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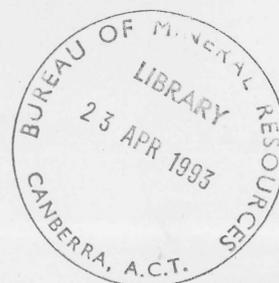
1993/21

THE PETROLEUM GEOLOGY OF THE CLARENCE-MORETON BASIN

by

P.E. O'BRIEN, T.G. POWELL, AND A.T. WELLS

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DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY
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DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

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ABSTRACT

The Triassic to Jurassic rocks of Clarence-Moreton Basin contain abundant oil-prone organic matter of terrestrial origin particularly in the Walloon Coal Measures and to a lesser extent in the Koukandowie Formation. This is reflected in petrographic composition, pyrolysis yields, elemental composition and extractable hydrocarbon yields. Maturation levels vary from immature to marginally mature in the west to overmature in the eastern part of the basin in NSW. Calculations based on Rock Eval data show that significant oil generation occurred in a narrow maturation range (0.8-1.0% vitrinite reflectance) and that migration has been highly efficient. Potential reservoirs are present in quartzose sandstones in the Koukandowie Formation, Gatton Sandstone, Ripley Road Sandstone and Raceview Formations. Maturation modelling and fission track analyses indicate that hydrocarbon generation occurred in the period 80-100 Ma during a period of high heat flow when the Tasman Sea spreading ridge was adjacent to the southeastern side of the Logan Sub-basin. Despite the abundance of oil-prone source rocks, the basin is considered to be largely gas-prone because the drainage areas for most larger structural traps are overmature. The main difficulty in exploration is predicting the distribution of porosity and permeability which varies because of both depositional facies and diagenesis, even in quartzose units.

The area with the greatest hydrocarbon prospectivity is the New South Wales part of the Logan Sub-basin which has gas potential throughout and a chance of minor oil discoveries along its western margin. The northern Logan Sub-basin has some prospectivity for oil and gas and the Laidley Sub-basin has minor prospectivity for oil in the Raceview Formation.

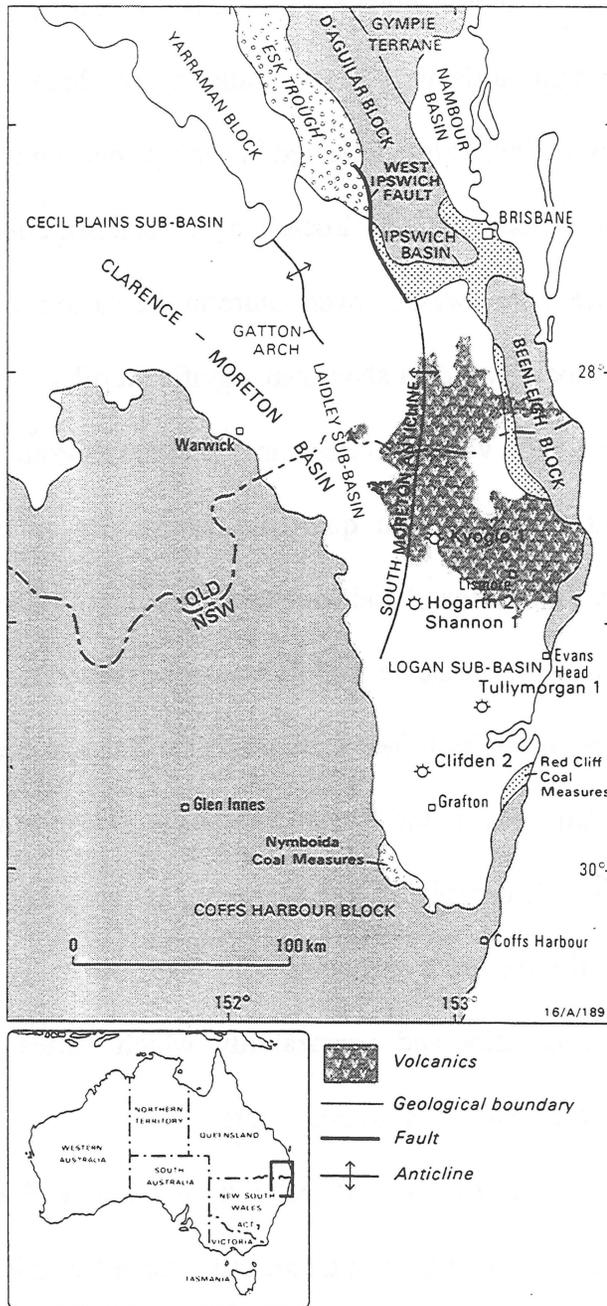


Figure 1. Major structural features of the Clarence-Moreton Basin and important petroleum exploration wells.

INTRODUCTION

Despite the similarity in age and depositional environment of sediments with hydrocarbon-bearing sequences of the contiguous Surat Basin and the Eromanga basin, the Clarence-Moreton Basin has undergone only minimal exploration. To date fifty 'deep' wells have penetrated the basin, but relatively few have been drilled in recent years. Oil and gas shows have been encountered throughout the stratigraphic section (Table 1). Information on these occurrences have been presented by the Queensland Department of Mines, (1960 through 1966); Nicholson, 1974; Benstead, (1976); Cranfield & others, (1976); Ties & others, (1985) and Willis, (1985). The main occurrences are of gas and mostly originated from either the Woogaroo or Marburg Subgroups in the Kyogle 1, Tullymorgan 1, Hogarth 2 and Clifden 2 wells (Fig. 1, Table 1). Minor gas shows have been recorded from the Walloon Coal Measures (Table 1) and also from the Ipswich and equivalent coal measures underlying the Clarence-Moreton sequence. The mid Triassic Chillingham Volcanics contain an unusual show where they crop out beneath the eastern basin margin in Queensland. Siliceous concretions ("thunder eggs") in a rhyolite contain small vugs lined with bitumen or a light crude oil (Wallis & others, 1984). The composition of these hydrocarbons indicates a non-marine source so they must have originated in Clarence-Moreton or Ipswich Basin sediments.

Source rock studies have been few, of limited areal extent and based upon relatively few samples. Cook (1975) commented on petroleum potential based on some petrographic analyses. Lockwood (1978) commented on the basin's source potential with particular emphasis on present day geothermal gradients and maturity trends. Martin & Saxby, (1982) assessed the source-rock potential of twenty six samples. Jackson & others, (1983) presented

TABLE 1. Lithologies, depositional environments and hydrocarbon shows in Clarence-Moreton Basin sediments. Isopachs for individual units are presented in O'Brien & Wells (this volume).

FORMATION	LITHOLOGIES	DEPOSITIONAL ENVIRONMENT	HYDROCARBON SHOWS
Grafton	Mudstone, labile sandstone	Mixed load fluvial channels, floodbasins	None
Kangaroo Creek	Qartzose sandstone	Sandy bedload fluvial channels	None
Walloon CM	Mudstone, labile sandstone, coal	Mixed & suspended load fluvial channels, floodbasins & mires	Gas, minor oil
Koukandowie	Labile sandstone, mudstone	Mixed & bedload fluvial channels, floodbasins & lakes	Abundant gas, minor oil
Heifer Creek Mbr	Qartzose sandstone	Sandy bedload channels	Abundant gas (14,000 m ³ /day in Hogarth-2)
Gatton Sandstone	Labile sandstone	Sandy bedload channels	Common gas
Ripley Road Sandstone	Qartzose sandstone	Sandy bedload channels	Abundant gas, minor oil
Raceview	Mudstone, sandstone composition variable	Floodbasins & mixed & suspended load fluvial channels	Abundant gas, minor oil
Layton's Range & Aberdare Congs.	Conglomerate, labile sandstone, mudstone.	Gravelly bedload streams, braidplains & valley fills	Common gas

analyses based on systematic sampling of subsidised wells and more recently Ties & others, (1985) reported on the source rocks and maturity of samples from the Shannon 1 well and adjacent areas. The results of these studies may be summarised as follows:

1. The Walloon Coal Measures have significant potential to generate oil whereas the older stratigraphic horizons are gas prone either due to over-maturity or nature of the organic matter.

2. There are significant maturation variations in the basin that cannot be readily accounted for by present geothermal gradients. Either palaeotemperatures were previously much higher than those observed today and/or a significant volume of sediments have been removed.

The most extensive discussion of potential reservoirs in the Clarence-Moreton Basin is that of Ties & others, (1985) who concluded that the Ripley Road Sandstone (their Pillar Valley Formation) was the most promising unit followed by the Koukandowie Formation (their Marburg Formation) and scattered sandstones in the Walloon Coal Measures. Russell (1986) considered reservoir quality in the northern Logan and Laidley Sub-basins, drawing on petrological work by Martin (1986). He reached similar conclusions to Ties & others (1985) with the additional finding that some Raceview Formation sandstone bodies were also porous and permeable.

The need for a modern assessment of the petroleum potential of the Clarence-Moreton Basin formed part of the rationale for a collaborative study between AGSO (formerly BMR) and the NSW and Queensland Geological Surveys of the depositional, structural and sedimentological history and source potential of the basin. This paper presents a complete re-appraisal of potential source rocks, their maturity and composition and migration scenarios

drawing upon modern concepts of hydrocarbon generation and source rock assessment in non-marine sequences (Powell, 1988; Powell & others, 1993). We also re-examine the distribution of potential reservoirs in the light of the revised stratigraphy set out in Wells & others (in press) and a survey of sandstone compositional variations summarised in O'Brien & Wells (in press). We also review the porosity and permeability data compiled by Thompson (1987) and the reservoir quality work discussed by Martin (1986) and Russell (1986). The structural and tectonic model proposed in O'Brien & others (in press) and apatite fission track thermochronology (Gleadow & O'Brien, in press) are combined with maturation data to assess the temporal relationship of trap formation to hydrocarbon generation and the possible distribution of oil and gas plays in the basin.

GEOLOGICAL FRAMEWORK

Structure and Tectonics

The Clarence-Moreton Basin is a broad intracratonic basin extending from the Kumbarilla Ridge, in the west, to the east coast of Australia. It consists of three sub-basins. These are from the west, the Cecil Plains Sub-basin, the Laidley Sub-basin and the Logan Sub-basin (Fig. 1). The Cecil Plains Sub-basin is separated from the Surat Basin in the west by the Kumbarilla Ridge and from the Laidley Sub-basin to the east by the Gatton Arch. The Laidley Sub-basin is separated from the Logan Sub-basin by a complex structural high called the South Moreton Anticline (Fig. 1,2). Korsch & others (1989) identified this as a zone of strike slip faulting that has been active since the Early Triassic or Late Permian. The West Ipswich and East Richmond Faults form the west and eastern boundaries of the South Moreton Anticline.

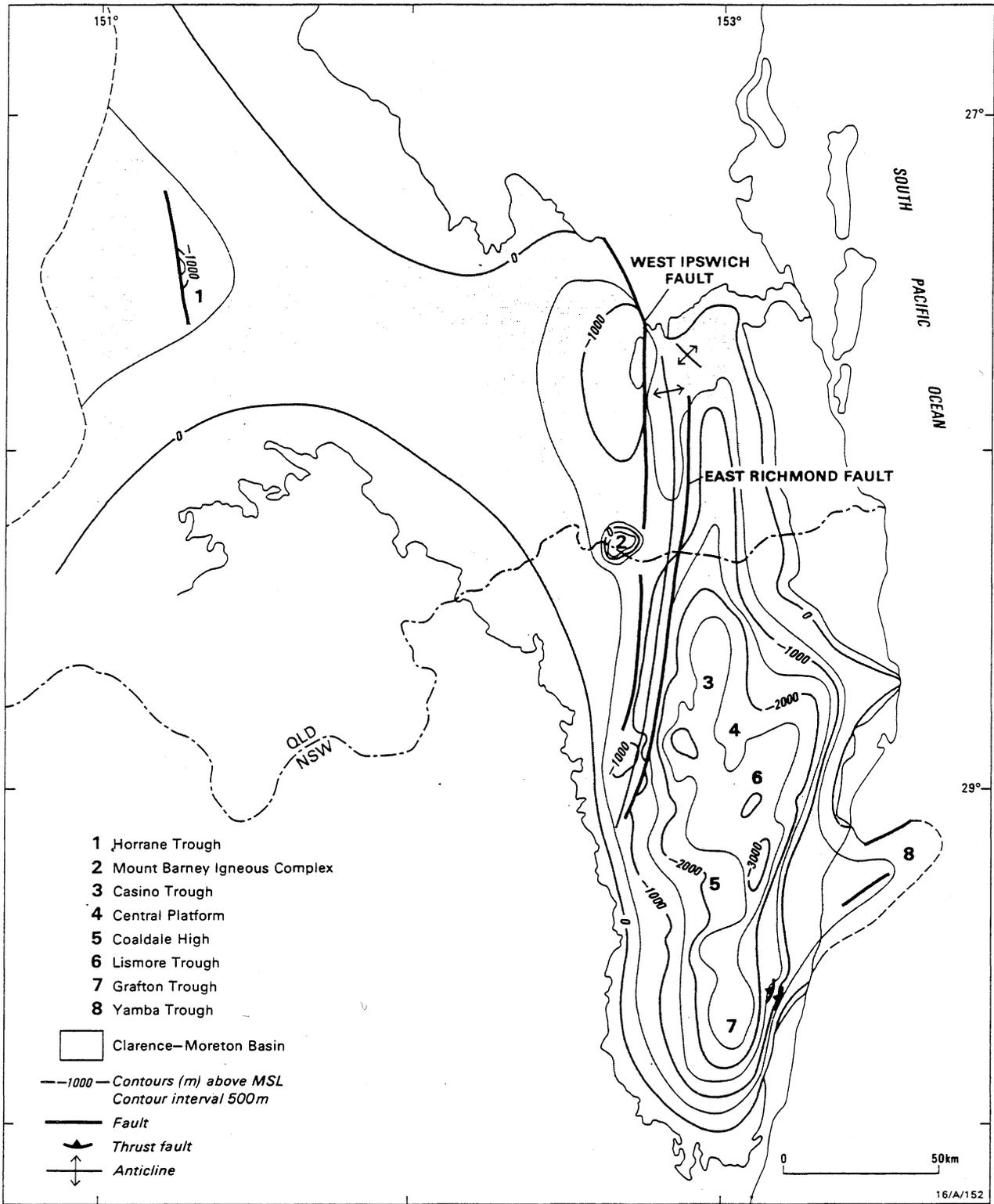


Figure 2. Structure contour map of the base of the Clarence-Moreton Basin and smaller structural features

Within the sub-basins are subsidiary structures (Fig. 2). The deepest part of the Cecil Plains Sub-basin is a half graben, probably formed by strike-slip faulting, called the Horrane Trough (Fig. 2, O'Brien & others, in press). The Logan Sub-basin consists of a complex series of highs and troughs that probably reflect the trend of older faults (Fig. 2, O'Brien & others, in press). In addition, the Logan Sub-basin is divided along the Queensland - New South Wales border by a group of imposing intermediate intrusions of Tertiary age. Smaller dykes are abundant in this region and extensive basalt shields obscure the Mesozoic geology (Fig. 1). The structure contour map of the base of the Clarence-Moreton Basin shows steep up-turning by the Mount Barney intrusion that also brings Palaeozoic basement and Ipswich Coal Measures to the surface (Fig. 2).

The tectonic history of basin formation in the region can be summarised as follows (Korsch & others, 1989, O'Brien & others, in press):

1. Late Permian dextral transtension on the West Ipswich Fault formed a basin beneath the Laidley Sub-Basin.
2. In the Early Triassic, transtension stepped eastward to the Logan Sub-basin and the Esk Trough formed by thermal relaxation subsidence.
3. Thermal subsidence and continued minor strike slip faulting formed the Ipswich Basin in the east and the Horrane Trough in the west. The area of the Esk Trough-Laidley Sub-basin was a region of non-deposition.
4. From the Late Triassic to probably the Cretaceous, thermal subsidence right across the region saw deposition of the Clarence-Moreton Basin. Minor dextral strike slip movements

along the basin forming faults produced locally enhanced subsidence or uplift.

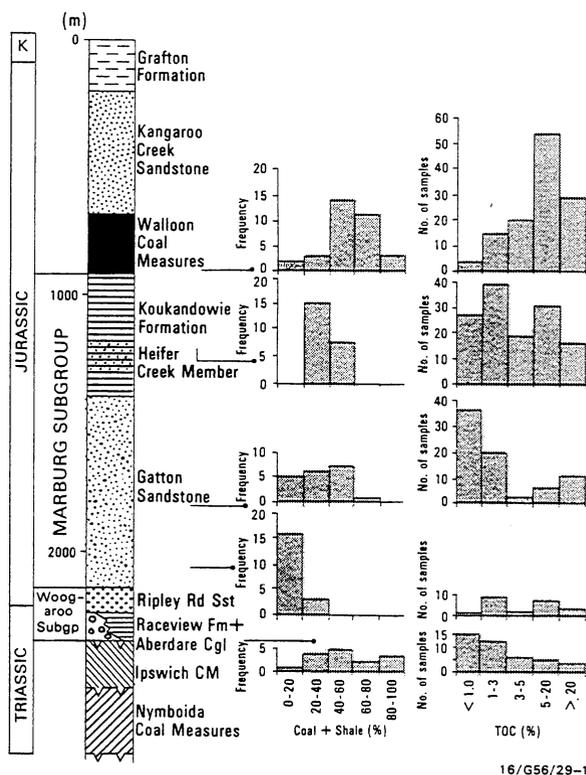
5. Compression or transpression during the Late Cretaceous formed minor thrusts with hanging wall anticlines, flower structures and inverted some normal faults.

6. Initiation of rifting and sea floor spreading along the eastern Australian continental margin in the Palaeogene saw heating and uplift of the eastern part of the Clarence-Moreton Basin and the end of dextral transpression.

7. Intermediate to basic volcanics and intrusions produced extensive heating and disruption of parts of the basin during the Miocene.

Stratigraphy

The Clarence-Moreton Basin is filled with non-marine clastic sediments (Table 1). Stratigraphic units within the basin are defined on the basis of sandstone composition and proportions of fine-grained facies (Fig. 3, Etheridge & others, 1985; Wells & others, in press). Sedimentation history and facies distributions are discussed by O'Brien & Wells, (in press). Potential reservoir rocks are best developed in quartzose sandstone units, the most widespread being the Ripley Road Sandstone and the Heifer Creek Sandstone Member of the Koukandowie Formation that are sheet-like, braided-stream deposits (O'Brien & Wells, in press). Organic-rich rocks are present in greater abundance in the finer-grained units such as the Walloon Coal Measures, Koukandowie Formation, Raceview Formation and the Ipswich Coal Measures that underlie the Clarence-Moreton Basin.



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Figure 3. Potential petroleum source rock abundance in the Clarence-Moreton Basin. The histograms show the percentage of shale+coal in each stratigraphic unit versus number of sections and Total Organic Carbon versus number of samples.

SOURCE POTENTIAL

Samples and Methods

Four hundred samples from 82 bores and some outcrops were analysed by Rock Eval pyrolysis and measurement of total organic carbon (TOC) content. Mudstone and coal lithologies were preferentially sampled and their stratigraphic distribution was governed by the availability of suitable core or cuttings material. The distribution of samples between the principal stratigraphic units is shown in Figure 3. For the calculation of volumes of organic matter, the proportion of organic-rich rocks was also estimated using sonic and density logs (Meyer & Nederlof, 1984). Selected samples were subjected to further analysis (Powell & others, 1993).

Source Rock Abundance and Organic Matter Type

A direct measure of the abundance of organic-rich sediments is obtained from both the frequency distribution of coal and shale lithofacies and the organic carbon content distribution in these lithofacies (Fig. 3). The Walloon Coal Measures contain the highest proportion of fine grained facies, followed by the Koukandowie Formation whereas the Ripley Road Sandstone and Raceview Formation and Aberdare Conglomerates contain the lowest proportion. These differences are also reflected in the organic carbon content of the fine-grained sediments. The most organic-rich rocks are found in the Walloon Coal measures and Koukandowie Formation (Fig. 3). Even though other units contain some finer-grained rocks they are generally low in organic carbon. The Ipswich and Nymboida Coal Measures of Triassic age contain coals and carbonaceous shales. Relatively few samples were obtained from these units and these were generally overmature for oil

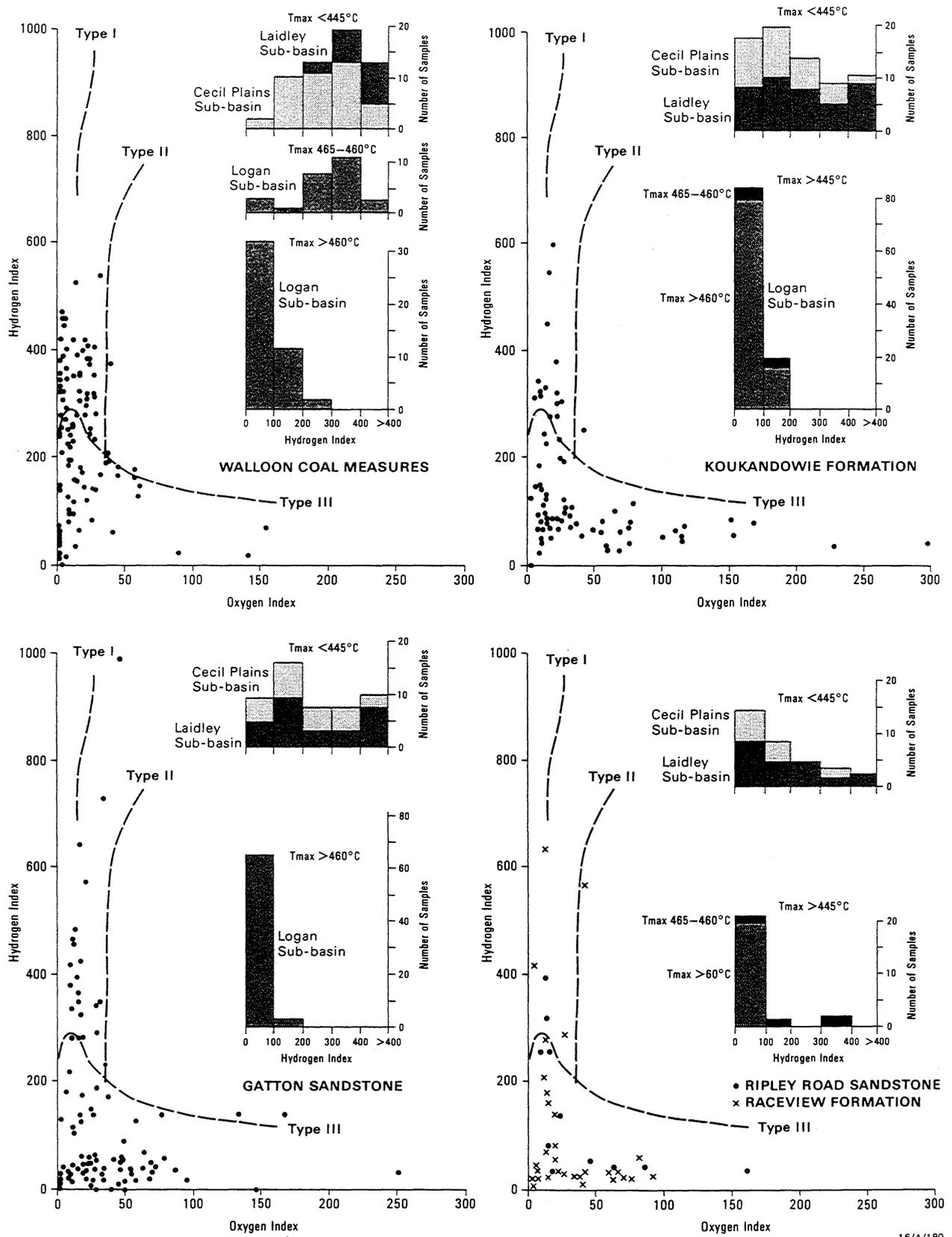


Figure 4. Classification of kerogen types based on Hydrogen and Oxygen Indices according to T_{max} and basin position. a. Walloon Coal Measures. b. Koukandowie Formation. c. Gatton Sandstone. d. Woogaroo Subgroup.

generation.

The Hydrogen Indices measured by Rock Eval analysis of immature to marginally mature Jurassic coals in the Clarence-Moreton Basin fall in the range 300-500 (Fig. 4) and are higher than most humic coals. They reflect the well-known perhydrous nature of the Walloon coals (Cook, 1975; Smith, 1980; Salehy, 1986; Khorsani, 1987) and it is worth noting that this characteristic may be found throughout the Jurassic section. The shales show a wider range in Hydrogen Indices than the coals reflecting the variable conditions of preservation of the organic matter in clastic sediments. The kerogen type varies from Type I to Type III with most samples falling between Types II and III. Elemental analysis of kerogens isolated from selected samples confirm the results obtained from Rock Eval analysis. Many samples have atomic H/C ratios between the mean values for Type II and Type III organic matter (Fig. 5).

The hydrogen-rich nature of the Jurassic samples reflects the relatively high abundance of liptinite macerals (Table 2) particularly in the dispersed organic matter (DOM). The coals in general show a much narrower range of petrographic composition than the DOM and are generally richer in vitrinite. A notable exception is the Walloon Coal Measures where the DOM tends to be slightly richer in vitrinite than the contemporaneous coals. The wide range of petrographic composition in the DOM reflects the variety of preservational conditions that occur during deposition of clastic sediments when compared with coals. Both coal and DOM compositions in the Marburg Subgroup vary according to basin position (Smyth, in press). The diversity of maceral compositions is particularly evident in the DOM where in the Ipswich area samples are particularly enriched in liptinite with values concentrating around 20 percent vitrinite, 70 percent

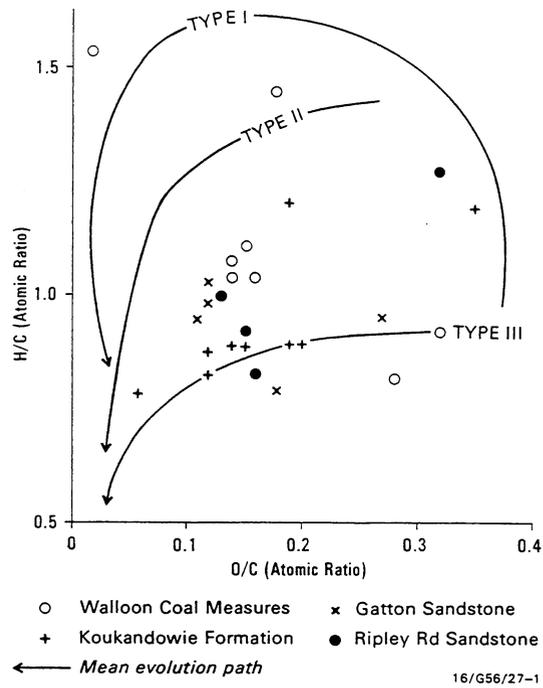


Figure 5. Van Krevelen diagram showing classification of kerogen types based on H/C and O/C ratios.

TABLE 2. Petrographic and geochemical data from selected samples, Clarence-Moreton Basin.

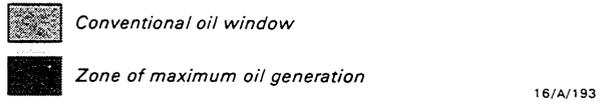
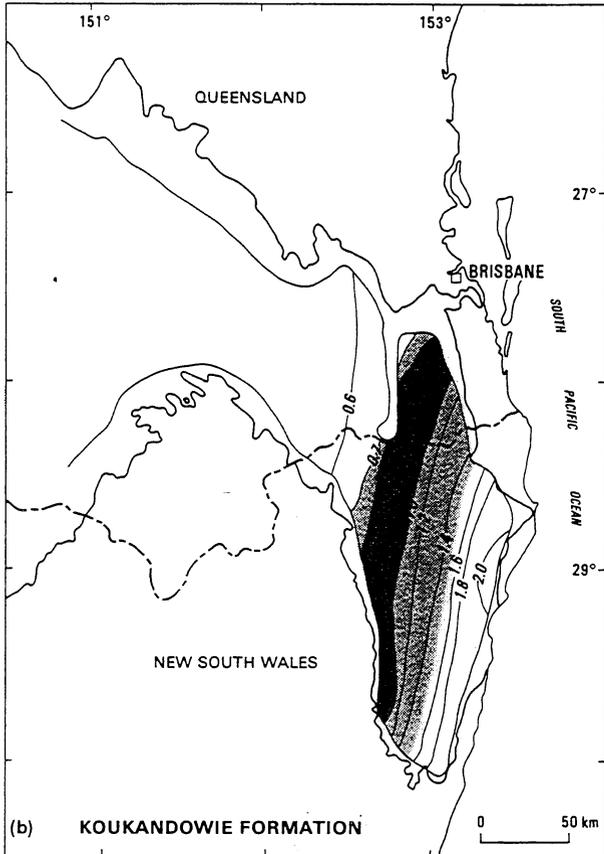
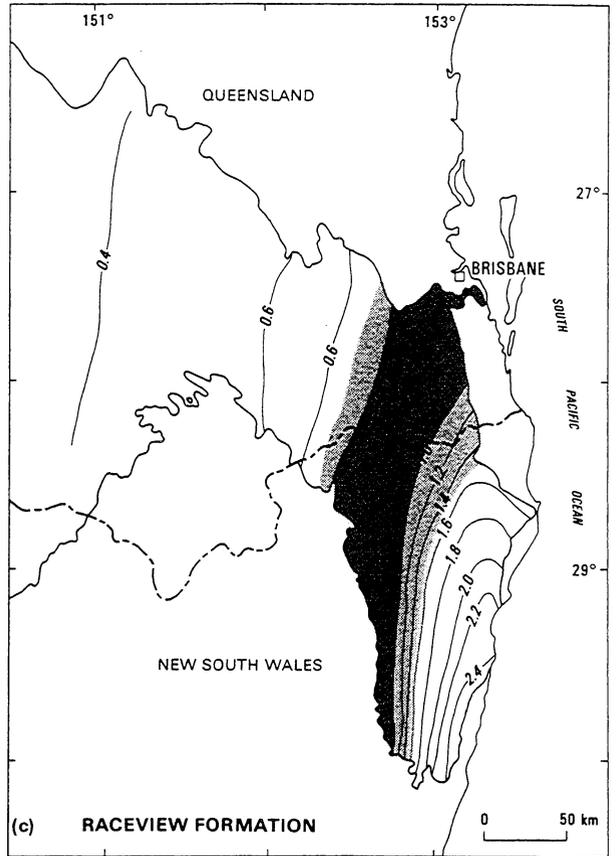
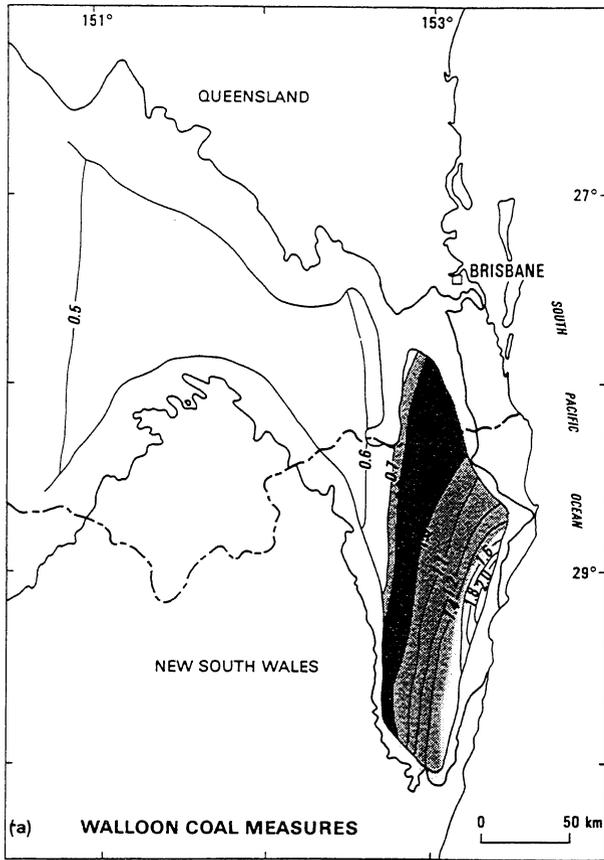
Sample Number	TOC	VR Ro%	Overall V/I/Lp	Liptinite S/C/R/Sb/Ld/A	Atoml H/C	Ratios O/C	Tmax deg C	HI mg/g	Alk mg/g	Wax %	Alk Arom
Samples <10% Liptinite											
1907	19.0	0.53	91/1/8	4/1/0/2/1/0	0.93	0.15	425	247	13	30	2.9
1646	5.1	0.55	94/0/6	tr/tr/4/0/2/0	0.93	0.32	443	150	20	48	4.0
1917	5.9	0.58	98/2/0		0.84	0.12	441	187	13	46	3.0
1914	78.3	0.67	90/1/9	3/tr/tr/5/1/0	0.89	0.18	433	152	9	40	1.8
2335	5.5	0.75	82/12/6	6/0/0/0/0/0	0.75	0.20	460	248		31	9.2
2313	14.9	0.91	100/0/0				453	283	29	9.0	9.0
Samples 10-30% liptinite											
2987	59.7	0.59	81/2/17	3/3/6/2/3/0	0.90	0.20	430	259		48	4.5
2985	12.6	0.58	89/0/11	9/0/tr/0/1/1	0.84	0.16	433	212	11	38	2.8
1913	49.4	0.58	88/1/11	1/7/3/0/0/0	0.98	0.12	436	372	42	48	10.4
2316	34.3	0.60	79/1/23	16/2/2/0/3/0	0.79	0.06	449	396	60	36	13.0
1921	43.4	0.63	81/2/17	3/0/7/7/0/0	1.22	0.19	435	379	53	53	7.8
Samples 30-40% liptinite											
2301	6.0	0.43	65/0/35	29/0/0/0/6/0	1.05	0.20	442	460			
2983	69.3	0.47	63/0/37	4/4/5/23/1/0	0.89	0.12	425	260	18	53	3.1
1926	56.6	0.49	40/30/40	8/tr/6/23/3/0	1.05	0.14	438	316	51	52	10.4
Samples 40-50% liptinite											
2990	28.7	0.55	54/3/43	1/1/1/0/31/0/0	1.01	0.13	432	326	52	61	14.4
1929	68.0	0.62	52/2/46	1/1/14/30/0/0	1.05	0.16	437	263	30	52	4.6
2999	17.6	0.65	58/2/40	2/tr/6/31/1/0	0.89	0.15	445	598	137	46	17.0
Samples >50% liptinite											
1897	12.8	0.36	45/2/53	29/4/1/0/17/2	0.96	0.11	439	530	64	54	16.8
1900	1.0	0.43	40/0/60	50/0/0/0/10/0	0.96	0.27	438	454	47	39	5.0
1932	1.4	0.43	29/14/57	29/14/0/0/14/0	0.90	0.14	443			43	5.3
1931	1.7	0.45	8/4/88	72/12/0/0/4/0	1.20	0.35	444			38	7.2
1928	8.4	0.43	44/2/54	33/3/2/3/12/1	1.08	0.14	436	512	88	60	18.6
1909	63.7	0.36	tr/5/95	56/0/0/0/39/tr	0.89	0.19	425	211	16	43	3.0
1923	11.3	0.50	27/1/72	32/23/1/0/16/tr	1.05	0.12	438	484	61	52	10.4
1649	62.9	0.52	40/1/59	1/0/3/55/0/0	1.12	0.15	434	341	32	58	10.8
1645	14.2	0.30	28/0/72	37/4/4/1/21/5	1.54	0.02	440	709	150	42	18.2
1647	9.5	0.30	42/3/55	33/3/5/3/8/3	1.45	0.18	447	906	196	54	29.0

TOC = Total organic carbon; Vr = mean maximum vitrinite reflectance calculated from mean average reflectance; Petrographic composition is in volume percent on mineral matter free basis; V = vitrinite; I = inertinite; Lp = liptinite; S = sporinite; C = cutinite; R = resinite; Sb = suberinite; Ld = liptodetrinite; A = alginite; HI = Hydrogen index; mg/g = milligrams per gram organic carbon; Alk = sum of C₇ and C₇, normal hydrocarbons; Wax = C₁₇ to C₂₇, normal hydrocarbons as percent of total normal hydrocarbons; Alk/Arom = ratio of normal hydrocarbons to C₇-C₇, aromatics.

liptinite and 10 percent inertinite (Smyth, in press). Suberinite is the most abundant liptinite maceral in the coals in keeping with previous observations on Walloon Coals (Smith, 1980; Salehy, 1986; Khorsani, 1987). In contrast, although the DOM is enriched in liptinite relative to the coals, suberinite is a less significant component. Comparison of petrographic and geochemical analyses shows that the major source maceral is suberinite and to a lesser extent cutinite (Powell & others, 1993). Sporinite is not a major source of liquid hydrocarbons. The regional variations observed in petrographic composition are only partly reflected in the Hydrogen Indices because of the interference of maturation effects. However, at comparable maturation levels, the proportion of samples in the Marburg Sub-group with Hydrogen Indices in excess of 400 is greater in the Ipswich area than in the Cecil Plains Sub-basin (Fig. 4).

Maturation, Hydrocarbon Yields and Composition

Vitrinite reflectance measurements and Tmax values from Rock Eval analysis have been used to determine maturation levels. Where vitrinite reflectance data were absent, a calibration of Tmax with vitrinite reflectance has been used to determine equivalent vitrinite reflectance values (Russell, in press). Regional maturation maps have been constructed for the Walloon Coal Measures, the Koukandowie Formation and the Woogaroo Subgroup (Fig. 6). It is immediately apparent that there are marked regional variations in maturation levels. The iso-reflectance maps for the Walloon Coal Measures show they are immature to marginally mature for oil generation in the western part of the basin, but reach peak oil generation levels in the south central part. They are overmature along the eastern margin. The deeper stratigraphic horizons show systematically higher



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Figure 6. Regional maturation maps for the Clarence-Moreton Basin. a. Walloon Coal Measures. b. Koukandowie Formation. c. Gatton Sandstone. d. Raceview Formation.

levels of maturation with a progression of the critical boundaries to the west. Thus the Raceview Formation is in the oil-generating zone where the Walloons are immature, and overmature where the Walloons are in the oil-generating zone. Based on current maturation levels the oil-prone area of the Walloons extends in a NNE trending zone in the NSW portion of the basin. At deeper stratigraphic levels the oil generation zone extends into the Queensland portion of the basin.

Relatively few wells have penetrated the zone of maximum oil generation in the basin. The progressive changes in extractable hydrocarbon yield and composition with maturation and the corresponding changes in Hydrogen Indices are shown in Figure 7. Gas chromatograms of the saturated hydrocarbons show all the changes associated with terrestrial organic matter namely: abundant waxy n-alkanes with a pronounced odd to even predominance in immature samples; abundant pristane in marginally mature samples and high pristane to phytane ratios. With increasing maturation the odd to even predominance and ratios of pristane to n-heptadecane decrease as hydrocarbon generation occurs. The few samples analysed from the mature zone show fair to good source potential based on present hydrocarbon yields although there it is now clear that use of present hydrocarbon yields may seriously underestimate source potential (Cooles & others, 1986). Thus the contrast between the highly variable hydrocarbon yields of the samples from the Walloons and the steady decline with increasing maturation of the Hydrogen Index of Walloon samples - representing residual hydrocarbon potential - illustrates that extensive migration must have occurred (Fig. 7).

The abundance of data and the apparent uniformity of organic matter in the Walloon Coal Measures allows the calculation of the amounts of hydrocarbons generated

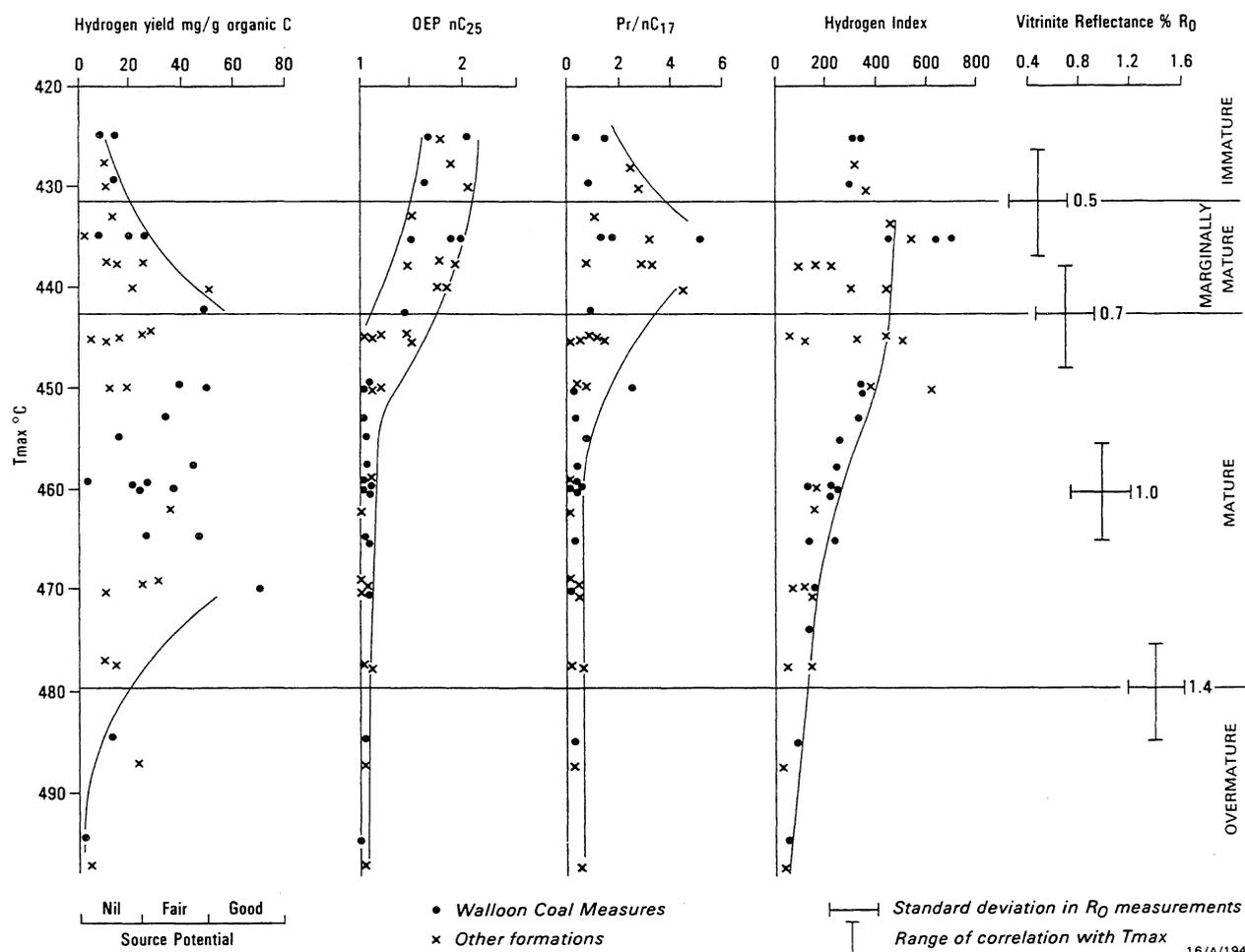


Figure 7. Maturation trends in yield and composition of extractable hydrocarbons and Hydrogen Indices. OEP nC₂₅ is the odd to even predominance of n-alkanes measured as n-pentacosane. Pr/nC₁₇ is the ratio of pristane to n-heptadecane. Source potential is based on hydrocarbon yield (after Powell, 1978).

and the relative timing of hydrocarbon generation and expulsion using the approach of Cooles & others, (1986). Routine geochemical data and particularly Rock Eval data is used to calculate the Petroleum Generation Index (PGI) and the Petroleum Expulsion Efficiency (PEE) defined as follows:

$$\text{PGI} = \frac{\text{Petroleum generated} + \text{Initial petroleum}}{\text{Total petroleum potential}}$$

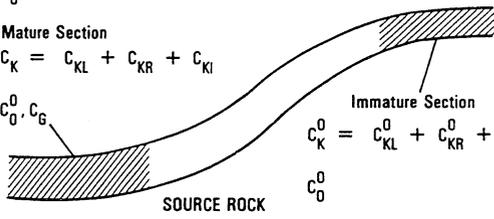
$$\text{PEE} = \frac{\text{Petroleum expelled}}{\text{Petroleum generated} + \text{Initial petroleum}}$$

The algebraic scheme used to calculate these values is illustrated in Figure 8 and the values used are give in Table 3. Petroleum in this context means both oil and gas. Immature samples were used to calculate an initial C_{KI} (Inert kerogen) which experimental data suggests does not change during maturation of a uniform source (Cooles & others, 1986). The C_{KI} values of more mature samples varied considerably because of differing total carbon contents. Accordingly, the values for labile and refractory carbon and soluble carbon of the mature samples were corrected in proportion to the variation in C_{KI} to arrive at the figures presented in Table 3 and from which PGI and PEE were calculated. This procedure is valid because of the relatively uniform behaviour of the Hydrogen Indices of the Walloon coals with increasing maturation (Fig. 7).

From the plot of PGI versus vitrinite reflectance (Fig. 9a) it is clear that the Walloon Coal Measures do not begin to generate significant amounts of hydrocarbons until a vitrinite reflectance level of 0.75%Ro (Tmax = 450-455°C). Comparison of the theoretical hydrocarbon yields with those actually measured on individual samples (Fig. 10) shows that there are changes in hydrocarbon yield and composition that precede the

When Immature
 $c_K^{0'} = c_{KL}^{0'} + c_{KR}^{0'} + c_{KI}^{0'}$
 $c_0^{0'}$

Mature Section
 $c_K = c_{KL} + c_{KR} + c_{KI}$
 c_0^0, c_G



Immature Section
 $c_K^0 = c_{KL}^0 + c_{KR}^0 + c_{KI}^0$
 c_0^0

(1) $TOC = c_{KL} + c_{KR} + c_{KI} + c_0$
 (2) $S_2 = (c_{KL} + c_{KR})/W_K$
 (3) $S_1 = c_0(1 - Z)/W_0$
 (4) $PGI = \frac{[(c_{KL}^{0'} + c_{KR}^{0'}) - (c_{KL} + c_{KR}) + c_0^{0'}]}{[c_{KL}^{0'} + c_{KR}^{0'} + c_0^{0'}]}$
 (5) $PEE = \frac{[(c_{KL}^{0'} + c_{KR}^{0'}) - (c_{KL} + c_{KR}) + c_0^{0'}] - (c_0 + c_G)}{[(c_{KL}^{0'} + c_{KR}^{0'}) - (c_{KL} + c_{KR}) + c_0^{0'}]}$

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Figure 8. Algebraic scheme used to calculate amounts of hydrocarbons generated and expelled (Cooles & others, 1985). Relative concentrations of total kerogen (c_K), inert kerogen (c_{KI}), labile kerogen (c_{KL}) and refractory kerogen (c_{KR}) for mature and immature source bed sections. Corresponding oil (c_0) and gas (c_G) concentrations are also shown.

TABLE 3. Average relative amounts of soluble, labile, refractory, inert and total carbon in source rocks in the Walloon Coal Measures as a function of maturation and calculated Petroleum Generation Indices (PGI) and Petroleum Expulsion Efficiencies (PEE) (see Fig. 8 for algebraic scheme).

LOCATION	Tmax°C ¹ Ro%	C _{KI} ²	C _{KL} +C _{KR} ³	C _o ³	TOC ⁴ %	PGI	PEE
A.Rosewood Mine	425-430 0.5	54.9	23.8	1.7	8.0	0	0
B.Wyan Creek- 1/Sextonville-1	445-450 0.75	83.4	27.3	2.5	12.9	0	0
C.Coaldale-1/ Shannon- 1	450-455 0.82	71.4	21.4	3.1	9.9	0.16	0.24
D.Shannon-1/Kyogle-1	455-460 0.96	81.0	12.2	2.2	10.2	0.52	0.77
F.Tullymorgan-1 G.Pillar Valley-1	460-465 1.03	74.5	10.3	3.2	9.3	0.59	0.79
H.Tabbimobile-1	470-480 1.43	90.0	6.0	1.1	10.2	0.76	0.79
	490-500 1.66	46.9	2.8	0.7	5.0	0.88	0.97
	495-505 1.98	88.1	2.9	0.6	9.4	0.87	0.97

1. Tmax range from Rock Eval and measured vitrinite reflectance (Ro%).
 2. Inert kerogen determined from Rock Eval data and measured organic carbon (Fig. 8).
 3. Corrected values using assumption inert kerogen is constant and location A as reference point.
 4. Measured organic carbon.
- C_{KI}, C_{KL}, C_{KR} and C_o measured in kilograms per tonne.

main phase of hydrocarbon generation as measured by PGI. Examination of gas chromatograms of samples from this interval show that the hydrocarbons retain their immature aspect *viz.* pronounced odd to even predominance and a high ratio of pristane to n-heptadecane (Powell & others, 1993). This is probably attributable to formation of hydrocarbons from free fatty acids, esters and alcohols prior to the main phase of kerogen cracking. This process is quantitatively much less significant and is not accounted for by the calculation of PGI which is based on changes in pyrolysis yields of kerogen. Thus, the small but regular increase in hydrocarbon yield in the marginally mature zone indicates that some hydrocarbon generation may have occurred. This is the maturation interval in which microveins of exsudatinite are observed in Walloon coals (Khorsani, 1987) indicating incipient migration has commenced, but again the extractable hydrocarbons retained their immature aspect. It is concluded that petroleum expulsion efficiencies are low during these initial stages of hydrocarbon generation which in this case is probably not quantitatively significant, but increase rapidly as the PGI increases to 0.5 (Fig. 9).

Once kerogen cracking commences hydrocarbon generation is extremely rapid (Fig. 9) and the bulk of oil generation occurs in the reflectance range 0.8 to 1.0%Ro (Fig. 10). As a result the zone of effective oil generation and migration becomes extremely narrow (Fig. 6). This is consistent with the paraffinic nature of the hydrocarbon product and the relative narrow range of bond energies in aliphatic precursors (Tissot & others, 1987). This suggests that the component of the terrestrial organic matter that is actually generating liquid hydrocarbons is equivalent to a Type I kerogen i.e. an aliphatic biopolymer analogous to that recently found in plant cuticles and bark (Tegelaar & others,

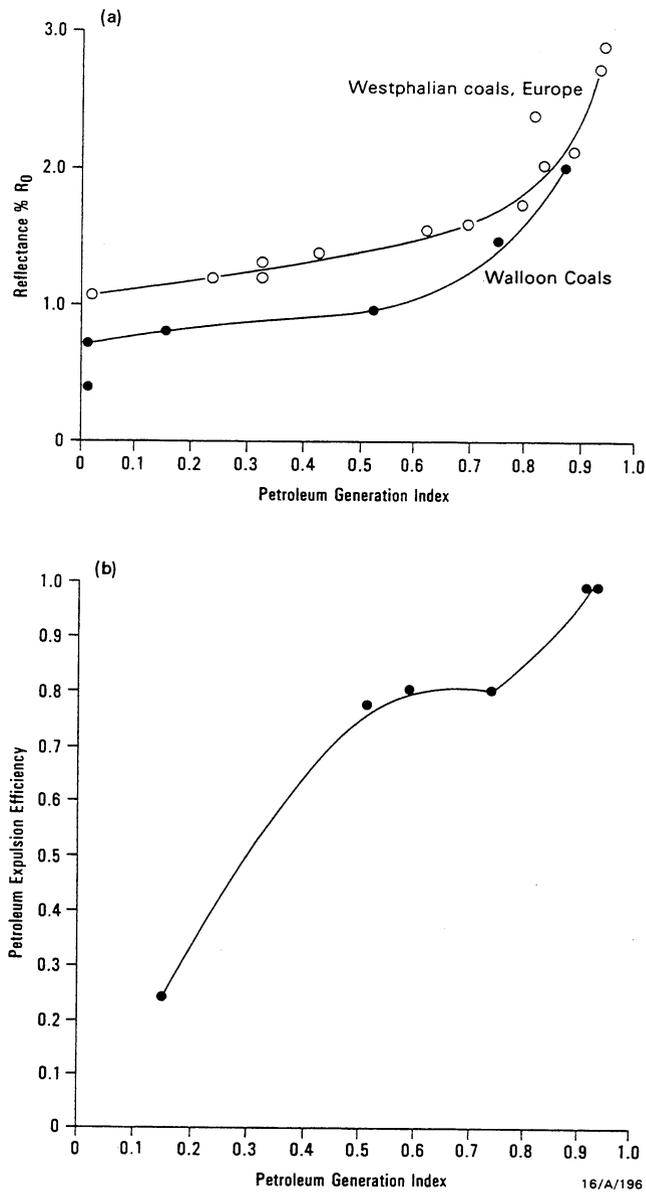


Figure 9. a. Evolution of Petroleum Generation Index with maturation in the Walloon Coal Measures. Note that the bulk of petroleum is generated between reflectance values of 0.75 and 1. Data for Westphalian coals of Europe is from Cooles & others (1986). b. Evolution of Petroleum Expulsion Efficiency with Petroleum Generation Index in the Walloon Coal Measures.

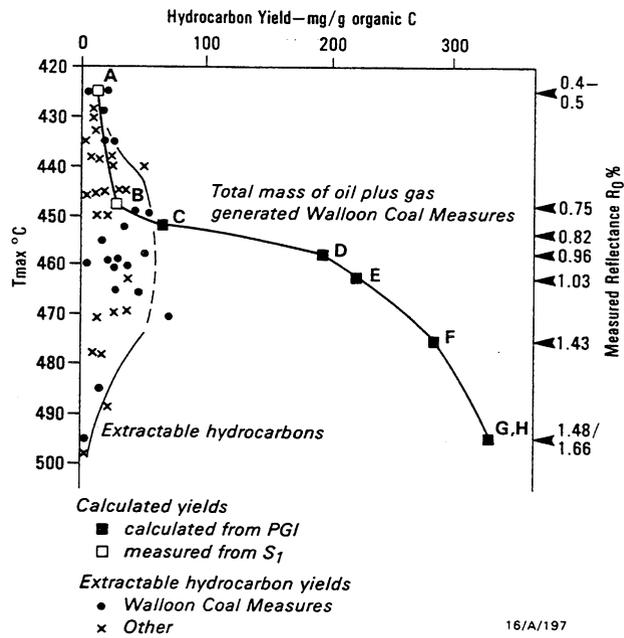


Figure 10. Comparison of theoretical hydrocarbon yields derived from calculation of Petroleum Generation Index in Walloon Coal Measures and measured hydrocarbon yields. Calculated yields were derived from averaged data listed in Table 3.

1989). During the early stages of hydrocarbon generation, expulsion is relatively inefficient - at a PGI of 0.16 the expulsion efficiency is 25 percent and rises to 75 percent at a PGI of 0.5. This reflects the importance of a high hydrocarbon saturation in primary migration and emphasises that petroleum expulsion will be more efficient in richer source rocks (Cooles & others, 1986). The Walloon coals begin to generate hydrocarbons at a lower level of maturation than the Westphalian coals of Europe consistent with their oil-prone nature. However at high maturation levels the Walloon coals behave more like these gas-prone coals in general and the increase in petroleum expulsion efficiency to 90 percent (Fig. 9b) reflects the efficiency of gas migration.

DISTRIBUTION AND NATURE OF POTENTIAL RESERVOIRS

A review of existing porosity and permeability data from cores (tabulated in Thompson, 1987) and inspection of well logs indicate that potential reservoirs are present in a number of units in the Clarence-Moreton Basin. Predominantly, the most quartzose units are the most porous and permeable with coarse channel base facies having the best reservoir characteristics. Reservoir quality sandstones are found in the Kangaroo Creek Sandstone, Koukandowie Formation, the upper part of the Gatton Sandstone, Ripley Road Sandstone and Raceview Formation. Rare sandstone bodies in the Walloon Coal Measures also display some porosity and permeability (Ties & others, 1985, Relph, 1963).

The Kangaroo Creek Sandstone is a sheet of interconnected quartzose sandstone bodies deposited by braided streams. Its extensive outcrop and the rarity of possible sealing rocks in it make it an unlikely target. The Walloon Coal Measures sandstones are typically volcanogenic (Fielding, in press) and have had porosity totally destroyed by

diagenesis and grain compaction. Even so, Kyogle-1 encountered a sandstone body that produced water to the surface (Relph, 1963). This suggests that secondary targets may be present in the Walloon Coal Measures.

The most porous parts of the Koukandowie Formation are coarse sandstone bodies, particularly the Heifer Creek Sandstone Member which is sheet-like and continuous across most of the basin (Wells & others, in press). The best porosities and permeabilities are found in granule conglomerates and coarse sandstone at the base of fining-up channel fills (Element A, O'Brien & Wells, in press) or at the base of storeys in multistorey channel sandstone sheets (Element B, O'Brien & Wells, in press). The Heifer Creek Member is thinner and less porous in the Logan Sub-basin than in the Laidley and Cecil Plains Sub-basins but is more likely to be sealed in the Logan Sub-basin by the more abundant mudstones. Many hydrocarbon shows have been encountered in the Heifer Creek Sandstone Member in the southern Logan Sub-basin with good indications of gas in Clifden-2 and 3 and Hogarth-2.

The Gatton Sandstone is typically impermeable because of its high labile grain content (O'Brien & Wells, in press, Thompson, 1987). However, some holes encountered quartzose sandstone bodies in the top of the Gatton Sandstone with good porosity and permeability. For example, cores from BMR Warwick-7 had porosities up to 25.9% and permeabilities of 961 md (Wells & others, 1989). The extent of such porous sandstone bodies is not clear from the present sparse drilling.

The Ripley Road Sandstone is the most extensive potential reservoir in the basin with excellent porosity and permeability encountered in many holes and indications of hydrocarbons in places (e.g. Tullymorgan-1, Ties & others, 1985). It shows a general

decrease in porosity from west to east with maximum permeabilities in the order of 2000 md in the Cecil Plains Sub-basin compared to a maximum of 59 md in one of the few cores from the Logan Sub-basin (Thompson, 1987). Higher values may be encountered in the Logan Sub-basin if future coring programs more carefully target porous intervals.

The Raceview Formation has not generally been considered a potential reservoir but quartzose sandstones are present (O'Brien & Wells, in press) and Ropeley-1, drilled in the Laidley Sub-basin, encountered sandstone bodies with porosities of 15 % and permeabilities of 2860 md (Webby, 1984, Martin, 1986). The best reservoir characteristics were found in coarse sandstone and granule conglomerate at the base of fining-up fluvial channel deposits (O'Brien & Wells, in press). These sandstones also contained residual oil. Good hydrocarbon shows were also found in the Raceview Formation channel sandstones in Rappville-1.

Diagenesis and porosity reduction

The few studies of sandstone diagenesis and porosity, (Martin, 1986, Scott, 1981) indicate the main causes of porosity reduction are growth of diagenetic clays, quartz overgrowths and carbonate cements and grain compaction. Diagenetic clays are mostly a mixture of illite and smectite or kaolinite (Martin, 1986). Carbonates are probably calcite, dolomite or siderite in different places. Labile sandstones suffer from severe mechanical compaction of the rock fragments and abundant cements probably because of abundant ions available from alteration of labile rock fragments and feldspars.

In quartzose sandstones, primary porosity retention is favoured by lesser amounts of grain compaction. Shallower burial and lower thermal maturity have favoured porosity

retention in the Cecil Plains Sub-basin. However, special diagenetic conditions have preserved porosity in the easterly sub-basins by inhibiting both clay growth and particularly syntaxial quartz overgrowths. Martin (1986) examined three porous samples that illustrate this. Two samples from the Raceview Formation displayed fine epitaxial quartz rim cement that probably inhibited large-scale quartz overgrowths and a Ripley Road Sandstone sample had thin authigenic chlorite rims on the quartz grains. Martin (1986) suggests variations in groundwater composition and flow rates are responsible for differences in diagenesis and hence porosity preservation in quartzose units.

The presence of abundant diagenetic illite-smectite means that most potential reservoirs are likely to be highly sensitive to fresh drilling muds (Ties & others, 1985, Martin, 1986). This may have contributed to some disappointing formation tests in the past. Chlorite and iron-bearing carbonates could also interfere with any attempts to enhance production by acid treatments (Davies, 1980, Martin, 1986).

SEALS

Potential seals within the Clarence-Moreton Basin are the floodbasin facies present within most units. The most extensive are the Ma Ma Creek Member of the Koukandowie Formation and the Calamia Member of the Gatton Sandstone (O'Brien & Wells, in press, Wells & others, in press). The Ma Ma Creek Member may provide a seal for the scattered porous sandstone bodies found at the top of the Gatton Sandstone and the Calamia Member for the Ripley Road Sandstone. Of these units, the Ma Ma Creek is the most consistently developed. In places, the Calamia Member is predominantly siltstone and fine sandstone (O'Brien & Wells, in press) and therefore will not always act as a seal. For

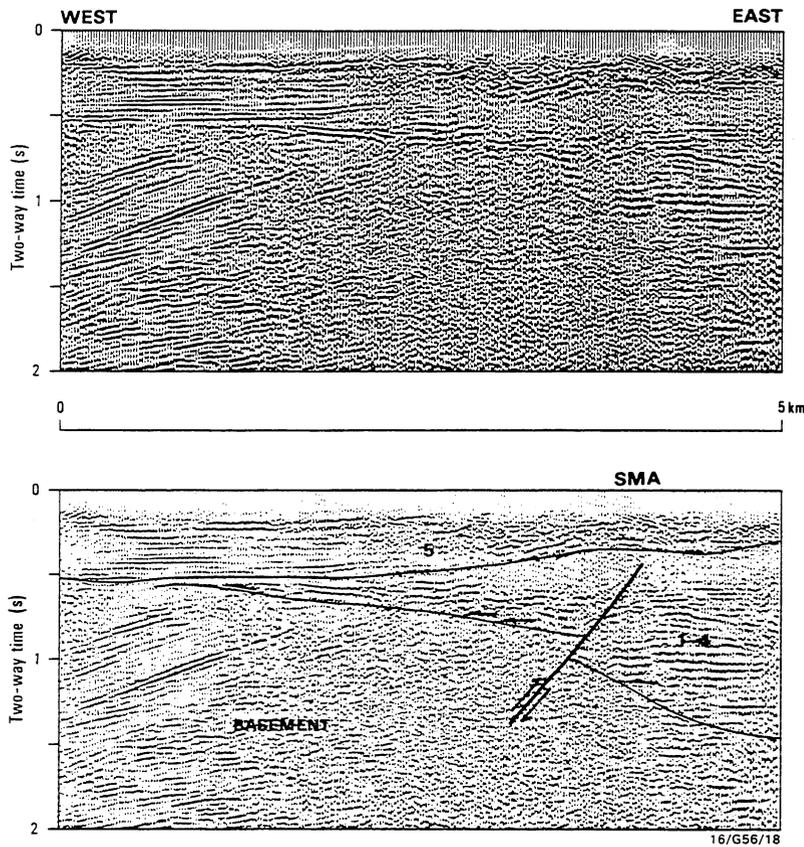


Figure 11. Seismic section across the eastern side of the South Moreton Anticline (SMA) showing pinch out of Clarence-Moreton Basin units against basement. Units 1-4 probably represent Raceview Formation with potential traps in fluvial channel sandstones sealed by onlapping floodplain shales and fed by hydrocarbons generated in the underlying Ipswich Coal Measures or the Raceview Formation.

other potential reservoirs in the Koukandowie and Raceview Formations, sealing is dependent on local development of suitable floodplain facies. Any porous and permeable sandstone bodies in the Walloon Coal Measures could be sealed by the typical, highly-labile sandstones of the Walloons as well as by fine-grained facies.

TRAPS

There are five styles of potential traps recognised in the Clarence-Moreton Basin (Ties & others, 1985):

1. Drape over sub-Clarence-Moreton topography: Ties & others (1985)

identified several large features with closure at Ripley Road and Koukandowie levels formed by drape over base-Clarence-Moreton structures such as the Central Platform (Fig. 2). Rappville-1 was drilled on a local culmination on one of these features and had indications of gas in the Raceview Formation that were not tested (Ties, Jessop & Cairnes, 1985). These traps rely on seals and reservoirs extending across the culmination. Ties & others, (1985) also identified some faulting on such structures.

2. Reservoir pinch outs against sub-Clarence-Moreton topography: Raceview

Formation and Ripley Road Sandstone reservoirs may pinch out against the flanks of base-Clarence-Moreton features such as the Central Platform, the South Moreton Anticline (Fig. 11) or the basin margin. Such targets rely on a top seal overlapping the reservoir sandstone and lateral sealing provided by facies changes in the reservoir unit or by basement.

3. Hanging-wall anticlines on minor thrusts: Most of the inferred strike-slip

faults in the basin exhibit positive flower structures on restraining bend or thrusts in zones

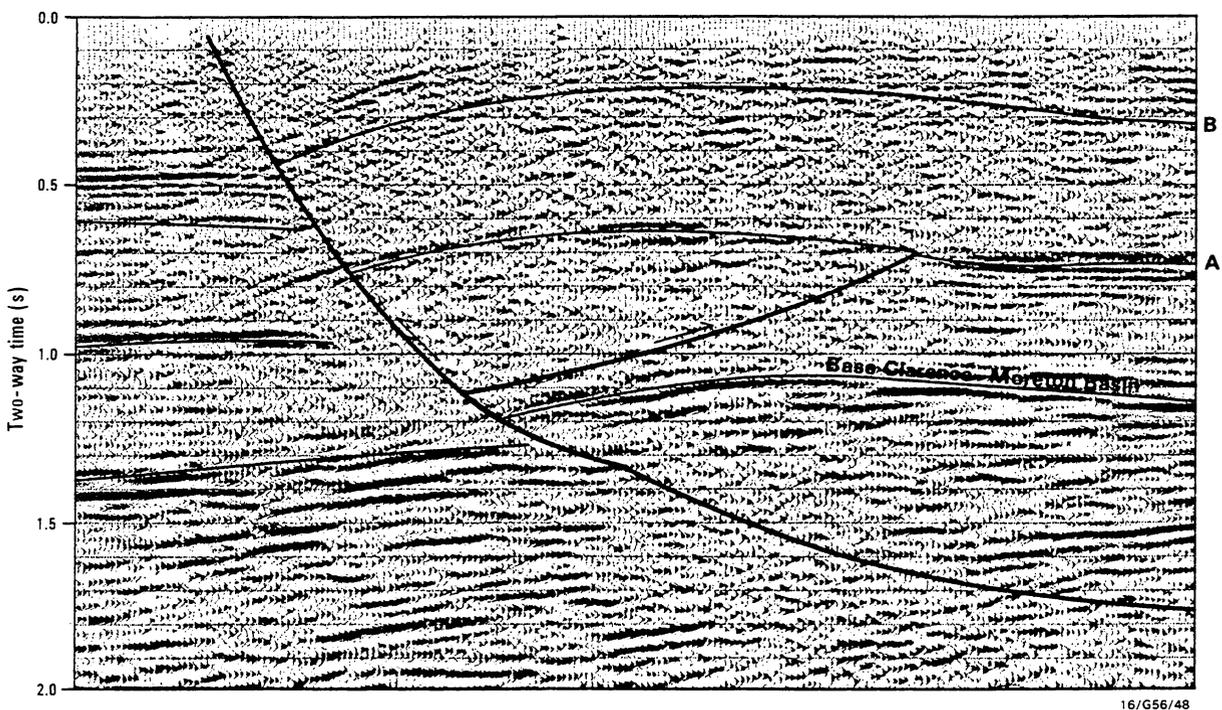
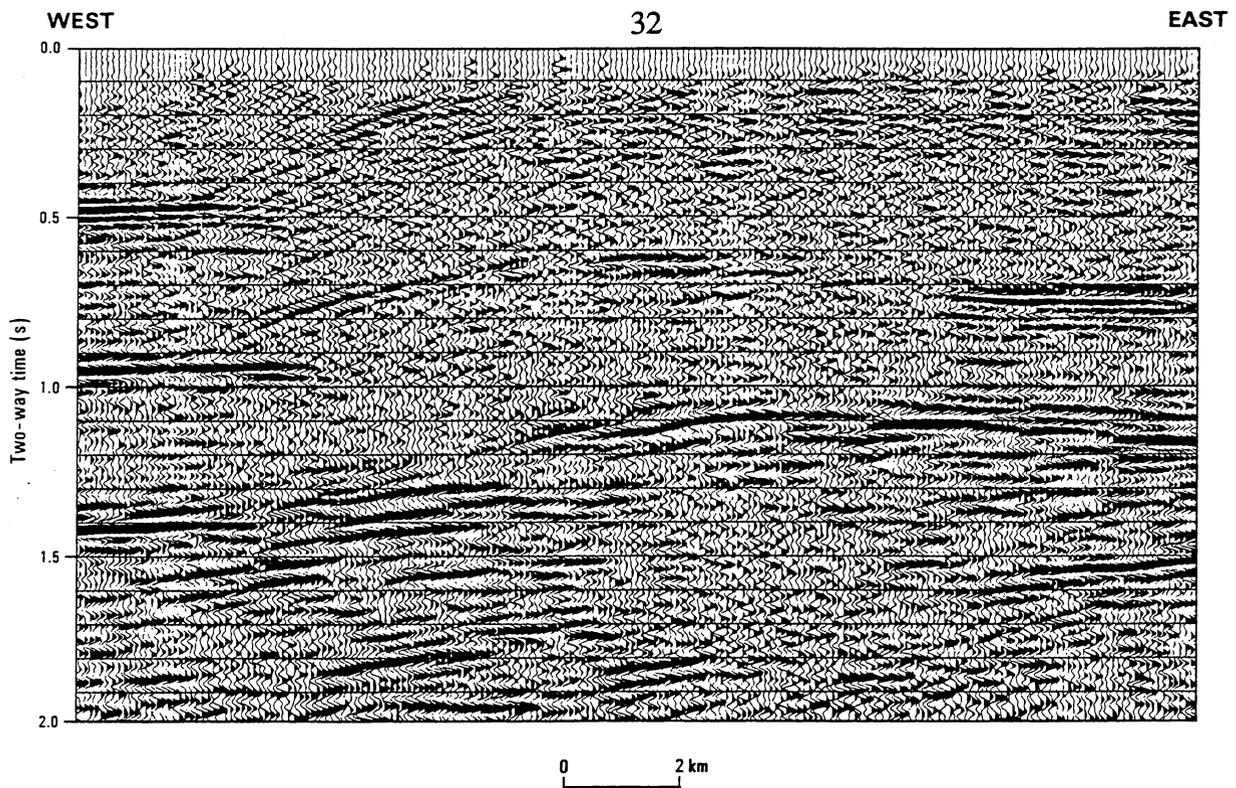


Figure 12. Hanging wall anticline on a thrust, Coraki area. These structures were probably in place before the main phase of petroleum migration. Horizon A is top Gattton Sandstone, Horizon B is base Walloon Coal Measures.

of transpression (O'Brien & others, in press, Fig. 12). These thrusts are arcuate and consequently provide four way closure in some places (O'Brien & others, in press). Some wells drilled on these structures before seismic coverage such as Clifden-2 & 3, may have missed the closures at likely reservoir depths. Others, such as Sextonville-1 and Tamrookum Creek-1 were situated on anticlines where potential reservoirs were virtually at the surface.

4. Stratigraphic traps: Facies variations are likely to play a major part in any style of entrapment in the Clarence-Moreton Basin because of the lateral variability of the sediments. In particular, less sandy units such as the Raceview and Koukandowie Formations are more likely to contain sealed traps because of the lower interconnectedness of sandstone bodies in them (Fielding & Crane, 1987). Ties & others (1985) suggested that facies changes caused the entrapment of gas at Hogarth on what is a plunging anticline lacking four way dip closure.

BURIAL AND THERMAL HISTORY

Vitrinite reflectance profiles in Clarence-Moreton Basin wells suggest that between 1.5 and 2.5km of sediment has been removed from the basin (Ties & others, 1985; Russell, in press). The youngest sediments preserved in the basin are Late Jurassic to earliest Cretaceous (Burger, in press) and hence subsidence continued into the Cretaceous. Fission track dating of apatite grains from outcrop samples gives ages that grade from 160Ma in the west to between 52 and 60Ma along the eastern basin margin (Gleadow & O'Brien, in press). The older ages approximate the depositional age of the sediments whereas the younger ones date the time at which rocks cooled below about 70°C (Gleadow

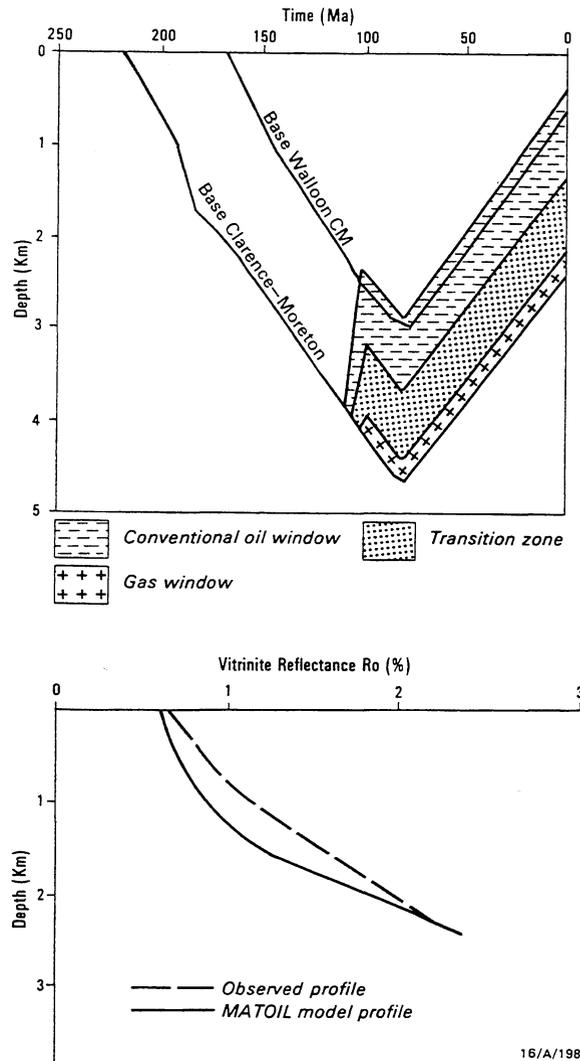


Figure 13. a. Burial history and source rock maturity in Shannon-1 modelled by MATOIL. **b.** Model and observed vitrinite reflectance profiles for Shannon-1. The separation between the middle parts of the curves is probably caused by the conductivity of the Gatton Sandstone being different to conductivities used for sandstone by the model.

& others, 1983). Therefore subsidence ceased and most of the uplift took place before the end of the Paleocene (Gleadow & O'Brien, in press). This conclusion suggests that uplift and heating were associated with break up along Australia's eastern continental margin (Shaw, 1978).

Superimposed upon the regular younging of apatite fission track ages from west to east, are numerous apparent ages of about 20Ma (Gleadow & O'Brien, in press) concentrated in areas of extensive Tertiary igneous activity along the Queensland-New South Wales border (Fig. 1). These ages correspond to radiometric ages obtained from the Tertiary volcanics and intrusives by Webb & others (1967) and indicate significant heating of basin sediments adjacent to volcanics.

During basin subsidence, dextral movement continued on major basin-forming faults. This movement was small compared to earlier movement but was sufficient to produce positive flower structures and thrusts that are the main structural traps in the Clarence-Moreton Basin (O'Brien & others, in press). These structures affect the youngest sediments preserved in the basin and are therefore post-Jurassic. Apparent fission track ages suggest that the main period of basin heating was associated with opening of the Tasman Sea to the east (Gleadow & O'Brien, in press). Shaw (1978) demonstrated sinistral strike-slip motion along the continental margin during rifting adjacent to the Clarence-Moreton Basin. Therefore, dextral strike-slip motion had probably ceased and the structures emplaced by the time the basin reached thermal maturity.

The systematic increase from west to east in thermal maturity of the sediments in the Clarence-Moreton Basin indicates that the eastern part of the basin has been subjected to greater depth of burial and higher heat flows than the western part (Fig. 6). Raw

subsidence curves were constructed for Shannon-1 well in the Logan Sub-basin. The timing and magnitude of uplift at this well (2.4km) were based on apatite fission track ages (Gleadow & O'Brien, in press) and vitrinite reflectance data (Russell, in press). The raw subsidence curves and lithologies were used to derive burial histories and model source rock maturity using the MATOIL program (Fig. 13a). Various heat flow histories were run and the model vitrinite reflectance profiles were compared with the profile measured in the well (Fig. 13b).

The model which produced the closest vitrinite reflectance profile to that observed (Fig. 13b) required a rise in heat flow from 50mW per m² to 110mW per m² between 100 and 90 Ma. This estimate of maximum heat flow is slightly lower than that obtained from consideration of the vitrinite reflectance data (124 mW per m², Russell, in press). The observed vitrinite reflectance profile differs slightly from the modelled profile being more linear compared to the convex-up shape of the model curve (Fig. 13b). This probably results from the lithic character of the Gatton and Ripley Road sandstones which may have higher thermal conductivities than is assumed by the model. Alternatively igneous sills and dykes in the shallower part of the section in the vicinity of the Shannon-1 well may have resulted in kinetic transfer of heat to the shallower parts of the section and is not accounted for in the model. These results indicate that both elevated heat flow and uplift were responsible for the maturation patterns of Clarence-Moreton sediments and that hydrocarbon generation and migration occurred between 80 and 100 Ma. At that time the principal structural traps were in place and were well placed to receive any migrating hydrocarbons.

The period of high heat flow probably represents the time during which the

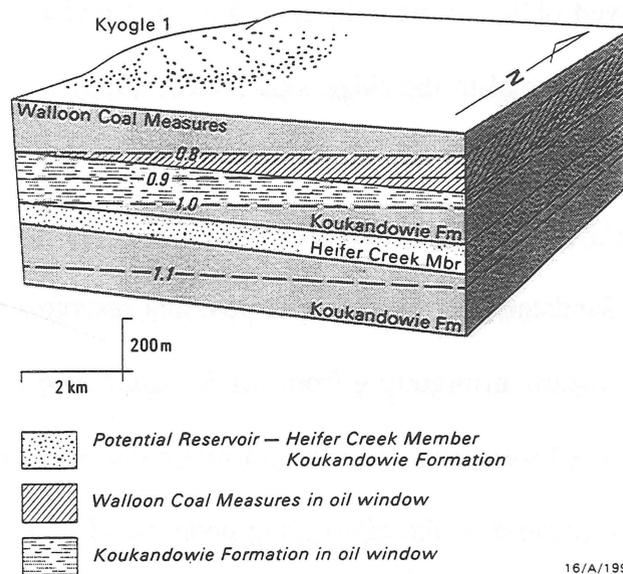


Figure 14. Block diagram of the source rock drainage area and a Koukandowie Formation reservoir for a trap in the Kyogle Anticline. East-dipping source rocks intersect west-dipping isoreference surfaces so that the trap is fed by source rocks mostly overmature for generation of liquid hydrocarbons.

Tasman Sea spreading ridge was adjacent to the southeastern side of the Logan Sub-basin. This interpretation is based on the co-incidence of apparent apatite fission track ages with the timing of sea floor spreading inferred from magnetic anomalies (Shaw, 1978, 1979; Gleadow & O'Brien, in press) and the observation that all stratigraphic units show their greatest thermal maturity along the basin margin that was adjacent to the Dampier fracture zone (Shaw, 1978; Gleadow & O'Brien, in press). During initial spreading, the margin moved obliquely past the spreading centre along this transform before moving more or less normal to the ridge axis (Shaw, 1978).

GEOCHEMICAL ASPECTS OF PROSPECTIVITY

The Heifer Creek Sandstone is a widespread potential reservoir horizon which is well placed to receive hydrocarbon migrating from the Koukandowie Formation and to a lesser extent the Walloon Coal measures. In order to refine the petroleum resource assessment of the basin, we examined the oil-bearing potential of two prominent structures in the southern Logan sub-basin. The Kyogle and Clifden anticlines were chosen because they are surface anticlines and have wells that penetrated Walloon Coal Measures that are mature for generating oil (Fig. 6a). The aim of the exercise was to see if oil-prone source rocks in the Walloon Coal Measures and Koukandowie Formation could have generated enough oil to saturate a reservoir in the Heifer Creek Sandstone member of the Koukandowie Formation and migration paths to it (Mackenzie & Quigley, 1988). Only the lower half of the Walloon Coal measures was likely to have contributed hydrocarbons to the Heifer Creek Sandstone because the upper part would lose them to the porous Kangaroo Creek Sandstone above (Mackenzie & Quigley, 1988).

Construction of a block diagram of the drainage areas for the anticlines (Fig. 14) emphasise an important fact: that the source rocks dip east and the isorefectance surfaces dip west. This geometry means that most of the source rocks that might drain into the Heifer Creek Member in both notional traps have reflectance values greater than 1 and are therefore gas-prone. This is particularly true for the Clifden structure. Even in the case of the Kyogle structure which has lower maturity values than Clifden, most source rocks feeding it are overmature.

In the Clarence-Moreton Basin, the maturation range over which oil generation occurs is much narrower than the generally accepted oil window (Fig. 9a). As a consequence of this observation, and the maturity levels observed in the basin, any oil targets in the Heifer Creek Member in the southern Clarence-Moreton basin will be restricted to a narrow zone along the western margin of the basin lying updip from the main area of oil generation (Fig. 6) and to the west of structures such as the Clifden Dome and Tullymorgan Anticline that are associated with the deep seated Coraki Fault (O'Brien & others, in press). Therefore structures associated with the South Moreton Anticline are the most likely to be oil-bearing. The only oil plays that might be more widespread are channel sandstone bodies in the Walloon Coal Measures, which tend to have poor reservoir quality, or Kangaroo Creek Sandstone traps above the Walloon Coal Measures. Its shallow depth and extensive outcrop suggests that the potential for sealed traps in the Kangaroo Creek Sandstone is low, although reservoir characteristics are generally good. The Heifer Creek Sandstone Member of the Koukandowie Formation must generally be considered as a gas play in most of the Logan sub-basin. In the Laidley and Cecil Plains Sub-basins, the Raceview Formation is mature for oil generation (Fig. 6c), but

organic-rich rocks are scarce in this unit (Fig. 3).

CONCLUSIONS

Abundant oil-prone source rocks occur in the Walloon Coal Measures and Koukandowie Formation. Older Jurassic and Triassic stratigraphic intervals in the Clarence-Moreton Basin are generally lean in organic matter, but coal-rich sediments occur in older sequences.

The organic matter in the Walloon Coal Measures and Koukandowie Formation is rich in liptinite and Hydrogen Indices of coals are commonly as high as 450. They are largely Type II/III kerogens. Comparison of petrographic and geochemical properties shows that sporinite is not a major hydrocarbon source and that suberinite as well as cutinite is a major source of waxy alkanes. These source rocks are mature for oil generation in the central part of the basin in NSW and southeastern Queensland, but are overmature along the eastern margin.

Calculation of theoretical hydrocarbon yields from Rock Eval data shows that hydrocarbon generation and migration is efficient, but is largely confined to a narrow vitrinite reflectance range of between 0.8 and 1.0%Ro. Based on observed hydrocarbon yields, this is preceded by a small amount of hydrocarbon generation in the marginally mature zone which is probably associated with decarboxylation and dehydration of fatty acids, alcohols and esters. This is not considered to be quantitatively significant for oil generation since the hydrocarbons generated retain their immature aspect.

Consideration of fission track data and maturation modelling shows that hydrocarbon generation occurred in the period 80 to 100 Ma at a time of maximum depth

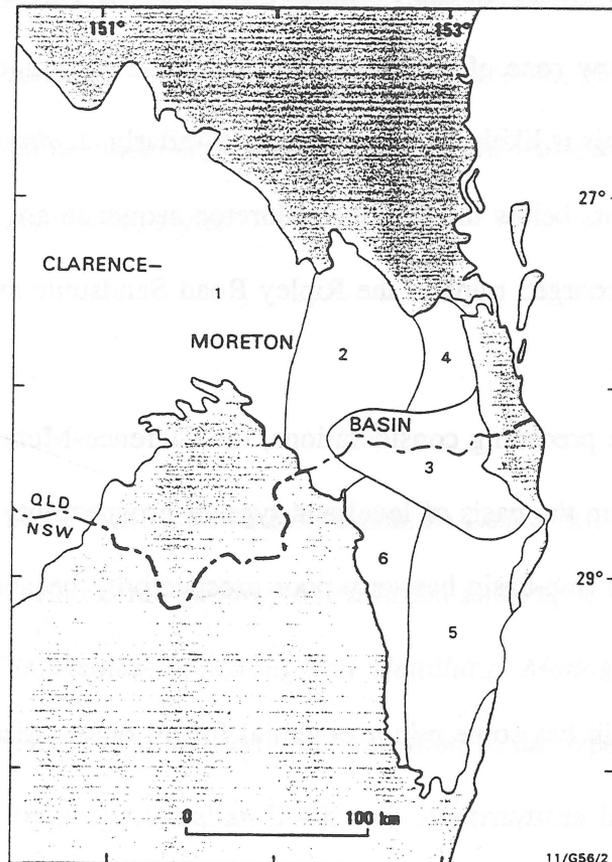


Figure 15. Areas of prospectivity in the Clarence-Moreton Basin:

1. The Cecil Plains Sub-basin has very poor prospectivity because of low thermal maturity.
2. Laidley Sub-basin has some minor potential for oil or gas discoveries in the Raceview Formation.
3. The area along the state border has very poor potential because of extensive intrusion by Tertiary igneous rocks and a thick basalt cover.
4. The northern Logan Sub-basin has some potential for oil and gas in the Raceview Formation, Ripley Road Sandstone and Koukandowie Formation though data are scarce. The underlying Ipswich Coal Measures may also have some gas potential.
5. Most of the southern Logan Sub-basin has potential for gas discoveries throughout the basin section.
6. The western side of the southern Logan Sub-basin has minor potential for small oil accumulations in addition to gas potential.

of burial and maximum heat flow associated with the time when the Tasman Sea spreading ridge was adjacent to the southeastern side of the basin. Extensive unroofing of parts of the eastern part of the basin then occurred.

The Heifer Creek Member of the Koukandowie Formation is the principal reservoir for the source rocks of the Koukandowie Formation and the Walloon Coal Measures. As a consequence of the narrow zone of oil generation and the distribution of maturity zones and structures, this reservoir is likely to be gas-prone. Similarly hydrocarbons originating from coal-bearing sediments below the Clarence-Moreton sequence are also likely to be gas. This gas could have charged traps in the Ripley Road Sandstone and the Raceview Formation.

On the basis of the preceding considerations, the Clarence-Moreton Basin can be subdivided into six areas on the basis of level and type of prospectivity (Fig. 15):

1. The Cecil Plains Sub-basin has very poor prospectivity because of low thermal maturity.

2. Laidley Sub-basin has some minor potential for oil or gas discoveries in the Raceview Formation.

3. The area along the state border has very poor potential because of extensive intrusion by Tertiary igneous rocks and a thick basalt cover.

4. The northern Logan Sub-basin has some potential for oil and gas in the Raceview Formation, Ripley Road Sandstone and Koukandowie Formation though data are scarce. The underlying Ipswich Coal Measures may also have gas potential.

5. Most of the southern Logan Sub-basin has potential for gas discoveries throughout the basin section.

6. The western side of the southern Logan Sub-basin has minor potential for small oil accumulations in addition to gas potential.

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