 2030'

LEEDERVILLE SST 2080'

TOP OF ORANGE ZONE (SANDSTONE UNIT) (TAI 2)

LEEDERVILLE SANDSTONE (APTIAN)

(SANDSTONE UNIT)

TOP OF ORANGE ZONE (TAI 2)

K III

2005'

2000'

2200'-2500' MIXED HUMIC KEROGENOUS

SHELL: "VERY POOR S.R. POTENTIAL, BUT SAMPLES CONTAMINATED"

GEOCHEMICAL LOG TOTAL ORGANIC CARBON

YARRAGADEE FM 2560'

TOP OF ORANGE ZONE

3000'

LOWER NEOCOMIAN 2950'

ABUNDANT REMANIE PALYNOMORPHS (PERMIAN AND TRIASSIC)

TOP OF ORANGE ZONE (TAI 2) WITHIN THIS INTERVAL

CORE 3 1·55% BFOC MAINLY HUMIC

CORRELATION POINT 'X' 5340'

58% F.C.

LOWER NEOCOMIAN CARNAC FM.

SOUTH PERTH SHALE 3765'

GAGE MBR 4430'

YARRAGADEE 4430'

HYDROCARBON ZONE 4432'-4468' FIT at 4435'- 12 litres oily water OIL AS EXTRACTED FROM CORE HAS NO LIGHT AND HEAVY ENDS AND ABNORMALLY LOW CONTENT IN NORMAL PARAFFINS. C13/C12 5·3% INTERPRETATION POSSIBLY MIGRATED AND WEATHERED LIGHT NAPHTENIC CRUDE GENERATED FROM SOUTH PERTH SHALE

61% F.C.

63% F.C.

67% F.C.

59% F.C.

CORE 4 STILL IN ORANGE ZONE (TAI 2)

CORE 4 1·98% BFOC MIXED HUMIC-SAPROPELIC

T.D. 7001'

MUD LOG OIL & GAS SHOW 5890'-5920' 5890'-5898' C1 to C2 5900'-5920' C1- to C4 OIL STAINING FIT at 5913'- 4·7 litres muddy water INTERPRETATION RESIDUAL OIL & GAS IN VERY TIGHT SAND

CORRELATION POINT 'X' 5885'

NOTE: POOR COINCIDENCE OF COAL RANKS AND PALYNOMORPH DISCOLOURATION PROBABLY DUE TO REMANIE PERMIAN AND TRIASSIC VITRINITE.

LOWER NEOCOMIAN (UNNAMED SANDSTONE UNIT)

GEOCHEMICAL LOG BITUMEN FREE CARBON PER CENT

ONE SAMPLE ONLY HAS POSITIVE INDICATION

ORGANIC CARBON <1·3 VERY POOR

SOUTH PERTH SHALE (UPPER NEOCOMIAN TO APTIAN)

SOUTH PERTH SH 4200'

GEOCHEMICAL LOG BITUMEN FREE ORGANIC CARBON

62% F.C.

66% F.C.

65% F.C.

66% F.C.

62% F.C.

S.P. ANALYSIS 4980' TOTAL ORGANIC CARBON 3·71% EXTRACT C13/C12 5·1%

GAGE ROADS MBR 5205'

MUDLOG WEAK GAS SHOW

MIXED HUMIC SAPROPELIC POTENTIAL SOURCE ROCKS FOR OIL AND GAS

MAINLY HUMIC SOURCE ROCKS FOR MAINLY GAS

YARRAGADEE FM 5720'

HYDROCARBON ZONES

Porosity: 21-28 % Permeability: 9 - 1100 m.d

1. 5775' - 5581'
2. 5590' - 5804' } 29'
3. 5838' - 5867'

INTERPRETATION ZONES 1 and 2: DST 1A IN OIL - WATER TRANSITION ZONE 60 bbls 37 API OIL 82 bbls WATER in 27 hours 27 minutes

MATURE PARAFFINIC HIGH POUR POINT CRUDE GENERATED FROM LOWER NEOCOMIAN SHALE ABOVE CORR POINT "Y"

ZONE 3: DST 2A 58·5 bbls 41·2 API OIL 25 bbls WATER in 8 hours 20 minutes

OIL FROM ZONE 3. HIGH POUR POINT 75°F VERY LOW SULPHUR: 0·019 C13/C12 9·5·8%

SOUTH PERTH SHALE 4035'

GAGE ROADS SANDSTONE (UPPER NEOCOMIAN)

LOWER NEOCOMIAN

UNNAMED UNIT 7100'

(SHALE, SHALY - SANDSTONE UNIT)

52% F.C.

56% F.C.

62% F.C.

59% F.C.

50% F.C.

T.D. 7990'

TOP OF BROWN ZONE NOT FAR BELOW T.D.

FORESETS DIP SOUTH - WEST

(SILTSTONE - SHALE UNIT)

MAINLY HUMIC POTENTIAL SOURCE ROCKS FOR GAS

MIXED HUMIC SAPROPELIC SOURCE ROCKS FOR OIL AND GAS

MIXED HUMIC SAPROPELIC

LOWER NEOCOMIAN (UNNAMED SANDSTONE UNIT)

TOP OF BROWN ZONE TAI 3

QUINNS SHALE 5240'

5200'

MAINLY HUMIC POOR S.R. POTENTIAL

5600'

JURASSIC

YARRAGADEE FM.

NOTE: NO FIXED CARBON % AVAILABLE FOR QUINNS ROCK No.1

THIS INTERVAL HAS ABNORMALLY HIGH BITUMEN CONTENT SAMPLES CONTAIN HEAVY EXTRACTABLE HYDROCARBONS BITUMEN MAY HAVE BEEN LEFT BEHIND ON MIGRATION PATH OR IT MAY BE INSPISSATED REMNANTS OF FORMER ACCUMULATION UNSOLUBLE ORGANIC CARBON MAY BE ASPHALTENES UNEXTRACTABLE WITH CHLOROFORM

T.D. 7248'

NO SHOWS BELOW QUINNS SHALE Shaly sand tight 100% water saturation

QUINNS SHALE 9343'

TOP OF BROWN ZONE (TAI 3)

JURASSIC

QUINNS SHALE 8410'

HYDROCARBON ZONE 8590' - 8680' Porosity 13 - 22 % Permeability 0 - 8md

81 % OF GAS 9 % OF OIL SHOW 26 % OF OIL-WATER TRANSITION FROM 1230 INTERPRETATIONS

INTERPRETATION HYDROCARBONS GENERATED BY QUINNS SHALE FROM DOWNDIP AREAS TO THE WEST (BATHURST SYNCLINE) POOR GAS RESERVOIR

MIXED HUMIC SAPROPELIC POTENTIAL SOURCE ROCKS FOR OIL & GAS

TOP OF BROWN ZONE TAI 3

T.D. 12009'

LOCALITY MAP

31° 40'

WA - 14 - P

WA - 13 - P

E.P 25

CHARLOTTE No.1

QUINNS ROCK No.1

ROE No.1

No.2

GAGE ROADS No.1

Perth

Rottnest Island

0 5 10 15 MILES

115° 50'

32° 10'

LEGEND

63% F.C. = Fixed Carbon % from reflectance of Vitrinite (Shell)

TOP OF ORANGE ZONE (TAI 2) = Approximate top of TAI zones by palynomorph discoloration determinations (P. Nygreen)

REVISIONS	WEST AUSTRALIAN PETROLEUM PTY. LTD.
	PERTH DISTRICT
	COMPOSITE PLOT OF L.O.M. — SOURCE ROCK DATA ROE No.1 — QUINNS ROCK No.1
	SUPERIMPOSED ON STRATIGRAPHIC CROSS SECTION (R.G. McKellar)
	G. I. DEMAISON FEB. 1972
DR. BY T.R. BY CH. BY	DATE FEB. 1972 — SCALE DIAGR. — A-16261-1

PLATE 3

2. GEOLOGICAL BACKGROUND

Three slices of prospective sediments accessible to the drill are present in this sub-basin from top to bottom:

2.1 An Upper Neocomian-Aptian sequence, the Warnbro Group, which is resting in unconformable relationship over the Lower Neocomian. The unconformity is a strongly dissected, juvenile, erosional surface featuring ancient valley and ridge systems. The bottom of the valley systems are filled by a fluviatile basal sandy unit: the Gage Sandstone, a subdivision of the Warnbro Group. Subsequent marine flooding created for some time sub-marine canyon conditions. The South Perth Shale, which overlaps the Gage Sandstone, contains fair to marginal amounts of mixed humic-sapropelic organic matter. It is followed by the Leederville Formation, an estuarine sandstone-shale unit.

2.2 A very thick Lower Neocomian paralic sequence, between the base of the Quinns Shale and the pre-Upper Neocomian unconformity. The environment of deposition, different from that of the Upper Jurassic, is documented by the presence of shale beds which have yielded microplankton (acritarchs and rare dinoflagellates). Formation water salinities are also distinctly higher than in the Upper Jurassic: over 30,000 ppm.

The Lower Neocomian includes shales (Carnac Formation and Quinns Shale) with fair to marginal humic and mixed humic-sapropelic source potential. Although humic matter is fairly abundant, there are only a very few thin coal beds recognized as such.

2.3 An Upper Jurassic continental sequence essentially made up of flood plain sands with variable reservoir potential but practically devoid of source characteristics. This is the typical Yarragadee Formation as known and defined in the onshore part of the Perth Basin. Formation water salinities are in the order of 10,000 to 14,000 ppm.

2.4 Above the Upper Neocomian-Aptian, a thin sediment cover of Upper Cretaceous age has been preserved in some areas. Tertiary sediments finally blanket, while thickening westward, the whole of the Vlaming Sub-basin.

2.5 Stratigraphic relationships indicate tectonic movements:

- prior to Upper Neocomian-Aptian deposition
- prior to Cenomanian deposition
- prior to Senonian deposition
- prior to Tertiary deposition

The major phase of structural deformation is the one which occurred prior to Upper Neocomian-Aptian deposition.

3. POTENTIAL SOURCE ROCKS

Organic carbon content determinations were performed on a closely sampled basis over selected intervals in the following wells:

- Gage Roads No. 1
- Gage Roads No. 2
- Charlotte
- Quinns Rock
- Warnbro

Organic carbon content determinations were also carried out on Core 5 (South Perth Shale) of Gage Roads 1, as well as in Cores 3 and 4 of Roe. Programmed temperature chromatography analysis and carbon isotopic ratio determinations have been performed on bitumen extract from the above-mentioned cores.

The results of all these investigations can be summarized as follows:

3.1 South Perth Shale

It is the thickest recognized, mixed sapropelic-humic interval in the Vlaming Sub-basin. Values are fair (about 1% BFOC) in Gage Roads No. 1, very poor in Gage Roads No. 2 and lean (about .5% BFOC) in Charlotte and Warnbro. The South Perth Shale is a good potential source rock.

3.2 Lower Neocomian (Carnac Formation and Quinns Shale)

The Quinns Shale has been recognized as a mixed sapropelic-humic interval in Gage Roads No. 1 (fair), in Warnbro (lean) and in Quinns Rock (poor).

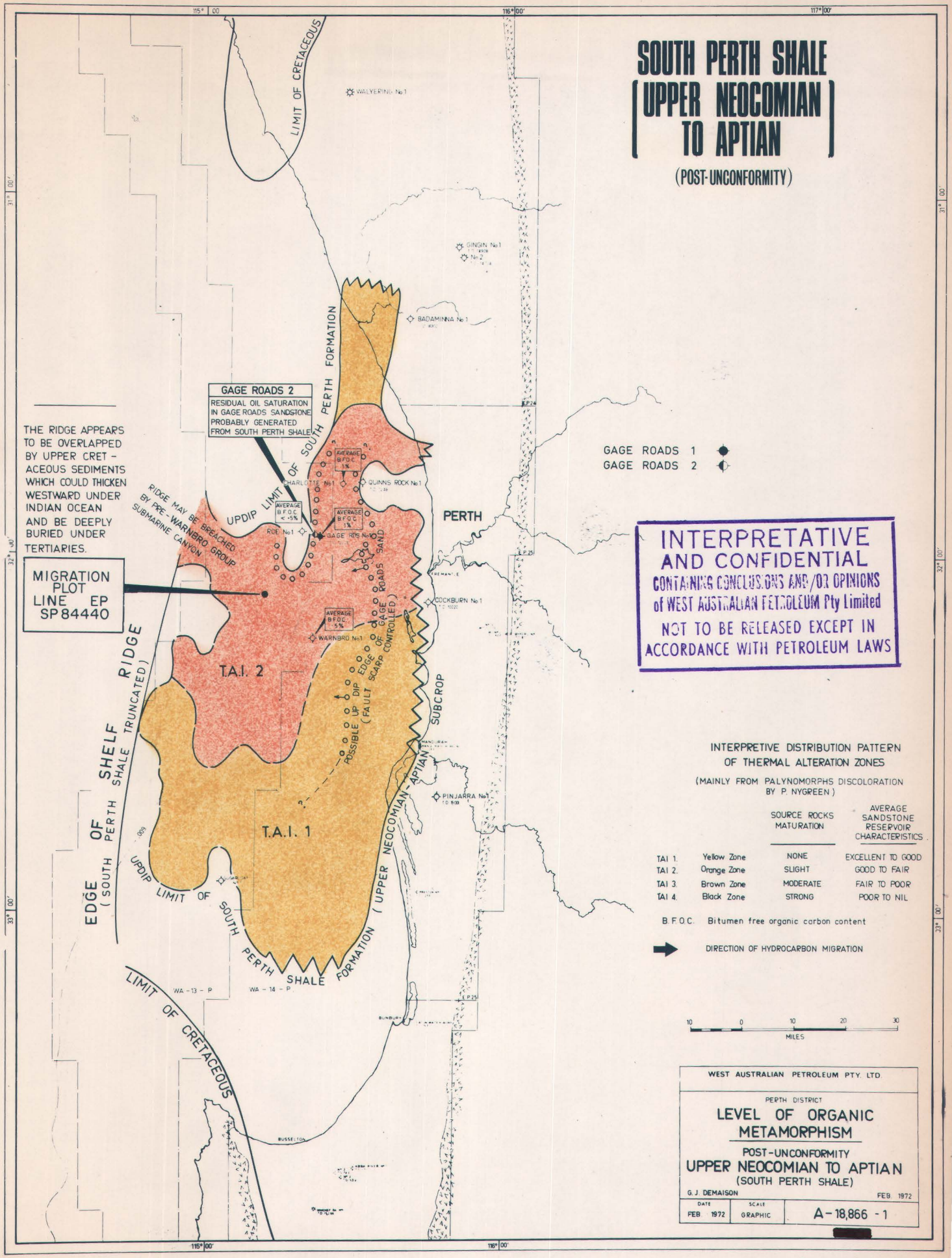
The base of the Carnac Formation, as sampled in Core 4 of Roe 1, is a good potential source rock for mainly gas and paraffinic oil (mixed sapropelic-humic). Core 3, higher up in the Carnac Formation, shows potential for mainly gas (humic).

3.3 Other Indications

The shale-siltstone unit above the South Perth Shale in Charlotte has moderate gas potential (mainly humic).

SOUTH PERTH SHALE (UPPER NEOCOMIAN TO APTIAN)

(POST-UNCONFORMITY)



WEST AUSTRALIAN PETROLEUM PTY. LTD.

PERTH DISTRICT

LEVEL OF ORGANIC METAMORPHISM

POST-UNCONFORMITY

UPPER NEOCOMIAN TO APTIAN

(SOUTH PERTH SHALE)

G. J. DEMAISON — FEB. 1972

DATE	SCALE	
FEB 1972	GRAPHIC	A-18,866 - 1

PLATE 4

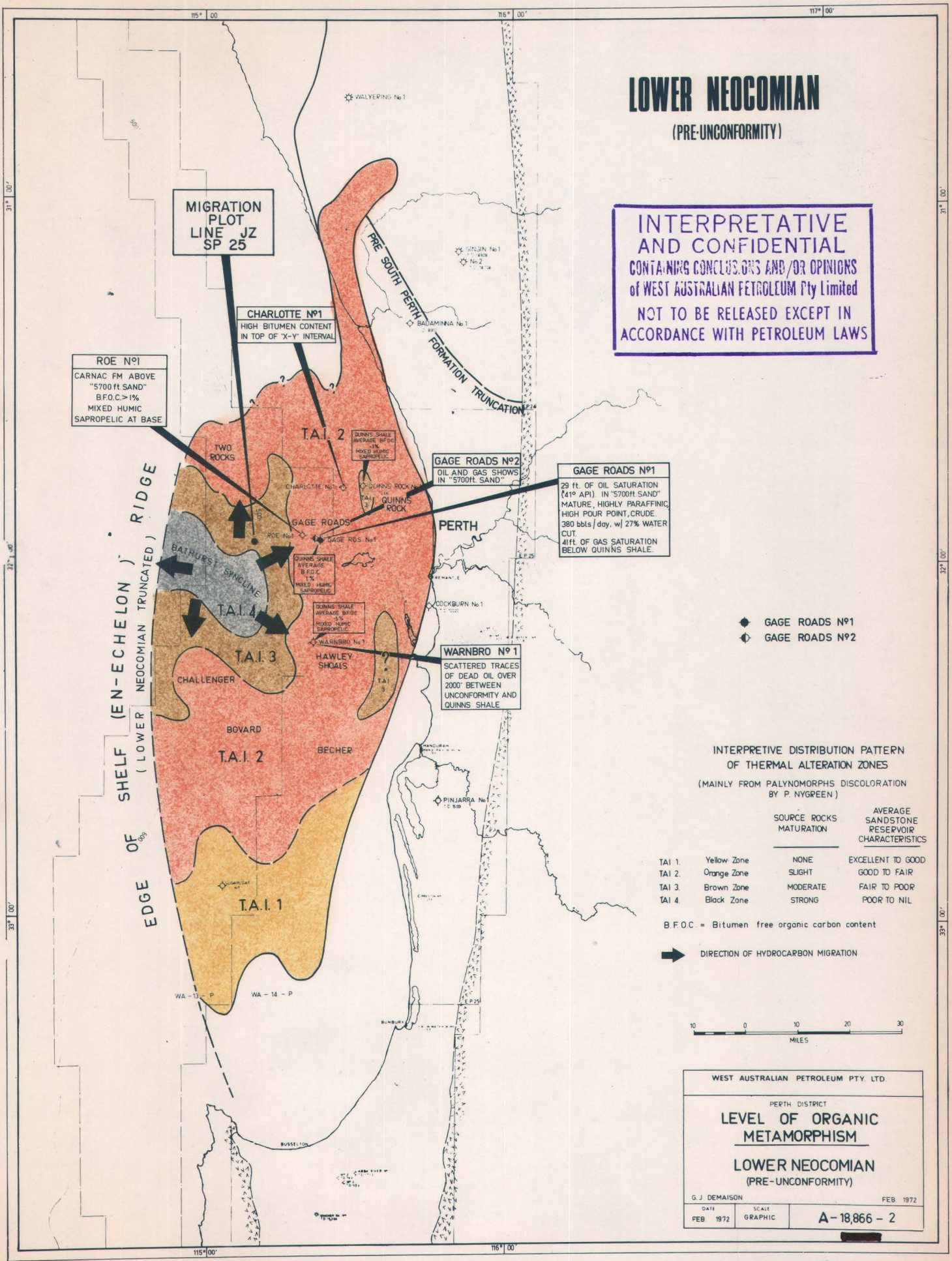

LOWER NEOCOMIAN
(PRE-UNCONFORMITY)
INTERPRETATIVE AND CONFIDENTIAL
CONTAINING CONCLUSIONS AND/OR OPINIONS of WEST AUSTRALIAN PETROLEUM Pty Limited
NOT TO BE RELEASED EXCEPT IN ACCORDANCE WITH PETROLEUM LAWS
MIGRATION PLOT LINE JZ SP 25
CHARLOTTE Nº1
HIGH BITUMEN CONTENT IN TOP OF 'X-Y' INTERVAL
ROE Nº1
CARNAC FM ABOVE "5700 ft SAND" B.F.O.C.>1% MIXED HUMIC SAPROPELIC AT BASE
GAGE ROADS Nº2
OIL AND GAS SHOWS IN "5700ft SAND"
GAGE ROADS Nº1
29 ft. OF OIL SATURATION (41° API) IN "5700ft SAND" MATURE, HIGHLY PARAFFINIC, HIGH POUR POINT, CRUDE. 380 bbls/day, w/ 27% WATER CUT. 41ft. OF GAS SATURATION BELOW QUINNS SHALE.
WARNBRO Nº 1
SCATTERED TRACES OF DEAD OIL OVER 2000' BETWEEN UNCONFORMITY AND QUINNS SHALE
PRE SOUTH PERTH FORMATION TRUNCATION
SHELF (EN-ECHELON) RIDGE EDGE OF (LOWER NEOCOMIAN TRUNCATED)
BATHURST SYNCLINE
T.A.I. 1
T.A.I. 2
T.A.I. 3
T.A.I. 4
TWO ROCKS
GAGE ROADS
PERTH
QUINNS ROCK
HAWLEY SHOALS
CHALLENGER
BOVARD
BECHER
WALYERING No 1
BADAMINNA No 1
CHARLOTTE No 1
ROE No 1
GAGE RDS No 1
QUINNS ROCK No 1
WARNBRO No 1
COCKBURN No 1
PINJARRA No 1
BUNBURY
BUSSELTON
WA - 13 - P
WA - 14 - P
EP 25
GAGE ROADS Nº1
GAGE ROADS Nº2
INTERPRETIVE DISTRIBUTION PATTERN OF THERMAL ALTERATION ZONES
(MAINLY FROM PALYNOMORPHS DISCOLORATION BY P. NYGREEN)
SOURCE ROCKS MATURATION
AVERAGE SANDSTONE RESERVOIR CHARACTERISTICS
TAI 1. Yellow Zone NONE EXCELLENT TO GOOD
TAI 2. Orange Zone SLIGHT GOOD TO FAIR
TAI 3. Brown Zone MODERATE FAIR TO POOR
TAI 4. Black Zone STRONG POOR TO NIL
B.F.O.C. = Bitumen free organic carbon content
DIRECTION OF HYDROCARBON MIGRATION
10 0 10 20 30
MILES
WEST AUSTRALIAN PETROLEUM PTY. LTD.
PERTH DISTRICT
LEVEL OF ORGANIC METAMORPHISM
LOWER NEOCOMIAN
(PRE-UNCONFORMITY)
G.J. DEMAISON
FEB 1972
DATE FEB 1972
SCALE GRAPHIC
A-18,866-2

PLATE 5

4. LEVEL OF ORGANIC METAMORPHISM

Level of organic metamorphism has been difficult to establish, both with reflectance of vitrinite data and by study of palynomorphs discolouration. There are appreciable amounts of reworked Permian and Triassic palynomorphs in the Lower Neocomian. The presence of remanie vitrinite is therefore considered as likely by the author.

These difficulties must have been suspected by the investigator for reflectance of vitrinite as a rerun of determinations was carried out for Warnbro. The investigator indicated then that, at least for Warnbro, results were not very reliable.

Following recognition of these difficulties, reflection of vitrinite data were checked against palynomorph discolourations, seismic velocities and sonic logs. A complete inspection of cores was carried out to appreciate the degree of compaction and fissility of shaly intervals and the cementation of sandstones.

These investigations helped in disregarding obvious inconsistencies and confirming the pattern as presented, which is essentially based on palynomorph discolouration data. The author is confident that it accurately exposes the broad picture even if some local details still need elucidation.

It is concluded that:

4.1 The South Perth Shale is only slightly mature (T.A.I. 2 - Orange Zone) wherever it has been penetrated by the drill. From seismic evidence, it does not reach the T.A.I. 3 (Brown Zone) stage in the Bathurst Syncline (synclinal area west of Roe) (see Figure 3).

4.2 The Lower Neocomian has been drilled so far in T.A.I. 2 (Orange Zone) with the exception of Sugarloaf where it is definitely immature (T.A.I. 1). It is predictable, from seismic evidence, that the base of the Carnac Formation and the Quinns Shale pass into T.A.I. 3 (Brown Zone) and T.A.I. 4 (Black Zone) in the Bathurst Syncline (see Figure 4).

4.3 The Leederville Formation, as well as the Upper Cretaceous and Tertiary, being in the upper part of the section, are largely immature (T.A.I. 1). However, the Leederville Formation could pass into the Orange Zone (T.A.I. 2) in the Bathurst Syncline while becoming increasingly shaly.

4.4 Level of organic metamorphism patterns in sediments are dependent on both depth of burial and geothermal gradient. The geothermal gradient map of the Perth Basin points to a favourable situation for the Vlaming Sub-basin, as the generative Bathurst Syncline is in an area of higher earth temperatures than the cooler, and therefore attractive, entrapment areas rimming the Bathurst Suncline to the south and west.

5. OCCURRENCES OF FREE HYDROCARBONS

With the exception of a thin (5 ft.) oil column in the Gage Roads sand member of the South Perth Formation and very weak gas shows at the top of the Gage Roads sand in Gage Roads No. 1 and Warnbro, all the hydrocarbon shows in the Vlaming Sub-basin have been found below the unconformity within the Lower Neocomian.

5.1 Gage Roads No. 1

5.1.1 In the interval 5,775 ft. - 5,847 ft., three sands totalling 29 ft. of the oil saturation are present in the topmost part of the Lower Neocomian (see Plate 1). Water saturation is too high to allow commercial production (57-89%).

Testing of the lowermost sand through perforations between 5,838 ft. - 5,847 ft. produced 41°API oil at rates up to 380 bbls./day with an average water cut of 27%. Salinity of the water is 40,000 ppm.

The salient analytical data for this oil are:

- API gravity: 40.9
- Sulfur content: 0.019
- C_{13}/C_{12} ratio: +5.6 °/oo
- Paraffinicity index: 3.02
- Pour point: approximately 70°F
- Asphalt : 0.19%
- Alkanes : 81.2%
- n-Alkanes % in alkanes: 87.02
- Aromatics: 12.1%
- ONS compounds: 6.6%
- Pristane/Phytane: 5.0%

This oil has been described by Powell and McKirdy (B.M.R.) as paraffin base with a low content in isoprenoids and naphthenic hydrocarbons as well as a high pristane to phytane ratio. These characteristics point to a high ranking mature oil of mainly humic to mixed sapropelic-humic origin.

5.1.2 A 90 ft. hydrocarbon column is present below the base of the Quinns Shale Member. Over the interval 8,590 ft. - 8,680 ft., log interpretation indicates the presence of 41 ft. of gas, 9 ft. of oil shows and 26 ft. of oil/water transition. Reservoir parameters being poor (k = 0-6 md.) no testing was attempted. Therefore, no analysis of these hydrocarbons is available.

5.2 Gage Roads No. 2

5.2.1 5 feet (4,431 ft. - 4,436 ft.) of non-commercial effective oil saturation was indicated above the unconformity in the Gage Roads sand by wireline logs within the oil stained interval 4,432 ft. - 4,460 ft. An FIT test at 4,435 ft. yielded 12.6 liters of oily water and 1.4 cubic feet of gas. Investigations were carried out on oil extracts from Core No. 1. The salient results are:

- Paraffinicity index: 0.95

- C_{13}/C_{12} ratio: $+5.3^{o}/oo$

This oil has the peculiarity of lacking both light and heavy ends and has a very low concentration in normal paraffins. This latter characteristic hints of naphthenic-aromatic crude. Additional analytical work is projected to be carried out provided sufficient oil extracts can be recovered from sealed core samples. The FIT fluids are currently being analyzed.

5.2.2 Below the unconformity, oil and gas shows were detected by mudlogging between 5,890 ft. and 5,920 ft., well within the Lower Neocomian. As noted in the final well report, it is significant that the elevation of the base of this zone (5,820 ft.) can be equated with the lowest saturation in Gage Roads (-5,818 ft.). These shows occurred in tight sandstone and an FIT performed at 5,913 ft. yielded 15.7 liters of muddy water (total solids: 5300 ppm).

5.3 Charlotte No. 1

Abnormally high quantities of chloroform-soluble matter were detected below the unconformity in the Lower Neocomian by geochemical analysis between 7,150 ft. and 7,990 ft. (T.D.). Values are in the order of 1% with peaks exceeding 2% and some up to 4%.

5.4 Warnbro No. 1

Numerous shows of dead oil were recorded in the Lower Neocomian, below the unconformity:

- 7,148 ft. - 7,160 ft.: Traces of dead oil. Brown oil stain on coarse sand grains. Light yellow to gold fluorescence. Cut.

- 7,860 ft. - 7,880 ft.: Brown oil stain on coarse sand grains. Light yellow to gold fluorescence. Cut.

- 8,800 ft. - 8,820 ft.: Traces of dark brown thick oil in unwashed cuttings giving pale cut.

- 9,330 ft. - 9,350 ft.: Traces of brown oil on unwashed sample under water, rises slowly to surface but does not spread. Dull gold fluorescence. No visible oil stain. Instant crush cut from shale.

- 9,390 ft. - 9,400 ft.: As above.

- 9,820 ft. - 9,830 ft.: As above.

A very weak gas show was recorded immediately below the Quinns Shale at 9,785 ft.

In contrast, there were no oil traces whatsoever above the unconformity in the Gage Roads sand, but only a very weak gas show at the very top of this unit.

6. INTERPRETATION OF DATA

6.1 Location of the Generative Area

Source rock characteristics (mixed sapropelic-humic) such as those of the South Perth Shale, the Carnac Formation and the Quinns Shale necessitate fairly strong thermal alteration (base of Orange to Brown) in order to release hydrocarbons. Humic matter in mixed humic-sapropelic source rocks retards primary migration at mild temperatures. For this reason, the critical generative area in the Vlaming Sub-basin is the synclinal area west of Roe (Bathurst Syncline) where the Lower Neocomian is well into the Brown Zone (T.A.I. 3). The South Perth Shale, on the other hand, does not appear to have reached sufficient maturity to trigger large scale expulsion of hydrocarbons.

6.2 Relations of Free Hydrocarbons to Generative Sequence

6.2.1 The hydrocarbons in Gage Roads No. 1 relate to the Lower Neocomian effective generative sequences (Carnac Formation and Quinns Shale) in the Bathurst Syncline.

This pre-unconformity origin for the hydrocarbons in Gage Roads 1 is documented by:

- the obvious correlation between the mature, highly paraffinic "facies" of the "5700 Ft. Sand" waxy crude oil and the nature of the organic matter in the Carnac Formation (humic to mixed humic-sapropelic) requesting fairly high temperature generation.

- the fact that the normal paraffin distribution pattern and n-alkane total alkane ratio in a bitumen extract of Carnac Shale in the Orange Zone (Core 4 of Roe 1) define an organic "facies" which given stronger thermal alteration, would yield an oil identical to the "5700 Ft. Sand" oil in Gage Roads 1.

- the fact that it is exceedingly difficult to visualize how the South Perth Shale, everywhere separated from the Lower Neocomian in the downdip areas by the Gage Roads sand member, could have fed hydrocarbons below the unconformity. This model is rendered even less acceptable by the fact that the base of the Gage Roads sand member is shaly and impervious in both Gage Roads wells and provides a seal on the unconformity. This seal has been seen at its thickest in Warnbro, which is basinward from the Gage Roads area, and it has every likeliness to be even more effective further downdip in the Bathurst Syncline.

6.2.2 The 90 ft. hydrocarbon column below the Quinns Shale is nearly 3,000 feet below the unconformity and has obviously been generated from the Quinns Shale itself which is a documented source rock for oil and gas with ample thermal maturation downdip to the west in the Bathurst Syncline.

6.2.3 The oil in Gage Roads No. 2, being very low in normal paraffins and highly aromatic, relates rather strongly to bitumen extracts from the South Perth Shale (Core 5 of Gage Roads 1). In any case, it is unrelated to the "5700 Ft. Sand" oil from Gage Roads 1.

7. TIMING OF PRIMARY MIGRATION

The oil entrapped in the 5700 Ft. Sand at Gage Roads 1 was emplaced during Upper Cretaceous time. This is documented by:

- The fact that the oil sands are only 55 ft. below the erosional unconformity surface. The 41° API oil recovered is a mature oil with nearly all its light ends and could not have subsisted as such so close to the surface if it had been already present there during the Neocomian erosional phase.

The hydrocarbon column under the Quinns Shale was also emplaced during Upper Cretaceous time.

The post-unconformity oil in Gage Roads 2 was generated and emplaced in late Tertiary time, and it is likely that migration may still take place to this day.

Signed,

G.J. Demaison
27.8.72

PERTH BASIN

HYDROCARBON-GENERATION ANALYSIS

PERTH BASIN (ONSHORE)

(PERMIAN TO JURASSIC)

by

G.J. Demaison
West Australian Petroleum Pty. Ltd.

May, 1972

TABLE OF CONTENTS

1. SUMMARY AND CONCLUSIONS

1.1 Northern Perth Basin

1.1.1 The Cattamarra (Coal Measures) Member of the Cockleshell Gully Formation is thermally immature in the northern Perth Basin, and therefore is not an effective generative sequence in this particular area.

1.1.2 Multicoloured shales in the Eneabba Member of the Cockleshell Gully Formation contain sufficient amounts of organic matter to have generative potential for mainly gas and some paraffinic oil. The oil tested at Erregulla in the Eneabba Member may be from the oil rim of a gas accumulation. This play is currently undervalued and will be for some time as it will not be readily accepted that the Eneabba Member is most probably its own source of hydrocarbons. If this possibility is confirmed by additional analytical work, to be carried out in 1973, then further exploration will be justified on the structurally-high Erregulla platform.

1.1.3 The Permian and Triassic of the Northern Perth Basin contain moderate to marginal, effective generative sequences for mainly natural gas, condensate and subordinate quantities of high pour point paraffinic oil.

Outside of the Dongara Field proper, reservoirs are poor as a result of high levels of organic metamorphism in the pre-Kockatea section due to high prevailing geothermal gradients in the potential entrapment areas. The pre-Kockatea prospective reservoirs, with the exception of the Basal Triassic Sand, are first generation sands which do not retain good reservoir characteristics below the Orange zone.

The upper part of the Kockatea offers limited objectives, as its source potential is only marginal and the sands of dubious lateral extension.

The results, to-date, on the Triassic play, confirm a documented background of moderate, at best, source potential for mainly gas, in conjunction with rather ineffective carrier beds and reservoirs.

1.2 Dandaragan Trough

The Jurassic play offers the best opportunity in the onshore Perth Basin for developing sizable natural gas and condensate reserves in a reasonably predictable fashion.

1.2.1 For the Cattamarra Member the west flank of the trough has high potential for the right combination of reservoirs in the immediate proximity of the effective generative area.

As a whole, the most favourable belt of potential hydrocarbon entrapment rims the TAI3 (Brown) zone around the central generative part of the Dandaragan Trough. This belt includes:

- Barberton
- Coomallo
- Dandaragan
- Gingin-Bullsbrook
- Walyering

1.2.2 The potential of the Cadda is marginal compared to that of the Cattamarra Member.

1.2.3 The Eneabba Member is too deep in the above prospects to retain useful porosities, except at Coomallo which should be tested at least down to the top of the Kockatea.

1.3 Southern Perth Basin

1.3.1 There is no Jurassic play in this part of the Basin because of lack of organic matter and the level of organic metamorphism is nil: Yellow Zone.

1.3.2 The Upper Triassic (Lesueur Formation) is also non-prospective for the same basic reasons. The Kockatea Formation equivalent, as seen in Whicher Range, has no hydrocarbon generative potential (sandy facies).

1.3.3 The only valid play is for Permian objectives, which have documented potential for gas and condensate.

The Whicher Range-Wonnerup-Koombana mid-graben arch has had the ideal geological history, in time and space, to drain and entrap, at an early stage, hydrocarbons from the adjacent generative synclines.

The very low geothermal gradient prevailing in the southern Perth Basin (1°F/100 ft.) offers strong justification for the current deep Permian gas play.

LOWER JURASSIC

L.O.M. ZONATION APPLIES TO BASE OF CATTAMARRA MEMBER

DONGARA Nº1
4 SPOT SAMPLES
NO RELIABLE
USABLE RESULTS

STRAWBERRY HILL Nº1
B.F.O.C. ⩽ 14% (HUMIC) IN CATTAMARRA MEMBER
B.F.O.C. ⩽ 1% (HUMIC) IN SHALES OF ENEABBA MEMBER

MONDARRA No. 1
OIL AND GAS SHOWS IN ENEABBA MEMBER

MONDARRA No.4
B.F.O.C ⩽ 7% (HUMIC) IN CATTAMARRA MEMBER
B.F.O.C. ⩽ 2% (HUMIC) IN SHALES OF ENEABBA MEMBER

ERREGULLA No.1
OIL SATURATION OVER 61 FT. IN 3 SANDS IN ENEABBA MEMBER
47° API WAXY CRUDE

ENEABBA No.1
5 SPOT SAMPLES IN ENEABBA MEMBER
NO USABLE RESULTS

ENEABBA AND DONKEY CREEK
WEAK GAS SHOWS IN ENEABBA MEMBER

GUN ISLAND Nº1
GAS SHOWS (CH_4 ONLY) IN CATTAMARRA MEMBER

MT. ADAMS No.1
WEAK GAS SHOWS IN ENEABBA MEMBER

WALYERING No.1
SOURCE ROCK AND REFLECTANCE OF VITRINITE DATA NOT RECEIVED

GINGIN No.1
INTERVALS:
10800'–11090'
11300'–12090'
13045'–13200'
13500'–13590'
CONTAIN EFFECTIVE SOURCE ROCKS FOR MAINLY GAS
% OF ETHANE AND PROPANE AS WELL
CONDENSATE/GAS RATIOS INCREASE WITH DEPTH

BADAMINNA No.1
INTERVAL 3900'–4900'
B.F.O.C. ⩽ 7% (HUMIC)
INTERVAL 4900'–7350'
B.F.O.C. ⩽ 1·5% (HUMIC)
INTERVAL 7350'–7900'
B.F.O.C. ⩽ 2% (HUMIC)

COCKBURN No.1
A FEW THIN SOURCE ROCK LAYERS FOR GAS IN TOP OF CATTAMARRA MEMBER.
POTENTIAL IS OTHERWISE NEGLIGIBLE

PINJARRA No.1
500' TO 1000' INTERVAL SAMPLING IS NOT REPRESENTATIVE
ORGANIC CARBON CONTENT NEGLIGIBLE IN ANALYZED SAMPLES
NO COAL BEDS IN CATTAMARRA MEMBER
ENVIRONMENT IS ONE OF VERY POOR SOURCE ROCK POTENTIAL

MIGRATION PLOT LINE AMP SP 94

PELSART SYNCLINE
GEELVINK
DRUMMOND SYNCLINE
TURTLEDOVE SHALLOW BASEMENT RIDGE
(UPLIFTED AND TRUNCATED IN NEOCOMIAN TIME)
BEAGLE RIDGE (COCKLESHELL GULLY FORMATION TRUNCATED)
UPDIP SUBCROP EDGE COCKLESHELL GULLY FORMATION
UPDIP EDGE (Zero Isopach) OF CATTAMARRA MEMBER
PERTH

TAI 1
TAI 2
TAI 3
TAI 4?

INTERPRETIVE DISTRIBUTION PATTERN OF THERMAL ALTERATION ZONES

FROM: REFLECTANCE OF VITRINITE DATA (Shell)
: PALYNOMORPHS DISCOLORATION (P.Nygreen)

		SOURCE ROCKS MATURATION	AVERAGE SANDSTONE RESERVOIR CHARACTERISTICS
TAI 1	Yellow Zone	NONE	EXCELLENT TO GOOD
TAI 2	Orange Zone	SLIGHT	GOOD TO FAIR
TAI 3	Brown Zone	MODERATE	FAIR TO POOR
TAI 4	Black Zone	STRONG	POOR TO NIL

➡ DIRECTION OF HYDROCARBON MIGRATION

49 FIXED CARBON % (Shell)

SCALE OF MILES 0 10 20 30 40 50

WEST AUSTRALIAN PETROLEUM PTY LTD
PERTH DISTRICT
LEVEL OF ORGANIC METAMORPHISM
COCKLESHELL GULLY FORMATION
G. J. DEMAISON MAR 1972
DATE 25 MAY 70 | SCALE 1:500,000 | A – 18,946

TRANSVERSE MERCATOR PROJECTION — AUSTRALIAN NATIONAL MAPPING GRID

PLATE 1

2. HYDROCARBON GENERATION ANALYSIS OF THE JURASSIC SECTION

2.1 Geological Background

There are four Jurassic lithostratigraphic units in the Perth Basin, listed in decending order of prospectiveness as source rocks:

Cattamarra Member of the Cockleshell Gully Formation (Lower Jurassic)

Interbedded sandstones, siltstones and carbonaceous shales with coal beds. Environment of deposition: flood plain to coal marsh to lacustrine.

Eneabba Member of the Cockleshell Gully Formation (Lower Jurassic)

Multicoloured siltstones and shales, with well sorted sands carrying hypersaline waters. Environment of deposition: flood plain to lacustrine.

Cadda Formation (Middle Jurassic)

A shallow water marine unit comprising glauconitic sandstones, fossiliferous siltstones and minor limestone.

Yarragadee Formation (Upper Jurassic)

Massive poorly sorted sandstones with minor siltstones and rare coals.

Environment: flood plain.

2.2 Potential Source Rocks

The Cattamarra Member contains large amounts (over 1% in parts) of mainly humic organic matter in:

- Gingin 1
- Badaminna 1
- Strawberry Hill 1
- Walyering (unmeasured but coal beds and thick Carbonaceous shales)

Moderate amounts have been measured in:

- Mondarra 4

Small to negligible amounts have been recorded in:

- Cockburn 1
- Pinjarra 1

The Cattamarra Member has good to excellent source potential for mainly gas, condensate and subordinate amounts of light, high grade oil in the Dandaragan Trough. In this particular part of the depositional basin, coals and carbonaceous shales are best developed and attain their greatest cumulative thickness.

The Cockleshell Gully Formation has no potential for hydrocarbon generation to the south of the city of Perth.

The Eneabba (Multicoloured) Member contains moderate to marginal amounts of humic organic matter, with potential for mainly gas, in:

- Mondarra 4
- Strawberry Hill 1

The quantities involved are in the same order as those found in the Kockatea Shale in the above wells. This appears surprising, at first hand, as the Eneabba Member is largely composed of variegated sediments.

However, two points have been noted:

- the presence of organic matter has been recorded, in the bottom part of this sequence only, in relation with shale beds.

- core inspections have revealed the presence of abundant carbonaceous debris in those shales (Eneabba 1 and Strawberry Hill 1).

A thorough geochemical, sedimentological and mineralogical study of the Eneabba Member will be carried out in 1973 to elucidate the presence of hypersaline formation water and of organic matter in what has been considered so far as an oxydized sequence without hydrocarbon generative potential.

2.3 Level of Organic Metamorphism (Jurassic)

Level of organic metamorphism is nil (TAI 1) to slight (TAI 2) in most of the Perth Basin, with the exception of the Dandaragan Trough, where the Cockleshell Gully Formation has attained at least the brown zone (TAI 3) stage and is therefore an effective generative sequence. Extrapolation of geothermal and seismic data points to the possible presence of the black zone (TAI 4) in the most depressed portion of the trough.

2.4 Occurrences of Free Hydrocarbons

Occurrences of hydrocarbons are known in both the Cattamarra Member and the Eneabba Member.

2.4.1 Cattamarra Member

Gingin 1 and 2

A potentially commercial gas and condensate accumulation is present on the Gingin Anticline (Dandaragan Trough) in up to 16 sands (Gingin 2) over a height of nearly 1,000 ft.

The gas is high in ethane (between 4.9% and 7.3%) with a trend of definite increase in C_2-plus hydrocarbons with depth.

The condensate varies in gravity between 43° and 51°API with a content in aromatics from 26 to 15% by volume.

The restricting factor is the mediocre quality of the reservoirs which gradually deteriorate with increasing depth.

Walyering 1 and 2

These two wells have also encountered multiple pay sands in the Coal Measures Member but at shallower depth and with somewhat better reservoir characteristics than in Gingin.

Mud logs (chromatographic analysis) and analysis of gas samples appear to show a similar trend to that in Gingin; an increase in the relative volume of ethane and higher hydrocarbons with depth.

Detailed analysis of condensate samples have not been received yet, but what has been analysed indicates that these liquid hydrocarbons are practically identical with those recovered in Gingin.

Other Shows in Cattamarra Member

No significant shows have been observed outside of Gingin and Walyering, with perhaps an exception at Badaminna, which had weak mud log gas shows.

The significance of this lack of shows outside the Dandaragan Trough proper will be further discussed in this report.

2.4.2 Eneabba (Multicoloured) Member

The Eneabba Member is not productive, so far, but has given shows of gas and oil in several wells of the northern Perth Basin.

Erregulla 1

Mud log gas shows (C_1 with traces of C_2) were recorded across five distinct sands. Three of these sands:

10,413 - 10,435'
10,587 - 10,618'
10,657 - 10,665'

have significant oil saturations. It is strongly suspected that Erregulla may have tested the oil rim of a gas accumulation.

A swab test of perforated interval 10,413-10,435' recovered about 58 bbls. of waxy crude oil:

API gravity	:	47.1°
Paraffinicity index	:	5.04
Pour point	:	about 80°F
Sulfur	:	0.03
C_{13}/C_{12} ratio	:	-2.3
Asphalt	:	0.05%
Alkanes	:	73.9%
Aromatics	:	24.4%
ONS compounds	:	1.6%
Pristane/Phytane	:	1.1

These shows were found in or near the top of the Brown Zone.

Mondarra 1

Good mud log shows were observed between:

6,660 - 6,677' C_1 to C_3
6,699 - 6,704' C_1 to C_4

with fluorescence, cut and presence of waxy oil (dead) in cuttings.

Mondarra 2 and 4 had only weak gas shows across this same part of the Eneabba Member. All these shows are in the Orange Zone.

Donkey Creek 1

Weak gas shows (C_1 only) across three sand beds in lower 300' of the Member (in Orange Zone).

Eneabba 1

Weak gas shows (C_1 only) across eight sand beds in the lower part of the member (in Orange Zone).

Mt. Adams 1

One weak gas show (C_1 - C_2) between 7,310-7,355' (probably in Orange Zone).

Strawberry Hill

Weak gas shows (C_1 - C_2) between 6200 and 6300 ft. (in Yellow Zone).

It is highly significant that the only major shows (Erregulla) were recorded in the top of the Brown Zone. Whereas, the Eneabba Member is an immature sequence in most of the northern Perth Basin, it is more than likely that in the synclinal areas to the southeast of Erregulla it is a mature (Brown to Black) effective generative sequence.

2.5 Interpretation of Data

2.5.1 Dynamics of Hydrocarbon Generation and Location of Generative Area

The Cockleshell Gully Formation is a predominantly humic source sequence, with good potential for mainly gas, condensate and subordinate amounts of paraffinic oil.

The most promising part of the section is the Cattamarra Member because of its locally very high content of humic organic matter (Coal Measures facies).

The Eneabba Member contains (in its lower part) marginal to moderate amounts of humic organic matter which are sufficient to explain the shows of gas and high pour point oil described above (particularly Erregulla). The presence of higher hydrocarbons (when present) is clearly related to high levels of organic metamorphism of the enclosing sediments and to adjoining mature synclinal areas. A geochemical investigation of bitumen extracts from the Eneabba Member shales has been initiated in order to completely elucidate this particular hydrocarbon generation problem.

Generation of hydrocarbons in both members has probably occurred wherever this formation has been brought into the Brown Zone and the Black Zone by burial.

The critical generative area, for the Cockleshell Gully Formation, is the Dandaragan Trough where such conditions have been met.

2.5.2 Migrational and Entrapment History

Sufficient depth of burial was reached in the central part of the Dandaragan Trough by the end of Yarragadee (Jurassic) time to attain temperatures capable of triggering hydrocarbon generation and migration.

Emplacement of accumulations probably took place during the Upper Jurassic faulting phase, prior to deposition of the Neocomian.

Structural trends formed at the end of the Neocomian tectonic phase, which is marked by the pre-Upper Neocomian-Aptian unconformity, have probably come too late to entrap hydrocarbons. This, or the lack of an adequate trap, could explain the lack of significant shows in Badaminna, although organic carbon contents and level of organic metamorphism were found to be quite adequate in this particular well.

The most favourable belt of potential entrapment is in TAI 2 (Orange zone) and rims TAI 3 (Brown zone) in the Dandaragan Trough. This belt includes:

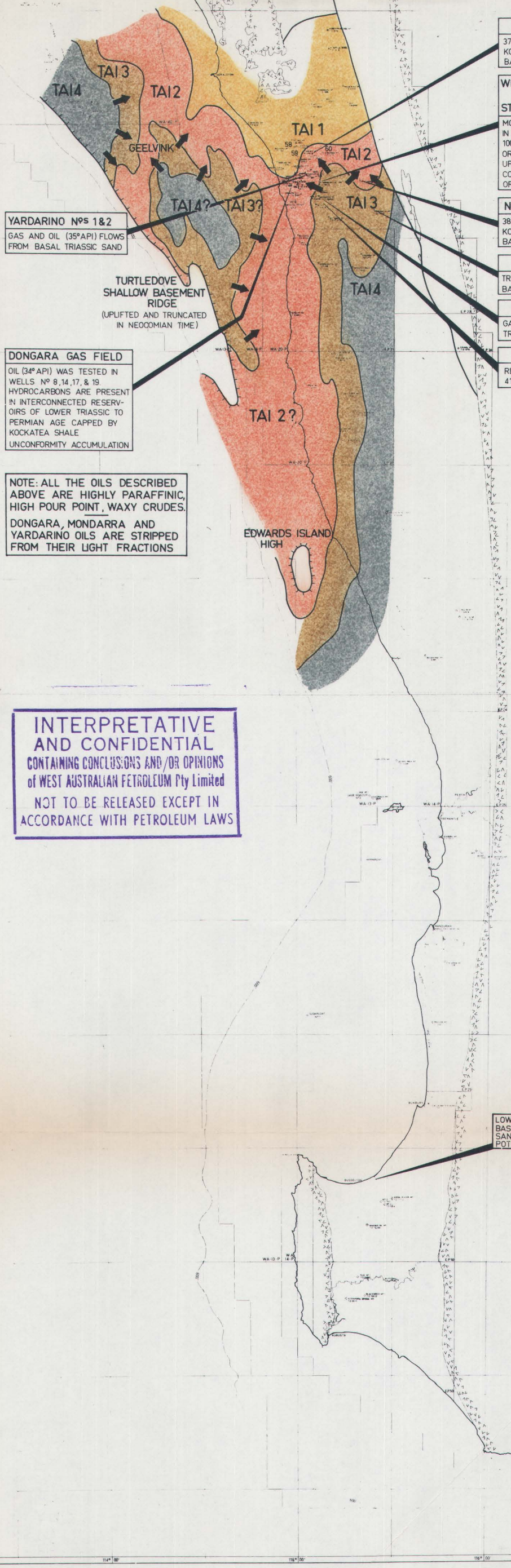
- Gingin-Bullsbrook
- Walyering
- Coomallo
- Dandaragan
- Barberton

The lack of shows associated with the Cadda Formation can be explained by insufficient level of organic metamorphism in conjunction with only moderate amounts of humic organic matter.

The lack of shows in the Coal Measures Member in the northernmost Perth Basin is explained by a low and insufficient level of organic metamorphism (for humic matter) in this particular area.

LOWER TRIASSIC
(KOCKATEA)

L.O.M. ZONATION APPLIES TO BASE



MT. HORNER Nº1

37° API OIL RECOVERED FROM KOCKATEA. RESIDUAL OIL IN BASAL TRIASSIC SAND

WEST WHITE POINT Nº1
MONDARRA Nº4
STRAWBERRY HILL Nº1

MODERATE OIL & GAS POTENTIAL IN BASE OF KOCKATEA (BOTTOM 100' MAINLY SAPROPELIC ORGANIC MATTER). MIDDLE AND UPPER PART OF KOCKATEA CONTAIN PREDOMINANTLY HUMIC ORGANIC MATTER.

NORTH ERREGULLA Nº1

38° API OIL RECOVERED FROM KOCKATEA. RESIDUAL OIL IN BASAL TRIASSIC SAND.

ERREGULLA Nº1

TRACES OIL AND GAS IN TIGHT BASAL TRIASSIC SAND

MONDARRA Nºs 1&2

GAS FLOW FROM BASAL TRIASSIC SAND. OIL TRACES

MONDARRA Nº3

RECOVED SMALL QUANTITY OF 41 API CRUDE

YARDARINO Nºs 1&2

GAS AND OIL (35° API) FLOWS FROM BASAL TRIASSIC SAND

TURTLEDOVE SHALLOW BASEMENT RIDGE
(UPLIFTED AND TRUNCATED IN NEOCOMIAN TIME)

DONGARA GAS FIELD

OIL (34° API) WAS TESTED IN WELLS Nº 8, 14, 17, & 19. HYDROCARBONS ARE PRESENT IN INTERCONNECTED RESERVOIRS OF LOWER TRIASSIC TO PERMIAN AGE CAPPED BY KOCKATEA SHALE UNCONFORMITY ACCUMULATION

NOTE: ALL THE OILS DESCRIBED ABOVE ARE HIGHLY PARAFFINIC, HIGH POUR POINT, WAXY CRUDES.

DONGARA, MONDARRA AND YARDARINO OILS ARE STRIPPED FROM THEIR LIGHT FRACTIONS

LOWER TRIASSIC IN S.PERTH BASIN IS PREDOMINANTLY SANDY AND W/OUT SOURCE POTENTIAL

INTERPRETIVE DISTRIBUTION PATTERN OF THERMAL ALTERATION ZONES

FROM: REFLECTANCE OF VITRINITE DATA (Shell)
PALYNOMORPHS DISCOLOURATION (P. Nygreen)

		SOURCE ROCKS MATURATION	AVERAGE SANDSTONE RESERVOIR CHARACTERISTICS
TAI 1	Yellow Zone	NONE	EXCELLENT TO GOOD
TAI 2	Orange Zone	SLIGHT	GOOD TO FAIR
TAI 3	Brown Zone	MODERATE	FAIR TO POOR
TAI 4	Black Zone	STRONG	POOR TO NIL

➡ DIRECTION OF HYDROCARBON MIGRATION

60 FIXED CARBON % (Shell)

SCALE OF MILES
0 10 20 30 40 50

WEST AUSTRALIAN PETROLEUM PTY LTD
PERTH BASIN
LEVEL OF ORGANIC METAMORPHISM
LOWER TRIASSIC
(KOCKATEA FORMATION)

G. J. DEMAISON			MAR 1972
DRN A.J.S.	DATE 25 MAY '70	SCALE 1:500,000	A-18946-2

PLATE 2

3. HYDROCARBON GENERATION ANALYSIS FOR THE TRIASSIC SECTION

3.1 Geological Background

The Triassic is divided into three lithostratigraphic units, from top to bottom:

- a coarse arkosic sandstone unit with minor silt interbeds: Lesueur Fm.
- a regressive interbedded siltstone and fine grained sandstone unit: Woodada Fm.
- a marine shale transgressive unit: Kockatea Fm.

In the southern Perth Basin (Whicher Range) the Kockatea Formation has changed into a paralic, fine grained sandstone unit which is resting conformably on the Permian. In the northern Perth Basin the Kockatea is resting on rocks ranging in age from Upper Permian to Precambrian through a strongly marked angular and erosional unconformity.

3.2 Potential Source Rocks

Organic carbon content determinations were performed:

- On a closely sampled basis for:
  - Mondarra 4
  - Strawberry Hill 1
  - West White Point 1
- On a spot sampled basis for:
  - Dongara 1
  - Eneabba 1
  - Jurien 1

Geochemical data for Mondarra 4, Strawberry Hill 1 and West White Point 1 document the following statements:

- The base of the Kockatea Shale (bottom 150 ft.) contains appreciable amounts of mixed humic-sapropelic matter (.5 to 1%). It can be considered as a fair source rock for oil and gas.
- The middle and upper parts of the Kockatea Shale contain up to .5% of organic matter of humic origin, and according to Shell would be only a marginal source for mainly gas.

- The Woodada and Lesueur contain negligible amounts of organic matter and are not potential source rocks for hydrocarbons.

Analytical results document the following statements:

- Results of compositional analysis of soluble bitumens from Kockatea samples (Yardarino 1 and 2) are very similar to those determined in oils recovered from:

  - Yardarino 1: Basal Triassic Sand
  - Dongara 8 : Basal Triassic Sand (oil)
  - Dongara 14 : Basal Triassic Sand (oil)
  - Dongara 9 : Basal Triassic Sand (condensate)
  - Dongara 17 : Basal Triassic Sand (condensate)

- Results of analysis on oil recovered from the upper part of the Kockatea in North Erregulla No. 1 show that this particular oil has a similar, but not necessarily identical source to Yardarino oil (Kockatea derived) tested from the Basal Triassic sand.

- North Erregulla Upper Kockatea crude oil shows a marked similarity to oils extracted or recovered from the Jurassic Eneabba (Multicoloured) Member at Mondarra 1 (Core 1) and Erregulla 1. (Swab test 10,413-10,435 ft.)

- All these above-discussed hydrocarbons have one point in common: low C_{13}/C_{12} ratios pointing to an origin from mainly land plant derived organic matter. This observation is consistent with the nature of the organic matter which is mainly humic to mixed humic-sapropelic (base of Kockatea Shale). The characteristics of all these oils (highly paraffinic, low sulfur and high pour point) are also typical of largely land plant derived crudes.

3.2 Level of Organic Metamorphism

The Kockatea is moderately to strongly mature (TAI 3 to 4) downdip from the accumulations except in the northernmost part of the basin as shown in West White Point, Dongara, Yardarino, Mt. Horner and North Erregulla (TAI 2). Further north, the Kockatea is in TAI 1 before reaching the outcrop. Maximum generation has occurred in the Brown Zone (TAI 3).

The base of the Lesueur Formation is in the Brown Zone (TAI 3) in Pinjarra.

The Kockatea equivalent in Whicher Range is in the base of the Orange Zone (TAI 2).

3.3 Occurrences of Free Hydrocarbons

Dongara

Relatively lean gas with a subordinate oil rim is present in interconnected reservoirs (Basal Triassic Sand, Wagina Sandstone, and Irwin River Coal Measures) capped by the Kockatea Shale.

Dongara 1 (Natural Gas) 5482-5494 ft.

- C_1 97.2%
- C_2 2.1%
- C_3 0.5%
- iC_4 0.1%
- ηC_4 0.1%
- C_5 nil

The gas produced from Dongara consists mainly of methane and is low in higher hydrocarbons.

Gas produced from the Permian Irwin River Coal Measures has the same composition as gas from the Basal Triassic Sand. The Jurassic and Permian reservoirs are interconnected and perform as a single reservoir as far as fluids are concerned.

Dongara 9 (Condensate)

- API gravity : 52°
- Sulfur : 0.006
- C_{13}/C_{12} ratio : -2.2

Condensate produced from Dongara is geochemically identical with the oil rimming the structure.

Dongara crude oil and condensate are fully compatible upon mixing them together, without asphalt precipitation.

Dongara 14 (Crude Oil)

- gravity: 35° API
- paraffin base (paraffinicity index: 3.62)
- high pour point: 90°F
- low sulfur: 0.06% to 0.07%
- low C_{13}/C_{12} ratio: -2.3 to -2.5 ?
- Asphalt: 0.05%
- Alkanes: 76.7%
- Aromatics: 20.2%
- ONS compounds: 3.0%

Pristane/Phytane: 1.2%

The characteristics of Dongara crude oil are absolutely consistent with the nature of the parent organic matter and the level of organic metamorphism attained in the generative area.

A notable anomaly, however, in Dongara crude oil is the gasoline content which is too low for oils of this gravity (35°API). Only 7% of the oil distills below 200°C.

Yardarino

Out of four wells drilled on the Yardarino structure:

- Yardarino No. 1 flowed wet gas
- Yardarino No. 3 flowed crude oil from the Basal Triassic Sand.

The oil recovered is virtually identical with Dongara oil and also has a very low gasoline content.

Yardarino No. 3 (Natural Gas)

- C_1 : 96.2%
- C_2 : 2.9%
- C_3 : 0.7%
- iC_4 : 0.1%
- nC_4 : 0.1%

and is also notable for its low content in C_2 plus hydrocarbons.

Mondarra

Mondarra 1 and 2 flowed gas from the Basal Triassic Sand. Analytical results on natural gas from a 5 day production test at Mondarra 1 (from interval 8822-8860 ft.):

- C_1 : 92.0%
- C_2 : 5.1%
- C_3 : 1.8%
- iC_4 : 0.3%
- nC_4 : 0.6%
- iC_5 : 0.1%
- nC_5 : 0.1%

Mondarra gas is notable for its significantly higher proportions in C_2 and C_3 hydrocarbons, as well as CO_2, than for Dongara and Yardarino gas.

Some oil (40.9°API) was recovered from Mondarra 3 from the Basal Triassic Sand which is oil saturated over a thickness of 11.5 ft. This oil is almost identical to Dongara and Yardarino crudes.

North Erregulla

32 ft. of tight oil-saturated sandstones are present in the upper part of the Kockatea Shale between 9584 and 9654 ft. DST 1 recovered 20 gallons of 38°API oil in one hour:

- gravity: 34.7°API
- paraffinicity index: 4.18 (paraffin base crude)
- pour point: about 70°F
- C_{13}/C_{12} ratio: -2.2
- Asphalt: 0.05%
- Alkanes: 73.9%
- Aromatics: 24.4%
- ONS compounds: 1.6%

Pristane/Phytane ratio: 1.1

56 ft. of residual oil saturation are present in the Basal Triassic Sand. This interval is water logged in the porous intervals. DST No. 2 (10,535-10,570 ft.) recovered 8 gallons of 38°API crude oil. No sample of this particular oil has been preserved.

Mt. Horner 1

A zone of oil saturation is present between 4834-4896 ft. in the Kockatea Shale of Mt. Horner 1.

DST No. 4 (4870-4890 ft.) produced on swabbing through perforations: 80 barrels of fluid, 50% water, 50% crude oil and no gas.

This crude oil has the following characteristics:

- gravity: 37.7°API
- paraffin base
- pour point: 70°F
- sulfur: 0.08%

The water mixed with this crude has a salinity of approximately 5400 ppm.

Evidence of residual oil saturation was observed in the Basal Triassic Sand, but no sample of free oil was obtained.

Erregulla

High saturations of residual oil were observed in the Basal Triassic Sand and in Permian sandstones, but these reservoirs were all tight.

3.4 Interpretation of Data

3.4.1 Dynamics of hydrocarbon generation and location of generative area

The Kockatea Shale is a marginal to moderate source sequence for mainly natural gas and subordinate amounts of highly paraffinic crude oil.

It is not, by any presently recognized standards, an excellent or even good source sequence for oil. This is due to the fact that although it is a marine shale, the nature of the organic matter is mainly humic or at best mixed humic-sapropelic near its base.

The effective generative area for the Kockatea, in the onshore Perth Basin, is that where this shale sequence has at least attained the TAI 3 (brown zone) rank.

3.4.2 Relations of free hydrocarbons to generative sequence

The question has been raised whether the oil and gas in Dongara were not of Permian (Wagina, Irwin River Coal Measures or Carynginia) origin.

The presently available evidence does not confirm this hypothesis, for:

- Dongara hydrocarbons are geochemically identical to those in the Yardarino structure, where the Irwin River Coal Measures and the Carynginia DO NOT subcrop under the pre-Triassic unconformity.

- Dongara and Yardarino hydrocarbons are geochemically very similar to hydrocarbon extracts from Kockatea shale samples taken in Yardarino No. 1 (Core 10) and Yardarino 2 (Core 1). Oil occurrences within the Kockatea Formation (North Erregulla, Mt. Horner) were generated within this formation.

3.4.3 Migrational and Entrapment History

Assuming a stable, in time, geothermal gradient since Triassic deposition, sufficient temperatures were attained in downdip generative areas (Mt. Adams - Donkey Creek) by Yarragadee (end of Jurassic) time to generate and mobilize hydrocarbons.

It is likely that entrapment was virtually completed before the Neocomian movements which affected most of the Perth Basin.

PERMIAN

NORTH ERREGULLA Nº 1

8 OIL SATURATED SANDS (TIGHT) IN WAGINA (?) FORMATION

DONGARA Nos. 3,4,9 & 15

GAS SATURATION IN IRWIN RIVER COAL MEASURES BUT INTERCONNECTION BETWEEN THESE RESERVOIRS AND BASAL TRIASSIC SAND THROUGH UNCONFORMITY

YARDARINO No.2

1 SAMPLE IN CARYNGINIA GOOD POTENTIAL FOR OIL
OIL AND GAS SHOWS (C_1-C_4) IN IRWIN RIVER COAL MEASURES

DONGARA No. 1

6 SAMPLES IN HOLMWOOD GOOD POTENTIAL FOR MAINLY GAS

ARROWSMITH No.1

9235′ – 9265′
4 MMCF (DECREASING) FROM CARYNGINIA
OIL AND GAS SHOWS (TIGHT) IN IRWIN RIVER COAL MEASURES

WOOLMULLA Nº1

GAS SHOWS (C_1-C_4) IN IRWIN RIVER COAL MEASURES (TIGHT)

JURIEN Nº1

10 SAMPLES IN CARYNGINIA AND BASE OF IRWIN RIVER COAL MEASURES.
POTENTIAL FOR MAINLY GAS

BLACK ZONE IN CENTRAL PERTH BASIN IS ASSUMED FROM SEISMIC PLUS GEOTHERMAL DATA.

THIS FEATURE PRESENTLY UNDER GEOPHYSICAL REVIEW

WHICHER RANGE No.1

13662′ — 13694′
2·1 MMCFD
NO ORGANIC CARBON CONTENT ANALYSIS
TYPICAL COAL MEASURES SEQUENCE WITH POTENTIAL FOR MAINLY GAS

TAI 1 TAI 2 TAI 3 TAI 4 KOOMBANA WONNERUP PERTH

INTERPRETIVE DISTRIBUTION PATTERN OF THERMAL ALTERATION ZONES

FROM: REFLECTANCE OF VITRINITE DATA (Shell)
: PALYNOMORPHS DISCOLORATION (P.Nygreen)

		SOURCE ROCKS MATURATION	AVERAGE SANDSTONE RESERVOIR CHARACTERISTICS
TAI 1	Yellow Zone	NONE	EXCELLENT TO GOOD
TAI 2	Orange Zone	SLIGHT	GOOD TO FAIR
TAI 3	Brown Zone	MODERATE	FAIR TO POOR
TAI 4	Black Zone	STRONG	POOR TO NIL

➡ DIRECTION OF HYDROCARBON MIGRATION
62 FIXED CARBON % (Shell)

SCALE OF MILES 0 10 20 30 40 50

WEST AUSTRALIAN PETROLEUM PTY LTD

PERTH BASIN

LEVEL OF ORGANIC METAMORPHISM

PERMIAN (NEAR TOP)

G. J. DEMAISON MAR 1972

DATE 25 MAY 70 | SCALE 1 500,000 | A-18,946-1

TRANSVERSE MERCATOR PROJECTION AUSTRALIAN NATIONAL MAPPING GRID

PLATE 3

4. HYDROCARBON GENERATION ANALYSIS FOR THE PERMIAN SECTION

4.1 Geological Background

The Permian sequence in the Perth Basin comprises three main slices of sediments, from top to bottom:

Upper Permian (Ufinian-Kazanian)

Upper Permian sediments are represented:

- in the northern Perth Basin:

  WAGINA FORMATION: very fine to coarse often silicified quartz sandstones, dark siltstones, minor shales and coals. Deltaic environment with marine influences.

- in the southern Perth Basin:

  UPPER SUE COAL MEASURES: The Upper Permian was deposited in a flood plain environment with coal marshes.

  The upper boundary of the Upper Permian is marked by a strong erosional unconformity.

Artinskian

- Carynginia Shale: marine.
- Irwin River Coal Measures: flood plain to coal marsh to deltaic to marginal marine.

The Artinskian in the Perth Basin was deposited as a deltaic sequence prograding to the north within a broad rift valley system.

- SLIGHT ANGULAR AND EROSIONAL UNCONFORMITY -

Sakmarian

- HOLMWOOD SHALE: A marine sequence deposited in ice-free waters. The Fossil Cliff, a shallow water fossiliferous carbonate unit, is found in lenses at the top of the Holmwood.

- NANGETTY FORMATION: A thick tillitic claystone unit possibly deposited at the edge of a melting ice cap.

4.2 Potential Source Rocks

Organic carbon content determinations were performed:

On a closely sampled basis for two wells only:

- Strawberry Hill 1 : Wagina Fm.
- Dongara 1 : Holmwood Fm.

On a spot sample basis for three wells:

- Dongara 1 : Carynginia Fm.
- Jurien 1 : Carynginia and Fossil Cliffs Fms.
- Yardarino 2 : one sample on Carynginia

- The Nangetty is undocumented for organic carbon content.

- The Holmwood is a potential source for mainly gas (humic) in Dongara 1.

- The Irwin River Coal Measures are undocumented for organic carbon content. However, we are dealing here with a typical coal measures sequence, with coal beds and carbonaceous shales. By analogy with other known instances (i.e. Artinskian coal measures of the Cooper Basin, S.A.) the I.R.C.M. are assumed to have good potential for mainly gas (humic) and subordinate amounts of highly paraffinic oil.

- The Carynginia has potential for mainly gas (humic) in Jurien 1.

- Analysis of one sample from Yardarino 2 indicates some potential for hydrocarbon generation from the Carynginia.

- The Upper Permian contains mixed sapropelic-humic organic matter in Strawberry Hill.

- In the southern Perth Basin, the Upper Permian, in its coal measures facies, has obvious good potential for mainly gas and condensate with subordinate light oil.

4.3 Level of Organic Metamorphism (Permian)

The Permian is everywhere moderately (TAI 3) to stongly mature (TAI 4) and therefore hydrocarbon generative in the Perth Basin, except for two restricted areas:

4.3.1 Northern Perth Basin

Permian sediments are in the Orange (TAI 2) to Yellow (TAI 1) Zones:

- On the northern Beagle Ridge north of B.M.R. 10, up through Dongara and on to the Northampton Block.
- North of a line joining Yardarino to North Erregulla (the Allanooka Fault).

4.3.2 Southern Perth Basin

- The Upper Permian is in the Orange (TAI 2) to top of Brown (TAI 3) zones in Whicher Range and probably along the crestal area of the mid-graben arch (Whicher Range-Wonnerup-Koombana).

- All the synclinal areas are, by extrapolation of seismic and geothermal data, in mature generative zones (TAI 3 to TAI 4) for gas generation and expulsion from mainly humic source rocks.

4.4 Occurrences of Free Hydrocarbons

Northern Perth Basin

- Nangetty

The only genuine, if very weak, shows recorded in the Nangetty are mudlog gas shows (up to C_2) in Yardarino 2.

- Holmwood

Mudlog gas show (up to C_2).

- Irwin River Coal Measures

A large number of significant gas and oil shows have been recorded in this sequence, thus confirming its hydrocarbon generative potential:

- Abbarwardoo 1	: weak mudlog gas shows
- Arrowsmith 2	: mudlog gas shows and fluorescence
- B.M.R. 10	: oil staining in Core 40 (3710-3722')
- Cadda 1	: mudlog gas shows (C_1) and fluorescence
- Erregulla 1	: mudlog gas shows (C_1 to C_3) between 13,220 and 13,245 ft. Scattered fluorescence and cuts.
- Jurien 1	: Fluorescence
- North Erregulla*	: Mudlog gas shows (up to C_4) across 8 beds, oil staining.
- Woolmulla 1	: mudlog gas shows (up to C_4).
- Yardarino 2	: mudlog gas shows (up to C_4). DST No. 3 (8000-8701') recovered 20 cc. of waxy oil.

*There is doubt of the identification of the Irwin River Coal Measures which could be in fact Wagina.

Finally, the Irwin River Coal Measures produce gas in the Dongara Field (wells No. 3, 4, 9 and 15). These Permian reservoirs freely communicate through an unconformity surface with the Basal Triassic Sand. There is evidence that the Permian, here, is just hosting gas from Triassic origin.

- Carynginia

  - Arrowsmith 1 : 4 MMCFD decreasing to 48 MCFD from an 8 ft. sand (perforations 9244 to 9256').

  - Yardarino 2 : mudlog gas shows (up to C_3) and oil staining.

    DST No. 2 (9198-8244') small flow of gas (less than 100 MCFD).

- Wagina (Upper Permian)

  - Mt. Adams 1 : Fluorescence and gas shows
  - North Erregulla 1 : See Irwin River Coal Measures
  - Strawberry Hill 1 : mudlog gas shows up to C_4.
  - Yardarino 2* : mudlog gas shows up to C_2.

The shows present in the Wagina could have had their origin from migrated Kockatea-generated hydrocarbons.

Southern Perth Basin

- Upper and Lower Permian (Sue Coal Measures)

  - Whicher Range 1 : Non-commercial gas flows, with condensate.

    DST No. 6 (13,622-12,694 ft.) 2.1 MMCFD plus some condensate on ½" choke.

    DST No. 7 (13,780-13,794 ft.) 1.8 MMCFD plus some condensate on ½" choke.

    Strong mudlog gas shows and fluorescence throughout Permian section.

  - Blackwood 1 : minor weak gas shows below 9190 ft.

*There is a doubt as to the age of the oil and gas reservoirs on the Yardarino structure. They are ascribed to the Basal Triassic Sand but could be Wagina (R. McKellar, Personal Communication).

4.5 Interpretation of Data

4.5.1 Dynamics of Hydrocarbon Generation and Location of Generative Areas

It is reasonably well established that the Permian as a whole (with the exception of the Nangetty) has generated mainly gas with minor amounts of highly paraffinic crude oil. This is entirely consistent with the predominantly humic nature of the present organic matter and with the prevailing high levels of organic metamorphism. The Irwin River Coal Measures and Sue Coal Measures are considered to have the highest potential within the Permian System.

The generative areas are those where the Permian is in the Brown and Black Zones (TAI 3 to TAI 4).

With the exception of the gas in the Irwin River Coal Measures in the Dongara Field, and of shows in the Wagina, all other occurrences of free hydrocarbons have been generated within the Permian itself.

4.5.2 Migrational and Entrapment History

Northern Perth Basin

To sum up the northern Perth Basin for the Permian, the useful belt of potentially favourable reservoirs (TAI 2 zone) adjacent to the generative area (TAI 3 and 4) is very narrow.

To the north the Irwin River Coal Measures facies prograde into marine shales which are presently structurally updip. This situation could create stratigraphic trapping possibilities.

On the Beagle Ridge, the Padbury Horst and the Arrowsmith structure are both in the black zone (TAI 4) as far as the Permian is concerned. Although porosities could still be adequate to retain gas saturation, the presence of useful permeabilities is very much open to doubt.

The Artinskian was probably buried under much greater thicknesses of Upper Permian than know meets the eye, particularly on the Beagle Ridge, thus resulting in reduced porosities in the entrapment areas prior to the main hydrocarbon movements.

This concept is substantiated by the presence of sandstone silicification on all the southern part of the Beagle Ridge, which given reverse geothermal conditions and a different history of burial would be a prime shallow Permian (Artinskian) gas play.

The general situation is not favourable for the following reasons:

- The generative synclinal area, between the Beagle Ridge and the Darling Fault, is in an area of moderate geothermal gradient.

- The potential entrapment area (Beagle Ridge) is in an area of high geothermal gradient.

This means that when sufficient burial is attained in the cool generative area to bring potential source rocks to their generative threshold, the hot entrapment area has already lost most of its reservoir characteristics through high thermal diagenesis of sandstones.

Primary migrations within the Artinskian probably initiated, at least in the Dandaragan Trough, at some time during late Triassic deposition.

Southern Perth Basin

The Whicher Range-Wonnerup-Koombana mid-graben arch has had the ideal geological history, in time and space, to drain and entrap, at an early stage, large quantities of hydrocarbons from adjacent generative synclines. Hydrocarbon generation is likely to have initiated near the end of Triassic time.

The very low geothermal gradient prevailing in this part of the Perth Basin (1°F/100 ft.) provides strong justification for the current deep Permian play.

The future success of this play is largely hinging on whatever measures will be taken to avoid formation damage while drilling due to swelling clays.

Signed,

G.J. Demaison.
14.8.72

ABROLHOS SUB-BASIN

PERTH BASIN

HYDROCARBON-GENERATION ANALYSIS of the ABROLHOS SUB-BASIN

by

G.J. Demaison

West Australian Petroleum Pty. Limited

May, 1972

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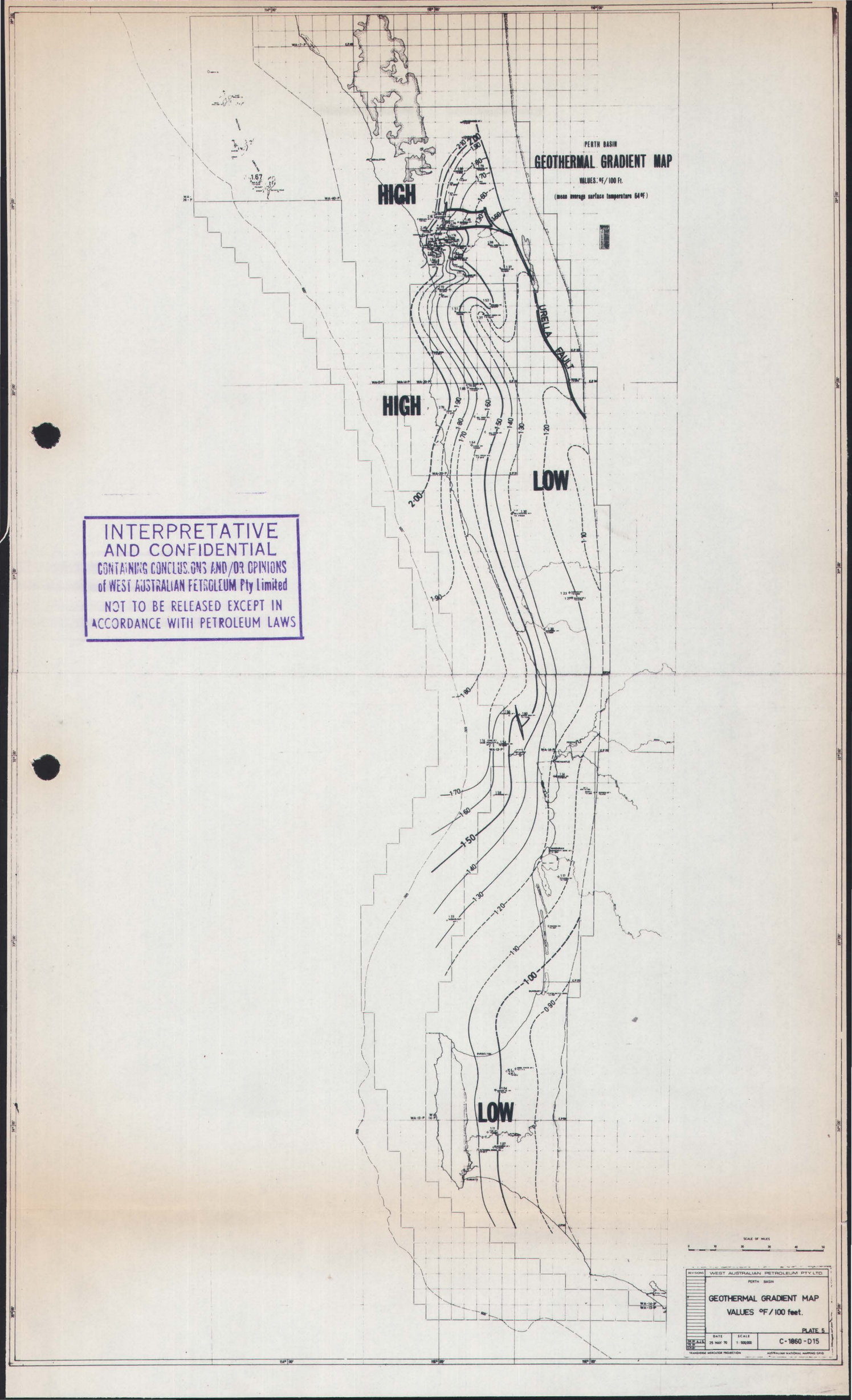
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VALUES: °F/100 Ft.
(mean average surface temperature 64°F)
HIGH
HIGH
LOW
LOW
URELLA FAULT
2·00
1·90
1·80
1·70
1·60
1·50
1·40
1·30
1·20
1·10
1·00
0·90
INTERPRETATIVE
AND CONFIDENTIAL
CONTAINING CONCLUSIONS AND/OR OPINIONS
of WEST AUSTRALIAN PETROLEUM Pty Limited
NOT TO BE RELEASED EXCEPT IN
ACCORDANCE WITH PETROLEUM LAWS
SCALE OF MILES
0 10 20 30 40 50
WEST AUSTRALIAN PETROLEUM PTY. LTD.
PERTH BASIN
GEOTHERMAL GRADIENT MAP
VALUES °F/100 feet.
PLATE 5
DRAWN
DATE
25 MAY 70
SCALE
1: 500,000
C-1860-D15
TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL MAPPING GRID

1. SUMMARY AND CONCLUSIONS

1.1 Analysis has been performed with the control of only one well - Gun Island No. 1. Level of organic metamorphism zoning has therefore been drawn by the extrapolation of Gun Island thermal alteration data to seismic controlled depth of burial data. This assumes that, except for the Turtle Dove Ridge, present depth of burial is roughly the maximum ever attained.

For the Abrolhos Sub-basin itself (excluding the Turtle Dove Ridge), the following conclusions can be reached:

1.2 The Jurassic section is largely immature (assuming that organic matter is mostly of the humic type) except in a narrow area in the deepest part of the Pelsart and Drummond Synclines.

1.3 The Lower Triassic Kockatea Formation is likely to be a good effective generative sequence for mainly gas over large areas in both the Pelsart and the Drummond Synclines. Sufficient exposure to strong thermal effects was reached by the end of Jurassic time to initiate migration of hydrocarbons prior to Neocomian earth movements.

1.4 The Permian section is likely to be severely mature in both the Pelsart and Drummond Synclines. Its level of organic metamorphism under the Geelvink Arch is conjectural as the importance of erosional unloading prior to the Triassic transgression is unknown.

1.5 The most promising entrapment area is the Geelvink Arch, which is ideally located to have focused early drainage of Triassic hydrocarbons from both the Pelsart and Drummond Synclines.

For the Turtle Dove trend, the following conclusions can be reached:

1.6 There is a strong possibility that the Triassic has been largely breached on the crest of the arch during the erosional phase following Neocomian uplift. Dissipation of hydrocarbons, if they were present, has, in that case, probably happened.

If the pre-Triassic section is fully preserved and Kockatea-capped over the arch, it remains a valid objective with the limitation that its reservoir potential is as conjectural as its stratigraphy and level of organic metamorphism. It is only hoped that it would prove better than on the Beagle Ridge where the pre-Triassic section is in the

Black Zone and therefore invariably tight. The most favourable model would be Kockatea unconformably draping Tumblagooda Sandstone. This combination could create ideal conditions for a giant accumulation.

1.7 A model for potentially large accumulations could also have been created by the juxtaposition of westward thickening, marine Cretaceous shales overlapping the Turtle Dove Ridge.

The ideal model would be (assuming that the Kockatea has been breached):

- Cretaceous Shale resting unconformably on:
  - weathered Tumblagooda Sandstone (Ordovician)

As there is no structural reversal at the base of the Cretaceous, such a model would be dependent upon two critical factors:

- A barrier to the east to be provided by Lower Jurassic or Triassic shales along the down-dropped side of the ridge's eastern boundary fault.
- A tight seal over the unconformity surface. The overlapping Cretaceous would have to be entirely shaly without basal sand. The evidence from Gun Island is not encouraging in that respect (the Cretaceous is in a coarse sandy facies).

However, failures to find effective closures for Cretaceous hydrocarbons on the ridge itself would not preclude the potential existence of Cretaceous-draped horst blocks to the west of the Turtle Dove Ridge. The present limitation is depth of water, but the prime potential of such features, if they exist, should be seriously considered.

2. GEOLOGICAL BACKGROUND

The Abrolhos Sub-basin is a half-graben, wedged between the Turtle Dove Ridge and the Northampton Block.

The stratigraphy, offshore, is controlled from the Tertiary down to the Eneabba Member of the Cockleshell Gully Formation from data provided by B.P.'s Gun Island No. 1 well.

The Triassic section is anticipated to be identical to that known in the northern Perth Basin. The Kockatea Formation could be found unconformably resting on anything, from Upper Permian down to Basement.

The nature of the Permian section is conjectural. It is even conceivable that there could be no Artinskian or Sakmarian present as the Permian rift, in Lower Permian time, could have been restricted to a north-south system only, extending only into the southern Carnarvon Basin (Byro-Coolcalalaya Trough).

3. POTENTIAL SOURCE ROCKS

Organic carbon content determinations for Gun Island have not been run yet.

Interpretation of geological data from Gun Island 1 can allow the following assumptions:

3.1 The Warnbro Group (B.P.'s Winning Group equivalent) is in a coarse feldspathic sandstone facies. It may grade laterally to the west into a potentially generative shaly sequence identical to the South Perth Shale of the Vlaming Sub-basin.

3.2 The Yarragadee Formation also appears to be very lean in organic matter, and identical in character with the typical flood plain type Yarragadee of the onshore Perth Basin. There seems to be no equivalents of the generative shales present in the Lower "Neocomian" part of the uppermost Yarragadee of the Vlaming Sub-basin.

3.3 The Cadda Formation, although obviously deposited in a marine, near-shore, environment appears, from descriptions in Gun Island's palynological report, to contain mainly humic organic matter.

3.4 The Cattamarra Member of the Cockleshell Gully coal measures is probably a potential generative sequence for gas. This is substantiated by the presence of thin coal beds and carbonaceous shales as seen in Gun Island.

3.5 The Kockatea Shale, if present in the same facies as in the northern Perth Basin, is expected to contain mixed sapropelic-humic organic matter, particularly at its base. Then it would be a potential generative sequence for gas and mature paraffinic crude oil.

3.6 The stratigraphy of the Permian system being conjectural, no attempt is made to predict its organic facies.

4. LEVEL OF ORGANIC METAMORPHISM

T.A.I. zonation has been established for Gun Island by P. Nygreen.

The top of the Orange Zone is somewhere around 6,000 ft and the top of the Brown Zone between 9,400 ft and 11,000 ft.

T.A.I. zonation has been drawn mainly from extrapolation of these data and use of structure contour maps derived from seismic data.

It is being assumed in our interpretations that:

- The Turtle Dove Ridge has a history of relatively recent (Neocomian) uplifting and truncation.
- The Geelvink Arch is a feature which broadly developed its present shape prior to the Neocomian movements.

4.1 The potentially generative Cattamarra member of the Cockleshell Gully Formation has probably reached early stages of maturity (for a humic source sequence) in the bottom parts of the Pelsart and Drummond Synclines (Brown Zone).

Mudlogging gas shows (CH_4 only) were recorded across the Cattamarra at Gun Island.

4.2 The Triassic Kockatea Shale is likely to have reached levels of sufficient thermal maturation (Brown Zone and Black Zone) over large areas of both the Pelsart and Drummond Synclines.

The Geelvink Arch should bear a Triassic sequence, if present, in the Orange Zone.

4.3 Permian sediments, in whatever facies they may be, are without a doubt in the Brown and Black Zones under the Pelsart and Drummond Synclines.

Their presumed level of organic metamorphism under the Geelvink Arch cannot be predicted. A major erosional unconformity is present under the Lower Triassic (Kockatea) sequence.

The Kockatea could rest on anything, from Basal Triassic sand or Upper Permian (Wagina Formation) on down to Lower Paleozoic Tumblgooda Sandstone, or even Basement.

5. INTERPRETATION OF DATA

5.1 Abrolhos Sub-Basin (excluding the Turtle Dove Ridge)

The most promising objective is whatever reservoir (Upper Permian? Lower Permian? Lower Palaeozoic?) will be found under the Kockatea Formation. The most optimistic model would be weathered Tumblagooda Sandstone draped by Kockatea Shale.

The Cockleshell Gully Formation, particularly the Cattamarra Member, is a less attractive, but nevertheless quite legitimate, objective.

The Geelvink Arch, assuming it has had a history of early growth, is ideally located as a focus for migration from the adjacent synclinal generative areas. The actual volumes of mature sediments are large and there is little doubt that hydrocarbon generation has effectively taken place.

Time of primary migration from the Kockatea was probably in the Yarragadee (Upper Jurassic), prior to Neocomian movements. Sufficient depth of burial was reached before these movements to bring the Kockatea into the Brown Zone in the Pelsart and Drummond Synclines.

The Cadda and Cockleshell Gully Formations reached their present level of organic metamorphism relatively late (Cretaceous time). The volume of the effective generative sequence appears much smaller and less mature (Black Zone level has probably not been attained) than in the Dandaragan Trough. Unless the geothermal gradient is much higher in the Drummond Syncline than in the Pelsart Syncline (1.7°F/100 ft. at Gun Island), hydrocarbon generation and explusion has probably been marginal.

5.2 Turtle Dove Ridge

The Turtle Dove Ridge is a major horst block (over 60 miles long) which marks the western, offshore, edge of the Abrolhos Sub-basin.

It has been uplifted and truncated during Neocomian movements. Basement may occur at shallow depth on the crest of the Ridge.

The Ridge is unconformably overlapped at shallow depth by a westerly-dipping homoclinal wedge of Warnbro Group (Upper Neocomian-Aptian) which is overlain in turn by thin Upper Cretaceous and Tertiary sediments.

The nature, age, and level of organic metamorphism of the sediments subcropping under the Cretaceous, on the crestal area of the ridge, are unpredictable. The most favourable model would be unbreached Kockatea resting unconformably over Tumblagooda Sandstone.

The Warnbro Group is present, in Gun Island in an unfavourable facies. It has no source potential, and perhaps worse, it does not provide a seal over the pre-Cretaceous unconformity surface. This negative point has been emphasized by B.P. in their Gun Island report. A rapid change of facies from sand to shale in a westerly direction is, however, a distinct possibility as this occurs very rapidly between the onshore Perth Basin and the Vlaming Sub-basin. This change could perhaps be found along the Turtle Dove Ridge if it had acted as a depositional hingeline during Cretaceous time.

G.J. Demaison.

GJD:ct
11.8.72