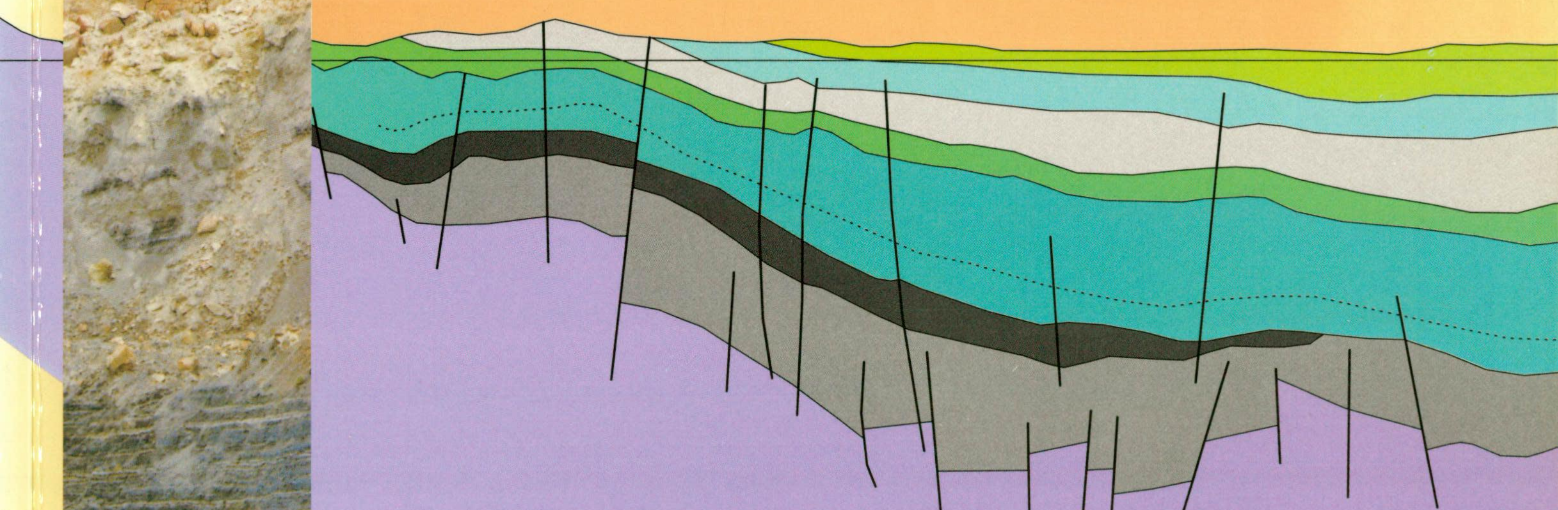
PETROLEUM PROSPECTIVITY

CLARENCE-MORETON BASIN

NEW SOUTH WALES



MINERAL RESOURCES

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GEOLOGICAL SURVEY OF NSW
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PETROLEUM BULLETIN 3

PETROLEUM PROSPECTIVITY OF THE CLARENCE-MORETON BASIN IN NEW SOUTH WALES

by

F.T. Ingram and V.A. Robinson
(R.A. Facer, Editor)

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SUMMARY

The study was designed to evaluate the petroleum exploration potential in the New South Wales portion of the Clarence-Moreton Basin, using the existing geological, geophysical and drilling data. If the initial results of the study indicated that a significant exploration potential existed, then a consequent goal was to identify areas or subjects that needed new and additional data, and to recommend what new data were required.

It has been established, for the Clarence-Moreton Basin in New South Wales, that a definite potential exists for accumulations, of commercial size, of both conventional hydrocarbons and coal seam methane. Additional exploration work in the area is certainly warranted.

The sedimentary sequence of the New South Wales portion of the Clarence-Moreton Basin is predominantly Mesozoic — from mid-Triassic to Early Cretaceous. The section is similar to that of the Surat Basin, but the Clarence-Moreton Basin section is much thicker and has greater source rock potential. Reservoir sandstones are plentiful, with permeability ranging from poor to fair to occasionally good. Reservoir quality is sufficient to sustain commercial production of oil or gas, but is somewhat unpredictable.

Four source rock intervals — the Walloon Coal Measures; Koukandowie Formation; Raceview Formation; and the Ipswich/Nymboida Coal Measures — have been identified in the Clarence-Moreton Basin. Maturation levels in the Basin range from early generation of oil to mature generation of methane. Two widespread primary reservoir targets are the Heifer Creek Sandstone Member of the Koukandowie Formation and the Ripley Road Sandstone. Several gas flows and oil saturation in cores have been noted, mostly in the Casino Trough area.

The New South Wales portion of the Clarence-Moreton Basin has been divided into nine play areas for conventional hydrocarbons and ranked according to potential. The Casino Trough area has the highest ranking and the Eastern Margin area the lowest. Gas is the most likely conventional hydrocarbon to be found, with oil having a lesser probability. One prospect and seven leads have been identified from seismic data and surface geology mapping.

Two distinct coal measures sequences have potential for coal seam methane production in the Clarence-Moreton Basin. The first, and best defined, of these is the Middle Jurassic Walloon Coal Measures in the Casino and Grafton Troughs. The second, and very poorly defined, sequence is the Middle to Late Triassic Ipswich/Nymboida Coal Measures sequence along the south-western margin of the Basin.

Several recommendations have been reached which could further evaluate the petroleum prospectivity of the (New South Wales portion of the) Clarence-Moreton Basin. Four new studies could be fruitfully conducted: acquisition of new seismic data (total 302 km); stratigraphic drilling (four drillholes); diagenetic studies of the reservoir rocks; and dating of igneous intrusions. Such studies will enhance an understanding of the tectonothermal history of the Basin and of its petroleum prospectivity.

This study has been undertaken by RobSearch Australia Pty Limited (formerly Robertson Australia Pty Limited) for the New South Wales Department of Mineral Resources.

ACKNOWLEDGMENTS

A number of people have contributed to this study, which was funded by the *Discovery 2000* program of the New South Wales Department of Mineral Resources. Several members of the Department have assisted — especially David Alder, Sean Hawley, and Jim West and the Cartography staff.

Permission was generously provided by the Australian Geological Survey Organisation to reproduce several figures from their *Bulletin* **241**. (Geology and petroleum potential of the Clarence-Moreton Basin, New South Wales and Queensland, compiled and edited by A.T. Wells and P.E. O'Brien, 1994.)

Other drafting assistance was provided by Oil on Film (Andy Marosszeky) and Corporate Montage (Fred Garside).

Colleagues from RobSearch Australia Pty Limited (formerly Robertson Australia Pty Limited), especially John Blumer and Wendy Collins, greatly assisted with the study.

All this assistance is gratefully acknowledged.

CONTENTS

TABLES

FIGURES

INTRODUCTION AND PURPOSE OF STUDY

The purpose of the study for this *Bulletin* was to assess all of the existing geological, geophysical and drilling data pertaining to the exploration for conventional oil and gas, as well as coal seam methane, in the New South Wales portion of the Clarence-Moreton Basin (Figure 1). Following this assessment, areas where new geological or geophysical data are needed — whether further studies of existing data or acquisition of new data — were to be defined. And lastly, once these areas were defined, recommendations as to what specific types of new data would be required were to be described in detail. A broader study of the petroleum prospectivity of New South Wales has been compiled by Stewart and Alder (1995).

A reference list is included in this *Bulletin.* Readers are referred to that list as a direct, and indirect, source of additional information because reference citations have otherwise been kept at a minimum.

One of the principal aims of the study was to gather and integrate all relevant data and to evaluate all aspects of the hydrocarbon potential of the Clarence-Moreton Basin in a single study. This study was meant to evaluate all of the sedimentary sequence from the Nymboida Coal Measures of Middle Triassic age, to the youngest prospective unit, the Walloon Coal Measures of Middle Jurassic age. Younger sedimentary units are not considered prospective because of their shallow depth and lack of seal.

This study was initiated because, in the opinion of the New South Wales Department of Mineral Resources, the Clarence-Moreton Basin is still considered to have considerable exploration potential for hydrocarbons, but that this potential is poorly understood or not well appreciated by the petroleum industry. Hence, this study was designed to highlight that potential; to recommend additional work that would clarify important aspects regarding the quality and maturation levels of the various source rock units; and to identify the various reservoir units and the areas where reservoir conditions would be most favourable. In particular, this study addressed:

- evaluation of the timing of the structural development in relation to hydrocarbon generation and migration;
- identification of potential structural and stratigraphic traps and plays, or trends, which might harbour these hydrocarbons; and, ultimately,
- preparation of recommendations (to the Department) as to what additional work — ie gravity, magnetic and seismic surveys, drilling, palynological investigations, petrographic studies, reservoir analyses, source rock studies, etc. — would upgrade the conventional oil and gas exploration potential of the Basin.

At the same time, the coal seam methane potential of the Clarence-Moreton Basin was to be evaluated and recommendations were to be made regarding additional exploration work which might upgrade the potential for economic development of that source of energy. In this latter case, this present study is a complement to the more general evaluation of coal seam methane prospectivity in New South Wales carried out by Brown et al (1996).

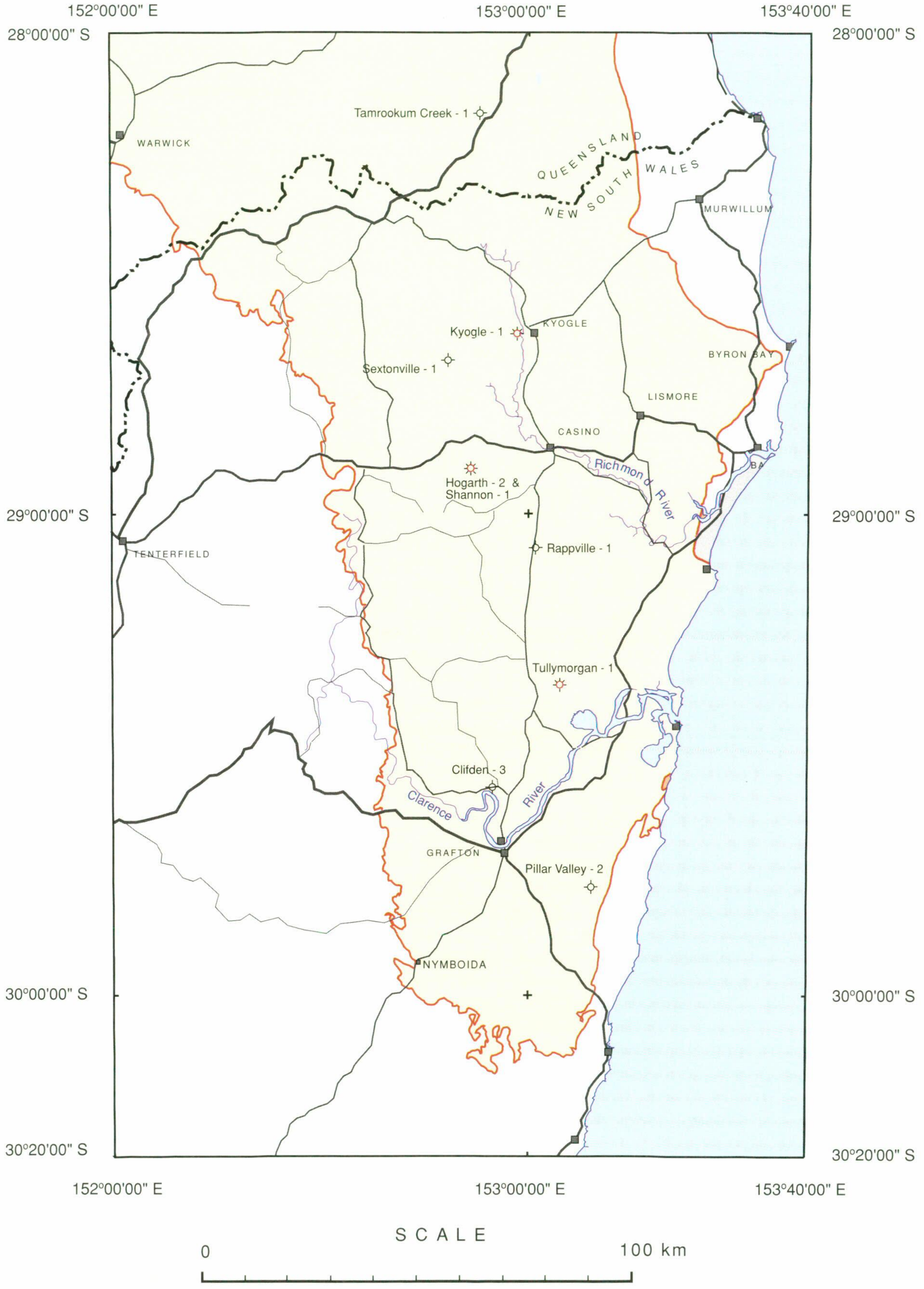


Figure 1a. Locality map for Clarence-Moreton Basin in New South Wales.

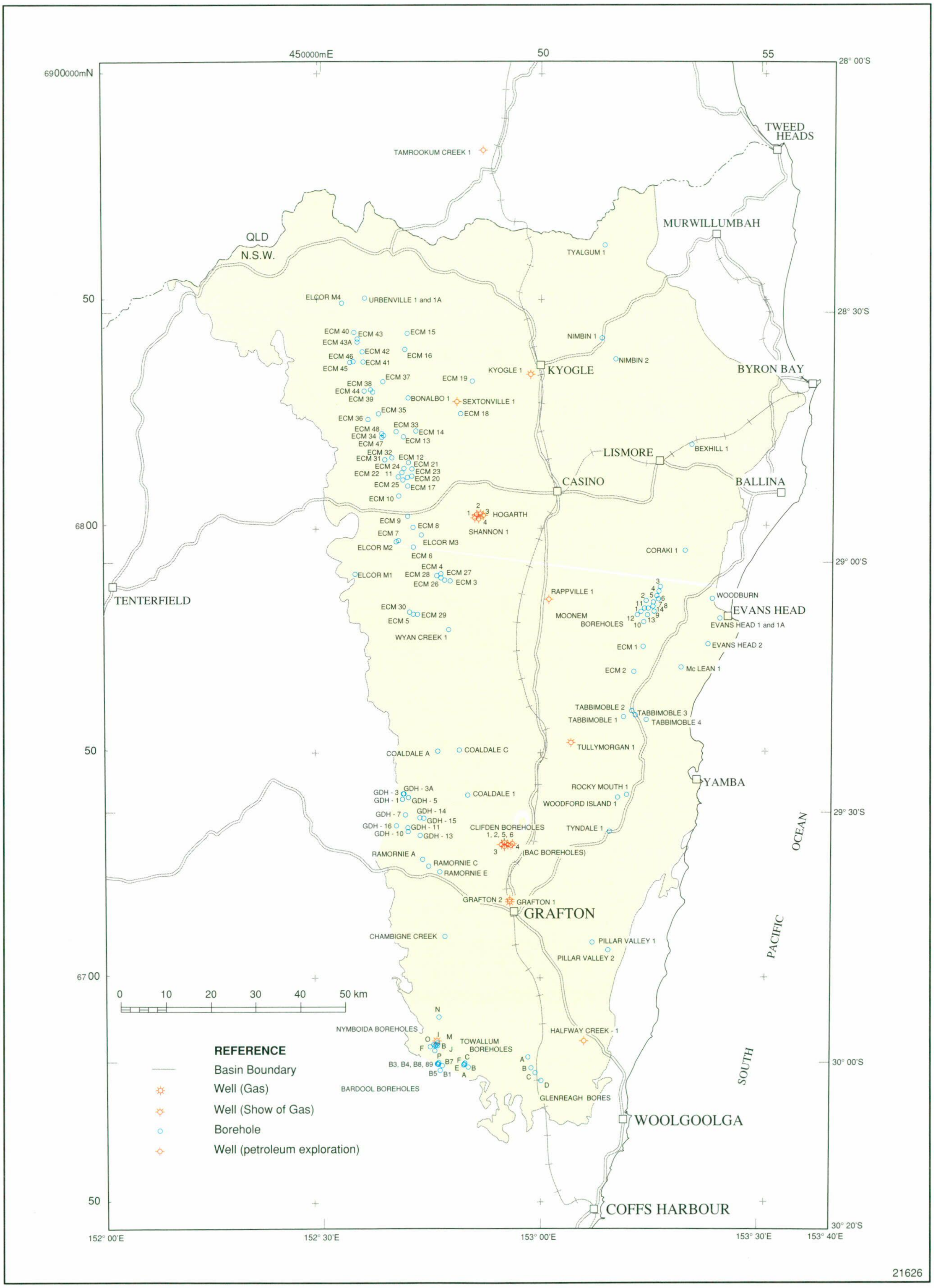


Figure 1b. Borehole locations, New South Wales portion of the Clarence-Moreton Basin. (See Appendix 2 for listing.)

STRATIGRAPHY

INTRODUCTION

The stratigraphy of the Clarence-Moreton Basin has been thoroughly described in Wells and O'Brien (1994) (*Bulletin* **241** of the Australian Geological Survey Organisation [AGSO]). The chapters on lithostratigraphy (Wells and O'Brien), regional reconnaissance (Willis) and sedimentology of the Bundamba Group (O'Brien and Wells) in Wells and O'Brien (1994) have given a detailed description of important sections of the stratigraphy of the Clarence-Moreton Basin in south-eastern Queensland and New South Wales. Additional information on the petroleum prospectivity was contained in Willis (1985) and Alder, Byrnes and Cameron (1993), and in Stewart and Alder (1995), and [for coal seam methane] Brown et al (1996).

In Wells and O'Brien (1994), the , Ipswich Coal Measures, Chillingham Volcanics and Nymboida Coal Measures (Figure 2) are not considered part of the Clarence-Moreton Basin stratigraphic succession and, for that reason, were not treated in any depth. These older units in New South Wales were described by McElroy (1962) and Alder et al (1993), and in numerous well completion reports on file at the New South Wales Department of Mineral Resources. The Ipswich Coal Measures are well known in the Ipswich area of Queensland, and a range of publications on the stratigraphy of that unit is available. Recent summaries of the coal-bearing horizons of the Clarence-Moreton Basin have been presented by Goscombe and Coxhead (1995) and Wells (1995). Additional information on the coal measures (and coal seam methane) has been presented in Brown et al (1996).

The stratigraphic nomenclature established in (various sources in) Wells and O'Brien (1994) is used in this *Bulletin* (Figure 2). The wireline log characteristics and correlations of stratigraphic units across the entire Clarence-Moreton Basin to the Surat Basin are shown in Figure 3.

The stratigraphic divisions presented by Wells and O'Brien (1994) are, for the most part, easily recognisable in petroleum exploration wells and other boreholes where wireline geophysical logs are available (Figure 4). Formation tops and thicknesses for exploration wells and significant boreholes in the Clarence-Moreton Basin are shown in Table 1. The most difficult stratigraphic boundary to distinguish in wells and boreholes is the contact between the Walloon Coal Measures and the underlying Koukandowie Formation. The volcanolithic sandstones of the Walloon Coal Measures are lithologically distinct from the more quartzose sandstones of the Koukandowie Formation, but this distinction is often very subtle on gamma ray or other logs. The distinctive ferruginous oolites of the Ma Ma Creek Member at the base of the Koukandowie Formation in Queensland have not been observed in the New South Wales portion of the Basin. The Ma Ma Creek Member in this area is present as thinly bedded claystones, siltstones and sandstones.

The principal stratigraphic units having relevance to the exploration for conventional hydrocarbons, or for coal seam methane, in the New South Wales portion of the Clarence-Moreton Basin are the following:

- Ipswich and Nymboida Coal Measures, and the Chillingham Volcanics;
- Raceview Formation (Woogaroo Subgroup);
- Ripley Road Sandstone (Woogaroo Subgroup);
- Gatton Sandstone (Marburg Subgroup);
- Koukandowie Formation (Marburg Subgroup); and
- Walloon Coal Measures.

The Gatton Sandstone probably has limited source rock potential and is considered only as a secondary reservoir objective. For this reason, no detailed study of this unit has been made in this *Bulletin*. However, it should be noted that one small flow of dry gas (3 000 cubic feet per day or 85 cubic metres per day) from the top of this unit was recorded in the Tullymorgan-1 well, and the sandstones of this unit cannot be disregarded entirely. The Kangaroo Creek Formation overlies the Walloon Coal Measures and is in turn overlain by the Grafton Formation. These two younger units have no source rock potential, no seals, are widely exposed to the surface and have limited areal extent. They are important only in that they provide a certain amount of overburden and hydrostatic pressure to the Walloon Coal Measures — needed to contain any coal seam methane or conventional hydrocarbons that might be trapped in the coal measures rocks.

Palaeocurrent measurements in the field indicate that the sediments of the Bundamba Group were derived from the south-western, southern and south-eastern margins of the Clarence-Moreton Basin and were deposited by northward-flowing streams (Figure 5).

Various maps have been prepared for this study showing stratigraphic thicknesses and lithologies, at least in part using gamma ray log data. The gamma ray curve has been used to distinguish 'clean' sandstones and shaly, coaly, carbonaceous beds.

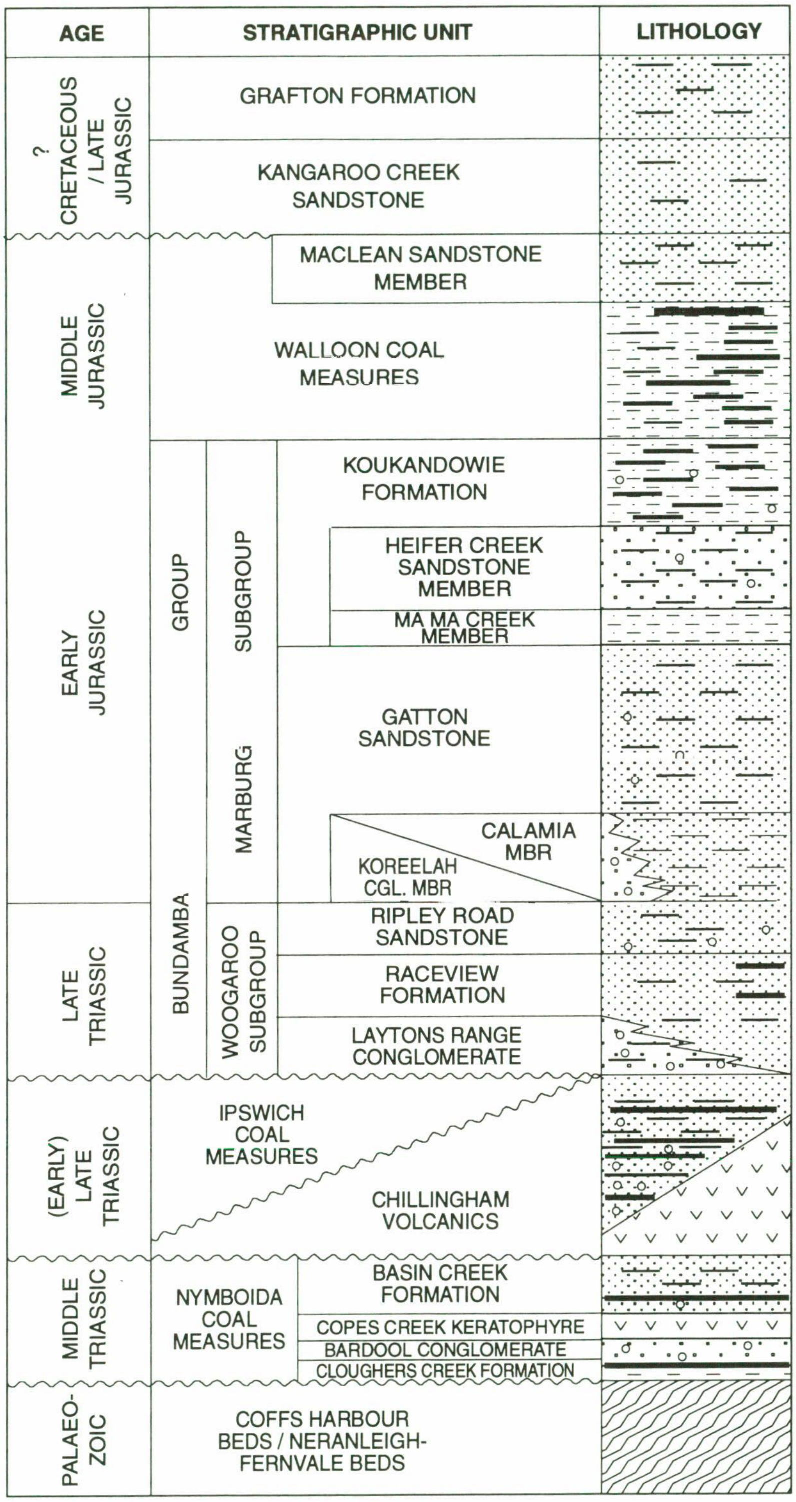


Figure 2. Stratigraphy of the New South Wales portion of the Clarence-Moreton Basin, after Wells & O'Brien (1994). No vertical scale implied.

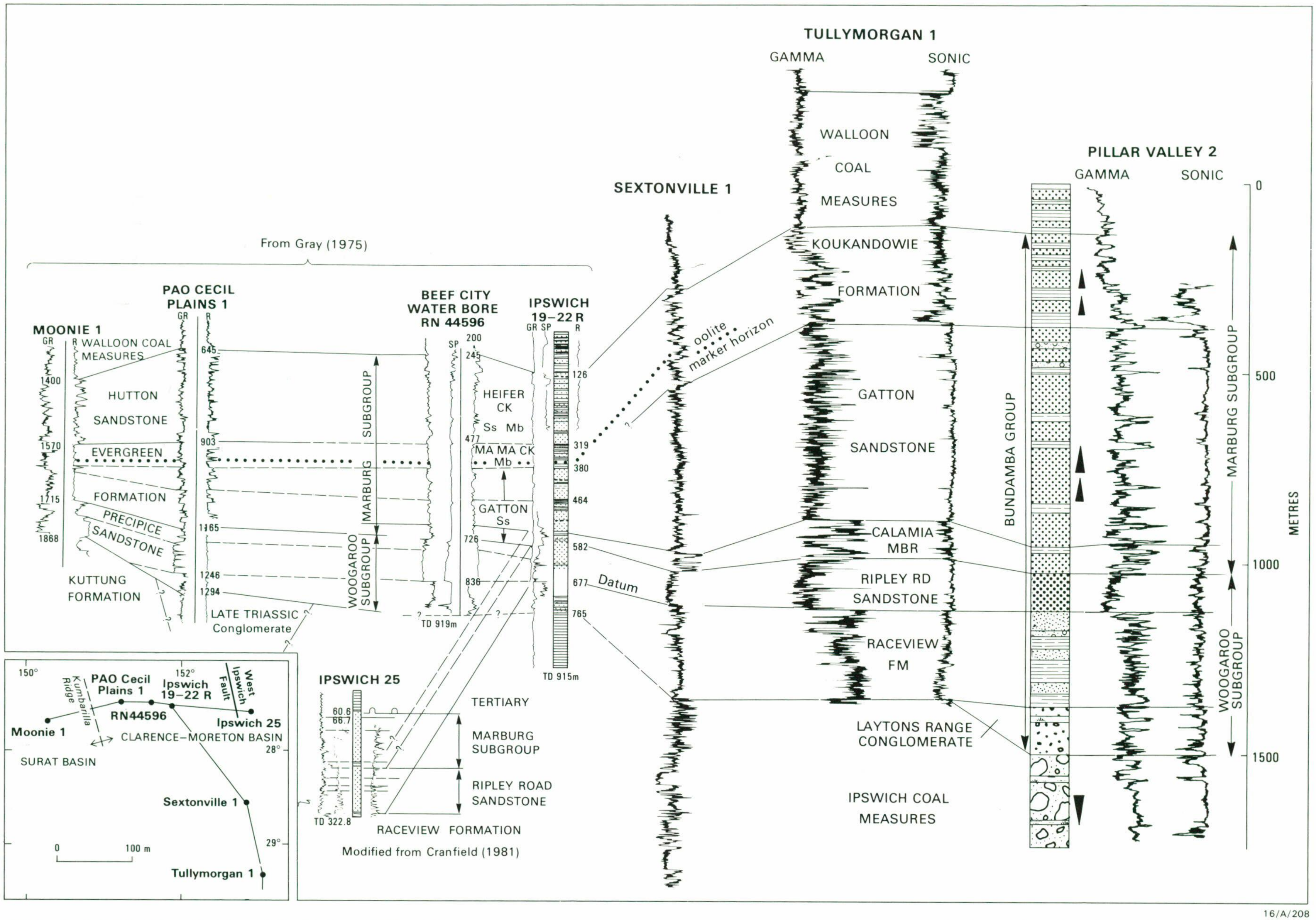


Figure 3. Wireline log characteristics of the Clarence-Moreton Basin section with correlations, including to the Surat Basin. Reproduced with permission from Wells & O'Brien (figure 35) in Wells & O'Brien (1994), AGSO Bulletin ***241****.*

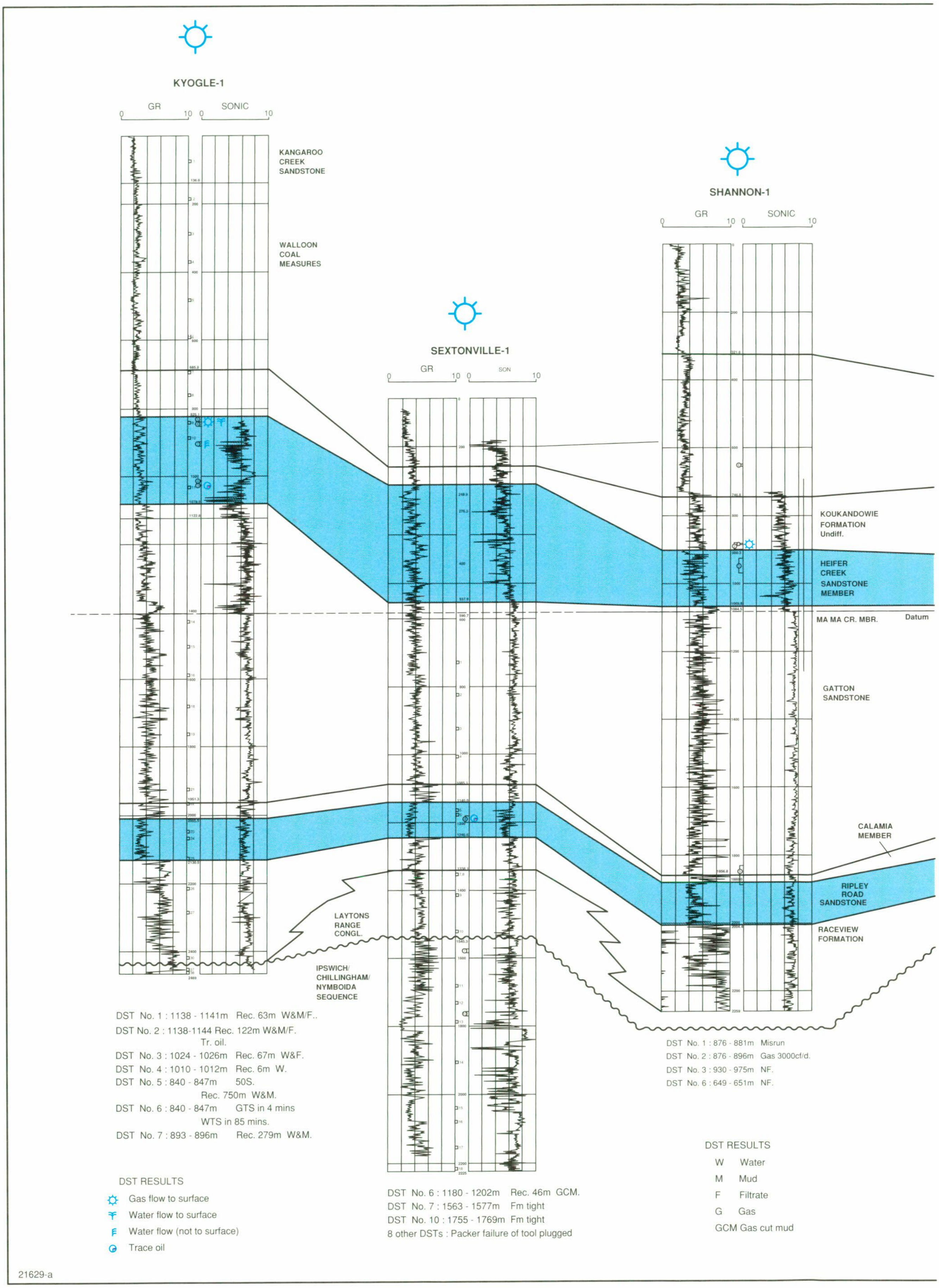
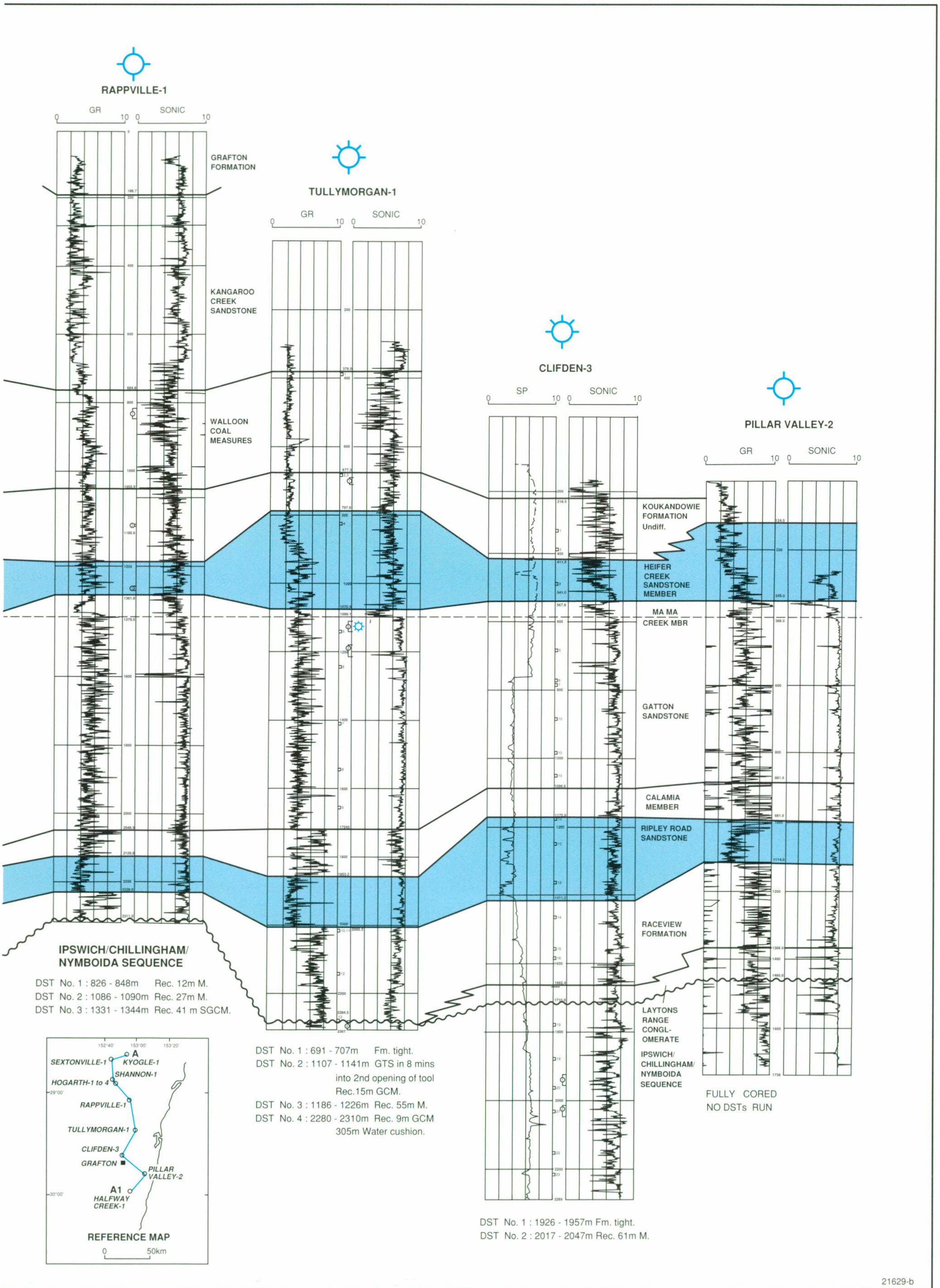


Figure 4. Wireline log correlations, Kyogle-1 to Pillar Valley-2.



RAPPVILLE-1
GR
SONIC
0
10
GRAFTON FORMATION
KANGAROO CREEK SANDSTONE
WALLOON COAL MEASURES
TULLYMORGAN-1
CLIFDEN-3
SP
PILLAR VALLEY-2
KOUKANDOWIE FORMATION Undiff.
HEIFER CREEK SANDSTONE MEMBER
MA MA CREEK MBR
GATTON SANDSTONE
CALAMIA MEMBER
RIPLEY ROAD SANDSTONE
RACEVIEW FORMATION
LAYTONS RANGE CONGL-OMERATE
IPSWICH/ CHILLINGHAM/ NYMBOIDA SEQUENCE
IPSWICH/CHILLINGHAM/ NYMBOIDA SEQUENCE
DST No. 1 : 826 - 848m Rec. 12m M.
DST No. 2 : 1086 - 1090m Rec. 27m M.
DST No. 3 : 1331 - 1344m Rec. 41 m SGCM.
DST No. 1 : 691 - 707m Fm. tight.
DST No. 2 : 1107 - 1141m GTS in 8 mins into 2nd opening of tool Rec.15m GCM.
DST No. 3 : 1186 - 1226m Rec. 55m M.
DST No. 4 : 2280 - 2310m Rec. 9m GCM 305m Water cushion.
DST No. 1 : 1926 - 1957m Fm. tight.
DST No. 2 : 2017 - 2047m Rec. 61m M.
FULLY CORED
NO DSTs RUN
A
SEXTONVILLE-1
KYOGLE-1
SHANNON-1
HOGARTH-1 to 4
RAPPVILLE-1
TULLYMORGAN-1
CLIFDEN-3
GRAFTON
PILLAR VALLEY-2
A1
HALFWAY CREEK-1
REFERENCE MAP
0
50km
21629-b

TABLE 1A
CLARENCE-MORETON BASIN DRILLHOLE INTERSECTIONS FORMATION TOPS
DEEP PETROLEUM EXPLORATION WELLS

Well/Borehole	KB Elev	Walloon Coal Measures		Koukandowie Formation		Gatton Sandstone		Ripley Road Sandstone		Raceview Formation		Laytons Range Conglomerate		Ipswich/Nymboida Coal Measures		Chillingham Volcanics	
		Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness
CLIFDEN-3	35.8	SURF	218.5+	218.5 (-182.7)	349.3	567.8 (-532.0)	608.1	1175.9 (-1140.1)	235.3	1411.2 (-1375.4)	251.2	1662.4 (-1626.6)	47.6	1710.0 (-1674.2)	578.1+		
KYOGLE-1	59.4	129.8 (-70.4)	556.0	685.8 (-626.4)	437.0	1122.8 (-1063.4)	882.8	2005.6 (-1946.2)	124.9	2130.5 (-2071.1)	301.2	NP		NP		2431.7	58.3+
RAPPVILLE-1	78.0	684.6 (-606.6)	366.3	1050.9 (-972.9)	328.6	1379.5 (-1301.5)	749.5	2129.0 (-2051.0)	100.6	2229.6 (-2151.6)	81.4	NP		2311.0 (-2233.0)	20.7+	NR	
SEXTONVILLE-1	104.2	SURF	249.9+	249.9 (-145.7)	340.8	590.7 (-486.5)	549.3	1140.0 (-1035.8)	106.6	1246.6 (-1142.4)	91.5	1338.1 (-1233.9)	207.2	1545.3 (-1441.1)	684.9	NR or NP	
SHANNON-1	120.9	321.6 (-200.7)	425.2	746.8 (-625.9)	337.7	1084.5 (-963.6)	795.5	1880.0 (-1759.1)	124.4	2004.4 (-1883.5)	259.0+	NR or NP		NR			
SWAN CREEK-1	522.7	NP		SURF	292.0+	(292.0)	119.8	NP		NP		NP		NP		(Basement) 350.5 (+172.2)	
TAMROOKUM CREEK-1	90.0	NP		NP		NP		SURF	200.0+	NP		NP		200.0 (-110.0)	581.0	781.0 (-691.0)	1159.0+
TULLYMORGAN-1	247.5	310.9 (+63.4)	366.4	677.3 (-429.8)	421.8	1099.1 (-851.6)	754.1	1853.2 (-1605.7)	152.1	2005.3 (-1757.8)	279.2	NP		2284.5 (-2037.0)	26.5+	NR or NP	

NOTES

The KB (Kelly Bushing) elevation; depth, RKB and relative to sea level (the "relative to sea level depths" are in brackets); and thickness values are all in metres.

NP Not present.

NR Not reported (or not reached).

+ The symbol + after a thickness indicates that the intersection is not complete (the top is probably above the present surface or the base has not been reached).

± Values are approximate.

TABLE 1B
CLARENCE-MORETON BASIN DRILLHOLE INTERSECTIONS FORMATION TOPS
SHALLOW PETROLEUM EXPLORATION WELLS

Well/Borehole	KB Elev	Walloon Coal Measures		Koukandowie Formation		Gatton Sandstone		Ripley Road Sandstone		Raceview Formation		Laytons Range Conglomerate		Ipswich/Nymboida Coal Measures		Chillingham Volcanics	
		Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness
CLIFDEN-1	83.8	SURF	199.6+ (-115.8)	199.6		NR											
CLIFDEN-2	85.0±	SURF	307.0+	307.0± (-222.0±)		NR											
CLIFDEN-4	70.0±	SURF	244.0+	244.0 (-174.0±)		NR											
CLIFDEN-5	60.2	SURF	243.8+	243.8 ? (-183.8 ?)		NR											
CLIFDEN-6	60.4	SURF	366.0+	366.0 ? (-305.6 ?)		NR											
HALFWAY CREEK-1	90.0±	?	?	371.0± (-281.0±)	250.0±	621.0± (-531.0±)											
GRAFTON-2	5.0±	563.0± (-558.0±)	? ?	? ?		? ?	? ?										
HOGARTH-1	103.6	323.6 (-220.0)	423.2	746.8 (-643.5)		1090.5 (-996.9)	NR										
HOGARTH-2	98.2	315.2 (-211.7)	410.2	725.4 (-627.2)		1072.9 (-974.7)	NR										
HOGARTH-3	97.8	316.0± (-218.2)	424.7	740.7 (-642.9)		NR											
HOGARTH-4	276.8	423.1± (-146.3±)	480.6±	903.7± (-626.9)		NR											

NOTES

The KB (Kelly Bushing) elevation; depth, RKB and relative to sea level (the "relative to sea level depths" are in brackets); and thickness values are all in metres.

NP Not present.

NR Not reported (or not reached).

\+ The symbol + after a thickness indicates that the intersection is not complete (the top is probably above the present surface or the base has not been reached).

± Values are approximate.

TABLE 1C
CLARENCE-MORETON BASIN DRILLHOLE INTERSECTIONS FORMATION TOPS
SIGNIFICANT COAL, WATER, STRATIGRAPHIC AND MINERAL BOREHOLES

Well/Borehole	KB Elev	Walloon Coal Measures		Koukandowie Formation		Gatton Sandstone		Ripley Road Sandstone		Raceview Formation		Laytons Range Conglomerate		Ipswich/Nymboida Coal Measures		Chillingham Volcanics	
		Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness
BAC-1	34.2	SURF	220.0+	220.0 (-185.8)		NR											
BAC-2	54.3	40.0 (+14.3)	256.6	296.6 (-242.3)		NR											
BAC-3	53.5	70.7 (-17.2)	240.7	311.4 (-257.9)		NR											
BAC-4	63.4	83.9 (-20.5)	253.6	337.5 (-274.1)		NR											
BAC-5	12.9	96.0 (-83.1)	239.5	335.5 (-322.6)		NR											
BEXHILL-1	2.7	SURF	130.0±	130.0± (-127.3±)		NR											
CHAMBIGNE CREEK-1	28.0	80.0 (-52.0)	105.0±	185.0? (-157.0?)		NR											
CORAKI-1	5.0	SURF	302.0±	302.0± (-297.0±)		NR											
GRAFTON-1	5.0±	567.0? (-562.0?)	149.0?	716.0 (-711.0±)		970.0? (-965.0?)		NR									
MACLEAN-1	24.0	NP		NP		SURF	590.0	590.0 (-566.0)	74.8+								
MOONEM-1	10.0±	20.7 (-10.7±)	282.2?	NR?													
NIMBIN-2	119.0	SURF	145.0+	145.0 (-26.0)	5.0+	NR											
PILLAR VALLEY-1	18.0	180.0 (-162.0)		120.0+	NR												
PILLAR VALLEY-2	38.3	SURF		124.0 (-85.7)	244.0	368.0 (-329.7)	621.0	989.0 (-950.7)	125.0	1114.0 (-1075.5)	254.0	1368.0 (-1329.7)	92.8	1460.8 (-1422.5)			
TABBIMOBLE-2	48.5	18.5 (+30.0)	327.3	345.8 (-297.3)	8.9+	NR											
TABBIMOBLE-3	39.0	SURF	147.2+	147.2 (-108.2)	56.6+	NR											
TABBIMOBLE-4	39.0	SURF	188.6+	188.6 (-149.6)	126.4+	NR											
TYALGUM-1	124.0	SURF	242.0+	242.0 (-118.0)	104.0+	NR											
URBENVILLE-1	385.5	8.7 (+376.8)	371.3	380.0 (+5.5)	204.4+	NR											

Notes

The KB (Kelly Bushing) elevation; depth, RKB and relative to sea level (the "relative to sea level depths" are in brackets) and thickness values are all in metres.

NP Not present.

NR Not reported (or not reached).

+ The symbol + after a thickness indicates that the intersection is not complete (the top is probably above the present surface or the base has not been reached).

± Values are approximate.

Generally, for the purposes of this study, sandstone intervals with a gamma ray value of 60 API units or less have been considered as 'clean' — for reservoir considerations. Beds having a gamma ray value of 120 or more API units have been considered to be shale, claystone or shaly siltstone for source rock considerations.

In determining the thickness of stratigraphic units, generally non-fragmental igneous rocks, ie sills and flows, but not tuffs, have been subtracted from the overall thicknesses. This is because such rocks have not been part of the sedimentary process, although for flows the units may have been intercalated with (strictly) sedimentary layers.

The gamma ray curve only indicates the amount of clay/mud/carbonaceous material originally deposited in a sedimentary interval. Authigenic clays such as illite, smectite, chlorite and kaolin are not usually radioactive and thus do not cause a 'shale' effect on the gamma ray curve. Sandstones containing such clays can thus commonly appear to be 'clean', but are often severely clogged with authigenic clays and commonly cemented with non-radioactive silica and carbonates. These sandstones may have good porosities as determined by sonic or density logs, but with essentially no permeability.

One of the major problems in evaluating reservoirs by wireline logs is in determining beds which have effective porosity, ie beds with sufficient permeability to be considered as reservoirs suitable for testing. Two wireline logs, the spontaneous potential (SP) and the Micr至log, are best as visual indicators of permeability. The SP is only good in this respect when resistivity of the mud filtrate (Rmf) and resistivity of the mud (Rm) are not similar, as may be the situation in the shallower parts of a borehole (eg Walloon Coal Measures). Resistivity logs may show an invasion profile where thick permeable beds have been invaded by mud filtrate, but thin beds (less than one metre) are usually poorly defined. These logs give only visual indications of permeability without providing any quantitative measurements. The quality of these logs depends on certain hole or fluid conditions and can be misleading. Unfortunately, the Microlog is no longer run by logging companies.

MIDDLE TO EARLY LATE TRIASSIC

IPSWICH AND NYMBOIDA COAL MEASURES, AND CHILLINGHAM VOLCANICS

The Ipswich Coal Measures are well known from many drillholes, outcrops and mining operations in the Ipswich area of Queensland where they have been dated as Late Triassic (Karnian) in age. The Nymboida Coal Measures are known from outcrops, drillholes and mining operations only in a small area around Nymboida at the very south end of the Clarence-Moreton Basin. The Nymboida Coal Measures in the Nymboida area have been subjected to higher palaeotemperatures than the Ipswich Coal Measures in the Ipswich area. Vitrinite reflectance values in the Nymboida area, on average, are about 0.95%, whereas at Ipswich they are about 0.7%. The higher palaeotemperatures at Nymboida have rendered the microflora difficult to identify more precisely than Triassic (McElroy, 1962). Identification by Flint and Gould (1975) of megafloras collected in the Nymboida area indicate a closer affinity to megafloras in the Esk and Neara beds of Middle Triassic age in the Esk Trough in Queensland, than to the . In addition, an isolated basalt flow in the lower part of the Nymboida Coal Measures (Bardool Conglomerate) has been dated isotopically as late Middle Triassic in age. If this Middle Triassic age determination is correct, the Ipswich Coal Measures are distinct from and overlie the Nymboida Coal Measures. There still remains, however, the possibility that these two units are equivalent or partly equivalent in age.

In the north-eastern corner of the Clarence-Moreton Basin a thick sequence of rhyolites and tuffs is exposed in the Murwillumbah area. These extrusive rocks are known as the Chillingham Volcanics and are of the order of 1500 m thick. They have been encountered beneath the Ipswich Coal Measures in the Tamrookum Creek-1 well in Queensland where 1159 m were drilled without reaching the base of the unit. Because of their stratigraphic position beneath the Ipswich Coal Measures and their similar lithology to the Brisbane Tuff of known Late Triassic age, the Chillingham Volcanics are believed to be of Late Triassic age.

In the Kyogle-1 well, a section of altered tuff was drilled from 2431.7 m to the total depth of 2472.4 m. This 40.7 m thick unit has been correlated with the Chillingham Volcanics. In the Sextonville-1 well, 18 km to the south-west of Kyogle-1, this volcanic unit is absent. (An interval in the Sextonville-1, 2051.9 m to 2109.2 m, was originally described as a felsic volcanic rock, but was later described as siliceous mudstone.) No other volcanic units similar to the Chillingham Volcanics have been drilled in the remaining wells or drillholes in the New South Wales portions of the Clarence-Moreton Basin.

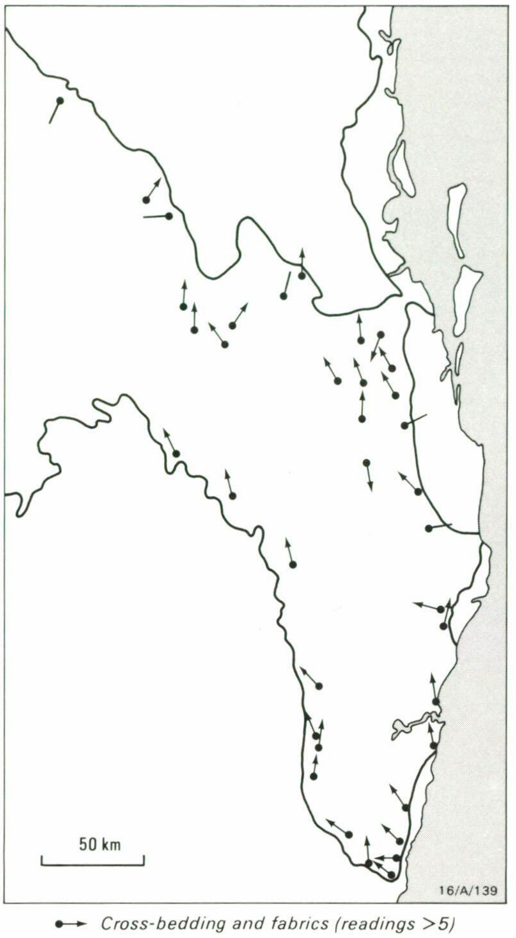
In the Nymboida area, the Copes Creek Keratophyre (tuff) occurs within the Nymboida Coal Measures, at the boundary between the uppermost unit, the Basin Creek Formation, and the underlying Bardool Conglomerate. This tuff is about 30 m thick, with a striking resemblance (McElroy, 1962) to the Brisbane Tuff (cf. the Chillingham Volcanics). If the Copes

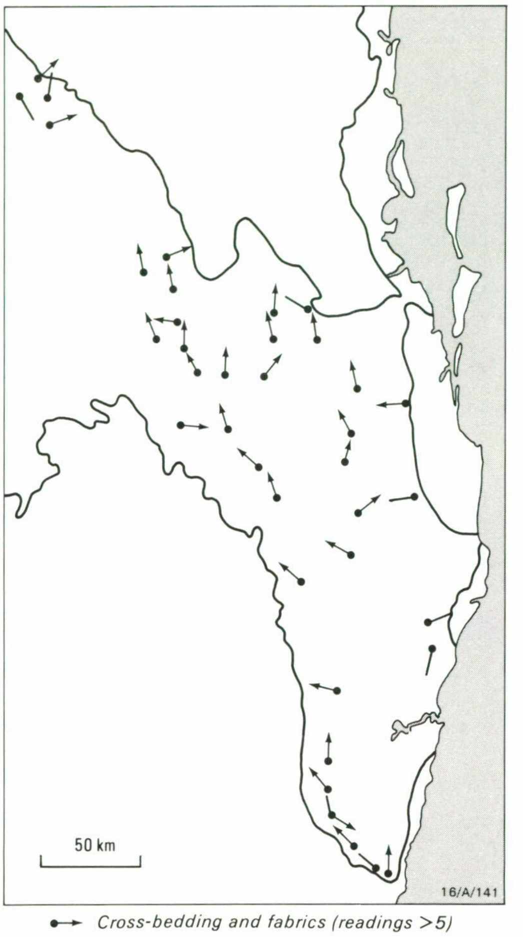
Figure 5. Palaeocurrent directions for Clarence-Moreton Basin units. From left: Aberdare and Laytons Range Conglomerates (equivalents); Ripley Road Sandstone; Gatton Sandstone; to right: Koukandowie Formation.

Creek Keratophyre is the distant correlation of the Chillingham Volcanics then the volcanic units in Kyogle-1 are probably of the same age. This suggests that the Basin Creek Formation, lying above the Copes Creek Keratophyre, is equivalent to the Ipswich Coal Measures and that the sequence beneath the tuff is equivalent to the Esk Trough sequence.

A great amount of uncertainty exists concerning the age of the pre-Bundamba Group sedimentary rocks as encountered in wells in the New South Wales portion of the Clarence-Moreton Basin. In the Clifden-3 well, for example, the section was originally identified as the Nymboida Coal Measures. This was later equated to the Chillingham Volcanics by AGL Petroleum, the tenement holder at the time in 1992. Wells and O'Brien (1994) subsequently assigned this section to the . In the Pillar Valley-2 drillhole, 35 km to the south-west of Clifden-3, the pre-Bundamba Group was identified as the Ipswich Coal Measures (Etheridge et al, 1985). The pre-Bundamba Group section is interpreted from seismic data to thicken from about 500 m at Pillar Valley-2 to about 1300 m to 1400 m in the area south of Grafton. The section is seen to continue southward from Grafton (on seismic line 84-SG5), where it has a very gentle dip and maintains a thickness of greater than 1100 m. The 1000 m of exposed Nymboida Coal Measures at Nymboida are only 20 km south-west of this seismic line and dip to the north-east at about 15°. It is reasonable to assume that the Nymboida Coal Measures at Nymboida are equivalent to the section interpreted on that seismic line. This would mean that the sections in Clifden-3 and Pillar Valley-2 may possibly be equated with the Nymboida Coal Measures, as seen in drillholes and outcrops in the Nymboida area (Figure 6).

In the northern part of the Logan Sub-basin (see later discussion), the pre-Bundamba sequence is seen as three distinct seismic stratigraphic sequences, each bounded by subtle angular unconformities. The upper sequence in that area is probably the Ipswich Coal Measures as seen in the Sextonville-1 well, the middle sequence may correlate with the Chillingham Volcanics, and the lower sequence is most likely the





[caption continued] Reproduced with permission from O'Brien & Wells (figures 2, 32, 59, 85, respectively, from left to right) in Wells & O'Brien (1994), AGSO Bulletin, ***241***.

Nymboida Coal Measures or an Esk Trough equivalent. The section in Sextonville-1, in the interval 2051.9 m to 2230.2 m (TD), has been identified by previous workers as Palaeozoic in age. Seismically, this carbonaceous shale/siltstone/sandstone section appears to be part of the Ipswich/Chillingham/Nymboida sequence and not part of the highly folded (basement) sequence of Permo-Carboniferous sedimentary rocks immediately west of the Clarence-Moreton Basin in the New England area. Vitrinite reflectance values for this section are similar to the overlying. (The interval 2051.9 m to 2109 m was originally described as 'felsic volcanics', but a handwritten note in the well completion report stated that this was later revised to 'siliceous mudstone'.)

The tripartite division of the Ipswich/Chillingham/Nymboida section is not apparent on seismic lines in the Grafton area (Figure 7). There the section appears to be one continuous sequence with a barely discernible unconformity between it and the overlying Bundamba Group.

The combined thickness of the Ipswich/Chillingham/Nymboida sequence is shown, along with the vitrinite reflectance values, in Figure 8. The basinal configuration is much the same as that shown by the overlying Bundamba Group sedimentary sequence. A southern depression, the Grafton Trough, and a northern depression, the Casino Trough, are clearly evident as sites of thicker deposition. There is no evidence of a fault-bounded, rift-type trough similar to the Esk Trough.

Intrusive igneous rocks, except for one localised basalt layer about 15 m thick mentioned above, are not present in the Nymboida Coal Measures in the Nymboida area. In the Clifden-3 well, however, some 58 km to the north, a number of mafic intrusions and other igneous rocks were encountered through the section. These have been interpreted as sills because of their petrographic description and what appear to be coked coals occurring both above and below the igneous rock. These coked coals are marked by very low resistivity spikes on the resistivity log. Additional sills totalling some 70 m occur in the

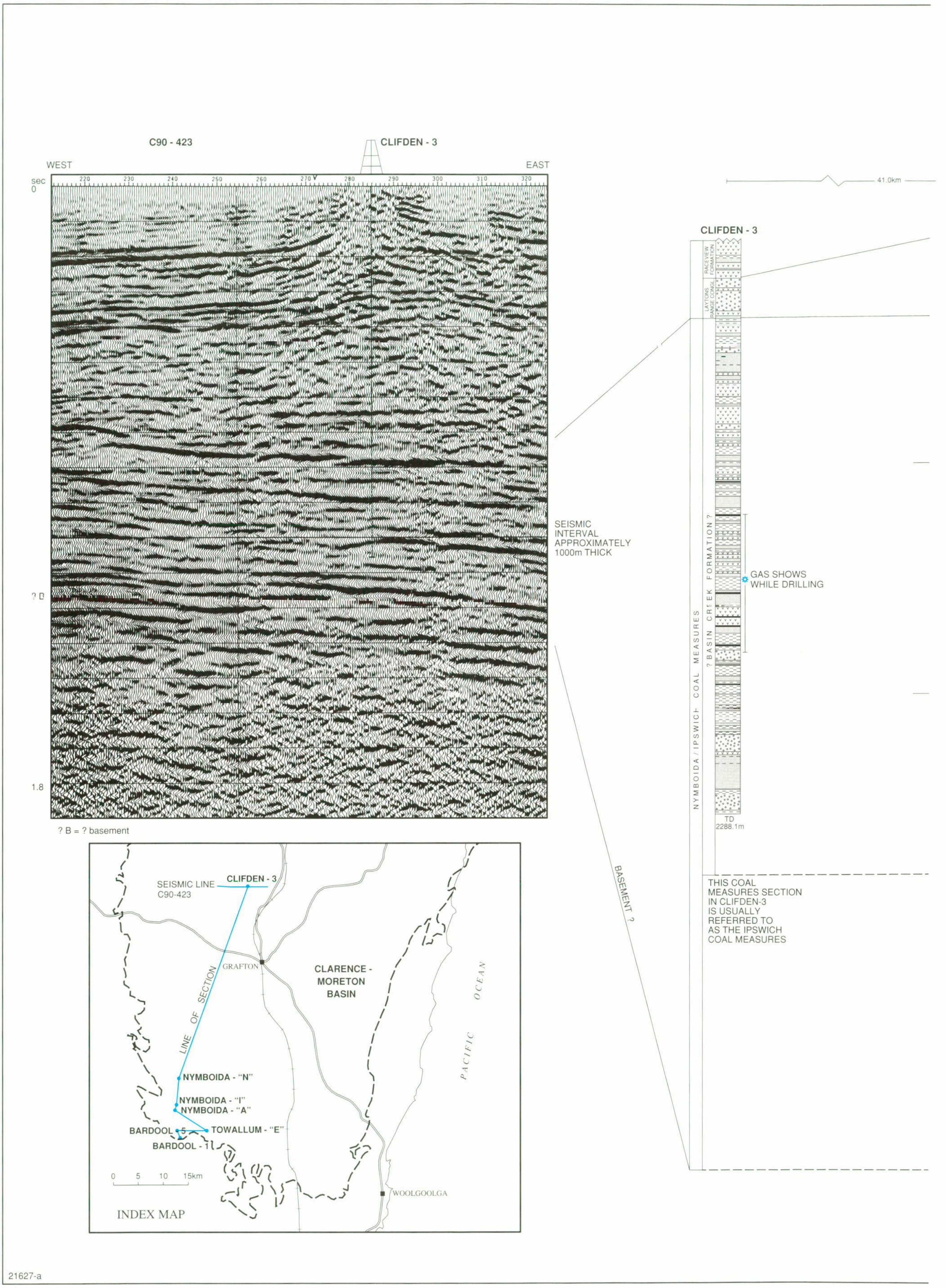
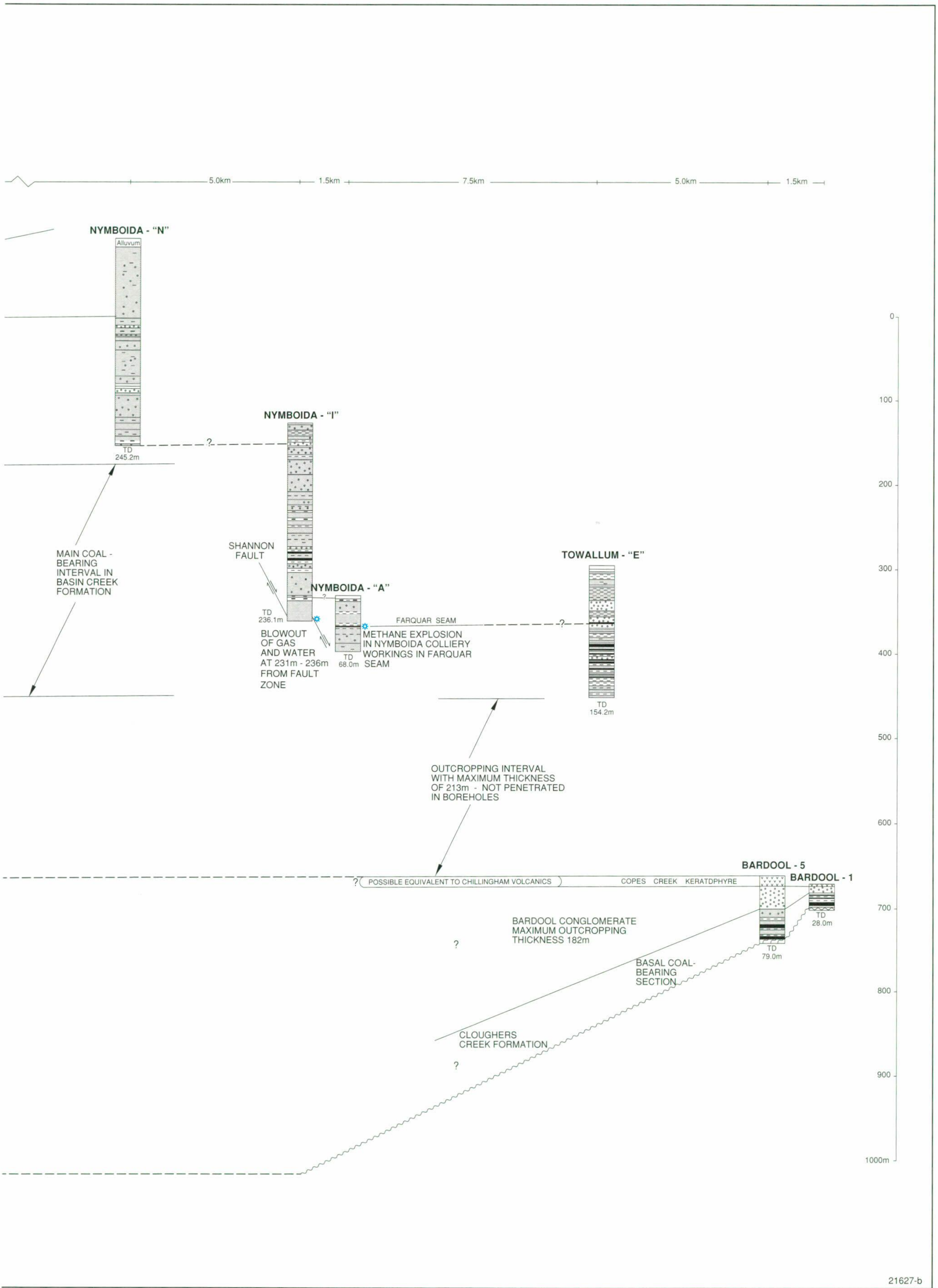


Figure 6. Stratigraphic correlation/reconstruction of the Nymboida Coal Measures in the New South Wales portion of the



Clarence-Moreton Basin.

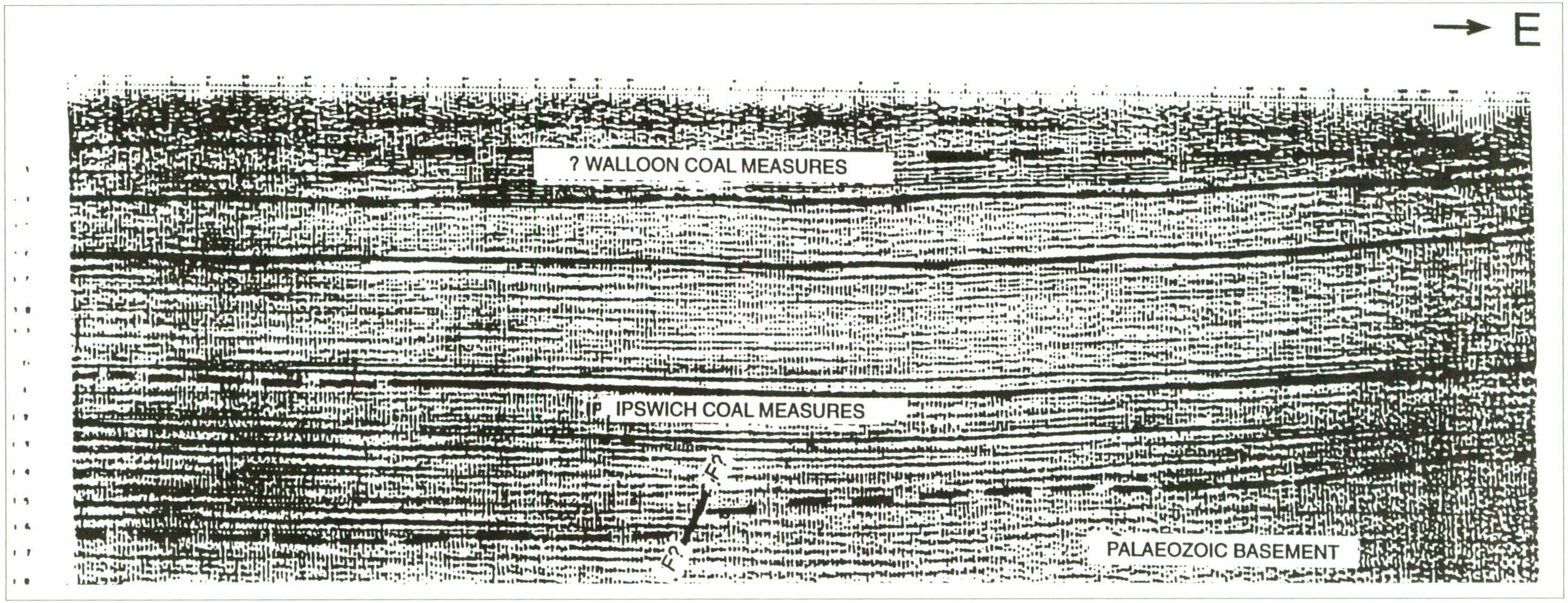


Figure 7. Interpreted seismic line 84 SG-1 west of Pillar Valley-2 and south-east of Grafton. This interpretation shows the apparent conformity between the Bundamba Group and the underlying Ipswich Coal Measures (and Nymboida Coal Measures). (Taken from figure in the Petroleum Data Package for the Clarence-Moreton Basin.)

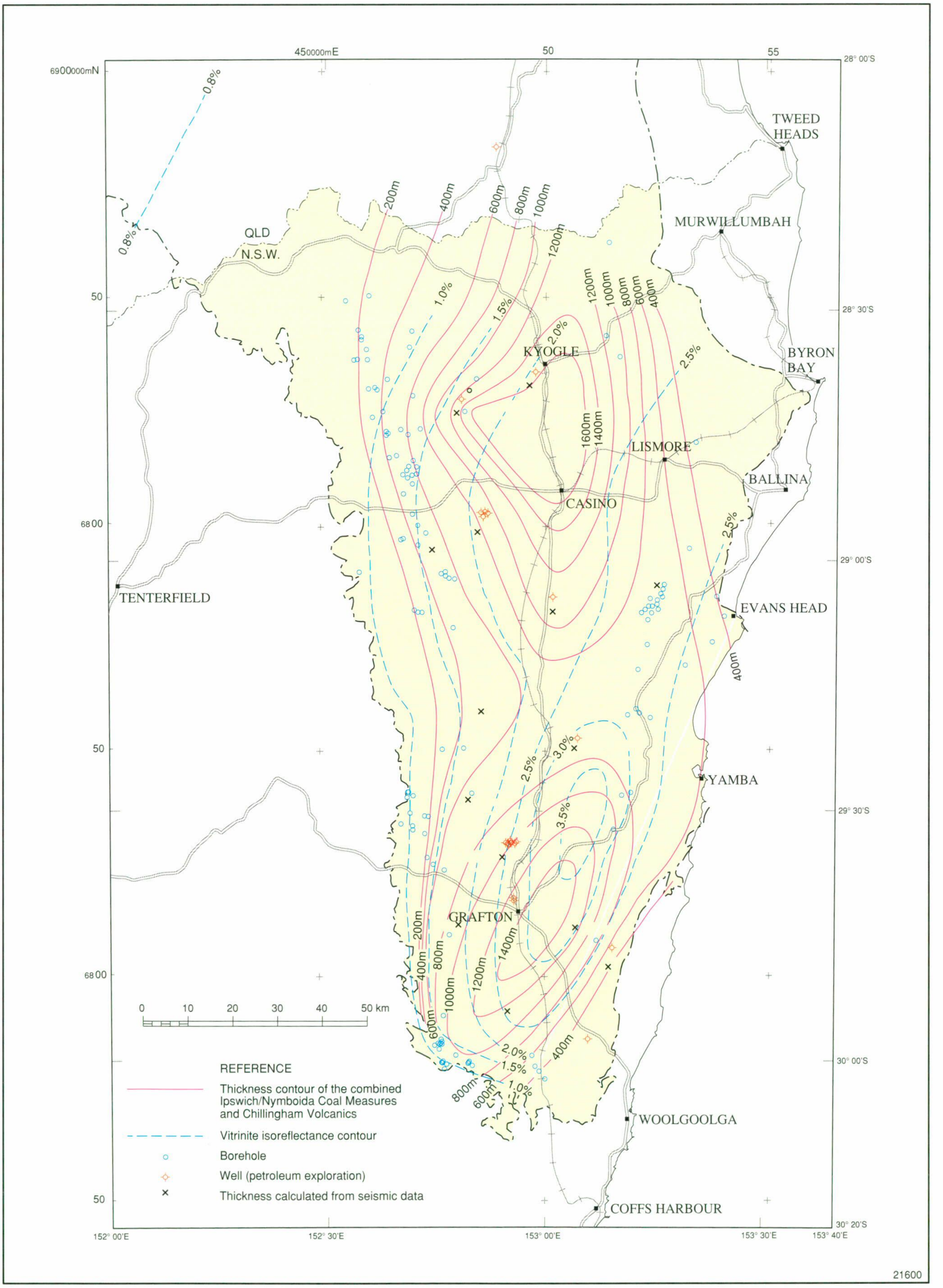


Figure 8. Ipswich Coal Measures and Nymboida Coal Measures, and Chillingham Volcanics, in the Clarence-Moreton Basin in New South Wales, showing combined thickness and vitrinite reflectances.

overlying Laytons Range Conglomerate and Raceview Formation. If these sills are Tertiary in age, as are the surface volcanic rocks, they probably also equate to the dolerite sills in the Walloon Coal Measures that were intersected in Clifden-1, -2, -4, -5 and -6.

The uplift caused by the sills emplaced into the Walloon Coal Measures is easily visible on seismic sections in the Clifden area. No such noticeable uplift, or doming, is evident at the Ipswich/Chillingham/ Nymboida level or above. There is, however, a distinct hinge-like change of dip in the Clifden area from near horizontal in the north-west of the area to a rather steep dip to the south-east, with noticeable thickening of the section below the Ripley Road Sandstone — and this may be associated with sill emplacement. This igneous activity in the Clifden area may be associated with a north-west–south-east lineation and possible strike-slip faulting along the Powapar Fault Zone where the western basin margin is offset and where two dolerite dykes are present at the surface (Figure 9).

LATE TRIASSIC TO MIDDLE JURASSIC

RACEVIEW FORMATION AND LAYTONS RANGE CONGLOMERATE

The Raceview Formation unconformably overlies the Ipswich/Chillingham/Nymboida sequence in the New South Wales portion of the Clarence-Moreton Basin. This regional unconformity is usually marked by some angularity around the flanks of the Basin, but often appears to be conformable on seismic lines in the deeper parts of the Basin. The thickness distribution of the Raceview Formation is shown in Figure 10.

The Raceview Formation consists of thinly interbedded shale, siltstone, sandstone, thin coal beds and minor conglomerate. Rocks of the Formation are generally carbonaceous and argillaceous in the deeper parts of the Grafton and Casino Troughs. The Shannon-1 and Kyogle-1 wells encountered the most argillaceous sections. Kyogle-1 encountered, by far, the greatest amount of coal (9 seams with thicknesses of about 1 m to 3 m each). The grain composition is shown in Figure 11.

On the flanks of the Clarence-Moreton Basin, the Raceview Formation grades laterally into conglomeratic sandstones, and is replaced by a basal conglomerate around the perimeter of the Basin. These coarse clastic units are known as the Laytons Range Conglomerate and represent alluvial fans originating from adjacent basement highlands to the south-east, south and west of the Basin margin. They typically are very poorly sorted with sand/silt/clay matrices and are lacking in any porosity or permeability.

The combined percentage of coal, shale and shaly siltstone, as interpreted from gamma ray logs, is shown in Figure 12. No attempt to map the thickness of the Laytons Range Conglomerate has been made because of the limited data points.

The Raceview Formation was deposited in a mixed fluvial environment. Channel fill sands were deposited on the flanks of the Clarence-Moreton Basin. Crevasse splay, overbank and accreting sand bodies were deposited in intermediate areas while fine-grained, floodplain, swamp and lacustrine deposits accumulated in the most basinal positions. The Kyogle-1 well penetrated the thickest and most basinal section, the thickness in that well being 301.2 m, with the shale/argillaceous siltstone/coal fraction constituting 35% of the total thickness. The Raceview Formation section in Kyogle-1 has a general coal measure appearance, and was originally incorrectly identified as the

No drillholes or wells in New South Wales have been drilled to a depth great enough to encounter the Raceview Formation in the Warrill Creek Syncline west of the West Ipswich Fault (Figure 9). It is present in the Warrill Creek Syncline further north in Queensland, where it may be up to 176 m thick.

RIPLEY ROAD SANDSTONE

The Ripley Road Sandstone in the Clarence-Moreton Basin consists mainly of quartz-dominated, fine- to -medium-grained sandstone and conglomeratic sandstone. Lithic fragments are substantially subordinate to quartz, unlike any of the other more lithic sandstones in the Basin (Figure 11). Some clay, probably authigenic in origin as it lacks much expression on the gamma ray curves, is present, along with variable amounts of quartz and calcite cement. The unit crops out along the eastern margin of the Basin, but is not present in outcrop along the southern or western margin of the Basin because of overlap by the Gatton Sandstone. Large-scale cross-bedding is a common feature of the Ripley Road Sandstone when exposed at outcrop.

The Ripley Road Sandstone is overlain conformably by the Calamia Member of the Gatton Sandstone (Figure 13) in the Clarence-Moreton Basin (New South Wales portion). This Member is markedly shaly and forms a regional seal over the Ripley Road Sandstone. The Ripley Road Sandstone conformably overlies the impermeable shaly beds of the Raceview Formation or its updip lateral equivalent, the impermeable Laytons Range Conglomerate. This updip pinchout of the Ripley Road Sandstone presents a possible stratigraphic trap play, 100 km in

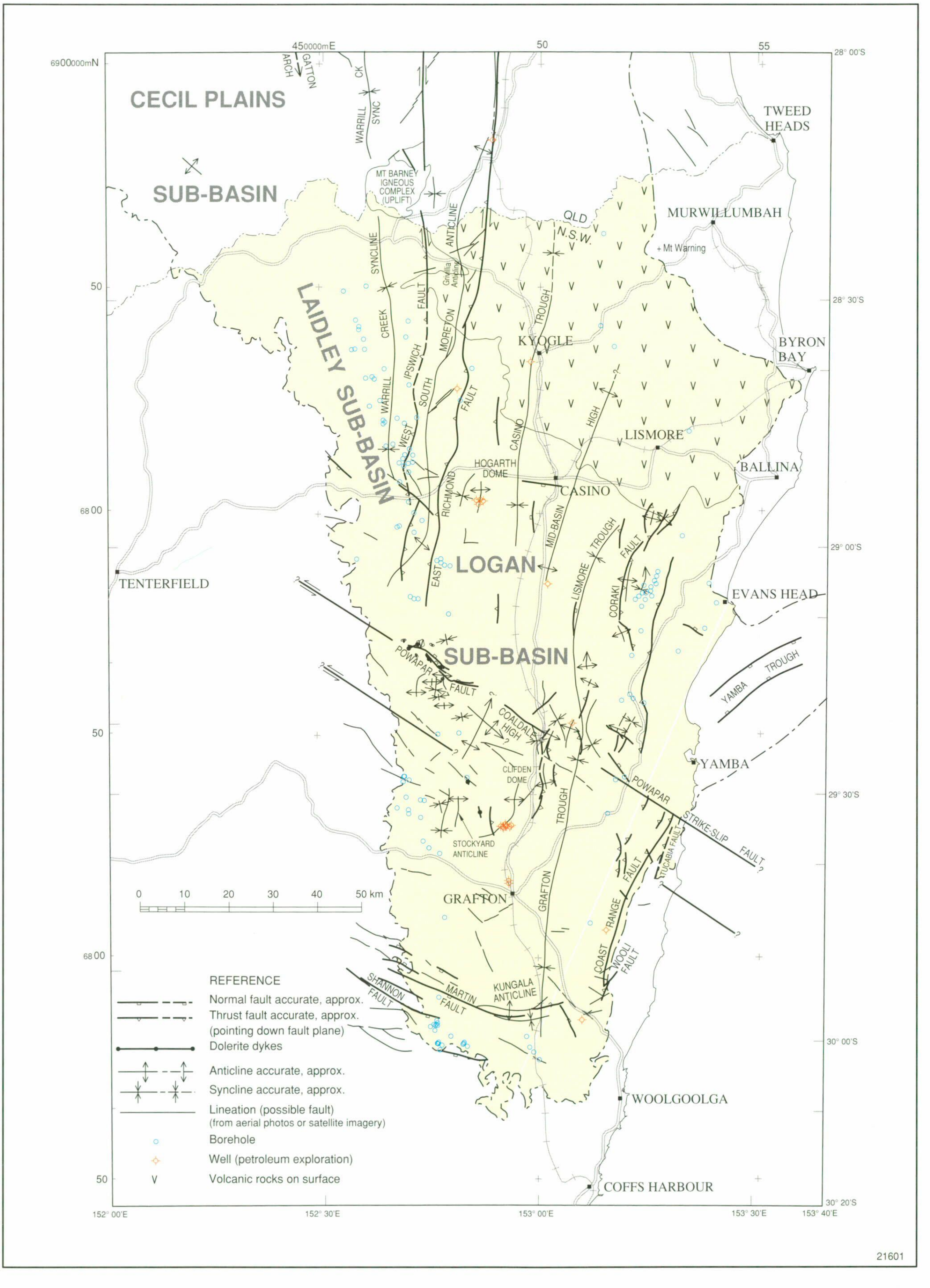


Figure 9. Structural framework of the Clarence-Moreton Basin in New South Wales.

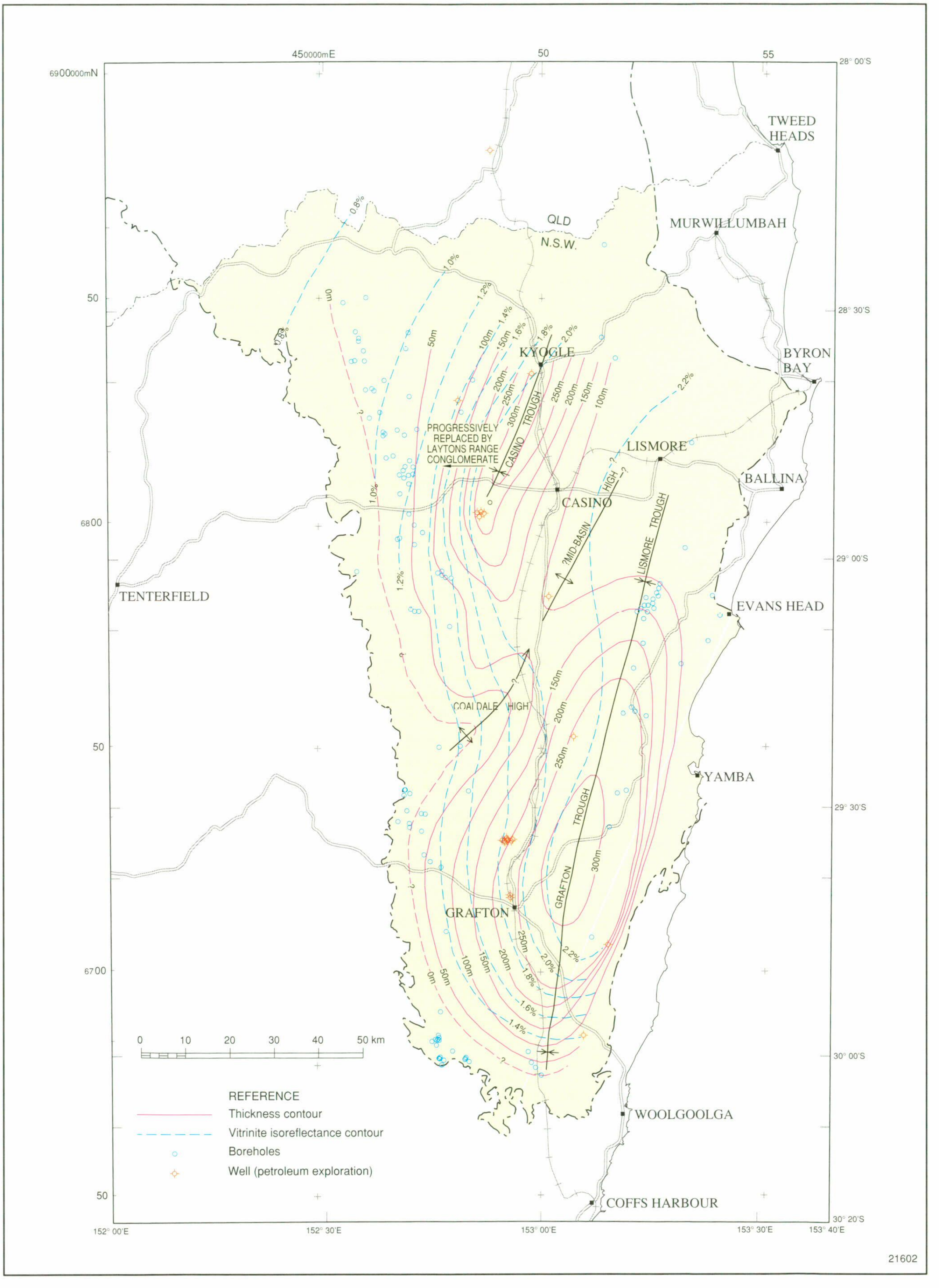


Figure 10. Thickness of the Raceview Formation in the Clarence-Moreton Basin in New South Wales, with vitrinite reflectance also shown.

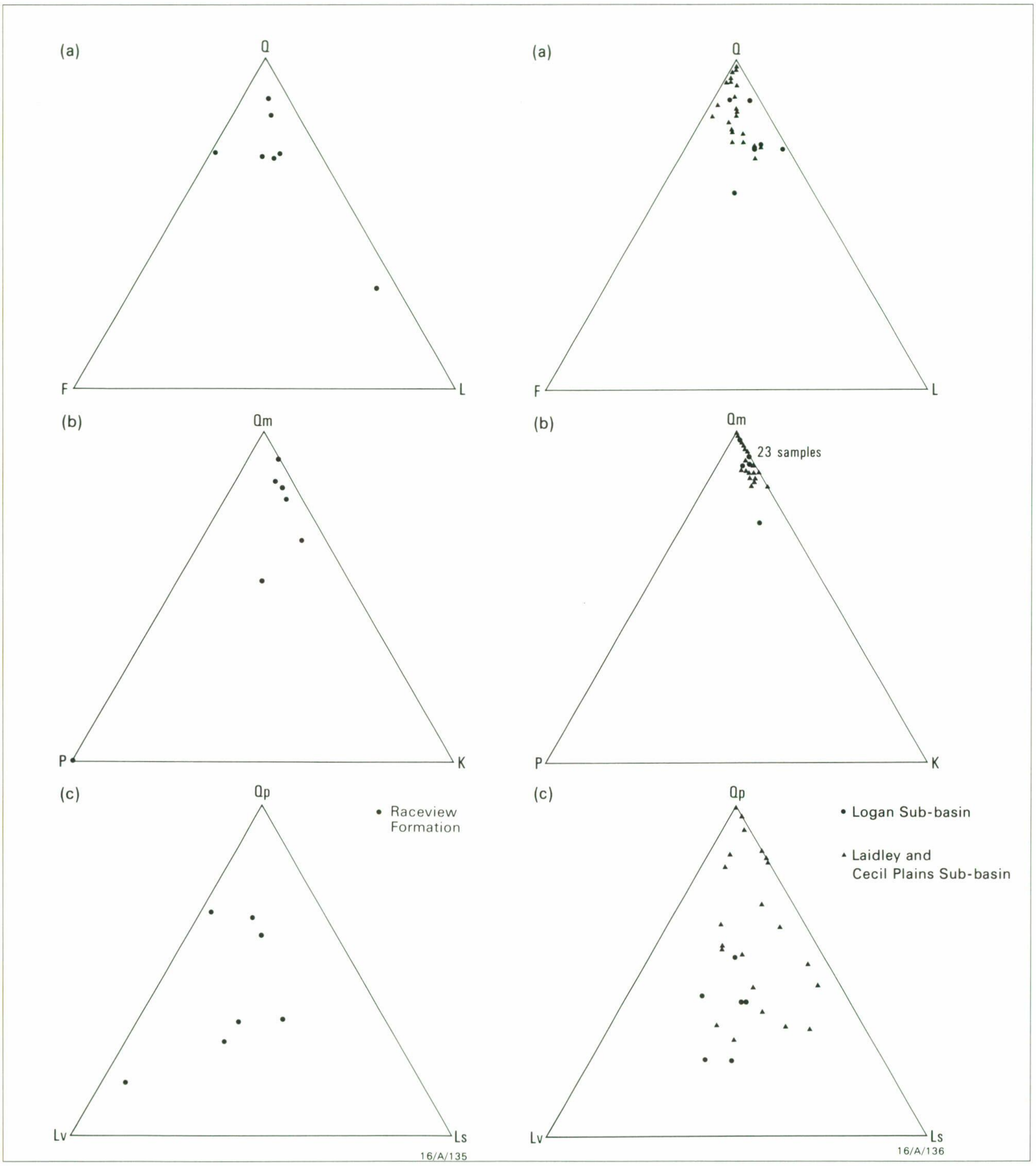


Figure 11. Left-hand side: Composition of Raceview Formation sandstone. Right-hand side: Composition of the Ripley Road Sandstone. In upper plots Q — monocrystalline and polycrystalline quartzose fragments, F — monocrystalline feldspar grains, L — unstable lithic grains. In middle plots Qm — monocrystalline quartz, P — plagioclase, K — K-feldspar. In lower plots Qp — polycrystalline quartz, Lv — volcanic and metavolcanic grains, Ls — sedimentary and metasedimentary grains. Reproduced with permission from O'Brien & Wells (figures 21 [left] and 31 [right] after others) in Wells & O'Brien (1994), AGSO Bulletin ***241****.*

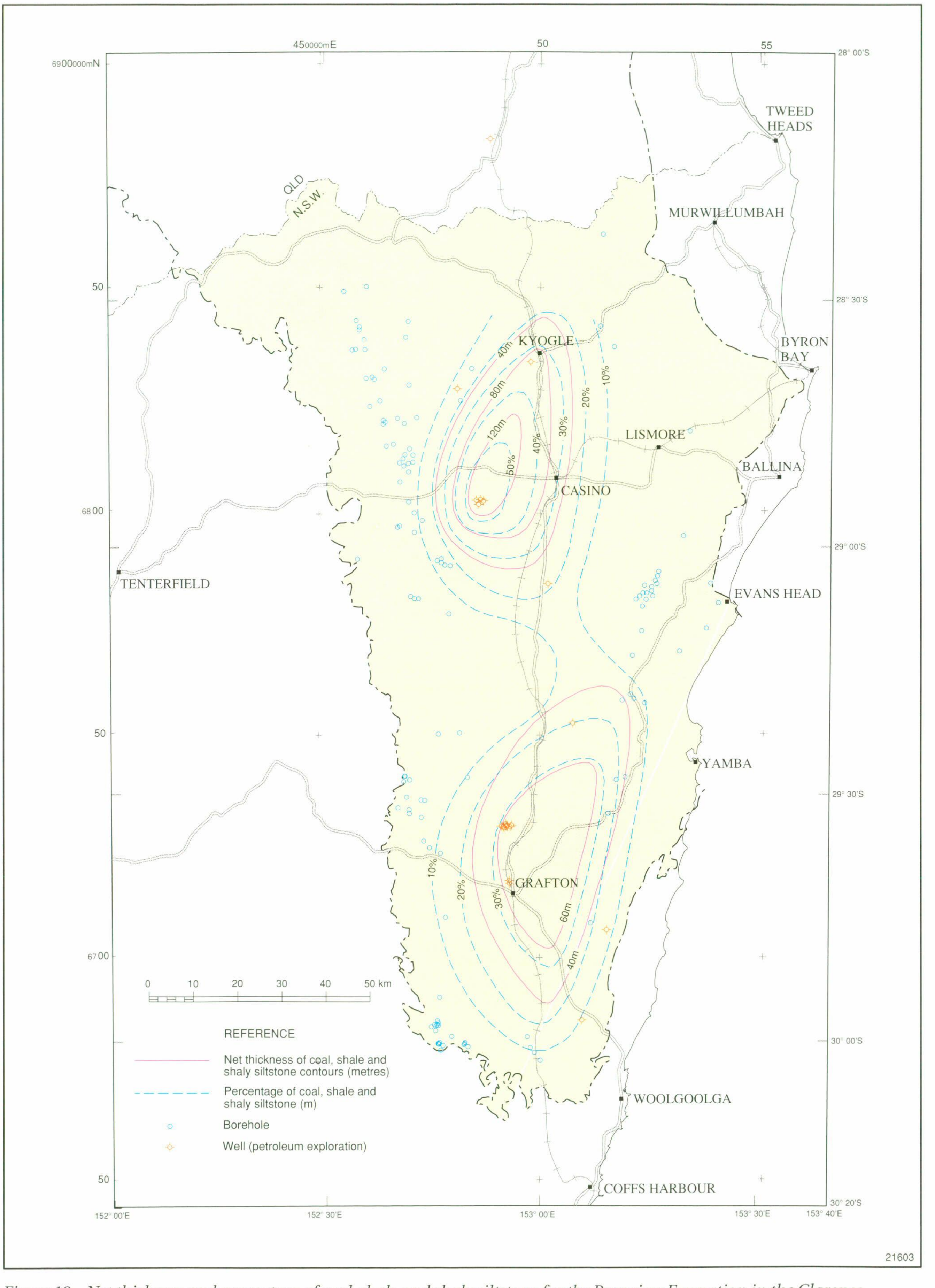


Figure 12. Net thickness and percentage of coal, shale and shaly siltstone for the Raceview Formation in the Clarence-Moreton Basin in New South Wales.

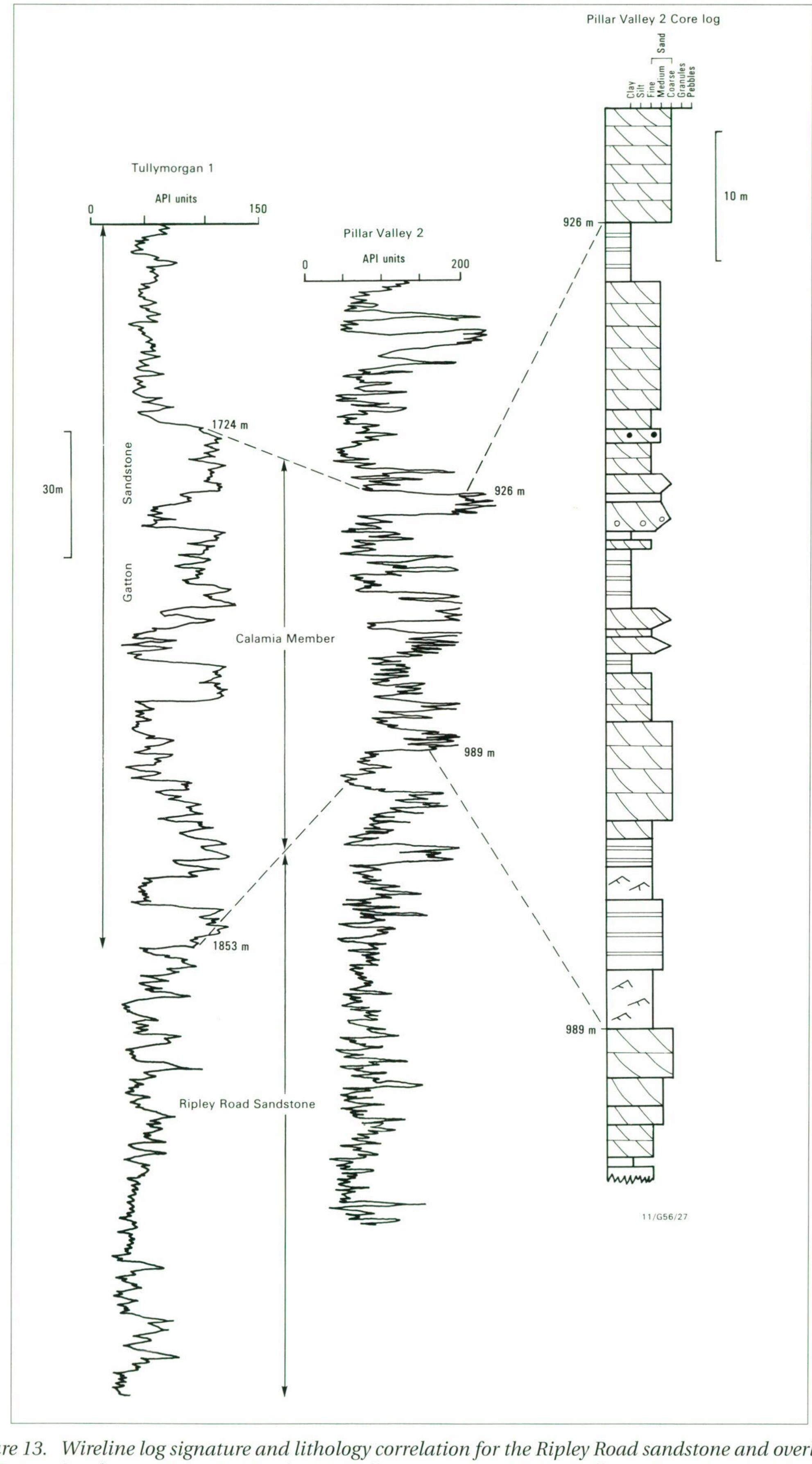


*Figure 13. Wireline log signature and lithology correlation for the Ripley Road sandstone and overlying Gatton Sandstone (Calamia Member) in Tullymorgan-1 and Pillar Valley-2. Reproduced with permission from O'Brien & Wells (figure 56) in Wells & O'Brien (1994), AGSO Bulletin **241**.*

length, along the southern and south-western margins of the Basin. Because of the lack of seismic data in this area, the pinchout edge has not been defined to date.

The Ripley Road Sandstone is thickest in the two main basinal areas of the Grafton and Casino Troughs (Figure 9), reaching its maximum thickness of 235.3 m in the Clifden-3 well. The percentage of 'clean' sands increases in a north-easterly direction, reaching a maximum in the Sextonville-1 and Kyogle-1 wells of 88.3% and 79.8%, respectively (Figure 14).

Most of the sandstones in the Ripley Road Sandstone are coarse- to medium-grained with large-scale, planar cross-bedding. These are commonly associated with irregular sheets and lenses of massive, coarse-grained sandstones and granule conglomerates (Willis, 1994). The environment was probably one of mature topography, slow subsidence, rapid avulsion of streams, and with deposition occurring as bars and channel fills. Rapid channel migration in relation to the slow subsidence favoured the winnowing (out) of clay and fine detrital material, resulting in reasonably clean quartz-rich sands.

GATTON SANDSTONE

The Gatton Sandstone is the most widespread unit in the Clarence-Moreton Basin. It overlaps the Ripley Road Sandstone, the Raceview Formation and the Laytons Range Conglomerate to various degrees. It may extend over older units in the west to rest on basement rocks. In the central parts of the Basin it conformably overlies the Ripley Road Sandstone.

The Gatton Sandstone consists predominantly of thick-bedded, medium- to coarse-grained quartz–lithic and feldspathic sandstone (Figure 15). Pebble conglomerates and shales are common, but are subordinate to the sandstones. The sandstones were deposited as stacked channel sands in streams having low sinuosity and high avulsion rates. Calcareous cement is common.

At the base of the Gatton Sandstone there is a unit of thinly bedded claystone, siltstone and sandstone, which is known as the Calamia Member (Figure 13). It is generally only a few tens of metres thick, but is probably thick enough to act as a seal over reservoir in the Ripley Road Sandstone.

The Gatton Sandstone, because of its apparent lack of permeable reservoir, is not considered a primary exploration target, nor does it appear to have much potential as a source rock (cf. Figure 16). For this reason, no maps illustrating the thickness, maturation, reservoir or source rock aspects of the unit have been prepared for this *Bulletin*. It should, however, be considered as a secondary target because secondary porosity could be developed under favourable conditions.

KOUKANDOWIE FORMATION

The Koukandowie Formation is the major objective for oil and gas deposits in the Clarence-Moreton Basin (New South Wales portion) as it contains both source and reservoir rocks. The gross thickness and percentage of coal/shale/shaly siltstone values are shown in Figure 17, the net thickness and percentage of 'clean' sands are shown in Figure 18, and the percentage of coal/coaly shale and vitrinite reflectance values are shown in Figure 19. The grain composition is shown in Figure 15.

The Koukandowie Formation is subdivided into three parts. At the base is the Ma Ma Creek Member (Figure 16), with the Heifer Creek Sandstone Member overlying that, and occupying approximately the lower half of the formation.

The Ma Ma Creek Member overlies the well-cemented quartz–lithic and feldspathic sandstones of the Gatton Sandstone. That Member consists of thinly interbedded siltstones, claystones and fine-grained sandstones, generally 10 m to 20 m thick, and probably forms an effective seal over any reservoir of the Gatton Sandstone.

The Ma Ma Creek/Gatton Sandstone boundary is one of the most distinctive boundaries on sonic logs in the Clarence-Moreton Basin (Figure 16). The high interval transit times (seismic surveying or sonic velocity logging) of the Koukandowie Formation are in sharp contrast to the lower interval transit times of the Gatton Sandstone. It can be mapped seismically over most of the Clarence-Moreton Basin. The boundary is also well marked by higher resistivity and higher density in the Gatton Sandstone compared to the Koukandowie Formation.

The Heifer Creek Sandstone Member, consisting of interbedded sandstone, siltstone and shale with minor coal (except in Kyogle-1, where numerous coal seams are present) is the main drilling objective for oil and gas in the Clarence-Moreton Basin in New South Wales. The sandstones become increasingly cleaner upward, with the best-developed sandstones being in the top 70 m to 80 m (Figure 20). The sands were deposited mainly as channel fills and commonly have well-developed planar cross-bedding. Some upwardly fining units near the top of the Member have characteristics typical of point bar sands. The sandstones are quartzose, fine- to coarse-grained, thin- to very thick-bedded with variable amounts of lithic grains, clay and calcareous cement. The shales and siltstones are typically carbonaceous. The percentage of 'clean' sandstones and the gross

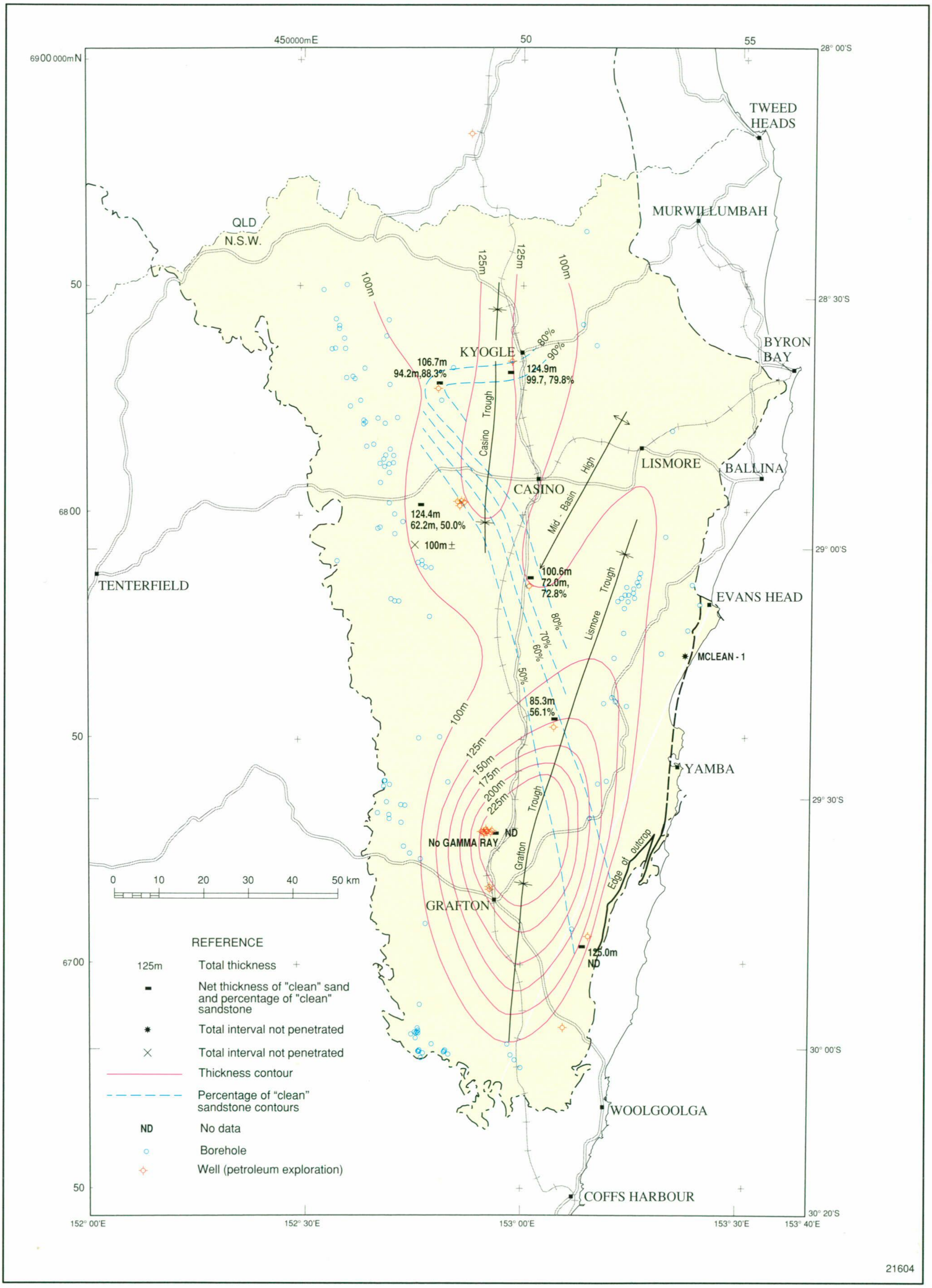


Figure 14. Thickness and percentage of 'clean' sandstones for the Ripley Road Sandstone in the Clarence-Moreton Basin in New South Wales.

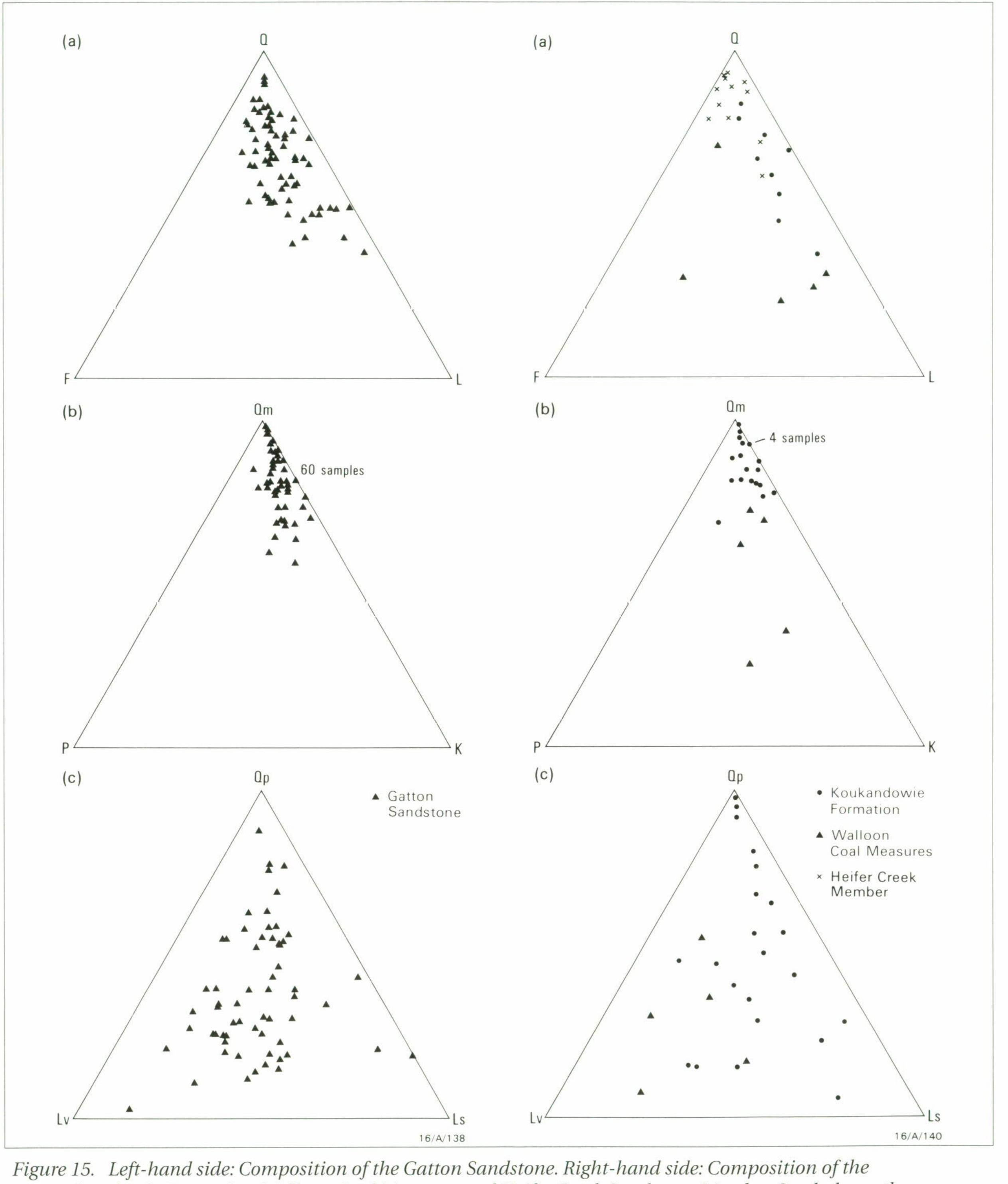


*Figure 15. Left-hand side: Composition of the Gatton Sandstone. Right-hand side: Composition of the Koukandowie Formation, Walloon Coal Measures and Heifer Creek Sandstone Member. Symbols are the same as in Figure 11. Reproduced with permission from O'Brien and Wells (figures 58 and 84) in Wells & O'Brien (1994), AGSO Bulletin **241**.*

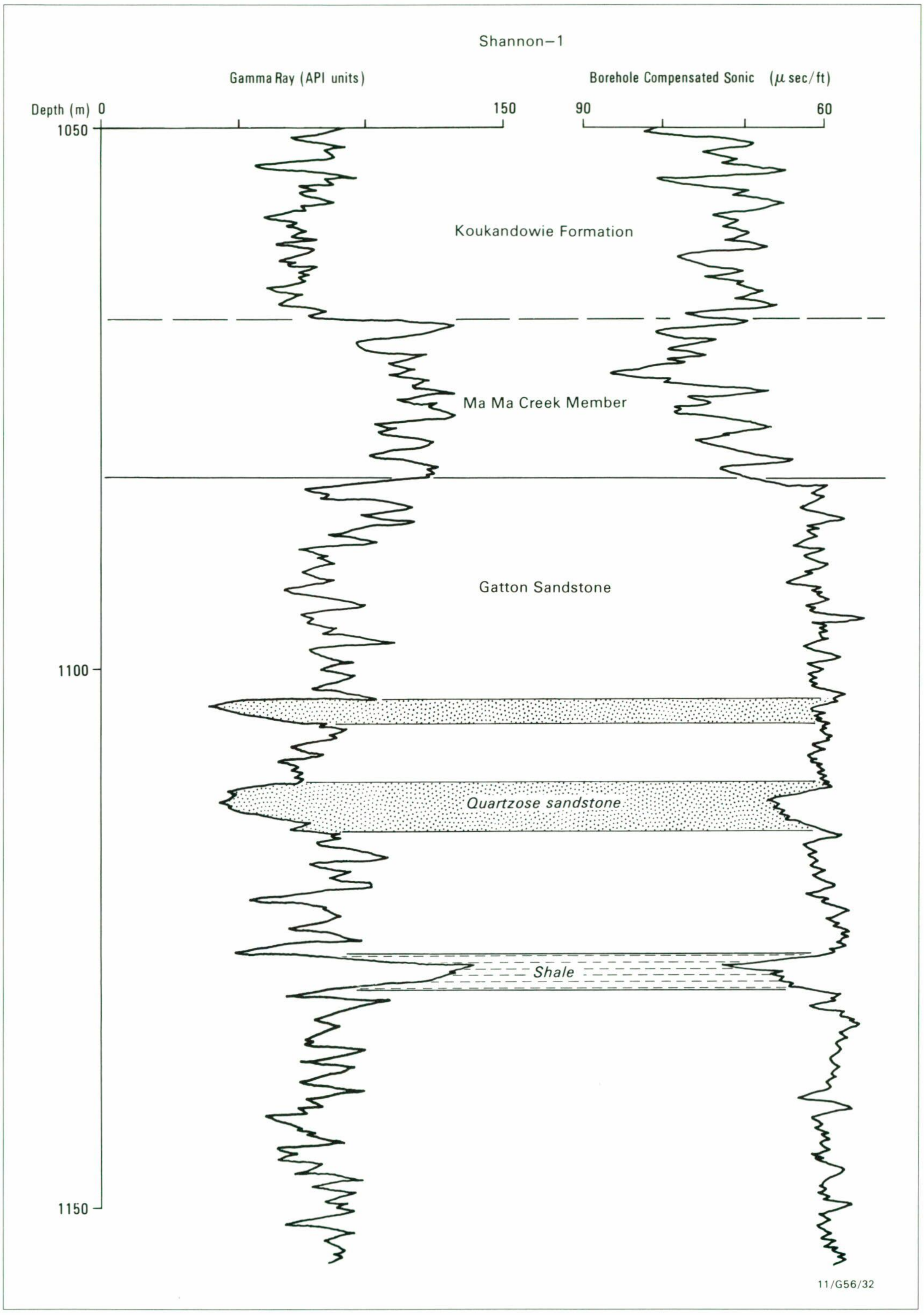


Figure 16. Gamma and sonic logs for the upper Gatton Sandstone, Ma Ma Creek Member and the lower part of the Koukandowie Formation in Shannon-1. The upper part of the Gatton Sandstone contains mudstone beds and quartzose sandstone beds with high gamma and low velocity signatures with lower gamma readings than the typical labile Gatton Sandstone. The change to the Ma Ma Creek Member is marked by a rise in gamma values and a reduction in sonic velocities, indicating a rapid change from sandy to muddy sedimentation environments. Above the Ma Ma Creek Member, sandstone is the main constituent of the Koukandowie Formation. Reproduced with permission from O'Brien & Wells (figure 62) in Wells & O'Brien (1994), AGSO Bulletin ***241****.*

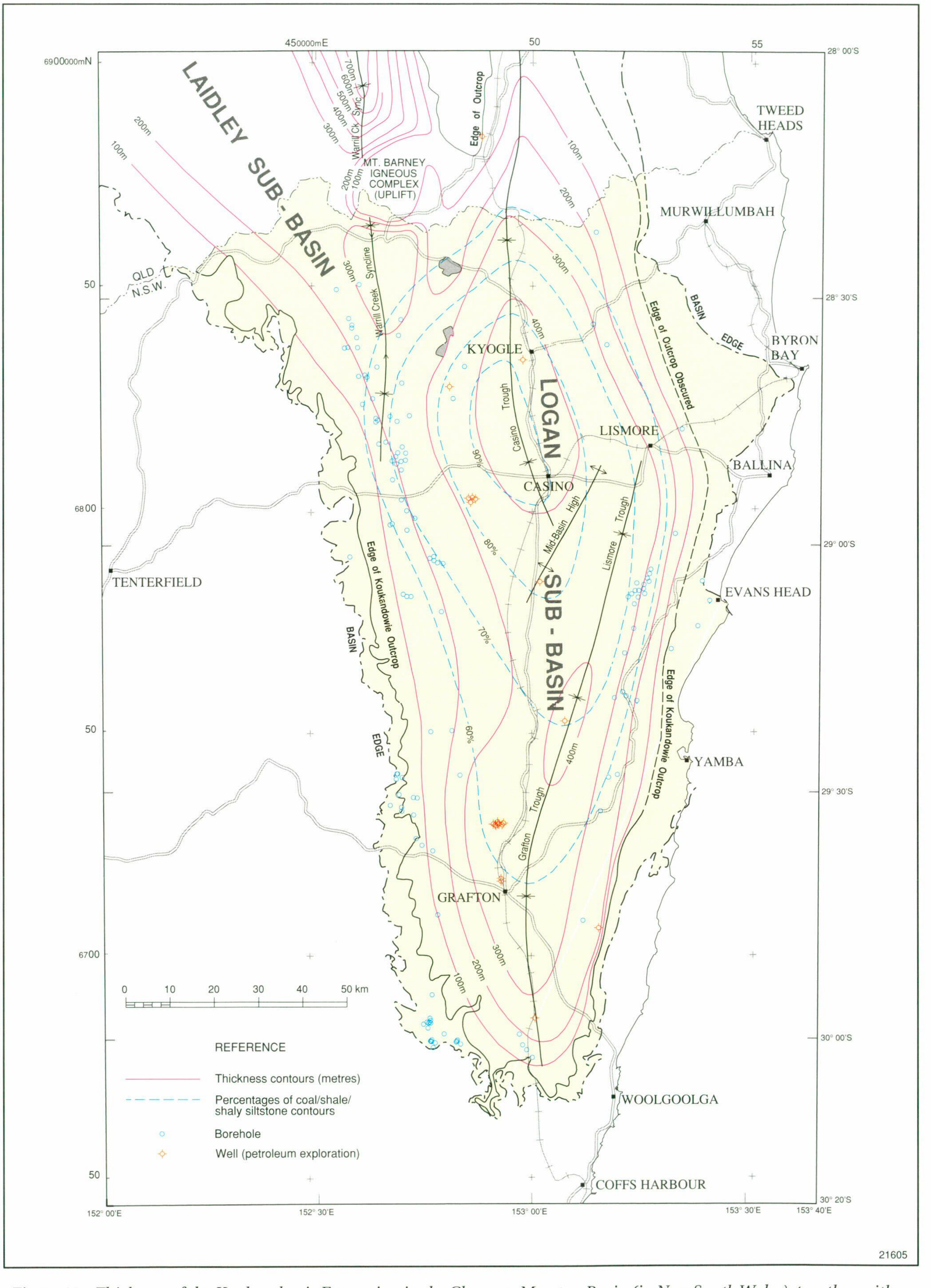


Figure 17. Thickness of the Koukandowie Formation in the Clarence-Moreton Basin (in New South Wales), together with the proportion of coal, shale and shaly siltstone.

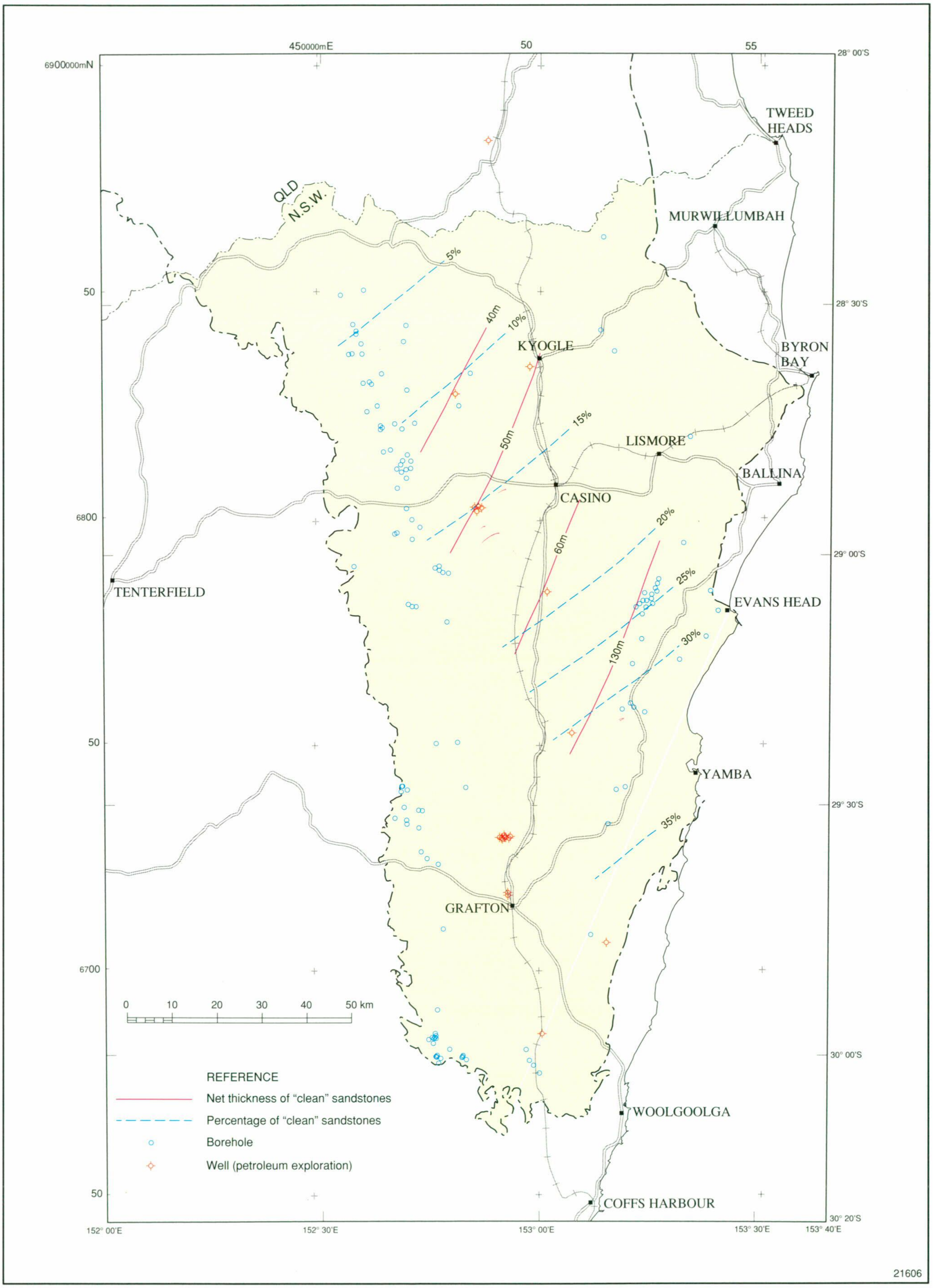


Figure 18. Net thickness of 'clean' sandstones in the Koukandowie Formation in the Clarence-Moreton Basin, New South Wales, together with the percentage of 'clean' sandstones.

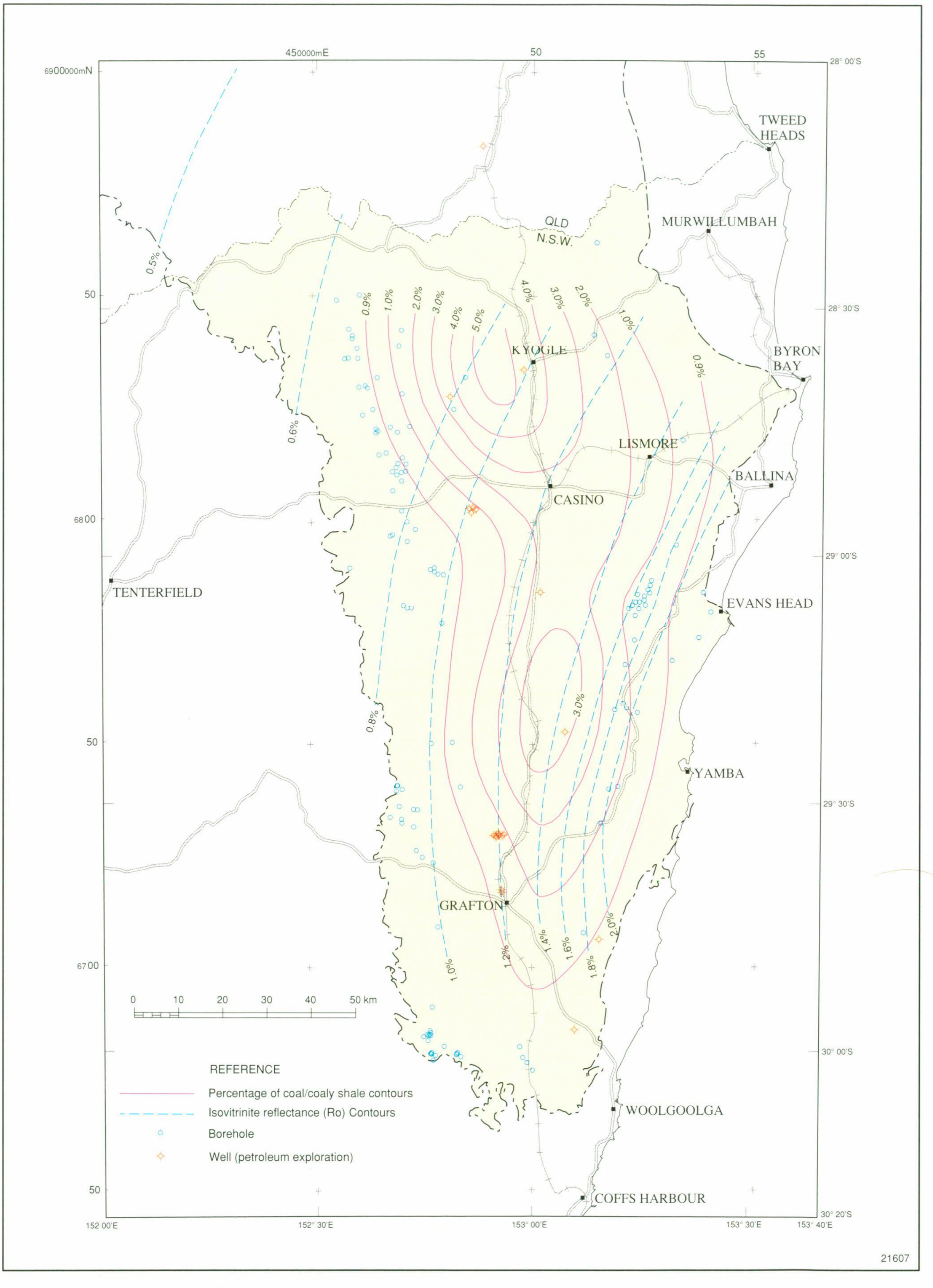


Figure 19. Percentage of coal/shale/shaly siltstone in the Koukandowie Formation in the Clarence-Moreton Basin, New South Wales, together with vitrinite reflectance.

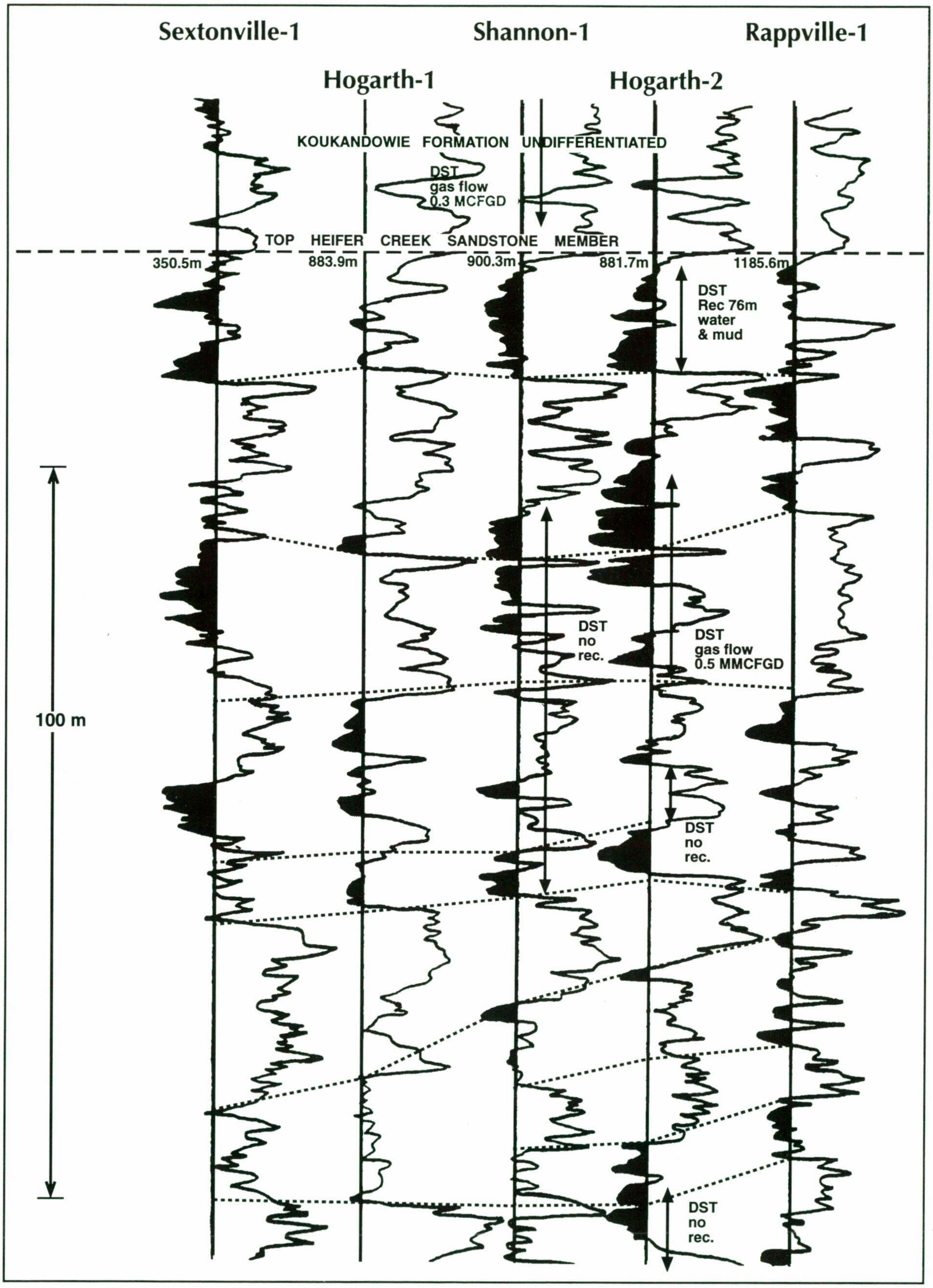


Figure 20. Gamma ray curve correlations for the Heifer Creek Sandstone Member of the Koukandowie Formation in the Clarence-Moreton Basin. Also shown is a comparison of 'clean' sandstone content (shaded), using 60 API units (vertical lines) as the higher cut-off limit. Depths are in metres.

thickness of the Heifer Creek Sandstone Member, are shown in Figure 21. The thickest development of the Member is in the Sextonville-1 well, apparently reflecting a more basin margin position where the Member constitutes almost the entire Koukandowie Formation.

The upper part of the Koukandowie Formation in the Clarence-Moreton Basin is an undifferentiated sequence of interbedded argillaceous lithic sandstones, carbonaceous siltstones and shales. This part of the Formation is essentially devoid of reservoir quality sandstones, and is more important as a source rock and seal over the Heifer Creek Sandstone Member.

WALLOON COAL MEASURES

The Walloon Coal Measures crop out over large areas around the perimeter of the Clarence-Moreton Basin in New South Wales. The unit originally extended over a much broader area, especially in the east, but uplift and erosion have greatly reduced its extent. The Walloon Coal Measures are distinguished by numerous coal seams, and by the volcaniclastic, lithic and silty nature of the sandstones with interbedded claystones and siltstones. A feldspathic sandstone unit, the Maclean Sandstone Member, is present at the top of the coal measures. The sandstones throughout the Walloon Coal Measures have a high clay content, mainly kaolinite, but commonly with montmorillonite and chlorite, and are generally calcareous. Carbonaceous material, in addition to coal, is common in all lithologies.

The thickness distribution of the Walloon Coal Measures is shown in Figure 22. The thickest complete section encountered to date is 499.3 m in the Kyogle-1 well. The thinnest complete section is in the Chambigne Creek-1 borehole, where 105 metres were drilled. The net thickness of coal (including coaly shale) encountered in wells and drillholes is shown in Figure 23. The greatest amount of coal/coaly shale found in complete sections to date was 116.1 m in Kyogle-1, whereas the least amount was about 1 metre in the Tabbimoble drillholes.

The depositional environment for the Walloon Coal Measures in the Clarence-Moreton Basin was one of sluggish streams meandering across a wide floodplain. Volcanic ash falls were a common event, clogging the drainage system. Floodplains and swamps were most prevalent in the Casino Trough area. Avulsion rates were high, resulting in coal seams that are very discontinuous. In the peripheral area of the Basin, channel sand deposition was more common and swamp deposition less common.

The boundary between the Walloon Coal Measures and the underlying Koukandowie Formation is difficult, if not impossible, to pick on wireline geophysical logs. The distinction is best made on lithological grounds — ie where the fine-grained volcanolithic sandstones above change to more quartzose, coarse-grained, commonly pebbly sandstones below.

Igneous sills are often encountered in the Walloon Coal Measures in the New South Wales portion of the Clarence-Moreton Basin. These igneous intrusions may have caused bulging of the overlying sedimentary section, giving rise to, or being instrumental in, the formation of structures — such as the Clifden and Hogarth Domes.

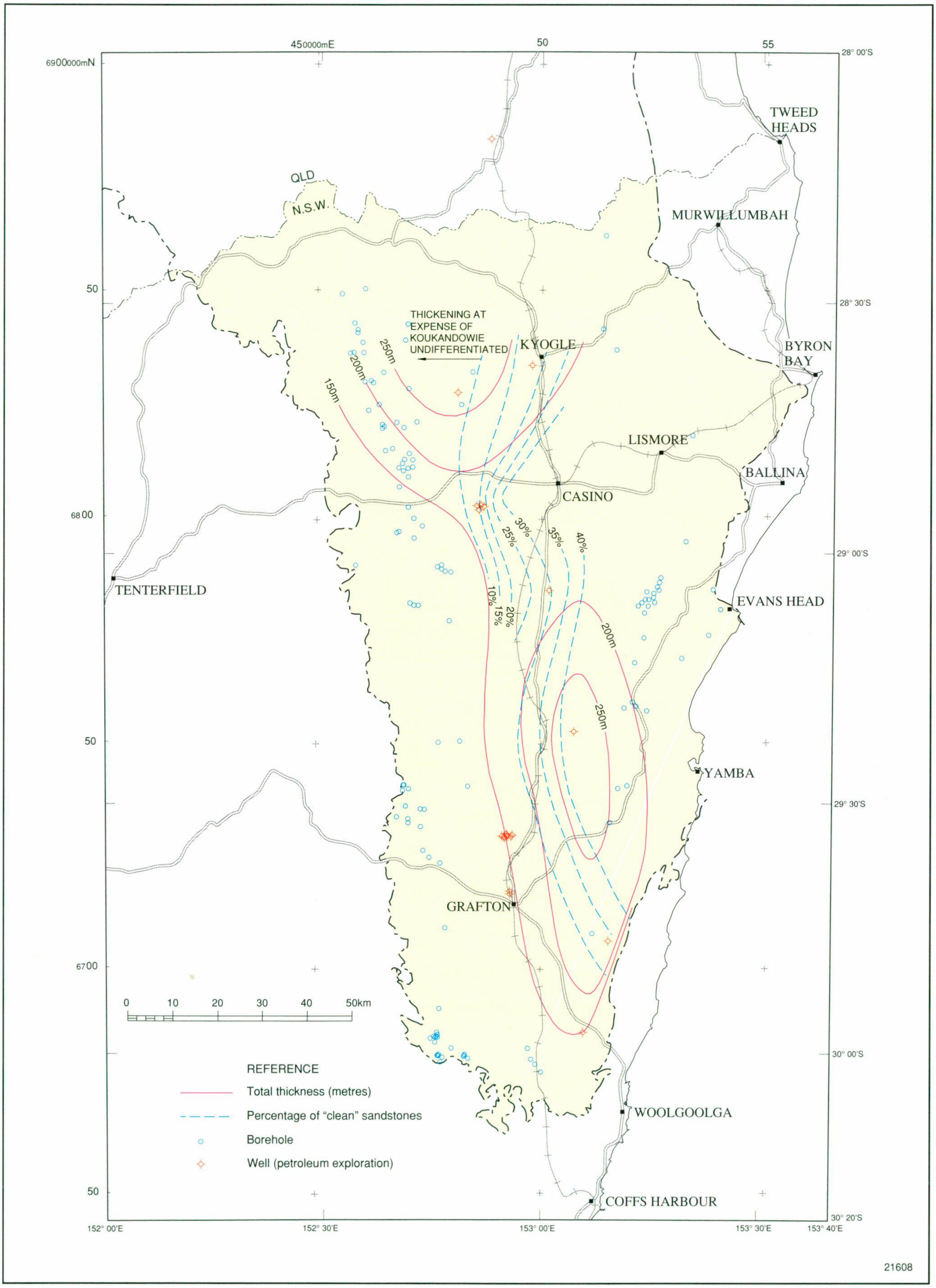


Figure 21. Thickness and percentage of 'clean' sandstones in the Heifer Creek Sandstone Member (Koukandowie Formation) in the Clarence-Moreton Basin in New South Wales.

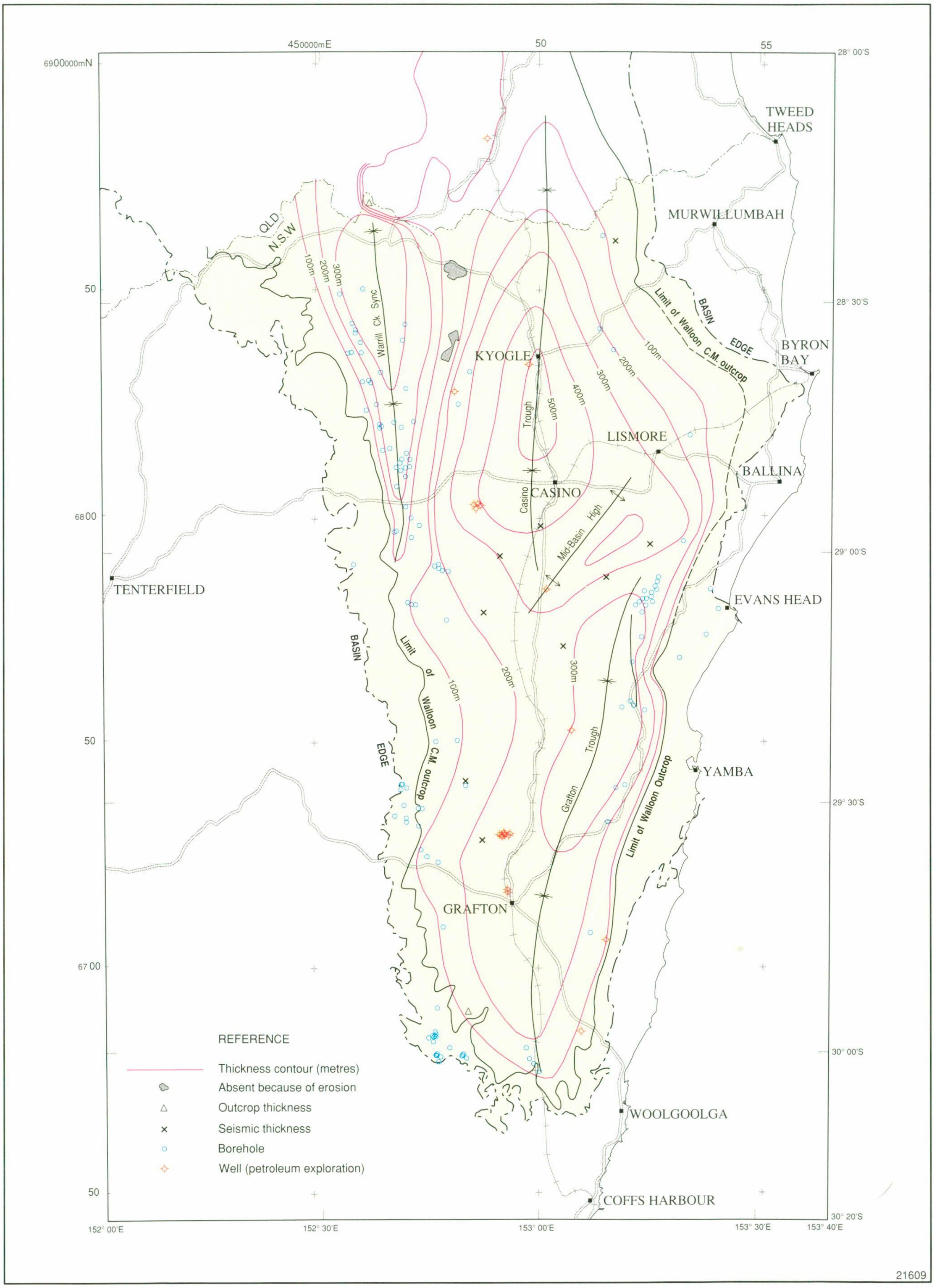


Figure 22. Thickness of Walloon Coal Measures in the Clarence-Moreton Basin in New South Wales.

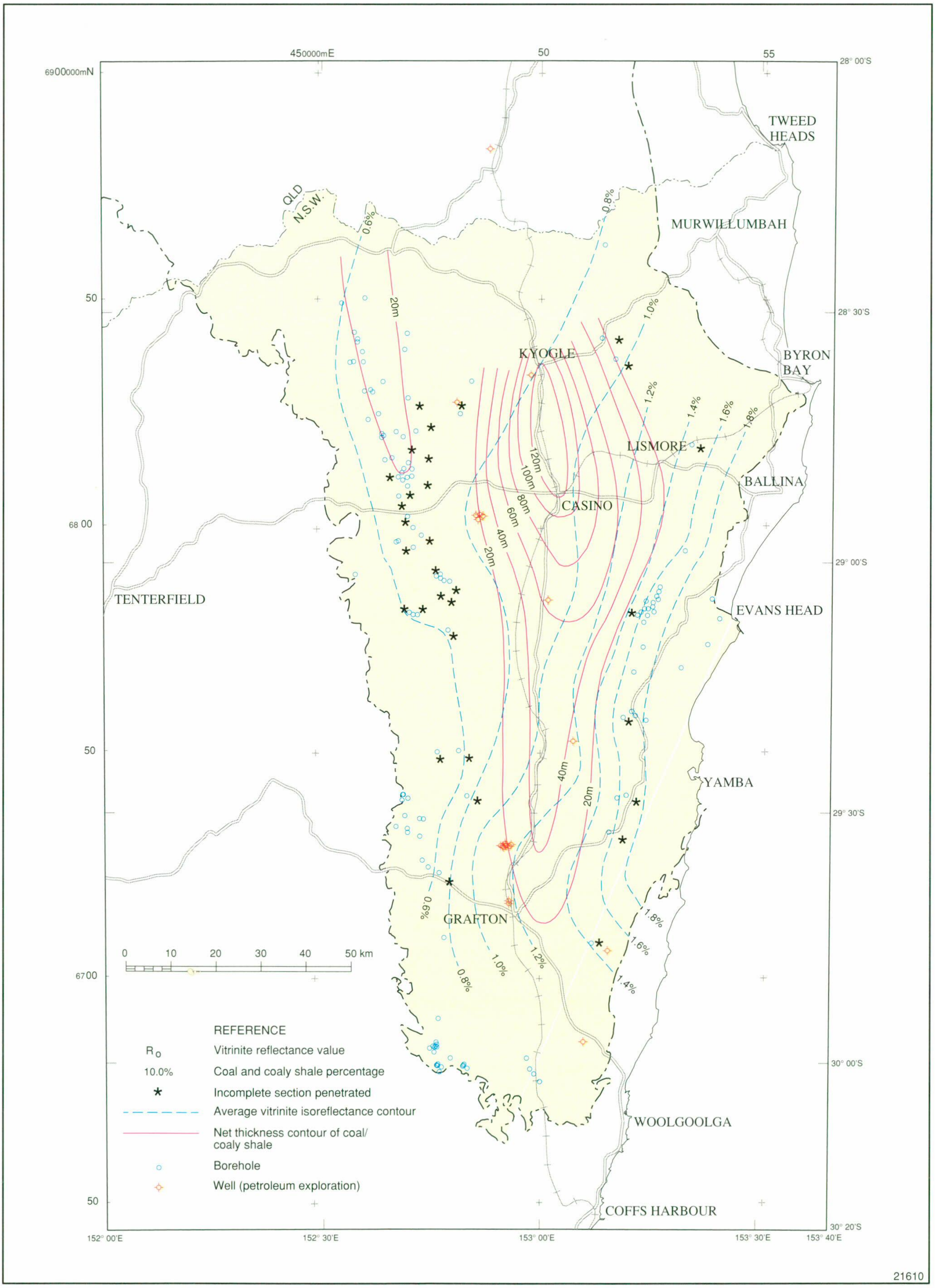


Figure 23. Net thickness of coal and coaly shale of the Walloon Coal Measures in the Clarence-Moreton Basin in New South Wales, together with vitrinite reflectance range.

POTENTIAL FOR CONVENTIONAL OIL AND GAS

SOURCE ROCKS

In the Clarence-Moreton Basin in New South Wales there are four stratigraphic intervals which have source rock potential. These are:

- Walloon Coal Measures;
- Koukandowie Formation;
- Raceview Formation; and
- Ipswich and Nymboida Coal Measures.

WALLOON COAL MEASURES

The Walloon Coal Measures are well known for their high volatile, sub-bituminous coals over large areas of Queensland and New South Wales. In addition to coal, the unit contains claystones, shales and siltstones rich in carbonaceous material. TOC (total organic carbon) values determined by AGSO on about 115 samples fall mostly in the 1% to 20% range (Figure 24). In the well completion report (WCR) of Shannon-1, the TOC values were reported as ranging from 3.78% to 15.8%. Mean average reflectance trends are shown in Figure 25, and maceral content is shown in Figure 26.

The S_1+S_2 values determined for Shannon-1 range from 7.79 mg/gm to 43.96 mg/gm and the HI values range from 119 to 282 (HI values are in mg of hydrocarbon per gram of organic matter, and see Glossary of Selected Terms at the end of *Bulletin*). The kerogen types in the Walloon Coal Measures are mostly Types II and III, with a minor amount of Type I (Figure 27). The volatile content of the coal may be as high as 54% (Bonalbo area) and the hydrogen content is, on average, about 6% to 7%. Yield data for the Walloon Coal Measures, and other formations, are shown in Figure 28. HI values shown in Figure 28 from O'Brien, Powell and Wells (1994, figure 6) are as high as 700, but the specific sources of these data (within the Walloon Coal Measures) were not stated. From the above description there seems little doubt that the Walloon Coal Measures would yield both oil and gas on reaching maturation levels equal to vitrinite reflectance values of 0.8% or more. Indeed, both oil and gas shows have been observed in this unit.

The thickest development of the Walloon Coal Measures in the New South Wales portion of the Clarence-Moreton Basin is in the Kyogle-1 well in the northern part of the Casino Trough (Figure 22). The greatest percentage of coal/coaly shale (23.2%) and the greatest net amount of coal/coaly shale (116.1 m) are in that well (Figure 23). This unit in the Kyogle-1 area is in the peak oil generation area, with vitrinite

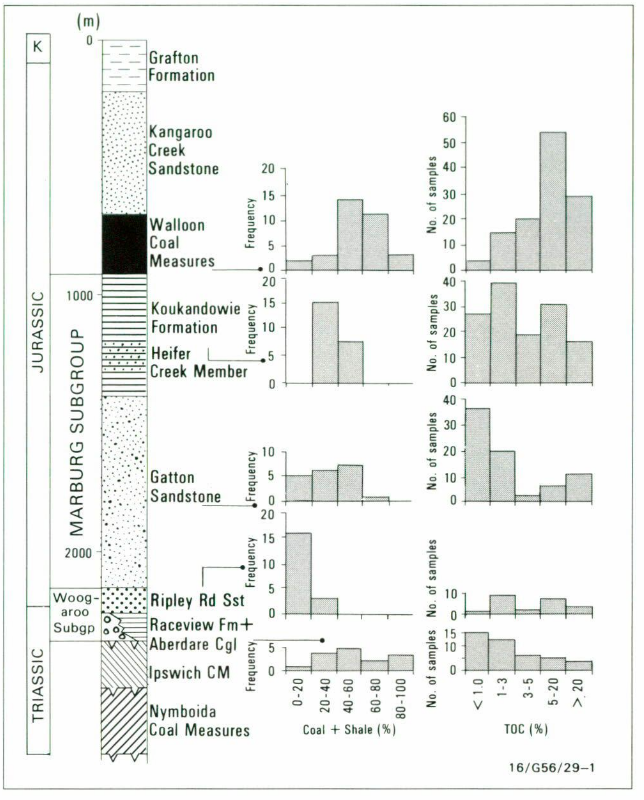


Figure 24. Potential petroleum source rock abundance in the Clarence-Moreton Basin. The histograms show the percentage of shale + coal in each stratigraphic unit plotted against the number of sections, and total organic carbon (TOC) plotted against the number of samples. Reproduced with permission from O'Brien, Powell & Wells (figure 2) in Wells & O'Brien (1994), AGSO Bulletin ***241****.*

reflectance values of 0.75% to 0.9%. In the Kyogle-1 well, over 30 gas peaks (total gas) were recorded while drilling these coal measures (drilled before the availability of rig-site chromatographs). Oil shows were reported as traces to fair precipitates obtained from sidewall cores. (The conventional cores in the coal measures were apparently not analysed.)

In the Shannon-1 well, at the southern end of the Casino Trough, numerous strong gas shows containing C_1 to C_2 gases were recorded, along with slight blue–white fluorescence and cut (with solvent). There is ample proof then, that hydrocarbons — gas and possibly some oil and wet gas — have been generated in the Walloon Coal Measures in the area of the Casino Trough. Some of that gas has probably been adsorbed within the coal seams, much is probably locked into impermeable sandstones and a few thin permeable sandstones, but a significant amount may have migrated out of the coal measures into other stratigraphic units, or has escaped to the atmosphere.

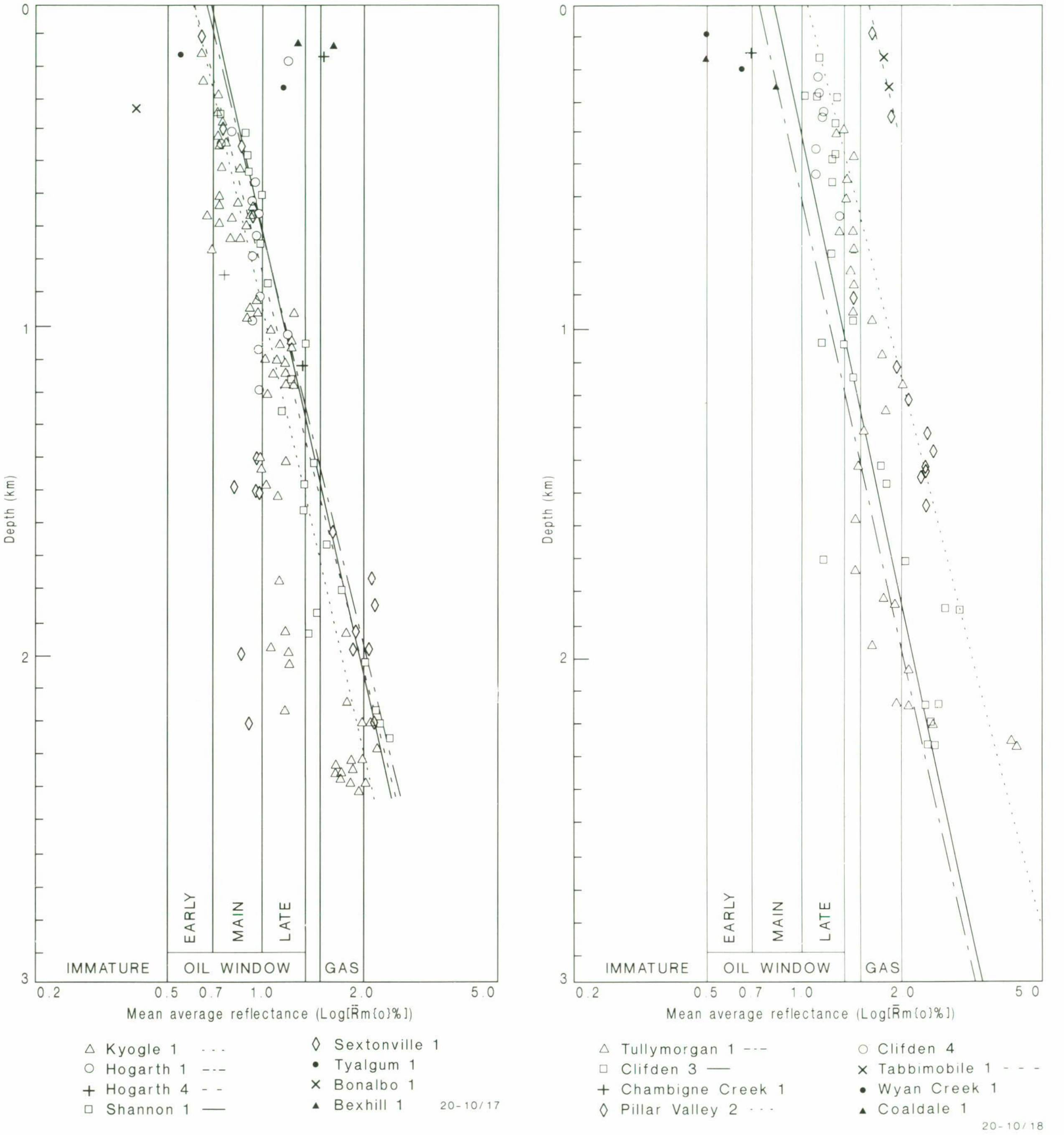


*Figure 25. Profiles of vitrinite reflectance against depth for groups of wells/drillholes in the south-eastern (left-hand side) and far south-eastern parts of the Clarence-Moreton Basin, in New South Wales (being, respectively, the northern part from and including Hogarth and Shannon drillholes and the southern part south from and including Wyan Creek-1). Reproduced with permission from Russell (figures 15 and 16) in Wells & O'Brien (1994), AGSO Bulletin **241**.*

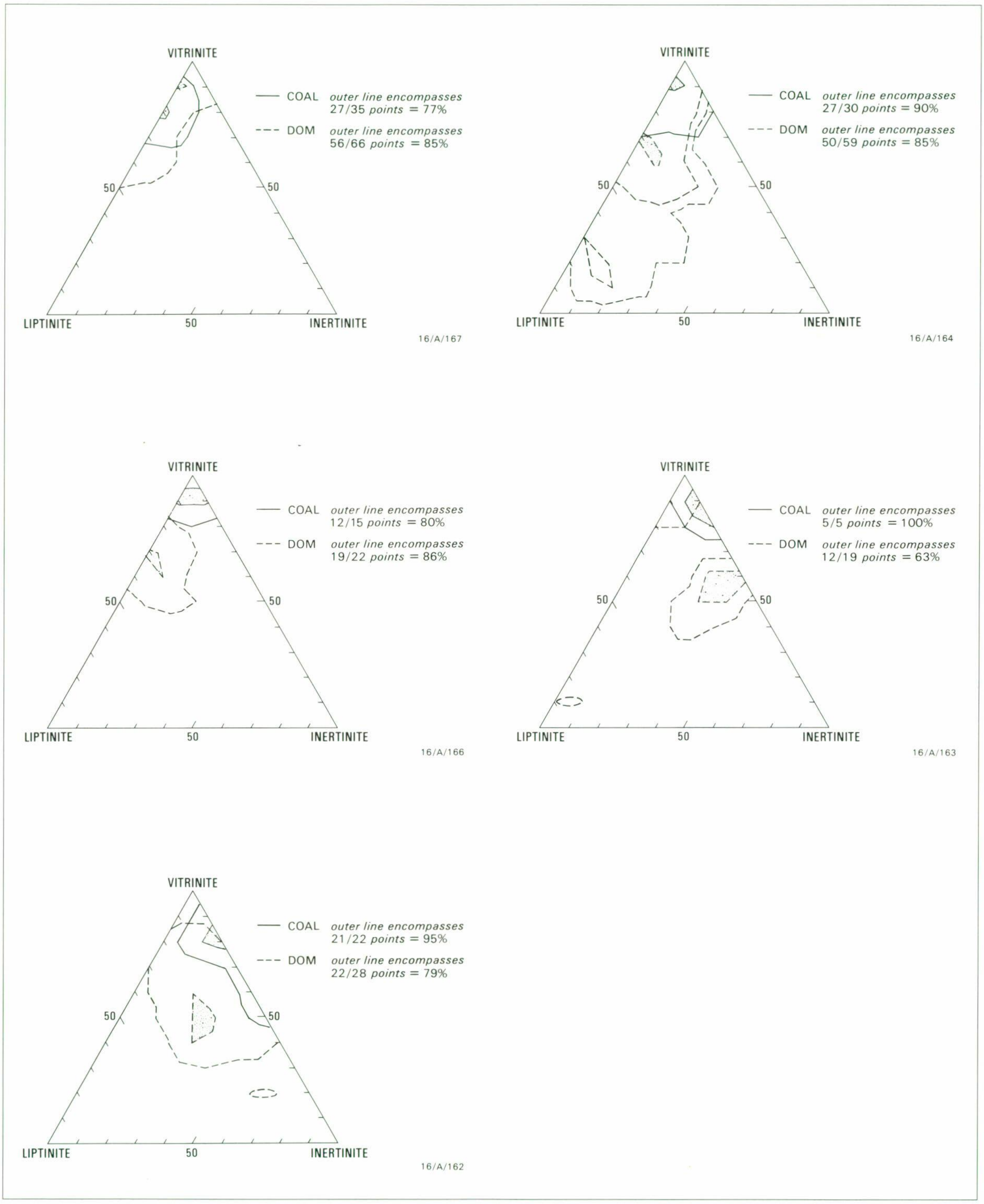


*Figure 26. Maceral types (compositions) for coals and dispersed organic matter (DOM) in the Clarence-Moreton Basin. For drillhole details, see Smyth (1994). Reproduced with permission from Smyth (figures 8 for Walloon Coal Measures (Rosewood Mine and 13 wells), top left, 5 for Marburg Subgroup (10 wells, including Kyogle-1), 7 for Marburg Subgroup (Kyogle-1 only), middle left, 4 for Woogaroo Subgroup (4 wells), 3 for Ipswich Coal Measures (Clifden-3 and Pillar Valley-2), respectively from left to right and down) in Wells & O'Brien (1994), AGSO Bulletin **241**.*

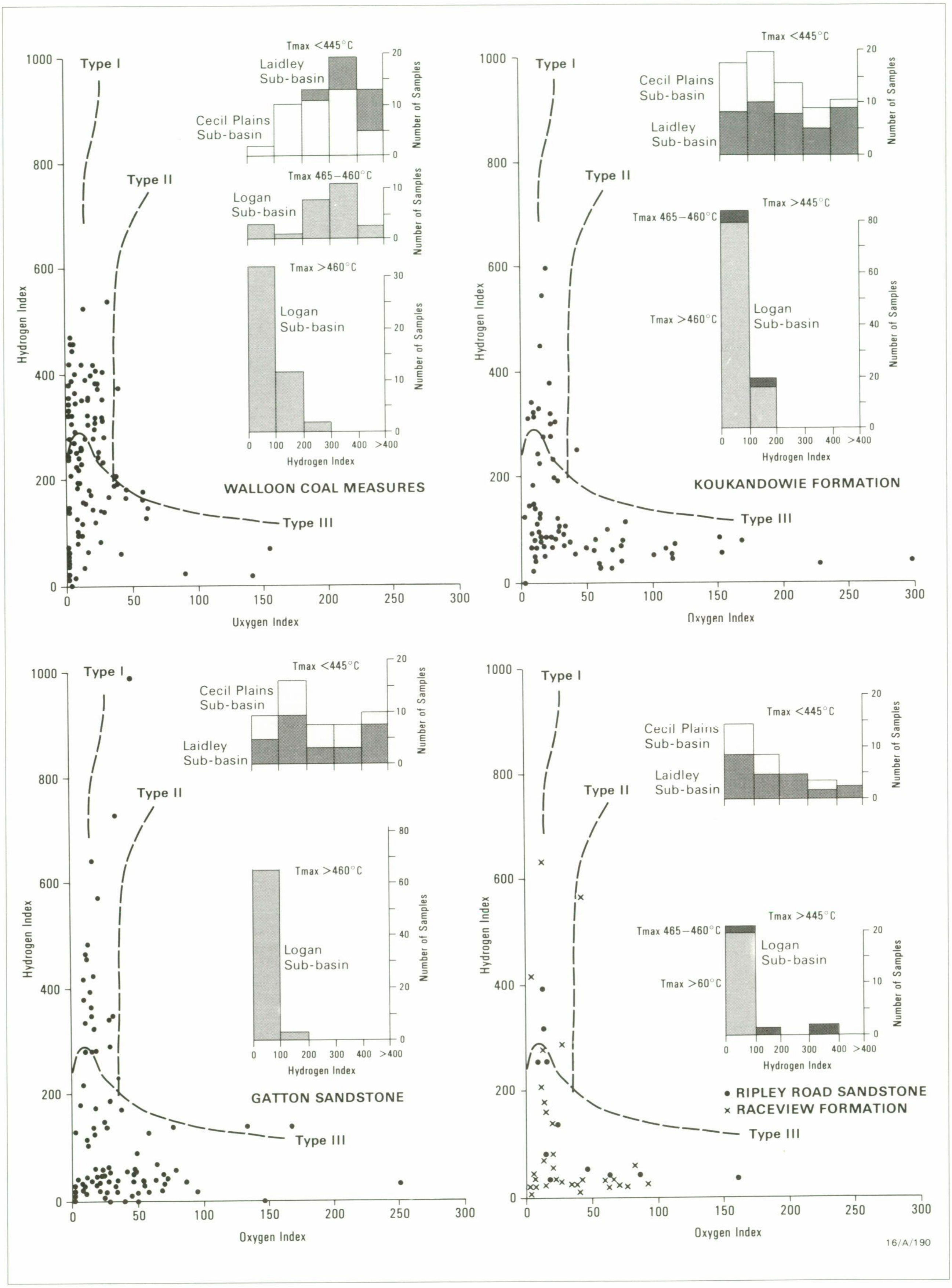


Figure 27. Classification of kerogen types based on hydrogen indices (HI) and oxygen indices plotted according to Tmax and basin position (Clarence-Moreton Basin). Reproduced with permission from O'Brien, Powell & Wells (figure 3) in Wells & O'Brien (1994), AGSO Bulletin ***241****.*

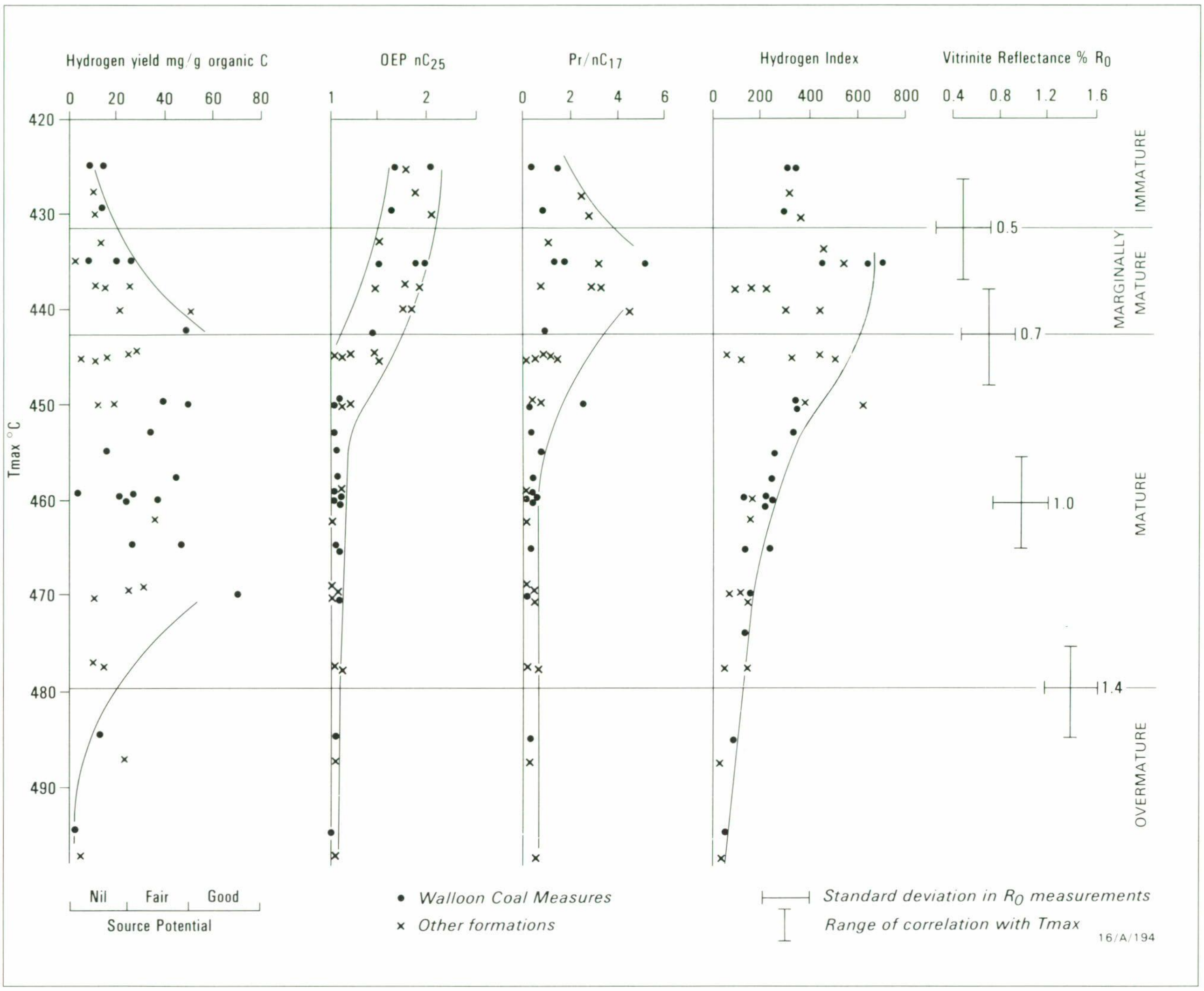


Figure 28. Maturation trends in yield and composition of extractable hydrocarbons, hydrogen indices, and other parameters for the Walloon Coal Measures and "other" formations. OEP nC_{25} is the odd-to-even predominance of n-alkanes measured as n-pentacosane. Pr/nC_{17} is the ratio of pristane to n-heptadecane. Source potential is based on hydrocarbon yield. Reproduced with permission from O'Brien, Powell & Wells (figure 6) in Wells & O'Brien (1994), AGSO Bulletin ***241****.*

The maceral composition of the coals in the Walloon Coal Measures in the Clarence-Moreton Basin is mainly vitrinite, whereas the disseminated organic material consists of vitrinite with lesser amounts of liptinite and inertinite (Figure 26). The high vitrinite levels may suggest that the potential for oil generation is not very good. However, the coals in the productive Gippsland Basin have similar compositions and the petroleum in that basin are considered to be derived from vitrinite and liptinite in both coals and DOM (Smith and Cook (1984), cited *in* Smyth, 1994). The palaeoburial and temperature history in the Sextonville-1 well is shown in Figure 29 — which indicates that maximum sedimentation ended in mid-Cretaceous time and that maximum palaeoheating occurred in mid- to Late Cretaceous time.

KOUKANDOWIE FORMATION

The Koukandowie Formation contains both source and reservoir rocks. Therefore it is not surprising that the most significant shows of hydrocarbons — mainly gas, but with some oil saturation in cores — have been found at that stratigraphic interval.

Work by AGSO, based on about 135 samples, suggests that the average TOC values are about 3%, but values up to 20% are common (Figure 24). The maceral content is mainly vitrinite, but with substantial amounts of liptinite and minor amounts of inertinite (Figure 26). This maceral combination, together with the kerogen types II and III, and HI values less than 200 (Figure 27), would be expected to yield gas with small amounts of oil. The coals and DOM in the Koukandowie Formation are similar to those of the

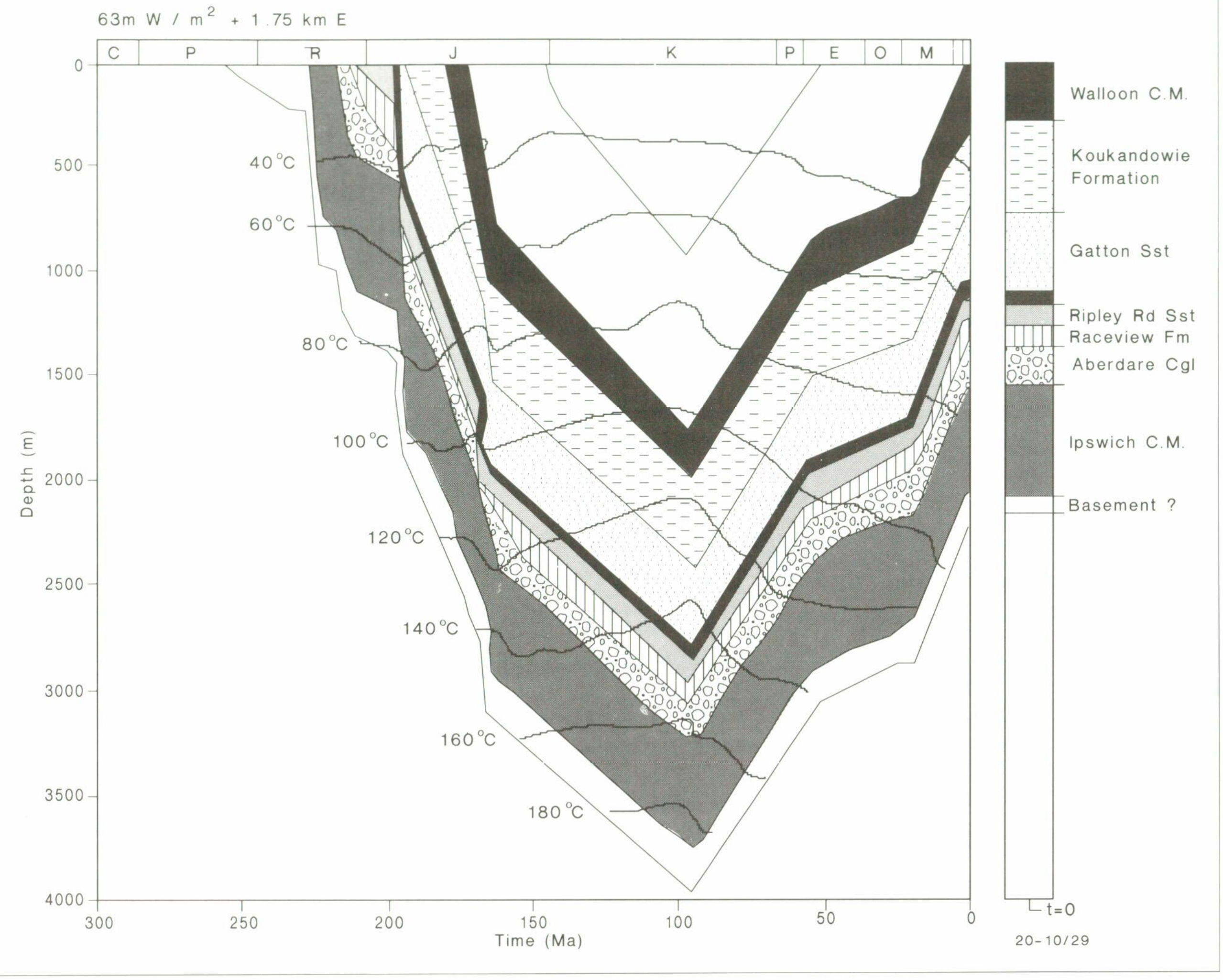


*Figure 29. Palaeoburial history plot for Sextonville-1. Reproduced with permission from Russell (figure 29) in Wells & O'Brien (1994), AGSO Bulletin **241**.*

Walloon Coal Measures and the comment in the previous subsection on the Walloon Coal Measures about similarity with the Gippsland Basin is again applicable.

Data from the well completion report for Shannon-1 show that the TOC values in that well range from 0.42% to 5.10%. S_1+S_2 values are 0.38 mg/gm to 9.03 mg/gm, and HI values are to 147. These values suggest that the Koukandowie Formation is a marginal to good source of gas with some potential for oil.

The flows of gas from the Koukandowie Formation to date have been essentially all methane (92.4% to 97.1%). This is typical of gas generated from coals and possibly indicates gas-prone source rocks. Oil shows have been identified in cores, in intervals closely associated with the gas flows. Gas peaks and background gas detected by mud logging equipment generally indicate the presence of gas from C_1 through to C_5. Various interpretations of those occurrences can be made. At this early stage of exploration it appears that gas is more in abundance than oil, but that oil accumulations are still possible. Possibly the coal is the source of the gas, whereas the DOM is the source of the oil.

Vitrinite reflectance values for the Koukandowie Formation range from 0.6% in the west to 2.0% in the east. These values are shown in Figure 19, along with the percentages of coal plus coaly shale. The coal plus coaly shale is best developed in the Casino Trough, especially in the Kyogle-1 area, where coal plus coaly shale constitutes about 5% of the total thickness.

The thickness contours for the Koukandowie Formation and the contoured percentages of coal, shale and shaly siltstone are shown in Figure 17. The area of greatest development of coal, shale and shaly siltstone is in the Casino Trough, where the Kyogle-1 section contains 88.7% of such rocks. As the Casino Trough contains the thickest section, the greatest percentage of coal and the greatest percentage of the combined coal/shale/shaly siltstone, it is readily apparent that the Koukandowie Formation in that area has the greatest potential for the generation of hydrocarbons.

RACEVIEW FORMATION

The Raceview Formation has, in the past, not been regarded as having significant source rock potential. This is probably true in areas outside of the deeper parts of the Casino and Grafton Troughs. In those Troughs, especially the Casino Trough, the Raceview Formation is very shaly, with considerable coal appearing in the Kyogle-1 well. AGSO has analysed many samples for maceral content from the Woogaroo Subgroup over both the Queensland and New South Wales portions of the Clarence-Moreton Basin. The maceral content for four wells, as shown in Figure 26, illustrates that vitrinite is the principal maceral in the Subgroup (probably mainly the Raceview Formation), with secondary amounts of inertinite. This, plus mainly kerogen type III and HI values less than 100, and with vitrinite values ranging from 0.8% to 2.2%, suggests that gas with minor oil would be the most likely products generated. This is a very generalised interpretation and many more samples need to be analysed, especially from the Kyogle-1 well, in order to obtain a more precise evaluation of the generation potential of the unit.

TOC values for the Raceview Formation, based on approximately 20 samples analysed by AGSO, are more or less evenly spread over a range of less than 1% to 20% (Figure 24). No specific hydrocarbon yield data are given in the AGSO data for the Raceview Formation. Data from the well completion report for Shannon-1 gave TOC values in the range 0.2% to 2.05%, $S_1 + S_2$ values of 0.12 mg/gm to 0.77 mg/gm and HI values of 15 to 55. In the Rappville-1 well, three analyses of sidewall cores yielded TOC values of 0.94% to 1.72%, $S_1 + S_2$ values of 0.28 mg/gm to 0.37 mg/gm and HI values of 15 to 35. These values suggest that the Raceview Formation is a poor to marginal source of gas. As the Kyogle-1 section contains much more coal than any other well, the Raceview Formation may well have the best gas source potential in the northern Casino Trough area. In the Grafton Trough, the Raceview Formation is considered to be a poor to, at best, fair source of gas.

IPSWICH COAL MEASURES AND NYMBOIDA COAL MEASURES

The sequence (or units) between the base of the Bundamba Group and economic basement has been grouped together as a single source rock interval. The sequence consists of coal measures with a possible intervening unit, the Chillingham Volcanics, which has no source rock potential. Very few source rock analyses have been performed on the coals and carbonaceous shale in the sequence. The most comprehensive study of the sequence was by AGSO, in which approximately 40 samples were analysed for maturation levels and 29 samples for maceral content. Results of those analyses are shown in Figures 25 and 26. The macerals are dominated by vitrinite. TOC values range from less than 1% to over 20%, but are mostly less than 3%. Maturation levels (vitrinite) are shown in Figure 8, where R_o values can be seen to range from 0.95% to as high as 4.0%. There seems little doubt that hydrocarbons generated from these coal measures at such levels of maturation would be essentially methane, with only very minor wet gases. Considering the thickness of the sequence and the net amount of coal present, a considerable quantity of methane has probably been generated. That gas may now be contained in coal seams (coal seam methane reservoirs) and/or sandstone reservoirs within the sequence, or in overlying sandstone reservoirs of the Bundamba Group.

Many shows of gas have been found in the Ipswich and Nymboida Coal Measures in the New South Wales portion of the Clarence-Moreton Basin. Gas peaks have been logged wherever the Ipswich and Nymboida Coal Measures have been penetrated by petroleum exploration wells. Gas has also been noted seeping from coal in cores and cuttings from those wells. The Nymboida corehole 'I' blew out while coring at 231 m to 236 m in the upper part of the Nymboida Coal Measures, and continued to flow gas and water for at least four years or more (cf. Figure 6).

In the Nymboida Colliery a large explosion caused by methane seepage occurred in 1956 (killing several miners and causing a shutdown of part of the colliery). Other small blowouts have been noted in coreholes in the Nymboida Colliery area.

RESERVOIRS

In the Clarence-Moreton Basin, there are two primary reservoir targets and five secondary targets.

Primary reservoir targets:
- Koukandowie Formation (Heifer Creek Sandstone Member); and
- Ripley Road Sandstone.

Secondary reservoir targets:
- Walloon Coal Measures;
- Gatton Sandstone;
- Raceview Formation; and
- and Nymboida Coal Measures.

All of the reservoir units, with the exception of the Raceview Formation, have demonstrated the capability to flow either gas or water in various wells or drillholes, although permeabilities are generally low. The problem facing the explorer in the search for hydrocarbons is in predicting where effective porosity with sufficient permeability for economic flows of gas or oil may be found.

Diagenesis has been the principal factor in the reduction of the original porosity. The diagenetic history of the Clarence-Moreton Basin is very poorly understood, but is believed to be broadly as outlined below.

- *Compaction* — this was especially effective in reducing the permeability of the more lithic sandstones.
- *Introduction of silica* — this initially resulted in the coating of some quartz grains with silica. Later, quartz overgrowths occurred with increasing depth of burial.
- *Authigenic clay development* — various percentages of kaolin (including kaolinite), illite, smectite and chlorite are present in all of the sandstones. The exact timing of the growth of these pore-filling clays is not known. Possibly, this occurred after uplift and erosion, which allowed surface waters to migrate through porous zones and interact with formation waters and lithic components in the rocks.
- *Calcite deposition* — calcite is ubiquitous throughout the sedimentary section as both cement and fracture filling. The calcite deposition appears to have occurred late in the diagenetic history, but it may have been a more or less continuous process.
- *Secondary solution* — considering the variety of the pore-filling minerals and lithic fragments in the section, some secondary solution of minerals has probably occurred. However, no report of a definite recognition that this phenomenon has occurred is known in the literature.

Apparently, no systematic and comprehensive study of the diagenetic history of the Clarence-Moreton Basin has been made. Such a study would be hampered by a lack of continuous cores through reservoir sections. Also, nearly all of the deep wells which penetrated the lower part of the sedimentary sections are located in the deeper parts of the Basin. Very little information is available on the reservoir properties of the section below the Walloon Coal Measures on the flanks of the Basin.

PRIMARY RESERVOIR TARGETS

KOUKANDOWIE FORMATION

The Koukandowie Formation consists of three parts, two of which, the Ma Ma Creek Member at the base and the Koukandowie Formation (undifferentiated) at the top, have very little reservoir potential. The third and intervening part of the formation, the Heifer Creek Sandstone Member (with the underlying Ma Ma Creek Member) occupies approximately the lower half of the Formation and has the best reservoir properties of any unit in the Clarence-Moreton Basin. The best flow of gas in the Basin (500 000 cf/d or approximately 14 000 cubic metres per day) came from sandstones in the upper part of this Member in the Hogarth-2 well. The best developed, ie the most quartzose and least shaly, sandstones occur in the top 70 m to 80 m (Figure 20). No conventional cores were taken in the productive interval at Hogarth-2 but sidewall cores taken across the interval had porosities of 22% to 29%, with permeabilities of 812 md to 1349 md. The high permeability in the Hogarth-2 samples is most probably due to artificially created fractures caused by the sidewall coring process and thus should be discounted.

The Hogarth-1 well appears to have three permeable sandstones which have been interpreted to be gas-productive (Figure 30).

In the Hogarth-4 well, the upper 111 m of the Heifer Creek Sandstone Member was continuously cored to give an excellent stratigraphic record of this interval. Measured porosities over that cored interval ranged from 7.8% to 20.5%, with permeabilities of 0.13 md to 69 md. Several sandstones in this interval have properties that suggest they could sustain production on a commercial scale. However, this well was never successfully tested.

In the Hogarth-2 well the permeability of the productive sandstone, calculated from DST pressure data, was 4.5 md. The calculated skin effect was 540 psi, suggesting a considerable degree of formation damage caused by swelling clays in the presence of mud filtrate.

The Shannon-1 well was drilled within a few hundred metres of the Hogarth-2 well, but the gas-bearing interval was found to be impermeable and non-productive. The most logical explanation for this is that the Shannon-1 well was drilled on the shaly edge of the productive sand body, and that the gas accumulation has both a stratigraphic and structural component.

The Sextonville-1 and Rappville-1 wells did not have effective reservoir development in the Heifer Creek Sandstone Member. The reasons for this are not clear, but most likely diagenetic processes are responsible.

Seventeen wells have encountered the Koukandowie Formation and a total of 19 successful DSTs have been taken over separate intervals. The results of these tests are shown could be deleted in Table 2.

HOGARTH - 1

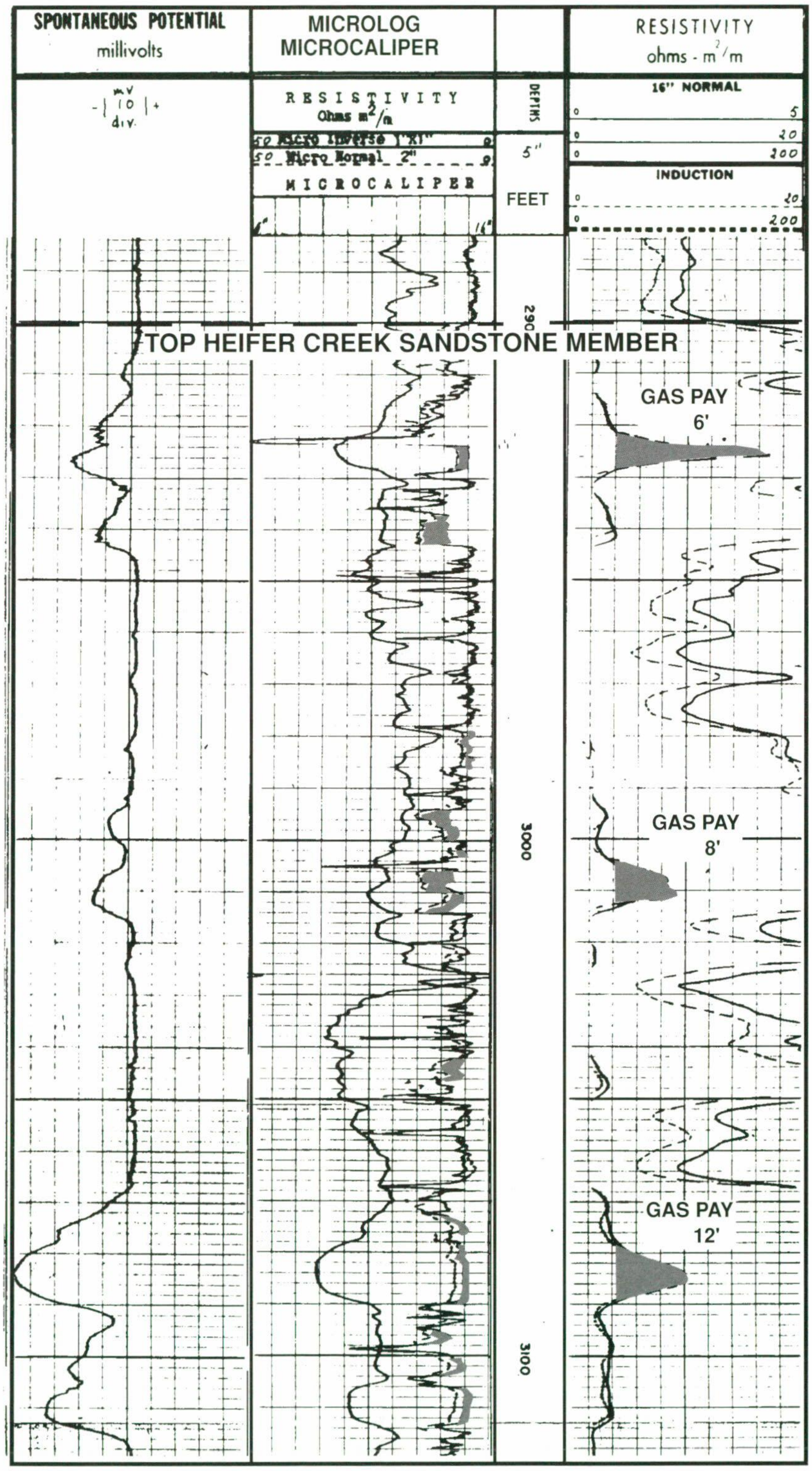


Figure 30. Composite log illustrating porosity and permeability in the upper part of the Heifer Creek Sandstone Member in Hogarth-1. The total permeable interval shown is 61 ft (18.6 m) and the net pay is 26 ft (7.9 m). Two DSTs were attempted in this interval, but were unsuccessful due to packer failure.

TABLE 2
DST RESULTS IN THE KOUKANDOWIE FORMATION

Well	DST No.	Metres Interval	Recovery
Clifden-1 [Grafton-3]	1*	268.2 - ?	Flowed inflammable gas at low pressure
Clifden-2		~585 - 592	Test (?not DST) estimated 100 000 cfg/d (2800 m³/d) after ?blowout, horizon uncertain
Clifden-5	2*	516.9 - 518.8	Fair air blow dying in 30 minutes, recovery about 90 m of muddy water
Hogarth-2	3*	751.3 - 771.1	No recovery, tight formation
	5*	884.2 - 894.5	Recovered 76.2 m water and mud, tight formation
	6*	906.7 - 932.6	Gas to surface in 7 minutes flowed 0.5 million cfg/d (14 000 cubic metres per day)
	7*	941.2 - 948.5	No recovery, tight formation
	8*	991.2 - 999.7	No recovery, tight formation
	9*	949.7 - 955.5	No recovery, tight formation
	10*	912.3 - 912.4	Gas flowed, 3400 cf/d (approx. 95 cubic metres per day)
	11*	912.3 - 921.4	Gas flowed, 8400 cf/d (approx. 240 cubic metres per day)
Kyogle-1	3*	1024.1 - 1025.6	Recovered 67 m of water and filtrate
	4*	1010.4 - 1011.9	Recovered 6.1 m of water
	5*	839.7 - 847.3	Weak flow of gas to surface, recovered 750 m of water and mud
	6*	839.7 - 847.3	Gas to surface in 4 minutes, rate TSTM; water to surface in 85 minutes, recovered 838 m
	7*	893.0 - 896.1	Recovered 279.2 m of water after 123 minutes, closed-in pressure indicates water would have flowed to surface
Rappville-1	2	1085.7 - 1090.0	Recovered 27 m of mud
	3*	1332.9 - 1344.5	Recovered 41 m of slightly gas-cut mud
Shannon -1	2	876.3 - 896.1	Gas flow to surface at 3000 cfg/d (85 cubic metres per day), recovered 146 m of gas-cut mud
	3*	929.6 - 974.8	No flow, tight formation
Tullymorgan -1	1	691.0 - 707.0	No flow, tight formation

NOTES:

* DSTs (drill stem tests) in Heifer Creek Sandstone Member, remainder in Koukandowie Formation undifferentiated.

cfg/d — cubic feet of gas per day

TSTM — too small to measure

The data have been collected from various well completion reports. (Conversions for gas volumes have been rounded, especially when there were few significant figures.)

The permeable sandstones in the Hogarth-1 well are shown in Figure 30, where the correspondence of SP deflections and Microlog curve separations are easily discernible. (No Microlog is available for the productive well, Hogarth-2.)

From core analyses and DST results, it is apparent that the sandstones of the Heifer Creek Sandstone Member typically have fair to good porosities, but with low permeabilities. One significant exception to this is the interval tested by DST-6 in the Kyogle-1 well. On that DST the well flowed water to the surface with a small amount of gas from a fifteen-metre thick sandstone interval having about 7 m of net permeable sandstone (Microlog) (Figure 31). A sidewall core from the sandstone interval was analysed as having a porosity of 24%, with 26 md of permeability, while 0.5% of the pore volume contained oil with a strong yellow cut. The water flow rate is unknown, but the indication is that accumulations of hydrocarbons in that interval would flow at substantial rates. Another fifteen-metre thick sandstone interval in Kyogle-1, tested by DST-7, recovered 279.2 m of water. There are no core data from that interval, but the net permeable thickness appears to be about 5.5 m (as estimated from the Microlog).

The two sandstones described above are in the top part of the Heifer Creek Sandstone Member in the interval 838 m to 899 m in Kyogle-1. This interval roughly correlates with the interval 882 m to 920 m in the Hogarth-2 well. The gas flow in Hogarth-2 was from that interval, as were shows of oil in sidewall cores. In the Sextonville-1 well, the Heifer Creek Sandstone Member occupies almost the entire Koukandowie Formation interval (Figure 4), and correlation of individual sand bodies with other wells is very difficult.

KYOGLE - 1

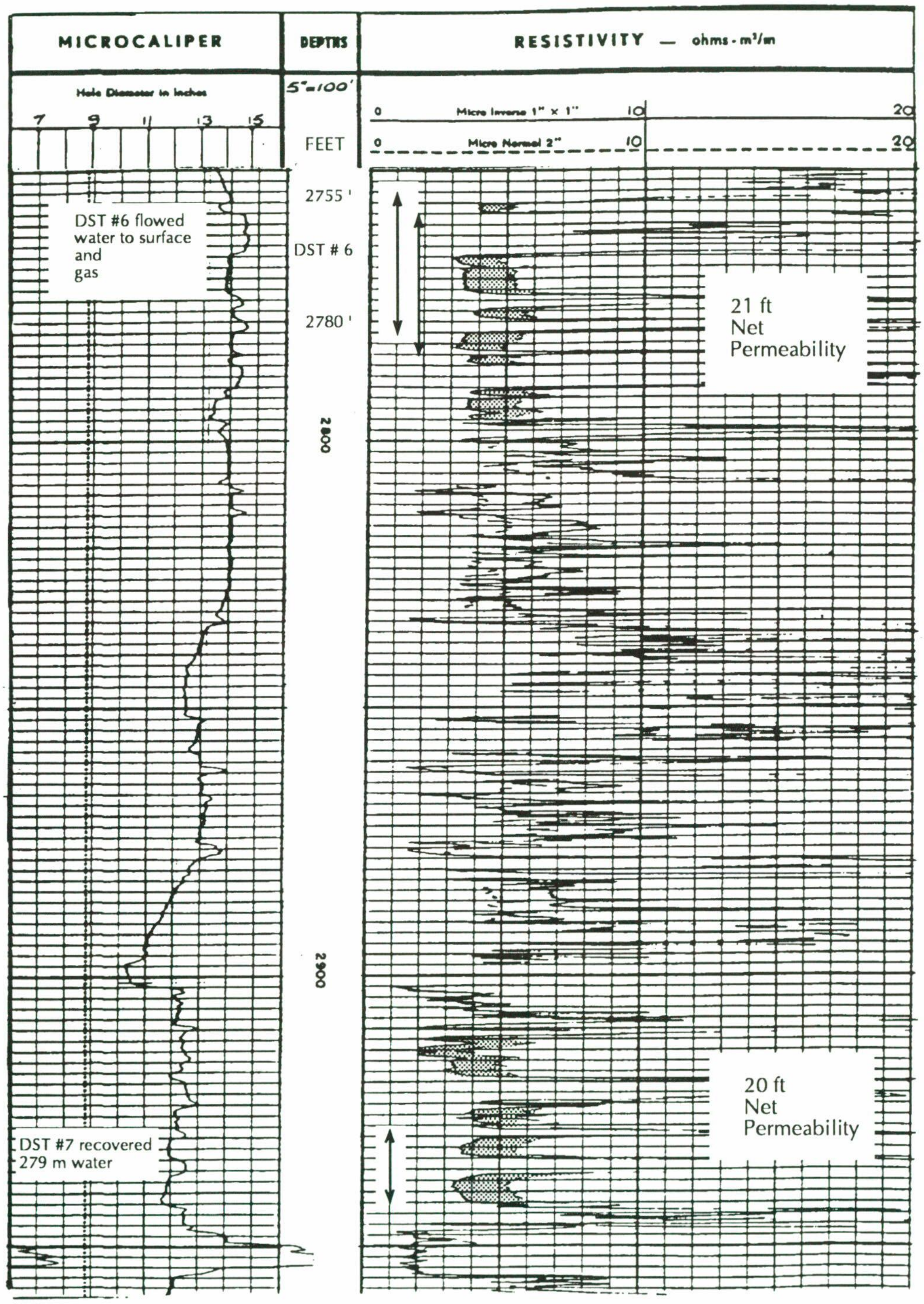


Figure 31. Microlog [electrical well log] illustrating permeable zones at the top of the Heifer Creek Sandstone Member in Kyogle-1.

If sandstones similar to those of the upper part of the Heifer Creek Sandstone Member are found elsewhere to constitute a sedimentary package and a common depositional environment, it is possible that the sandstone is a reservoir target over much of the Casino Trough. The lack of effective porosity in the Sextonville-1 well may be the result of surface water entering the formation nearby at outcrop and causing the growth of authigenic clays and deposition of quartz and calcite cement. In the deeper area, much further from outcrop, the formation may have been to a lesser extent invaded by surface water — thereby reducing the growth of pore-filling authigenic clays and cementing agents. Also, some special depositional/petrographic characteristics of these sandstones may have helped preserve their permeability. These porous sandstones are located in the midst of source rocks with potential for both oil and gas generation where the maturation levels are in the oil window. A play thus exists in the Casino Trough where those sandstones may produce gas and/or oil in structural and/or stratigraphic traps.

The Heifer Creek Sandstone Member is present in the Grafton Trough, but the reservoir quality, based on limited data, appears to be less than that found in the Casino Trough. Although gas shows have been recorded from the unit in the three wells drilled in the Casino Trough (considering Rappville-1 as being associated with the Grafton Trough), the potential is considered much greater in the Casino Trough, where better reservoirs and better source rocks are present.

In the Urbenville-1 well, located in the Warrill Creek Syncline, a water flow to the surface was encountered while drilling in what is interpreted to be the upper part of the Heifer Creek Sandstone Member. Urbenville-1 is the only drillhole in this area to have reached the sandstones (of the Heifer Creek Sandstone Member).

RIPLEY ROAD SANDSTONE

The Ripley Road Sandstone is recognised as the most widespread and most quartzose sandstone interval in the Clarence-Moreton Basin. It is recognised by its low gamma ray levels in logs and by the best-developed negative SP values of any unit. It has, surprisingly, been tested by only one successful DST in one well, Sextonville-1, where 46 m of gas-cut mud with a trace of oil were recovered. A DST was attempted in the Ripley Road Sandstone in the Kyogle-1 well, but failed due to lack of a packer seat.

Porosities from a limited number of conventional cores range from 3% to 29%, with permeabilities of 0.21 md to 57 md in Kyogle-1. Log-derived porosities in the Ripley Road Sandstone commonly range from 15% to 25%. Permeabilities are probably generally less than 50 md because of diagenetic clays and calcareous/siliceous cement. Percentages and net thickness of the 'clean' Ripley Road Sandstone (readings of less than 60 API units on the gamma ray log), are shown in Figure 14. Kyogle-1 has the greatest percentage and the greatest net thickness of 'clean' sandstones at 79.8% and 99.7 m, respectively. Log analysis for that well indicates a net porous interval of 35.7 m having porosities of 16% to 21%. The Ripley Road Sandstone was continuously cored in the Pillar Valley-2 drillhole and the most porous intervals (6) were analysed as having porosities of 3.6% to 11.7% and permeabilities of 0.18 md to 2.4 md. The (apparent) reduction of significant porosity and permeability in this drillhole appears to be caused mainly by quartz cement.

No effective porosity was found in the Ripley Road Sandstone in the Rappville-1 well, mainly because of siliceous cement and quartz overgrowths. In Tullymorgan-1 there were several thin, slightly porous zones (marked by drilling breaks with methane shows on the gas detector), but mostly the unit there was lacking in permeability. The loss of porosity was caused by a kaolinitic matrix, probably authigenic in origin, and silica cement.

The Ripley Road Sandstone in the Clifden-3 well is poorly described. A single analysis from the only core taken in the unit in the well gave a porosity of 4.1%, with permeability of 1.0 md. There are several well-developed zones having good negative SP deflections indicative of some permeability. The sandstones in Clifden-3 are well-cemented by calcite, with only minor silica cement.

In summary, the Ripley Road Sandstone is a sheet-like stratigraphic unit that has reservoir characteristics covering the entire Clarence-Moreton Basin. The unit appears to have permeability, as indicated by the SP curve. However, there are insufficient DST and core analysis data to properly assess the reservoir quality. From the available well data, it appears that porosities have a range of 10% to 20%, with permeabilities up to 50 md. Kaolinite and other clays, probably mostly authigenic in origin, plus silica and calcite cements, are responsible for the low permeabilities. Some of the effective porosity may be the result of secondary solution, but no petrographic studies have been carried out to support this hypothesis.

SECONDARY RESERVOIR TARGETS

WALLOON COAL MEASURES

The Walloon Coal Measures appear to have limited reservoir potential in the New South Wales portion of the Clarence-Moreton Basin. This comment is based on the results of three DSTs in the unit (one each in the Rappville-1, Hogarth-1 and Shannon-1 wells) where no gas or other fluids were recovered. However, the unit is not totally devoid of permeability — as several of the drillholes drilled by Endeavour Resources Ltd on the western flank of the Basin flowed water at fair rates. The best of these was at drillhole No. 47, where a flow of 5000 gallons/day (142 barrels/day or about 23 cubic metres/day) was recorded.

In the Kyogle-1 well, several thin permeable zones are indicated on the Microlog (Figure 32). The net thickness of these amounts to about 40 m in 29 separate horizons. Porosities and permeabilities from sidewall cores taken in these beds range from 19% to 23% and zero to 69 md, respectively. The permeabilities are mainly in the range 2 md to 5 md and these are quite probably valid considering the Microlog indications of permeability. The many gas peaks logged in Kyogle-1 appear to be associated with coal seams, but a few appear to relate to the permeable zones indicated by the Microlog. Kyogle-1 is the only well in which these permeable beds are recognised, but unfortunately they were not tested. They were not seen on Micrologs in the Sextonville-1 and Hogarth-1 wells. The Microlog (Gearhart's micro-electric log) was not run through the Walloon Coal Measures in the Shannon-1 well, and no Microlog was run in the Rappville-1 well — and the existence of permeable beds in these two wells thus cannot be determined. The single DST in Rappville-1, in which no gas or other fluids were recovered, is not conclusive. One DST was made in open hole in the Shannon-1 well to test a strong gas show in a sandstone interval logged while drilling the unit, but no gas or other fluids were recovered. With no wireline logs for this interval it is difficult to evaluate the DST results. No permeability was evident on the Microlog in Tullymorgan-1. The Walloon Coal Measures were not logged in the Clifden-3 well.

In summary, it is difficult to evaluate the reservoir potential of the Walloon Coal Measures because of the lack of definitive information. It appears that numerous permeable sands are present in Kyogle-1, but no DSTs were undertaken in these sandstones. Possibly, porosity and permeability improve in a northward direction, suggesting that productive sands may be found in the northern part of the Casino Trough.

GATTON SANDSTONE

The Gatton Sandstone, in the wells drilled to date, has exhibited generally poor reservoir conditions. However, because of its widespread distribution and substantial thickness, of 500 m to 900 m, reservoir-quality sandstones may exist in unexplored areas, and the unit, therefore, is considered as a secondary objective. Three DSTs have been run in the Gatton Sandstone, one of which flowed approximately 3000 cfg/d (85 cubic metres per day) from the top of the unit in the Tullymorgan-1 well. The other two DSTs recovered only small amounts of water and mud. The small flow of gas in the Tullymorgan-1 well is encouraging because it occurred at the top of the Gatton Sandstone beneath the shale seal of the Ma Ma Creek Member.

In the Shannon-1 well, a permeable interval indicated by the micro-electric log from 1830.5 m to 1856.8 m (net 18.0 m) occurs at the base of the unit, just above the shaly Calamia Member. A DST was attempted over that permeable interval, but was unsuccessful because of packer failure. A gas show was recorded at that horizon, but there is little doubt that the interval is water-bearing.

Near the western margin of the Clarence-Moreton Basin, the BMR Warwick-7 borehole yielded measured porosities up to 25.9%, with permeabilities up to 961 md (cf. O'Brien, Powell & Wells, 1994). The significance of this is not clear, but it could augur well for hydrocarbon accumulations in the Gatton Sandstone along the western margin in areas such as the Powapar Fault Zone or the Coaldale High (Figure 9).

RACEVIEW FORMATION

The Raceview Formation is usually regarded as being a source rock unit rather than a reservoir target in the Clarence-Moreton Basin. In the basinal areas this is apparently true, but only one well (Sextonville-1) has encountered the Formation on the western flank of the Basin. In that area, the Raceview Formation tends to become more sandy, before being replaced by poorly sorted, tight conglomerates (Laytons Range Conglomerate) further westward. That sandy section, similar to the section noted in Sextonville-1, may contain reservoir-quality sandstones. Those sandstones could possibly form a stratigraphic trap with an updip seal of conglomerates and an overlying seal formed by more impermeable units of the Raceview Formation.

IPSWICH COAL MEASURES AND NYMBOIDA COAL MEASURES

In the Nymboida area, borehole 'I' encountered a blowout from sandstones of the Basin Creek Formation of the Nymboida Coal Measures at a depth of 231 m to 236 m. The sandstone there is highly fractured as a result of movement along the Shannon Fault (Figure 9). The extent of the faulting is unknown, but there may be a sizeable area of fracture-enhanced porosity there or in other fault zones — such as the Martin Fault, the faults associated with the Richmond Horst and the Powapar Fault Zone (Figure 9).

KYOGLE - 1

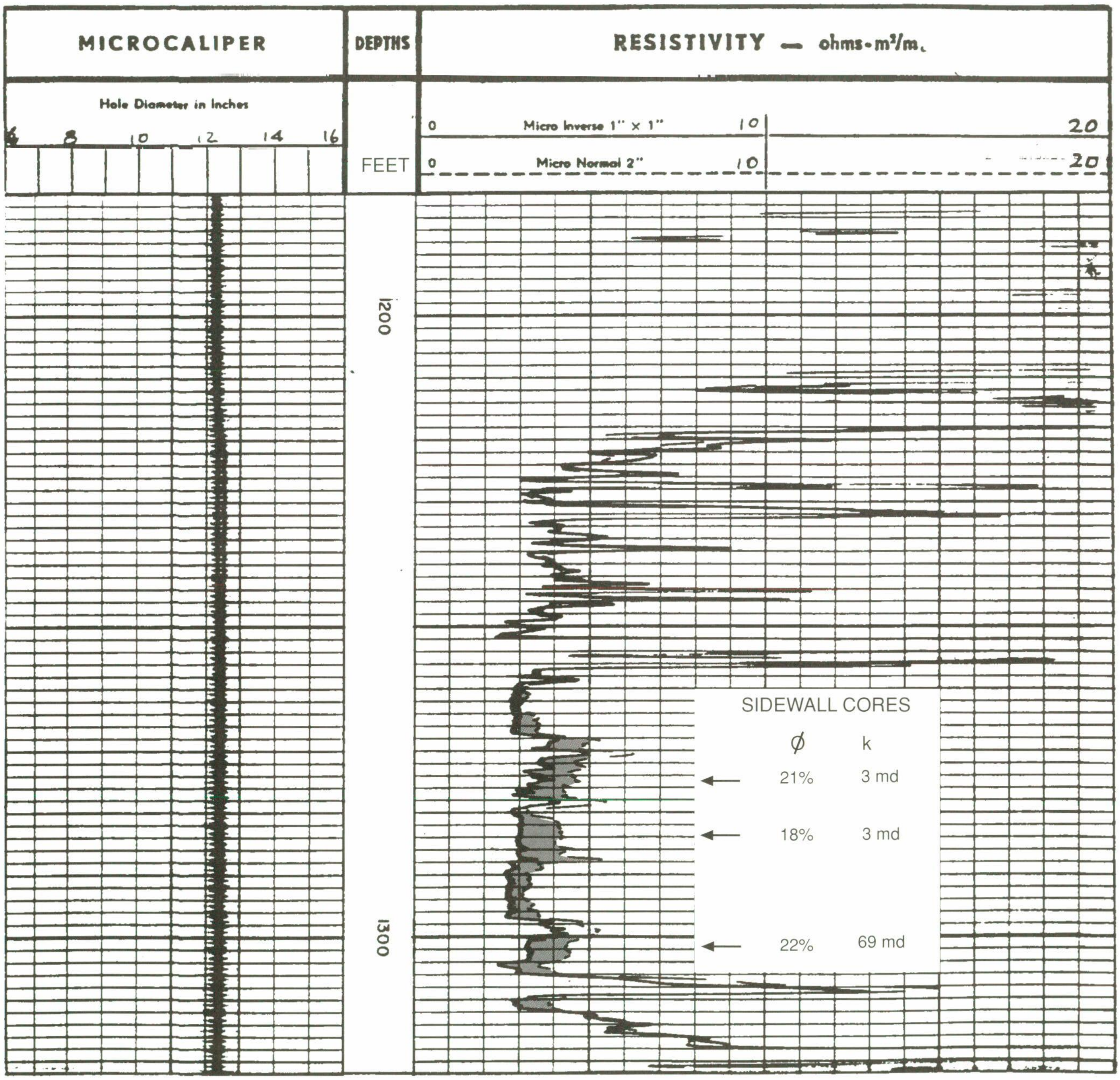


Figure 32. Microlog [electrical well log] and sidewall core analyses illustrating porosity and permeability in the Walloon Coal Measures in Kyogle-1. (The microcaliper log appears to have been inoperative.)

In the few wells or drillholes where the Ipswich/Nymboida Coal Measures have been penetrated, no reservoir quality sandstones have been reported. However, as the section is so poorly known, it should be regarded as a potential reservoir until proved otherwise by future drilling.

STRUCTURE

GENERAL

Deposition began in the New South Wales portion of the Clarence-Moreton Basin in Middle Triassic time. The southern limits of the Basin developed as a depression within the oroclinal bend of the Coffs Harbour basement block. Possibly the basement structure had a major influence on the development of the Basin, particularly the Logan Sub-basin (Figure 9). According to O'Brien, Korsch et al (1994), the Clarence-Moreton Basin and its precursors, the Esk Trough, Tarong Basin and Ipswich Basin, developed along major north-trending strike-slip faults, and that tectonic style continued and exerted a major influence on the deposition and deformation of those Mesozoic basins. Such large-scale horizontal movements are difficult to identify in the New South Wales portion of the Clarence-Moreton Basin. Strike-slip movements appear to have occurred along the Richmond Horst/South Moreton Anticline, but no major horizontal displacements can be identified with certainty. The Coraki strike-slip fault, proposed by O'Brien, Korsch et al (1994) as passing through the Coraki, Tullymorgan and Clifden structures, is not apparent on seismic sections as a continuous displacement and its existence is questionable.

The Clarence-Moreton Basin apparently developed as a sag on the older Palaeozoic rocks of the New England Fold Belt. This Basin may have been in the form of a large half graben with the controlling fault or faults being east of the present coastline. No basin-margin faults are known within the present limits of the Basin in New South Wales, but they may exist along the western margin where no seismic data have been obtained to date. The Nymboida/Chillingham/Ipswich sequence was interrupted by several mild periods of folding and erosion, and the younger sediments of the Bundamba Group were laid down over those older units at a regional unconformity. The Basin gradually broadened with time (as can be seen by comparing the thickness of the Raceview Formation with that of the Walloon Coal Measures in Figures 10 and 22).

Non-marine sedimentation in the Clarence-Moreton Basin continued without any significant interruption from the Raceview Formation to the Grafton Formation. Sediments were supplied by streams flowing northward from highlands to the west, south and south-east of the Logan Sub-basin. Additional younger sediments of Early Cretaceous age, up to 3000 m in the east and 1500 m in the west, are believed to have been deposited over the Basin — but were later removed by erosion (Russell, 1994).

STRUCTURAL ELEMENTS

The structural features discussed below can be seen in Figure 9.

This discussion has been compiled by study of several published (referred to in text) and unpublished sources.

SOUTH MORETON ANTICLINE/RICHMOND HORST

The South Moreton Anticline has been defined by O'Brien, Korsch et al (1994, p. 198) as 'a broad structural high in the basement over which Clarence–Moreton Basin sediments thin and are folded'. The anticline is usually shown as extending from about latitude 27°50'S to about latitude 29°00'S (Figure 33). The eastern margin of the high is formed by the East Richmond Fault and the western margin by the West Ipswich Fault (Figures 9, 33). Both faults are believed to have a component of strike-slip and high-angle reverse movements. The anticline in Queensland appears to have been a basement high until deposition of the Ripley Road Sandstone and to have been affected by significant faulting during that time. In contrast, the anticline in New South Wales was not developed until the main period of folding in mid-Cretaceous time. The West Ipswich Fault was active until the time of deposition of the Gatton Sandstone, and was rejuvenated again in mid-Cretaceous time, but with only minor movement and in localised areas (Figure 34).

The South Moreton Anticline (Richmond Horst of Ties et al, 1985) is usually presented in the literature as a continuous anticlinal or horst-like structure. However, the seismic interpretation (Figures 35, 36) shows that no continuous anticlinal structure exists, and that in much of the area only basinward dip occurs across the structure. Likewise, the bounding faults appear to be discontinuous — eg in the Grevillia Anticline area there appears to be only minor faulting. In other areas, eg in the Pickabooba Prospect area (Figures 37 to 40), the estimated displacement of the East Richmond Fault is of the order 400 m to 500 m, as shown in Figure 34. The West Ipswich Fault on the south end of the South Moreton Anticline has movement confined to the basal Gatton Sandstone and older units. Further north, this fault apparently is visible on the surface and represents both older and younger movements. The displacement, however, is probably mostly confined to older units.

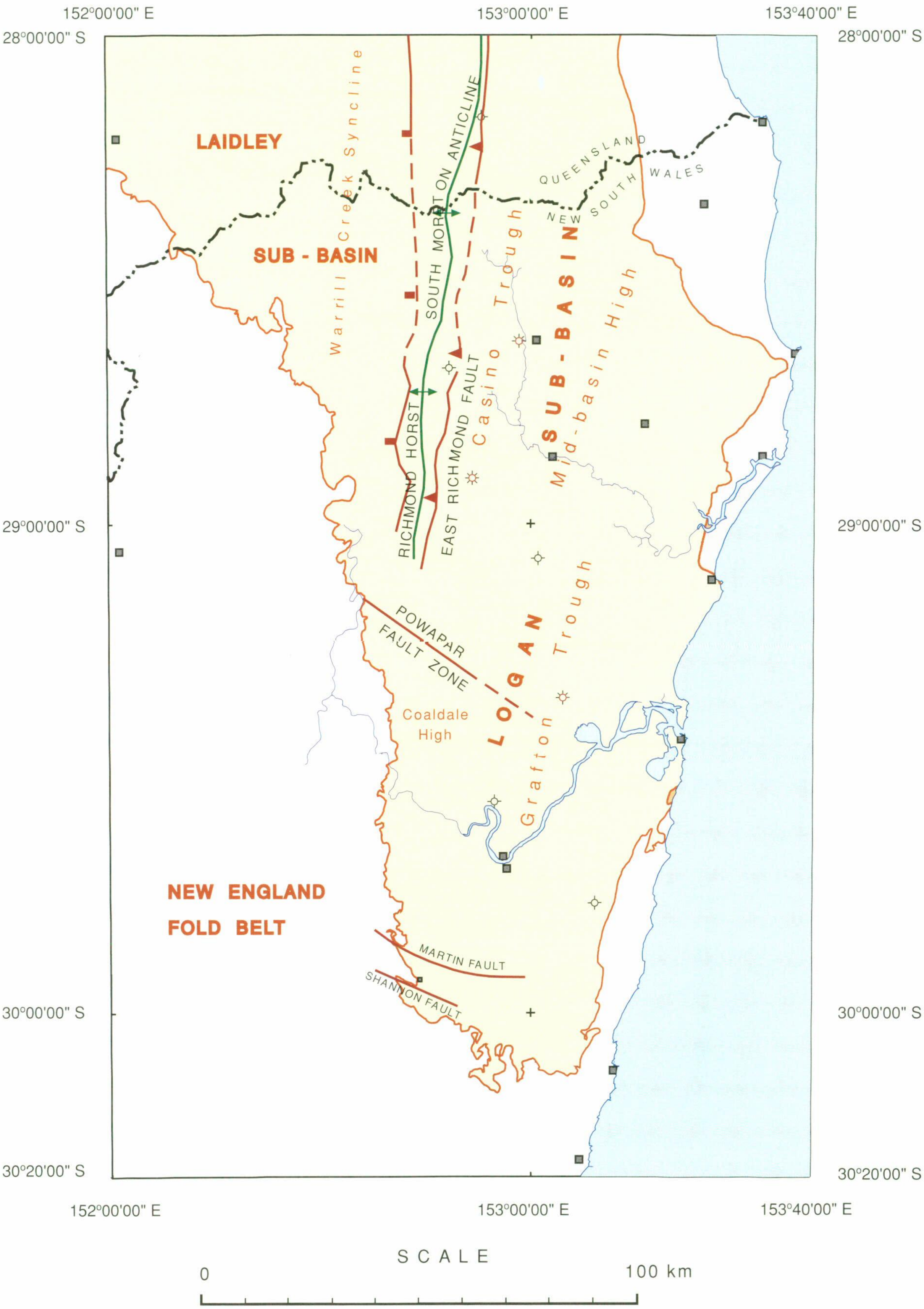


Figure 33. Selected major structural elements in the New South Wales portion of the Clarence-Moreton Basin.

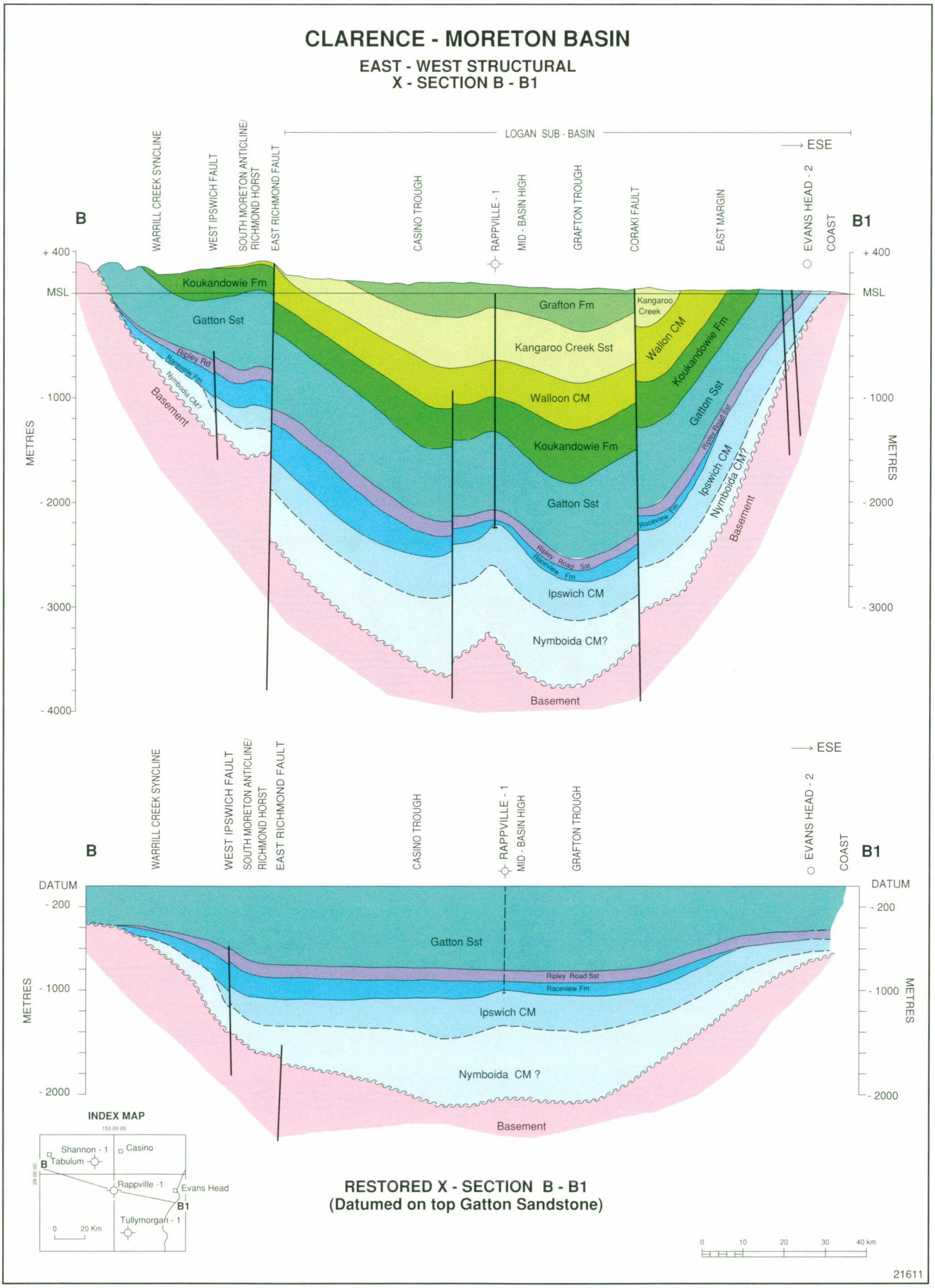


Figure 34. East–west cross-section across the central New South Wales portion of the Clarence-Moreton Basin, with a restored reconstruction on top Gatton Sandstone as a datum.

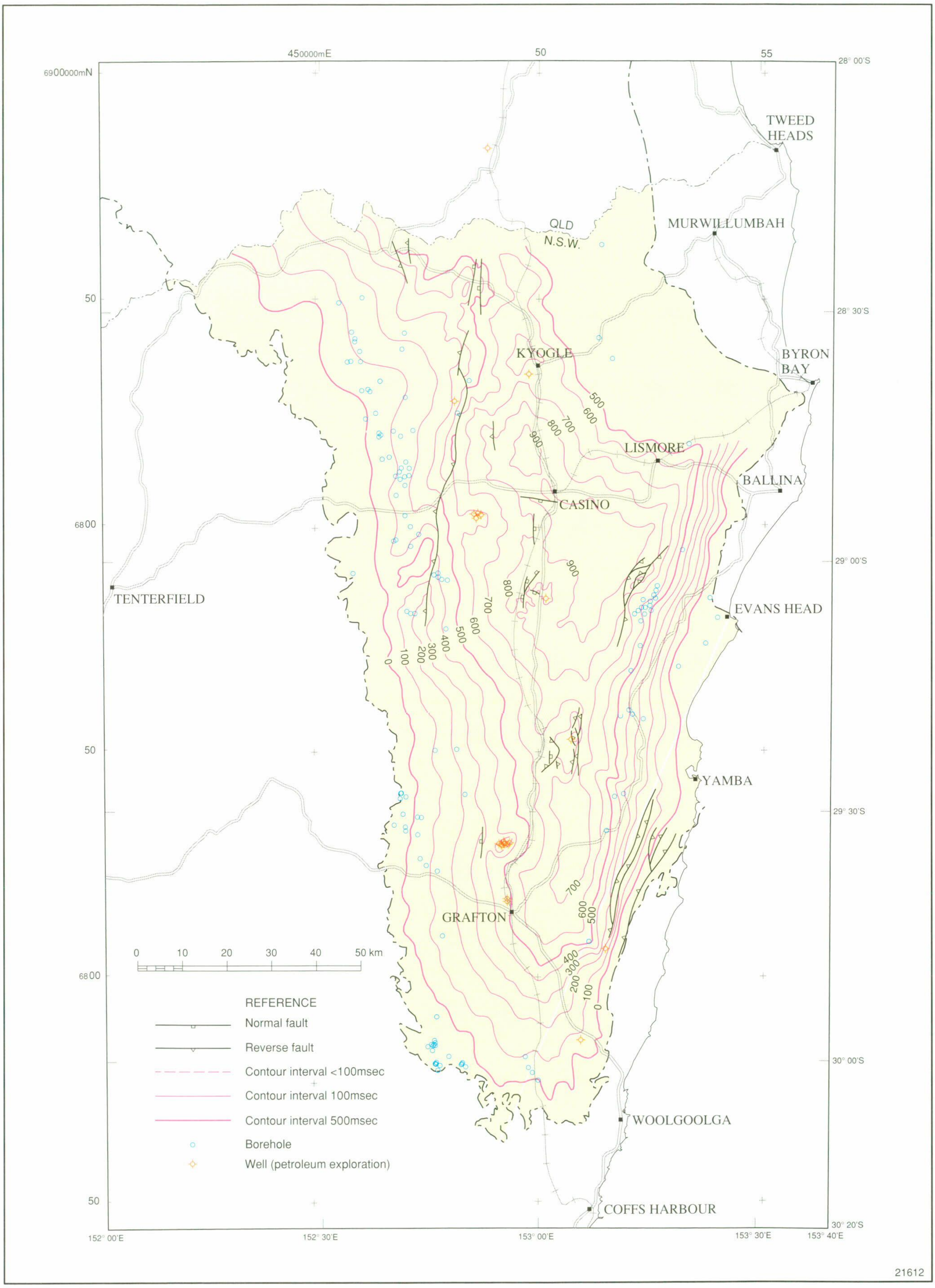


Figure 35. Two-way time structure map, top of Gatton Sandstone (Early Jurassic) in the New South Wales portion of the Clarence-Moreton Basin.

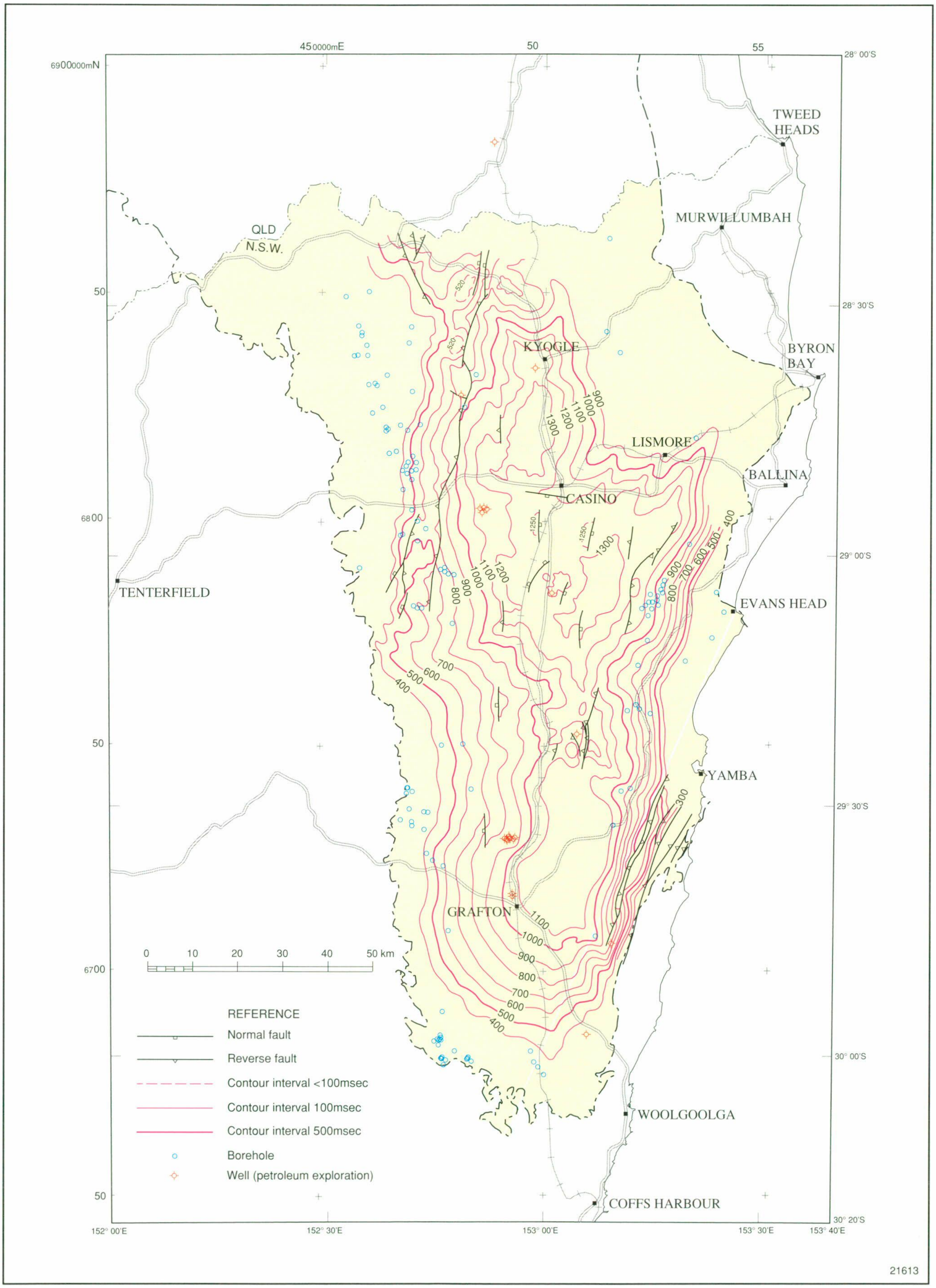


Figure 36. Two-way time structure map, top of Walloon Coal Measures (Late Triassic) in the New South Wales portion of the Clarence-Moreton Basin.

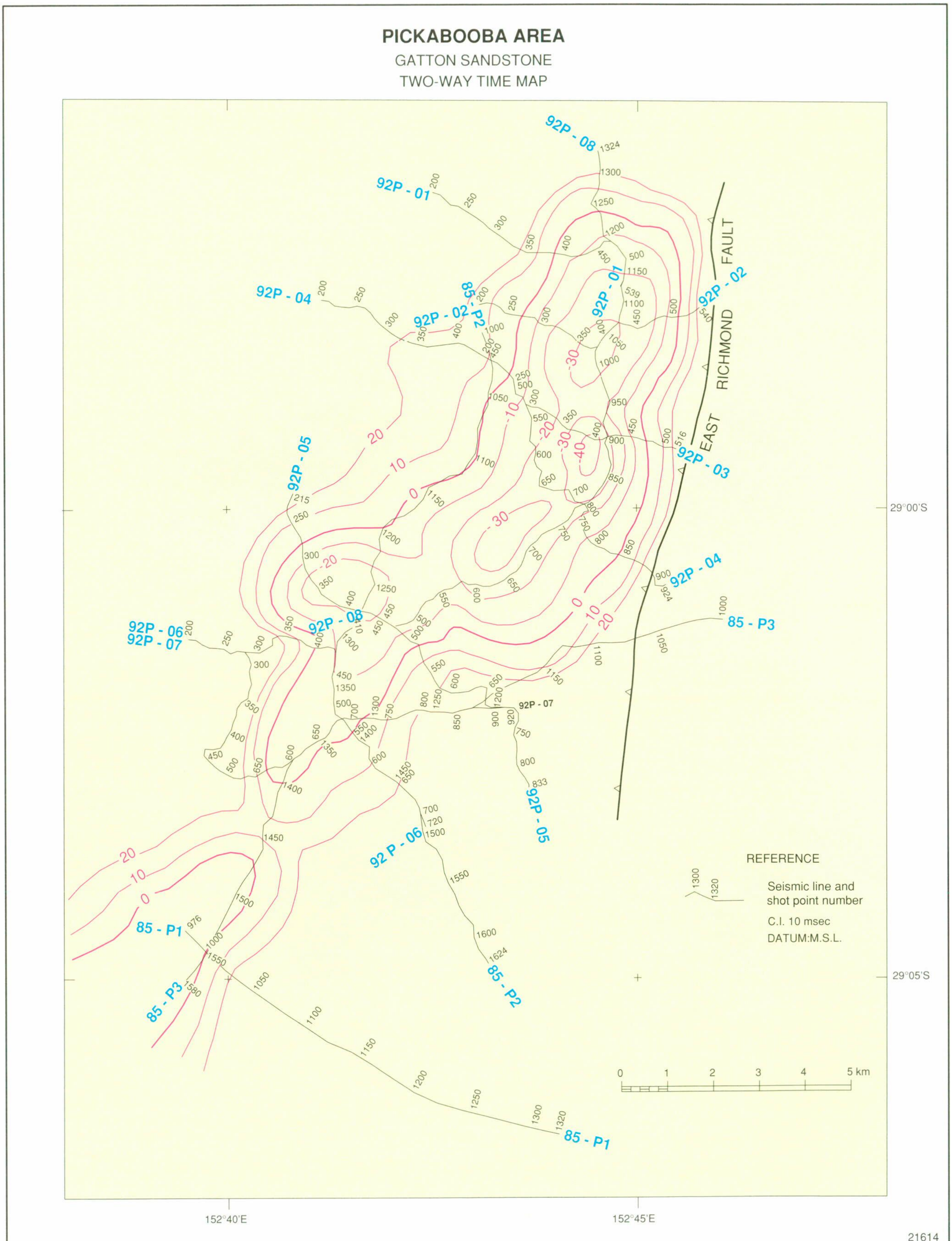


Figure 37. Two-way time map on the top of the Gatton Sandstone for the Pickabooba Prospect area, Clarence-Moreton Basin (New South Wales).

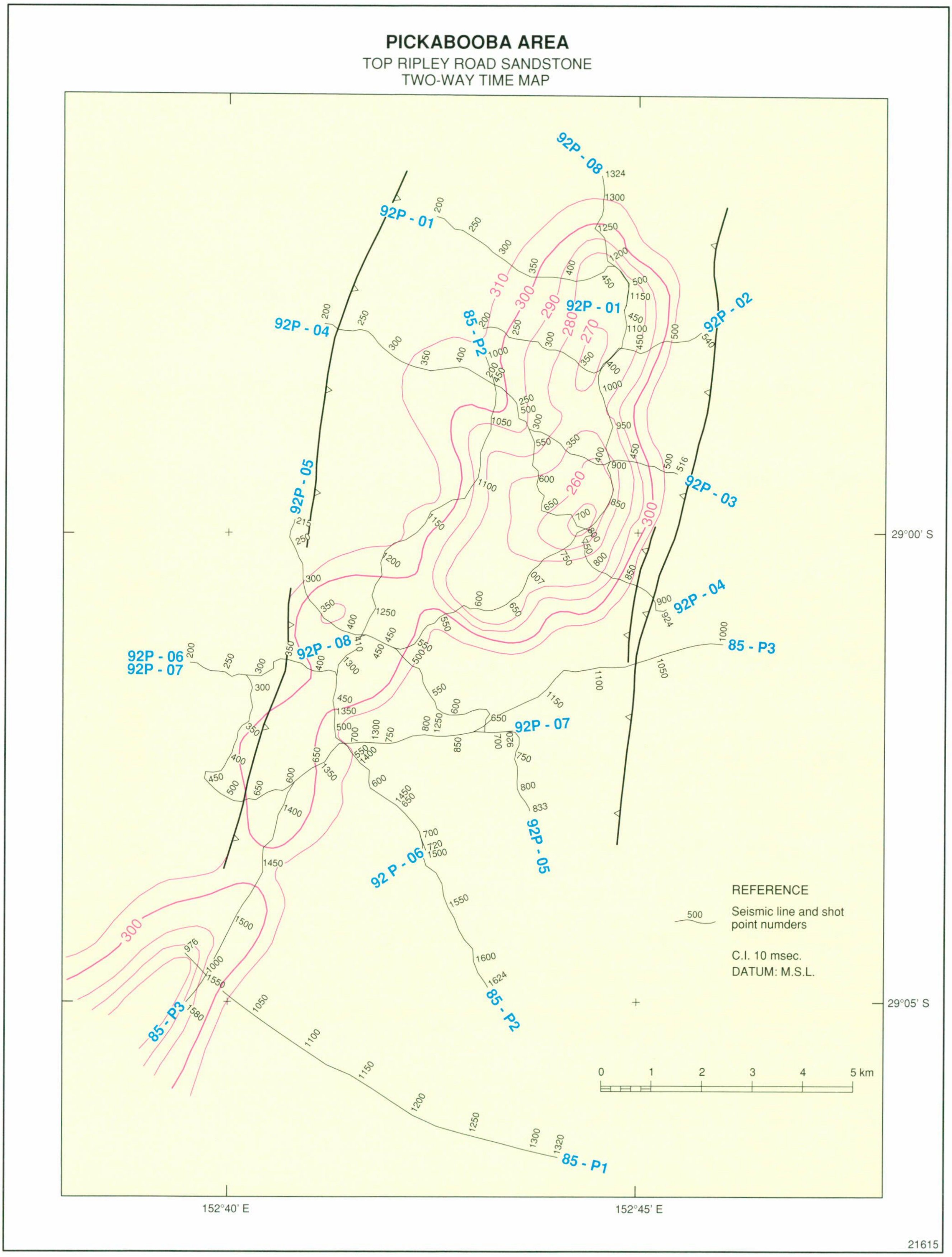


Figure 38. Two-way time map on the top of the Ripley Road Sandstone for the Pickabooba Prospect, Clarence-Moreton Basin (New South Wales).

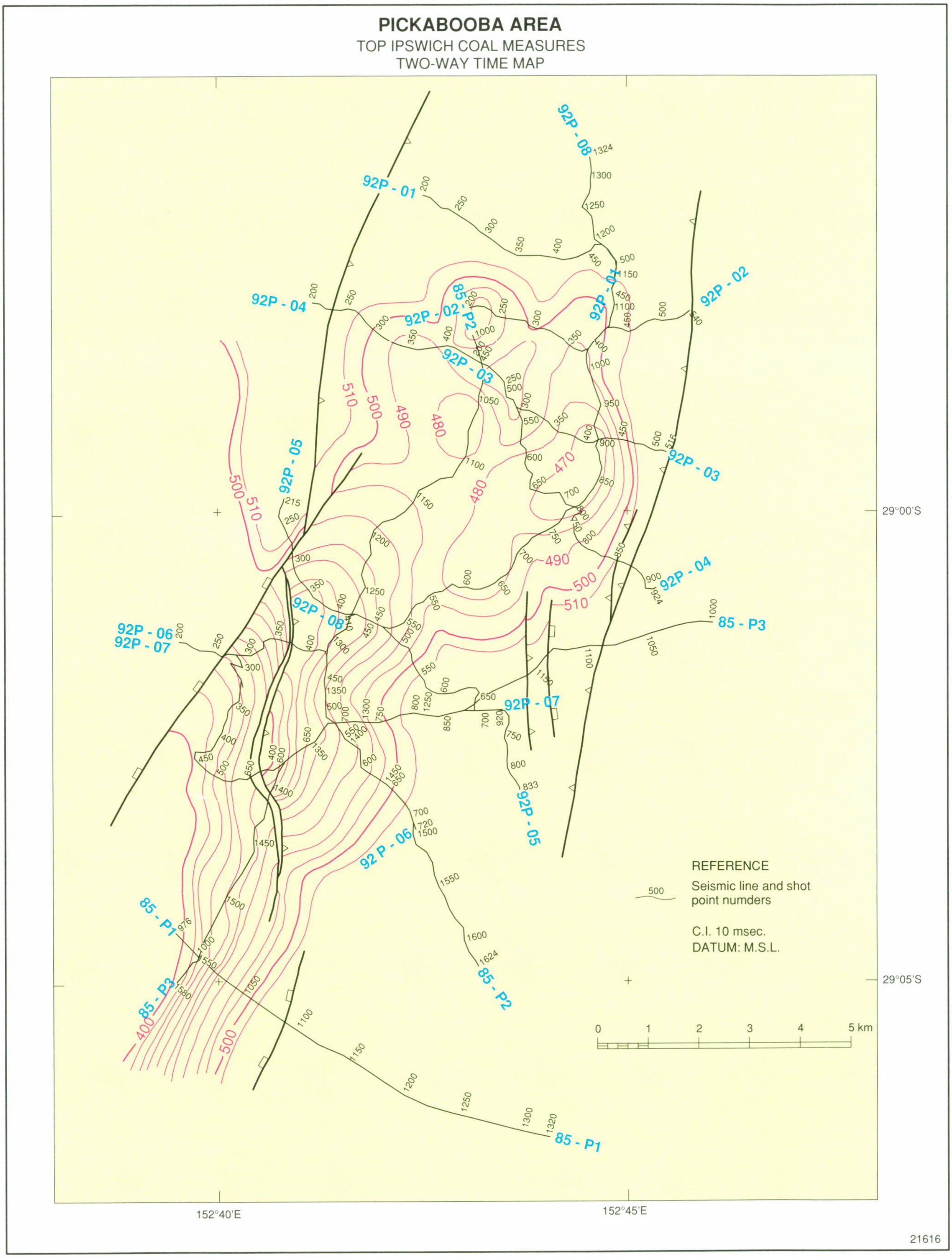


Figure 39. Two-way time map on the top of the Ipswich Coal Measures for the Pickabooba Prospect, Clarence-Moreton Basin (New South Wales).

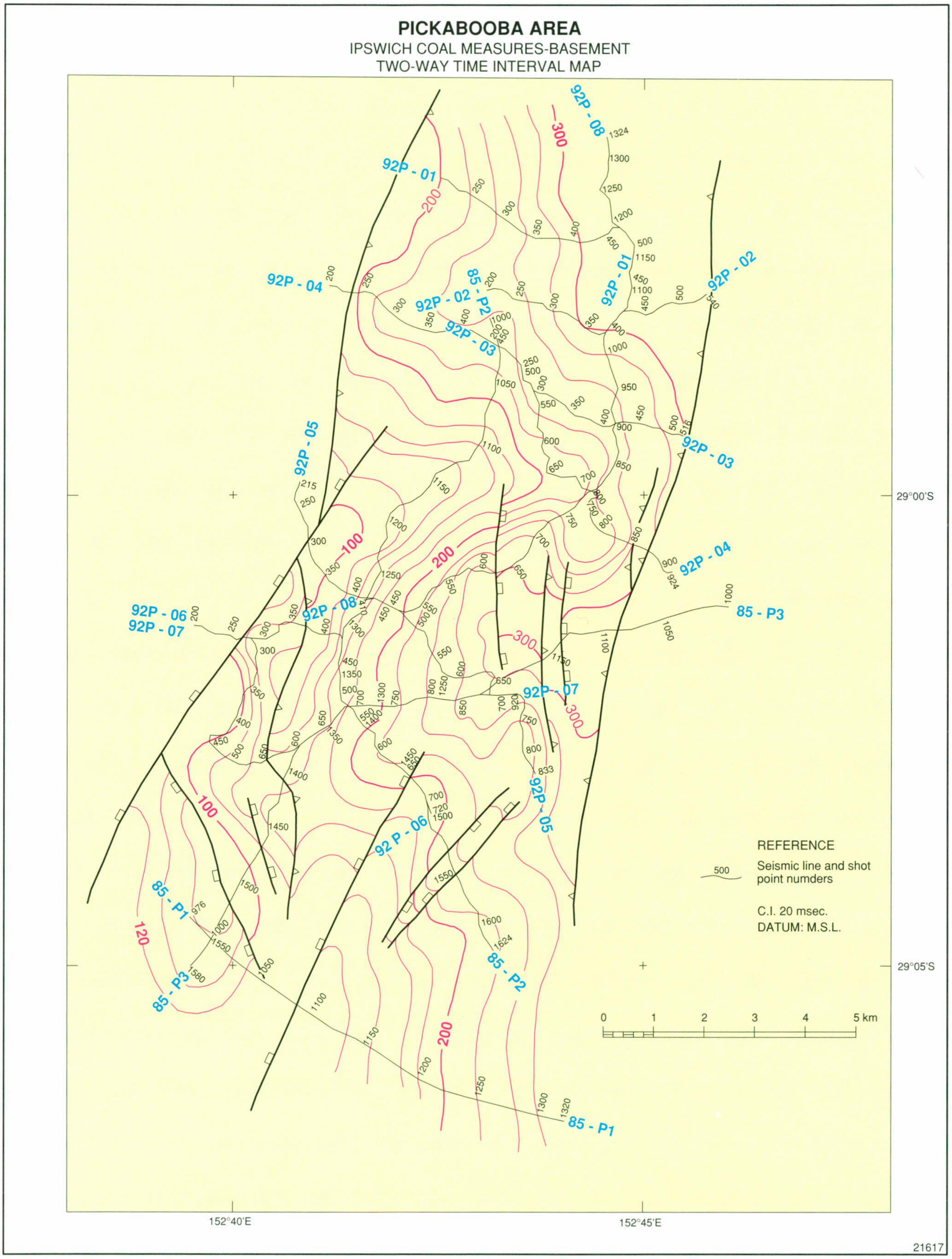


Figure 40. Two-way time interval map for the section from the Ipswich Coal Measures to basement, Pickabooba Prospect, Clarence-Moreton Basin (New South Wales).

In Queensland, the West Ipswich Fault forms the eastern margin of the Esk Trough — which contains sedimentary rocks of Middle Triassic age, which are possibly correlative to the Nymboida Coal Measures. The Esk Trough sedimentary rocks are confined to the area west of the West Ipswich Fault. The Nymboida Coal Measures, in the outcrop area around Nymboida, are east of the southern extension of the fault. This may be the result of the fault and the South Moreton Anticline not extending beyond latitude 29°S, allowing the Nymboida Coal Measures to extend along the western margin of the Clarence-Moreton Basin. Another possibility is that the South Moreton Anticline has been offset to the east by the Powapar Fault and again by the interpreted parallel fault to the south (Figure 9). The anticline would thus pass to the east of the Nymboida Coal Measures. Or, the Nymboida Coal Measures may have been deposited in the ancestral Logan Sub-basin and have had no lateral continuity with Esk Trough sediments.

The South Moreton Anticline, with its bounding faults, is more complex than suggested by current maps. Seismic lines, close together in the same area, may show features that are structurally quite different. This is to be expected where strike-slip, wrench tectonics have been in play. Much of the structuring may be a series of en echelon faults, splays and folds along deep-seated strike-slip basement faults. Until the nature of this structure is better known, it would probably be better to refer to it, at least in the New South Wales portion of the Clarence-Moreton Basin, as the 'Richmond Fault Zone' or the 'Richmond High'.

The East Richmond Fault appears to have been active during deposition of the Ipswich and Nymboida Coal Measures, but the amount of growth is difficult to estimate. Therefore, this possibility has been ignored in constructing the thickness map (Figure 8). The main period of displacement, however, was in mid-Cretaceous time.

LOGAN SUB-BASIN

The Logan Sub-basin is the basinal area between the South Moreton Anticline (Richmond Fault Zone) and the eastern margin of the Clarence-Moreton Basin. That Sub-basin is in turn divided into two basinal areas, the Casino Trough and the Grafton Trough (Figures 9, 33). These two Troughs were distinct areas of subsidence from Middle Triassic time through the Jurassic and probably into the Early Cretaceous. The Troughs were separated by a basement high known as the Mid-Basin High. That high area gradually disappeared as sedimentation progressed, and by Gatton Sandstone time the high was barely in evidence (Figure 34). The high was uplifted again during the mid-Cretaceous tectonic event. Whether or not the Mid-Basin High was present during deposition of the Ipswich/Chillingham/Nymboida sequence is not clear from the seismic data. However, it most probably came into existence during tectonic movements after deposition of the Ipswich Coal Measures.

The offshore Yamba Trough (Figures 9, 41) may be an extension of the Logan Sub-Basin — but, because no sub-surface stratigraphic data exist for this area, any correlation is conjectural.

COALDALE HIGH

The structural feature identified as 'Coaldale High' (Figure 9) is poorly understood as it is interpreted from surface geology in an area where no seismic data are available. It may be an extension of the Mid-Basin High in the form of a northeast-plunging basement high. It could be of importance, if that interpretation

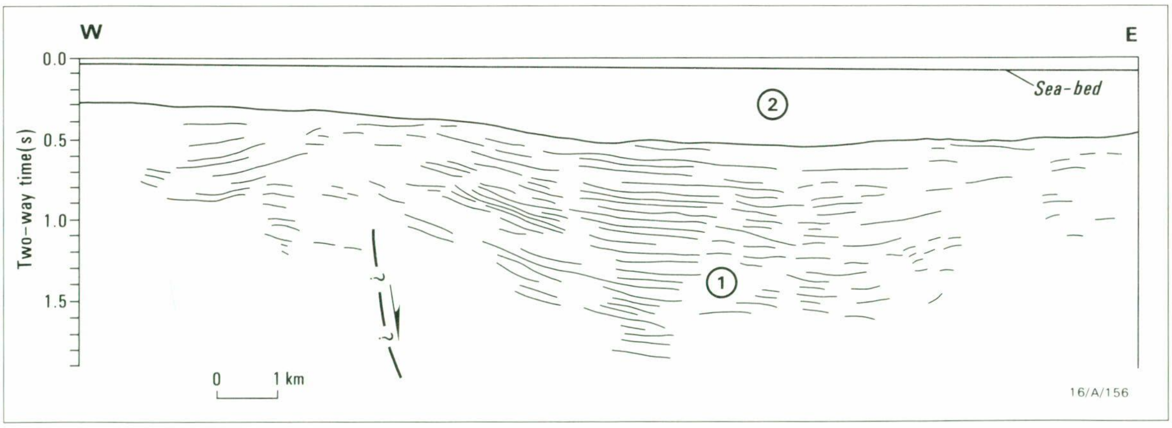


*Figure 41. Traces of seismic events from an approximately east–west line across the Yamba Trough. (The line is approximately north-west at left to south-east.) Sequence 1 is probable Clarence-Moreton Basin sedimentary section, although Ipswich Basin equivalents may be present. Sequence 2 is a veneer of Tertiary to Quaternary continental shelf deposits. Reproduced (with minor changes) with permission from O'Brien, Korsch et al (figure 15, qv for original source, Alin 1970) in Wells & O'Brien (1994), AGSO Bulletin **241**.*

is correct, as it would focus hydrocarbon migration southward out of the deep basinal area from further north in the Clarence-Moreton Basin.

POWAPAR FAULT ZONE

The Powapar Fault Zone (Figures 9, 33) appears to be a major fault or fault zone in the Clarence-Moreton Basin, with probable (sinistral) strike-slip and vertical down-to-the-northeast movements. It appears to be responsible for an offset in the Basin margin and for the intrusion of several dykes along the trace of the fault zone. It appears, in projection, to pass just south of the Tullymorgan thrust-faulted structure and may be involved in the development of that complex structure.

WARRILL CREEK SYNCLINE

A north–south trending syncline, the Warrill Creek Syncline, is located in the Laidley Sub-Basin (Figures 9, 33). The Syncline is well-developed between the West Ipswich Fault and the Gatton Arch in Queensland and appears to extend into the New South Wales portion of the Clarence-Moreton Basin. That syncline is poorly known in New South Wales because no wells or drillholes have penetrated below the mid-Koukandowie Formation in that area. The deepest drillhole to date is Urbenville-1, which penetrated a well-developed (thick) Walloon Coal Measures section. The only seismic line shot in that area shows that the Warrill Creek Syncline formed by uplift along the Richmond Horst/South Moreton Anticline — which reversed the eastward monoclinal dip. This uplift occurred after deposition of the Walloon Coal Measures, probably in mid-Cretaceous time. The Koukandowie Formation in that area is still well-developed, but the Gatton Sandstone, Ripley Road Sandstone and Raceview Formation are interpreted to be substantially thinner. An Ipswich/Chillingham/Nymboida sequence is present, but is difficult to interpret on the one seismic line available.

SHANNON AND MARTIN FAULTS

Two parallel faults traverse the south end of the Clarence-Moreton Basin in a west-northwest direction — the Shannon Fault and Martin Fault (Figures 9, 33). The movement was up-to-the-north, with a suspected horizontal component. The movement affected mainly Nymboida Coal Measures and older Palaeozoic basement rocks, but some movement has apparently occurred later which affected the overlying Bundamba Group and Walloon Coal Measures. The Kungala Fault appears to be an extension of the Martin Fault, but with reversed vertical displacement. The Kungala Anticline (Figure 9) developed in association with that fault, but has not been defined seismically. Vertical displacement along the Shannon and Martin Faults in the Nymboida Coal Measures may be of the order of 600 m to 700 m, but is of apparently substantially less magnitude in the overlying sedimentary section.

O'Brien, Korsch et al (1994) stated that the Clarence-Moreton Basin developed as 'Strike-slip movement continued, at least intermittently, into the Jurassic and Cretaceous' (p. 213). The evidence for this is not clear, although there does appear to be some reverse fault movement in the southern area of the Dyraaba lead (see later discussion), based on limited seismic control, that is of probable Early Jurassic age. In several sources used in compiling this review (cf. reference list) it has been accepted that the main period of compression, folding and faulting was in the mid-Cretaceous. These tectonic movements were caused by the sinistral clockwise rotation of the Lord Howe Rise against the Australian continent.

Opening of the Tasman Sea in Late Cretaceous time along the Dampier Fracture Zone, accompanied by sea-floor spreading, resulted in maximum maturation levels being reached in the Clarence-Moreton Basin during that time (Figure 42). That heating event, accompanied by uplift, is clearly indicated by apatite fission-track dating (Gleadow & O'Brien, 1994). The entire Tertiary period was occupied by erosion, or unroofing, of the Clarence-Moreton Basin. The effects of Miocene intrusive and extrusive igneous activity could have been important in the generation of hydrocarbons on a local scale. (For a more detailed discussion of structural evolution, see Shaw, 1978; Gleadow and O'Brien, 1994; Russell, 1994; O'Brien, Korsch et al 1994; and O'Brien, Powell and Wells, 1994). (There still exists the possibility that the Miocene igneous activity may have been a general heating event in the Clarence-Moreton Basin, which could have affected hydrocarbon generation on a regional scale.)

STRUCTURAL EVOLUTION AND HYDROCARBON MIGRATION

In several of the sources used in compiling this discussion (cf. reference list) it is considered that the major period of folding (ie structural trap formation) in the New South Wales portion of the Clarence-Moreton Basin occurred in mid-Cretaceous time. The maximum palaeotemperatures were reached in mid-to-Late Cretaceous time (Figure 29). As stated by O'Brien, Powell and Wells (1994): 'At that time the principal structural traps were in place and well placed to receive any migrating hydrocarbons' (p. 288).

Structural traps, considering the fluvial style of sedimentation throughout the Clarence-Moreton Basin, will probably have a significant stratigraphic

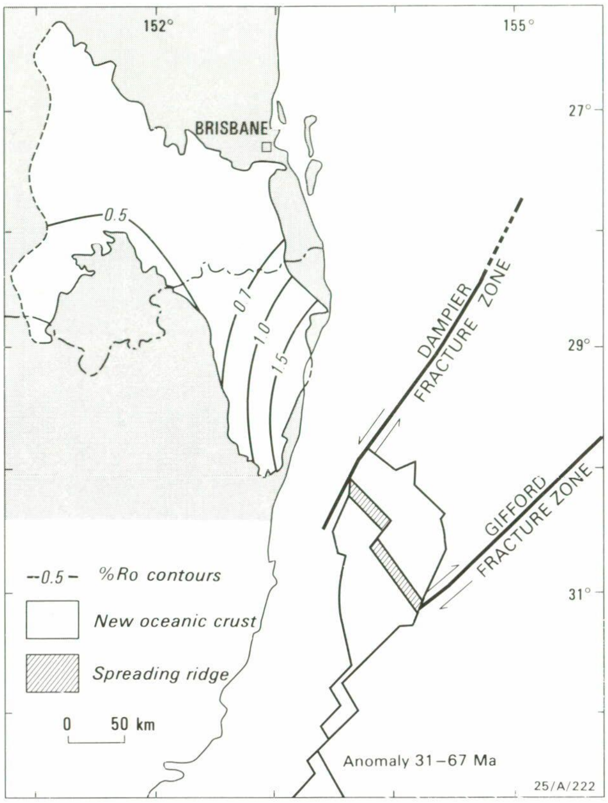


Figure 42. Geometry of the Tasman Sea opening relative to the Clarence-Moreton Basin. The Dampier Fracture Zone runs along the coast adjacent to the south-eastern corner of the Clarence-Moreton Basin (which also shows the highest level of thermal maturity). Because the spreading ridge met the coast at a high angle, the thermal anomaly stayed close to the coast along this segment of the fracture zone for longer than would occur on a normal margin. Vitrinite reflectance is designated '% Ro'. Reproduced with permission from Gleadow & O'Brien (figure 5, qv for original source, Shaw 1979) in Wells & O'Brien (1994), AGSO Bulletin ***241****.*

component. Depositional facies (eg point bars, channel sands, etc) plus diagenetic factors (eg permeability barriers, secondary porosity, etc) may result in the productive areas being located on the flanks of a structure rather than on the culmination. If such entrapment has occurred, the relatively limited exploration to date may not have identified the traps. Simple stratigraphic traps related to pinchouts, unconformities or isolated sandstone bodies may be common in the Basin. These could have received and trapped hydrocarbons before the main period of structural development. Hydrocarbons in the latter traps may have remained in these sandstone bodies until the present time, or may have re-migrated during the mid-Cretaceous tectonic activity.

Structures that developed early, ie growth structures, would have the best chance of trapping hydrocarbons, as they could have trapped hydrocarbons at any or all periods of generation subsequent to trap formation. The 'Rappville High' appears to be one of the best examples of a growth structure. Rappville-1 was probably dry because of impermeable rocks which prevented the migration of hydrocarbons into the structure. Figures 43, 44 and 45 show the generation and migration patterns for the Walloon Coal Measures, Koukandowie Formation and the Raceview Formation at the time of maximum deposition — prior to folding, faulting and uplift.

In the Warrill Creek Syncline (cf. Figure 9), the lower part of the Koukandowie Formation and older units have maturities ranging from early to peak generation of oil (Figure 44). Very little, however, is known about the source rock qualities in that area. Structural deformation in that area has been very mild and any structural prospects will probably be of low relief and have a stratigraphic trapping component. The time of the synclinal development is post-Walloon Coal Measures time, probably mid-Cretaceous.

Because of the non-continuous nature of the sandstone bodies in the sedimentary section, it is unlikely that long-range migration of hydrocarbons has occurred. The maximum limit of migration is probably about 10 km to as much as 15 km.

Large quantities of gas have probably been generated in the Ipswich Coal Measures and Nymboida Coal Measures. The most likely migration route for the gas would be via fractures and faults into overlying reservoirs. Structural closures in the Bundamba Group, next to major faults, could thus be charged with gas from this relatively deep coal measures source. Structures (Figures 9, 33) along the East Richmond Fault, the Martin and Shannon Faults, and possibly the Powapar Fault Zone, probably have the greatest potential for accumulations of this type. These same areas would have the greatest potential for reservoirs having fracture porosity.

HYDROCARBON INDICATIONS

Gas shows in petroleum exploration wells in the New South Wales portion of the Clarence-Moreton Basin have been common in the section from the Walloon Coal Measures to the Ipswich/Nymboida Coal Measures. In Shannon-1, C_1 to C_5 gases were logged in the Walloon Coal Measures and Koukandowie Formation, decreasing to C_1 to C_3 at total depth in the Raceview Formation. This same pattern existed in the Rappville-1 well, except that no C_5 was present. In the Tullymorgan-1 well only C_1 was present. The Hogarth-3 well, located less than 1 km from Shannon-1, inexplicably logged only C_1 and C_2 gas in the Walloon Coal Measures and the Koukandowie Formation. One reasonable explanation for this might be that the chromatographic equipment at

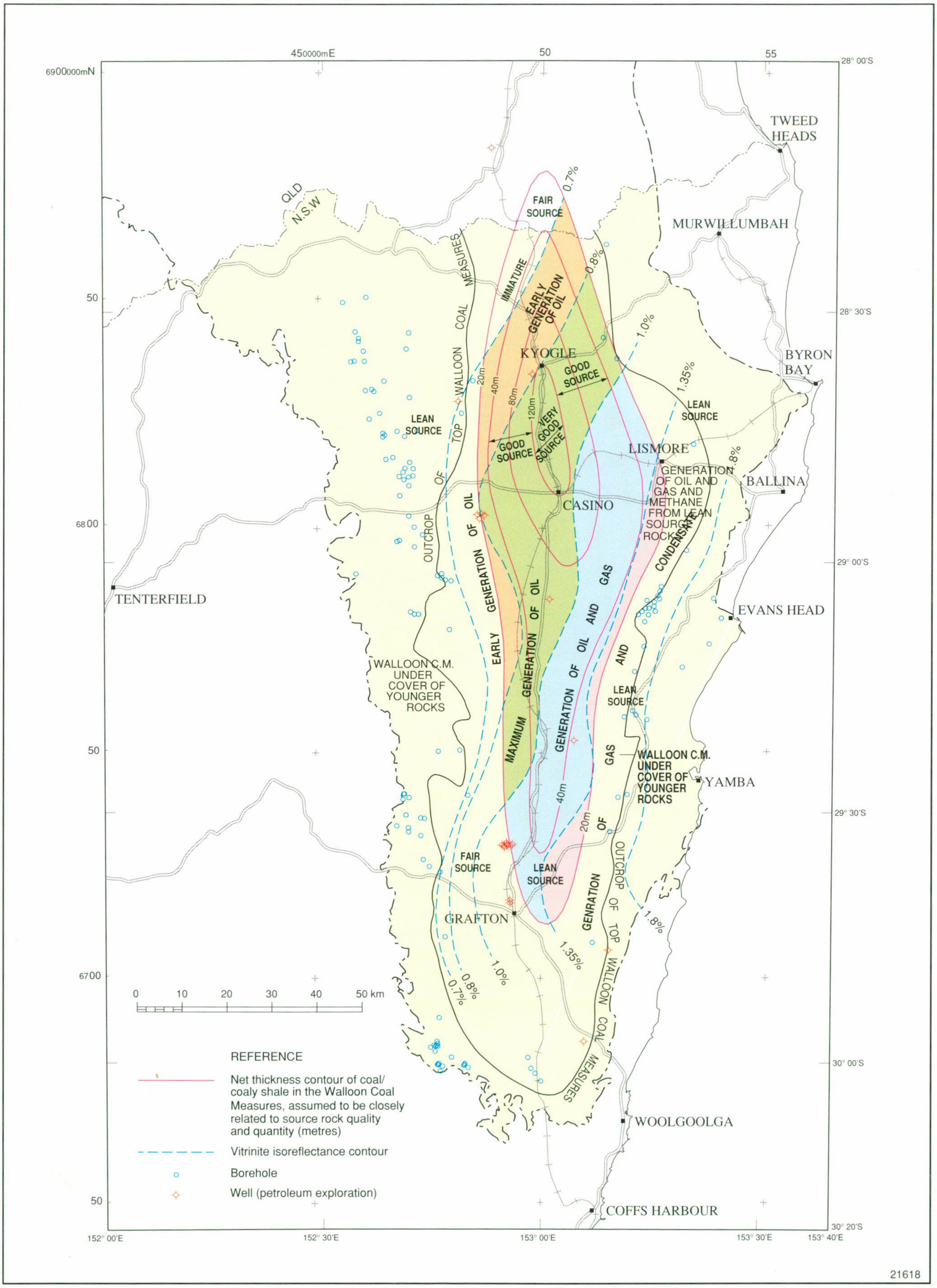


Figure 43. Map of the hydrocarbon generation areas for the Walloon Coal Measures in the New South Wales portion of the Clarence-Moreton Basin.

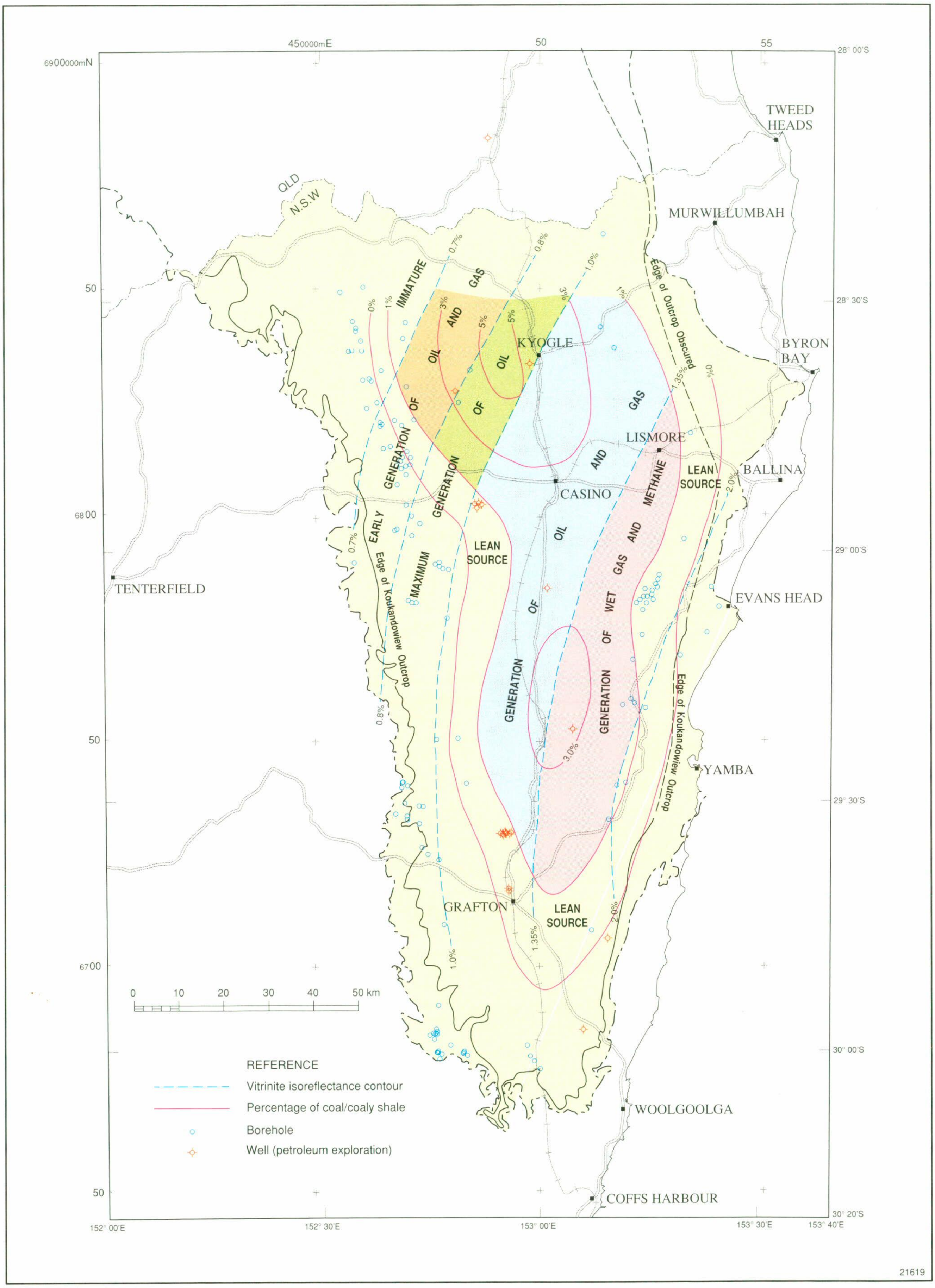


Figure 44. Map of the hydrocarbon generation areas for the Koukandowie Formation in the New South Wales portion of the Clarence-Moreton Basin.

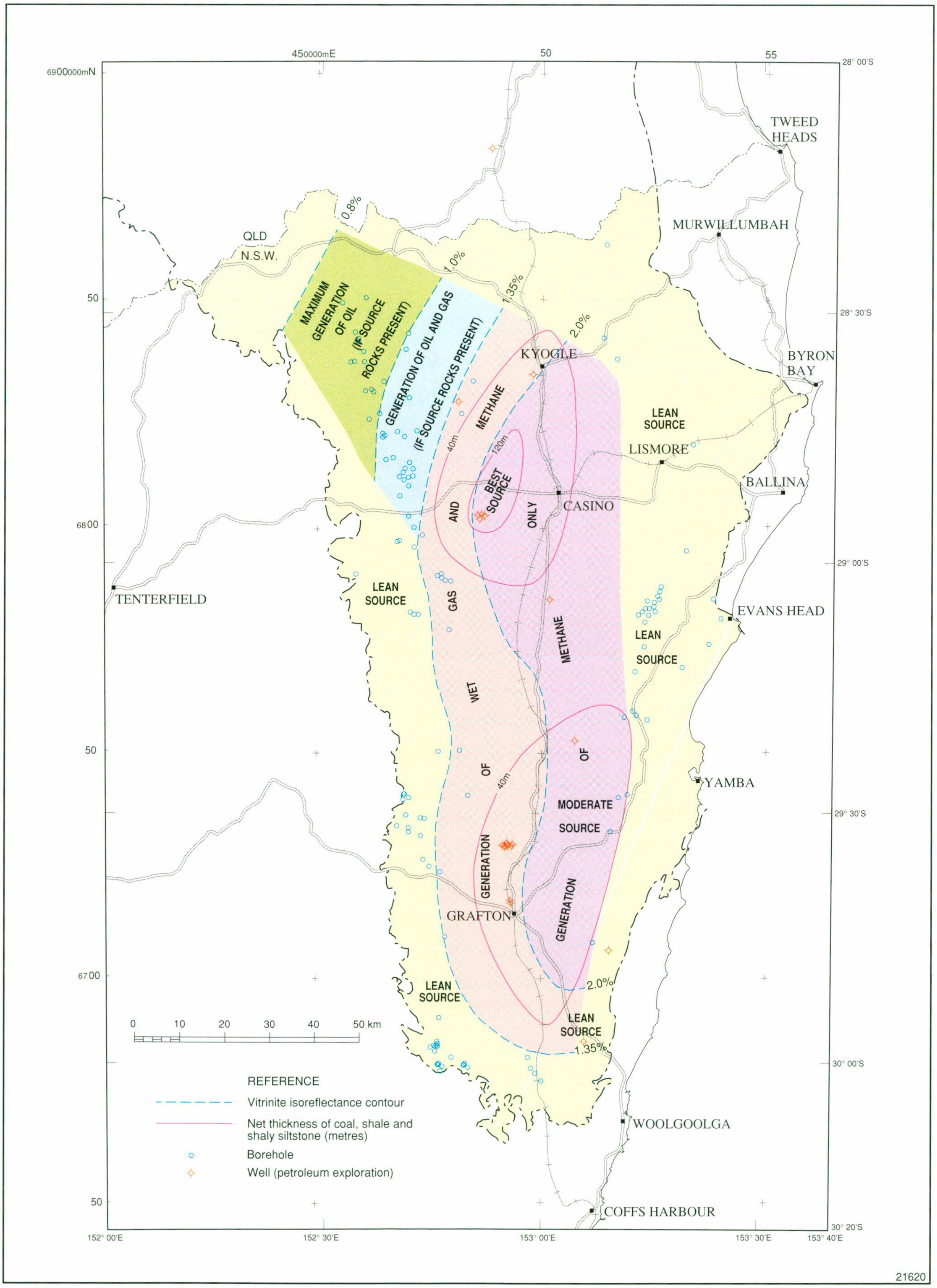


Figure 45. Map of the hydrocarbon generation areas for the Raceview Formation in the New South Wales portion of the Clarence-Moreton Basin.

Hogarth-3 was not functioning properly. A chromatographic log was apparently made for the Hogarth-2 well, but this log is not available. No other wells were logged using gas chromatography.

From the few available data noted, it appears that: methane is the most likely gas to be produced in the Grafton Trough; but methane plus heavier gases up to pentane may be present in the Casino Trough. Why the gas produced from the Koukandowie Formation in Hogarth-2 contained nearly all methane (94.1%), with only 3.65% of heavier petroleum gases, when gas shows in the nearby Shannon-1 consisted of C_1 with significant quantities of C_2 to C_5 is not easily explained. Possibly the gas originated from a more gas-prone source lower in the section or from coaly rocks within the Koukandowie Formation.

All of the (known) significant shows of hydrocarbons in the Clarence-Moreton Basin are listed in Table 3.

PLAY AREAS

There are nine play areas where varying geological conditions exist for the potential accumulation of hydrocarbons (Figure 46). These are described below, in order of decreasing potential — as perceived by the authors and based on presently available data.

CASINO TROUGH

The Casino Trough (Figure 46) has the thickest and richest source rocks in the Clarence-Moreton Basin. The Walloon Coal Measures and the Koukandowie Formation in that area have the greatest coal and carbonaceous shale percentages and those units should be sources for both oil and gas. The Raceview Formation in that area has, by far, the greatest coal and carbonaceous shale content found in the unit to date, indicating that the Raceview Formation may be a significant source of hydrocarbons (mainly gas) in the Casino Trough.

The Heifer Creek Sandstone Member has the best reservoir properties, as seen in Kyogle-1 and the Hogarth group of wells. The only permeable sandstones in the Walloon Coal Measures, as indicated on Micrologs, are in Kyogle-1 well. The Ripley Road Sandstone has permeabilities of zero to 57 md in the Kyogle-1 well and zero to 69 md in the Hogarth wells.

The best shows of gas have been encountered in Hogarth-2 (500 000 cfg/d or 14 000 cubic metres/day) and Kyogle-1 (gas flow to surface — rate TSTM), both from the Heifer Creek Sandstone Member. A 3000 cfg/d (85 cubic metres/day) flow in the Shannon-1 well came from a thin sandstone immediately above the Heifer Creek Sandstone Member.

The Ipswich and Nymboida Coal Measures may have supplied gas to overlying reservoirs, but are not in themselves considered very prospective for conventional hydrocarbons in the Casino Trough.

The north–south fault on which the Dyraaba lead (Figure 46) is located may extend northward beyond the present seismic control, and prospects may be developed along that fault. Other north–south faults may be present, as would be expected in a strike-slip fault regime, along which additional prospects may be developed.

RICHMOND HORST/SOUTH MORETON ANTICLINE (RICHMOND FAULT ZONE)

The Richmond Fault Zone is a structurally high area adjacent to and west of the Casino Trough of the northern New South Wales portion of the Clarence-Moreton Basin (where the best-developed source rocks are found). The Richmond Horst and South Moreton Anticline constitute two important components of the Zone.

The Heifer Creek Sandstone Member and
Ripley Road Sandstone

would be the primary reservoir objectives in the area of the fault zone. The sandstones of:

the Gatton Sandstone;
Raceview Formation (laterally between the shaly/coaly facies of the Casino Trough and the Laytons Range Conglomerate near the Basin margin); and
the Ipswich Coal Measures and Nymboida Coal Measures

would be secondary objectives.

Fractured reservoirs may be present near the East Richmond Fault. In areas of significant down-to-the-east displacement on that fault, source rocks of the Walloon Coal Measures and Koukandowie Formation are faulted against older units. Accordingly, hydrocarbons from the Walloon Coal Measures may have migrated into the Koukandowie Formation, or Koukandowie Formation hydrocarbons may have migrated into the Gatton Sandstone. The Ripley Road Sandstone would be sourced, via faults, from the Raceview Formation or the Ipswich/Nymboida Coal Measures.

Hydrocarbon accumulations on the South Moreton Anticline/Richmond Horst would be dependent on several conditions or considerations.

(i) The East Richmond Fault would need to be a conduit for hydrocarbon migration, rather than migration barrier or a sealing fault.

(ii) Migration of hydrocarbons over a distance of 5 km to 15 km from the main generating area of the Casino Trough would be required.

TABLE 3
EXPLORATION RESULTS (PETROLEUM), NEW SOUTH WALES PORTION OF THE CLARENCE-MORETON BASIN

WELL NAME	OPERATOR	YEAR	TD (m)	SHOWS
Grafton-1	N.S.W. Dept Pub. Wks	1902	1127	Flowed gas to surface (methane) from interval about 945 m, possibly Heifer Creek Sst. Mbr. When tested in 1950s (2.25 cf/h to 2.55 cf/h or 1.5 m^3/day), paraffin oil in water sample.
Halfway Creek-1	Clarence R. Pros. Co.	1931	784	Oil staining from sandstone at 409 m.
Grafton-2	C.R.B.O.E. Co.	1955	1397	No shows.
Nymboida 'I'	JCB	1955	236	Blew out gas and water from Basin Creek Fm. of the Nymboida CM — still blowing after 4 years.
Nymboida Colliery	-	1956	-	Methane explosion which killed several miners and caused abandonment of this section of the colliery. Explosion occurred in Farquar seam in Basin Creek Fm.
Clifden-1	C.R.B.O.E. Co.	1959	393	Minor gas shows — 606 ft and 880 ft (185 m and 268 m). [Grafton-3]
Clifden-2	C.R.B.O.E. Co.	1962	592	0.1 million cfg/d (2800 m^3/d) (mainly methane) from Marburg Subgroup (probably Heifer Creek Sst. Mbr) at 585 m to 592 m.
Clifden-3	Burmah Oil Co.	1963	2288	Gas shows in Ipswich (?Nymboida) Coal Measures, 1920 m to 1966 m, 2027 m to 2057 m.
Kyogle-1	Mid Eastern Oil	1963	2490	Numerous gas peaks in Walloon CM and Koukandowie Fm., with trace to good fluorescence, and cut, DST at top of Heifer Creek Sst. Mbr flowed water to surface with gas (mainly methane) at rate TSTM. Oil show with fluorescence at top of Gatton Sst. with trace oil recovered on DST. Minor fluorescence in Ripley Road Sst.
Clifden-4	C.R.B.O.E. Co.	1963	762	Fluorescence and minor gas shows in the Heifer Creek Sst. Mbr.
Sextonville-1	Mid Eastern Oil	1964	2230	Gas shows in Heifer Creek Sst. Mbr, Gatton Sst, Ripley Road Sst., and Raceview Fm. and Ipswich CM.
Tullymorgan-1	Cities Services Inc.	1965	2311	Faint petroliferous odour and cut fluorescence from cores in Koukandowie Fm. undiff. and the Heifer Creek Sst. DSTs recovered mud; gassy mud; gas cut cushion; with gas to surface in 8 min. (TSTM) (then died) from 1107.3 m to 1141.2 m (Bundamba Gp).
Clifden-5	C.R.B.O.E. Co.	1965	608	Minor gas shows.
Hogarth-1	C.R.B.O.E. Co.	1968	1218	Numerous gas peaks in Walloon CM., Koukandowie Fm. undiff. and Heifer Creek Sst. Mbr. Residual oil and fluorescence from cores in Heifer Creek Sst. Mbr and Walloon CM.
Clifden-6	C.R.B.O.E. Co.	1969	604	No shows.
Hogarth-2	C.R.B.O.E. Co.	1970	1113	Good oil saturation in cores of Koukandowie Fm. undiff. and in Heifer Creek Sst. Mbr. DST in top of Heifer Creek Sst. Mbr flowed at rate of 500 000 cfg/d (14 000 m^3/d). Trace oil saturation in Walloon CM. Other gas occurrences.
Hogarth-3	C.R.B.O.E. Co.	1970	957	No shows.
Hogarth-4	C.R.B.O.E. Co.	1974	1171	No data (well abandoned and operating company liquidated).
Shannon-1	Endeavour Resources	1983	2264	Numerous gas shows in Walloon CM associated with coal seams and sandstones, trace fluorescence. Several gas shows in Koukandowie Fm. undiff. and Heifer Creek Sst. Mbr. DST in basal Koukandowie Fm. undiff. flowed gas estimated at 3000 cfg/d (85m^3/d). Gas peaks in Gatton Sst., Ripley Road Sst. and Raceview Fm.
Pillar Valley-2	NSW Mines Dept	1984	1740	Stratigraphic well. Gas show at 1481.7 m, coaly bands degassed vigorously.
Rappville-1	Endeavour Resources	1985	2332	Good fluorescence and cut in Kangaroo Creek Sst. and Walloon CM, with high background of C_1 to C_4. Several gas peaks of C_1 to C_4 in top of Heifer Creek Sst. Mbr. DST recovered 135' (41.1 m) gas cut mud from Marburg Subgroup, 1331.4 m to 1344.1 m. Gas peaks in Gatton Sst., Ripley Road Sst., and Raceview Fm.; C_1 to C_3.
Maclean-1	BMR	1985	665	Stratigraphic well.

cf/h = cubic feet per hour.

cfg/d = cubic feet of gas per day (one cubic metre equals 35.315 cubic feet).

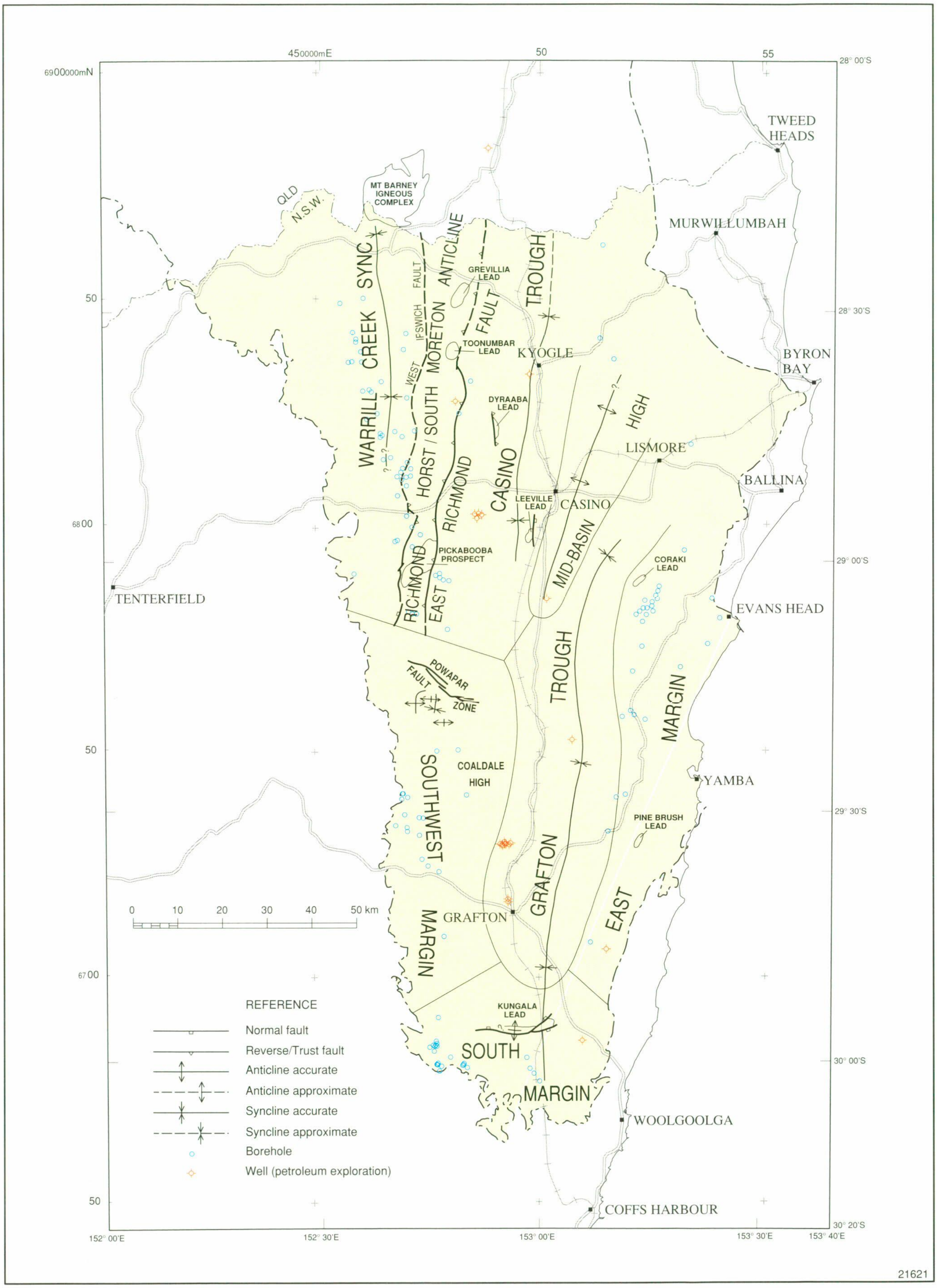


Figure 46. Map of the identified play areas, prospects and leads in the Clarence-Moreton Basin in New South Wales.

(iii) Although no core analyses are available for Sextonville-1 (the only deep well drilled in this play area), visible porosities from core and cuttings were very poor and no effective reservoirs were observed — the extent of this condition over the whole area being unknown.

(iv) The sandstones of the Heifer Creek Sandstone Member may be at depths of only a few hundred metres in some parts of the area — in which case the overlying portion of the Koukandowie Formation would need to be a good seal. However, at such depth the reservoir pressure and the volume of the gas reserves may be too low for an economic accumulation of gas, with shallow oil, if present, being a more viable 'target'.

One prospect, the Pickabooba Prospect, has been delineated by seismic data in the southern end of the area (Figure 46, cf. Figures 37 to 40).

In the northern end of the play area, two leads are known:

the Grevillia Anticline, defined by surface geology and one seismic line; and

the Toonumbar Anticline, defined by surface geology alone.

The Grevillia Anticline is a slightly faulted anticlinal turnover within a larger, gentle anticlinal structure across the entire Richmond Horst/South Moreton Anticline. The Toonumbar Anticline (surface mapping), south of and on trend with the Grevillia Anticline, is possibly an extension of the Grevillia Anticline and these two structures could be part of a single large anticlinal structure. The Koukandowie Formation is on the surface, and the Heifer Creek Sandstone Member is shallow, at about 200 m depth, which may preclude hydrocarbon accumulation in that unit. The major objective in those structures would be the Ripley Road Sandstone, with secondary objectives being the Heifer Creek Sandstone Member, Gatton Sandstone, Raceview Formation and the Ipswich/Nymboida Coal Measures.

GRAFTON TROUGH

The Grafton Trough (in the centre of the southern portion of the Clarence-Moreton Basin in New South Wales, Figure 46) appears to have fair quality source rocks in the Koukandowie Formation, Walloon Coal Measures and Raceview Formation, but of poorer quality and/or quantity than in the Casino Trough. The Grafton Trough is more likely to contain gas or gas/condensate, with a much lower chance for oil because of the higher maturation levels.

Permeabilities in the Heifer Creek Sandstone Member and Ripley Road Sandstone are fair to poor in the few wells drilled to date in the Grafton Trough. Some permeability exists in the top of the Gatton Sandstone, as seen in the Tullymorgan-1 well (DST flow of 3000 cfg/d, 85 cubic metres per day). The Clifden-2 well flowed about 100 000 cfg/d (2800 cubic metres/day) from what appears to be the top of the Heifer Creek Sandstone Member, but this is poorly documented.

No undrilled leads or prospects are currently known in the Grafton Trough area. The most likely prospects to be developed would be faulted anticlines, or tilted fault blocks.

The Ipswich and Nymboida Coal Measures are very poorly known in the Grafton Trough. This section should have generated a considerable quantity of gas, and this gas could now be entrapped in sandstones within or above the coal measures.

SOUTH-WEST MARGIN

The 'South-west Margin' of the Clarence-Moreton Basin in New South Wales extends from the southern end of the Richmond Horst/South Moreton Anticline along the south-western margin of the Logan Sub-basin south to about latitude 29°45'S (Figure 46). It lies between the Grafton Trough and the south-western limit of the Logan Sub-basin. Very little is known of the structure, source rock or reservoir conditions in the South-west Margin because there are essentially no seismic data and very little drillhole data below the Walloon Coal Measures.

Hydrocarbons generated in the Grafton Trough could have migrated updip into this area if migration was possible over distances of 5 km to 10 km. Hydrocarbons would most likely be gas, with little possibility of oil. The Ipswich/Nymboida Coal Measures could be a significant source of gas in the area.

A possible regional stratigraphic trap may be present in the South-west Margin play area where the Ripley Road Sandstone overlies impermeable Raceview Formation, or some older impermeable unit, and is overlapped by the shaly Calamia Member of the Gatton Sandstone.

No data are available on reservoir conditions, but the Heifer Creek Sandstone Member and Ripley Road Sandstone would be the major objectives in the South-west Margin play area. The Gatton Sandstone, Raceview Formation and Ipswich/Nymboida Coal Measures would be secondary objectives.

The northwest-trending Powapar Fault Zone, located in the South-west Margin play area, appears to be a strike-slip (?transfer) fault with sinistral movement. Several north-trending surface anticlines are associated with this fault, and others may be present at depth. The wrench-like movements along the fault may have created fractured reservoirs in any of the sedimentary units and possibly even in basement rocks.

The Coaldale High (Figure 46) has been identified from the surface outcrop pattern. It is about 25 km long and about 15 km wide and appears as a broad, low-relief nose plunging basinward. Very few seismic data are available in the Coaldale High area and the basic structure at depth is unknown. It may be an extension of the Mid-Basin High, or it may be associated with the Powapar Fault Zone or with other northwest-trending strike slip faults, or it may have its origin associated with all of these structural elements. It could have prospective structural or stratigraphic traps around its eastern margin. If the overall structure is a plunging nose into the main part of the Clarence-Moreton Basin, this would act as a focussed migration route for hydrocarbons out of the Basin toward the Coaldale High.

Conceptually, the South-west Margin play area should rank ahead of the Grafton Trough, but because of the lack of both seismic and well data, it has been ranked lower than the Grafton Trough in this assessment.

MID-BASIN HIGH

The Mid-Basin High (Figure 46) would be ranked third if it were not for the poor results of the Rappville-1 well. For reasons unknown at this time, Rappville-1 had poor reservoir development in all of the objective horizons. The Mid-Basin High is ideally positioned to be charged with oil and gas from the Walloon Coal Measures, gas/condensate from the Koukandowie Formation, and gas from the Raceview Formation. The 'High' was a major growth structure from Raceview Formation time through to Ripley Road Sandstone time, and was further uplifted again during the main period of deformation in mid-Cretaceous time.

Very little is known about the Mid-Basin High to the north of the Rappville-1 well. It apparently extends north-northeasterly towards the Nimbin area beneath the cover of Tertiary volcanic complex rocks. The western flank of this 'High' borders the Casino Trough, where the best source rocks in that part of the Basin are present. This western area, because of more favourable maturation levels, higher quality source rocks and better reservoir conditions, should be considered as more prospective than the eastern flank of the 'High'. The lack of effective reservoirs in the Rappville-1 well could be a localised diagenetic occurrence, as seen in other areas, and the Mid-Basin High could be more prospective than the results of Rappville-1 would at first indicate.

EAST RICHMOND FAULT

The narrow area to the east of the East Richmond Fault (Figure 46), ie the downthrown area, may have traps associated with closure against the Fault, provided the Fault is sealing. Structural closure or cutoff of isolated permeable zones against the Fault would be the main trap types. Faulting may have created fractured reservoirs in any of the sedimentary units.

One lead is suggested opposite the Toonumbar Anticline at a bend in the East Richmond Fault where structural closure is possible, but where no seismic data are available.

Because the East Richmond Fault play area adjoins the Casino Trough, where the best source potential exists, any trap of significant size there would be highly regarded.

SOUTH MARGIN

The southern portion of the Logan Sub-basin, south of about latitude 29°45'S (Figure 46) is considered a separate play area because of the known east–west faulting and associated folding, plus the known gas potential of the Nymboida Coal Measures in the area.

The Koukandowie Formation and Walloon Coal Measures are believed to be a poor source of hydrocarbons in the South Margin area. The Raceview Formation may be a poor to fair source for gas/condensate. The principal source would probably be the Ipswich/Nymboida Coal Measures sequence — which is known to have generated gas, as seen in mining operations and drillholes in the area. That gas could have migrated into sandstones in the Ipswich/Nymboida Coal Measures and/or into sandstones in the Bundamba Group. Fractured reservoirs near the major faults in the area are a distinct possibility, as indicated by the Nymboida-'I' drillhole that blew out with gas and water from the upper member of the coal measures. That drillhole 'blew' for at least four years from a sandstone interval in a fractured fault zone, indicating a gas volume of some significance.

The Kungala Anticline, associated with a major fault, possibly the extension of the Martin Fault, is known from surface geological studies (Figure 9). No seismic data are available in that area, but the possible structural closure there could be sufficiently large to contain substantial gas resources.

The Ripley Road Sandstone may pinch out in the South Margin play area in a fashion similar to that in the South-west Margin play area. In such a setting, the sandstone could be a target — apart from the faulted, anticlinal structures.

WARRILL CREEK SYNCLINE

The Warrill Creek Syncline, in the Laidley Sub-basin (north-western part of the Clarence-Moreton Basin in New South Wales, Figures 9, 33 and 46), has some exploration potential in that good permeability has been demonstrated by a water flow to surface from the top of the Heifer Creek Sandstone Member in the Urbenville-1 bore. Maturation levels in the Koukandowie Formation are at the early oil generation level, while the Raceview Formation is at peak maturity for oil generation. Those two units, however, may be low in TOC and would thus be ranked as poor sources of hydrocarbons, probably limited to gas only.

The Ipswich and Nymboida Coal Measures, if present, may be a source of gas.

One lead, a well-developed anticlinal turnover in the Ipswich/Chillingham/Nymboida section near Urbenville, has been identified on the only seismic line in the Warrill Creek Syncline play area. As no drillholes or wells have penetrated this section, the source rock and reservoir potential are unknown.

The Warrill Creek Syncline is a broad, low relief synclinal structure developed in post-Walloon Coal Measures time, probably during the major folding/faulting event in mid-Cretaceous time. Any prospective structures will, accordingly, probably be low relief anticlinal or domal structures.

EAST MARGIN

The East Margin play area of the Logan Sub-basin (Figures 9 and 46) is considered, because of the high maturation levels in this area, to be prospective only for dry gas. However, because of the highly faulted and complex nature of the prospective structures, the possibility of breached structures is a major concern.

Also, the steep dip and exposure of all units at the surface in the East Margin play area would have enabled the great majority of hydrocarbons to escape to the atmosphere.

Two structures, Coraki and Pine Brush, have been mapped using seismic data, but these are not considered to be drillable prospects at the present time.

GEOPHYSICAL DATA

Seismic, gravity and magnetic data exist for the Clarence-Moreton Basin, with seismic data providing the most effective means of identifying potential hydrocarbon traps. Favourable and less favourable aspects of the available geophysical data are presented below.

SEISMIC DATA

SEISMIC DATA COVERAGE

There have been approximately 2000 line kilometres of seismic data recorded in the onshore area of the New South Wales portion of the Clarence-Moreton Basin. Those data were acquired between 1962 and 1992 — those acquisitions being made during 16 different surveys (Table 4). In addition to this onshore coverage, approximately 1000 line kilometres of seismic data were acquired in the offshore Yamba–Evans Head area during 1969 to 1971. A seismic coverage map for onshore surveys shows locations of the existing control (Figure 47).

The quality of the seismic data varies from good to poor depending on the vintage of the data and the nature of the energy source. The 1992 multi-fold Vibroseis data (92P — Pickabooba Survey) is the best quality seismic data in the New South Wales Clarence-Moreton Basin, and the 1962 single fold dynamite data (Lismore Survey) is the poorest. However, it has been demonstrated that improvement can be achieved by reprocessing the

TABLE 4
CLARENCE-MORETON BASIN SEISMIC SURVEYS

Year	Report No. DMR	Name or Area, Type, Contractors	Survey Length, km
1962	SS018	Casino Seismic Survey, single fold dynamite, Austral	200.0
1963	SS030	Blue Knob Seismic Survey, single fold dynamite, General Geophysical	34.6
1966	SS062	Lismore (Nimbin) Seismic Survey (LIS-M), single fold dynamite, Austral	55.5
1968	SS072	South Grafton Seismic Survey, single fold dynamite, Namco	17.6
1969	SS094	Yamba–Evans Head Marine Seismic Survey (MA), 24-fold airgun, Teledyne (processed by Teledyne, Houston)	772.6
1970	SS102	Yamba–Evans Head Marine Seismic Survey No. 2, 24-fold airgun, Teledyne (processed by Teledyne, Houston)	65.5
1971	SS103	Yamba–Evans Head Marine Seismic Survey No. 3, 24-fold airgun, Teledyne (processed by Teledyne, Houston)	?
1981	SS113	Richmond MiniSosie Seismic Survey (H81), 6-fold 'rammer', Layton (processed by Digicon, Singapore)	49.7
1982	SS121	Shannon Seismic Survey (S82), 12-fold 'Vibroseis'®, SSL (processed by Digicon, Brisbane)	325.0
1983	SS122	Hogarth Seismic Survey (HS81), 12-fold dynamite, WOWCO (processed by Seismic Data Processors, Sydney)	108.0
1984	SS130	Richmond Range–Grafton (84SG), 12-fold dynamite, GES (processed by Digicon, Brisbane)	231.5
1983	SS132	Braemar Seismic Survey (83B), 12-fold dynamite, GES (processed by SEFEL, Sydney)	125.0
1984	SS133	Stratheden Seismic Survey (84-C), 12-fold dynamite, by GES (processed by GSI, Sydney)	110.0
1985	SS140	Richmond Range Extension — Grafton Seismic Survey (85-G; -R), 12-fold dynamite, GES (processed by Digicon, Brisbane)	207.1
1985	SS144	Grevillia Seismic Survey (85-G-1), 24-fold dynamite, GES (processed by Digicon, Brisbane)	42.4
1985	SS149	C-1985 Seismic Survey (85-D), 12-fold dynamite, GES (processed by Digicon, Brisbane)	172.6
1987	SS160	Clarence River Seismic Survey (87CR), 12-fold dynamite, GES (processed by Digicon, Brisbane)	49.1
1990	SS164	Clarence C90 Seismic Survey (C90), 40-fold 'Vibroseis'®, SSL (processed by HGS, Adelaide)	149.0
1992	SS167	Pickabooba Seismic Survey (92P), 75-fold 'Vibroseis'®, GECO PRAKLA (processed by Digicon, Brisbane)	66.3

NOTE: SS = 'Open File Seismic' — reports held in New South Wales Department of Mineral Resources.

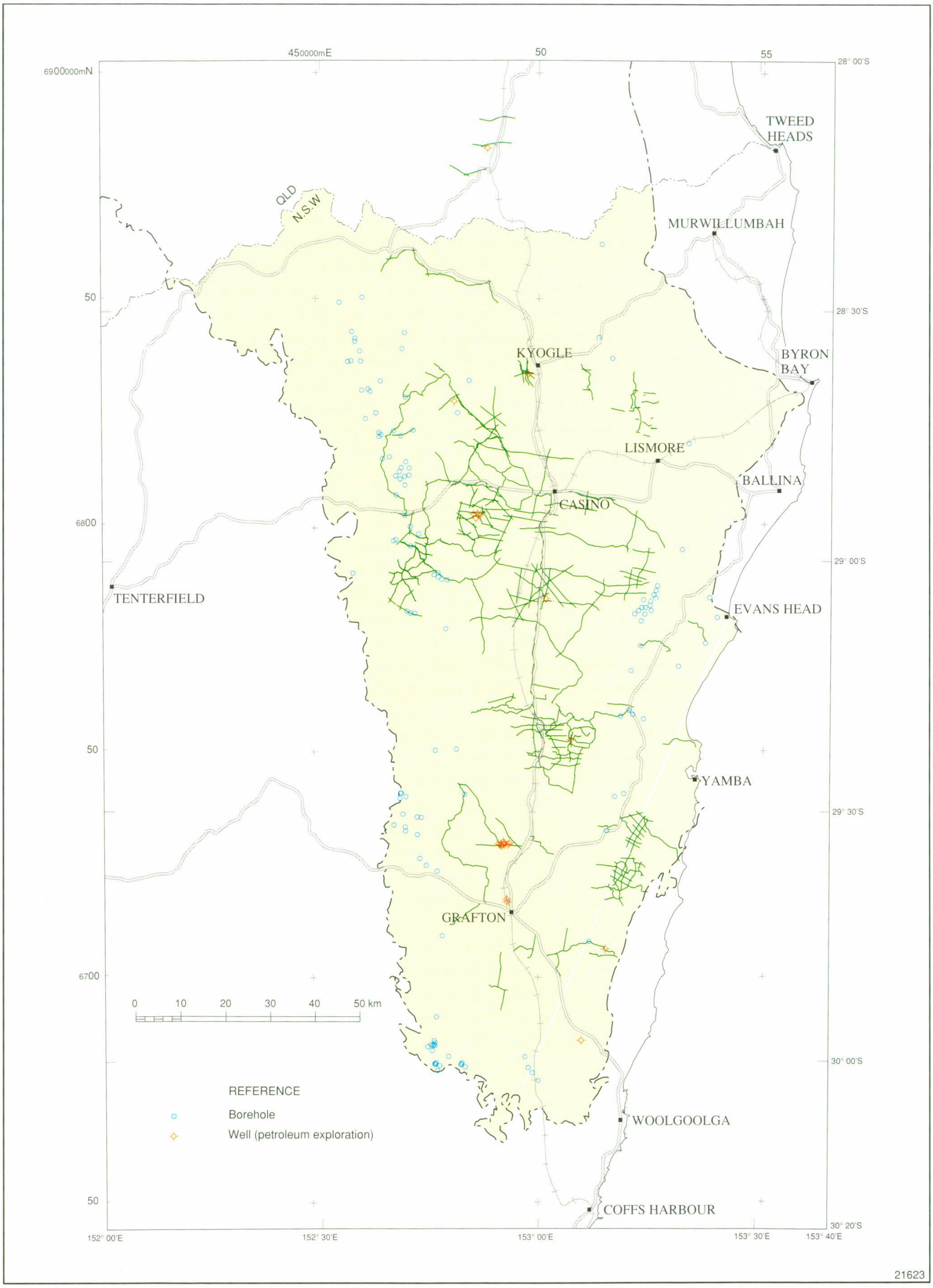


Figure 47. Map of onshore seismic survey lines for the New South Wales portion of the Clarence-Moreton Basin.

pre-1990 data, including the single-fold data, using 'state of the art' technology.

The seismic data have been processed using a datum of mean sea level (MSL) for all conventional seismic surveys except the HS81 survey in the Hogarth Dome area, where a datum of +100 metres (+328 feet) was used. The well velocity survey for Shannon-1 was corrected to a datum of +100 m in order to tie the seismic data. The well velocity survey for Rappville-1 was also originally corrected to +100 m, although all seismic surveys in that area have been processed using a seismic datum of MSL. The well velocity data for Rappville-1 were subsequently re-corrected to MSL for seismic section calibration.

There is a number of seismic time-structure contour maps included in the seismic survey reports submitted (1982 to 1987) to the New South Wales Department of Mineral Resources (present name) which do not designate the elevation of the seismic datum used. Unfortunately, a datum reference of 250 m ASL annotated on the November, 1986 report for the Grevillia Survey is incorrect as the seismic sections state that the seismic datum is MSL.

INTERPRETATION OF SEISMIC DATA

The seismic interpretation carried out previously (1982 to 1990) was restricted to areas of individual surveys, and there appears to have been little effort made to construct regional maps. The maps constructed are usually at a scale of 1:25 000 or 1:50 000 and the seismic markers selected for mapping are often different for the various survey areas. Formation names have also changed during the course of exploration, and the most recent stratigraphic nomenclature (that used in *AGSO Bulletin* **241**, 1994) was selected for the study reported in this *Bulletin* and is shown on the stratigraphic chart in Figure 2.

The formation tops identified in the deepest exploration wells used in this study are summarised in Table 1. These tops have been calibrated with the most representative seismic section closest to those seven exploration wells. Well velocity surveys were conducted at Shannon-1, Rappville-1 and Pillar Valley-2 and those wells provide the most accurate depth conversion control. Seismic calibration at the other wells was accomplished by using the V_{RMS} stacking velocity data provided on the headers of the seismic section. The time-depth-velocity curves for each of the seven deepest wells, including the formation tops, are included in Appendix 1.

In order to better understand the structural framework of the Clarence-Moreton Basin, approximately sixty seismic sections were selected from different parts of the Basin and reduced to a vertical scale of 10 cm/sec. These sections were correlated with the well data and used to construct two regional time-structure maps. These two maps are for the 'Top Gatton Sandstone' and the 'Top Ipswich Coal Measures' (Figures 35 and 36). Where available in existing reports, seismic maps for the two selected horizons were used in the construction of these regional maps.

An east–west geological cross-section B–B1 was constructed across the Clarence-Moreton Basin from the western margin to the Pickabooba Prospect, to Rappville-1, to the south of the Coraki lead and to the eastern margin near Evans Head (Figure 34). That cross-section is based on the seismic interpretation shown on the two regional maps, which has been converted to depth using the Rappville-1 velocity function. Surface geology was also used to complete the shallow part of the section and at the basin margins where no seismic control exists.

The restored section of this same profile (Figure 34) utilises the top of the Gatton Sandstone as a datum and shows that the majority of the structural deformation has taken place since the Early Jurassic. Other geological data strongly suggest that most of the structures in the Clarence-Moreton Basin formed during mid-Cretaceous time.

There is seismic evidence that there was some movement along the East Richmond Fault and West Richmond Fault zones (Figures 9 and 46) during the Triassic, but the main displacement for the East Richmond Fault occurred in mid-Cretaceous time— which was also the time of the structuring at the Pickabooba Prospect. There is also seismic evidence that there was Triassic structural growth (pre-Raceview Formation) at the Rappville-1 anomaly (Mid-Basin High) and that both the eastern and western margins of the Clarence-Moreton Basin were structurally high areas during the time of Triassic deposition.

Based on the seismic study of the areas where the six deepest exploration wells (Pillar Valley- 2 has been excluded) are located, only two (Rappville-1 and Tullymorgan-1) appear to be valid structural tests. The wells drilled on the Clifden Dome (Clifden-1 to -6) and the Hogarth Dome (Hogarth-1 to -4 and Shannon-1) are located on relatively shallow structural closures which are interpreted to have been formed or influenced by intrusive activity during the Tertiary.

Kyogle-1 and Sextonville-1 were drilled in 1963 on surface-mapped structures and the limited amount of seismic coverage obtained subsequently indicates that those two tests are most likely located where no structural closure exists.

GRAVITY DATA

The Bureau of Mineral Resources (BMR) (now Australian Geological Survey Organisation, AGSO) conducted helicopter-supported regional gravity surveys in the Clarence-Moreton Basin in 1964 and 1968. Subsequent work by BMR/AGSO and others has extended the gravity network.

Wellman, Williams and Maher (1994, p. 217) noted that 'surveys have all been integrated to give a station spacing over most of the Clarence-Moreton Basin of about 5 km'. A Bouguer Anomaly map, based on the 1:250 000 scale map sheets published by the BMR in 1970, is included as Figure 48.

The wide spacing of the gravity stations across the Clarence-Moreton Basin does not provide sufficient control to detect the majority of the structures in the sedimentary section. Therefore, it is concluded that the anomalies mapped are caused by density variations within the basement complex (Palaeozoic and older). Some gravity anomalies are also believed to have been generated by intrusive igneous rocks which have been identified throughout most of the sedimentary section. One such positive anomaly is shown on the map in the vicinity of the Hogarth Dome (Figure 48), located about 20 km south-west of Casino.

A gravity positive anomaly is also located about 40 km south-west of Casino (Figure 48) — which is approximately coincident with a mapped seismic closure (Pickabooba Prospect). Therefore, that gravity anomaly may be an expression of structure within the sedimentary section or at the basement contact.

MAGNETIC DATA

A Total Magnetic Intensity map (gradients enhanced by illumination) for the Clarence-Moreton Basin, published in 1993, is available from the Geological Survey of New South Wales. That map (two sheets) is based on airborne geophysical data flown by Geometrics (for New South Wales Department of Mineral Resources) and AGSO during the period from 1981 to 1985.

The magnetic anomalies are interpreted to be primarily the result of magnetic susceptibility variations within the basement complex. Wellman (1987) carried out an interpretation of the gravity and magnetic data available at that time and stated that depths to magnetic basement have low accuracy throughout most of the Clarence-Moreton Basin. Wellman, Williams and Maher (1994) have presented a more recent appraisal of the magnetic and gravity data for the Basin.

It is observed that a number of high frequency magnetic anomalies exist which are due to Cainozoic mafic volcanic rocks. One such anomaly exists at Clifden Dome, where sub-surface control from several wells confirms the presence of intrusive rocks within the sedimentary section penetrated. Other high frequency anomalies mapped in the area south of Grafton are regarded as structural leads which require additional seismic control.

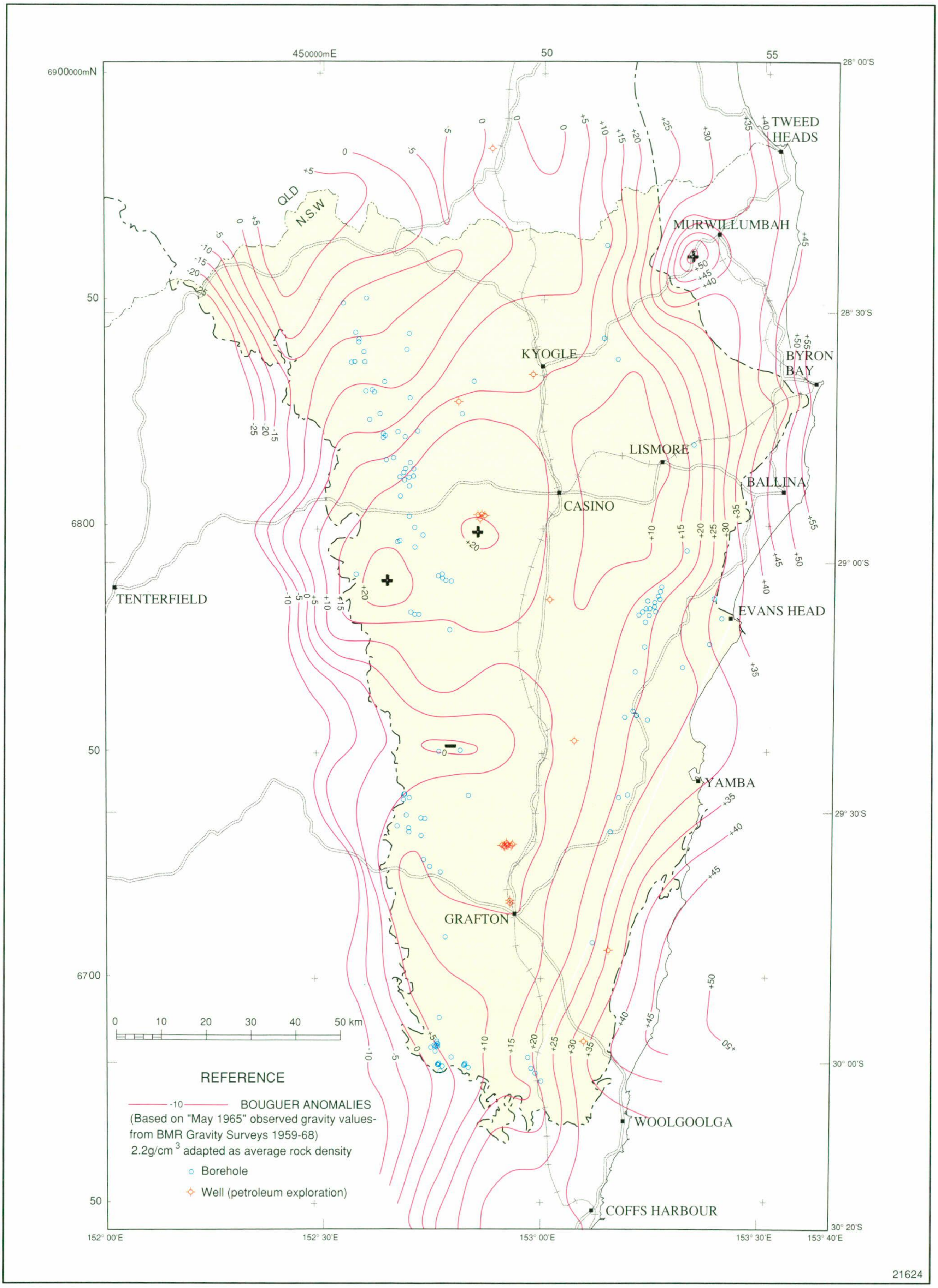


Figure 48. Simplified map of Bouguer anomalies ('gravity map') for the New South Wales portion of the Clarence-Moreton Basin, based on BMR (AGSO) data.

PROSPECTS AND LEADS

One prospect and seven leads have been identified from seismic data and surface geology (Figure 49). The name, approximate size and estimated depths to key horizons for the prospect and leads are included in Table 5.

PICKABOOBA PROSPECT

The only mature prospect that appears to be ready to drill is Pickabooba, located on the western margin of the Clarence-Moreton Basin about 15 km south-west of Shannon-1 (Figures 46 and 49). Four-way dip closure is mapped on the upthrown (west) side of the East Richmond Fault based on the interpretation of seismic data from the 92P Seismic Survey and reprocessed lines 85-P2 and 85-P3. A significant areal closure (about 25 km^2), with approximately 50 msec (two-way time) of vertical relief is mapped at the top of the Gatton Sandstone (Figure 37). Closure of about the same size is also mapped at the top of the Ripley Road Sandstone (Figure 38) and a smaller closure is mapped at the top of the Ipswich Coal Measures (Figure 39).

An isochron map of the time interval from the top of the Ipswich Coal Measures to basement (Figure 40) shows some local thinning near the main culmination of the closure. More significant thinning is present to the south-west, adjacent to the upthrown (east) side of a northeast–southwest-trending normal fault. Seismic section 92P-04 is believed to be the most representative profile across Pickabooba Prospect (Figures 37 and 50) (Figure 50 on pages 84 and 85). The sequence boundary which is interpreted between the top of the Ipswich Coal Measures and the basement horizon is believed to be the top of the Nymboida Coal Measures.

It is recommended that any exploration well drilled on Pickabooba Prospect be programmed to basement in order to evaluate the coal seam methane and conventional sandstone reservoir potential of the entire sedimentary sequence at this basin margin location for the Clarence-Moreton Basin.

GREVILLIA LEAD

The Grevillia lead is a surface anticline located about 24 km north-west of Kyogle-1, where the Marburg Subgroup is exposed. A time-structure map of the top of the Gatton Sandstone is shown on Figure 51. One seismic line from the 1985/1986 Grevillia survey crosses this feature and significant east–west dip reversal is shown on line 85-G-1B. (Figure 52, pages 88 and 89). The data quality of the seismic section is fair to poor, and the identification of the stratigraphic markers and the correlation across the faults is questionable. There is no direct seismic tie to any well control, but regional seismic correlation and surface geology suggests that the Heifer Creek Sandstone Member is very shallow (about 200 m), and the primary reservoir objective is the Ripley Road Sandstone.

TOONUMBAR LEAD

Toonumbar is a surface anticline, located about 17 km west of Kyogle-1 (Figures 46, and 53 on page 87). It is believed to be on structural trend with the Grevillia Anticline, which is about 16 km to the north. The Marburg Subgroup (Koukandowie Formation) is exposed at the surface, and the most likely reservoir sequence is the Ripley Road Sandstone. There is no seismic control across the Toonumbar lead. Road access exists at the Toonumbar lead in the east–west direction and that road continues to the east — which could provide access for a seismic tie to the Kyogle-1 well. A north–south seismic line at Toonumbar should also be extended to cross the Grevillia lead in order to help confirm north–south dip reversal for the two surface anticlines.

DYRAABA LEAD

The Dyraaba lead is located about 16 km south-southwest of Kyogle-1 and about 17 km north-northeast of Hogarth-2 (Figures 46, and 54 on page 90). East–west dip reversal is observed at the top of the Koukandowie Formation on seismic line 85-D8 (SP 1085), which is interpreted to be on the upthrown side of a reverse fault (Figure 55, page 91). A lesser amount of dip reversal is present on line 84-D2, which is the next line south of 85-D8.

Four 1985 lines were also shot in the area of the Dyraaba lead. Those lines indicate that there is very limited dip reversal to the north (85-D10). However, seismic coverage is still inadequate and structural closure at the Heifer Creek Sandstone Member level is believed to exist.

The central basinal position of the Dyraaba lead, ie on the western flank of the Casino Trough (cf. Figure 46), is favourable for hydrocarbon generation, particularly for the Heifer Creek Sandstone Member play. Reprocessing of the existing data, with particular attention given to the shallow section, and re-interpretation, is recommended to determine whether or not additional seismic data are required.

LEEVILLE LEAD

The Leeville lead is located in the southern end of the Casino Trough (New South Wales Clarence-

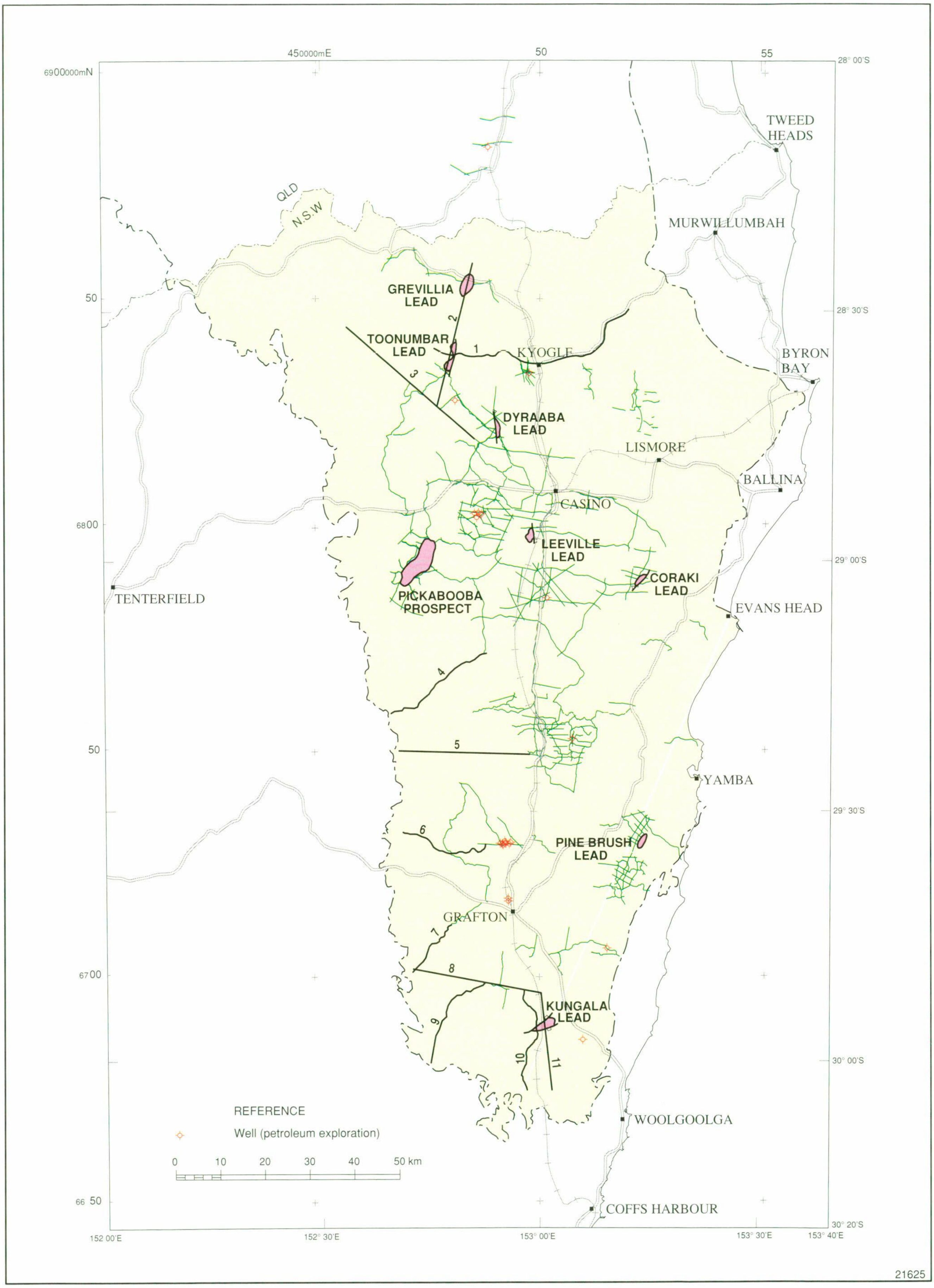


Figure 49. Map showing the prospect and seven leads identified (in this study) for the Clarence-Moreton Basin, together with a suggested program of seismic data acquisition (black numbered lines 1 to 11).

TABLE 5
PROSPECTS AND LEADS INVENTORY

Name of Prospect or Lead	Areal Closure (approx sq. km)	Depth (metres) Koukandowie Formation	Depth (metres) Heifer Creek Sandstone Member	Depth (metres) Ripley Road Sandstone	Total Depth (metres) (estimated unit)
Pickabooba	25	31	181	903	1800 (Basement)
Grevillia	20	(Top Missing) 0	100 ?	1270	2020 (Ipswich)
Toonumbar	10	(Top Missing) 0	100 ?	1300	2050 (Ipswich)
Dyraaba	5	650	800	1880	2400 (Ipswich)
Leeville	4	790	940	2090	2650 (Ipswich)
Coraki	2	660	810	1830	2200 (Ipswich)
Pine Brush	4	Missing	Missing	350	900 (Basement)
Kungala	8	230	300 ?	1030	1550 (Ipswich)

Depths are relative to ground level, to top of Formations or units: Koukandowie Formation; Heifer Creek Sandstone Member; and Ripley Road Sandstone.

Moreton Basin), about 11 km east-southeast of Hogarth-3 and about 15 km north-northwest of Rappville-1 (Figures 46, and 56 on page 92). Seismic line 84-L1 shows east–west dip reversal at the top of the Koukandowie Formation and the top of the Gatton Sandstone. The high point of the structure, at about shot-point 1180, is interpreted to be on the upthrown side of a north–south-trending normal fault (Figure 57, page 93). There is also evidence that this fault and east–west dip reversal may be present on line 84-L3 (SP 1185) about 3.5 km to the north, but poor data quality makes the interpretation unreliable. The (central) basinal position of this lead, and its nearness to the gas accumulation on the Hogarth Dome, are favourable for hydrocarbon generation and accumulation, particularly in the Heifer Creek Sandstone Member.

Seismic data reprocessing with emphasis on the Heifer Creek Sandstone Member interval, and re-interpretation, are recommended to determine if the Leeville lead warrants additional seismic control.

CORAKI LEAD

The Coraki (seismic) lead is located on the eastern margin of the Clarence-Moreton Basin about 20 km east-northeast of Rappville-1 (Figures 46, and 58 on page 94). This structural anomaly is interpreted to be a complexly faulted anticlinal closure, based on a grid of seven seismic lines (1982 to 1985). It is situated on the upthrown (east) side of a major north–south-trending strike slip fault with secondary low angle reverse faults dissecting the closure (Figures 58, and 59 on page 95). It is uncertain whether these secondary faults intersect the Heifer Creek Sandstone Member reservoir target as data quality is poor.

Seismic data reprocessing is recommended, with particular attention being given to the interval between 0.200 second and 0.500 second. Re-interpretation of this lead using a common dataset should provide a more reliable picture of this structurally complex anomaly.

PINE BRUSH LEAD

This lead (Pine Brush) is located about 25 km north-northeast of the Pillar Valley-2 stratigraphic drillhole (Figures 46, and 60 on page 96). It is interpreted as an anticlinal structure which was formed on the upthrown (west side) of a major reverse fault which is part of the Coast Range Fault system (Figure 9). The structure is well-controlled by seismic data recorded in 1985, 1986 and 1990. The time-structure map for the near top of the Ripley Road Sandstone constructed by AGL (1992) shows an areal closure of about 4 km^2 with a vertical relief of approximately 50 milliseconds (Figure 60). The mapped culmination is at a relatively shallow depth (about 300 m relative to GL) at the top of the Ripley Road Sandstone (as interpreted by AGL on seismic line C90-412), which is the most likely target for a conventional hydrocarbon reservoir (Figure 61, page 97). However, regional seismic correlation with other seismic sections to the north of this line suggests that the mapped horizon may be the top of the Ipswich Coal Measures — which would further downgrade the prospectivity of this lead.

KUNGALA LEAD

The Kungala Anticline is identified on the surface geological map prepared by F.N. Hanlon (1964d) (Figure 62, page 98). It is located in the southern portion of the Clarence-Moreton Basin about 20 km to the south-southwest of Pillar Valley-2, and about 9 km north-west of Halfway Creek-1, where a show of gas was reported. No seismic control exists in the area of the Kungala Anticline, and at least one line is

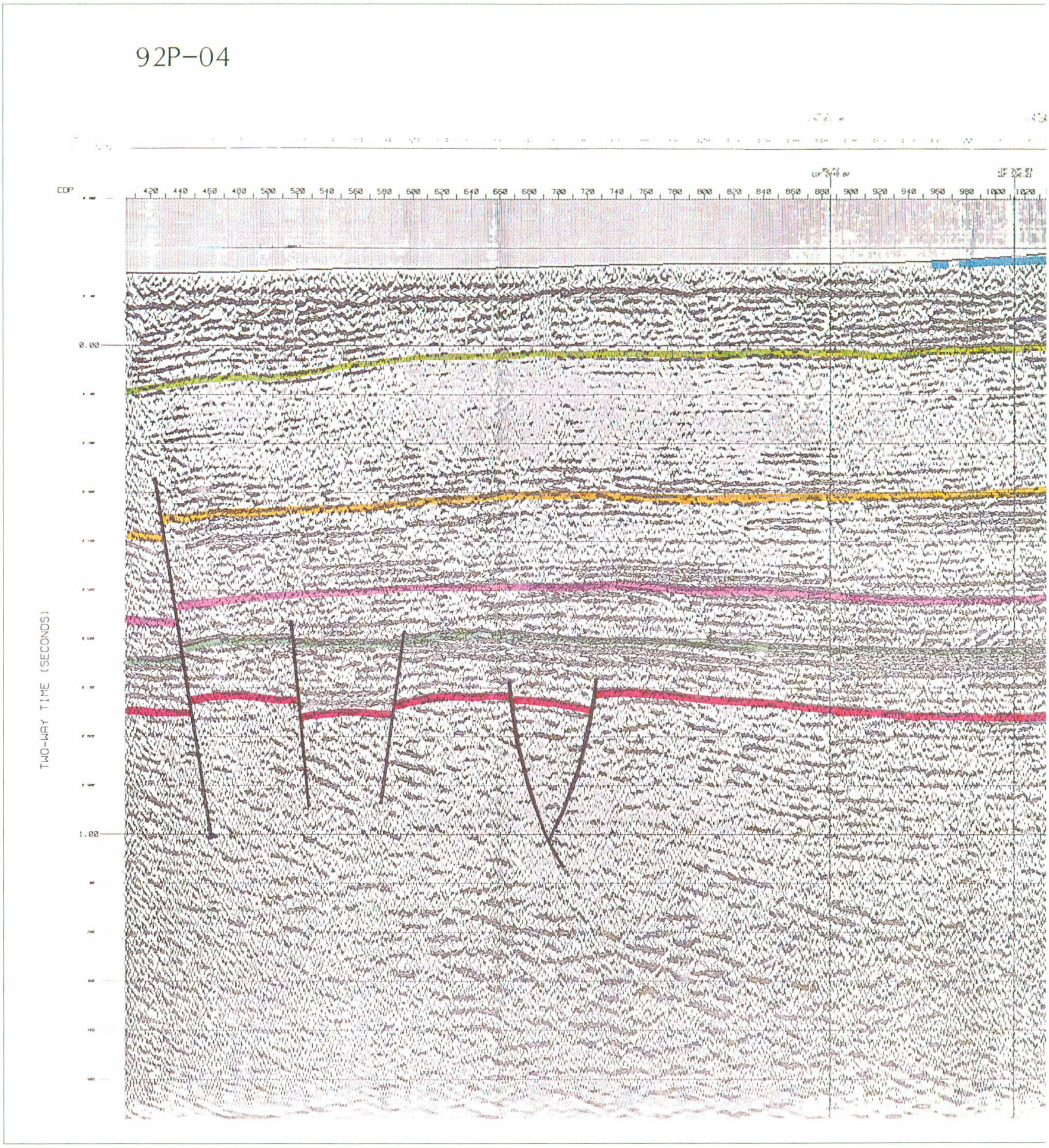
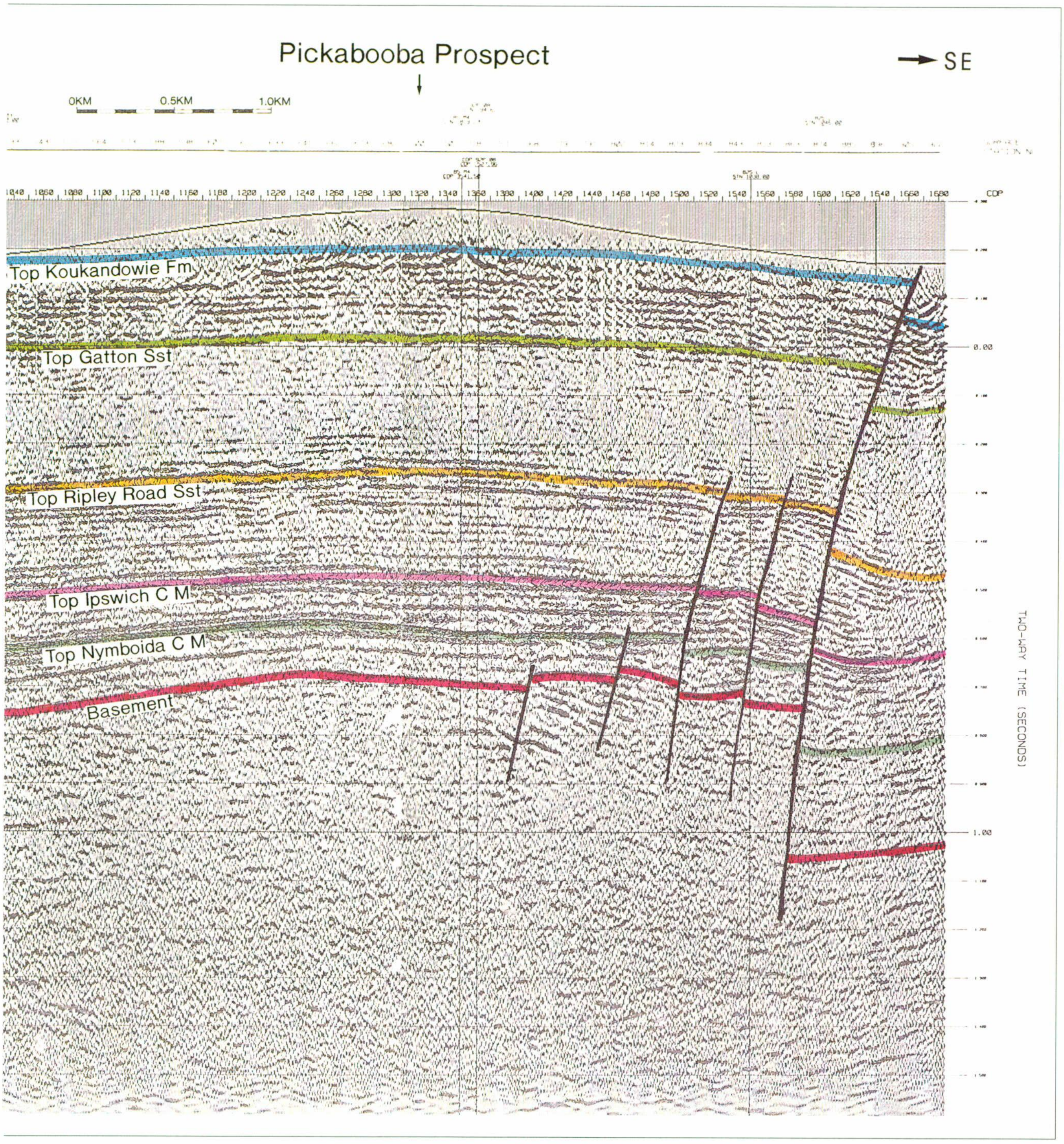


Figure 50. Interpreted seismic line (part) 92P-04 (cf. Table 4) across the Pickabooba Prospect. (Modified after Claremont



Petroleum NL.)

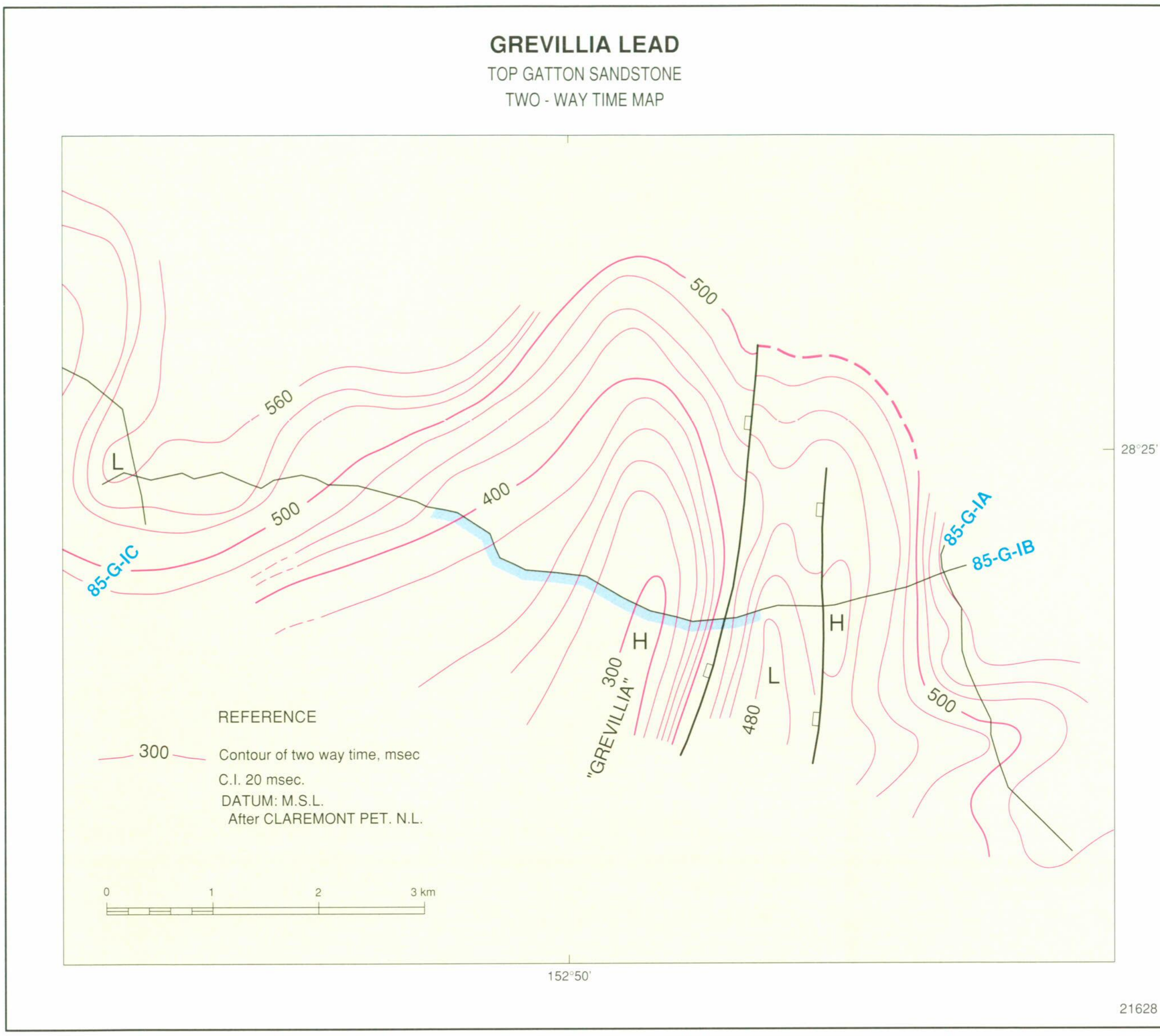


Figure 51. Grevillia lead, Clarence-Moreton Basin, New South Wales. Two-way time map for the top of the Gatton Sandstone. (Modified after Claremont Petroleum NL.)

required to confirm that north–south dip reversal exists in the subsurface. The Heifer Creek Sandstone Member and the Ripley Road Sandstone are the primary targets. These are estimated to be at depths of about 300 m and 1000 m (below GL), respectively.

A well at the Kungala lead should be drilled to Palaeozoic basement to investigate the potential for both coal seam methane and hydrocarbons in conventional sandstone reservoirs in the Ipswich Coal Measures/Nymboida Coal Measures section.

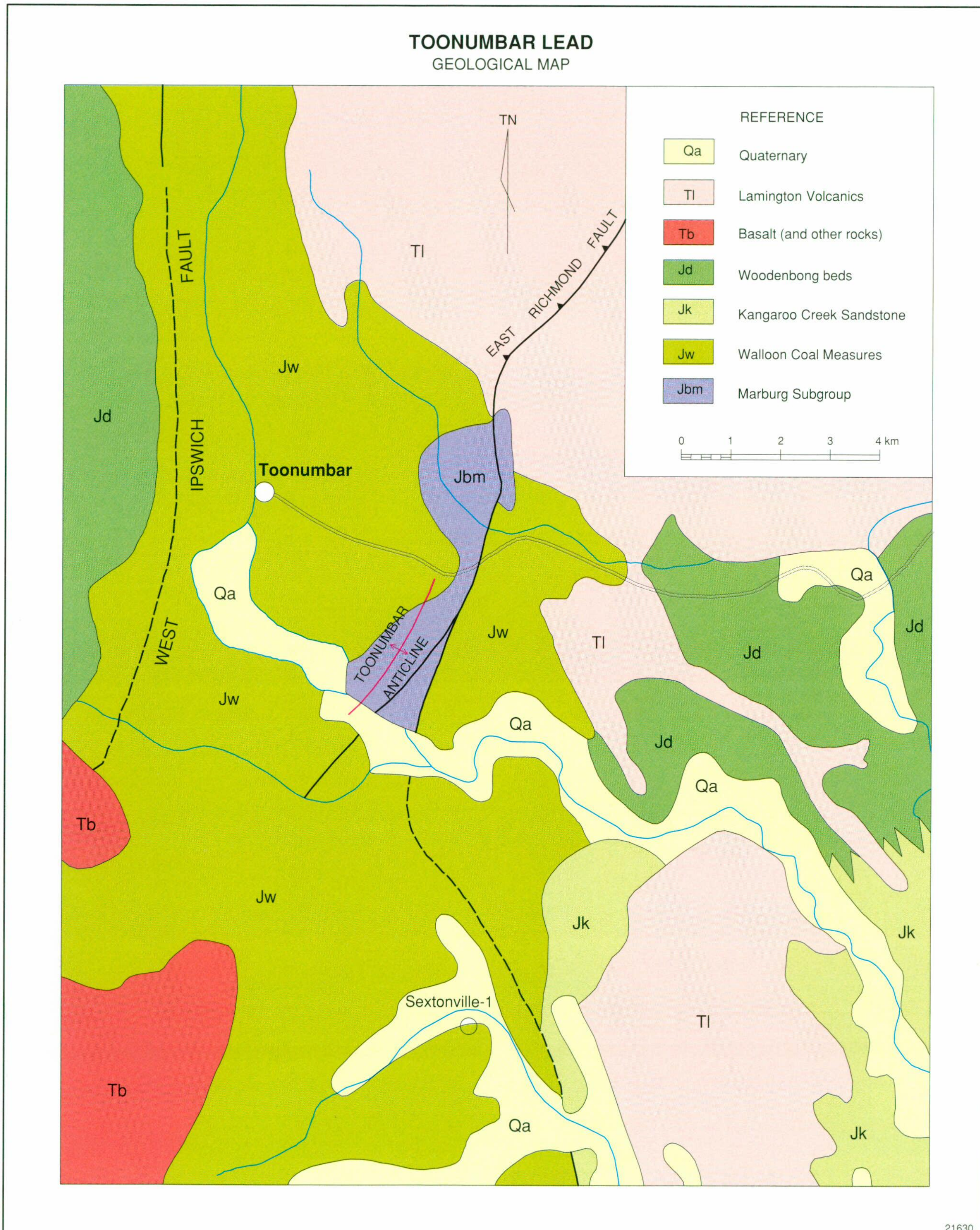


Figure 53. Geological map of the Toonumbar lead, Clarence-Moreton Basin, New South Wales. Note: Jd refers to the Woodenbong beds in the Laidley Sub-basin, equivalent to Grafton Formation/Kangaroo Creek Sandstone in the Logan Sub-basin (Bradshaw et al, 1994). (Redrawn from Wells & O'Brien, 1994.)

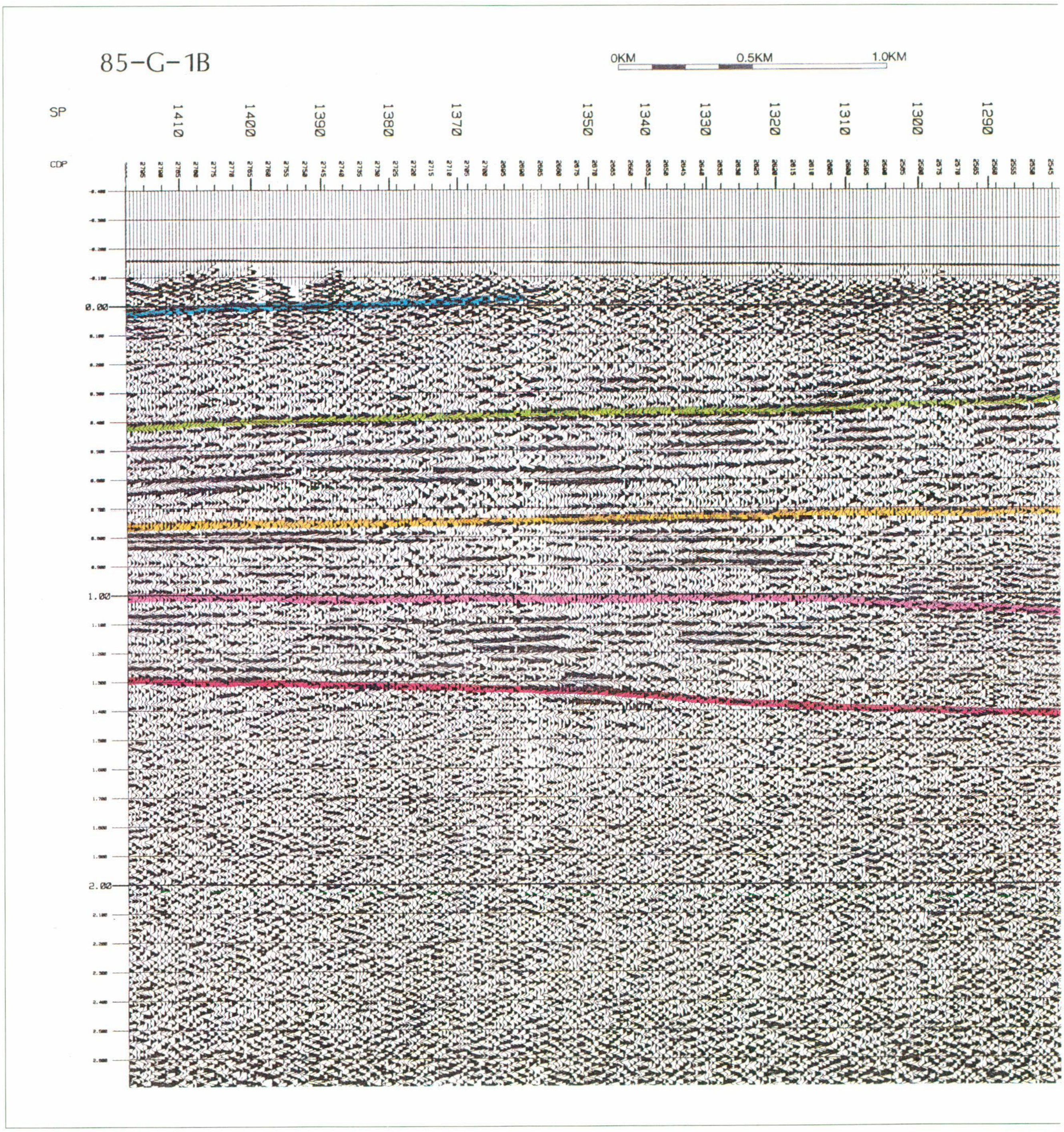
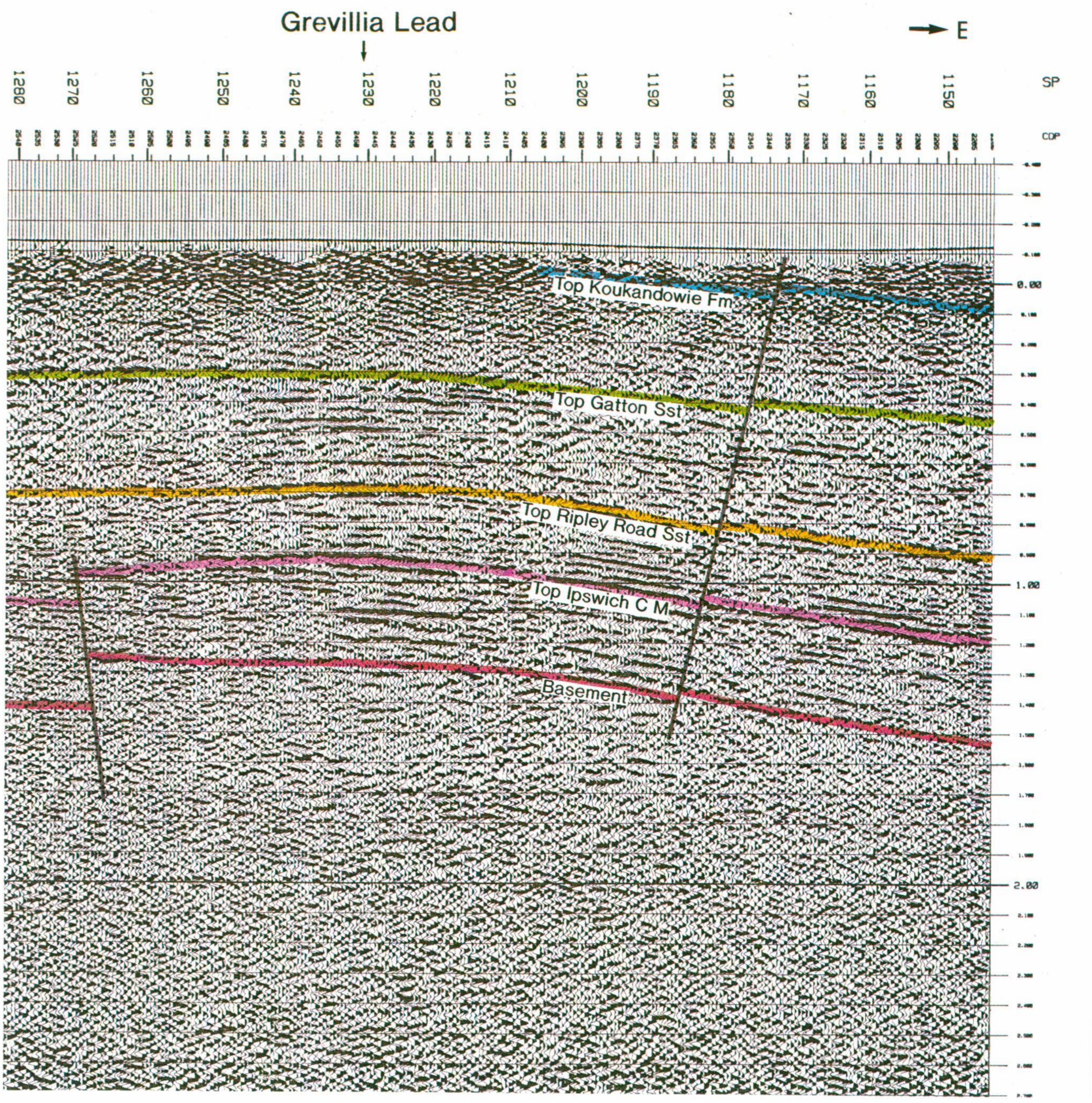


Figure 52. Seismic line 85-G-1B, with interpretation across the Grevillia lead, Clarence-Moreton Basin (New South



Wales). (Modified after Shaw, 1986a.)

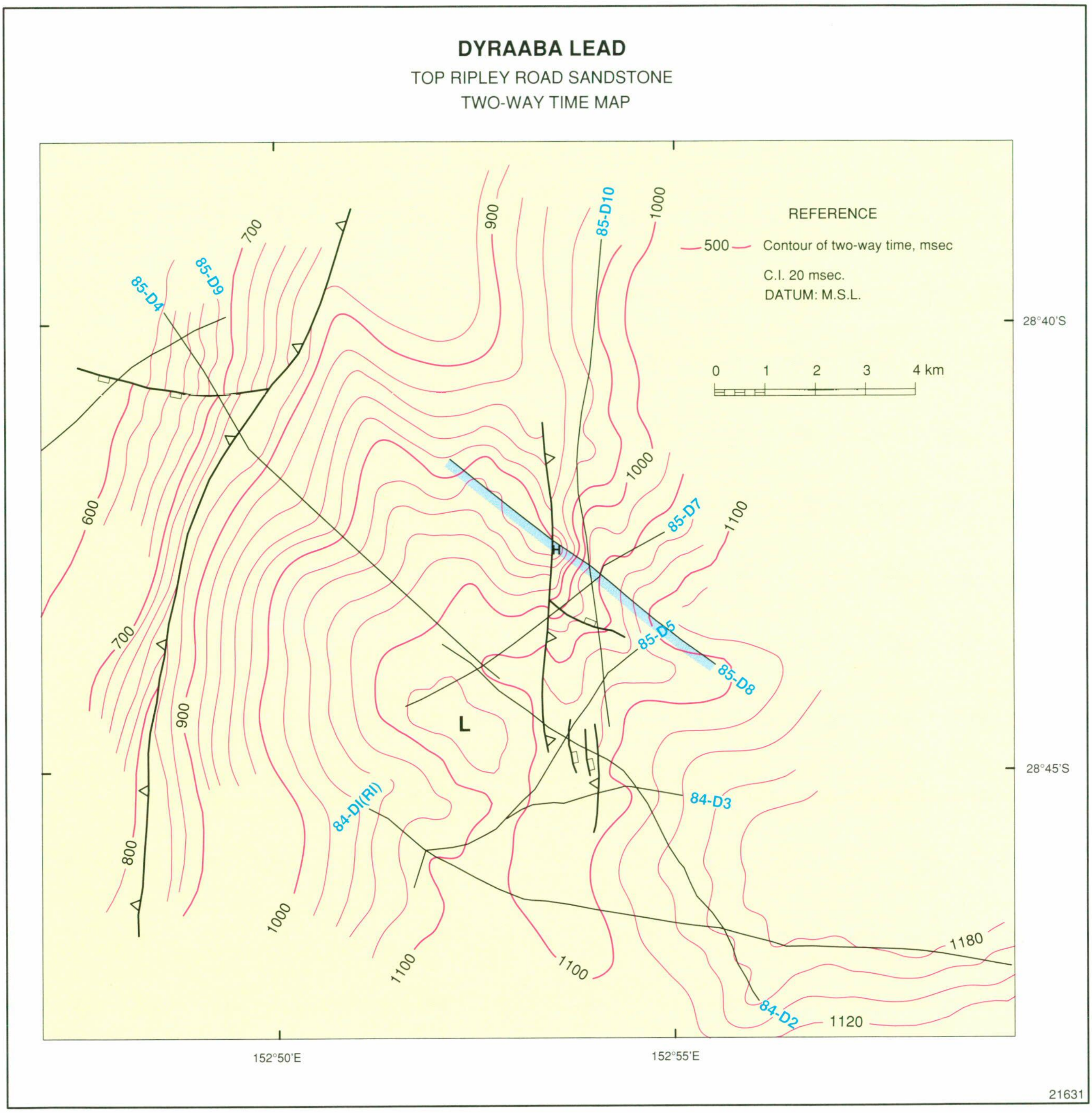


Figure 54. Dyraaba lead (Clarence-Moreton Basin, New South Wales). Two-way time map to the top of the Ripley Road Sandstone. (Modified after Shaw, 1987, for Claremont Petroleum NL.)

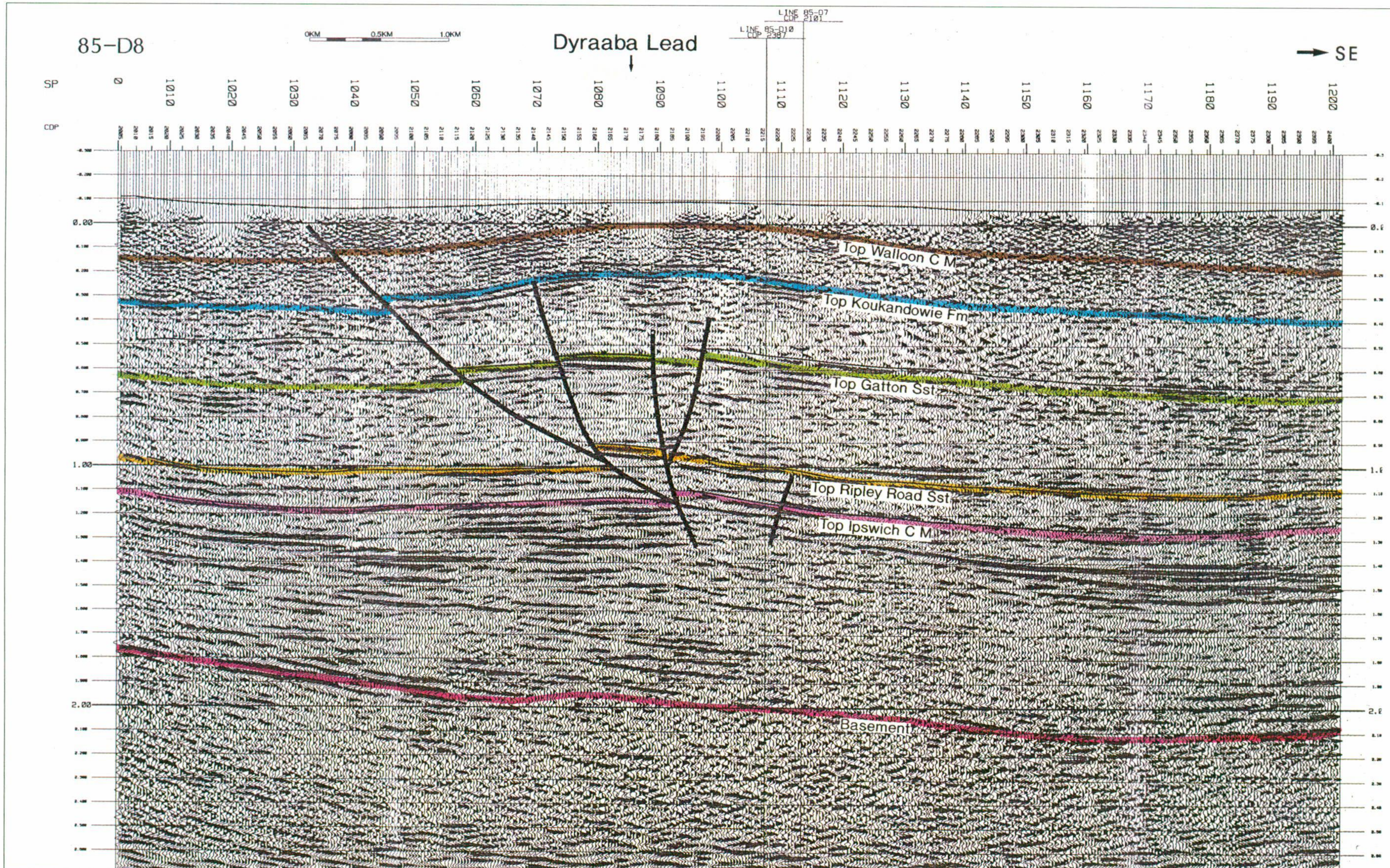


Figure 55. Seismic line 85-D8, with interpretation across the Dyraaba lead, Clarence-Moreton Basin (New South Wales). (Modified after Shaw, 1987.)

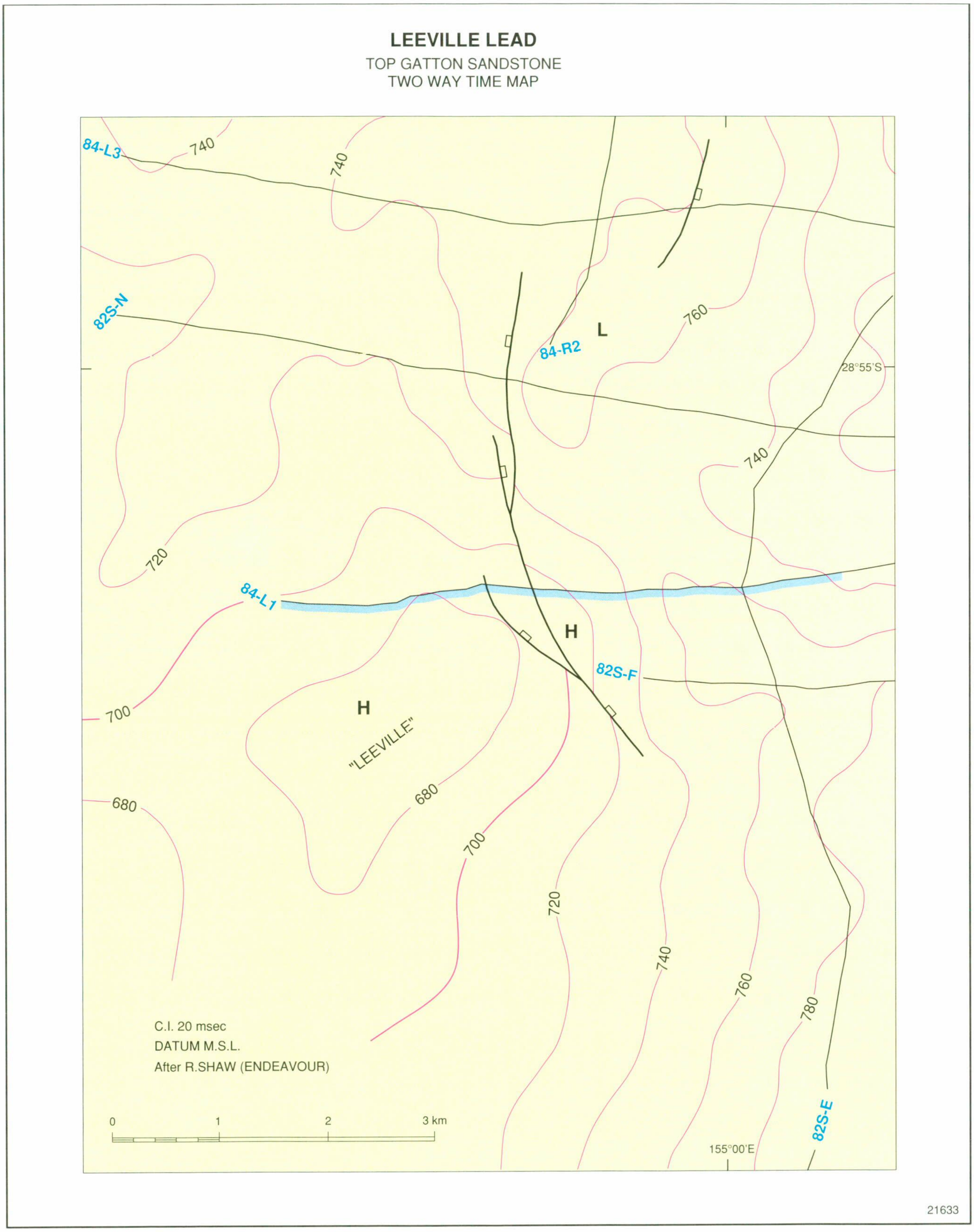


Figure 56. Leeville lead (Clarence-Moreton Basin, New South Wales). Two-way time map of the top of the Gatton Sandstone. (Modified after Shaw, 1986b, for Endeavour Resources Limited.)

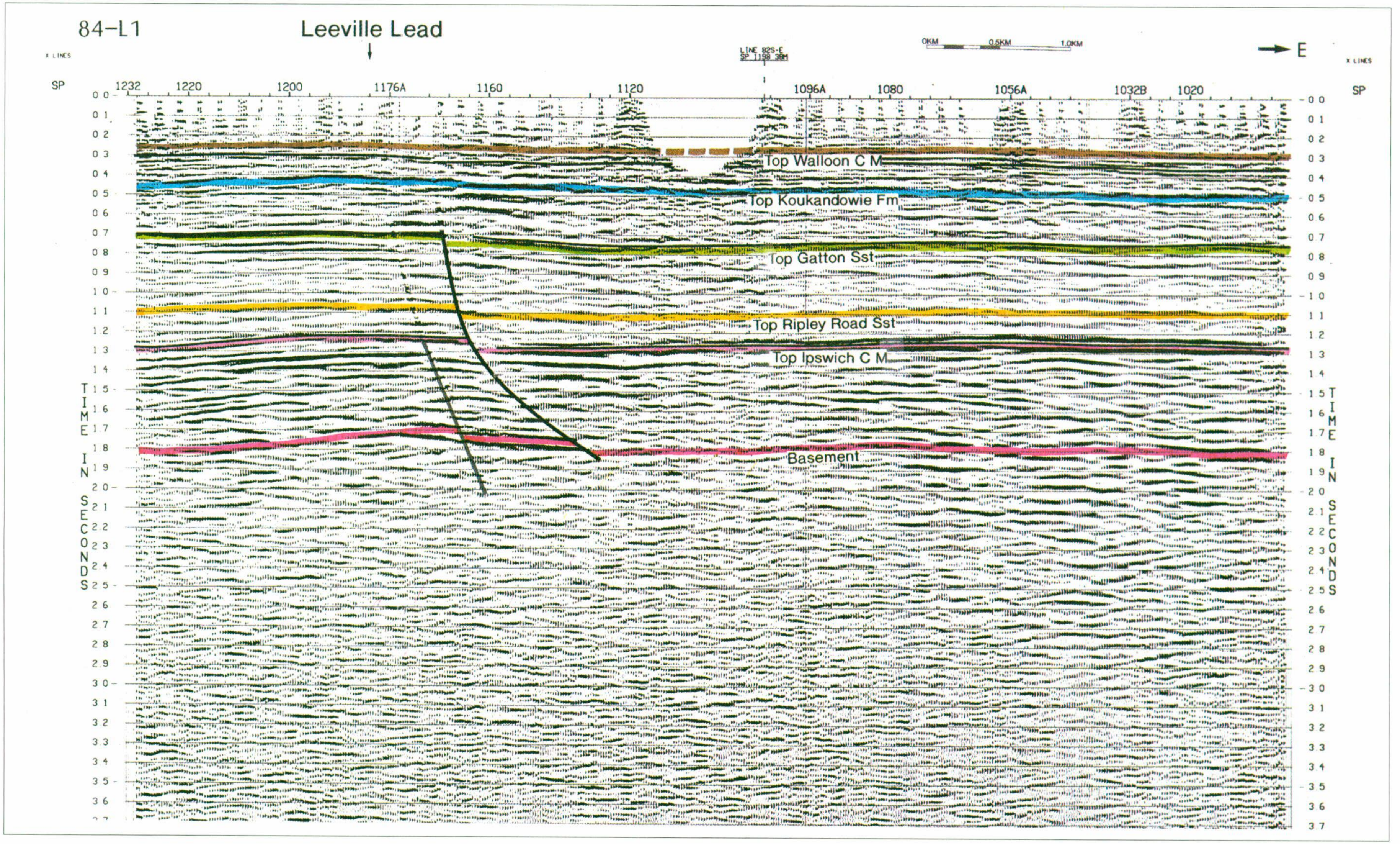


Figure 57. Seismic line 84-L1, with interpretation across the Leeville lead, Clarence-Moreton Basin, New South Wales. (Modified after Shaw, 1986b.)

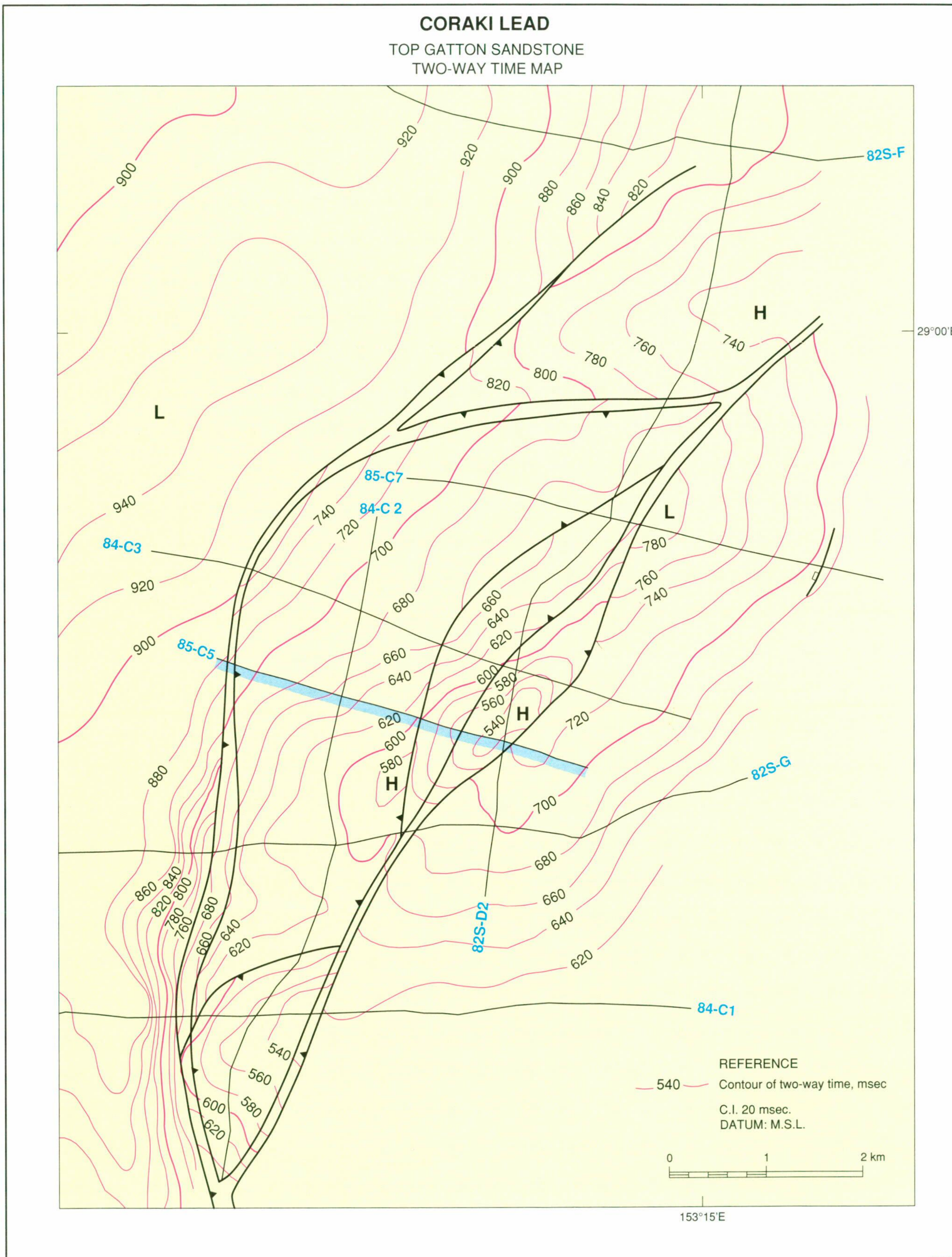


Figure 58. Coraki lead, (Clarence-Moreton Basin, New South Wales). Two-way time map to the top of the Gatton Sandstone. (Modified after Shaw, 1987, for Claremont Petroleum NL.)

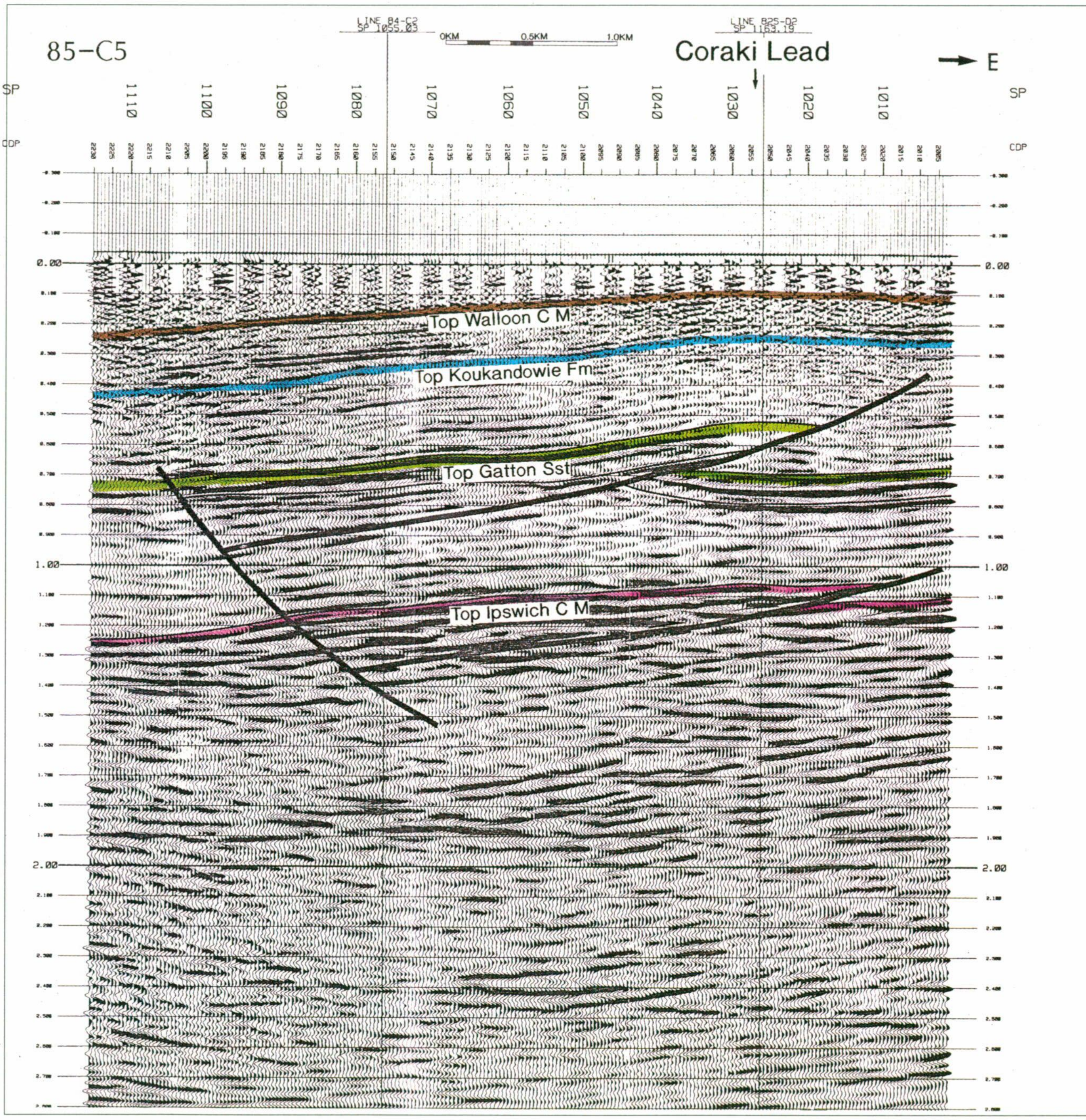


Figure 59. Seismic line 85-C5, with interpretation across the Coraki lead, Clarence-Moreton Basin, New South Wales. (Modified after Shaw, 1987.)

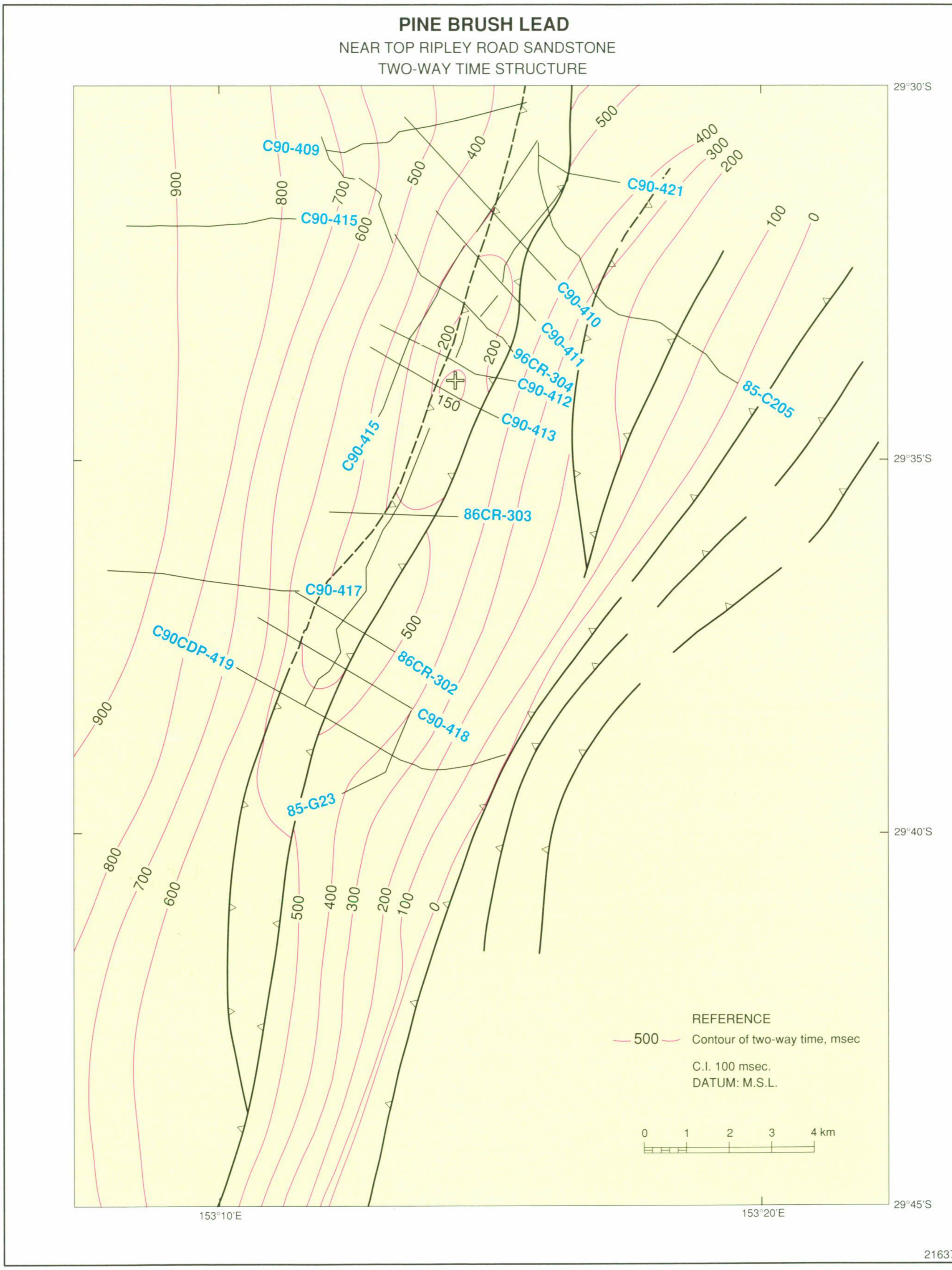


Figure 60. Pine Brush lead, Clarence-Moreton Basin, New South Wales. Two-way time map for the near-top of the Ripley Road Sandstone. (Modified after Wecker, for AGL, 1992)

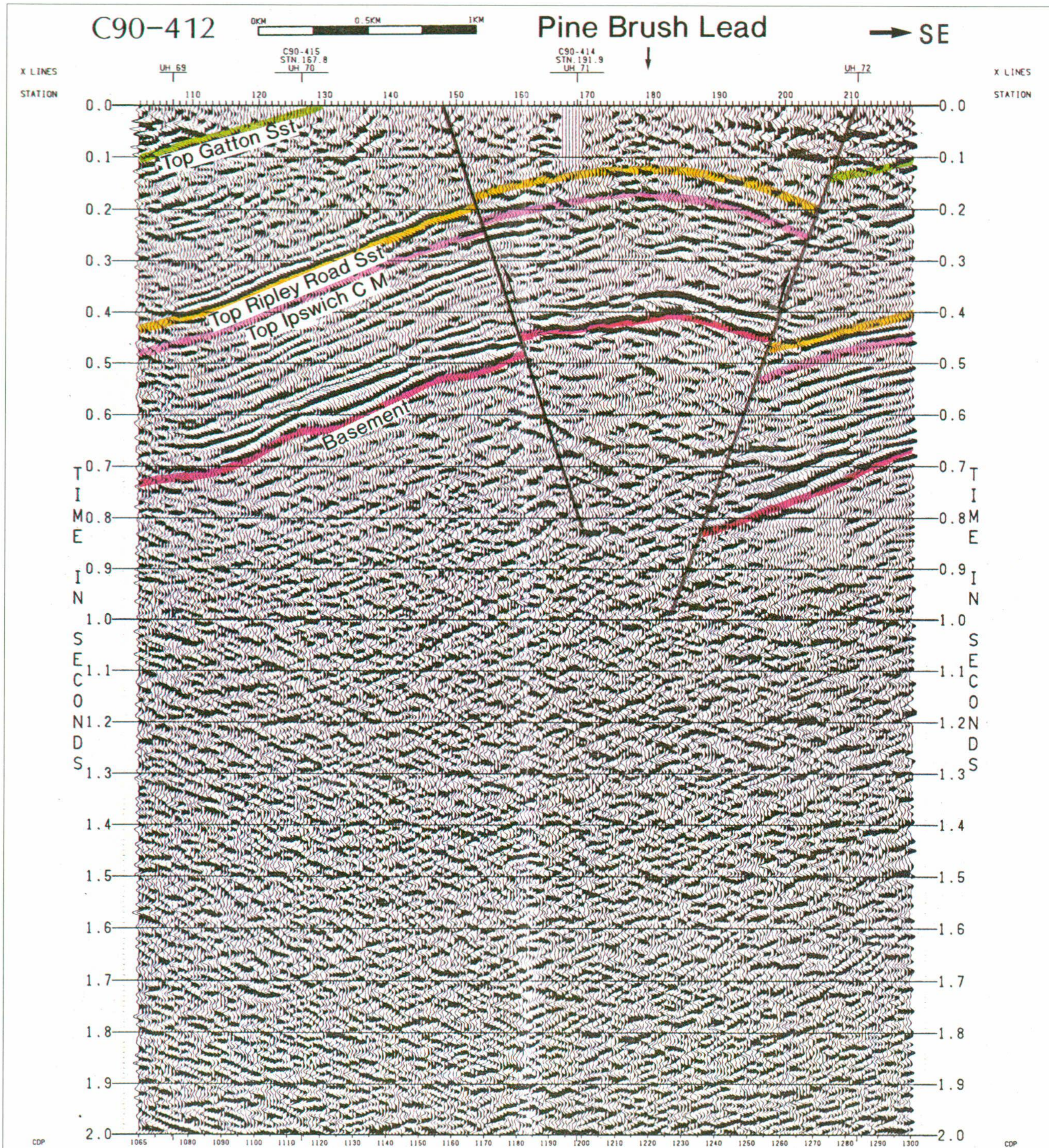


Figure 61. Seismic line C90-412, with interpretation across the Pine Brush lead, Clarence-Moreton Basin, New South Wales. (Interpretation modified from AGL, 1992b)

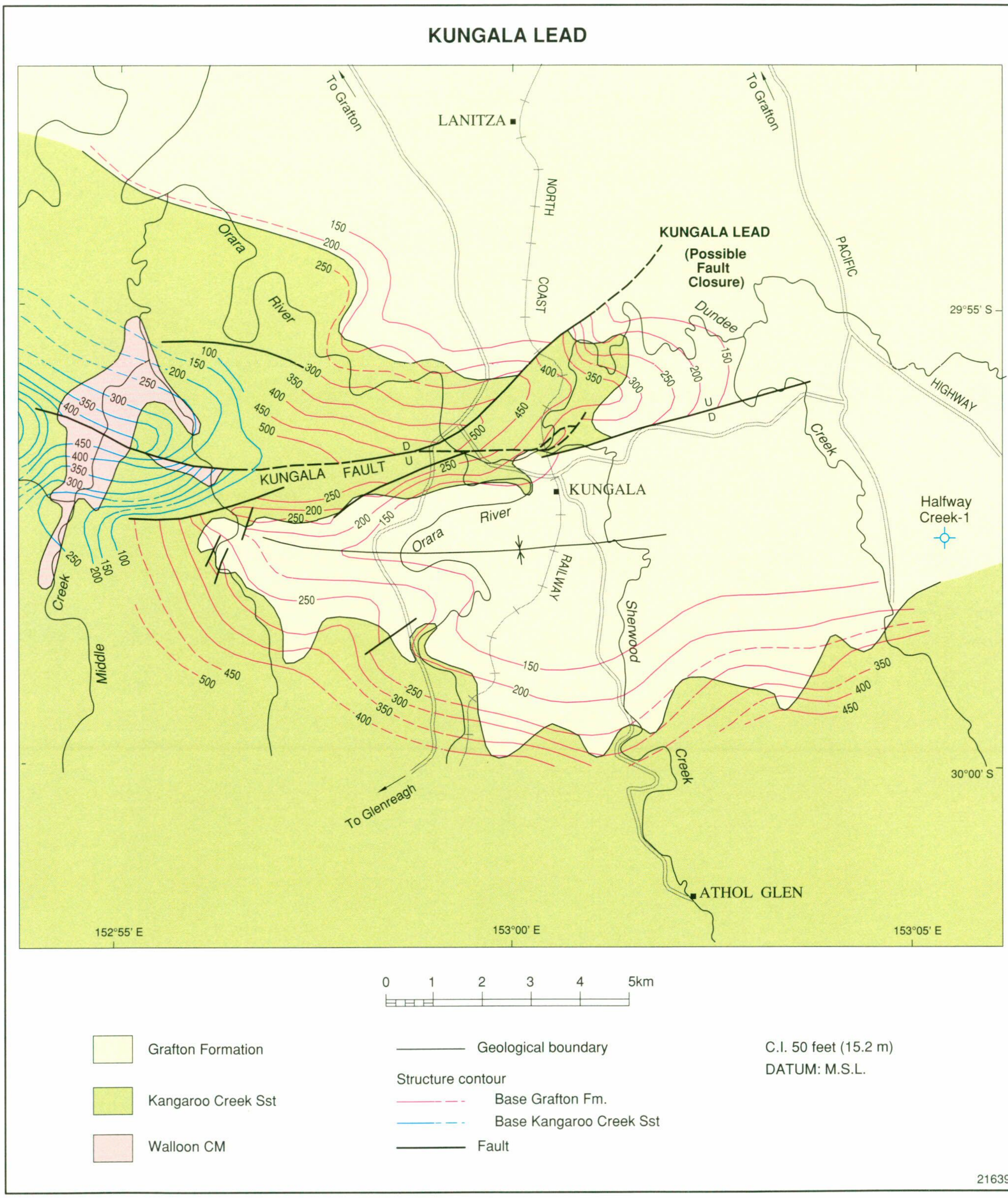


Figure 62. Kungala lead, (Clarence-Moreton Basin, New South Wales), geological map, based (with modifications) on Hanlon (1964d).

COAL SEAM METHANE

INTRODUCTION

In recent years the production of methane from coal seams using purpose-drilled holes has become an economic reality. Coal (seams) can entrap methane by adsorption of the gas directly onto the coal. Exploration for coal seam methane is well under way in the Sydney Basin in New South Wales and in the Bowen Basin in Queensland. Encouraging results have been reported from both those areas. A discussion of the coal seam methane prospectivity in New South Wales — including the Clarence-Moreton Basin — has been presented by Brown et al (1995) and Brown et al (1996).

The Clarence-Moreton Basin in New South Wales has two coal-bearing sequences that appear to have potential for coal seam methane production. The shallower of the two is the Walloon Coal Measures of Middle Jurassic age. That unit is well known from surface exposure and mining operations around the perimeter of the Basin, from numerous shallow coal exploration drillholes, and from a few deep petroleum exploration wells. The second, deeper, coal-bearing interval is the combined , Chillingham Volcanics and Nymboida Coal Measures section. These latter three units have never (apparently) been penetrated in a single well or drillhole and their ages and lithologies are uncertain. For the purpose of this discussion, the three are considered as a single stratigraphic unit.

No concerted exploration for coal seam methane has yet been undertaken in the New South Wales portion of the Clarence-Moreton Basin. The exploration activity for coal seam methane in the Queensland portion of the Basin is uncertain, but no such activity is known to have taken place to date.

KEY TECHNICAL CHARACTERISTICS

Certain characteristics of a coal-bearing sequence are necessary before commercial production of coal seam methane can be established (Waller, 1993). Brown et al (1996) have also discussed technical factors in coal seam methane production. These are: permeability; burial depth; ash content; diagenesis; coal lithotype; gas content; gas composition; thermal maturity; reservoir thickness; coal density; and hydrologic isolation.

Permeability

Bulk permeability is probably the most important characteristic in determining the flow rate of coal seam methane and the economic viability of any development project. Permeability should be greater than 1 md (millidarcy) for commercial production. Establishing the true permeability of coal is particularly difficult in the laboratory because of the irregularity of the cleat system. The best measurements can be made by well tests and production history.

Depth of Burial

The maximum depth of burial for coal seam methane production (at commercial rates) appears to be about 1200 m to 1500 m, although some wells produce methane at greater depths. The minimum depth of burial is about 200 m to 300 m, depending on the sealing efficiency of the overburden.

Ash content

Increasing ash content causes coal (rock) strengths to increase, thereby decreasing the potential for fracturing. Coals with lesser amounts of ash are, therefore, most likely to have the greatest cleat development — and the highest permeabilities. Also, as the ash component cannot adsorb methane, it reduces the volume of gas contained in a unit volume of coal. The maximum allowable ash content has not been established, but this will probably vary according to other parameters — eg maturation levels.

Diagenesis

Diagenesis may cause deposition of mineral matter in the coal cleats, causing a significant decrease in (seam) permeability. Carbonate infilling is the most common, but silica, pyrite, illite, smectite, kaolinite and other clays are also frequently observed as cleat infillings. Prospective coals, accordingly, should be relatively free of such cleat-filling substances.

Coal Lithotype

The fracture, or cleat, density is greater in the brighter lithotypes — such as vitrain and bright clarain, and substantially less in the dull lithotypes — like durain.

Gas Content

The gas content should be greater than 8.5 cc/gm (300 scf/t). The measurements of gas content should generally be carried out in the laboratory, or some other controlled facility, by desorbing the coal sample and adding the estimated volume of gas lost during core recovery. This operation obviously requires a great deal of care and experience in order to obtain reliable results.

Gas Compositions

The gas recovered from the coal seam should be dominantly methane, with only minor amounts of carbon dioxide or nitrogen. As with any hydrocarbon exploration/evaluation, the nature of the gases present with coal seam methane can provide information about source and maturity, or other changes (such as metamorphism by intrusion of igneous rocks). In some cases, 'rare' gases may be important.

Thermal Maturity

The coals need to reach a certain level of thermal maturity in order to generate gas and to produce the structure and chemistry necessary for storing commercial quantities of methane. The vitrinite reflectance should be within the range R_o 0.7% to R_o 2.0%. In general, the higher the maturity, the greater the adsorption capability of any coal.

Reservoir Thickness

The most economical coal seam methane wells known to date are in the San Juan Basin, United States of America. In the area of those fields, the net productive thickness of coal seams ranges from 6 m to 24 m, with up to 10 seams per well having individual thicknesses up to 5 m. From that, it appears that the minimum amount of coal would be about 5 m to 6 m in no more than 3 or 4 seams.

Coal Density

Coal specific density, as measured by high resolution density logs, should be relatively low — no higher than 1.6 to 2.0. However, lower values of 1.35 to 1.45 are preferable.

Hydrologic Isolation

The producing coal seams must be isolated from aquifers in order that they may be successfully dewatered. This is necessary because coal seam methane is produced from a seam after the water is allowed to flow in the well — to effect an altered pressure regime suitable for desorption of the methane from the coal. (Paradoxically, too high a permeability in the coal can allow too much water flow, thus inhibiting the methane desorption and recovery.)

PROSPECTIVE INTERVALS

WALLOON COAL MEASURES

The Walloon Coal Measures are present over almost the entire area of the Clarence-Moreton Basin. However, over much of the outer parts of the Basin the Walloon Coal Measures are on the surface and do not have sufficient overburden to provide a seal for any methane that might be contained in the sequence. There are three areas where sufficient cover does exist in New South Wales: the Casino Trough; the Mid-Basin High; and the Grafton Trough.

The Walloon Coal Measures in the Grafton Trough have much less coal/coaly shale than in the other two areas to the north (Figure 22). The Kyogle-1 well has approximately 116 m of coal/coaly shale. The next highest amount is in the Rappville-1 well where only about 63 m are present. It appears, then, that the northern part of the Casino Trough has the greatest content of coal/coaly shale in the Walloon Coal Measures. The coal/coaly shale thicknesses were taken from sonic log data using a lower cut-off value of 105 microseconds per foot (or 345 microseconds per metre). Coal, coaly shale and shaly coal are thus all grouped together as the sonic log tends to average values over several metres.

In the central part of the Casino Trough, the depth to the top of the Walloon Coal Measures is about 130 m to 320 m, with the base being about 530 m to 750 m. This places the unit in the upper part of the required depth range of 200 m to 1500 m. The net thickness of coal in Kyogle-1 is estimated at about 39 m to 58 m (one-third to one-half of the coal/coaly shale measurement). This thickness fits well the minimum required thickness of five metres and is more than double the maximum thickness in the San Juan Basin. In the Kyogle-1 well, numerous coal seams (coal/coaly shale) in the Koukandowie Formation have a net thickness of about 20 m, and these may be as prospective as coals in the Walloon Coal Measures.

Vitrinite maturation levels in the Walloon Coal Measures in Kyogle-1 are in the range R_o 0.68% to R_o 0.9%. Further to the south-west, in the Rappville-1 well, the range is about R_o 0.75% to R_o 1.0%. The maturation levels thus fall within the lower part of the acceptable range (cf. Figure 23).

Ash content in the Walloon Coal Measures is high, ranging from about 15% upward to 60%, but most commonly in the 20% to 30% range. This high ash content will undoubtedly have a detrimental effect on the permeability and adsorption capacity of the coals but, until laboratory measurements are available, the seriousness of this aspect is unknown.

From core and cuttings descriptions, there are considerable quantities of both bright and dull coal. No information is available on the amount or degree of fracturing in the coals. The high vitrinite content (Figure 26) of coals in these coal measures indicates that vitrain and clarain should be in abundance.

Calcite is a common cementing material in the Walloon Coal Measures, and calcite filling of cleats in coal has been noted. How pervasive this condition is has not been determined, but sufficient core material probably exists to enable studies to better define this potential problem. (Shields (1994) has outlined a range of procedures for study of cleat fillings.)

No analyses of gas from the Walloon Coal Measures are available. Gas shows detected while drilling in petroleum exploration wells commonly have C_1 through to C_5 gases. Any gas produced from the Walloon sequence will probably consist mostly of methane, but substantial amounts of C_2 to C_3 may be included. Carbon dioxide and nitrogen content are unknown.

The Walloon Coal Measures are probably isolated from any aquifers. The Maclean Sandstone Member at the top of the coal measures may be a problem aquifer, but the section beneath this is highly impermeable and well-protected from aquifers.

In the Kyogle-1 well, numerous thin sandstones appear to have permeability, as seen on the Microlog (Figure 31). If these are gas-bearing, they may flow when the dewatering of the coals is attempted. This could present an interesting problem, or opportunity.

In the Urbenville-1 drillhole in the Warrill Creek Syncline area (Figure 9), the Walloon Coal Measures contain approximately 16 m of coal in 8 seams, a sufficient thickness for commercial coal seam methane production. However, the vitrinite maturation levels in the area are about R_o 0.6% to R_o 0.7%, slightly below the required maturation level. That area, therefore, is not considered prospective for coal seam methane.

IPSWICH COAL MEASURES/NYMBOIDA COAL MEASURES

The sequence incorporating the Ipswich Coal Measures to the Nymboida Coal Measures is very poorly known as only a few wells and drillholes have encountered the sequence, and none of these have penetrated the entire sequence. The Chillingham Volcanics appear to separate the two coal measures, but this has not been firmly established.

The best coal-bearing sequence has been found in the Sextonville-1 well, where a net thickness of coal/coaly shale of about 41 m in numerous seams was drilled. In the Clifden-3 well, the net thickness was about 8 m. In Pillar Valley-2, Evans Head-1 and in the sections exposed at Red Cliff and Evans Head on the coast, coal is a minor constituent of the sequence.

In the Nymboida area the Nymboida Coal Measures contain several thin coal seams in the Basin Creek Formation (upper unit of the Coal Measures), the thickest being the Farquar seam with a maximum thickness of about 2 m. Up to three seams are present in the Cloughers Creek Formation (basal unit of the Coal Measures), with a maximum net thickness of about 8 m. Drillholes indicate that the coal seams are not laterally continuous beyond 1 km to 2 km. The drillholes are concentrated in very small areas and the regional extent and thickness of the coal seams is essentially unknown. From all the data at hand, it appears that the main coal bearing areas lie in the western half of the Clarence-Moreton Basin in New South Wales.

The ash content of the coals from both the Cloughers Creek Formation and the Farquar seam of the Basin Creek Formation range upward from almost 8%, with the majority being in the range of 10% to 30%.

The vitrinite reflectance maturity levels for the Farquar seam are, on average about R_o 0.95% and is classified as medium-volatile bituminous coal. The coals from the Cloughers Creek Formation are classified as low-volatile bituminous, with a tendency towards semi-anthracite.

Because of the northward dip of about 15° in the Nymboida area, the coals quickly become buried beneath the Basin Creek Formation and the Bundamba Group in that direction. At a point 15 km north of the outcrop area, the top of the Nymboida Coal Measures is estimated to be at a depth of 1000 m, with the base at 2000 m or more.

The Shannon and Martin Faults, major west-northwest-trending, reverse, up-to-the-north faults, with probable dextral strike-slip movements, traverse the area north of Nymboida. Those faults undoubtedly have an effect on the depth and structure of the coal measures in that area, not to mention the degree of fracturing imposed on the coal seams.

Calcium carbonate is a common constituent of the sandstones in the Nymboida Coal Measures. No reference to calcite filling of fractures or cleats in the coals in this sequence can be found in the literature, but it quite likely occurs. Personal communication with K. Wright (1995), who recently visited the Nymboida area, reports that there is little calcite in the cleats, that the coal is mainly of the bright variety, and that the cleat is well developed with spacings of about 1 cm.

The Farquar seam, according to McElroy (1962, p. 90), 'is characterised by the presence of much semi-fusinite, with vitrinite, micrinite and resin bodies'. Also, the 'coals of the seam include clarain, duro-clarain and durain in varying proportions and are mostly extremely friable' (p. 90). The Cloughers Creek Formation coal is 'principally a duro-clarain, containing bands and irregular lenses of vitrinite and semi-fusinite with much micrinite' (McElroy, 1962, p. 81). Both dull and bright bands have been described from cores and outcrops. The Ipswich Coal Measures (Smyth, 1994) consist mainly of vitrinite, with lesser amounts of inertinite (Figure 26), suggesting that the main lithotypes are vitrain/clarain/duro-clarain and that cleat systems will be well-developed.

The Nymboida 'I' drillhole blew out with a 'violent' discharge of gas and water after crossing a fault while drilling in the Basin Creek Formation. No analyses of the gas are available. McElroy (1962) noted that the drillhole was still vigorously bubbling gas and water four years later.

The disastrous methane explosion in the Nymboida Colliery in 1956, and the blowout in the 'I' drillhole, are dramatic evidence of gas in the Nymboida Coal Measures. Thus, the area north from Nymboida has an obvious potential for coal seam methane exploration. One or more seismic lines, extending northward from the outcrop area, across the Shannon and Martin Faults, tying into existing seismic lines, would be necessary to establish the basic structural conditions. Following this, one or more drillholes, drilled to basement, would be required to establish the prospectivity of the area for coal seam methane.

The western margin of the Clarence-Moreton Basin in New South Wales appears to be prospective for coal seam methane. The prospective zone could lie between the updip edge of the Ipswich/Nymboida section and the area where the depth to the top of the sequence is about 1000 metres. That updip edge has not been determined because the sequence does not outcrop and no holes have been drilled in this area below the Bundamba Group. The estimated area between the updip limit and the 1000 metre depth are shown in Figure 63. A series of seismic lines would be required to establish the two limits, as well as to establish the thickness of the coal measures sequence. Following this, one or more drillholes to basement would be required to establish the prospectivity for coal seam methane.

The Sextonville-1 well encountered the Ipswich Coal Measures in the interval 1545.3 m to 2051.9 m. (The section below that depth is of uncertain age and correlation.) This is slightly below the optimum producing depth but, as Waller (1993) stated, 'some wells produce at greater depths' ie below 1500 m. There were numerous gas peaks while drilling that well, and coal chips were noted to be seeping gas. The net thickness of coals in Sextonville-1 was about 41 m, and the vitrinite reflectance maturation was R_0 1.7% to R_0 2.0%. The well could possibly be re-entered and production testing of the coal measures section could be attempted without a major expense. If the well happened to be productive, there is a large area to the west where the coal measures rise to shallower depths that could be explored.

In the Warrill Creek Syncline area (Figure 9) the prospectivity of the Ipswich/Nymboida Coal Measures is difficult to establish because of the almost complete lack of seismic and drillhole data. If the Coal Measures are present and contain sufficient coal, they could be prospective because they would be at a favourable depth and maturity.

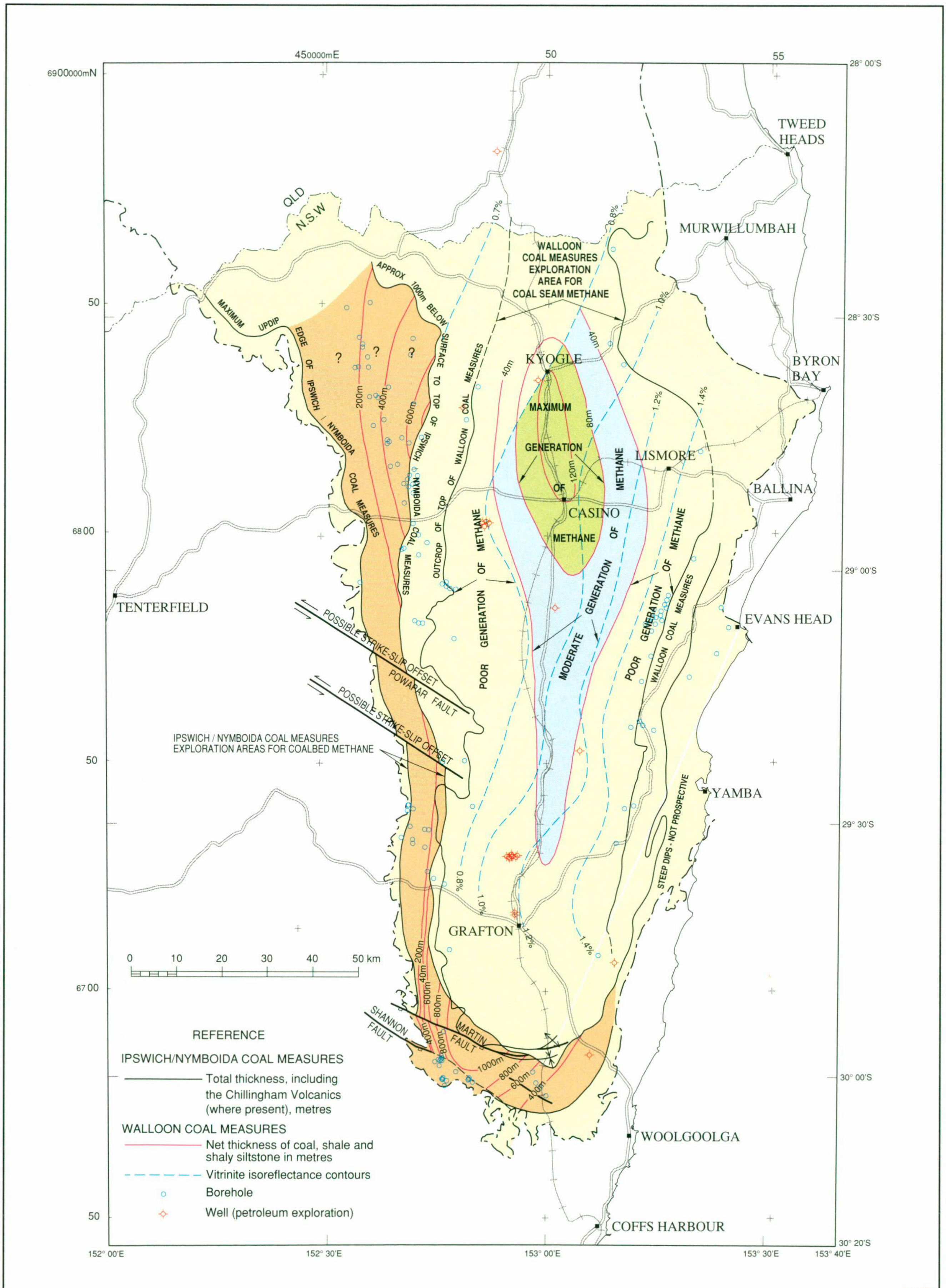


Figure 63. Coal seam methane exploration areas in the Clarence-Moreton Basin, New South Wales, for the Ipswich Coal Measures/Nymboida Coal Measures sequence and Walloon Coal Measures, showing thickness and vitrinite reflectance — and methane generation.

RECOMMENDATIONS

GEOPHYSICAL

In order to further evaluate the hydrocarbon potential of the Clarence-Moreton Basin in New South Wales, a program of reprocessing of seismic data, acquisition of new seismic data and new interpretation is recommended. There is a possibility that seismic modelling of the Heifer Creek Sandstone Member at Hogarth Dome would help to delineate the gas reservoir penetrated at Hogarth-2.

It is also reasonable to expect that some detailed gravity coverage in the highly faulted areas of the Clarence-Moreton Basin would be a cost-effective method of providing control for any additional seismic lines required. (The present gravity station coverage is rather sparse.) Similarly, acquisition (and processing) and interpretation of modern detailed (aero)magnetic data should enhance knowledge of the Basin.

REPROCESSING OF EXISTING SEISMIC DATA

It has been demonstrated that the reprocessing of the 1985 data in the Pickabooba area significantly improves the quality of the older seismic data (Section describing the Pickabooba Prospect). The examples noted are lines 85-P2 and 85-P3, which were reprocessed by Digicon, Brisbane using the crooked line technique in 1994. Those 12-fold data were acquired in 1985 using explosives as a source. The two sections were processed to the Migrated Stack stage and the quality of the reprocessed data compares favourably with the 75-fold Vibroseis data acquired in 1992 and processed by Digicon, Brisbane in 1993 using similar parameters.

Other lines that have been successfully reprocessed include a 1983, 12-fold dynamite line (R104) from the Tullymorgan area (which was reprocessed in 1991), and a number of the 1962 single-fold lines from the Casino area (which were reprocessed in 1982). The quality of the reprocessed data is considerably better than the original processing in each instance.

There is no evidence that any of the 1984 lines in the South Grafton area have been reprocessed. A relatively thick Triassic section is interpreted in the southern end of the Clarence-Moreton Basin, and improved seismic data quality should help to identify the sequence boundaries in the interval from the top of the Ipswich Coal Measures to basement. The interpretation of line 1984 SG-5 12-fold dynamite data (processed by Digicon, Brisbane in June 1984) suggests that there is truncation near the top of the Ipswich Coal Measures near the south end of this line. Other relatively high amplitude events between 0.6 second and 1.2 seconds (two-way time) may represent coal seams or other facies changes within the underlying Nymboida Coal Measures sequence.

It is recommended that line 84-SG5 (4.6 km) be reprocessed in order to improve the data quality in the part of the Clarence-Moreton Basin where the Triassic coal measures appear to be relatively shallow.

ACQUISITION OF NEW SEISMIC DATA

Additional regional seismic lines are required in areas recognised as having the greatest prospectivity, particularly the western and southern margins of the Clarence-Moreton Basin. The proposed seismic program (Figure 49) provides for a survey line total coverage of 302 km. The length of each seismic line proposed, and comments regarding the objectives and road access, are included in Table 6.

SEISMIC MODELLING

The structural interpretation at Hogarth Dome (Figure 9) is based on several 1981 seismic lines which are oriented in various directions. A uniform grid does not exist and the data quality is relatively poor. The time-structure maps prepared by Endeavour Resources Limited following the completion of the Shannon-1 well (cf. Figure 1b) show a small closure at the well location at the top of the Marburg Subgroup (top of the Koukandowie Formation), but there is no direct seismic line extending from the Shannon-1 location to the south-west — which is the direction of critical dip. Therefore, it is uncertain whether Shannon-1 tested a valid structural trap.

Hogarth-2 recovered gas on test from a sandstone interval (912 mKB to 921 mKB) in the upper portion of the Heifer Creek Sandstone Member. The sandstones in the sequence appear to be laterally discontinuous, or variable, and they are poorly developed at Shannon-1, which is located 300 m to the south-west.

It is possible that the lateral distribution of the gas-bearing sandstones at Hogarth-2 can be mapped using high resolution seismic data. Detailed well calibration and seismic impedance modelling would be required to determine the seismic response to the relatively minor change in sandstone thickness between Hogarth-2 and Shannon-1. If this change is recognised on the existing data, then additional detailed seismic coverage would be necessary in order to map the trend of the sandstone reservoir

TABLE 6
RECOMMENDED SEISMIC PROGRAM

Proposed Line No	Length, km	Comments
	(On-Permit at time of writing)	
1	27	East–west road access across the Toonumbar lead, and tie to line 84-K1 for Kyogle-1 well calibration. (Reprocess line 84-K1, 7 km.)
2	32	North–south tie line across Toonumbar lead and Grevillia lead to confirm north–south dip reversal.
3	24	Additional control across East Richmond Fault and tie to line 85-D9 (Sextonville-1). (Reprocess line 85-D9, 6 km.)
4	12	Regional line south–west of the Mid-Basin High which extends across the Powapar Fault Zone.
Sub-Total	**95**	
	(Off-Permit at time of writing)	
1 Ext	14	Extension of Proposed Line 1 to the east of Kyogle using road access to identify leads in an area of favourable hydrocarbon generation. (Line 1 total 41 km.)
3 Ext	14	Extension of Proposed Line 3 to the north-west to evaluate the coal seam methane potential south of Urbenville. (Line 3 total 38 km.)
4 Ext	13	Extension of Proposed Line 4 to the south-west to identify structural leads in the area of the Powapar Fault zone and also evaluate coal seam methane potential on the western margin of the Clarence-Moreton Basin. (Line 4 total 25 km.)
5	29	A continuation of line 86CR-305 to the west in an area where no seismic data exist (Coaldale High) to identify leads for both conventional hydrocarbon accumulations and coal seam methane.
6	24	Continuation of C90-423 along road access to the west to identify potential exploration targets, including coal seam methane.
7	14	Continuation of 84-SG8 to the south-west using road access to identify leads along the south-western margin of the Clarence-Moreton Basin.
8	29	An east–west line which ties the south-western end of Proposed Line 7 and also Proposed Lines 9, 10 and 11, which extend into the southern portion of the Clarence-Moreton Basin.
9	23	A north-east–south-west line having road access for the northern portion. This line lies in the south-western portion of the Clarence-Moreton Basin where east–west faults are projected from surface geology to the west. This line also crosses Nymboida 'I' coal drillhole, where gas blew out from a fault zone within the Nymboida Coal Measures sequence. The area is prospective for both coal seam methane and conventional gas accumulations.
10	25	A road access line which extends into the southernmost portion of the Clarence-Moreton Basin (Glenreagh area), where potential exists for both conventional hydrocarbon accumulations and coal seam methane. This line also crosses the western end of the Kungala lead.
11	22	This north–south line has partial access along the east side of the railway easement. The line extends across the Kungala lead (surface geology) into the southern area of the Clarence-Moreton Basin.
Sub-Total	**207**	
Total	**302**	

NOTE: The locations of the proposed seismic lines are shown in Figure 49.

interval and select a possible follow-up drilling location.

GEOLOGICAL

Several studies could be undertaken to enhance the understanding of the geological processes that have occurred in the Clarence-Moreton Basin and which affect the exploration prospectivity.

Drilling

In order to evaluate the gas production capability of the Walloon Coal Measures a cored drillhole should be put down in the Kyogle area, preferably on a seismically-defined structural high. Such a hole would have a total depth of about 1150 m and should be cored from the top of the Walloon Coal Measures to the base of the Koukandowie Formation, using either air or oil-based mud (drilling fluid) as a circulating medium to prevent swelling of clays in the sandstones. Complete laboratory analyses relevant to productivity from both the sandstones and the coal seams should be made. Production tests should then be conducted if warranted by the drilling and laboratory results.

A second stratigraphic drillhole should be drilled in the area of the Coaldale High, based on information obtained from the acquisition of new seismic data. That drillhole should be cored from the top of the Walloon Coal Measures to basement. The data from that drillhole would be critical for exploration of both conventional hydrocarbons and coal seam methane.

A third stratigraphic drillhole should be drilled in the southern end of the 'South-west Margin Play Area', if results from the acquisition of new seismic data are encouraging. The drillhole should be designed to investigate the coal seam methane potential of the Ipswich Coal Measures/Nymboida Coal Measures, and to obtain information relevant to reservoir conditions and source rock quality for conventional hydrocarbon exploration. The drillhole should be cored from the top of the Koukandowie Formation to basement.

A fourth stratigraphic drillhole should be drilled in the 'South Margin Play Area' if the results of the new seismic data acquisition are encouraging. The information from such a hole would be useful in defining the potential for coal seam methane in the Ipswich Coal Measures/Nymboida Coal Measures, and would be helpful in evaluating the conventional hydrocarbon potential in the Kungala Anticline and other potential structures in the area. The drillhole should be cored from the top of the Koukandowie Formation to basement.

Reservoir Studies

The major problem confronting an exploration program is the loss of permeability — or at least variations in permeability — in the sandstones throughout the Clarence-Moreton Basin sedimentary section in New South Wales. There has apparently not been a comprehensive petrographic/diagenetic study of the pore-filling processes that have occurred in those sandstones. Any prospect in the Clarence-Moreton Basin — no matter how good the source rocks, trap, seal and maturation levels — may still be non-productive because of an impermeable reservoir. For explorers, such permeability variation could be particularly important in choosing the most prospective areas for future work: selecting the best prospects to drill; or even picking the best locations on a prospect. Such studies should help to establish answer(s) to the following questions.

1. What were the series of events which led to the filling of the pores? Which came first, authigenic clays, quartz cement or calcite cement?
2. When did the pore-filling events take place — before structural development or after?
3. Why is porosity found mainly in the top three or four sandstones in the Heifer Creek Sandstone Member?
4. What is the depositional origin and geometry of the sandstone bodies in the Heifer Creek Sandstone Member?
5. What is the relationship of depositional environments and diagenesis? How much of the clay in the sandstone is depositional and how much is diagenetic?
6. What type of sandstone bodies are most likely to have permeability and which are least likely?
7. What is the relationship between porosity and permeability, and how depth-sensitive is the permeability?
8. And lastly, and possibly most importantly, is there any development of secondary porosity? Perhaps, for example, the porosity in the Heifer Creek Sandstone Member in the Kyogle-1 well is the result of secondary solutions of one or more components. Why is the best permeability found to date located in the deepest part of the Casino Trough?

Perhaps, if the answers to the above questions were better known, prospects and well-sites could be better chosen to reduce the risk of drilling dry holes.

Dating of Igneous Intrusions

Another area of concern in understanding the hydrocarbon prospectivity of the Clarence-Moreton Basin in New South Wales is the presence of numerous (igneous) sills that have been found in many of the drillholes. Are they all the same age, ie Miocene, or are some older.

In some wells, eg Clifden-3, a substantial number of sills, totalling about 200 m in thickness, were intruded into an interval from the Laytons Range Conglomerate to the upper part of the Ipswich Coal Measures. If these were all intruded at the same time, it must have had some affect on the generation of gas in the coal-bearing sequences. Did that emplacement happen in Triassic or Miocene time, or some other time? If in Miocene time, the gas generated by this increased heat may have migrated into overlying beds. If in Triassic time, the gas may have been expelled to the atmosphere. If all the sills in the Clarence-Moreton Basin are of Miocene age, this may indicate a general heating event throughout the Basin which may have had a regional effect on the generation of hydrocarbons. It should, however, be pointed out that intrusion of even many (relatively) thin sills over an extended period of time may not have a major heating effect on a sequence (although naturally if emplaced into a coal seam, then the local effects can be quite dramatic — R.A. Facer (ed.), pers. comm., 1996).

Suggested Mechanism for Geological Studies

The questions under the previous sub-headings could possibly be addressed, and probably resolved to a large extent, in a series of university theses or other similar studies. A centrepiece of those theses or studies would be the detailed petrographic study of igneous and sedimentary rocks. Petrographic and sedimentological analyses of the Koukandowie Formation, which was continuously cored in the Hogarth-4 well, would be important. Sections in other wells would have to be analysed from logs and cuttings and a few widely scattered cores or sidewall cores. The Pillar Valley-2 drillhole was also continuously cored and those cores also would be very useful in providing data from the southern end of the Clarence-Moreton Basin. However, the area around Pillar Valley-2 is not considered to be in a very prospective part of the Basin.

CONCLUSIONS

After a thorough review of the geological and geophysical data for the New South Wales portion of the Clarence-Moreton Basin, the following conclusions have been reached concerning the hydrocarbon, including coal seam methane, potential.

1. The Clarence-Moreton Basin has been lightly explored. Many large areas have never been surveyed using seismic techniques or been subjected to anything but shallow coal exploration drillholes. Large areas with exploration potential have never been drilled.

2. Sufficient data exist to state, unequivocally, that the potential for commercial quantities of conventional hydrocarbons and coal seam methane is sufficiently high to warrant further exploration.

3. Source rock analyses and exploration results to date suggest that the most likely conventional hydrocarbon to be found will be gas, but the possibility for oil accumulation definitely exists.

4. Accumulations will probably be of small to moderate size. The potential gas reserves would be great enough to service the entire Clarence-Moreton Basin area and surrounding townships.

5. All the basic fundamentals — ie source rocks, appropriate maturation levels, traps, reservoirs, seals and timely development of traps compatible with generation and migration of hydrocarbons — are present.

6. The Heifer Creek Sandstone Member is the primary objective, and although the permeability in that unit may be erratic, it commonly exhibits fair to good reservoir characteristics. The Ripley Road Sandstone is a second primary reservoir objective. Other sandstone units are considered as secondary objectives.

7. The New South Wales portion of the Clarence-Moreton Basin has been divided into nine play areas with varying exploration potential. These are, with descending potential, as follows:
   - (i) Casino Trough;
   - (ii) Richmond Horst/South Moreton Anticline;
   - (iii) Grafton Trough;
   - (iv) South-west Margin;
   - (v) Mid-Basin High;
   - (vi) East Richmond Fault;
   - (vii) South Margin;
   - (viii) Warrill Creek Syncline; and
   - (ix) East Margin.

8. The only two wells drilled to date on well-established structural closures are Rappville-1 and Tullymorgan-1. The remaining wells were drilled on structures with inadequate seismic control and with doubtful closures.

9. Only one prospect, the Pickabooba Prospect, is currently delineated by seismic data and considered to be ready to drill. Several leads and play areas need to be investigated by reprocessing and re-interpreting the existing seismic data. Other leads need new seismic data.

10. The Walloon Coal Measures and the Ipswich Coal Measures/Nymboida Coal Measures have potential for coal seam methane production. The Walloon Coal Measures are prospective in the deeper parts of the Casino and Grafton Troughs, where the necessary overburden exists. The Ipswich/Nymboida Coal Measures are prospective in the Southern Margin play area, and possibly along the south-western margin of the Logan Sub-basin.

11. To further define the exploration potential for conventional hydrocarbons, as well as for coal seam methane, additional seismic data are needed in under-explored areas. The recommended new seismic coverage totals about 302 km in eleven lines. Following interpretation of (new) seismic data, one or more stratigraphic drillholes will be needed.

Given the possibility of finding commercial quantities of conventional hydrocarbons and/or coal seam methane in an area containing a ready market of 300 000 people, the current lack of exploration activity in the Clarence-Moreton Basin, in New South Wales, is surprising. Evidence is presented in this *Bulletin* to indicate that sufficient porosity and permeability are present in various reservoir units in certain areas to support commercial flows of hydrocarbons.

The potential for the commercial production of coal seam methane in the Clarence-Moreton Basin in New South Wales is largely unknown but, considering the substantial thicknesses of coal already encountered in the Walloon Coal Measures and Ipswich/Nymboida Coal Measures, the possibility of establishing coal seam methane production definitely exists.

The economics of operating in the north-eastern region of New South Wales are further enhanced by the existing infrastructure of roads, towns, communications, etc., and (petroleum) drilling depths are moderate. There appears to be good reason for expecting that hydrocarbon production could be established in the Clarence-Moreton Basin, and to conclude that, for enterprising companies, the rewards for exploring in this area could be very satisfying.

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GLOSSARY OF SELECTED ABBREVIATIONS

This listing, in alphabetical order, describes a selection of abbreviations used in the petroleum exploration industry, and referred to in the text and/or Figures in this *Bulletin*.

API	American Petroleum Institute
cf/d	cubic feet per day (1 cf/d = 0.028 cubic metres per day) [a million cubic feet per day may be abbreviated mmcf/d or Mcf/d, although the latter may also be used for thousand cubic feet per day]
cfg/d	cubic feet of gas per day
DOM	disseminated or dispersed or detrital organic material or matter
HI	Hydrogen Index (mg of hydrocarbons per gram of organic carbon or mgHC/gC_o or mgHC/g TOC)
KB	Kelly Bushing — a reference point on a drilling rig from which down-hole depths are measured (eg 999 mKB)
km	kilometre(s)
m	metre(s)
msec/ft	milliseconds per foot or
ms/ft	milliseconds/foot [seismic velocity in wireline log] (1 ms/ft = 0.305 msec/metre)
md	millidarcies, a measure of permeability (sometimes mD, named after Darcy)
ND	no data
NR	not reached
Ph	Phytane (or phytane) — a saturated isoprenoid with 20 carbon atoms (C_{20})
Pr	Pristane (or pristane) — a saturated isoprenoid with 19 carbon atoms (C_{19})
Rm or R_m	Resistivity of drilling mud
Rmf or R_{mf}	Resistivity of mud filtrate
Rw or R_w	Resistivity of formation water
S_1	Stage 1 of pyrolysis analysis; indicates amount of free petroleum liberated when sample heated to 300°C.
S_2	Stage 2 of pyrolysis analysis; indicates amount of petroleum generated from sample when heated from 300°C to 550°C.
$S_1 + S_2$	$S_1 + S_2$ is referred to as the generation potential, according to the following schedule:

0.0-1.0	Poor
1.0-2.0	Marginal
2.0-6.0	Moderate
6.0-10.0	Good
10.0-20.0	Very Good
greater than 20.0	Excellent

SP	self potential
Surf	surface
TOC	Total Organic Carbon
TSTM	Too small to measure (said of fluid which flows to the surface, or is recovered at the surface, when a drillhole or well is "tested" but that recovery flow is at a rate too small to measure).

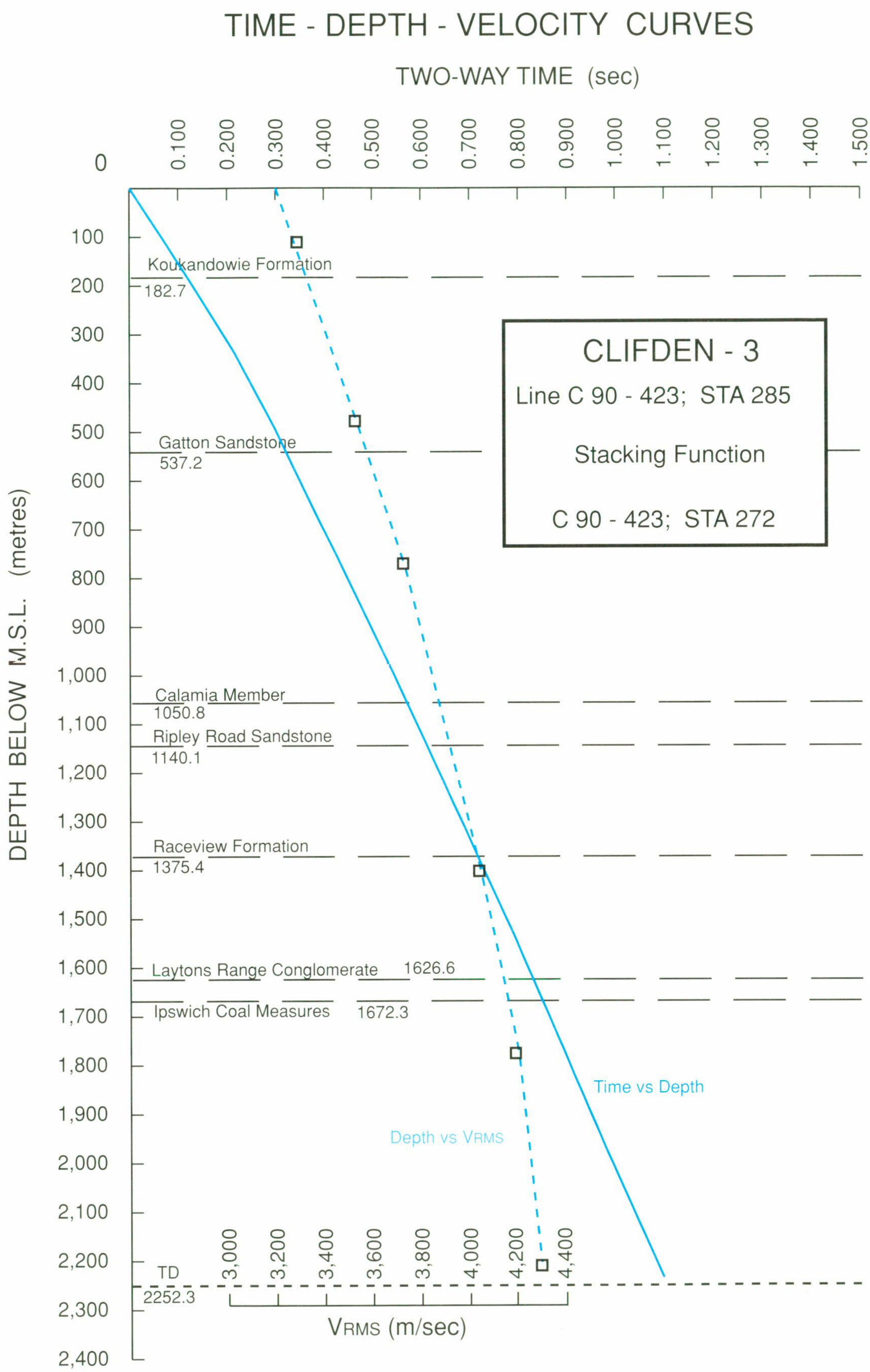
APPENDIX 1

TIME–DEPTH VELOCITY CURVES FOR SELECTED PETROLEUM EXPLORATION WELLS IN THE CLARENCE-MORETON BASIN

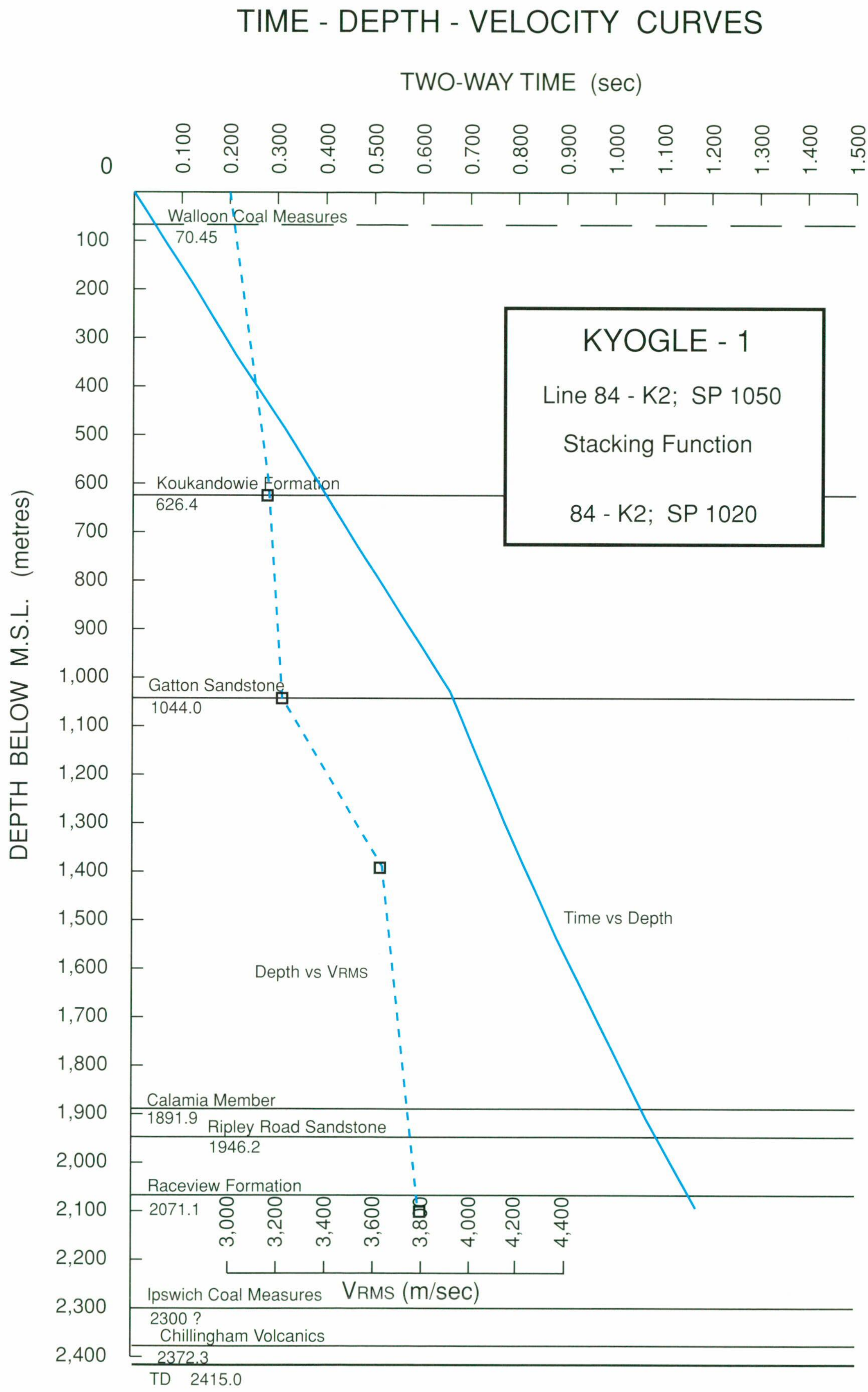
This appendix contains time-depth and velocity curves for seven petroleum exploration wells in the New South Wales portion of the Clarence-Moreton Basin. The wells are listed below.

- a Clifden-3
- b Kyogle-1
- c Pillar Valley-2
- d Rappville-1
- e Sextonville-1
- f Shannon-1
- g Tullymorgan-1

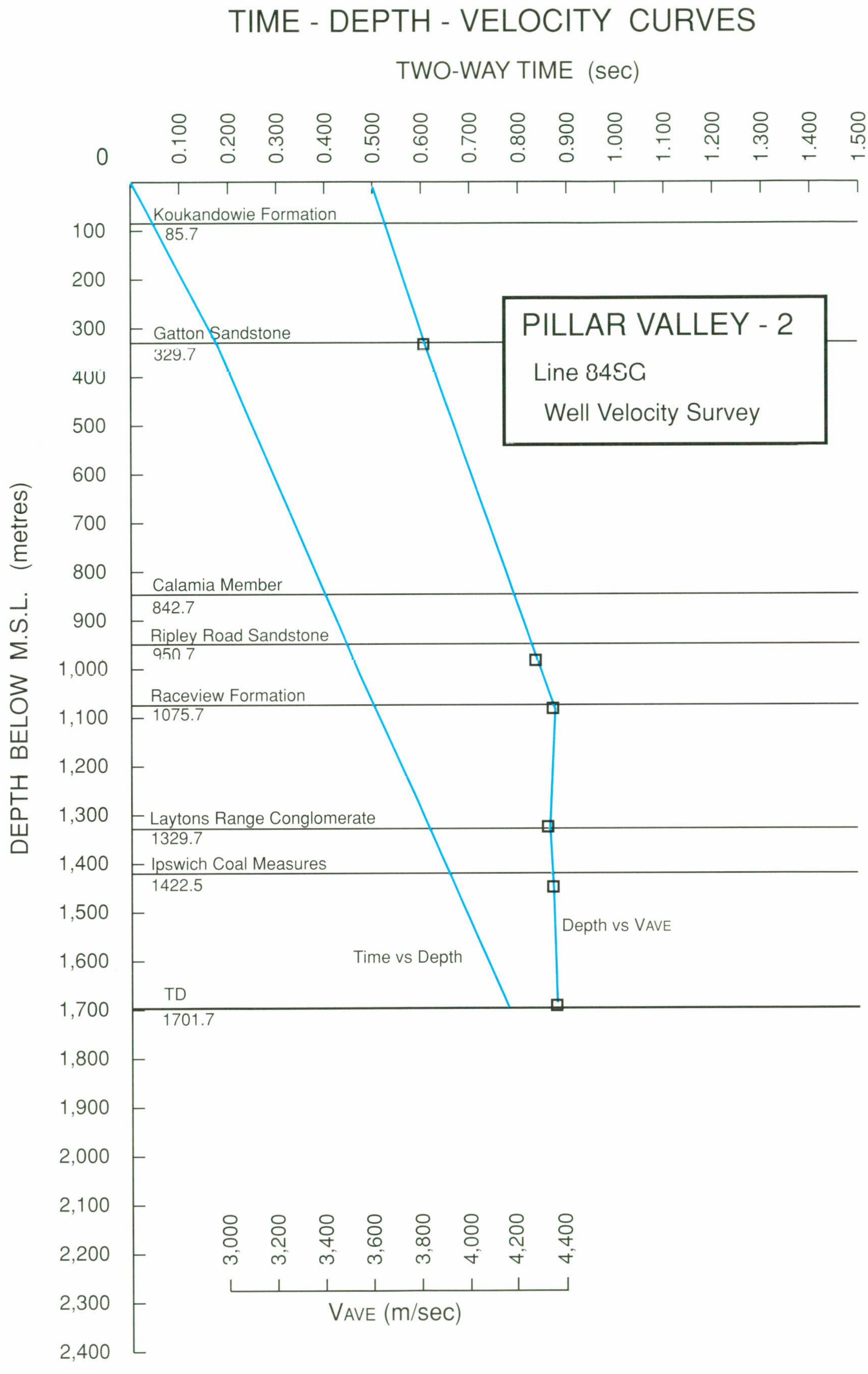
For all seven wells a plot of time versus depth is presented. For four of the wells, a stacking function has been utilised to provide a plot of depth versus $V_{RMS.}$ For the other three wells, a plot of depth versus V_{AVE} has been obtained by calculations from the well velocity survey.


TIME - DEPTH - VELOCITY CURVES
TWO-WAY TIME (sec)
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
DEPTH BELOW M.S.L. (metres)
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
1,400
1,500
1,600
1,700
1,800
1,900
2,000
2,100
2,200
2,300
2,400
Koukandowie Formation
182.7
Gatton Sandstone
537.2
Calamia Member
1050.8
Ripley Road Sandstone
1140.1
Raceview Formation
1375.4
Laytons Range Conglomerate 1626.6
Ipswich Coal Measures 1672.3
TD
2252.3
CLIFDEN - 3
Line C 90 - 423; STA 285
Stacking Function
C 90 - 423; STA 272
Time vs Depth
Depth vs VRMS
3,000
3,200
3,400
3,600
3,800
4,000
4,200
4,400
VRMS (m/sec)

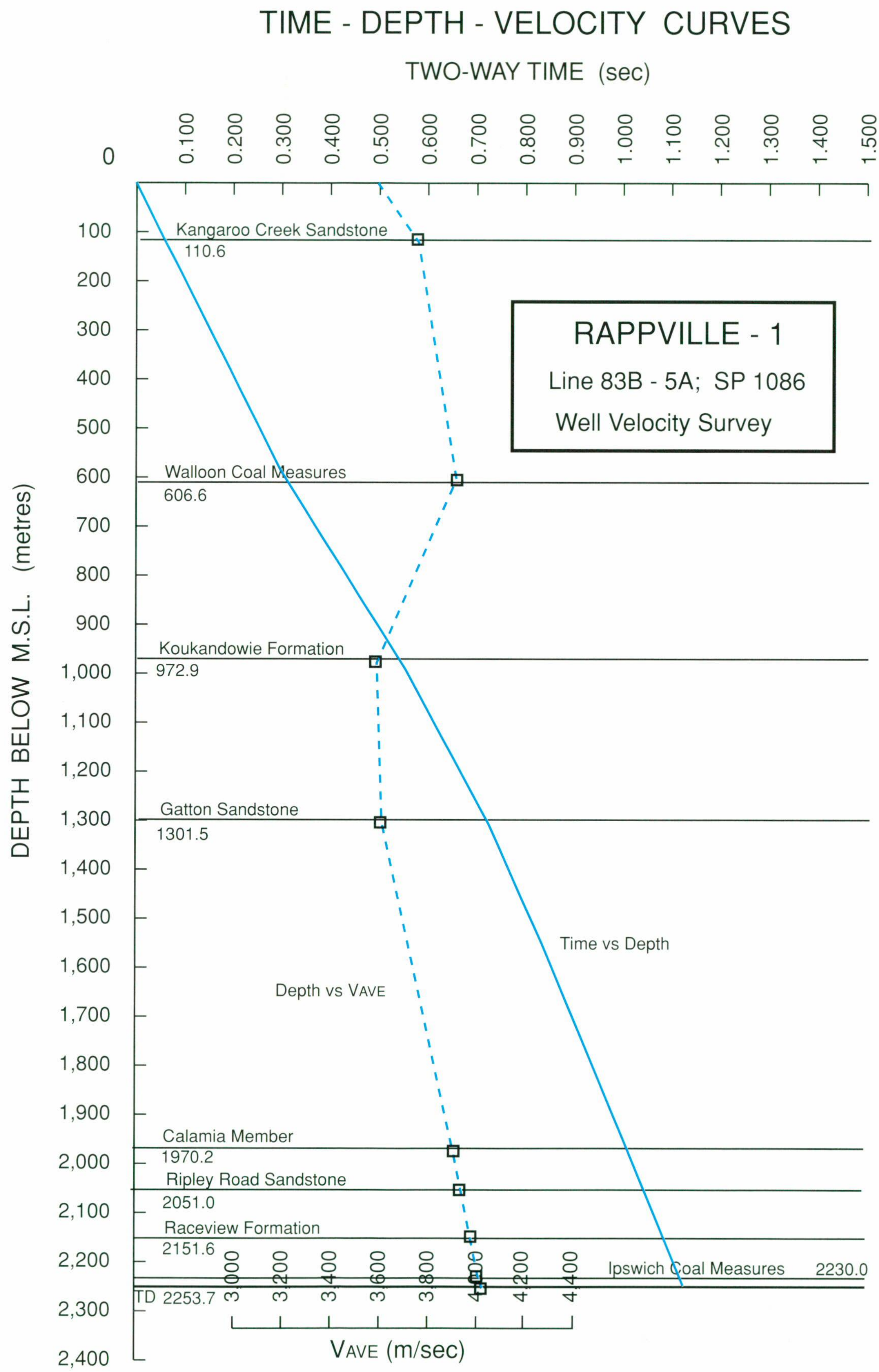
a. Clifden-3


TIME - DEPTH - VELOCITY CURVES
TWO-WAY TIME (sec)
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
DEPTH BELOW M.S.L. (metres)
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
1,400
1,500
1,600
1,700
1,800
1,900
2,000
2,100
2,200
2,300
2,400
KYOGLE - 1
Line 84 - K2; SP 1050
Stacking Function
84 - K2; SP 1020
Walloon Coal Measures
70.45
Koukandowie Formation
626.4
Gatton Sandstone
1044.0
Time vs Depth
Depth vs VRMS
Calamia Member
1891.9
Ripley Road Sandstone
1946.2
Raceview Formation
2071.1
3,000
3,200
3,400
3,600
3,800
4,000
4,200
4,400
VRMS (m/sec)
Ipswich Coal Measures
2300 ?
Chillingham Volcanics
2372.3
TD 2415.0

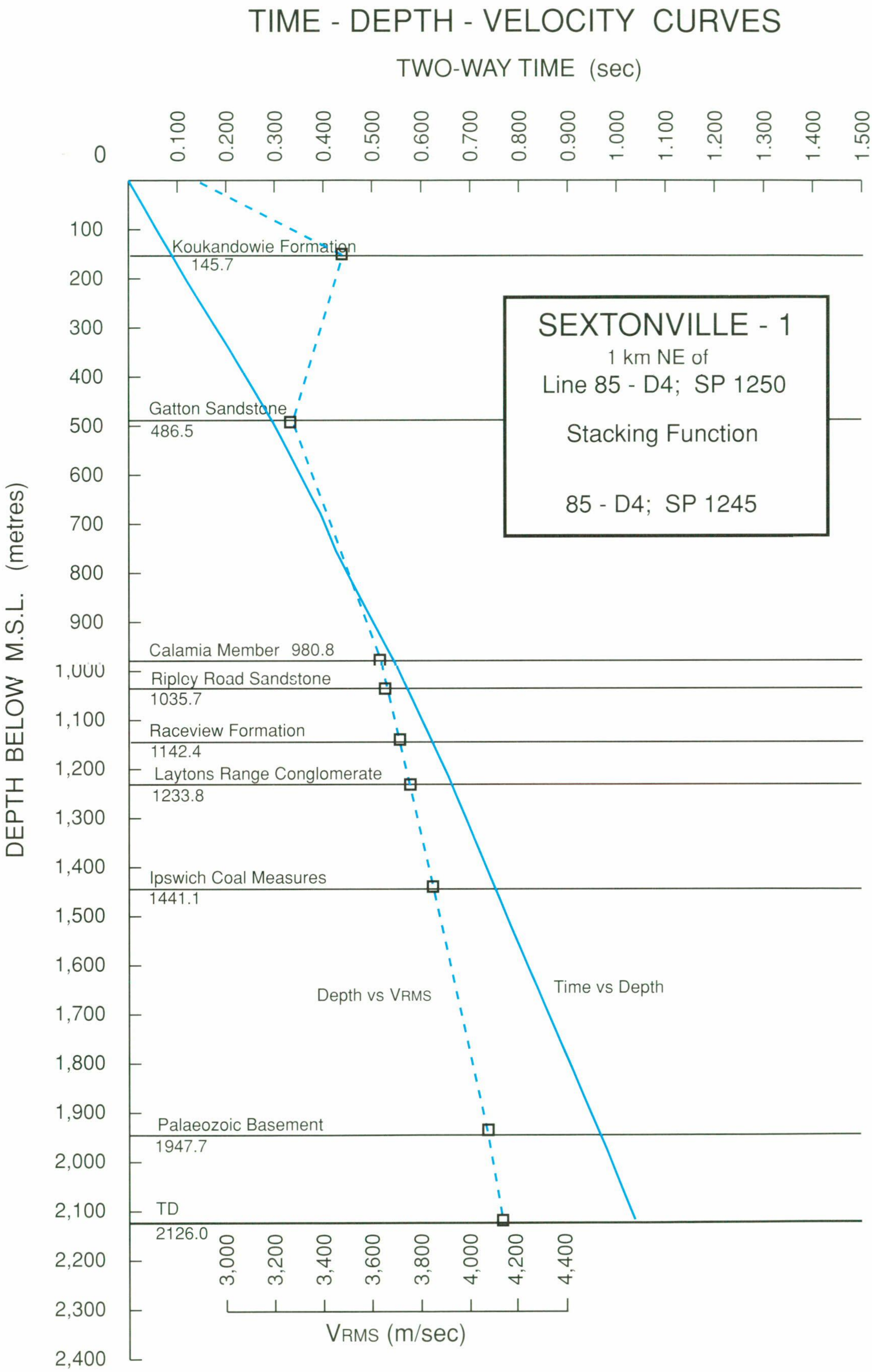
b. Kyogle-1



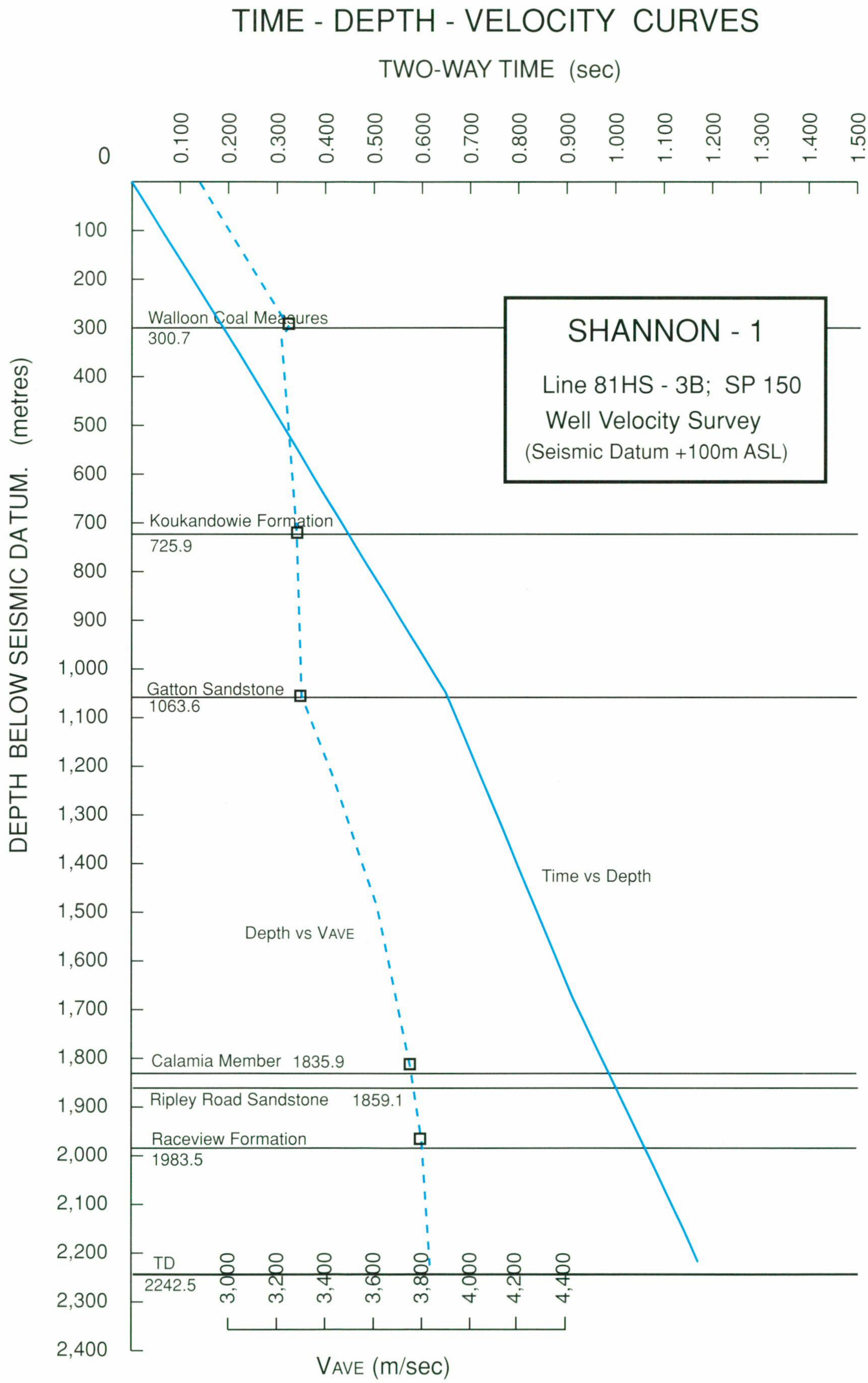
c. Pillar Valley-2



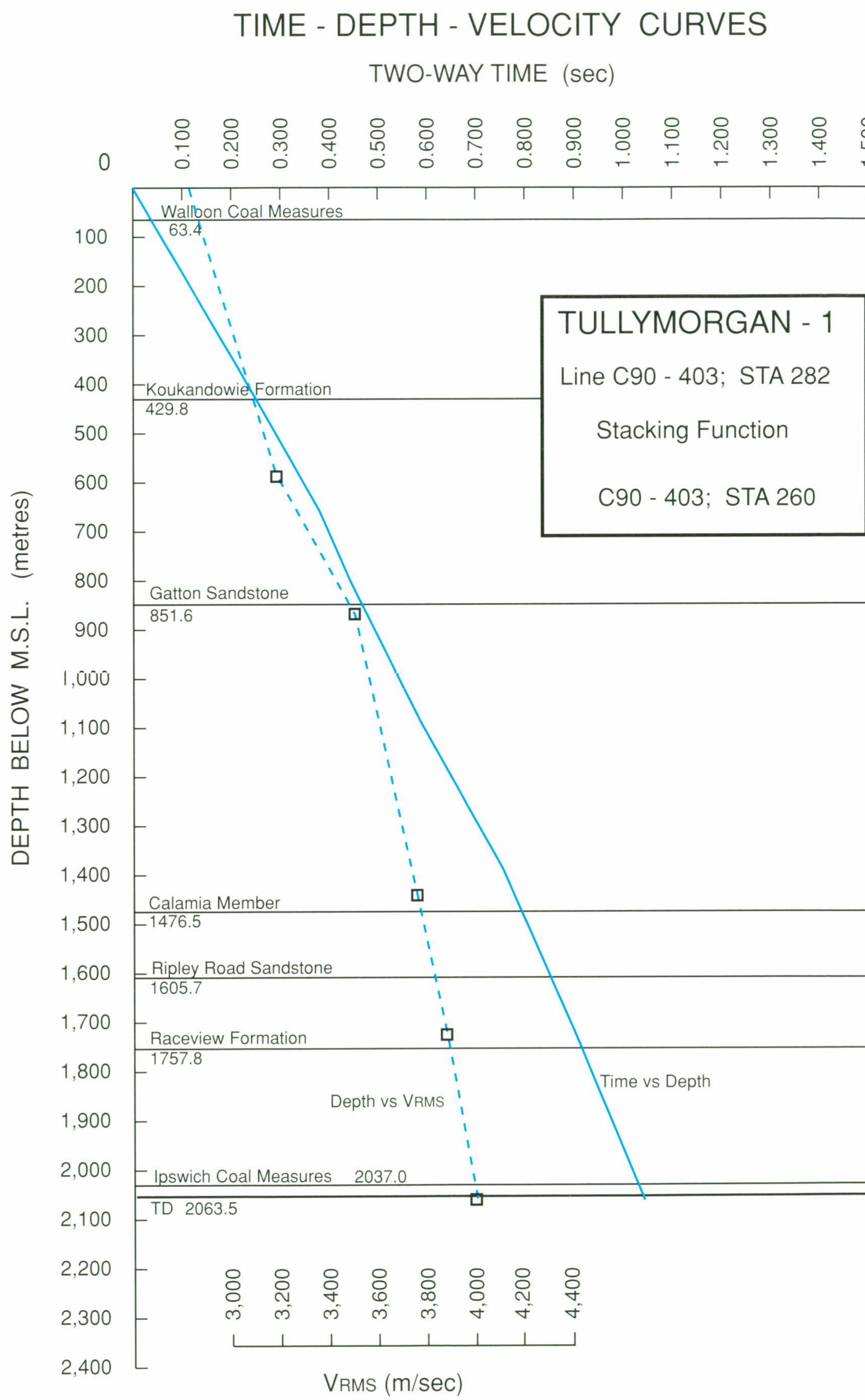
d. Rappville-1



e. Sextonville-1


TIME - DEPTH - VELOCITY CURVES
TWO-WAY TIME (sec)
DEPTH BELOW SEISMIC DATUM. (metres)
SHANNON - 1
Line 81HS - 3B; SP 150
Well Velocity Survey
(Seismic Datum +100m ASL)
Walloon Coal Measures 300.7
Koukandowie Formation 725.9
Gatton Sandstone 1063.6
Calamia Member 1835.9
Ripley Road Sandstone 1859.1
Raceview Formation 1983.5
TD 2242.5
Time vs Depth
Depth vs VAVE
VAVE (m/sec)

f. Shannon-1



g. Tullymorgan-1

APPENDIX 2

LIST OF WELLS AND DRILLHOLES IN THE NEW SOUTH WALES PORTION OF CLARENCE-MORETON BASIN

This appendix lists wells and drillholes that have been drilled in the New South Wales portion of the Clarence-Moreton Basin. Each hole's name, total depth, locality (grid) and year (if known) have been presented.

Note that in some cases there may be errors in available records and it has not been possible to check all entries. Figure 1b (page 3 in the main part of this *Bulletin*) provides a plot of many drillhole and well localities.

DRILLHOLE	LATITUDE	LONGITUDE	AMG ZONE	EASTING	NORTHING	MAP NO.	TD, m
AUST CITIES TULLYMORGAN DDH 01	29°21'18"S	153°04'44"E	56	507647	6752680	SH56-7	23.11
BARDOOL ADIT NO 2	30°00'37"S	152°46'21"E	56	478067	6680039	SH56-10	1.76
BOC CLIFDEN RDH3	29°34'05"S	152°54'50"E	56	491653	6729063	SH56-6	2287.80
CLARENCE CLIFDEN DDH1	29°33'60"S	152°55'16"E	56	492358	6729228	SH56-6	393.20
CLARENCE CLIFDEN RDH 2	29°33'60"S	152°55'15"E	56	492333	6729228	SH56-6	592.20
CLARENCE CLIFDEN RDH 4	29°34'00"S	152°55'24"E	56	492573	6729203	SH56-6	762.00
CLARENCE CLIFDEN RDH 5	29°34'00"S	152°55'13"E	56	492278	6729228	SH56-6	608.40
CLARENCE CLIFDEN RDH 6	29°34'00"S	152°55'14"E	56	492313	6729228	SH56-6	603.50
JM CHAMBIGNE CREEK	29°45'01"S	152°46'45"E	56	478655	6708842	SH56-6	200.47
CLARENCE GRAFTON DDH 2	29°40'40"S	152°47'10"E	56	479307	6716897	SH56-6	1396.60
CLARENCE GRAFTON DDH 3	29°34'00"S	152°55'16"E	56	492358	6729228	SH56-6	393.20
CLARENCE HALFWAY CREEK DDH 1	29°57'23"S	153°05'20"E	56	508577	6686017	SH56-7	784.25
CLARENCE HOGARTH RDH 1	28°54'12"S	152°51'05"E	56	485515	6802698	SH56-2	1218.00
CLARENCE HOGARTH RDH 2	28°54'08"S	152°51'38"E	56	486410	6802822	SH56-2	1113.40
CLARENCE HOGARTH RDH 3	28°54'18"S	152°52'03"E	56	487084	6802533	SH56-2	957.10
CLARENCE HOGARTH RDH 4	28°54'43"S	152°51'24"E	56	486015	6801748	SH56-2	1171.30
DM MOONEM DDH 01	29°05'59"S	153°13'44"E	56	522282	6780925	SH56-7	302.97
DM MOONEM DDH 02	29°04'40"S	153°14'25"E	56	523392	6783354	SH56-7	152.40
DM MOONEM DDH 03 A	29°02'59"S	153°16'21"E	56	526531	6786453	SH56-7	53.64
DM MOONEM DDH 04 B	29°03'33"S	153°16'11"E	56	526251	6785433	SH56-7	24.38
DM MOONEM DDH 05 C	29°04'06"S	153°15'53"E	56	525771	6784404	SH56-7	30.48
DM MOONEM DDH 06	29°04'28"S	153°16'06"E	56	526121	6783714	SH56-7	16.76
DM MOONEM DDH 07	29°04'51"S	153°15'24"E	56	524982	6783014	SH56-7	32.91
DM MOONEM DDH 08	29°05'22"S	153°15'22"E	56	524912	6782075	SH56-7	39.62
DM MOONEM DDH 09	29°05'58"S	153°15'32"E	56	525181	6780965	SH56-7	33.83
DM MOONEM DDH 10	29°07'13"S	153°14'07"E	56	522892	6778666	SH56-7	29.26
DM MOONEM DDH 11	29°05'36"S	153°14'13"E	56	523052	6781645	SH56-7	88.39
DM MOONEM DDH 12	29°06'22"S	153°13'14"E	56	521463	6780215	SH56-7	79.24
DM MOONEM DDH 13	29°06'24"S	153°14'37"E	56	523712	6780175	SH56-7	135.94
DM MOONEM DDH 14	29°05'35"S	153°14'43"E	56	523862	6781655	SH56-7	92.04
DM PILLAR VALLEY DDH 2	29°46'36"S	153°09'19"E	56	515006	6705955	SH56-7	1740.00
ENDEAVOUR CLARENCE-MORETON RDH 01	29°10'12"S	153°14'03"E	56	522760	6773160	SH56-7	274.00
ENDEAVOUR CLARENCE-MORETON RDH 02	29°13'11"S	153°12'47"E	56	520700	6767630	SH56-7	293.00
ENDEAVOUR CLARENCE-MORETON RDH 03	29°02'20"S	152°47'29"E	56	479692	6787668	SH56-6	201.20
ENDEAVOUR CLARENCE-MORETON RDH 04	29°01'29"S	152°46'12"E	56	477608	6789242	SH56-6	99.00
ENDEAVOUR CLARENCE-MORETON RDH 05	29°06'20"S	152°43'01"E	56	472469	6780260	SH56-6	135.00
ENDEAVOUR CLARENCE-MORETON RDH 06	28°58'16"S	152°42'28"E	56	471530	6795170	SH56-2	100.00
ENDEAVOUR CLARENCE-MORETON RDH 07	28°57'29"S	152°40'26"E	56	468211	6796610	SH56-2	94.00
ENDEAVOUR CLARENCE-MORETON RDH 08	28°55'54"S	152°42'26"E	56	471460	6799539	SH56-2	123.00
ENDEAVOUR CLARENCE-MORETON RDH 09	28°54'34"S	152°41'41"E	56	470250	6801998	SH56-2	129.00
ENDEAVOUR CLARENCE-MORETON RDH 10	29°46'16"S	152°40'18"E	56	468261	6706520	SH56-6	100.00
ENDEAVOUR CLARENCE-MORETON RDH 11	28°49'54"S	152°41'39"E	56	470160	6810615	SH56-2	100.00
ENDEAVOUR CLARENCE-MORETON RDH 12	28°48'08"S	152°41'49"E	56	470420	6813874	SH56-2	111.00
ENDEAVOUR CLARENCE-MORETON RDH 13	28°45'02"S	152°41'07"E	56	469260	6819602	SH56-2	271.00
ENDEAVOUR CLARENCE-MORETON RDH 14	28°44'21"S	152°42'49"E	56	472030	6820871	SH56-2	99.00
ENDEAVOUR CLARENCE-MORETON RDH 15	28°32'39"S	152°41'39"E	56	470070	6842469	SH56-2	148.00
ENDEAVOUR CLARENCE-MORETON RDH 16	28°34'34"S	152°41'19"E	56	469540	6838920	SH56-2	308.00
ENDEAVOUR CLARENCE-MORETON RDH 17	28°50'56"S	152°41'42"E	56	470240	6808705	SH56-2	90.20
ENDEAVOUR CLARENCE-MORETON RDH 18	28°42'16"S	152°48'54"E	56	481921	6824720	SH56-2	132.00
ENDEAVOUR CLARENCE-MORETON RDH 19	28°38'23"S	152°50'29"E	56	484490	6831918	SH56-2	147.00
ENDEAVOUR CLARENCE-MORETON RDH 20	28°49'45"S	152°42'16"E	56	471160	6810885	SH56-2	114.00
ENDEAVOUR CLARENCE-MORETON RDH 21	28°48'53"S	152°42'17"E	56	471190	6812484	SH56-2	95.94
ENDEAVOUR CLARENCE-MORETON RDH 22	28°49'50"S	152°40'24"E	56	468141	6810725	SH56-2	46.70
ENDEAVOUR CLARENCE-MORETON RDH 23	28°49'19"S	152°40'55"E	56	468961	6811684	SH56-2	5.00
ENDEAVOUR CLARENCE-MORETON RDH 24	28°48'50"S	152°41'11"E	56	469400	6812574	SH56-2	9.00
ENDEAVOUR CLARENCE-MORETON RDH 25	28°50'12"S	152°41'02"E	56	469160	6810045	SH56-2	50.20
ENDEAVOUR CLARENCE-MORETON RDH 26	29°02'15"S	152°46'43"E	56	478437	6787833	SH56-6	102.33
ENDEAVOUR CLARENCE-MORETON RDH 27	29°01'59"S	152°46'14"E	56	477648	6788332	SH56-6	101.96
ENDEAVOUR CLARENCE-MORETON RDH 28	29°01'42"S	152°45'39"E	56	476718	6788832	SH56-6	101.87
ENDEAVOUR CLARENCE-MORETON RDH 29	29°06'20"S	152°42'27"E	56	471550	6780280	SH56-6	48.26
ENDEAVOUR CLARENCE-MORETON RDH 30	29°06'04"S	152°41'56"E	56	470700	6780760	SH56-6	53.87
ENDEAVOUR CLARENCE-MORETON RDH 31	28°47'47"S	152°38'34"E	56	465152	6814509	SH56-2	185.00

DRILLHOLE	LATITUDE	LONGITUDE	AMG ZONE	EASTING	NORTHING	MAP NO.	TD, m
ENDEAVOUR CLARENCE-MORETON RDH 32	28°47'33"S	152°39'32"E	56	466721	6814958	SH56-2	176.00
ENDEAVOUR CLARENCE-MORETON RDH 33	28°44'25"S	152°40'07"E	56	467651	6820726	SH56-2	191.00
ENDEAVOUR CLARENCE-MORETON RDH 34	28°44'53"S	152°38'25"E	56	464872	6819877	SH56-2	66.00
ENDEAVOUR CLARENCE-MORETON RDH 35	28°42'16"S	152°37'43"E	56	463712	6824685	SH56-2	111.00
ENDEAVOUR CLARENCE-MORETON RDH 36	28°42'57"S	152°36'17"E	56	461393	6823426	SH56-2	96.00
ENDEAVOUR CLARENCE-MORETON RDH 37	28°38'25"S	152°38'19"E	56	464672	6831803	SH56-2	196.00
ENDEAVOUR CLARENCE-MORETON RDH 38	28°39'24"S	152°36'38"E	56	461933	6829983	SH56-2	48.00
ENDEAVOUR CLARENCE-MORETON RDH 39	28°39'40"S	152°36'55"E	56	462403	6829493	SH56-2	131.00
ENDEAVOUR CLARENCE-MORETON RDH 40	28°39'33"S	152°35'45"E	56	460513	6829713	SH56-2	54.00
ENDEAVOUR CLARENCE-MORETON RDH 41	28°36'03"S	152°35'37"E	56	460254	6836161	SH56-2	60.00
ENDEAVOUR CLARENCE-MORETON RDH 42	28°34'50"S	152°35'29"E	56	460044	6838410	SH56-2	55.00
ENDEAVOUR CLARENCE-MORETON RDH 43	28°33'18"S	152°34'49"E	56	458954	6841219	SH56-2	5.00
ENDEAVOUR CLARENCE-MORETON RDH 43A	28°33'40"S	152°34'48"E	56	458914	6840550	SH56-2	54.00
ENDEAVOUR CLARENCE-MORETON RDH 44	28°32'31"S	152°34'22"E	56	458214	6842679	SH56-2	74.00
ENDEAVOUR CLARENCE-MORETON RDH 45	28°36'06"S	152°33'48"E	56	457295	6836061	SH56-2	18.00
ENDEAVOUR CLARENCE-MORETON RDH 46	28°36'01"S	152°34'16"E	56	458054	6836221	SH56-2	24.00
ENDEAVOUR CLARENCE-MORETON RDH 47	28°45'06"S	152°38'09"E	56	464452	6819467	SH56-2	106.00
ENDEAVOUR CLARENCE-MORETON RDH 48	28°44'39"S	152°38'09"E	56	464452	6820287	SH56-2	86.00
ENDEAVOUR RAPPVILLE RDH 1	29°04'11"S	153°01'01"E	56	501660	6784284	SH56-7	2322.90
ENDEAVOUR SHANNON RDH 1	28°54'16"S	152°51'32"E	56	486240	6802593	SH56-2	2264.00
JCB NYMBOIDA DDH "F"	29°58'17"S	152°44'45"E	56	475488	6684358	SH56-6	304.80
JCB NYMBOIDA DDH A OR DDH 1	29°58'09"S	152°45'28"E	56	476628	6684608	SH56-6	67.97
JCB NYMBOIDA DDH B OR DDH 2	29°58'01"S	152°45'37"E	56	476868	6684838	SH56-6	70.40
JCB NYMBOIDA DDH I	29°57'33"S	152°45'39"E	56	476928	6685697	SH56-6	236.09
JCB NYMBOIDA DDH J	29°58'08"S	152°45'45"E	56	477098	6684618	SH56-6	58.12
JCB NYMBOIDA DDH	29°57'50"S	152°45'45"E	56	477088	6685197	SH56-6	146.30
JCB NYMBOIDA DDH N	29°58'08"S	152°45'45"E	56	477093	6684618	SH56-6	245.24
JCB NYMBOIDA DDH O	29°58'02"S	152°45'14"E	56	476268	6684798	SH56-6	67.93
JCB NYMBOIDA DDH P	29°58'44"S	152°45'23"E	56	476488	6683518	SH56-6	85.86
JM BEXHILL DDH 1	28°45'56"S	153°20'37"E	56	533532	6817939	SH56-3	150.75
JM BONALBO DDH 1	28°40'23"S	152°41'46"E	56	470298	6828201	SH56-2	331.60
JM COALDALE DDH 1	29°28'03"S	152°49'52"E	56	483629	6740189	SH56-6	251.02
JM CORAKI DDH 1	28°58'38"S	153°19'46"E	56	532083	6794473	SH56-3	357.50
JM EVANS HEAD DDH 1&1A	29°06'46"S	153°24'34"E	56	539842	6779447	SH56-7	130.00
JM EVANS HEAD DDH2	29°09'51"S	153°22'57"E	56	537185	6773741	SH56-7	149.74
JM NIMBIN DDH 1	28°33'12"S	153°08'17"E	56	513492	6841480	SH56-3	227.00
JM NIMBIN DDH 2	28°35'43"S	153°10'09"E	56	516549	6836845	SH56-3	150.00
JM PILLAR VALLEY DDH 1	29°45'42"S	153°07'06"E	56	511437	6707616	SH56-7	300.10
JM TABBIMOBLE DDH 01	29°18'38"S	153°11'22"E	56	518395	6757582	SH56-7	263.48
JM TYALGUM DDH 1	28°22'01"S	153°08'38"E	56	514102	6862125	SH56-3	346.00
JM TYNDALE DDH 1	29°32'23"S	153°09'28"E	56	515296	6732192	SH56-7	346.55
JM URBENVILLE DDH1&1A	28°28'23"S	152°35'50"E	56	460570	6850308	SH56-2	584.35
JM WYAN CREEK DDH 1	29°08'11"S	152°47'17"E	56	479372	6776865	SH56-6	212.34
WMCC WOODFORD ISLAND DDH 1	29°28'17"S	153°10'35"E	56	517104	6739759	SH56-7	457.50
PMEO KYOGLE RDH 1	28°37'34"S	152°58'36"E	56	497721	6833417	SH56-2	2490.00
NRCC BARDOOL PDH B1	30°00'33"S	152°46'24"E	56	478142	6680179	SH56-10	28.00
NRCC BARDOOL PDH B3	30°00'19"S	152°45'45"E	56	477108	6680609	SH56-10	32.91
NRCC BARDOOL PDH B4	30°00'23"S	152°45'52"E	56	477283	6680479	SH56-10	56.69
NRCC BARDOOL PDH B5	30°01'07"S	152°46'07"E	56	477678	6679130	SH56-10	78.94
NRCC BARDOOL PDH B7	30°00'11"S	152°45'54"E	56	477343	6680854	SH56-10	75.28
NRCC BARDOOL PDH B8	30°00'22"S	152°45'48"E	56	477188	6680489	SH56-10	11.58
NRCC BARDOOL PDH B9	30°00'20"S	152°45'44"E	56	477058	6680579	SH56-10	63.67
NRCC RAMORNIE DDH "A"	29°35'46"S	152°43'43"E	56	473719	6725939	SH56-6	122.00
NRCC RAMORNIE DDH "C"	29°36'35"S	152°44'33"E	56	475068	6724424	SH56-6	36.27
NRCC RAMORNIE DDH "E"	29°37'15"S	152°46'04"E	56	477508	6723185	SH56-6	152.43
NRCC TOWALLUM DDH "A"	30°00'27"S	152°49'20"E	56	482856	6680374	SH56-10	143.87
NRCC TOWALLUM DDH "B"	30°00'42"S	152°49'57"E	56	483855	6679899	SH56-10	82.29
NRCC TOWALLUM DDH "C"	30°00'12"S	152°49'31"E	56	483146	6680814	SH56-10	146.54
NRCC TOWALLUM DDH "E"	29°59'27"S	152°47'38"E	56	480127	6682199	SH56-6	154.20
NRCC TOWALLUM DDH "F"	29°59'27"S	152°47'38"E	56	480127	6682199	SH56-6	153.25
NYMBOIDA COLL SS "A"	29°58'18"S	152°45'39"E	56	476928	6684308	SH56-6	
NYMBOIDA COLL SS "B"	29°58'15"S	152°45'06"E	56	476053	6684418	SH56-6	

DRILLHOLE	LATITUDE	LONGITUDE	AMG ZONE	EASTING	NORTHING	MAP NO.	TD, m
NYMBOIDA COLL SS "D"	29°59'35"S	152°45'46"E	56	477113	6681949	SH56-6	
NYMBOIDA COLL SS "D"	29°58'12"S	152°45'39"E	56	476933	6684493	SH56-6	
NYMBOIDA COLL SS "E"	29°58'28"S	152°45'52"E	56	477288	6683998	SH56-6	
NYMBOIDA COLL SS "F"	29°58'18"S	152°45'60"E	56	477488	6684308	SH56-6	
NYMBOIDA COLL SS "G"	29°58'21"S	152°45'15"E	56	476278	6684228	SH56-6	
NYMBOIDA COLL SS 01	29°58'09"S	152°45'29"E	56	476668	6684593	SH56-6	
NYMBOIDA COLL SS S77A	29°58'15"S	152°45'54"E	56	477333	6684398	SH56-6	
NYMBOIDA COLL SS S78A	29°58'28"S	152°45'58"E	56	477448	6684018	SH56-6	
NYMBOIDA COLL STR SAM C	29°58'15"S	152°44'58"E	56	475828	6684418	SH56-6	
PPWD GRAFTON DDH 1	29°40'48"S	152°47'10"E	56	479312	6716637	SH56-6	1127.10
ROCKY MOUTH MACLEAN DDH 1 APPROX LOC	29°27'57"S	153°11'49"E	56	519104	6740369	SH56-7	122.95
WOODBURN DDH	29°04'24"S	153°23'31"E	56	538147	6783814	SH56-7	446.53

NOTE: The latitude and longitude values have been rounded to the nearest second (").

INDEX

This single index has been designed to provide information on selected main terms — although "Clarence-Moreton Basin" is not included. Drillhole and well names (and numbers) are given without the identifier term "well" or "borehole" or other, and without the operator identifier — eg Tamrookum Creek-1. Appendix 2 has not been separately indexed here because of its arrangement. Figure captions, and Figures and Tables, have generally not been indexed.

MINERAL RESOURCES