REPORT
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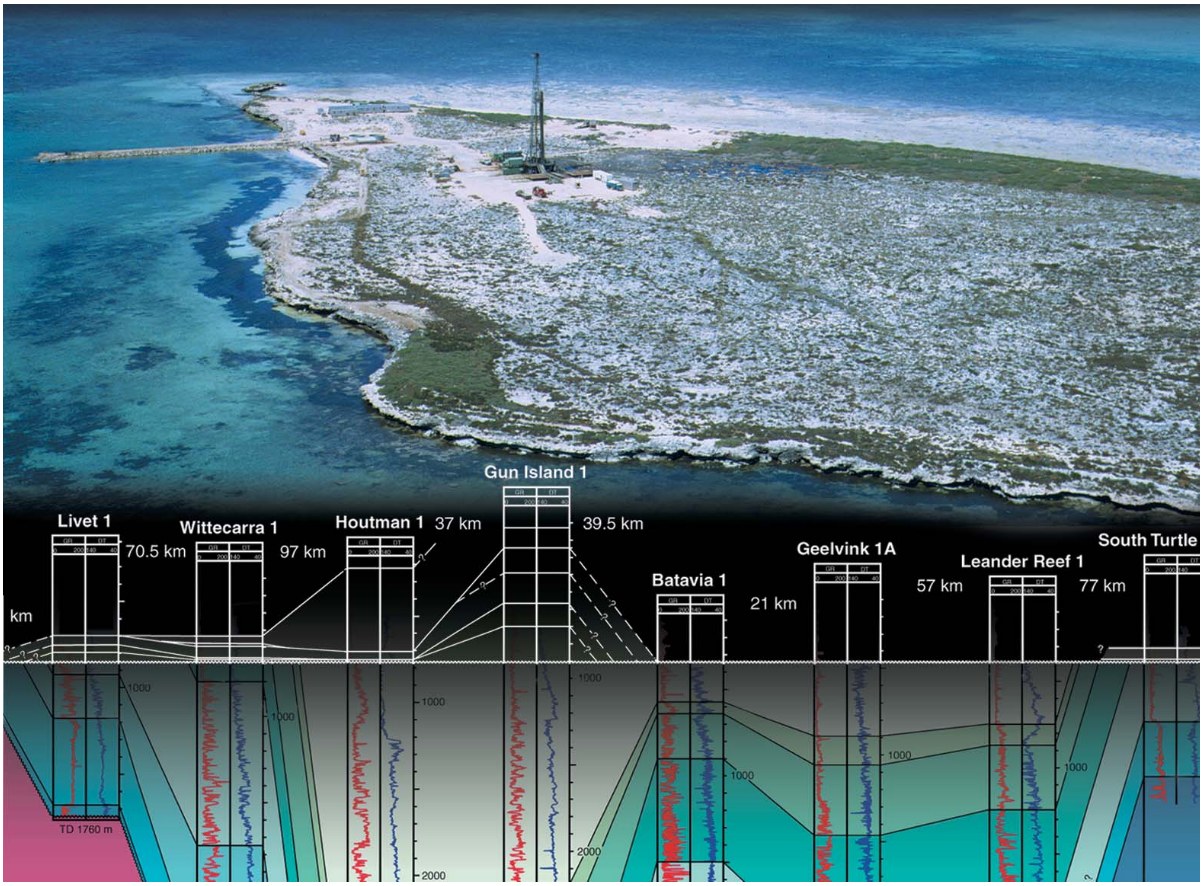
GEOLOGY AND PETROLEUM POTENTIAL OF THE ABROLHOS SUB-BASIN WESTERN AUSTRALIA

by A. Crostella



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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GEOLOGY AND PETROLEUM POTENTIAL OF THE ABROLHOS SUB-BASIN, WESTERN AUSTRALIA

by
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with a contribution from J. Backhouse
Backhouse Biostrat Pty Ltd

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Cover photograph:
Aerial view of Gun Island 1 in 1968, the first well in the Abrolhos Sub-basin (photograph by P. E. Playford).

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Geology and petroleum potential of the Abrolhos Sub-basin, Western Australia

by

A. Crostella

Abstract

The offshore Abrolhos Sub-basin is analysed on the basis of post-mortems of nine petroleum exploration wells and their structural setting from seismic data. The presence of the Ordovician Tumblagooda Sandstone indicates an affinity between the inner part of the Abrolhos Sub-basin and the Gascoyne Platform of the Southern Carnarvon Basin. The thin Lower Permian section (Irwin River Coal Measures and Carynginia Formation) above the Tumblagooda Sandstone is in turn unconformably overlain by the Triassic Wittecarra Sandstone, and shows limited similarities to the onshore northern Perth Basin. Stratigraphically, the southernmost tip of the area under investigation in the vicinity of South Turtle Dove 1B can, however, be closely correlated with the northern Perth Basin.

A line of magnetic anomalies, probably related to deep-seated igneous intrusions, is subparallel with the coastline and is interpreted to be related to Permian–Triassic rifting. For the remainder of the Triassic and the Jurassic, the connection with the onshore northern Perth Basin is firmly established. The early Neocomian breakup tectonism is characterized by oblique extension, with right-lateral strike-slip zones and compressional anticlines produced by converging faults. The Cretaceous to Cainozoic succession shows a close similarity to the Southern Carnarvon Basin lithostratigraphy, with the exception of the South Turtle Dove 1B area.

The best petroleum exploration objective within the inner Abrolhos Sub-basin appears to be the Wittecarra Sandstone, sourced by the gas-prone Lower Permian Irwin River Coal Measures and Carynginia Formation, sealed by the Kockatea Shale, and trapped in early Neocomian anticlines. However, the petroleum potential of the South Turtle Dove 1B area may be more favourable considering its similarities to the onshore northern Perth Basin.

KEYWORDS: magnetic anomalies, igneous intrusions, strike slip faults, petroleum potential, petroleum plays, source beds, anticlines.

Introduction

The offshore Abrolhos Sub-basin is a northwesterly trending deep trough which forms a transitional area between the Southern Carnarvon Basin to the north and northeast, and the Perth Basin to the south (Fig. 1). The Abrolhos Sub-basin, as defined herein, covers an area of about 65 000 km^2 and contains a Permian–Jurassic succession that can be correlated with that of the Perth Basin, whereas the Ordovician and Cretaceous–Cainozoic sections are similar to those of the Carnarvon Basin. Consequently, under the present definition of Western Australian basins as geographic rather than time-rock entities, the assignment of the sub-basin to either basin is arbitrary and is here left as an open question. The Abrolhos Sub-basin is bounded to the east by the Beagle Ridge, the Dongara Saddle, the Proterozoic Northampton Complex, and the Southern Carnarvon Basin, and extends westwards to the continental–oceanic crust contact. Although it occupies a clearly defined transitional position between the two major basins of the western margin of Western Australia (Fig. 1), in the literature the Abrolhos Sub-basin has been consistently considered to represent (entirely or in part) the northernmost sub-basin of the Perth Basin (Playford, 1971; Smith and Cowley, 1987; Marshall et al., 1989; Hocking, 1994).

The Abrolhos Sub-basin has been variously subdivided. In its northern part Smith and Cowley (1987) recognized three regions, separated by pre- or syn-depositional extensional faults, which they named (from west to east) the Yalgoo Trough, Wittecarra Terrace, and Edel Platform. Marshall et al. (1989) defined the entire area as the offshore North Perth Basin and subdivided it (from west to east) into the Houtman Sub-basin, Abrolhos Sub-basin, and Edel Sub-basin, their boundaries being defined by post-depositional north-northwesterly trending

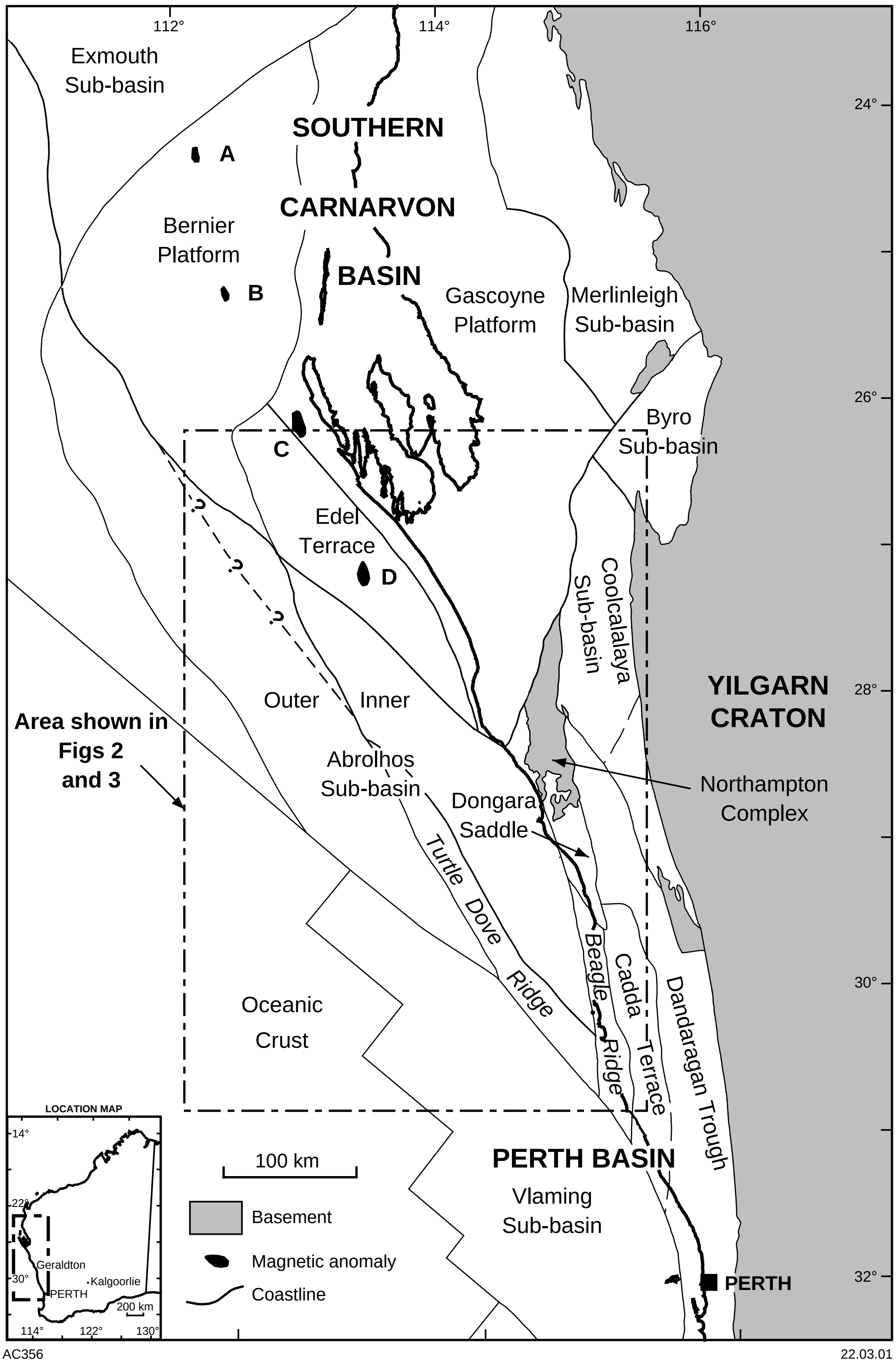

Figure 1. **Regional geological setting of the Abrolhos Sub-basin. Magnetic anomalies A to D after Middleton (1993)**

strike-slip faults. Stein et al. (1989), using a plate tectonic context, differentiated the area generically into a northern Edel Platform and a southern Abrolhos Sub-basin. Hocking (1994) placed the Edel Terrace in the Southern Carnarvon Basin, and divided the offshore northern Perth Basin into a southern Abrolhos Sub-basin to the east of the Turtle Dove Ridge, and seawards, the Houtman Sub-basin, in a way not very different from that of Marshall et al. (1989), but without implying strike-slip faulting.

North of the Northampton Complex, the eastern boundary of the Abrolhos Sub-basin coincides with the western margin of the Edel Terrace. This line has been considered to be the northeasternmost part of the Abrolhos Sub-basin (Edel Platform of Smith and Cowley, 1987) or the southwesternmost part of the Carnarvon Basin (Hocking, 1994). This Report follows Hocking (1994), who described the terrace as a structural feature between the shallow Palaeozoic southern Gascoyne Platform to the east and the Mesozoic trough of the Perth Basin to the west. Because Wittecarra 1 (Fig. 2) penetrated a thick, predominantly sedimentary, Permian to Jurassic section, the Edel Terrace is here restricted to that area around Edel 1 where igneous rocks are abundant, as proposed by Smith and Cowley (1987) and Purcell and Fisher (1997). Edel 1 is included in this Report because of its significance in defining the Abrolhos Sub-basin.

In this Report, the Abrolhos Sub-basin is treated as a discrete feature because the differences in thickness of the drilled sections are considered to be due only to the varying basinal positions of the controlling wells. The structural divisions within the sub-basin have been defined differently by all those concerned with the area. Additional information is required to further subdivide the sub-basin in a non-subjective way, if such divisions are indeed warranted. In this Report, an inner and an outer sub-basin are tentatively proposed, separated by the Turtle Dove Ridge and its northerly extension (Fig. 2). The inner Abrolhos Sub-basin is characterized by Permian–Triassic rifting and, where present, up to 1500 m of Jurassic rocks. Conversely, Jurassic rifting characterizes the outer Abrolhos Sub-basin, where pre-Jurassic strata have not been reached.

This Report is based on the evaluation (‘post-mortems’) of the geological succession from the nine wells drilled in the area within the framework of the regional setting and basin evolution. Relevant seismic lines have been utilized to define the relationships between the wells and the structural style of the youngest tectonism, which overprints previous structural movements and is critical to the possible presence of hydrocarbon accumulations. Finally, reservoirs, seals, source rocks, and traps are analysed in order to evaluate the petroleum potential of the region.

Exploration activities

The Abrolhos Sub-basin has been poorly explored, with only nine wells within an area of approximately 70 000 km^2. Petroleum exploration activities in the region commenced in 1965 with the 1226 km Abrolhos MSS seismic survey (Appendix 1). The first exploration well, Gun Island 1, was drilled in 1968 (Appendix 2). Exploration has continued sporadically until recent times. The only current exploration permit (WA-226-P) is in the northernmost part of the sub-basin.

Although potential reservoirs, seals, source rocks, and traps are present, the lack of economically significant results has slowed the pace of petroleum exploration drilling in the region. To date, some 63 500 km of seismic data (Appendix 1) have been recorded, although their distribution is uneven (Fig. 3).

Gun Island 1 was followed by Edel 1 in 1972, on the Edel Terrace. The southernmost tip of the region was investigated in 1975 with South Turtle Dove 1B. More intense drilling activities took place in 1978 with the drilling of Geelvink 1A, Houtman 1, and Batavia 1, all in the central part of the sub-basin. After a period of re-evaluation, the petroleum potential of the region was further tested in 1983 with Leander Reef 1 and in 1985 with Wittecarra 1, within the southern and northern parts of the sub-basin respectively. No further drilling took place until 1996 when Livet 1, the last well drilled in the region, tested the area to the west of Edel 1.

Regional geology

The geological information provided by the nine wells in the region, seismic data, palynological information, (summarized on Plate 1) and the limited published literature allow the Phanerozoic geological setting of the Abrolhos Sub-basin to be defined within a regional framework. The regional stratigraphy is summarized in Figure 4 and formation tops for the petroleum wells, as here revised, are listed in Appendix 3. In the Edel Terrace, the pre-Cretaceous section is represented only by the Tumblagooda Sandstone (Hocking et al., 1987), an Ordovician unit that is best known from the Gascoyne Platform of the Southern Carnarvon Basin (Hocking, 1981; Iasky and Mory, 1999).

Two wells, Geelvink 1A and Livet 1, were completed within unnamed formations, represented by quartzitic and red-bed intervals respectively, which were considered by the relevant petroleum companies to be economic basement for petroleum exploration in the region. Edel 1 penetrated a monotonous interval of interbedded igneous rocks and sandstone, referred by Ocean Ventures Pty Ltd (1972) to the informal Edel formation. The three sections, however, show sufficient similarities to the Tumblagooda Sandstone to be ascribed to that formation. Structural cross section A in Figure 5, based on seismic sections H78-110A and B, corroborates this interpretation.

The oldest sedimentary rocks of economic interest for the petroleum industry are Early Permian in age. After the deposition of the Tumblagooda Sandstone, the Abrolhos Sub-basin had a similar depositional history to that of the onshore Perth Basin (Fig. 6). To the end of the Devonian the Abrolhos Sub-basin may have had a depositional history similar to that of the Gascoyne Platform but, as yet, a Silurian–Devonian

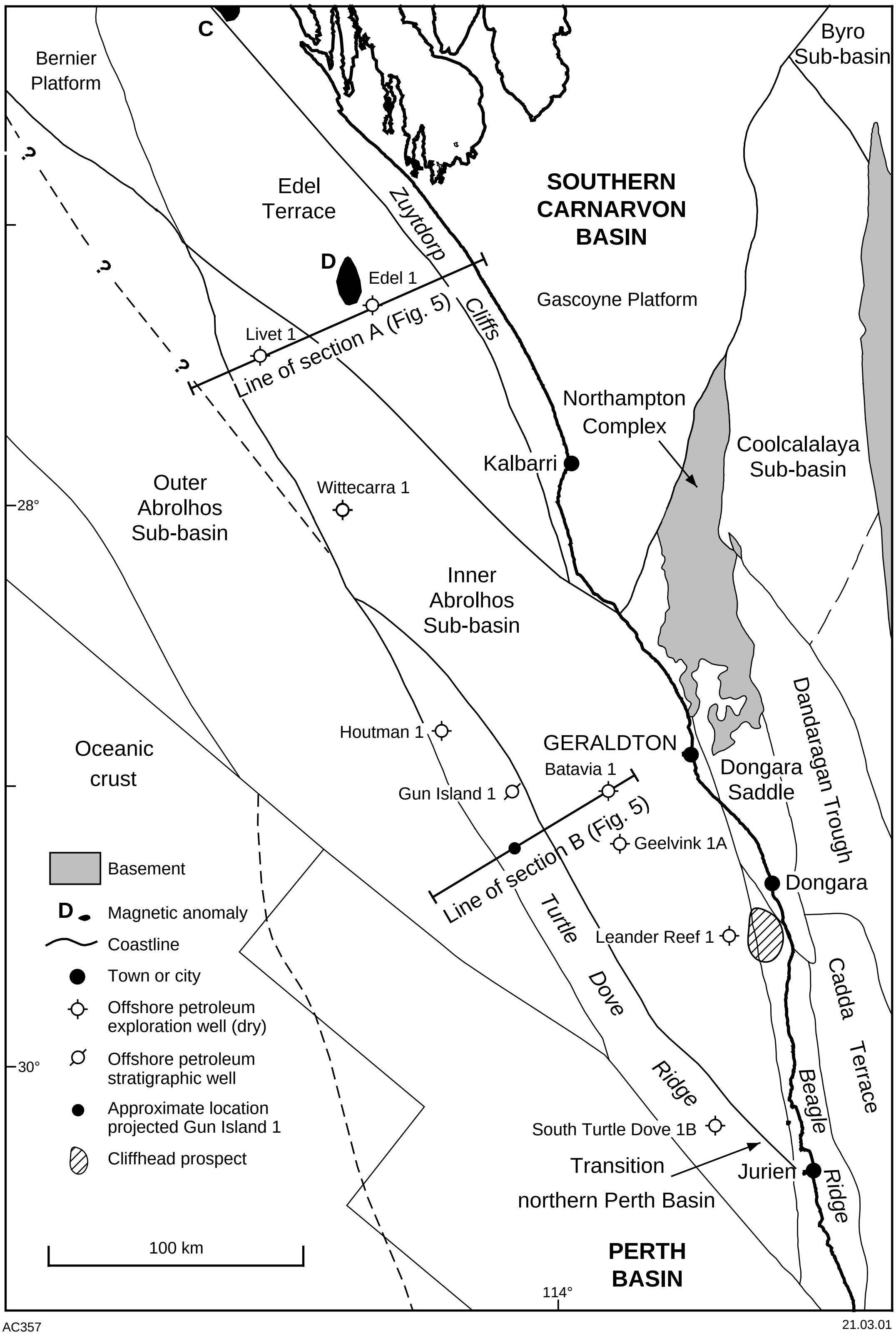

Figure 2. Well location map, showing details of the proposed subdivision of the Abrolhos Sub-basin

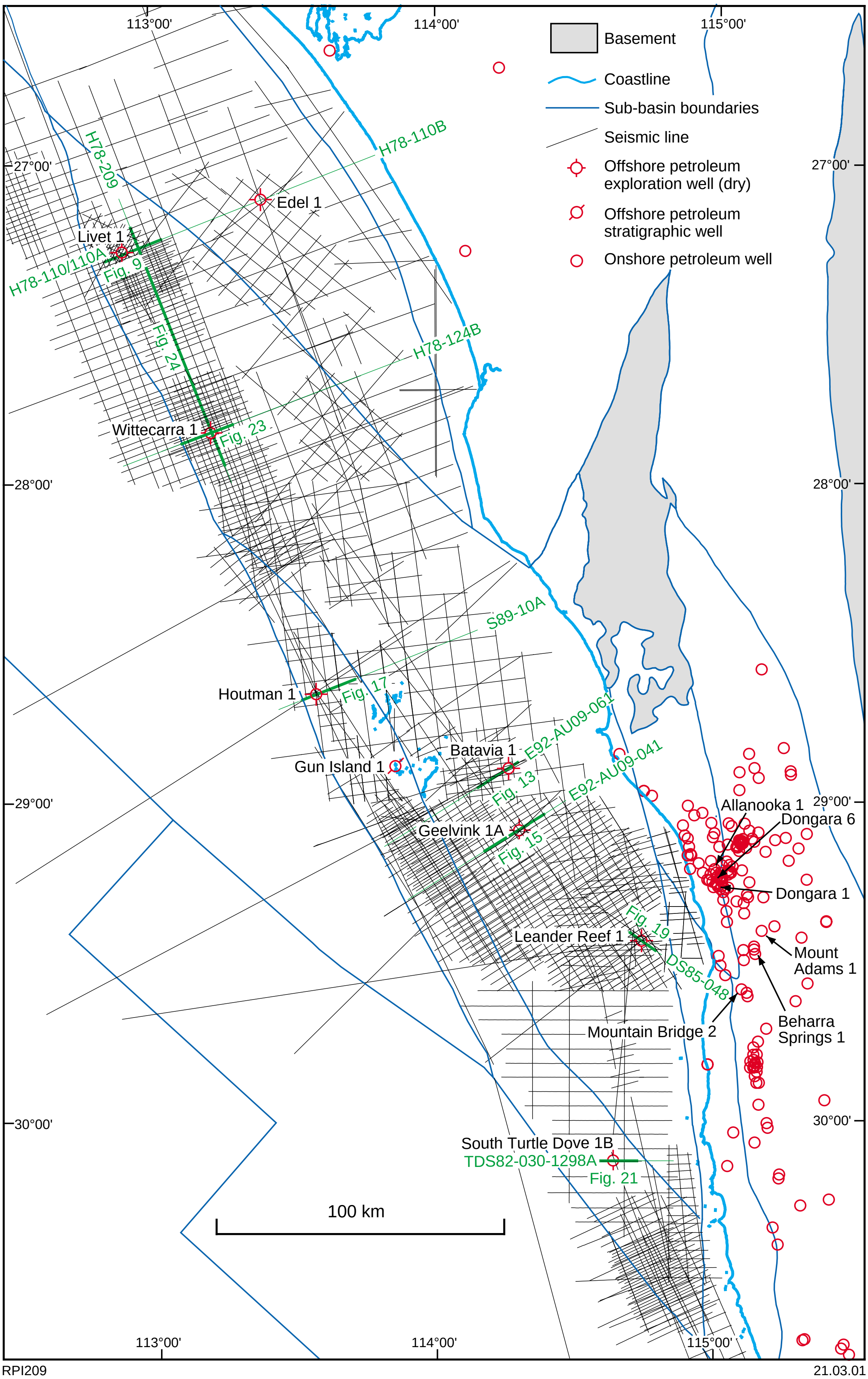

Figure 3. Seismic and well control over the Abrolhos Sub-basin. Seismic lines illustrated in this report are highlighted in green

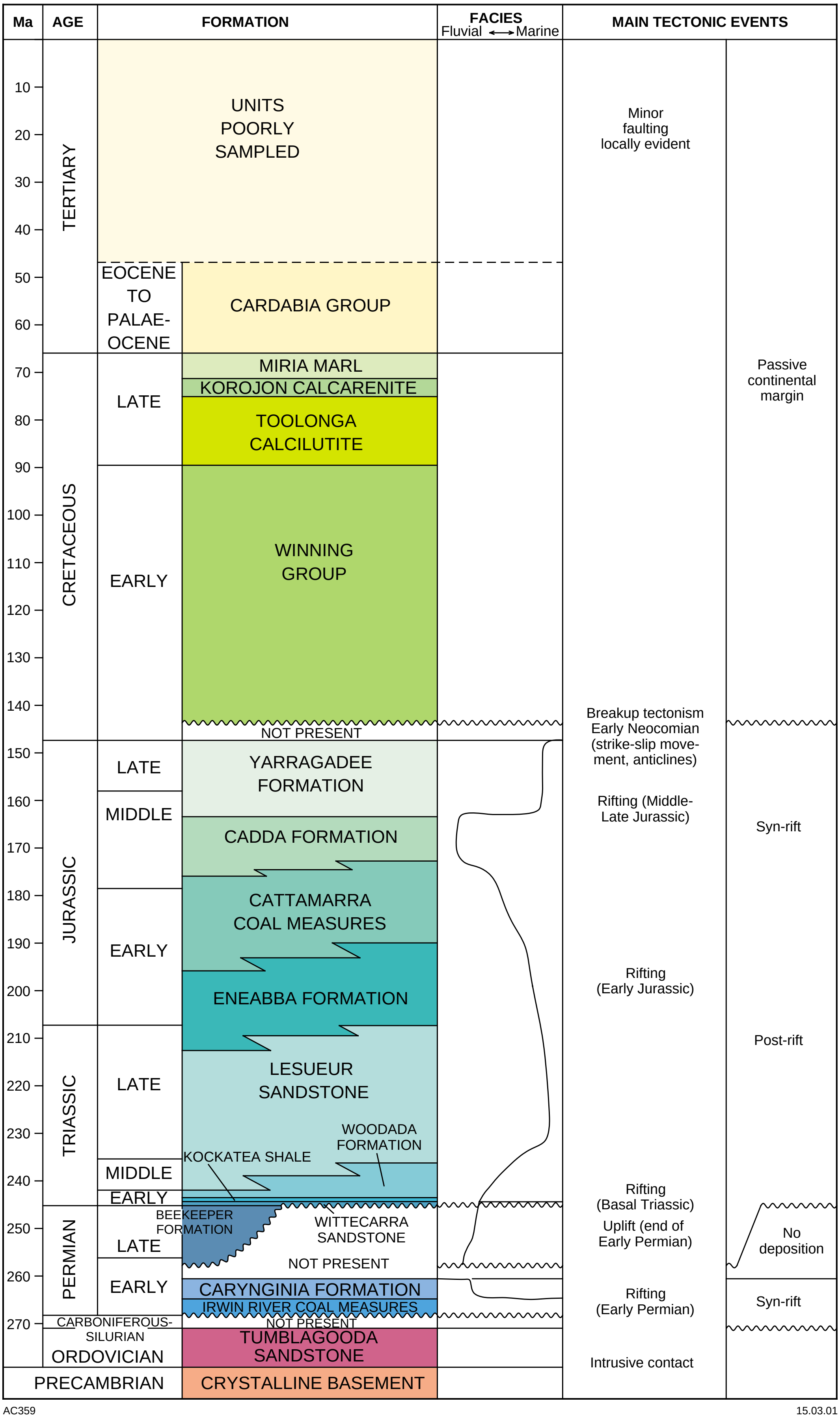

Figure 4. Stratigraphy, facies, and structural evolution of the Abrolhos Sub-basin

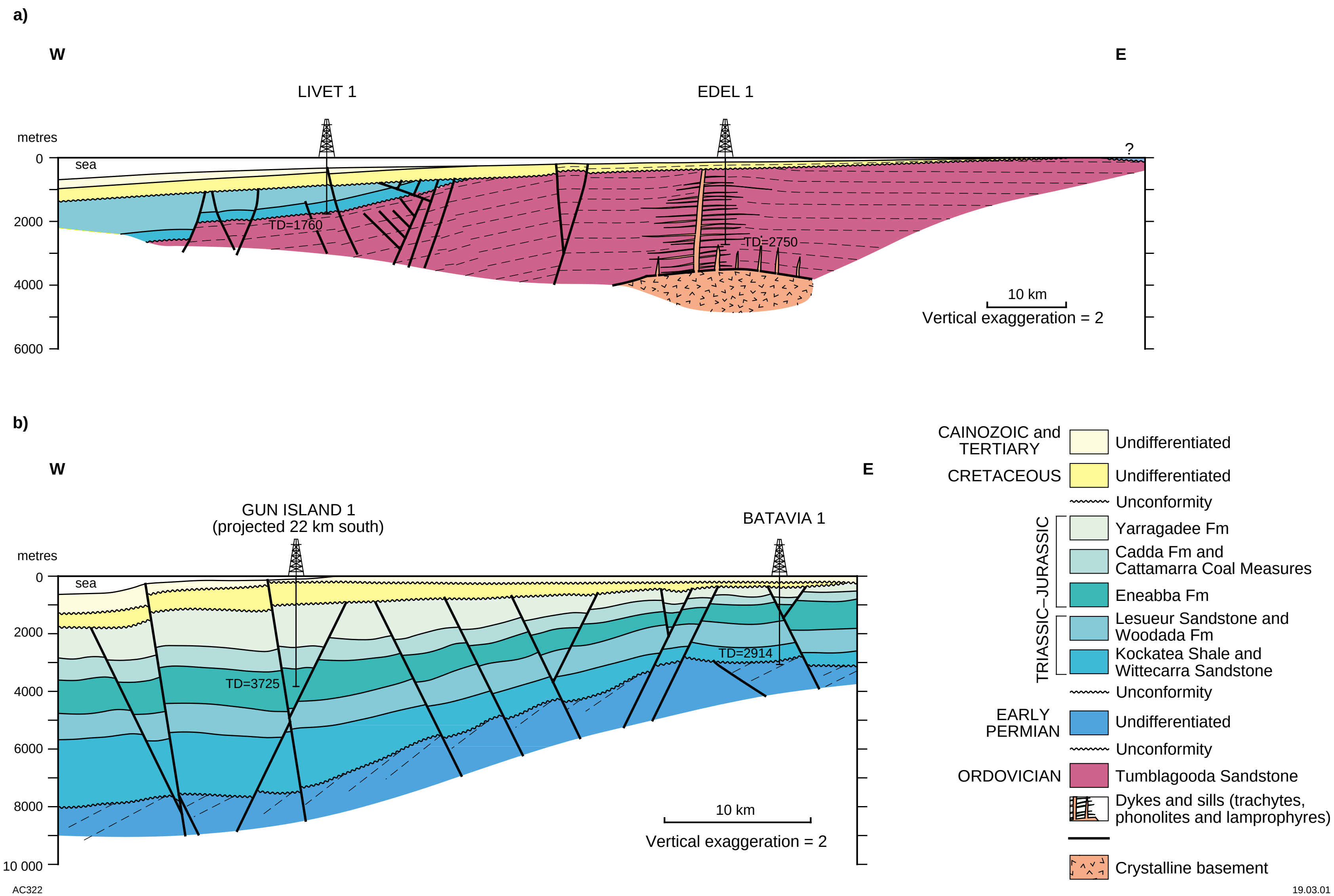

Figure 5. Structural west–east sections across the Abrolhos Sub-basin and Edel Terrace: a) section Livet 1 to Edel 1 (from H78-110A and B seismic sections; see Figure 9), Triassic outcrop on eastern end of section projected from Kalbarri; b) section Gun Island 1 to Batavia 1 (from E92-AU09-061 seismic section; see Figure 15). Locations shown in Figures 2 and 3

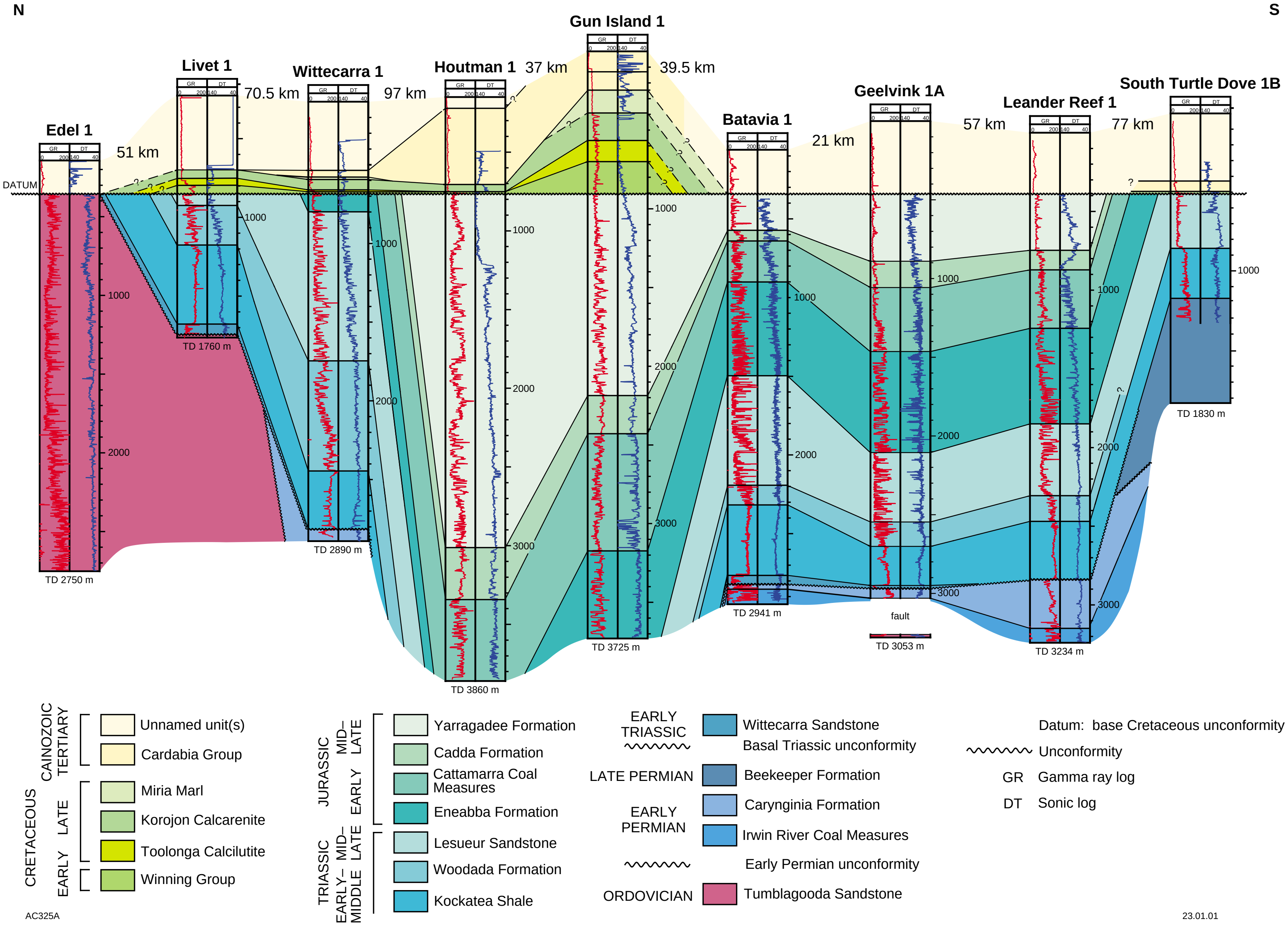

Figure 6. Simplified stratigraphic correlation along the Abrolhos Sub-basin. Tertiary and Cretaceous sections too poorly sampled to subdivide in some wells (after Plate 1)

section has not been found offshore in this region. Furthermore, on the adjoining Gascoyne Platform, the predominant dip is to the north so that the youngest part of the succession is present only in the north (Iasky and Mory, 1999).

The main phase of sedimentation within the Perth Basin commenced during latest Carboniferous – earliest Permian rifting. Characteristic features of Permian sedimentary rocks within almost the entire Abrolhos Sub-basin are their limited thickness and the absence of Upper Permian units (Fig. 6). The westward thinning of the Permian towards the Beagle Ridge suggests that this ridge was a positive feature during the Early Permian. Although only two wells reached basement, it appears that the entire Permian section is only a few hundred metres thick, the thickest penetrated interval in the main sub-basin being 397 m, in Leander Reef 1. This contrasts with the several thousand metres of Permian strata within the onshore Perth Basin (Playford, et al., 1976) and Merlinleigh Sub-basin (Hocking, et al., 1987). Only marginally, over the structurally high areas of the northern Perth Basin, such as the Beagle Ridge and the Allanooka High, is the Permian succession thinner than 1000 m. The only exception is in South Turtle Dove 1B, at the southernmost end of the Abrolhos Sub-basin, where the presence of the Upper Permian Beekeeper Formation indicates that this is a typical northern Perth Basin well, quite different from the other wells in the sub-basin (Fig. 6, Plate 1).

The lack of Upper Permian rocks corresponds to the gap in the northern Perth Basin within the Late Permian (Mory and Iasky, 1996; Fig. 7) and the absence of this section in the Byro and Coolcalalaya Sub-basins, close to the high area represented by the Northampton Complex, the Dongara Saddle and the Beagle Ridge (Fig. 1). Conversely, both the Lower Permian and the Upper Permian are present in the southern Perth Basin (Crostella and Backhouse, 2000) and the Merlinleigh Sub-basin (Hocking et al., 1987).

A tectonic uplift took place near the end of the Early Permian, with some erosion, but basically there was no deposition until the basal Triassic transgression, which is represented by the Wittecarra Sandstone (Fig. 7). The hiatus between the Early Permian and the Triassic corresponds to the condensed sequence in the onshore northern Perth Basin (represented by the basal part of the Dongara Sandstone and Beekeeper Formation) and thick shales in the South Turtle Dove 1B area (Fig. 7). Within the onshore northern Perth Basin, a second episode of rifting took place in the earliest Triassic along the Urella Fault and, in the offshore Abrolhos Sub-basin, along the Beagle Ridge and the edge of the Northampton Complex (Fig. 8). A dichotomy in the distribution of the Permian and Mesozoic successions is evident between latitudes 28° and 30°S. The Permian depocentre, controlled by the Darling and the Wandagee Faults, evolved separately to the east (Byro, Coolcalalaya, and Merlinleigh Sub-basins), whereas the Mesozoic trough, controlled by a series of en echelon rift faults, developed to the west (Abrolhos Sub-basin). It may be that this Mesozoic trough continues northwards to the western part of the Bernier Platform and on to the Exmouth Sub-basin (Fig. 1). Igneous intrusions dated as Permian–Triassic expressed as a number of northerly trending magnetic anomalies, subparallel to the coastline and cutting across all the tectonic units of the region (Fig. 1), imply a rifting stage at this time. The basal Triassic transgression represented by the Wittecarra Sandstone is well documented in Batavia 1, Geelvink 1A, South Turtle Dove 1B, Livet 1, and also onshore near Kalbarri in the southern Carnarvon Basin, where Hocking et al. (1987) ascribed a continental origin to the type section, which unconformably overlies the Tumblagooda Sandstone and is conformably overlain by the Kockatea Shale. The Wittecarra Sandstone lies above the Carynginia Formation in the majority of the offshore wells, but directly overlies the Tumblagooda Sandstone in Livet 1, as it does onshore (Hocking et al, 1987; Fig. 5a). The unit probably correlates with the subsurface Bookara Sandstone Member near the base of the Kockatea Shale in the onshore northern Perth Basin. Deposition of the marine Kockatea Shale and Woodada Formation followed, with the regressive continental Lesueur Sandstone concluding the Triassic cycle. The Woodada Formation thickens northwards, where it reaches its maximum regional thickness of 715 m in Wittecarra 1.

A third major period of rifting in the early Jurassic may have taken place onshore along the Darling Fault between the deposition of the Eneabba Formation and the Cattamarra Coal Measures. The fault probably was still active at this time as far north as latitude 30°S. Offshore, coeval rifting probably took place along the western margin of the Turtle Dove Ridge, and farther seaward to the north-northwest. The Jurassic section comprises (in ascending order) the continental Eneabba Formation, the deltaic Cattamarra Coal Measures, the marine Cadda Formation, and the regressive fluvial Yarragadee Formation, which concludes the pre-breakup cycle in the Abrolhos Sub-basin. The top of the Cadda Formation is the most continuous and reliable seismic horizon over most of the area, whereas deeper horizons cannot be correlated reliably. The last period of rifting may be dated as Middle–Late Jurassic.

A pattern of en echelon rift faults is evident in the region (Fig. 8). Movements along these faults in each rifting episode accompanied a period of infilling. In some parts of the region the rifting took place along the same fault, for example the Darling Fault, whereas in the Byro, Coolcalalaya, and Merlinleigh Sub-basins, neither rifting nor deposition took place after the Permian. The four major rifting episodes in the Abrolhos Sub-basin (end of Early Permian, earliest Triassic, Early Jurassic, and Middle–Late Jurassic) activated several faults, with the youngest episode affecting the western-most section. The Abrolhos Sub-basin may be subdivided into an inner sub-basin in which the Jurassic succession, if present, is thin, and an outer sub-basin, in which the Jurassic is substantially thicker (Fig. 2). The limited well control, however, does not allow a precise definition of the boundary.

When Australia separated from Greater India in the early Cretaceous the cycle of rifting–infilling characterizing the region was interrupted by right-lateral strike-slip zones related to oblique faulting and the

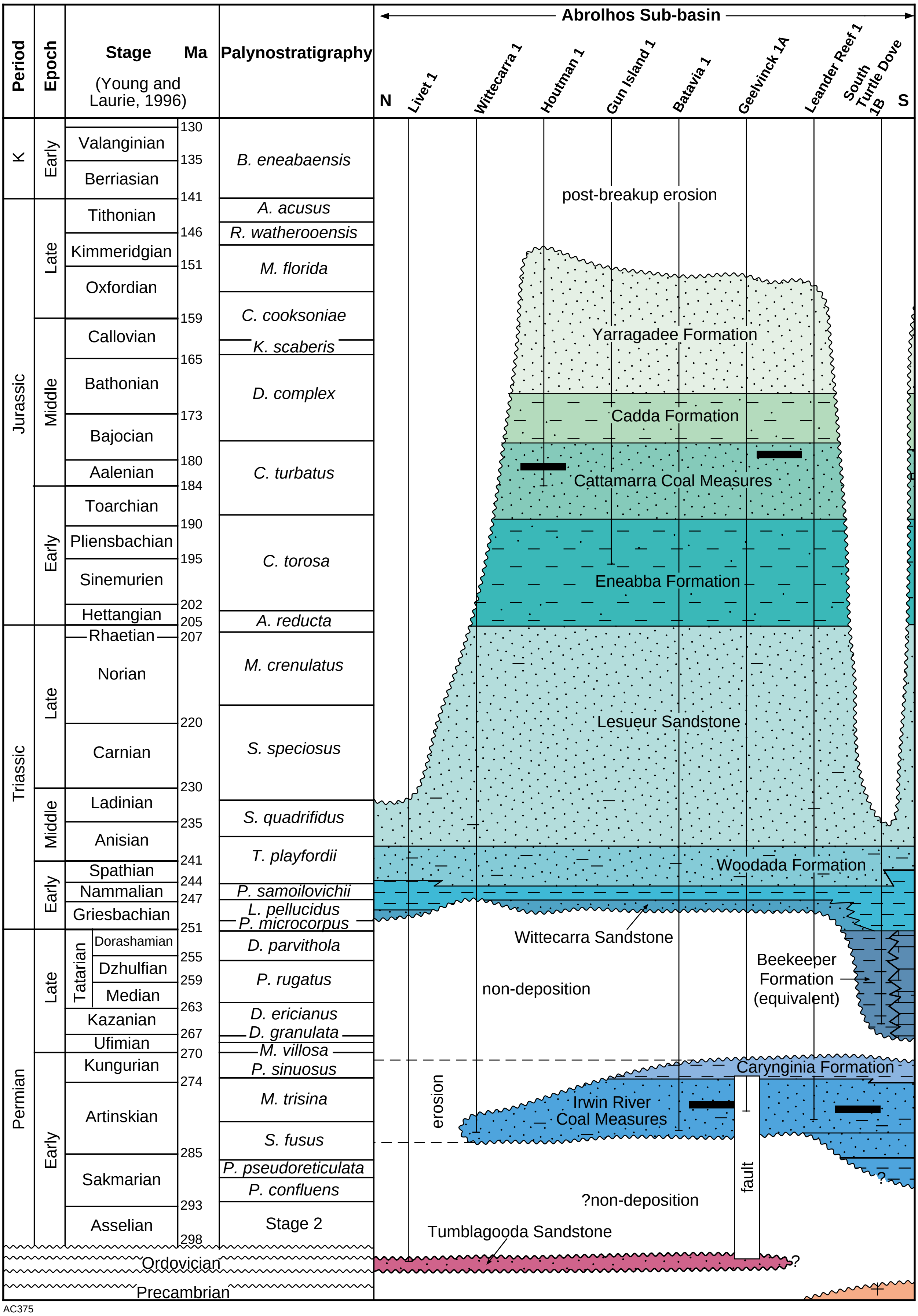

Figure 7. Chronostratigraphic section of the Abrolhos Sub-basin, from north to south, and onshore northern Perth Basin, from south to north **(figure continued on page 11)**

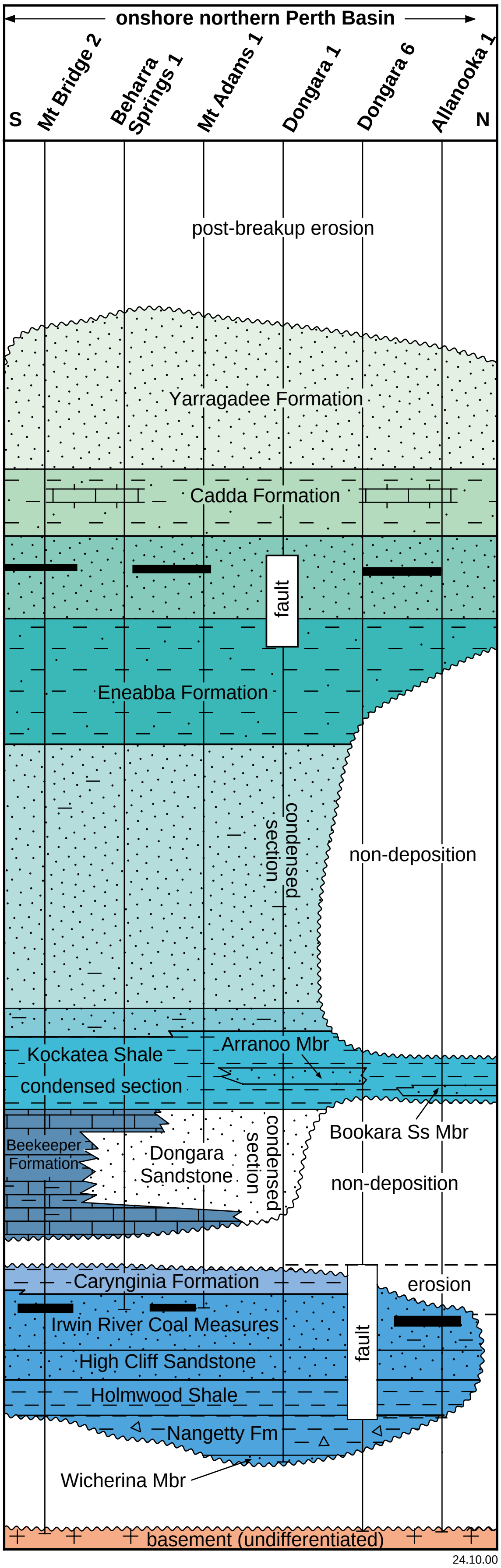

Figure 7. (continued)

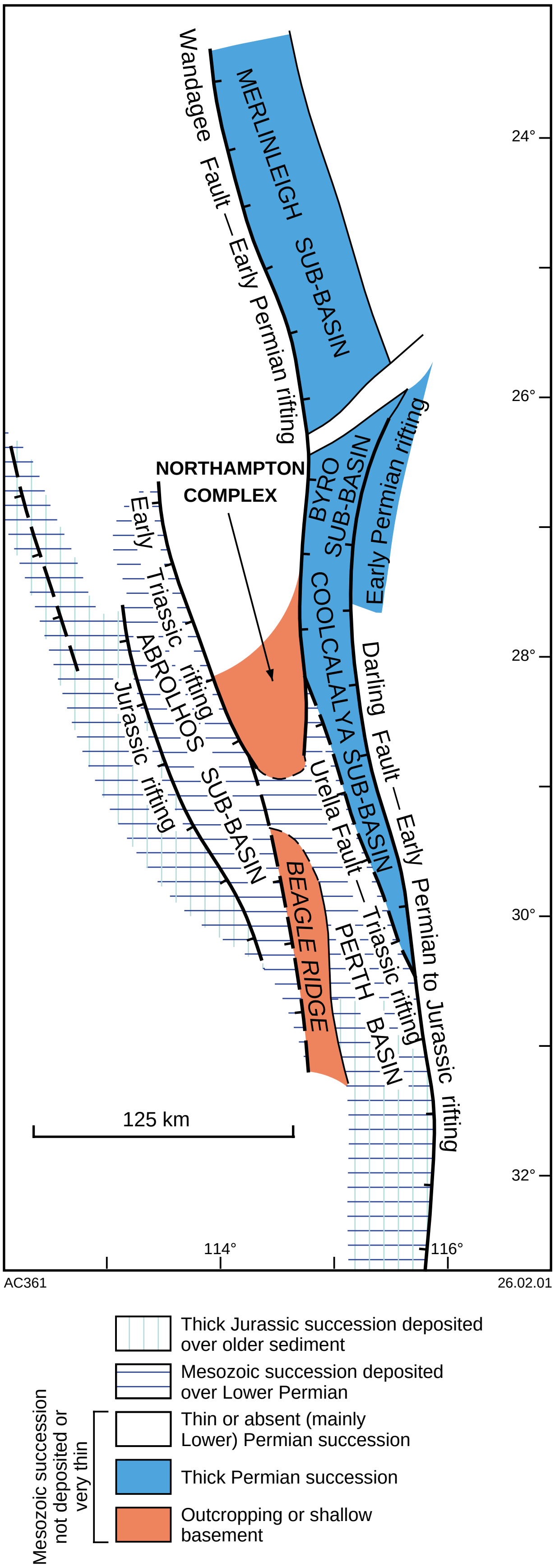

Figure 8. Regional tectonic framework of the Abrolhos Sub-basin

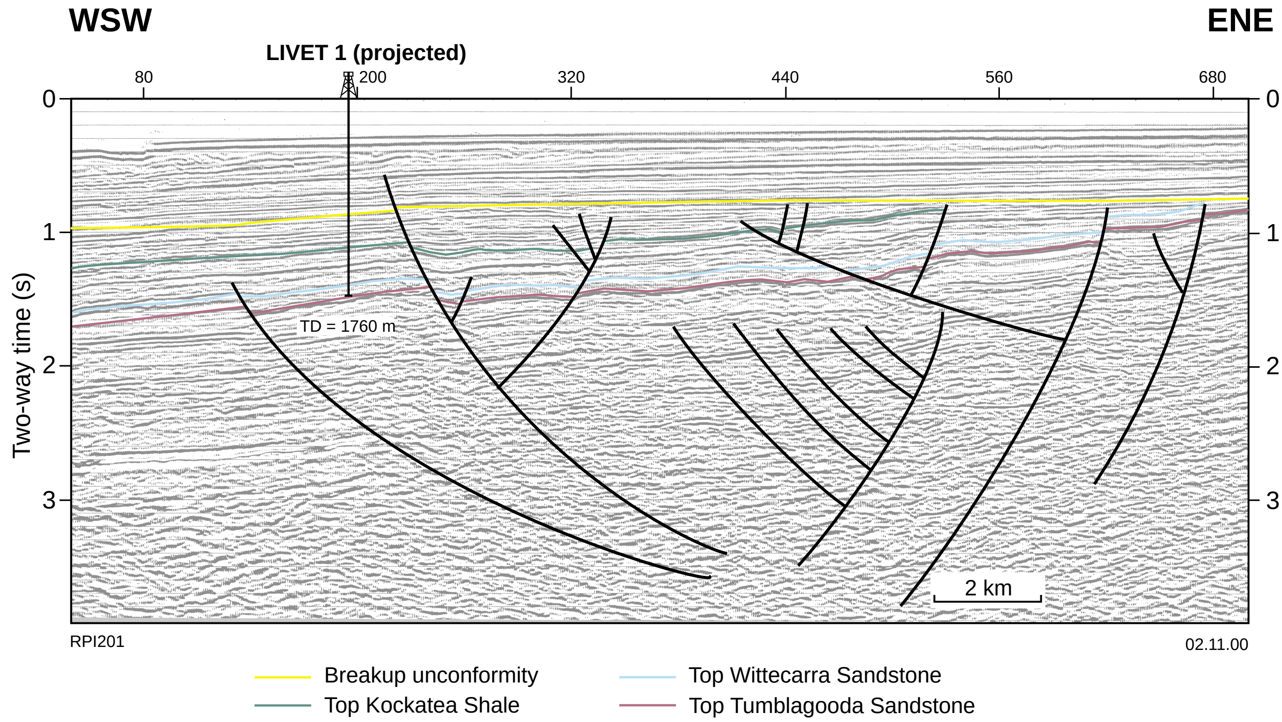

Figure 9. Seismic section H78-110A, showing the structure at Livet 1. Location shown in Figures 3 and 20

development of compressional anticlines where faults converged (Figs 5b and 8). The oblique extension typical of the sub-basin has been discussed in detail by Marshall et al. (1989), and in the southern part of the sub-basin by Heath et al. (1993). The breakup tectonism is the most recognizable structural event over the entire area; the structural setting of the older events has not yet been defined and, without further well control, depends entirely on seismic interpretation.

Following the separation of Australia from India, marine incursions covered the Abrolhos Sub-basin. Cretaceous and Cainozoic units can be correlated with those of the Carnarvon Basin, although they are not as well known as the pre-Cretaceous units because in many wells they were poorly sampled, if at all (Appendix 3).

The gradual transition from the Perth Basin to the Carnarvon Basin is evident throughout the succession. For example, even though the basal Triassic Wittecarra Sandstone can be correlated with the Bookara Sandstone Member in the northern Perth Basin, its type section is documented within the Carnarvon Basin in outcrop south of Kalbarri (Hocking et al., 1987). The Lower to mid-Middle Triassic Woodada Formation becomes thicker and more marine from south to north (Wittecarra 1), approaching the characteristics of the coeval Locker Shale within the Northern Carnarvon Basin. In the southernmost well within the Abrolhos Sub-basin, namely South Turtle Dove 1B, units equivalent to the Korojon Calcarenite and Toolonga Calcilutite have been identified (based on wireline logs) in the Cretaceous section.

Although some basins are clearly defined, in many cases the boundaries between depositional areas are gradational and, therefore, to some degree, arbitrary. Well control within the Abrolhos Sub-basin is very limited, but it appears that the sub-basin is a discrete entity that cannot be entirely assigned to either the Southern Carnarvon Basin or the Perth Basin: only the South Turtle Dove 1B area has a strong affinity with the Perth Basin.

Although the combined duration of the Cretaceous and Cainozoic is close to that of the Permian and Jurassic (Fig. 4), deposition during the Cretaceous and Cainozoic periods is minor in the area, and only the Winning Group, Toolonga Calcilutite, Korojon Calcarenite, Miria Marl, and Cardabia Group (in ascending order, Fig. 4) have been recognized in the sub-basin. Locally, tectonic movements of possible pre-Trealla Limestone age (Cainozoic) are evident (Fig. 9), implying that the middle Miocene tectonism so well documented in the Northern Carnarvon Basin also had an effect in the Abrolhos Sub-basin.

Post-mortems of exploration wells

Analyses of the results from each well are included in the post-mortems, together with relevant revisions to the stratigraphy, and the most likely reasons for the lack of hydrocarbons. Revisions to the operating company's original stratigraphy are specified where appropriate. The structural maps shown are the pre-drilling maps produced by the operating company. The seismic interpretations of the relevant lines are original to this Report. The assessment of reservoirs, seals, and source-rock potential is derived from company data. Source-rock (Appendix 4) and maturity data (Appendix 5) are presented graphically in Figures 10–12. No attempt

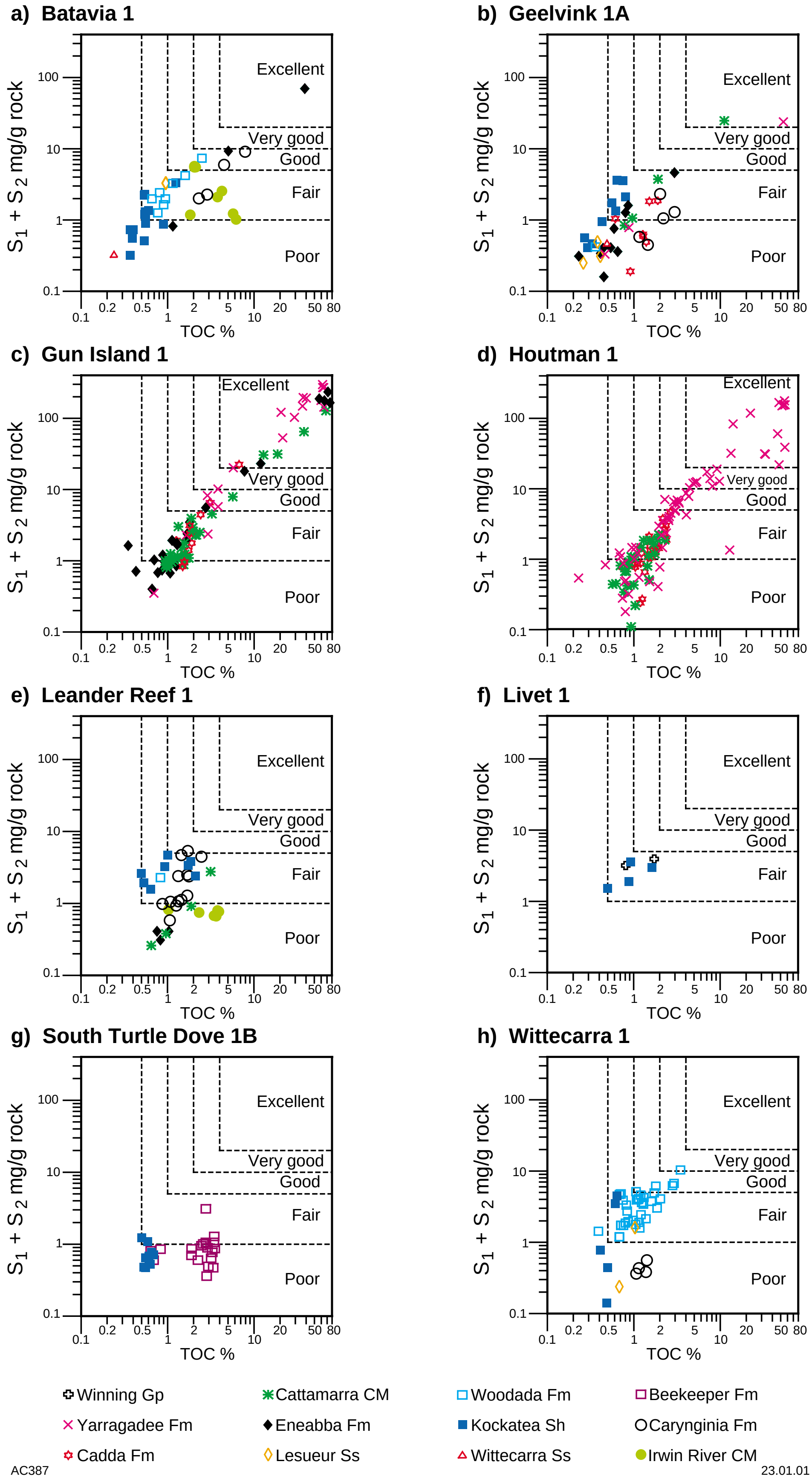

Figure 10. Petroleum-generating potential of the Jurassic to Permian succession, Abrolhos Sub-basin: a) Batavia 1; b) Geelvink 1A; c) Gun Island 1; d) Houtman 1; e) Leander Reef 1; f) Livet 1; g) South Turtle Dove 1B; and h) Wittecarra 1. Data from Appendix 4

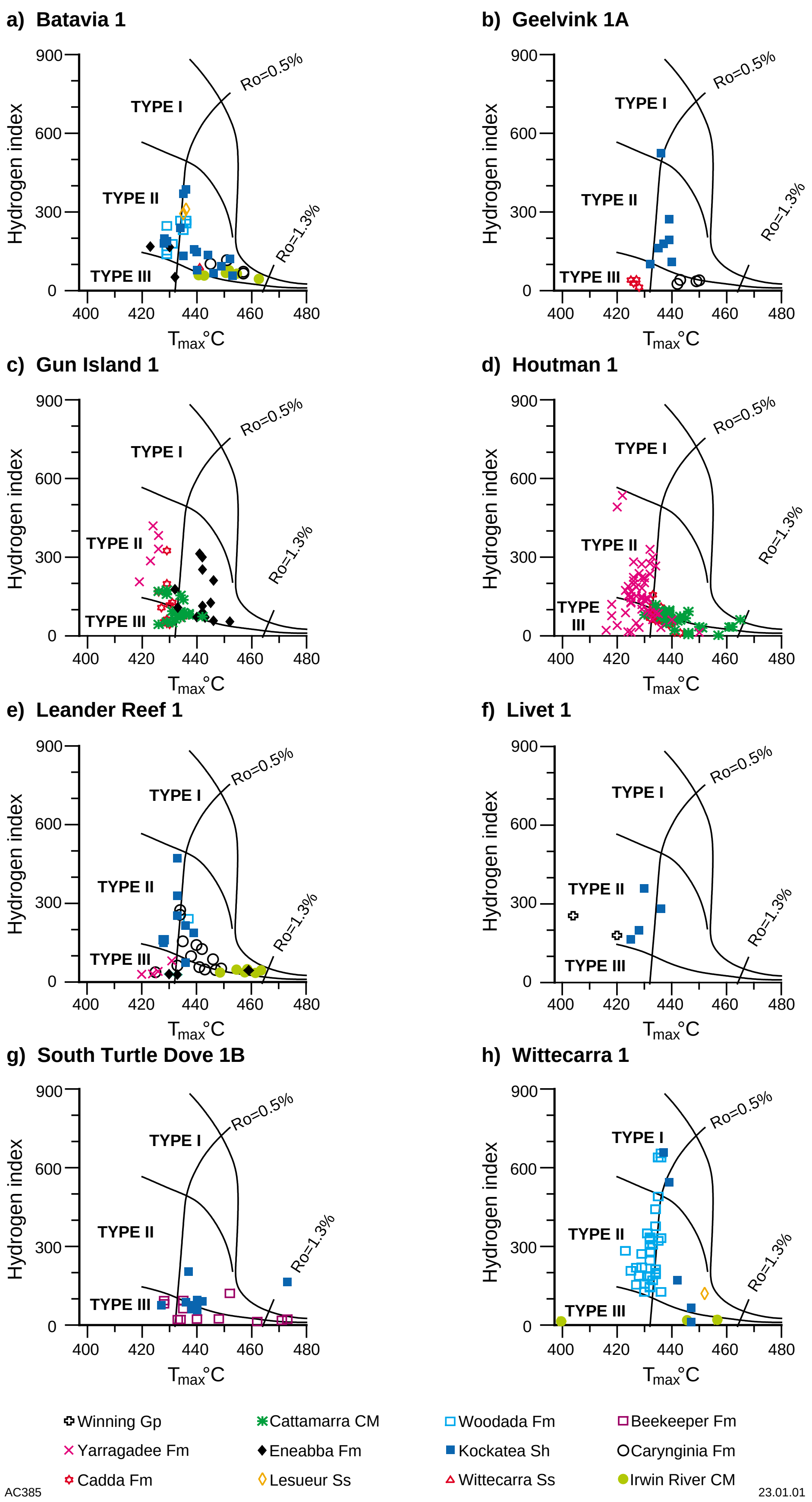

Figure 11. Rock-Eval kerogen typing of the Jurassic to Permian succession, Abrolhos Sub-basin: a) Batavia 1; b) Geelvink 1A; c) Gun Island 1; d) Houtman 1; e) Leander Reef 1; f) Livet 1; g) South Turtle Dove 1B; and h) Wittecarra 1. Data from Appendix 4

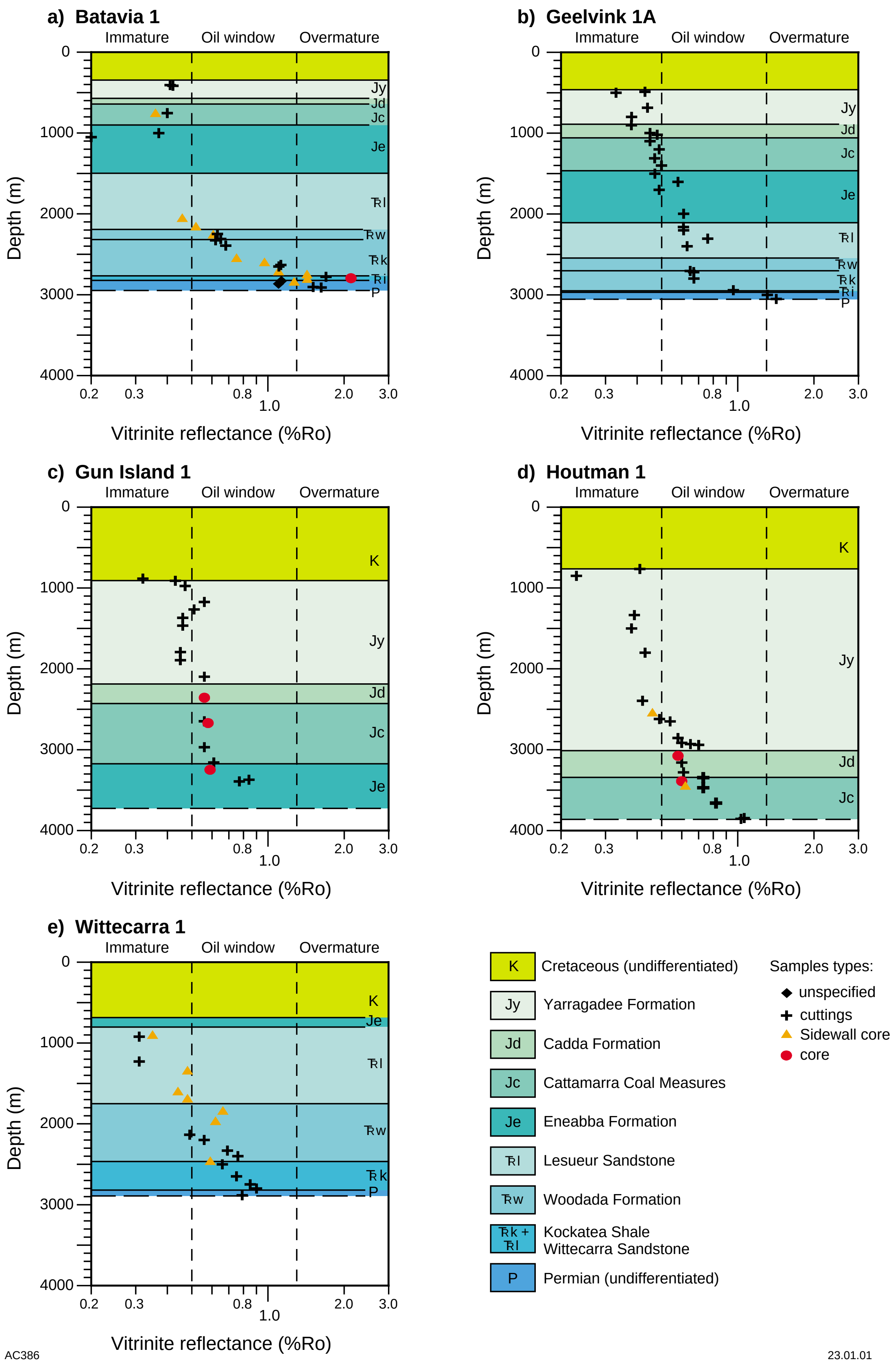

Figure 12. Percentage vitrinite reflectance versus depth plots for a) Batavia 1, b) Geelvink 1A, c) Gun Island 1, d) Houtman 1, and e) Wittecarra 1. Data from Appendix 5

has been made to screen these results, although the high values of temperature of maximum pyrolitic yield (T_{max}) from analyses with no organic carbon dioxide (S_3) readings have been excluded in Figure 11. The suggested reasons for the lack of hydrocarbons are original, unless stated otherwise.

Batavia 1

Batavia 1 was drilled in 1978 by Esso Australia Ltd within the Abrolhos Sub-basin, 36 km west-southwest of Geraldton (Fig. 2).

Stratigraphy

Below the unsampled interval (seabed–345 m), a Jurassic succession commencing with the Yarragadee Formation was penetrated to 1498 m, and this formation conformably overlies a Triassic section. In the Jurassic section the only modification to the company's formation picks is to raise the top of the Cadda Formation to 571 m to be consistent with the picks in Geelvinck 1A and Leander Reef 1 (Plate 1). The lowermost Triassic rocks (2766–2822 m) were referred to an undated 'clean quartz sandstone' by Galloway (1978a), but on regional grounds it is here assigned to the Wittecarra Sandstone. Early Triassic palynomorphs dominated by *Kraeuselisporites septatus* are present in cuttings from this interval, although they were considered by Partridge and Helby (in Galloway, 1978a, appendix 6) to be caved from the overlying Kockatea Shale. The Wittecarra Sandstone is locally pyritic, and overlies Lower Permian formations (such as the Carynginia Formation) with an angular unconformity (Fig. 13). The lowermost interval (2854–2941 m) is represented by undated sandstone, which may be referred to either the High Cliff Sandstone or, more likely, the Irwin River Coal Measures.

Structure

Batavia 1 tested the upthrown side of a fault trap (Fig. 13), produced by early Neocomian tectonic movements. Intense faulting and the widely spaced seismic control make the definition of the structure less than satisfactory.

A sharp change in the gradient of vitrinite reflectivity towards the base of the Lower Triassic Kockatea Shale (Fig. 12a) indicates an abrupt change in thermal and burial history, which is consistent with a tectonic event that probably coincides with the angular unconformity shown in Figure 13. If it is assumed that the vitrinite present within the base of the Triassic is reworked — consistent with the transgressive nature of the basal Triassic interval — this would place the tectonic event between the Early Permian and the Early Triassic. The position of Batavia 1 is shown in its regional context in Figure 5b.

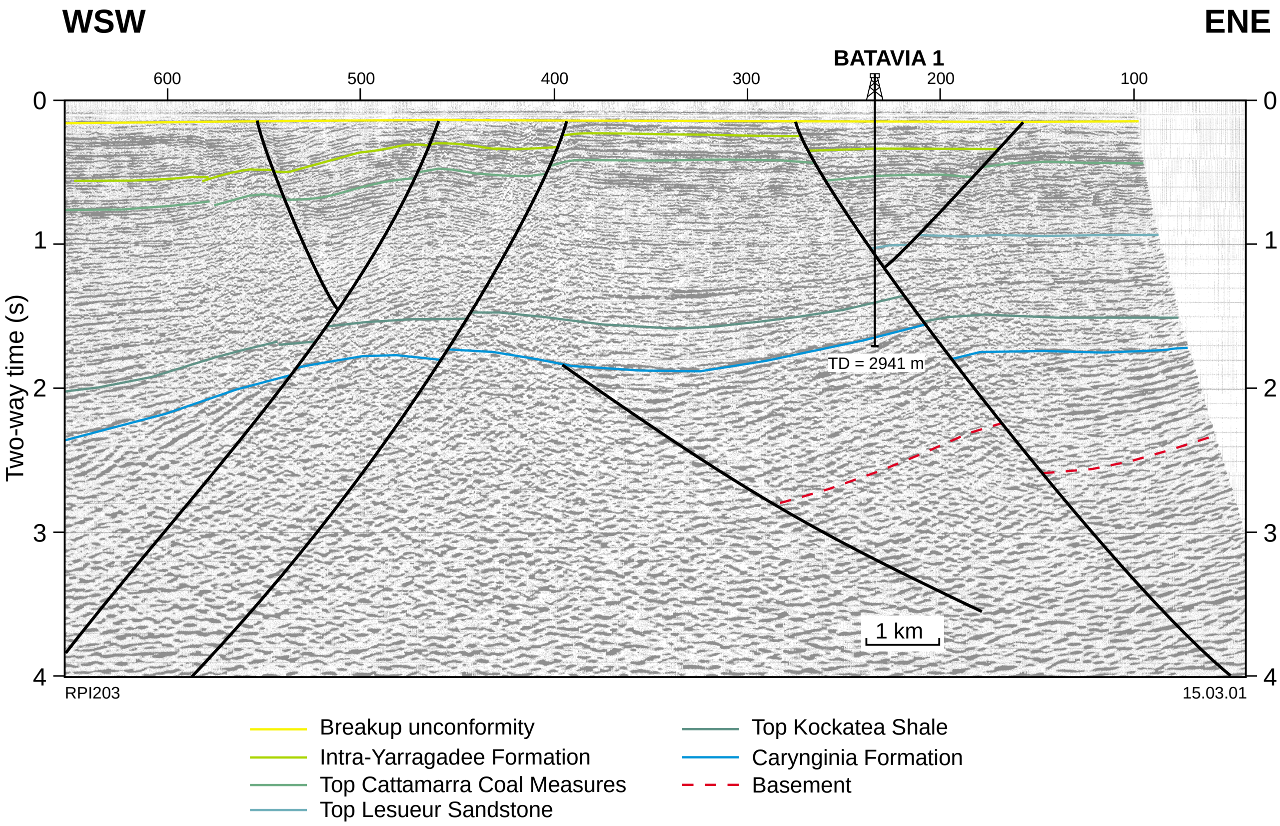

Figure 13. Seismic section E92-AU09-061, showing the structural setting of Batavia 1. Location shown in Figure 3

Table 1. Total organic carbon and extracted hydrocarbon (≥C_{15}) analyses for Batavia 1

Unit	Depth (m)	TOC (%)	SOM (ppm)	Total HCs (ppm)	Composition of SOM (%) SATS	AROM	Soluble NSO	Insol. NSO	Asphal-tene	HC/SOM	AROM/SATS	HC/Non-HC
Kockatea Shale (Lower Triassic)	2 385	0.69	534	250	28.7	18.2	8.2	6.4	38.6	46.8	0.63	0.88
	2 430	0.48	461	239	29.9	21.9	4.8	4.3	39.0	51.8	0.73	1.08
	2 475	0.50	535	334	40.7	21.7	8.0	4.5	25.0	62.4	0.53	1.66
	2 520	0.55	507	302	39.4	20.1	10.8	5.5	24.1	59.6	0.51	1.47
	2 565	0.59	548	317	38.0	19.9	10.8	5.3	26.1	57.8	0.52	1.37
	2 595	0.57	1 156	675	31.9	26.5	8.9	6.7	26.0	58.4	0.83	1.44
	2 640	0.60	670	428	47.2	16.7	7.9	3.0	25.2	63.9	0.35	1.77
	2 685	0.56	614	370	46.1	14.2	7.0	7.3	25.4	60.3	0.31	1.52
	2 730	0.55	414	250	45.7	14.7	9.4	8.0	22.2	60.4	0.32	1.52
	2 775	0.52	362	170	25.4	21.8	14.1	5.8	32.9	47.2	0.86	0.90
	2 820	0.55	487	273	41.1	15.0	9.9	10.5	23.6	56.1	0.36	1.28
Caryngingia Formation (Lower Permian)	2 865	0.56	775	324	20.3	21.5	7.7	5.4	45.0	41.8	1.06	0.72
Irwin River Coal Measures (Lower Permian)	2 910	0.64	686	307	21.3	23.5	9.9	4.4	41.0	44.8	1.10	0.81
	2 940	0.55	510	251	26.9	22.2	8.9	7.7	34.3	49.1	0.83	0.96

NOTES:
AROM: Aromatic hydrocarbons
TOC: Total organic carbon
SOM: Soluble organic matter
Non-HC: NSO plus asphaltene
HCs: Hydrocarbons
SATS: Saturated hydrocarbons
NSO: Nitrogen, sulfur, and oxygen compounds
Insol.: Insoluble

SOURCE: Galloway (1978a)

Reservoir and seal

Although the best regional objective is the Wittecarra Sandstone sealed by the Kockatea Shale, in Batavia 1 the sandstone has been cemented by secondary quartz overgrowths. The Cadda Formation (602–641 m) could seal underlying sandstone of the Cattamarra Coal Measures. A further possible seal is the intraformational shaly interval (1940–1974 m) within the Lesueur Sandstone.

Hydrocarbons

No significant shows were encountered.

Source rock

The petroleum-generating potential of the section in Batavia 1 is shown in Figure 11a, and samples analysed from both the Lower Triassic Kockatea Shale and the Permian units can be classified as good source rocks for oil (Fig. 10a, Table 1). The Woodada Formation and Kockatea Shale are within the oil-generation zone, whereas the Permian section is partly within the oil window, and partly overmature (Fig. 12a). However, total organic carbon (TOC) analyses from the Kockatea Shale average 0.54%, and therefore the unit is not organically rich in this section. Nevertheless, the Kockatea Shale here is depleted in ^{13}C (Table 2), as it is in onshore sections (Summons et al., 1995), confirming that the depositional environment is essentially unchanged.

Reason for failure

The limited vertical relief of the structure, its poor definition, and the intense faulting cast doubts on the integrity of the Batavia structural trap.

Edel 1

Edel 1 was drilled in 1972 by Ocean Ventures Pty Ltd within the Edel Terrace, approximately 45 km offshore from the Zuytdorp Cliffs (Fig. 2).

Stratigraphy

Beneath an unsampled interval from 94 m (seabed) to 354 m, interbedded sandstone and igneous rock was penetrated to total depth (2750 m), with minor siltstone below 930 m. The age of the Edel 1 section has been variously interpreted (Table 3). Quite apart from seismic correlations, the main reason to refer the unsampled interval to the Cretaceous–Tertiary (Ocean Ventures Pty Ltd, 1972) is the presence in the underlying section of igneous rocks, interpreted by Ocean Ventures Pty Ltd (1972) to be related to the breakup tectonism. Limited age information is available on the monotonous 354–2750 m interval. The radiometric dating obtained by Amdel from biotite crystals using the potassium–argon method was rejected by Ocean Ventures Pty Ltd (1972, appendix 6; summarized in Table 3), who considered the entire section to be of Middle to Late Triassic age, as per the

Table 2. Batavia 1 carbon-isotope values

Formation	*Depth (m)*	*δ C^12/13‰*	
		Saturates	*Aromatics*
Kockatea Shale	2 385	-35.9	-34.4
"	2 520	-35.5	-34.1
"	2 640	-35.1	-33.6
"	2 730	-35.2	-32.5
Wittecarra Sandstone	2 775	-33.1	-29.5
Caryngina Formation	2 865	-33.7	-26.8
Irwin River Coal Measures	2 940	-35.7	-27.8

palynological determination of Balme (in Ocean Ventures Pty Ltd, 1972, appendix 2). The section was referred to the informal 'Edel Formation', and was considered to be a time equivalent of the Lesueur Sandstone in the Perth Basin. Smith and Cowley (1987) correlated the Edel 1 section from 354 to 1861 m to a 'large part' of the Triassic, proposing an unconformity between 1861 and 1880 m, and considered the 1880–2444 m interval to be Artinskian (Early Permian), and the deeper section undifferentiated Permian in age. Marshall et al. (1989) considered the palynological dating to be unreliable and referred the interval below 1500 m to the Caryngina Formation, leaving the 354–1500 m interval unassigned. Quaife et al. (1994) followed the same line of thinking of Marshall et al. (1989), but referred the entire Edel 1 section below 354 m to the Late Permian.

Cores and cuttings from the 354–2750 m interval in the Geological Survey of Western Australia (GSWA) depository were found by Hocking et al. (1987) to be lithologically very similar to outcrop of the Tumblagooda Sandstone, in that they consist predominantly of red–purple–yellow sandstone. In the region, such coloured sandstone is known only from the Ordovician Tumblagooda Sandstone, Lower Devonian Kopke Sandstone, and Lower Triassic Wittecarra Sandstone, of which only the Tumblagooda Sandstone is more than 500 m thick. Furthermore, radiometric ages from Ocean Ventures Pty Ltd (1972) indicate two discrete groups separated by an undated interval, the upper corresponding to the lower Middle Triassic and the lower to the Late Permian (Table 3). The different ages may be explained by a slowly rising magmatic body that injected sills and dykes at progressively later dates (Hocking et al., 1987). However, the greatest proportion of igneous rocks are lamprophyre dykes (Le Maitre, 1975), which are not suitable for determining the age of the succession. Specific dating of the extrusive trachytes and phonolites is necessary to indicate the true age of the enclosing sedimentary rocks. Unfortunately, the available dating has not differentiated ages from the intrusive and extrusive volcanics; therefore, the significance of the available dating is unclear, and the Permian–Triassic ages do not necessarily match the age of the enclosing sedimentary strata. In addition, the presence of palynomorphs in only 21 m (1463–1484 m) of a section 2396 m thick is suspicious, and implies that the Triassic dating (Table 3) is unreliable. Finally, the cross section based on seismic section H78-110B (Fig. 5a) shows that the strata penetrated by Edel 1 below 354 m belong to the same formation as that penetrated at total depth in Livet 1, and that formation lies unconformably below the Triassic Wittecarra Sandstone, both in Livet 1 and in outcrop (Fig. 5a). The section, therefore, is believed to be Tumblagooda Sandstone as interpreted by Hocking et al. (1987).

Structure

Edel 1 was planned to test one of several interpreted structures identified by the Bernier marine seismic survey (Fig. 14). Ocean Ventures Pty Ltd (1972) did not believe that the vertically widespread igneous rocks are the main contributing factor to the high velocity of the section in the well. Higher velocity igneous rocks should increase the overall velocity only marginally, therefore not invalidating the notion of a closed structure (Fig. 14).

Reservoir and seal

The Tumblagooda Sandstone penetrated by Edel 1 has poor reservoir potential, with low porosities and permeability lower than 1 md, and is considered non-prospective. There is no information available on possible base Cretaceous sealing intervals.

Hydrocarbons

No hydrocarbons were encountered.

Reason for failure

The paucity of sealing horizons is the main reason for the failure of Edel 1. Lack of hydrocarbon indications or source rocks and poor reservoir potential within the

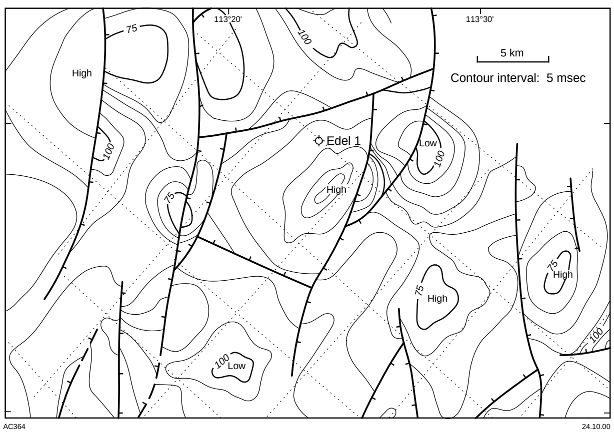

Figure 14. Pre-drilling two-way contour map of an intra-Tumblagooda Sandstone horizon, penetrated at approximately 930 m (RT) in Edel 1 (after Ocean Ventures Pty Ltd, 1972)

Table 3. Edel 1 stratigraphy

Interval (m)	*Lithology*	*Radiometric age (Ma)*	*Palynology*	*Stratigraphy*				
Reference	Ocean Ventures Pty Ltd (1972)	Amdel (in Smith and Cowley, 1987)	Balme (in Ocean Ventures Pty Ltd, 1972, appendix 2)	Ocean Ventures Pty Ltd (1972)	Smith and Cowley (1987)	Marshall et al. (1989)	Quaife et al. (1994)	GSWA (Hocking et al., 1987)
Seabed (94)–354	Unsampled	–	–	Cainozoic	Cretaceous–Tertiary	Cretaceous–Tertiary	Cretaceous–Tertiary	Cretaceous–Tertiary
354–930	Interbedded sandstone and volcanic rocks	246 ± 7	na	Cretaceous Winning Group equivalent	Triassic	?	Late Permian	Ordovician Tumblagooda Sandstone
930–~1500	Interbedded sandstone and volcanic rocks with minor siltstone	238 ± 15	Middle or Late Triassic (junk basket 1469–1484 m)	Triassic Edel Formation	–	–	–	–
~1500–1880	–	na	–	–	–	Late Permian Carynginia Formation	–	–
1880–2444	–	261–267 ± 5	na	–	Artinskian (Early Permian)	–	–	–
2444–TD (2750)	–	–	–	Undifferentiated	Permianequivalent	–	–	–

NOTES: na: not available
TD: total depth

Tumblagooda Sandstone downgrade the petroleum potential of the entire Edel Terrace.

Geelvink 1A

Geelvink 1A was drilled by West Australian Petroleum Pty Ltd in 1978 within the Abrolhos Sub-basin, about 60 km west-northwest of Dongara (Fig. 2).

Stratigraphy

The post-main unconformity (early Neocomian) succession was penetrated, but not sampled; therefore, the only data available for the overlying section are the wireline logs.

The shallowest sample (at 463 m) is from the Upper Jurassic Yarragadee Formation, and the top of the unit is tentatively placed at that depth (Appendix 3). The Yarragadee Formation overlies a conformable Jurassic–Triassic section that extends down to 2969 m. The tops of the Triassic Lesueur Sandstone and Woodada Formation have been adjusted from the company picks up to 2107 m and down to 2544 m, respectively, to be more in accord with the formation tops in the closest wells (Batavia 1 and Leander Reef 1; Fig. 6, Plate 1). The lowermost Triassic formation unambiguously confirmed by palynology is the Kockatea Shale, which conformably overlies a sandstone unit here referred to the Wittecarra Sandstone. The Wittecarra Sandstone is not positively dated, as it contains both Early Triassic and Early Permian palynomorphs. Those of Triassic age are better preserved (Meath and Wright, 1979) and the Permian palynomorphs here are considered to be reworked. The Wittecarra Sandstone lies unconformably over the Lower Permian Carynginia Formation, which in turn overlies an unnamed quartzitic interval, with numerous pyrite nodules, interpreted by Meath and Wright (1979) to represent economic basement. Drilling was terminated at 3053 m within this interval, here interpreted as either the Tumblagooda Sandstone, or part of the Lower Permian succession.

Structure

The Geelvink structure was interpreted by Meath and Wright (1979) as a complexly faulted, northerly trending anticlinal feature with a transgressive Permian, Triassic, and younger succession over a basement high. The thickness of the Kockatea Shale was considered sufficient to provide a seal for hydrocarbons possibly trapped beneath it or across faults.

The Geelvink structure is here interpreted as a possible fault trap on a major down-to-the-east fault. The most recent movement on the fault appears to be associated with breakup in the Early Cretaceous, but was probably first active in either the Early Permian or Ordovician, as was the fault at SP1140–1300 (Fig. 15).

Reservoir and seal

The basal Triassic Wittecarra Sandstone has low permeability and porosity (Table 4), due to extensive silica cement, and displays secondary quartz growth. The very poor reservoir potential of the unit is considered to be the result of local precipitation of such cement. The regionally sealing Kockatea Shale is present.

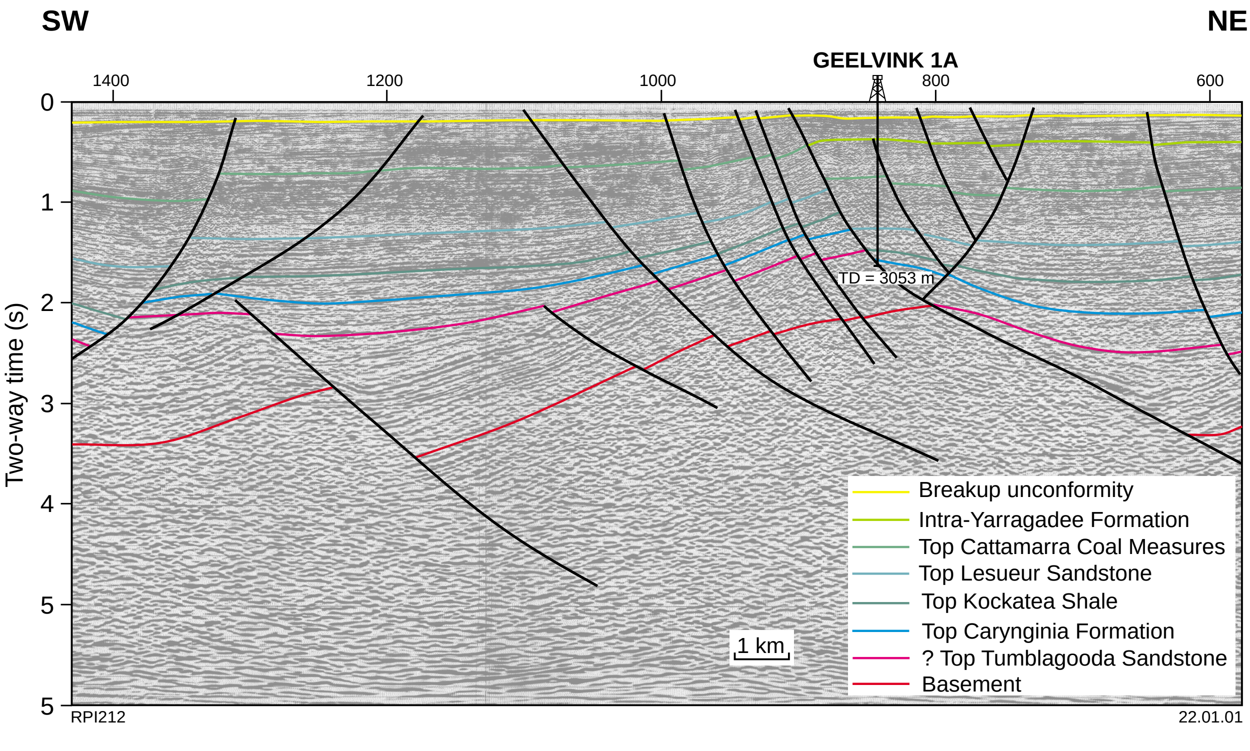

Figure 15. Seismic section E92-AU09-041, illustrating the structural setting of Geelvink 1A. Location shown in Figure 3

Table 4. Log-derived average porosities for the cleanest sandstones in Geelvink 1A

Formation/unit	*Interval (m)*	*Average sandstone porosity (%)*
Yarragadee Formation	457– 889	25
Cadda Formation	889 – 1 058	25
Cattamarra Coal Measures	1 058 – 1 464	14–18
Eneabba Formation	1 464 – 2 158	16
Lesueur Sandstone	2 158 – 2 429	12
Woodada Formation	2 429 – 2 702	12
Kockatea Shale	2 702 – 2 949	6
Wittecarra Sandstone	2 949 – 2 969	2–6
Caryngina Formation	2 969 – 3 039	–
Tumblagooda Sandstone	3 039 – 3 053	?5

SOURCE: Meath and Wright (1979)

Hydrocarbons

No hydrocarbons shows were recorded.

Source rock

The petroleum-generating potential and Rock-Eval kerogen typing of samples from Geelvink 1A are shown in Figures 10b and 11b. The Eneabba Formation, Woodada Formation, and Kockatea Shale are within the oil window whereas the underlying Caryngina Formation is overmature (Fig. 12b).

Reason for failure

There is no rollover associated with this fault trap. Therefore, sealing is reliant on the presence of shales across the fault from the Lower Permian objectives as well as the overlying Kockatea Shale. Neither the age nor the lithology of the section across the fault are certain. In any case, the 250 m thickness of the Kockatea Shale alone is considered insufficient to provide an effective seal. Lack of trap integrity was also proposed by Meath and Wright (1979).

Gun Island 1

Gun Island 1 was drilled in 1968 by BP Petroleum Development Australia Pty Ltd on Gun Island, towards the southern end of the Abrolhos Sub-basin, 72 km west-southwest of Geraldton (Fig. 2).

Stratigraphy

A Cainozoic–Cretaceous succession was penetrated from surface to the main regional unconformity at 908 m, below which the Jurassic Yarragadee Formation, Cadda Formation, Cattamarra Coal Measures, and Eneabba Formation were penetrated to a total depth of 3725 m. The interval above 908 m can be correlated with the Carnarvon Basin succession of the same age, whereas the underlying section is correlated with that of the Perth Basin.

Structure

No definite structural setting has been established for Gun Island 1, which was drilled as a stratigraphic test (Hawkins, 1969). Nearby marine seismic data suggest that the well was located on a north-trending fault-bounded high; an anticlinal feature was postulated (Hawkins, 1969), but no axial closure was established. Figure 5b shows the southern extension of the high trend probably drilled by the well, although lack of seismic control on the island does not allow a proper correlation.

Reservoir and seal

Excellent potential reservoirs are present within the Lower Cretaceous sandstone, referred to the Winning Group, but these have no seal. Potential reservoirs are also present within the Jurassic interval, for which the Cadda Formation offers the best seal.

Hydrocarbons

No hydrocarbon shows of significance were detected in Gun Island 1. Very minor indications of methane were recorded in association with carbonaceous shales and rare coal seams while drilling the Cattamarra Coal Measures.

Source rock

The petroleum-generating potential and Rock-Eval kerogen typing of samples from Gun Island 1 are shown in Figures 11c and 12c. The well entered the oil window at a depth of approximately 2000 m near the base of the Yarragadee Formation and stayed within that window to total depth in the Eneabba Formation (Fig. 12c).

Reason for failure

A trap was not identified.

Houtman 1

Houtman 1 was drilled in 1978 by Esso Australia Ltd within the outer Abrolhos Sub-basin, approximately 100 km west of Geraldton (Fig. 2).

Stratigraphy

Apart from the unnamed 130–246 m interval, the Cainozoic–Cretaceous section is referred to the Cardabia Group, Korojon Calcarenite, Toolonga Calcilutite, and Winning Group of the Carnarvon Basin to a depth of 764 m, based on wireline log character and palaeontology. Beneath this interval, the Jurassic section penetrated to total depth (3860 m) is correlated with the Yarragadee Formation, Cadda Formation, and Cattamarra Coal Measures of the onshore north Perth Basin.

Structure

Houtman 1 tested the hydrocarbon potential of the eastern flank of a complexly faulted north-northwesterly trending structural high (Galloway, 1978b; Fig. 16), here interpreted as Tertiary rejuvenation of early Cretaceous faults (Fig. 17).

Reservoir and seal

The best potential reservoirs are sandstones within the upper part of the Cattamarra Coal Measures (3342–3600 m), overlain by shale of the Cadda Formation that should be an adequate seal. Porosities have been calculated in the range of 3 to 18%.

Hydrocarbons

Beneath the Cadda Formation, indications of hydrocarbons were detected at 3342 m by gas chromatography. A production test over the 3367–3382 m interval, however, recovered only water with solution gas. The presence of 20% by volume of the C_{2+} fraction indicates some condensate (Table 5). Furthermore, the occurrence of C_5 and C_6 components suggests that the gas should be associated with light liquid.

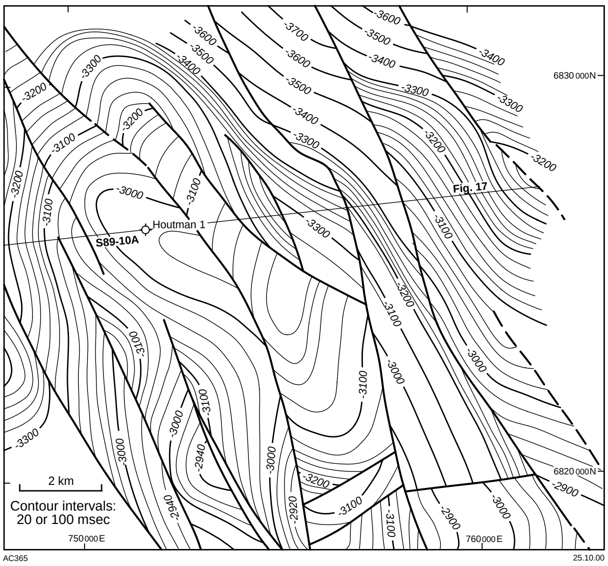

Figure 16. Pre-drilling two-way time contour map on the top of the Cadda Formation for the Houtman area (after Galloway, 1978b)

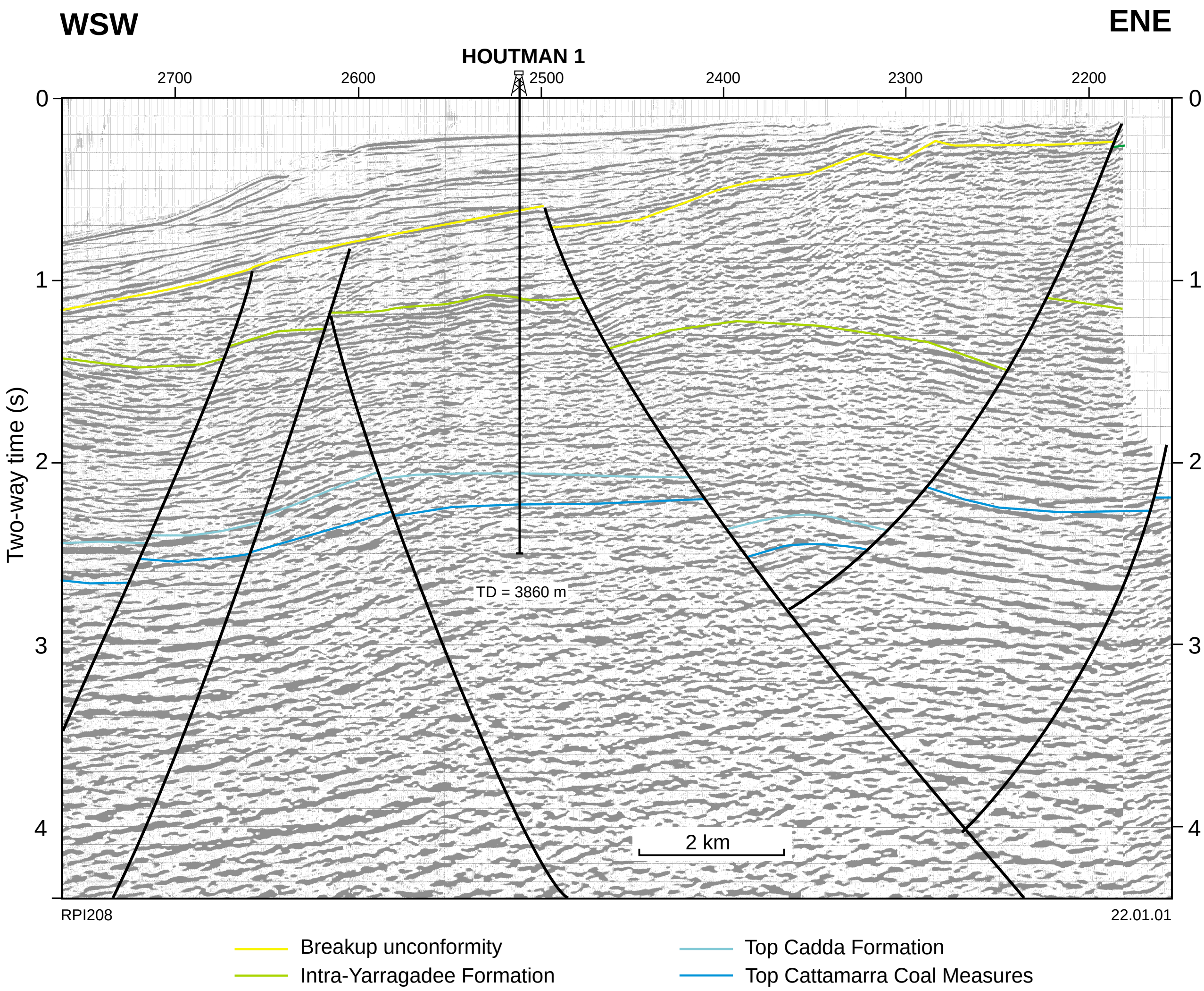

Figure 17. Seismic section S89-10A, showing the Houtman structure. Location shown in Figures 3 and 16

Table 5. Gas composition from Houtman 1 production test 1 (open flow) and formation interval tests (FITs) 3 and 4

Test	Sample	Gas composition (%)						
		C_1	C_2	C_3	C_4	C_5	C_{6+}	Total 'wet' $C_{(2+)}$ gas
Production test 1 3 367 – 3 382 m	first sample	78.7	11.7	6.0	1.8	1.2	0.5	21.3
	second sample	79.8	10.6	6.0	1.6	1.1	0.9	20.2
Formation interval test 3 3 378.5 m		92.3	6.6	0.8	2	traces	traces	7.6
Formation interval test 4 3 378 m	first sample	82.1	13.1	1.3	1.8	0.4	traces	16.6
	second sample	83.8	12.7	1.2	1.7	0.4	traces	16.0

SOURCE: Galloway (1978b)

Source rock

The gasoline range of C_{4-7} hydrocarbons as demonstrated by Burns (in Galloway, 1978a, appendix 9b) suggests that the Yarragadee Formation below 2160 m, the Cadda Formation, and the part of the Cattamarra Coal Measures above 3500 m have good source potential for gas and some possibility for oil, as shown by analyses of extracted hydrocarbons (Table 6) and confirmed by Rock-Eval kerogen typing (Fig. 11d).

Vitrinite reflectance data indicate that the well entered the oil window at a depth of around 2700 m (Fig. 12d, Appendix 5) and stayed within the early mature stage for hydrocarbons generation to total depth. On the other hand, the gas composition from production test 1 and formation interval tests 3 and 4 (Table 5) possibly indicate the presence of overmature gas. An explanation for this apparent contradiction, as provided by Burns (in Galloway, 1978a, appendix 9), is that the overmature gases migrated through the upper part of the Cattamarra Coal Measures from deeper source rocks.

Reason for failure

Galloway (1978b) suggested that Houtman 1 produced only gaseous water because the hydrocarbons present are locked in nonconnected pore space. Onshore, in the Gingin–Bootine area, similar results have been obtained from the Cattamarra Coal Measures (Crostella, 1995) and possibly also from Bullsbrook 1 (Crostella and Backhouse, 2000). An alternative interpretation is that the hydrocarbons are either migrating from deeper sources or generated in situ, but no valid trap is present.

Leander Reef 1

Leander Reef 1 was drilled in 1983 by Diamond Shamrock Oil Company (Australia) Pty Ltd within the Abrolhos Sub-basin, 30 km southwest of the town of Dongara (Fig. 2)

Stratigraphy

Ditch cuttings were not collected between seafloor and 400 m. The shallowest formation sampled was the Yarragadee Formation (Fig. 6), the top of which is here picked at 400 m on log character, beneath which the remaining Jurassic section continues to 1849 m and the Triassic to 2837 m. The top of the Cadda Formation is here placed at 755 m at a lithological break just above the first downhole appearance of the *Dissiliodinium caddaense* dinoflagellate zone at 760 m (Ingram and Purcell, 1989), which indicates a marine environment of deposition. The Middle to Lower Triassic Woodada Formation is identified here as the 2305–2468 m interval on the basis of the presence of glauconite, which is indicative of a shallow marine environment.

Beneath the Triassic, the Lower Permian Carynginia Formation was encountered to 3138 m. The possibility that the Irwin River Coal Measures is present near total depth (3234 m) was left open by Diamond Shamrock (1984) but is accepted here on the basis of palynological work by Couper (1984).

Diamond Shamrock Oil Company (Australia) Pty Ltd (1984) interpreted a fault zone between the Lower Triassic and the underlying Lower Permian strata, possibly to explain the lack of an Upper Permian section. The stratigraphic gap between the Lower Triassic and the Lower Permian is here interpreted to be the result of a late Early Permian tectonism, with subsequent erosion (or, more likely, lack of sedimentation), and is consistent with the westerly thinning of the Upper Permian strata onshore.

Structure

The Leander Reef structure was interpreted as a faulted anticline with an areal closure of more than 40 km^2 and vertical relief of approximately 200 m (Fig. 18). The anticline is here interpreted as a roll over onto a down-to-the-west normal fault. The associated folding may be due to a component of strike-slip movement (Fig. 19). Diamond Shamrock Oil Company (Australia) Pty Ltd

Table 6. Total organic carbon and extracted hydrocarbon ($\geq C_{15}$) analyses for Houtman 1

Unit	*Depth (m)*	*TOC (%)*	*Total SOM (ppm)*	*HCs (ppm)*	*Composition of SOM (%)*					*HC/ SOM (%)*	*AROM/ SATS*	*HC/ Non-HC*	*Pristane/ n-C_{17}*	*Phytane/ n-C_{18}*
					SATS	*AROM/*	*Soluble NSO*	*Insol NSO*	*Asphaltene*					
Cadda	3 140	2.18	834	156	5.4	13.3	12.8	7.1	61.4	18.7	2.46	0.23	1.14	0.29
	3 230	1.64	487	103	4.7	16.4	8.4	13.8	56.7	21.1	3.49	0.27	0.76	0.27
	3 320	1.54	734	154	6.5	14.4	11.6	8.2	59.3	21.0	2.22	0.27	0.48	0.18
Cattamarra	3 475	1.84	807	145	5.8	12.1	11.3	20.6	50.2	18.0	2.09	0.22	0.68	0.20
	3 740	1.01	377	77	8.2	12.2	4.0	2.7	72.9	20.4	1.49	0.26	0.43	0.19
	3 815	0.87	472	72	6.1	9.1	4.7	2.3	77.8	15.2	1.49	0.18	0.39	0.21

NOTES: AROM: Aromatic hydrocarbons; HCs: Hydrocarbons; NSO: Nitrogen, sulfur, and oxygen compounds; TOC: Total organic carbon; Insol.: Insoluble; SATS: Saturated hydrocarbons; SOM: Soluble organic matter; Non-HC: NSO plus asphaltene

SOURCE: Galloway (1978b)

(1984) placed faults at depths of 1010 m, 1200 m, 2510 m, 2640 m, and 2678 m, but they cannot be resolved seismically.

Reservoir and seal

Sandstone of reservoir quality is widespread throughout the drilled section. Shaly intervals are limited in thickness, which may well be less than the throw of the several possible faults intersected.

Hydrocarbons

Shows of oil were encountered near the top of the Cattamarra Coal Measures at 1010–1014 m and within the Eneabba Formation at 1415–1418 m, although log evaluation indicated high water saturation in both zones. A gas peak was noted at 1422 m with gases up to C_5. On the basis of oil shows in sidewall cores, the 1415–1418 m interval (Eneabba Formation) was tested, but produced water with only a trace of gas. Minor gas indications were also present within the Permian section.

Source rock

Diamond Shamrock carried out source-rock analyses on 34 ditch cuttings samples (from 950 to 3230 m). The Rock-Eval data from the samples in which organic richness is considered sufficient to generate hydrocarbons are shown in Figure 10e and Appendix 4. In this context, the Rock-Eval kerogen typing suggests gas- and oil-prone kerogen (Fig. 11e). The samples from the Cattamarra Coal Measures are immature, the Kockatea Shale samples are just within the oil window, and the Caryngina Formation cuttings are well within the oil window (from T_{max} and production index, PI; Fig. 11e, Appendix 4). Total organic carbon (TOC) data indicate that high organic richness in Leander Reef 1 is related to coal seams in the Cattamarra Coal Measures and shale of the Caryngina Formation. Although several gas peaks and good light-oil shows were noted during drilling of Permian sandstones, they were not significant.

Reason for failure

The severely faulted structure, the high sand:shale ratio, and the limited thickness of the clean shale beds suggest that the structure lacks an effective seal.

Livet 1

Livet 1 was drilled in 1996 by Seafield Resources within the Abrolhos Sub-basin (offshore northern Perth Basin), approximately 200 km northwest of Geraldton (Fig. 2).

Stratigraphy

Beneath an unsampled interval, the post-main unconformity Cretaceous section from 700 to 850 m is best assigned to Carnarvon Basin units (Korojon

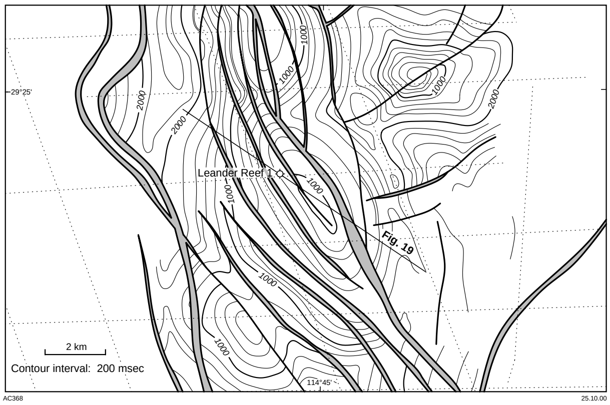

Figure 18. Pre-drilling two-way time contour map on the top of the Permian succession for the Leander Reef area (after Diamond Shamrock Oil Company (Australia) Pty Ltd, 1984)

Calcarenite, Toolonga Calcilutite, and Winning Group). The Cretaceous section unconformably overlies a Triassic interval that is assigned to units belonging to the Perth Basin. On log correlations the tops of the Woodada Formation and Kockatea Shale are placed at ?920 and 1175 m respectively. The sandstone interval 1678–1744 m was identified by Purcell and Fisher (1997) in part (1678–1685 m) as the basal section of the Kockatea Shale, whereas the remaining portion was correlated with the Wagina Formation. However, no major lithological difference is identifiable at 1685 m and no unconformity can be positively identified between the two sandy units. Furthermore, Upper Permian units or reworked Late Permian palynomorphs are yet to be identified within the main Abrolhos Sub-basin, suggesting that no Late Permian sediments were deposited in the area. A moderate number of the palynomorphs from the 1760 m ditch cuttings can be assigned to species also present in the overlying Lower Triassic Kockatea Shale (*K. septatus* Zone), and were considered by Purcell and Ingram (in Purcell and Fisher, 1997, appendix II) to be mud and caving contamination.

A regional sandy interval, with either Early Triassic (South Turtle Dove 1B) or mixed Early Triassic – Early Permian palynomorphs (Batavia 1 and Geelvink 1A), lies conformably below the Lower Triassic Kockatea Shale and unconformably above the Lower Permian Carynginia Formation. These sandy intervals are here correlated and referred, along with the 1678–1744 m interval, to the Lower Triassic Wittecarra Sandstone. This unit unconformably overlies a redbed section to total depth (1760 m), which was not named by Purcell and Fisher (1997), but here is referred to the Tumblagooda Sandstone (Figs 4 and 5).

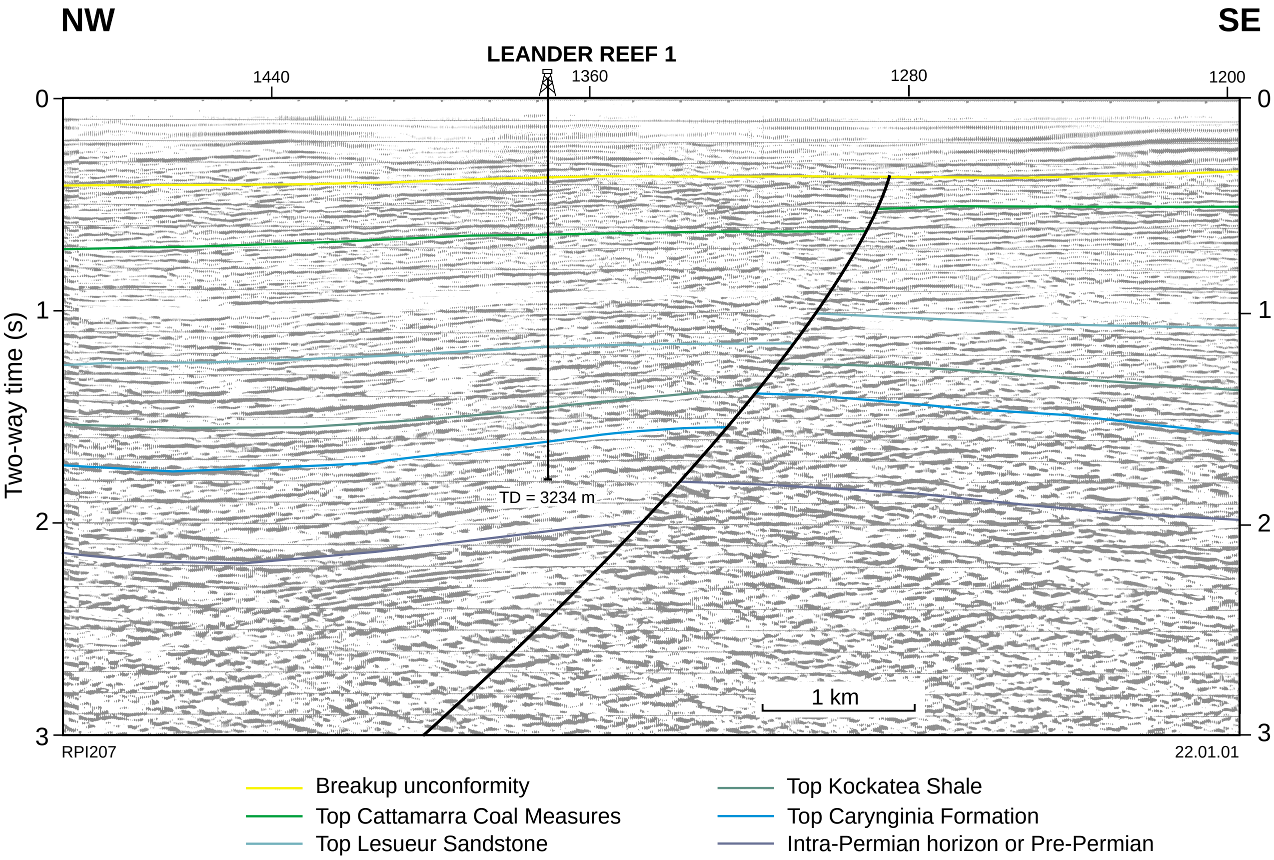

Figure 19. Seismic section DS85-048 showing the likely structural setting of Leander Reef 1. Location shown in Figures 3 and 18

Structure

Livet 1 was planned to test the hydrocarbon potential of a structure defined as a horst block by Purcell and Fisher (1997; Fig. 20), but here interpreted as a fault trap (Fig. 9). The downthrown side of the fault has a small roll-over anticline, probably associated with strike-slip movement, in contrast to the upward drag typical of an extensional fault.

Reservoir and seal

Although intraformational seals cover sandstones of the Lesueur Sandstone and Woodada Formation, the best reservoir potential is offered by the Wittecarra Sandstone, which has a log-derived porosity of 18 to 25%, and is overlain by the regional seal (Kockatea Shale).

Hydrocarbons

Hydrocarbon shows detected in 15 sidewall-core sandstone samples from the 1682–1709 m interval in the Wittecarra Sandstone were interpreted by Purcell and Fisher (1997) as indications of residual hydrocarbons. The gas chromatograph indicates that these shows are composed entirely of methane.

Source rock

Of the 19 sidewall cores analysed for TOC, only six warranted Rock-Eval pyrolysis (Appendix 4). Samples from the Kockatea Shale show moderate hydrocarbon-generating potential (Fig. 11f), whereas kerogen typing indicates a type II source (oil, Fig. 11f). The best sample from the basal Kockatea Shale, however, has only marginal potential.

The T_{max} values suggest that the Kockatea Shale samples from 1176 to 1295 m are immature and the 1640 m sample is early mature for hydrocarbon generation (Appendix 4). Extract yields from five Wittecarra Sandstone samples are high, up to 6.24 mg/g rock. Two of these samples contain a geochemical marker (C_{33} alkylcyclohexane) that is common in Perth Basin oil sourced from the Kockatea Shale (Purcell and Fisher, 1997, appendix 5).

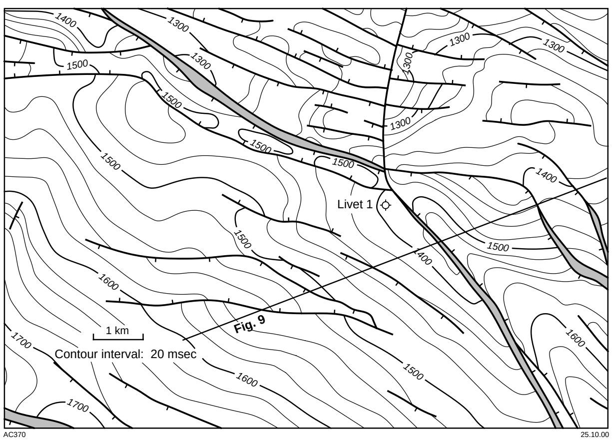

Figure 20. Pre-drilling two-way time contour map on the base of the Kockatea Shale in the Livet area (after Purcell and Fisher, 1997)

Reason for failure

Potential reservoirs, a seal, and hydrocarbons are present in the Livet area. A valid trap resulting from the basal Cretaceous breakup movements should have trapped hydrocarbons generated from the Kockatea Shale, and possibly from the Woodada Formation. The younger Miocene structure may have breached the trap, allowing the hydrocarbons to escape (Purcell and Fisher, 1997, fig. 8).

South Turtle Dove 1B

South Turtle Dove 1B was drilled by West Australian Petroleum Pty Ltd in 1975 at the southernmost tip of the Abrolhos Sub-basin (offshore northern Perth Basin), 40 km northwest of Jurien (Fig. 2).

Stratigraphy

The calcarenitic Cainozoic–Cretaceous section (0–513 m) does not clearly correlate with either the time-equivalent intervals of the Carnarvon or Perth Basins, but the underlying Jurassic–Permian interval is directly comparable with that of the Perth Basin. The lowermost palynozone identified above the Lower Cretaceous unconformity is the Cenomanian *Diconodinium multispinum* dinoflagelate zone in a sidewall core at 509.5 m (Marshall, 1995). The Lesueur Sandstone is the youngest formation encountered below the main regional unconformity. The Woodada Formation has not been recognized. At 1175 m, the Kockatea Shale overlies an Upper Permian interval which was considered by Broad and Bradley (1975) to be a basal section of the Wagina Sandstone, but is here referred to the upper part of the Beekeeper Formation.

The exact position of the Triassic–Permian boundary in the well is unclear, but the presence of a fault interpreted from dipmeter data between 1165 and 1210 m (Broad and Bradley, 1975) is not entirely consistent with the presence of a thin transgressive sand, at 1175 m, overlying the Beekeeper Formation (in which the well reached total depth at 1830 m). The Lower Triassic and Permian lithostratigraphy is supported by the palynological studies of Dolby et al. (in Broad and Bradley, 1975, appendix 3) and J. Backhouse (Appendix 6). South Turtle Dove 1B is the only well in the Abrolhos Sub-basin that penetrated Upper Permian strata, and therefore demonstrates the closest correlation with the onshore northern Perth Basin (Fig. 7).

Structure

The well was proposed to test a structural high on the Turtle Dove Ridge, defined at a level tentatively interpreted as ‘near basement’. Poor quality seismic data, possibly due to a high degree of deformation from faulting as indicated by the high dips (up to 32° within the Kockatea Shale), make the presence of a structural high in the area questionable. Broad and Bradley (1975) tentatively indicated the presence of a few faults in the well.

Reservoir and seal

Both Jurassic and post-Kockatea Shale Triassic sandstones lack a suitable seal. No potential objectives have been recognized within the Beekeeper Formation.

Hydrocarbons

No shows of hydrocarbons were encountered.

Source rock

The Beekeeper Formation contains post-mature source rocks of good organic carbon content, whereas the Kockatea Shale has fair to good source potential and is near-mature (Figs 10g and 11g). Rock-Eval typing of kerogen indicates predominantly type III with subordinate type II kerogen (Fig. 11g).

Reason for failure

No suitable objectives were penetrated by South Turtle Dove 1B. Furthermore, the high dips indicate that the well was located on a poorly defined structure. In particular, a structural trap may not be present at the base of the regional seal, namely the Kockatea Shale (Fig. 21).

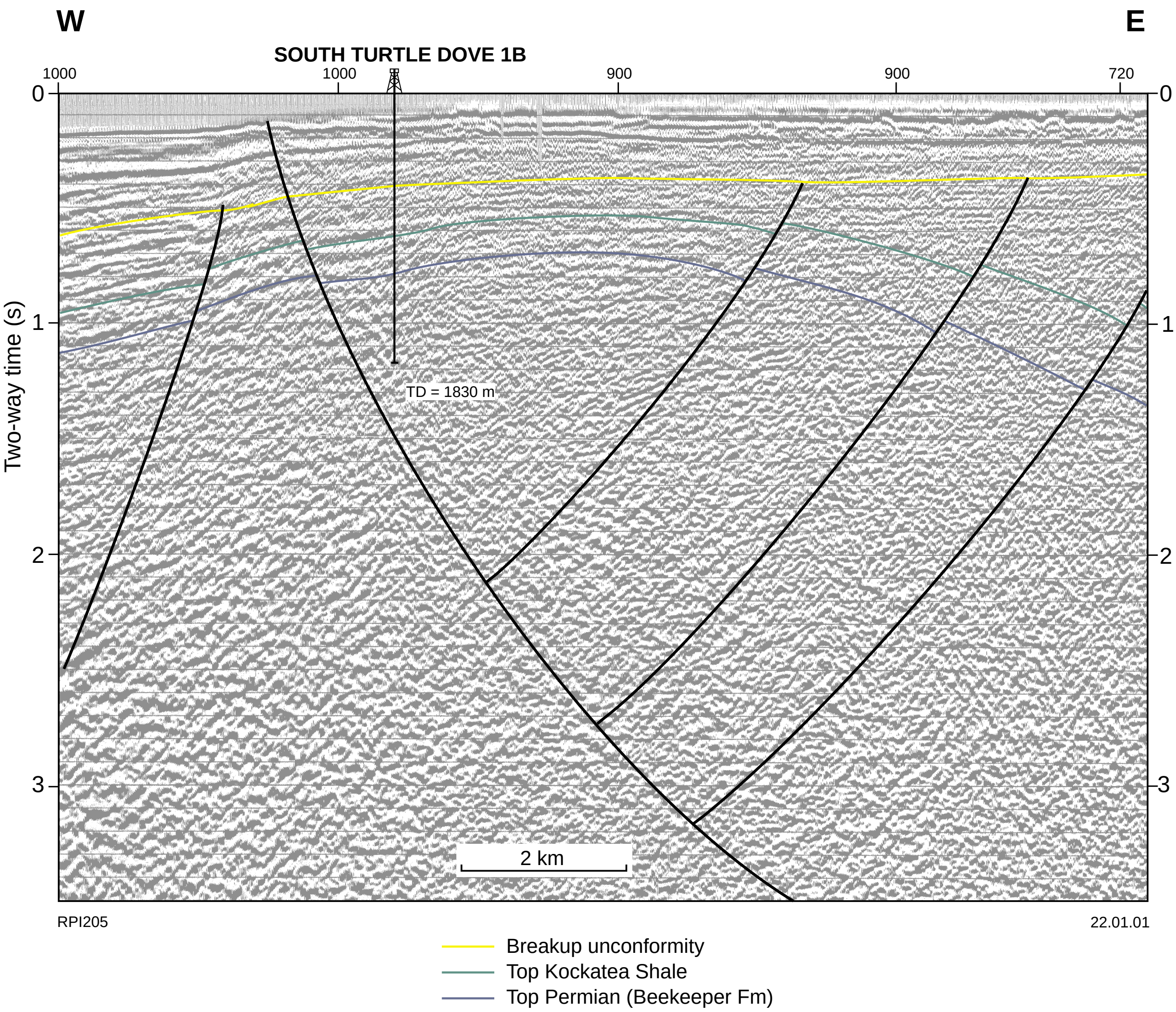

Figure 21. Seismic section TDS82-030-1298A, showing the structural setting of South Turtle Dove 1B. Location shown in Figure 3

Wittecarra 1

Wittecarra 1 was drilled in 1985 by BHP Petroleum Pty Ltd within the Abrolhos Sub-basin (offshore northern Perth Basin), approximately 95 km west of Kalbarri (Fig. 2).

Stratigraphy

The main regional unconformity, penetrated at 686 m, separates the Cainozoic–Cretaceous section from a sandy interval with minor shales barren of microfossils (686–803 m), which in turn overlies the Lesueur Sandstone, Woodada Formation, Kockatea Shale, and Caryngínia Formation to the total depth of 2890 m (BHP Petroleum Pty Ltd, 1986). The siltstone to claystone marine Woodada Formation is unusually thick — 715 m compared with a maximum of 230 m in the onshore northern Perth Basin. The presence of the *Triplexisporites playfordii* to *Samaropollenites speciosus* palynozones is consistent with an Anisian–Ladinian age, as indicated by R. Helby (in BHP Petroleum Pty Ltd, 1986, appendix 4.2). The *T. playfordii* Zone, however, has been indentified only from 1962.6 m and deeper (Ingram and Purcell, 1989). Therefore, it appears that in Wittecarra 1, the Woodada Formation covers a timespan greater than that in the northern Perth Basin, but closer to that of the Locker Shale in the Northern Carnarvon Basin. Within the Woodada Formation, plant debris and microfossils are present in equal proportion, but spore and pollen are more prominent than microplankton, although microplankton abundance increases markedly with depth. An igneous intrusion is present within the Kockatea Shale at 2763 m.

The Cainozoic–Cretaceous interval appears to be better correlated to the stratigraphic succession of the Carnarvon Basin than to that of the Perth Basin (Appendix 3). In contrast, the Triassic–Permian section is referred to the Perth Basin succession on the basis of palaeontological age dating. Although the alkaline composition of the lamprophyre in the Kockatea Shale is similar to that of the igneous rocks encountered by Edel 1, dating of this intrusion has not been attempted, but probably would not indicate the age of the surrounding sedimentary rocks. The pre-Cretaceous of the Wittecarra area therefore falls within a transition zone between the Carnarvon and the Perth Basins, and on the present limited control its inclusion in the latter is somewhat arbitrary.

Structure

Wittecarra 1 was located on a north-northwesterly trending anticlinal structure with fault-independent four-way dip closure (Fig. 22). Down-to-the-west faults that converge to the south bound the north-dipping Wittecarra compartment both to the west and to the east. These north-northwesterly trending faults control the symmetric anticlinal Wittecarra anticline (Figs 23 and 24), and are here interpreted as normal faults with a possible strike-slip component and of breakup age. Seismically, the structure is well imaged below the main unconformity down to the base of the Triassic, but the quality of the seismic data below this level deteriorates so that the structural setting of deeper horizons can be defined only

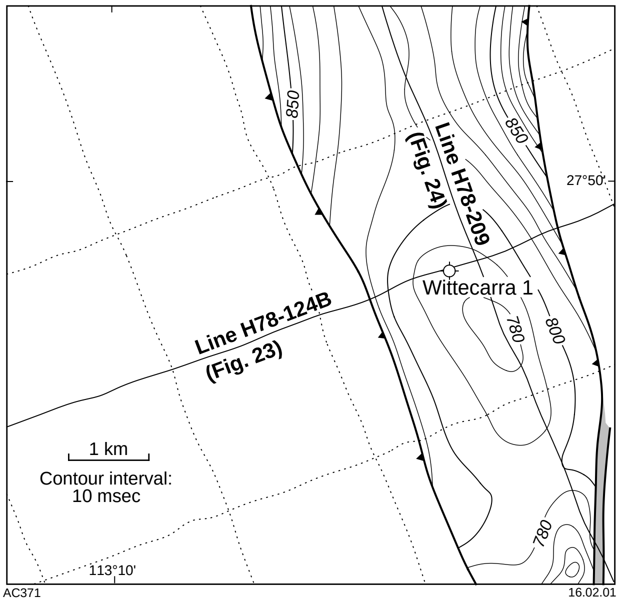

Figure 22. Pre-drilling two-way time contour map of the Wittecarra area on an intra-upper Lesueur Sandstone horizon (BHP Petroleum Pty Ltd, 1986)

with a low level of confidence. BHP Petroleum Pty Ltd (1986) considered the Permian succession to be block faulted.

Reservoir and seal

The Lesueur Sandstone and the Woodada Formation offer good reservoir potential, but are sealed by thin, and therefore probably laterally discontinuous, horizons. The Kockatea Shale could provide a good cover to underlying sandstones of the Caryngínia Formation, but these are tight in Wittecarra 1. Tables 7 and 8 attempt to quantify the reservoir and sealing potential, respectively, of the Jurassic–Permian interval. The Upper Permian Wagina and Dongara Sandstones, probably the best regional objectives, are absent, as is the basal Triassic Wittecarra Sandstone.

Hydrocarbons

No significant hydrocarbon shows were encountered in the well.

Source rock

BHP Petroleum Pty Ltd (1986) carried out extensive geochemical studies for the well: 181 ditch cuttings samples over the 350–2885 m interval were pyrolysed for Rock-Eval analyses, and 70 samples had reflectance values determined from both vitrinitic and inertinitic material. Appendix 5 lists the most reliable mean vitrinite reflectance values (%Ro), although additional data are available from the GSWA files. Only 11 samples, however, demonstrate effective source-rock potential (Appendix 4); they are all from the Woodada Formation and their

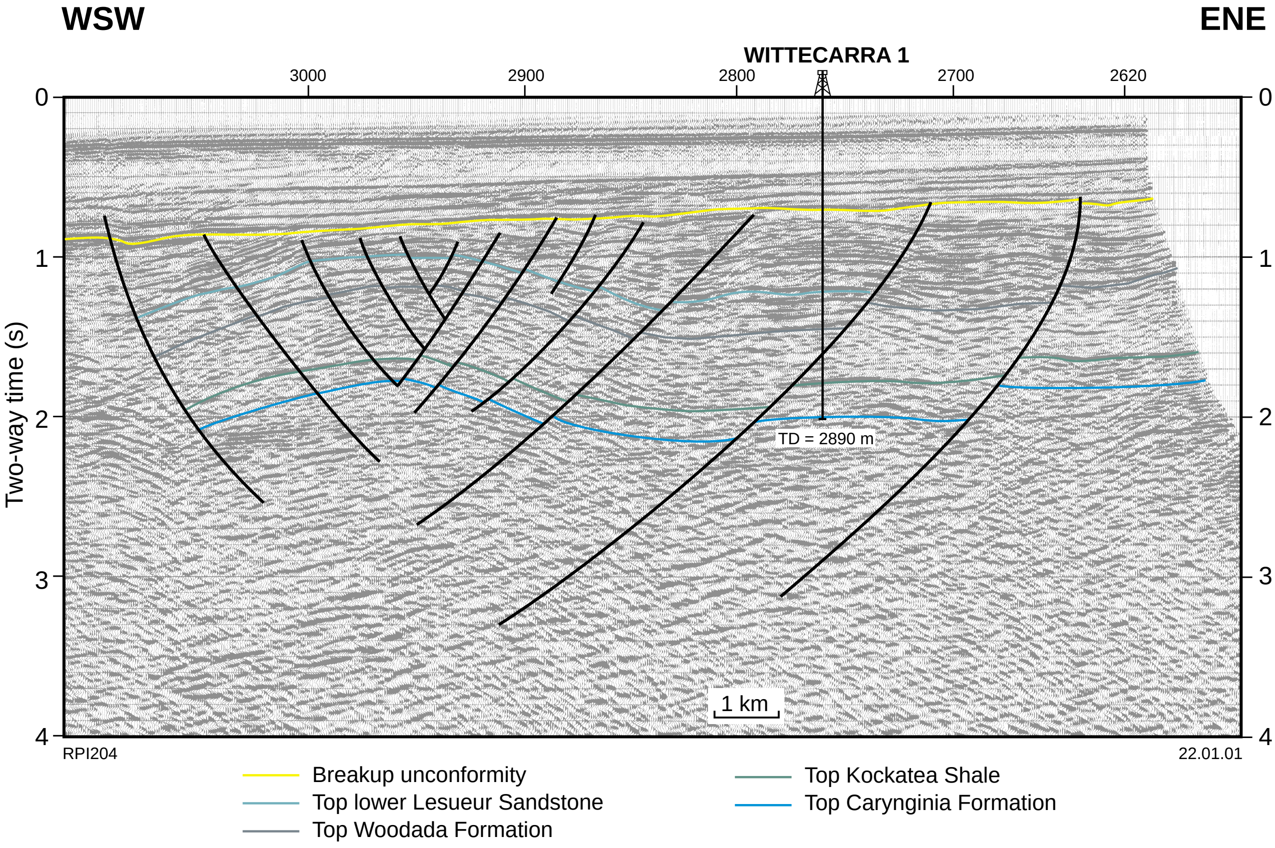

Figure 23. Seismic section H78–124B, showing the Wittecarra structure, from west-southwest to east-northeast. Location projected from 400 m west-southwest and shown in Figures 3 and 22

potential is poor to fair (Fig. 10h). The T_{max} and PI values indicate that only the Woodada Formation has potential for generating oil and gas, whereas the basal part of the Kockatea Shale and all of the Carynginia Formation are gas prone (Fig. 12). The oil window commences at the top of the Woodada and continues within it to total depth (Fig. 12e).

Reason for failure

The post-Kockatea Shale section is not effectively sealed and the post-breakup interval is unstructured; therefore, no valid trap has been tested at Mesozoic level. The Lower Triassic Wittecarra Sandstone is absent and no potential reservoir has been penetrated within the Permian section, the structural setting of which is poorly defined.

Basin evolution

The structural history of the Abrolhos Sub-basin has affinities with that of both the adjacent Gascoyne Platform and the northern Perth Basin to the east (Fig. 1). In turn, its stratigraphic succession and consequently its evolution are at variance with these regions. The evolution of the sub-basin will therefore be described with specific reference to that of these two contiguous areas.

To the north, the thick continental–shallow-marine Tumblagooda Sandstone was probably deposited over basement in a sag basin (Hocking et al., 1987; Hocking, 1994). This competent formation is flat lying and almost undisturbed, as it is in the adjacent Gascoyne Platform, and sufficiently far from local deformation by igneous intrusions (Fig. 5a). Following a period of emergence, the Tumblagooda Sandstone was unconformably overlain by the shallow-marine Wittecarra Sandstone in the Edel Terrace, the adjacent western part of the Gascoyne Platform, and the northern inner Abrolhos Sub-basin (Fig. 5a). In the remaining part of the inner Abrolhos Sub-basin the Wittecarra Sandstone transgresses over Lower Permian strata, in turn unconformably covering the Tumblagooda Sandstone, as indicated by Geelvink 1A (Fig. 6, Plate 1). In the South Turtle Dove 1B area, however, the Lower Triassic Kockatea Shale conformably overlies the Upper Permian Beekeeper Formation (Fig. 6, Plate 1).

The north-northwesterly trend of deep-seated igneous intrusions in the inner Abrolhos Sub-basin is shown by magnetic anomalies (Fig. 1). The intrusions were emplaced in the Permian – Early Triassic, as indicated by the age of the dykes penetrated by Edel 1 (Table 2) and the igneous sill present within the Kockatea Shale in Wittecarra 1. The intrusives may represent early stages of aborted sea-floor spreading centres. The main, northerly

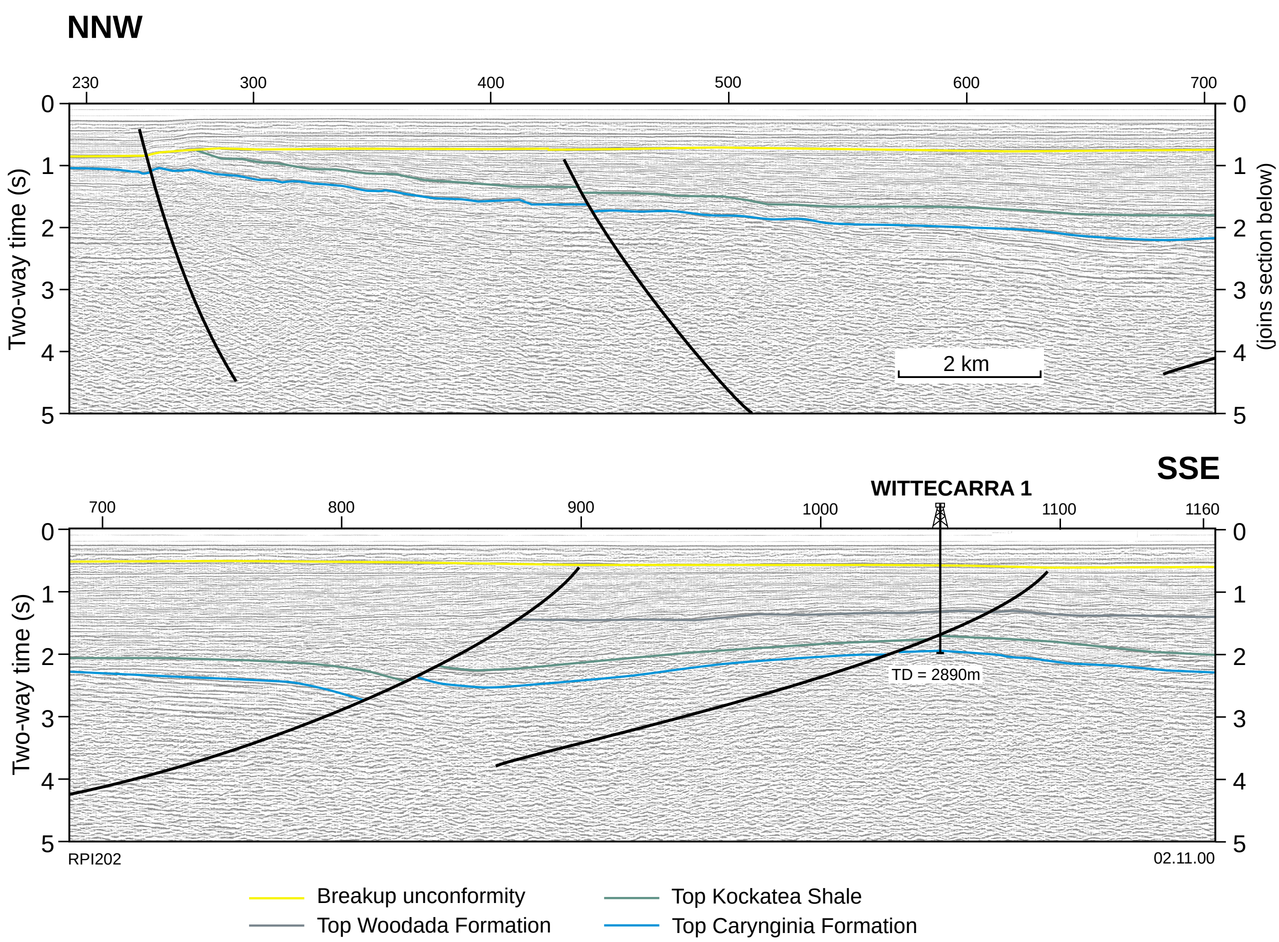

Figure 24. Seismic section H78-209 showing the Wittecarra structure, from north-northwest to south-southeast, with Wittecarra 1 projected east about 400 m. Location shown in Figures 3 and 22

trending Late Carboniferous rifting appears to have been compartmentalized by narrower elongated Mezosoic rifting, with either a northeasterly or northwesterly orientation. A similar evolution for the Northern Carnarvon Basin has been discussed by Gartrell (2000). No information is available on the presence or otherwise of the Tumblagooda Sandstone and of the Permian–Triassic tectonism in the outer Abrolhos Sub-basin. A minor Permian movement probably occurred in the South Turtle Dove 1B area, where Late Permian deposition is represented by the marine Beekeeper Formation, as it is within the northern Perth Basin (Fig. 6).

A Triassic and Jurassic sedimentary succession was then deposited (Fig. 6, Plate 1). The much greater thickness of the Jurassic section in the outer part of the Abrolhos Sub-basin, compared with the inner part, suggests greater subsidence farther westwards, consistent with rifting to the west. In the Wittecarra area, the marine Woodada Formation thickens and represents the greater part of the Middle Triassic succession in a way that closely correlates with the Locker Shale of the Exmouth Sub-basin. The great thickness of the Middle Jurassic to Lower Cretaceous succession in the outer Abrolhos Sub-basin indicates the onset of the final stage of rifting, prior to the separation of Greater India from Australia. Jurassic rifting also occurred in the onshore northern Perth Basin, as indicated by the thickening of the Lower Jurassic Cattamarra Coal Measures to the west and of the Upper Jurassic Yarragadee Formation to the east (Crostella and Backhouse, 2000, figs 6 and 7). Westward thickening is also demonstrated in the same area by the Upper Jurassic succession (Crostella, 1995, fig. 56). The relevant extensional stress field for the Jurassic succession was northwest trending, in contrast to the east-northeast trend of the earlier extension phases (Song and Cawood, 1999, fig. 2b).

The fragmentation of Gondwana resulted in a major regional unconformity, followed by the deposition of the Cretaceous to Miocene succession below the Trealla Limestone (Fig. 6), reaching a maximum thickness of 1000 m. The facies of this succession can be closely correlated with that typical of the Carnarvon Basin (Fig. 4). The entire Cretaceous–Recent section indicates stable conditions (Fig. 4), although in places rejuvenation, including faulting and anticlines, has been observed in seismic sections (Fig. 9). Minor reverse faults (Fig. 24), resulting from Miocene movements, overprint the geology of the area.

Table 7. Porosity evaluation summary for Wittecarra 1

Formation	*Depth interval*	*Density/neutron porosity (m)*	*Sonic porosity (Juhasz model)*	*Remarks (%)*
Undifferentiated Jurassic	686 – 803	Not readable	50	Poor hole conditions caused sonic to read mud
Lesueur Sandstone	803 – 1 000	Not readable	50	As above
"	1 000 – 1 200	Not readable	49	As above
"	1 200 – 1 500	Not readable	41–45	As above
"	1 500 – 1 590	25–35%	37–41	Density/neutron more accurate
"	1 590 – 1 750	15–25%	26–34	As above
Woodada Formation	1 870 – 2 000	15–20%	2–24	As above
Carynginia Formation	2 818 – 2 890	Not readable	6–9	Poor hole conditions caused sonic to read mud

SOURCE: BHP Petroleum Pty Ltd (1986)

Table 8. Net/gross ratios and shale thicknesses for Wittecarra 1

Formation	*Interval (m)*	*Net/gross ratio (Shale/sand ratio)*	*Average shale thickness (m)*
Tertiary–Cretaceous	198–787	100% porous carbonates	na
?Jurassic	676–686	100% siltstone–shale	10
"	686–803	0.92	2
Lesueur Sandstone (Triassic)	803 – 1 085	0.64	3
"	1 085 – 1 200	0.58	3
"	1 200 – 1 360	0.73	3
"	1 360 – 1 750	0.52	4
Woodada Formation (Triassic)	1 750 – 1 850	0.15	15
"	1 850 – 1 950	0.59	4
"	1 950 – 2 080	0.65	2
"	2 080 – 2 170	0.31	8
"	2 170 – 2 410	0.18	3
"	2 410 – 2 465	0.18	5
Kockatea Shale (Triassic)	2 465 – 2 818	100% siltstone–shale	353
Carynginia Formation (Lower Permian)	2 818 – TD	0.46	3

NOTES: na: not available **SOURCE:** BHP Petroleum Pty Ltd (1986)

Petroleum potential

Potential reservoirs, seals, source rocks, and traps are discussed in chronological order. Identified traps appear to be all related to breakup tectonics. A comparison is made with the petroleum potential of the onshore northern Perth Basin.

Reservoirs and seals

Thin sandstone beds are present within the Lower Permian Carynginia Formation, but are localized and tight. Similar tight reservoirs, with only limited economic potential, are present onshore in the Dongara Gasfield (Crostella, 1995), but are considered even less attractive targets offshore.

Regionally, the Wittecarra Sandstone offers the best objective because it is widespread and covered by the thick, regionally sealing Kockatea Shale. In Livet 1, the density log and neutron porosity tool indicate a porosity of 18–25%. The Wittecarra Sandstone is younger than the onshore Upper Permian Beekeeper Formation and Dongara Sandstone, but is as attractive an objective as these hydrocarbon-bearing units. Onshore data indicate that diagenesis is prevented by the presence of hydrocarbons, without which the sandstone would be more likely to have a silica cement.

Potential reservoirs also are present within the Kockatea Shale, Woodada Formation, Lesueur Sandstone, Cattamarra Coal Measures, and Yarragadee Formation, but are not considered primary targets because they rely mainly on discontinuous and thin intraformational seals.

The only possible exception is sandstone within the topmost Cattamarra Coal Measures, sealed by the overlying Cadda Formation. Hydrocarbon shows have been identified in sandstone within the Cattamarra Coal Measures, and also in the Eneabba Formation, with porosities calculated in the range of 3 to 18%; they do not appear to be controlled by the Cadda Formation. The shows from these units in Houtman 1 and Leander Reef 1 justified drillstem tests (DSTs), but only water with solution gas was obtained. Galloway (1978b) suggested that the hydrocarbons in Houtman 1 are locked in non-connected pore space. Alternatively, the intraformational shaly horizons are not sufficiently extensive or thick enough to provide effective seals. The hydrocarbons may have migrated from deeper sources or been generated in situ, but a valid trap is not present.

Similar uncommercial hydrocarbon occurrences also exist onshore, the most notable being in the Gingin area, where gas reached the surface but only limited production took place for a short period (Crostella, 1995) after the drilling of four wells (Gingin 1 to 3 and Bootine 1). In 1998, an additional well, Gingin 4, proved to be water wet. Another onshore well that encountered interesting shows within the Cattamarra Coal Measures was Walyering 1, in which 39 m of potential pay was calculated from logs, but no economic production was ever achieved. However, an intra-Cattamarra Coal Measures Sandstone (the ‘F’ sand) is the main productive interval in the small Mount Horner Oilfield (Warris, 1988). Thus, the Cattamarra Coal Measures is considered to have adequate reservoir qualities. Better results may be achieved by maximizing the density of the perforations, perforating with a 1000 psi differential, using a clay stabilizer and a low drawdown pressure (Stolper, 1992).

Excellent potential reservoirs are represented by the basal Lower Cretaceous sandstone, with the overlying shale offering source potential as regional seal, but no trap has been as yet identified at this level. The possibility of middle Miocene traps, however, cannot be entirely ruled out and if present would upgrade the economic potential of Lower Cretaceous sands.

Source rocks

Analytical geochemical data for the Abrolhos Sub-basin are available for all nine wells in the region. These wells are somewhat spread out within the sub-basin, thereby allowing the regional source potential to be assessed.

The Lower Permian Irwin River Coal Measures, in particular, contains significant gas-prone source material (Dolan and Associates, 1993; Fig. 11).

Limited potential for hydrocarbon generation is offered by the Carynginia Formation in the northern part of the sub-basin (Wittecarra 1). In the southern part, data are equivocal: in Batavia 1 good potential for oil generation is indicated by the source-rock plot (Fig. 10), but this indication is supported by only one sample. The highest organic content (3%) in an Upper Permian sample is from South Turtle Dove 1B and suggests good source-rock potential within the Beekeeper Formation, at least for gas (Fig. 12), thereby confirming the analogy with the Perth Basin. With the understanding that the well control of this Permian section is minimal, it is possible, furthermore, that in the undrilled southern portion of the sub-basin this section may contain good source rocks. The lithological similarity with the onshore northern Perth Basin is promising.

The very good source rocks near the condensed base of the Kockatea Shale, characteristic of the onshore northern Perth Basin, are poorly represented in the Abrolhos Sub-basin as the time-equivalent interval is mainly represented by the Wittecarra Sandstone. Where possible source facies are developed, such as in South Turtle Dove 1B, Geelvink 1A, and Leander Reef 1, the basal Kockatea Shale shows no or marginal source potential for hydrocarbon generation (Dolan and Associates, 1993). Lower Triassic source rocks of potential economic interest, however, are present throughout the entire sub-basin. Fine-grained clastic rocks of the Kockatea Shale and Woodada Formation have fair to good potential for generating hydrocarbons, especially oil, in Wittecarra 1, Batavia 1, Leander Reef 1 (Figs 10 and 13), and South Turtle Dove 1B (Broad and Bradley, 1975). Gas chromatograms show, in particular, that the thick Woodada Formation in Wittecarra 1 contains relatively rich oil-prone source beds (Fig. 11h; Dolan and Associates, 1993; PGA Consultants, 1994), indicating that the northern part of the Abrolhos Sub-basin has geochemical characteristics different from those in the northern Perth Basin.

The Kockatea Shale and Woodada Formation source rocks encountered in Wittecarra 1 may extend northwards into the western part of the poorly known Bernier Platform of the Southern Carnarvon Basin.

Further source-rock potential, mostly for gas, is offered by the Cattamarra Coal Measures in Houtman 1 (Fig. 11d), where interesting hydrocarbon shows were detected, although subsequent DSTs failed to confirm an accumulation. Therefore, the potential for hydrocarbon generation in the Cattamarra Coal Measures in the offshore Abrolhos Sub-basin is considered to be similar to that onshore. Onshore, an oil pool is present within the Cattamarra Coal Measures (Crostella, 1995) in the Mount Horner Oilfield, where poor reservoir characteristics allow production from only a small percentage of thin, coarse-grained, low-permeability sandstone stringers that are only partially sealed by shale beds of limited extent. In North Yardanogo 1, some 295 kL of oil were produced from the Cattamarra Coal Measures where the oil was thought to have been trapped in an anticline, but lack of oil saturation in the thicker sands within closure indicates a depositionally controlled accumulation (Crostella, 1995).

Within the northern onshore Perth Basin, geohistory and thermal modelling suggest that hydrocarbon generation from Permian source rocks commenced in the Early Jurassic prior to the regional uplift, but continued into the Early Cretaceous and lasted to the present day (West Australian Petroleum Pty Ltd, 1996). Similar favourable conditions for gas entrapment are expected in the Abrolhos Sub-basin, at least in its southern part. The Kockatea Shale (and Woodada Formation) is mature for petroleum generation in all the three wells of the Abrolhos Sub-basin for which vitrinite reflectance data are available (Fig. 12). The Cattamarra Coal Measures is mature in Houtman 1, where the unit is moderately deeply buried, and probably mature within the entire outer Abrolhos Sub-basin. Onshore the Cattamarra Coal Measures is thought to be within the oil window in the Dandaragan Trough (West Australian Petroleum Pty Ltd, 1996).

Traps

In the Early Neocomian, structural movements associated with breakup produced anticlines throughout virtually the entire sub-basin. These are considered to be the most attractive traps in the region, especially if unfaulted dip closure is present. Fault sealing is also possible, but the high percentage of sandstone throughout the Middle to Upper Triassic and the Jurassic suggests that only the Kockatea Shale, Carynginia Formation, and, locally, the Woodada Formation may provide an effective lateral seal (Table 8). Several of these traps have been identified but left untested by past operators, who apparently weighted the risk attached to these prospects higher than the potential reward. The best example is Cliff Head, a large structure located on the Beagle Ridge (Fig. 2). An accumulation there would be restricted to hydrocarbons migrating from the Abrolhos Sub-basin to the west, as the Beagle Ridge prevents hydrocarbon migration from the mature source rocks of the Dandaragan Trough (West Australian Petroleum Pty Ltd, 1996). The potential reservoirs and the seal could exist as for the Dongara Field, although an Upper Permian section is unlikely.

In five wells, lack of a structural trap is the main reason proposed here for the failure to discover an accumulation of hydrocarbons (Table 9). Edel 1, which also failed for this reason, was drilled in the Edel Terrace and cannot be compared with the Abrolhos Sub-basin wells. Lack of trap integrity is the reason for the failure of Geelvink 1A and Leander Reef 1, in both of which faults intersecting the structures are expected to made the seal ineffective. The combined effect of there being no seal above, and no reservoir below, the Kockatea Shale is considered the reason why Wittecarra 1 was dry.

Table 9 . Main reasons for the failure of Abrolhos Sub-basin petroleum exploration wells

Well	*Reason for failure*
Batavia 1	no structural trap
Edel 1	no reservoir
Geelvink 1A	ineffective seal
Gun Island 1	no structural trap
Houtman 1	no structural trap
Leander Reef 1	ineffective seal
Livet 1	no structural trap
South Turtle Dove 1B	no structural trap
Wittecarra 1	no seal at Mesozoic level, no reservoir at basal Triassic or Permian levels

Conclusions

Source rocks, potential reservoirs, seals, and structural traps are present in the Permian, Triassic, and Jurassic successions of the Abrolhos Sub-basin. Lower Permian strata are more intensely folded, as both the late Early Permian and the early Neocomian events affected them. It is therefore difficult to define their structural setting, but the local presence of both anticlinal and horst traps has been recognized.

The Kockatea Shale (and the Woodada Formation in the northernmost part of the area) is the best regional seal, already proven to be effective in the onshore northern Perth Basin. In comparison, the Cadda Formation has not yet been proven to control a hydrocarbon accumulation of economic significance.

The Wittecarra Sandstone is considered to be the best objective for petroleum exploration where it is sealed by the Kockatea Shale within an anticlinal dip closure. This play is most attractive in the eastern part of the sub-basin, because in the west the presence of a thick Jurassic section makes the Wittecarra Sandstone too deep to be tested economically at present.

A secondary objective is the Cattamarra Coal Measures, sealed by the Cadda Formation or intra-formational shales. This play is the most attractive in the west, but should be tested within a dip closure free of faults.

A more remote possibility is contingent on Tertiary movements that may have created attractive traps with Cretaceous objectives in the northernmost part of the region and within the western Bernier Platform.

The main difference between the Abrolhos Sub-basin and the onshore northern Perth Basin is the absence of the lowermost Kockatea Shale, containing the best source potential for oil within the region. The source potential of the Abrolhos Sub-basin, therefore, is restricted to gas-prone intervals in the Permian and Mesozoic sections.

The area around South Turtle Dove 1B can be closely correlated with the northern Perth Basin and, as such, has a similar potential for petroleum exploration. Onshore, such exploration potential is accompanied by an extensive production infrastructure and a growing market.

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Appendix 1

Seismic surveys conducted for petroleum exploration within the Abrolhos Sub-basin and the Edel Terrace

S number	*Survey name*	*Year conducted*	*Tenement*	*Basin*	*Company*	*Reflection (km)*	*Line prefix*
209	Abrolhos MSS	1965	PE-193,236-H	Perth	BP	1 225.9	A65-
249	Snag Island MSS	1965	PE-228-H	Perth	French Petroleum	45	SI65-
331	Abrolhos D1 MSS	1966	PE-193,236-H	Carnarvon, Perth	BP	247.8	AD66-
298	Carnarvon Basin West MSS	1966	PE-235-H	Carnarvon	Canadian Superior	2 205	CBW66-
17	Dongara MSS 1967	1967	PE-27,225-H	Perth	WAPET	661	D67~BU, etc
410V2	Dongara MSS 1968	1968	PE-27,225-H	Perth	WAPET	1 110	D68~
436	Beagle MSS	1968	WA-13,14,20-P	Perth	WAPET	267	B68~
388	Direction Bank MSS	1968	PE-27,225-H	Perth	WAPET	1 628	DB68~
410V1	Turtle Dove MSS	1968	PE-225-H	Perth	WAPET	381	TD68~
520V2	Wedge Island MSS	1969	WA-14-P	Perth	WAPET	379	WI69~
460	Pelsart MSS	1969	WA-13-P	Perth	WAPET	506	P69~BW, etc
626V2	Perth North MSS	1970	WA-13,14,20-P	Perth	WAPET	24	PN70~
558	Geelvink Channel MSS	1970	WA-39,40-P	Carnarvon, Perth	BP	1 435.5	GC70-
786	Murchison MSS & Mag S 1970	1970	WA-7-P	Carnarvon	WAPET	65.8	M70~
639	Teledyne Expl 1970 Line	1970	WA-27-P	Carnarvon	Canadian Superior	?	TE70~
611V2	Houtman MSS, Grav & Mag S	1971	WA-13,14,20-P	Perth	WAPET	360	H71~
616	Geelvink Channel D1 SS	1971	WA-40-P	Perth	BP	301.8	GC71-
672	Bernier MSS & Mag S	1971	WA-26-P	Carnarvon	Canadian Superior	1 451.6	B71~OE-
660	Indian Ocean Offshore MSS	1971	WA-26-P	Carnarvon	Ocean Ventures	246.2	IOO71~OV-
671	Scien. Inv. 1SL (Petrel Roving 1971)	1971	Vacant acreage	All offshore	Shell	8 005.5	N
812	WA-7-P MSS, Grav & Mag S	1972	WA-7-P	Carnarvon	Oceania Petroleum	408	7P72~
803V2	Cervantes (DW) MSS, Grav & Mag S	1972	WA-13-P	Perth	WAPET	116	C~P73-
825V1	Fisherman MSS, Grav & Mag S	1972	WA-13,14,20-P	Perth	WAPET	429	F~P72-
788V1	Lancelin (SW) MSS	1972	WA-14-P	Perth	WAPET	210	L~P72-
706	Kalbarri MSS & Mag S	1972	WA-39-P	Carnarvon	Ocean Ventures	228.5	K72~
769	Murchison MSS & Mag S 1972	1972	WA-39-P	Carnarvon	Ocean Ventures	579.4	M72~
831	Quoin Head MSS & Mag S	1972	WA-7,26-P, EP45	Carnarvon	Ocean Ventures	1 012.3	QH72~QH-
715	Zeewyk MSS	1972	WA-40-P	Perth	AMOCO	195	W72-
779	Scien. Inv. 1SL (Petrel Roving 1973)	1972	WA-13,43,44,47,50,51-P	All offshore	Shell	6 194	N
830	Tamala MSS	1972	WA-26-P	Carnarvon	Ocean Ventures	83	T72-
924	Webb (SW) MSS	1973	WA-20-P	Perth	WAPET	209	W~P73-
808	Zuytdorp MSS & Mag S	1973	WA-26,27-P	Carnarvon	Canadian Superior	978.5	Z73-
1296	A76A MSS	1976	WA-59-P	Carnarvon, Perth	Esso	2 384	A76A-
743	Abrolhos (DW) MSS	1976	WA-13-P	Perth	WAPET	732	A~P76-
1171	Cliff Head MSS	1976	WA-14-P (R1)	Perth	WAPET	86	C~P76-

Appendix 1 (continued)

S number	*Survey name*	*Year conducted*	*Tenement*	*Basin*	*Company*	*Reflection (km)*	*Line prefix*
1325	A77A MSS	1977	WA-59-P	Carnarvon, Perth	Esso	290	A77A-
1321	Casuarina MSS	1977	WA-13-P (R1)	Perth	WAPET	83	C~P77-
1320	Batavia MSS	1977	WA-13-P (R1)	Perth	WAPET	70	B~P77-
1319	Arranoo MSS	1977	WA-13-P	Perth	WAPET	202	A~P77-
1356	Indoon MSS	1977	WA-13-P (R1)	Perth	WAPET	128	I~P77-
1364	Hartog MSS & Ext Mag S	1978	WA-81-P	Carnarvon	CONOCO	1 961	H78~
1433	A78A Exp MSS	1978	WA-59-P	Perth	Esso	781	A78A-
1439	A78A MSS	1978	WA-59-P	Perth	Esso	77	Exp-
1500	WA-81-P II MSS	1979	WA-81-P	Carnarvon	CONOCO	1 387	81P79-
1741	A80A MSS	1980	WA-59-P, EP88,89,91	Perth	WMC	833	A80A-
1712	Murchison 81P MSS	1980	WA-81-P	Carnarvon	CONOCO	1 276	M80-
1718	Green Head MSS	1980	WA-115-P	Perth	Geometals Oil	301	GH80-
1882	A81A MSS	1981	WA-59-P	Perth	WMC	416	A81A-
1858	Helga MSS	1981	WA-144-P	Perth	Mesa Australia	307	H~81-
1898	Rhonda (SW) S Refl S	1981	WA-115,144-P	Perth	Mesa Australia	190	R81~IS-
2214	Green MSS	1982	WA-171-P	Perth	Balmoral Resources	697	G82-
2187	Alison S Refl S	1982	WA-144-P	Perth	Mesa Australia	50	A82
2046	Dongara Offshore MSS	1982	WA-162-P	Perth	Diamond Shamrock	871	DO~DS82-
2105	Turtle Dove South MSS	1982	WA-165-P	Perth	Alberta Eastern Gas	1 099	TDS~82-
2489	Cervantes MSS	1983	WA-171-P	Perth	Balmoral Resources	364	C83-
2386	WA-196-P 1983 SS	1983	WA-196-P	Carnarvon	Petrofina	131	196P83-
2619	WA-162-P 1984 MSS	1984	WA-162-P	Perth	Diamond Shamrock	945	162P~DS84-
2814	WA-162-P 1985 MSS	1985	WA-162-P	Perth	Diamond Shamrock	1 670	162P~DS85-
3619V1	SPA 9SL/1988-89 (Abrolhos Spec)	1989	Vacant acreage	Perth	GSI	1 588.1	SPA~S89-
10128	Beagle 2D MSS	1992	WA-228-P	Perth	Woodside	1 200.7	B2D~B92-
10113	Plum MSS	1992	WA-230,231-P	Perth	Enterprise Oil	3 984	P~E92AU09-
10114	Scarlett MSS	1992	WA-231-P	Perth	Enterprise Oil	2 319.8	S~E92AU08-
10100	Abrolhos West MSS	1992	WA-232-P	Perth	CONOCO	2 798	WA91-
10121	Fiddich MSS	1992	WA-226-P	Perth	Seafield Resources	204.4	F~S92-
10189	Blackpoint MSS	1993	WA-228-P	Perth	Woodside	381.7	B93-
10187	Peacock MSS	1993	WA-231-P	Perth	Enterprise Oil	498.9	P~E93AU22-
10191	Livet MSS	1993	WA-226-P	Carnarvon	Seafield Resources	467.5	L~AS93-
10203	HP94 MSS	1994	WA-232-P	Perth	BHP Petroleum	1 263.8	HP94-
10333	Morangie MSS	1997	WA-226-P	Carnarvon, Perth	Seafield Resources	497.2	M~S97-

NOTES: Grav & Mag S: Gravity and magnetic survey
MSS: Marine seismic survey
S Number: Department of Mineral and Energy, Western Australia, statutory petroleum exploration report number
WAPET: West Australian Petroleum Pty Ltd
AMOCO: Amoco Australian Petroleum Company
CONOCO: Continental Oil Company
WMC: Western Mining Corporation Ltd
GSI: Geophysical Service International

Appendix 2

Petroleum exploration wells drilled in the Abrolhos Sub-basin and the Edel Terrace

Well	*S number*	*Latitude*	*Longitude*	*TD formation*	*Year*	*Operating company*
Batavia 1	1 425	28°53'58.69"S	114°15'36.40"E	Irwin River Coal Measures (?High Cliff Sandstone)	1978	Esso Australia Ltd
Edel 1	727	27°06'47.70"S	113°23'23.87"E	Tumblagooda Sandstone	1972	Ocean Ventures Pty Ltd
Geelvink 1A	1 382	29°05'47.13"S	114°17'53.39"E	Tumblagooda Sandstone	1978	West Australian Petroleum Pty Limited
Gun Island 1	425	28°53'30.11"S	113°51'27.0"E	Cattamarra Coal Measures	1968	BP Petroleum Development Australia Pty Ltd
Houtman 1	1 347	28°39'55.01"S	113°34'34.97"E	Cattamarra Coal Measures	1978	Esso Australia Limited
Leander Reef 1	2 499	29°26'22.6"S	114°44'10.2"E	Carynginia Formation	1983	Diamond Shamrock Oil Company (Australia) Pty Ltd
Livet 1	20 362	27°16'33.27"S	112°54'10.01"E	Tumblagooda Sandstone	1996	Seafield Resources
South Turtle Dove 1B	1 104	30°07'46.29"S	114°38'11.21"E	Carynginia Formation	1975	West Australian Petroleum Pty Limited
Wittecarra 1	2 882	27°50'37.67"S	113°12'32.73"E	Carynginia Formation	1985	BHP Petroleum Pty Ltd

NOTES: S Number: Department of Minerals and Energy, Western Australia, statutory petroleum exploration report number
TD: Total depth

Appendix 3

Formation tops for petroleum exploration wells within the Abrolhos Sub-basin and the Edel Terrace

				Tertiary	Cretaceous				Jurassic				Triassic				Permian			Ordovician	
Well	*RT/KB elevation (above MSL) (m)*	*Sea bed (m)*	*Unnamed*	*Cardabia Group*	*Miria Marl*	*Korojon Calcarenite*	*Toolonga Calcilutite*	*Winning Group*	*Yarragadee Fm*	*Cadda Fm*	*Cattamarra Coal Measures*	*Eneabba Fm*	*Lesueur Sandstone*	*Woodada Fm*	*Kockatea Shale*	*Wittecarra Sandstone*	*Beekeeper Fm*	*Carynginia Fm*	*Irwin River Coal Measures*	*Tumblagooda Sandstone*	*TD*
Batavia 1	3.1	53	–	nr	nr	nr	nr	nr	345	571	641	901	1 498	2 193	2 318	2 766	–	2 822	2 854	–	2 941
Edel 1	29.5	94.5	–	nr	nr	nr	nr	nr	np	np	np	np	np	np	np	np	–	np	np	354	2 750
Geelvink 1A	30	51.5	–	nr	nr	nr	nr	nr	?463	889	1 058	1 464	2 107	2 544	2 702	2 949	–	2 969	np	?3 039	3 053
Gun Island 1	7.3	onshore location	130	?	?246	nr	nr	705	908	2 187	2 429	3 174	np	np	np	np	–	np	np	np	3 725
Houtman 1	25.3	152	–	220	nr	705	750	753	764	3 012	3 342	np	np	np	np	np	–	np	np	np	3 860
Leander Reef 1	8.2	43	–	nr	nr	nr	nr	nr	?400	755	870	1 242	1 849	2 305	2 468	np	–	2 837	3 150	np	3 234
Livet 1	22	213	–	nr	nr	700	750	795	np	np	np	np	850	?920	1 175	1 678	–	np	np	1 744	1 760
South Turtle Dove 1B	30	63	320	429	nr	495 (eq.)	508 (eq.)	np	np	np	np	np	513	nr	857	np	1 175	np	np	np	1 830
Wittecarra 1	8.3	190	198	540	582	598	664	676	np	np	np	686	803	1 750	2 465	np	–	2 819	np	np	2 890

NOTES:

nr: not recognized
np: not present
eq.: equivalent
Fm: Formation
RT: Rotary table
KB: Kelly Bushing
MSL: Mean sea level
TD: Total depth

Appendix 4

Total organic carbon and Rock-Eval data for source-rock samples from Abrolhos Sub-basin petroleum exploration wells

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	*T_{max} (°C)*	*S_1*	*S_2*	*S_3*	*$S_1 + S_2$*	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Batavia 1	640	640		0.73	–	–	–	–	–	–	–	–	Cadda Formation	
	685	–		1.25	–	–	–	–	–	–	–	–	Cattamarra Coal Measures	
	730	–		2.03	–	–	–	–	–	–	–	–		
	785	–		1.87	–	–	–	–	–	–	–	–		
	820	–		1.48	–	–	–	–	–	–	–	–		
	865	–		1.89	–	–	–	–	–	–	–	–		
	1 000	–		0.73	–	–	–	–	–	–	–	–	Eneabba Formation	
	1 000	–		38.60	423	3.23	66.56	16.76	69.79	0.05	172	43		coal (?caved)
	1 035	–		5.05	430	0.67	8.60	4.60	9.27	0.07	170	91		
	1 110	–		1.15	432	0.18	0.64	9.52	0.82	0.22	56	828		
	1 195	–		0.55	–	–	–	–	–	–	–	–		
	1 840	–		0.93	–	–	–	–	–	–	–	–	Lesueur Sandstone	
	2 105	2 115	DC	0.95	435	0.42	2.83	7.16	3.25	0.13	298	754		
	2 110	–		0.57	–	–	–	–	–	–	–	–		
	2 150	2 160	DC	0.95	436	0.33	2.99	4.19	3.32	0.10	315	441		
	2 155	–		0.57	–	–	–	–	–	–	–	–		
	2 200	–		0.63	–	–	–	–	–	–	–	–	Woodada Formation	
	2 220	–		0.66	429	0.32	1.66	4.88	1.98	0.16	252	739		
	2 220	2 230	DC	1.60	435	0.45	3.76	3.74	4.21	0.11	235	234		
	2 230	–		0.90	429	0.23	1.41	10.11	1.64	0.14	157	1 123		
	2 240	2 250	DC	1.15	436	0.27	2.99	5.20	3.26	0.08	260	452		
	2 250	–		1.52	–	–	–	–	–	–	–	–		
	2 265	2 275	DC	2.49	434	0.60	6.77	5.28	7.37	0.08	272	212		
	2 275	–		0.94	431	0.26	1.72	7.44	1.98	0.13	183	791		
	2 310	2 315	DC	0.81	436	0.22	2.20	2.57	–	–	–	–		siltstone
	2 315	–		0.77	429	0.16	1.10	10.08	1.26	0.13	143	1 309		
	2 320	2 325	DC	1.24	434	0.28	3.03	1.26	–	–	–	–	Kockatea Shale	siltstone
	2 345	2 350	DC	0.54	436	0.17	2.11	1.67	–	–	–	–		siltstone
	2 350	–		0.60	429	0.20	1.16	6.94	1.36	0.15	193	1 157		
	2 385	–		0.69	–	–	–	–	–	–	–	–		
	2 400	–		0.55	428	0.19	1.12	6.30	1.31	0.15	204	1 145		
	2 405	2 410	DC	0.54	435	0.20	2.02	1.07	–	–	–	–		shale
	2 450	–		0.55	428	0.18	1.02	5.53	1.20	0.15	185	1 005		
	2 475	–		0.50	–	–	–	–	–	–	–	–		
	2 520	–		0.55	–	–	–	–	–	–	–	–		
	2 565	–		0.59	–	–	–	–	–	–	–	–		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	T_{max} (°C)	S_1	S_2	S_3	$S_1 + S_2$	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Batavia 1 (continued)	2 595	–		0.57	–	–	–	–	–	–	–	–		
	2 640	–		0.60	–	–	–	–	–	–	–	–		
	2 675	–		0.56	444	0.28	0.79	0.74	1.07	0.26	141	132		
	2 685	2 690	DC	0.56	435	0.13	0.77	1.30	0.90	0.14	138	232		shale
	2 685	–		0.56	–	–	–	–	–	–	–	–		
	2 730	–		0.39	452	0.20	0.49	0.82	0.69	0.29	126	210		
	2 730	–		0.55	–	–	–	–	–	–	–	–		
	2 730 (A)	–		0.37	439	0.13	0.60	0.97	0.73	0.18	162	262		
	2 745	–		0.39	449	0.17	0.38	0.85	0.55	0.31	97	218		
	2 755	–		0.40	440	0.12	0.61	0.71	0.73	0.16	153	178		
	2 760	–		0.37	453	0.09	0.23	0.85	0.32	0.28	62	230		
	2 765	–		0.89	440	0.13	0.74	0.66	0.87	0.15	83	74		
	2 765	–		0.54	446	0.13	0.38	0.72	0.51	0.25	70	133		
	2 775	–		0.52	–	–	–	–	–	–	–	–	Wittecarra Sandstone	
	2 780	–		0.24	441	0.10	0.22	0.40	0.32	0.31	92	167		
	2 820	–		0.55	–	–	–	–	–	–	–	–		
	2 830	2 835	DC	7.91	445	0.78	7.99	8.77	8.77	0.09	101	111	Carynginia Formation	shale
	2 830	–		2.88	457	0.35	1.84	0.55	2.19	0.16	64	19		
	2 835	–		4.50	451	0.59	5.17	0.83	5.76	0.10	115	18		
	2 840	–		2.30	457	0.29	1.64	0.82	1.93	0.15	71	36		
	2 850	–		4.35	455	0.32	2.97	2.55	3.29	0.10	68	59	Irwin River Coal Measures	
	2 850	–		1.89	463	0.13	0.92	1.18	1.05	0.12	49	62		
	2 860	–		2.20	441	0.44	1.50	5.54	1.94	0.23	68	252		
	2 865	–		0.56	–	–	–	–	–	–	–	–		
	2 880	–		2.10	441	0.33	1.32	5.75	1.65	0.20	63	274		
	2 890	2 895	DC	5.89	452	0.66	4.89	1.22	5.55	0.12	83	21		shale
	2 905	2 910	DC	6.34	452	0.55	5.28	1.03	5.83	0.09	83	16		shale
	2 910	2 915	DC	3.85	451	0.36	2.75	2.11	3.11	0.12	71	55		shale
	2 910	–		0.64	–	–	–	–	–	–	–	–		
	2 915	–		2.10	443	0.32	1.29	5.57	1.61	0.20	61	265		
	2 940	–		0.55	–	–	–	–	–	–	–	–		
Geelvink 1A	485	–		53.69	446	1.55	22.40	–	23.95	0.06	42	–	Yarragadee Formation	
	525	–		0.88	452	0.08	0.70	–	0.78	0.10	80	–		
	550	550		0.46	345	0.06	0.27	0.38	0.33	0.18	59	83		
	945	–		0.61	449	0.14	0.90	–	1.04	0.13	148	–	Cadda Formation	
	1 000	–		1.28	425	0.02	0.57	1.47	0.59	0.03	45	115		
	1 010	–		1.39	426	0.03	0.46	1.52	0.49	0.06	33	109		
	1 010	–		1.51	457	0.23	1.60	–	1.83	0.13	106	–		
	1 020	–		0.91	428	0.03	0.16	0.85	0.19	0.16	18	93		
	1 030	–		1.27	427	0.05	0.58	0.90	0.63	0.08	46	71		
	1 055	–		1.89	459	0.16	1.70	–	1.86	0.09	90	–		
	1 160	–		0.78	457	0.14	0.70	–	0.84	0.17	90	–	Cattamarra Coal Measures	

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	T_{max} *(°C)*	S_1	S_2	S_3	$S_1 + S_2$	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Geelvink 1A (continued)	1 200	–		0.96	456	0.16	0.90	–	1.06	0.15	94	–		
	1 360	–		11.12	457	0.51	24.20	–	24.71	0.02	218	–		
	1 445	–		1.90	458	0.13	3.60	–	3.73	0.03	189	–		
	1 485	–		0.45	–	–	0.16	0.40	0.16	0.00	36	89	Eneabba Formation	
	1 500	–		0.65	358	0.05	0.31	1.09	0.36	0.14	48	168		
	1 550	–		0.86	453	0.20	1.40	–	1.60	0.13	163	–		
	1 615	–		0.59	463	0.16	0.60	–	0.76	0.21	102	–		
	1 660	–		0.44	–	0.10	0.30	–	0.40	0.25	68	–		
	1 760	–		0.23	–	0.11	0.20	–	0.31	0.35	87	–		
	1 830	–		0.80	401	0.17	1.10	–	1.27	0.13	138	–		
	1 965	–		0.54	–	0.11	0.30	–	0.41	0.27	56	–		
	1 995	–		2.95	469	0.42	4.20	–	4.62	0.09	142	–		
	2 050	–		2.80	–	0.08	–	–	–	–	–	–		
	2 060	–		0.41	–	0.14	0.20–	–	0.34	0.41	49	–		
	2 120	–		0.38	–	0.19	0.30	–	0.49	0.39	79	–	Lesueur Sandstone	
	2 160	–		0.41	–	0.11	0.20	–	0.31	0.35	49	–		
	2 250	–		0.26	329	0.05	0.20	0.22	0.25	0.20	77	85		
	2 565	–		0.36	–	0.12	0.30	–	0.42	0.29	83	–	Woodada Formation	
	2 595	2 610	DC	0.12	–	–	–	–	–	–	–	–		
	2 640	–		0.24	–	0.11	0.20	–	0.31	0.35	83	–		
	2 710	–	DC	0.62	437	0.20	1.14	0.38	1.34	0.15	184	61	Kockatea Shale	shale
	2 720	–		0.27	435	0.11	0.45	1.13	0.56	0.20	167	419		
	2 730	–	DC	0.64	436	0.23	3.39	0.49	3.62	0.06	530	77		shale
	2 770	–		0.75	465	0.27	3.30	–	3.57	0.08	440	–		
	2 795	–		0.43	439	0.09	0.85	1.01	0.94	0.10	198	235		
	2 835	–		0.80	468	0.20	1.90	–	2.10	0.10	238	–		
	2 865	–		0.33	432	0.11	0.35	1.04	0.46	0.24	106	315		
	2 890	–	DC	0.56	439	0.18	1.55	0.87	1.73	0.10	277	155		shale
	2 945	–		0.29	440	0.08	0.33	1.19	0.41	0.20	114	410		
	2 950	–		0.49	471	0.16	0.30	–	0.46	0.35	61	–	Wittecarra Sandstone	
	2 990	–		2.20	450	0.16	0.85	1.27	1.01	0.16	39	58	Carynginia Formation	
	3 000	–		2.02	474	0.30	1.90	–	2.20	0.14	94	–		
	3 010	–		1.16	443	0.10	0.46	1.13	0.56	0.18	40	97		
	3 030	–		2.96	449	0.21	1.03	1.65	1.24	0.17	35	56		
	3 050	–		1.45	442	0.07	0.36	0.88	0.43	0.16	25	61		?cavings
Gun Island 1	1 054	–		2.92	462	0.07	2.30	–	2.37	0.03	79	–	Yarragadee Formation	
	1 201	–		0.69	–	0.05	0.30	–	0.35	0.14	43	–		
	1 274	1 283	DC	59.40	423	5.37	172.47	18.17	177.84	0.03	290	31		?coal
	1 274	–		63.89	450	3.39	267.60	–	270.99	0.01	419	–		?coal
	1 314	–		61.97	451	5.56	290.00	–	295.56	0.02	468	–		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	T_{max} *(°C)*	S_1	S_2	S_3	$S_1 + S_2$	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Gun Island 1	1 372	1 378	DC	29.30	426	4.60	98.43	7.84	103.03	0.04	336	27		shale + ?coal
(continued)	1 375	–		37.06	455	5.33	189.70	–	195.03	0.03	512	–		
	1 516	–		20.50	459	2.03	118.90	–	120.93	0.02	580	–		
	1 524	–		40.24	458	4.10	187.10	–	191.20	0.02	465	–		
	1 640	–		2.88	458	0.40	7.80	–	8.20	0.05	271	–		
	1 707	–		3.84	499	0.15	5.60	–	5.75	0.03	146	–		
	1 795	1 801	DC	36.40	426	7.44	140.74	8.61	148.18	0.05	387	24		shale
	1 795	1 801	DC	64.00	419	7.91	135.16	2.30	143.07	0.06	211	4		?coal
	1 799	–		5.75	458	0.53	19.70	–	20.23	0.03	343	–		
	1 860	–		3.11	464	0.14	6.00	–	6.14	0.02	193	–		
	1 905	–		3.82	458	0.32	9.80	–	10.12	0.03	257	–		
	2 037	–		21.44	458	1.56	51.30	–	52.86	0.03	239	–		
	2 047	–		1.65	464	0.09	2.20	–	2.29	0.04	133	–		
	2 101	–		62.09	424	6.73	263.30	–	270.03	0.02	424	–		
	2 191	2 191.0	core 16	1.26	431	0.27	1.66	0.28	1.93	0.14	132	22	Cadda Formation	
	2 219	2 228	DC	3.06	429	0.31	6.22	2.59	6.53	0.05	203	85		siltstone
	2 231	2 234	DC	2.41	426	0.28	4.15	2.58	4.43	0.06	172	107		
	2 249	2 252	DC	1.96	427	0.21	2.20	4.29	2.41	0.09	112	219		
	2 286	2 295	DC	1.75	435	0.05	1.35	2.95	1.40	0.04	77	169		shale
	2 293	–		1.80	–	0.34	2.80	–	3.14	0.11	156	–		
	2 301	2 307	DC	1.94	430	0.18	2.37	3.08	2.55	0.07	122	159		siltstone
	2 338	–		1.81	467	0.22	2.20	–	2.42	0.09	122	–		
	2 344	2 432	DC	6.70	429	0.28	22.08	2.25	22.36	0.01	330	34		shale
	2 357.0	2 357.2	core 17	1.49	430	0.11	0.72	0.65	0.83	0.13	48	44		
	2 358	–		1.90	466	0.07	1.70	–	1.77	0.04	89	–		
	2 365	2 368	DC	1.65	428	0.14	0.96	2.59	1.10	0.13	58	157		
	2 371	2 377	DC	1.56	429	0.14	0.82	2.56	0.96	0.15	53	164		siltstone
	2 408	2 411	DC	1.54	429	0.15	1.04	2.81	1.19	0.13	68	182		
	2 429	2 435	DC	1.76	431	0.13	0.96	1.51	1.09	0.12	55	86	Cattamarra Coal Measures	siltstone
	2 429	?	DC	1.65	429	0.15	0.95	2.68	1.10	0.14	58	162		
	2 430	–		2.08	464	0.18	2.10	–	2.28	0.08	101	–		
	2 448	2 451	DC	1.53	426	0.14	0.74	2.41	0.88	0.16	48	158		
	2 521	–		1.96	463	0.21	2.40	–	2.61	0.08	122	–		
	2 522.9	–	core 18	37.80	429	3.08	61.58	5.00	64.66	0.05	163	13		?coal
	2 545	2 548	DC	2.14	431	0.18	2.11	2.82	2.29	0.08	99	132		
	2 569	2 579	DC	1.88	426	0.65	3.28	1.90	3.93	0.17	174	101		siltstone
	2 627	?	DC	1.57	432	0.16	1.07	2.06	1.23	0.13	68	131		
	2 640	–		5.67	468	0.59	7.30	–	7.89	0.07	129	–		
	2 661.0	–	core 19	1.95	435	0.16	2.77	0.56	2.93	0.05	142	29		
	2 661.4	–	core 19	1.30	436	0.05	1.12	0.15	1.17	0.04	86	12		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	*T_{max} (°C)*	*S_1*	*S_2*	*S_3*	*$S_1 + S_2$*	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Gun Island 1	2 662	–		3.25	468	0.23	4.30	–	4.53	0.05	132	–		
(continued)	2 664	2 673	DC	18.70	434	1.64	29.76	3.75	31.40	0.05	159	20		shale
	2 664	2 673	DC	67.80	429	5.51	121.72	11.26	127.23	0.04	180	17		?coal
	2 671	–		12.84	462	1.64	28.90	–	30.54	0.05	225	–		
	2 707	2 710	DC	2.35	434	0.24	2.27	0.81	2.51	0.10	97	34		
	2 758	2 765	DC	0.94	437	0.16	0.84	0.78	1.00	0.16	89	83		siltstone
	2 799	–		1.11	–	0.16	0.80	–	0.96	0.17	72	–		
	2 817	–		1.33	453	0.51	2.50	–	3.01	0.17	188	–		
	2 851	–		1.03	468	0.13	0.80	–	0.93	0.14	78	–		
	2 865	2 871	DC	1.08	434	0.13	0.80	0.93	0.93	0.14	74	86		siltstone
	2 914	2 917	DC	1.55	432	0.39	1.38	3.62	1.77	0.22	89	234		
	2 921	–		1.18	469	0.12	0.90	–	1.02	0.12	76	–		
	2 969	2 975	DC	1.47	435	0.16	1.38	1.70	1.54	0.10	94	116		siltstone
	2 970	–		0.97	469	0.11	0.70	–	0.81	0.14	72	–		
	3 027	–		1.08	469	0.15	1.10	–	1.25	0.12	102	–		
	3 051	3 057	DC	1.00	442	0.10	0.78	1.47	0.88	0.11	78	147		siltstone
	3 064	–		1.13	469	0.13	0.90	–	1.03	0.13	80	–		
	3 110	–		1.32	473	0.09	1.00	–	1.09	0.08	76	–		
	3 158	3 167	DC	0.94	437	0.08	0.79	1.11	0.87	0.09	84	118		siltstone
	3 181	–		1.29	473	0.17	1.50	–	1.67	0.10	116	–	Eneabba Formation	
	3 252	–		0.66	–	–	0.40	–	0.40	0.00	61	–		
	3 280	–		1.13	473	0.23	1.70	–	1.93	0.12	150	–		
	3 251.0	–	core 20	0.49	–	–	–	–	–	–	–	–		
	3 283	3 292	DC	0.88	433	0.21	0.99	0.80	1.20	0.18	113	91		siltstone
	3 310	3 313	DC	1.62	442	0.41	1.53	3.23	1.94	0.21	94	199		
	3 351	–		0.91	–	0.17	0.80	–	0.97	0.18	88	–		
	3 359	–	DC	2.75	432	0.55	5.00	4.31	5.55	0.10	182	157		
	3 371	3 380	DC	1.28	442	0.24	1.52	2.51	1.76	0.14	119	196		siltstone
	3 383	3 392	DC	1.68	445	0.20	2.19	0.98	2.39	0.08	130	58		shale
	3 374	3 380	DC	64.90	442	9.00	167.00	4.70	176.00	0.05	257	7		coal
	3 393	–		7.77	473	1.51	16.50	–	18.01	0.08	212	–		
	3 397	3 502	DC	0.86	443	0.10	0.64	1.26	0.74	0.14	74	147		siltstone
	3 397	3 502	DC	56.70	441	7.92	180.09	4.05	188.01	0.04	318	7		coal
	3 423	3 426	DC	71.50	442	15.50	217.79	4.12	233.29	0.07	305	6		coal
	3 427	–		1.79	477	0.37	3.10	–	3.47	0.11	173	–		
	3 500	–		0.43	506	0.11	0.60	–	0.71	0.15	140	–		
	3 557	3 563	DC	0.96	443	0.11	0.73	1.38	0.84	0.13	76	144		siltstone
	3 566	3 575	DC	75.50	446	2.97	162.80	4.38	165.77	0.02	216	6		?coal
	3 566	3 575	DC	1.07	452	0.04	0.63	0.53	0.67	0.06	59	50		shale
	3 570	–		11.94	482	0.62	22.50	–	23.12	0.03	188	–		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	*T_{max} (°C)*	*S_1*	*S_2*	*S_3*	*$S_1 + S_2$*	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Gun Island 1	3 599.5	–	core 22	0.18	–	–	–	–	–	–	–	–		
(continued)	3 637	–		0.35	–	0.13	1.50	–	1.63	0.08	429	–		
	3 667	3 679	DC	0.77	440	0.09	0.59	1.01	0.68	0.13	77	131		siltstone
	3 709	3 719	DC	1.26	446	0.07	0.78	0.83	0.85	0.08	62	66		shale
	3 720	–		0.70	–	0.13	0.90	–	1.03	0.13	129	–		
	3 722	–	core 23	0.22	–	–	–	–	–	–	–	–		
Houtman 1	980	–		12.90	456	0.35	1.00	–	1.35	0.26	8	–	Yarragadee Formation	
	1 410	–		13.29	473	0.90	31.00	–	31.90	0.03	233	–		
	1 415	1 425	DC	47.90	420	0.66	21.20	32.24	21.86	0.03	44	67		
	1 420	1 425	DC	9.80	418	0.55	12.23	21.94	12.78	0.04	125	224		
	1 420	1 425		9.13	424	1.39	17.60	20.64	18.99	0.07	193	226		
	1 500	1 505	DC	33.45	435	0.79	29.90	11.16	30.69	0.03	89	33		?coal
	1 500	1 505	DC	32.60	434	1.50	29.82	12.50	31.32	0.05	91	38		shale/coal
	1 545	1 550	DC	22.30	420	7.04	110.61	6.53	117.65	0.06	496	29		shale/coal
	1 545	1 550		14.10	422	6.94	76.14	5.30	83.08	0.08	540	38		
	1 695	1 700	DC	1.53	416	0.08	0.40	0.95	0.48	0.17	26	62		
	1 700	1 705		0.74	424	0.13	0.15	1.28	0.28	0.46	20	173		
	1 700	–		1.15	–	0.40	0.15	–	0.55	0.73	13	–		
	1 710	1 715	DC	0.83	–	0.04	0.04	1.06	0.08	0.50	5	128		
	1 715	1 720	DC	0.75	–	0.04	0.01	0.86	0.05	0.80	1	115		
	1 720	1 725	DC	0.80	–	0.04	0.14	0.70	0.18	0.22	18	88		
	1 730	–		1.00	–	–	–	–	–	–	–	–		
	1 745	1 750	DC	0.78	427	0.07	0.41	1.03	0.48	0.15	53	132		
	1 745	1 750		0.47	429	0.33	0.50	0.95	0.83	0.40	106	202		
	1 760	1 770	DC	1.90	425	0.07	0.34	1.82	0.41	0.17	18	96		
	1 765	1 770		0.81	428	0.20	0.30	1.00	0.50	0.40	37	123		
	1 775	–		6.05	–	–	–	–	–	–	–	–		
	1 788	1 790		0.23	427	0.18	0.36	0.69	0.54	0.33	157	300		
	1 940	–		3.15	–	–	–	–	–	–	–	–		
	1 900	–		1.01	469	0.10	0.90	–	1.00	0.10	89	–		
	2 035	2 050	DC	0.70	425	0.14	0.94	0.65	1.08	0.13	134	93		
	2 070	–		0.95	473	0.16	1.30	–	1.46	0.11	137	–		
	2 075	2 085	DC	2.38	418	0.43	1.93	0.72	2.36	0.18	81	30		
	2 165	–		0.63	–	–	–	–	–	–	–	–		
	2 210	–		2.70	–	–	–	–	–	–	–	–		
	2 210	2 220	DC	2.29	426	0.49	6.56	0.49	7.05	0.07	286	21		
	2 255	–		3.28	–	–	–	–	–	–	–	–		
	2 305	–		1.09	477	0.23	1.00	–	1.23	0.19	92	–		
	2 385	2 390		0.68	425	0.22	1.01	0.47	1.23	0.18	149	69		
	2 440	2 450	DC	3.18	426	0.53	6.39	0.80	6.92	0.08	201	25		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	T_{max} *(°C)*	S_1	S_2	S_3	$S_1 + S_2$	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Houtman 1 (continued)	2 450	2 455	DC	1.96	430	0.17	2.78	0.55	2.95	0.06	142	28		
	2 455	2 470	DC	2.51	431	0.22	3.58	0.80	3.80	0.06	143	32		
	2 465	–		1.05	475	0.18	1.30	–	1.48	0.12	124	–		
	2 480	–		3.27	–	–	–	–	–	–	–	–		
	2 570	–		0.05	–	–	–	–	–	–	–	–		
	2 600	2 610	DC	5.35	426	0.40	12.20	1.41	12.60	0.03	228	26		
	2 615	–		11.70	–	–	–	–	–	–	–	–		coal
	2 620	2 625	DC	7.60	425	0.72	13.19	1.98	13.91	0.05	174	26		shale/coal
	2 650	2 665	DC	2.58	431	0.18	3.84	0.58	4.02	0.04	149	22		siltstone
	2 650	2 665	DC	46.20	429	3.28	57.12	10.20	60.40	0.05	124	22		coal
	2 660	–		3.56	–	–	–	–	–	–	–	–		
	2 665	2 675	DC	2.00	436	0.05	0.72	1.52	0.77	0.06	36	76		
	2 665	2 670		0.87	450	0.17	0.15	0.62	0.32	0.53	17	71		
	2 675	2 690	DC	2.15	433	0.05	1.42	1.58	1.47	0.03	66	73		
	2 675	2 700	DC	56.00	440	2.00	36.72	10.36	38.72	0.05	66	19		coal
	2 690	2 700	DC	2.10	431	0.11	2.08	1.61	2.19	0.05	99	77		siltstone
	2 690	–		8.12	474	0.52	10.40	–	10.92	0.05	128	–		
	2 700	2 705	DC	2.15	429	0.37	3.15	1.03	3.52	0.11	147	48		shale/coal
	2 705	–		2.36	–	–	–	–	–	–	–	–		
	2 720	2 730	DC	2.54	425	0.24	3.29	1.20	3.53	0.07	130	47		
	2 760	2 775	DC	2.68	424	0.28	4.22	0.75	4.50	0.06	157	28		
	2 770	2 775		0.76	432	0.15	0.72	0.54	0.87	0.17	95	71		
	2 780	2 785	DC	4.05	423	0.49	3.76	2.29	4.25	0.12	93	57		shale/coal
	2 810	2 825	DC	3.02	425	0.33	4.67	0.87	5.00	0.07	155	29		
	2 840	–		3.85	–	–	–	–	–	–	–	–		
	2 845	2 850		4.33	429	1.12	6.67	1.00	7.79	0.14	154	23		
	2 850	2 855	DC	51.80	432	5.39	145.39	5.19	150.78	0.04	281	10		shale/coal
	2 850	–		56.31	481	7.02	148.30	–	155.32	0.05	263	–		
	2 860	2 865	DC	3.35	423	0.25	5.99	1.37	6.24	0.04	179	41		
	2 885	–		27.95	–	–	–	–	–	–	–	–		coal
	2 888	2 890		3.00	430	0.56	4.24	0.54	4.80	0.12	141	18		
	2 890	2 900	DC	5.19	430	0.47	11.69	0.83	12.16	0.04	225	16		siltstone
	2 890	2 915	DC	53.90	429	7.72	149.60	6.43	157.32	0.05	278	12		coal
	2 900	2 910	DC	4.05	430	0.28	8.40	0.81	8.68	0.03	207	20		siltstone
	2 910	2 920	DC	4.83	428	0.33	11.70	0.99	12.03	0.03	242	20		
	2 920	2 930	DC	3.08	427	0.32	5.86	0.63	6.18	0.05	190	20		siltstone
	2 920	2 935	DC	55.40	433	8.55	168.65	6.05	177.20	0.05	304	11		coal
	2 925	2 930	DC	2.90	426	0.37	6.20	0.69	6.57	0.06	214	24		
	2 930	–		11.55	–	–	–	–	–	–	–	–		
	2 930	2 940	DC	4.41	429	0.34	10.01	1.00	10.35	0.03	227	23		siltstone

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	T_{max} *(°C)*	S_1	S_2	S_3	$S_1 + S_2$	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Houtman 1 (continued)	2 935	2 940	DC	47.90	432	6.76	160.00	6.28	166.76	0.04	334	13		shale/coal
	2 935	2 950	DC	54.10	434	6.63	146.63	7.11	153.26	0.04	271	13		coal
	2 940	2 950	DC	7.00	432	0.47	16.83	1.30	17.30	0.03	240	19		siltstone
	2 950	2 955	DC	3.29	429	0.45	6.13	0.60	6.58	0.07	186	18		
	2 975	–		18.65	–	–	–	–	–	–	–	–		
	3 045	3 050	DC	1.75	432	0.26	1.64	1.68	1.90	0.14	94	96	Cadda Formation	shale/coal
	3 045	3 050	DC	1.02	434	0.11	0.74	0.88	0.85	0.13	73	86		
	3 050	3 055	DC	1.55	431	0.08	1.26	1.37	1.34	0.06	81	88		
	3 095	–		1.54	–	–	–	–	–	–	–	–		
	3 120	3 125	DC	1.34	439	0.04	0.62	0.68	0.66	0.06	46	51		
	3 120	3 125	DC	1.10	441	0.10	0.76	0.52	0.86	0.12	69	47		
	3 140	–		2.18	–	–	–	–	–	–	–	–		
	3 140	3 145	DC	0.79	–	0.02	0.05	1.67	0.07	0.29	6	211		
	3 158.8	–	core 2	2.37	432	0.17	1.71	0.17	1.88	0.09	72	7		
	3 158.0	3 159.0	core 2	0.87	439	0.10	0.69	0.38	0.79	0.13	79	44		
	3 159.4	–	core 2	2.36	433	0.21	2.80	0.38	3.01	0.07	119	16		
	3 159.7	–	core 2	2.30	433	0.26	2.41	0.47	2.67	0.10	105	20		
	3 166.1	3 166.4	core 2	2.64	433	0.42	4.25	0.43	4.67	0.09	161	16		
	3 163.0	3 164.0	core 2	1.19	443	0.05	0.19	0.78	0.24	0.21	16	66		
	3 166.3	–	core 2	2.25	435	0.17	2.11	0.38	2.28	0.07	94	17		
	3 167.0	–	core 2	2.16	405	0.26	3.50	–	3.76	0.07	162	–		
	3 169.6	3 170.2	core 2	1.86	434	0.23	1.19	0.47	1.42	0.16	64	25		
	3 169.6	–	core 2	0.73	439	0.11	0.66	0.30	0.77	0.14	90	41		
	3 169.8	–	core 2	1.94	438	0.12	1.40	0.18	1.52	0.08	72	9		
	3 170	–	core 2	1.90	434	0.16	1.32	0.88	1.48	0.11	69	46		
	3 171.4	–	core 2	1.94	435	0.11	1.32	0.26	1.43	0.08	68	13		
	3 185.0	3 190	DC	1.23	437	0.19	1.03	0.71	1.22	0.16	84	58		
	3 185	–		1.98	–	–	–	–	–	–	–	–		
	3 190	3 195	DC	1.79	436	0.09	1.14	0.53	1.23	0.07	64	30		
	3 190	3 195	DC	1.50	434	0.08	0.99	1.03	1.07	0.07	66	69		
	3 190	3 195	DC	1.54	435	0.19	1.35	0.73	1.54	0.12	88	47		
	3 195	–		1.45	472	0.17	0.90	–	1.07	0.16	62	–		
	3 200	3 210	DC	1.25	441	0.03	0.24	0.84	0.27	0.11	19	67		
	3 230	–		1.64	–	–	–	–	–	–	–	–		
	3 230	3 235	DC	1.59	435	0.06	0.99	0.51	1.05	0.06	62	32		
	3 245	3 250	DC	1.20	441	0.16	0.71	0.79	0.87	0.18	59	66		
	3 275	–		1.70	–	–	–	–	–	–	–	–		
	3 280	3 285	DC	1.43	436	0.25	1.63	0.60	1.88	0.13	114	42		
	3 285	3 290	DC	1.20	438	0.15	0.99	0.91	1.14	0.13	83	76		
	3 300	3 305	DC	1.58	437	0.12	1.05	0.69	1.17	0.10	66	44		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	T_{max} *(°C)*	S_1	S_2	S_3	$S_1 + S_2$	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Houtman 1 (continued)	3 305	–		1.19	483	0.17	1.30	–	1.47	0.12	109	–		
	3 310	3 315	DC	0.89	438	0.13	0.80	0.76	0.93	0.14	90	85		
	3 320	–		1.54	–	–	–	–	–	–	–	–		
	3 320	3 325	DC	1.50	434	0.34	1.78	0.44	2.12	0.16	119	29		
	3 335	3 340	DC	1.04	440	0.15	0.62	0.65	0.77	0.19	60	63		
	3 350	3 355	DC	1.53	435	0.30	1.55	0.35	1.85	0.16	101	23	Cattamarra Coal Measures	
	3 360	–		1.64	–	–	–	–	–	–	–	–		
	3 362	3 363	core 3	0.93	439	0.19	0.90	0.73	1.09	0.17	97	78		
	3 362	–	core 3	1.70	430	0.20	1.44	3.67	1.64	0.12	85	216		
	3 362	–	core 3	1.89	437	0.09	1.81	0.63	1.90	0.05	96	33		
	3 364	–		1.30	434	0.25	1.60	–	1.85	0.14	123	–		
	3 370	3 375	DC	0.70	438	0.14	0.67	–	0.81	0.17	96	–		
	3 395	–		1.00	–	–	–	–	–	–	–	–		
	3 400	3 405	DC	1.04	446	0.05	0.17	0.76	0.22	0.23	16	73		
	3 400	3 405	DC	1.50	441	0.12	0.39	0.93	0.51	0.24	26	62		
	3 410	3 420	DC	1.44	438	0.06	0.74	0.62	0.80	0.08	51	43		
	3 415	3 420	DC	1.75	438	0.10	1.09	0.57	1.19	0.08	62	33		
	3 430	3 435	DC	0.82	441	0.10	0.57	0.35	0.67	0.15	70	43		
	3 430	–		1.75	–	–	–	–	–	–	–	–		
	3 460	3 465	DC	0.86	443	0.15	0.68	0.31	0.83	0.18	79	36		
	3 470	3 475	DC	2.28	436	0.16	1.72	0.75	1.88	0.09	75	33		
	3 475	–		1.84	–	–	–	–	–	–	–	–		
	3 490	3 495	DC	0.79	445	0.10	0.57	0.26	0.67	0.15	72	33		
	3 490	3 495	DC	1.95	439	0.24	2.00	0.33	2.24	0.11	103	17		
	3 610	3 615	DC	0.58	457	0.03	0.04	0.89	0.07	0.43	7	153		
	3 610	3 620	DC	0.87	–	0.02	0.01	0.58	0.03	0.67	1	67		
	3 620	3 625	DC	0.93	446	0.02	0.09	0.82	0.11	0.18	10	88		
	3 635	3 640	DC	1.22	446	0.27	1.19	0.34	1.46	0.18	98	28		
	3 640	3 645	DC	0.57	443	0.07	0.37	0.67	0.44	0.16	65	118		
	3 670	3 675	DC	0.85	462	0.09	0.33	0.55	0.42	0.21	39	65		
	3 670	–		1.01	491	0.17	0.90	–	1.07	0.16	89	–		
	3 700	3 705	DC	0.62	442	0.07	0.38	0.39	0.45	0.16	61	63		
	3 730	3 735	DC	0.84	461	0.10	0.32	0.74	0.42	0.24	38	88		
	3 740	–		1.01	–	–	–	–	–	–	–	–		
	3 755	3 760	DC	0.77	451	0.07	0.27	0.75	0.34	0.21	35	97		
	3 780	3 785	DC	1.00	450	0.04	0.39	0.52	0.43	0.09	39	52		
	3 815	–		0.87	–	–	–	–	–	–	–	–		
	3 835	–		0.88	504	0.22	0.70	–	0.92	0.24	80	–		
	3 855	3 860	DC	1.49	465	0.14	0.98	0.38	1.12	0.13	66	26	Cattamarra Coal Measures	
Leander Reef 1	980	990	DC	0.96	424	0.04	0.34	2.75	0.38	0.11	35	286		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	*T_{max} (°C)*	*S_1*	*S_2*	*S_3*	*$S_1 + S_2$*	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Leander Reef 1	990	1 000	DC	1.89	426	0.06	0.85	4.11	0.91	0.07	45	217		
(continued)	1 010	1 020	DC	0.65	420	0.04	0.22	1.60	0.26	0.15	34	246		
	1 030	1 040	DC	3.16	431	0.07	2.69	3.58	2.76	0.03	85	113		
	1 350	1 360	DC	0.76	459	0.04	0.37	1.05	0.41	0.10	49	138	Eneabba Formation	
	1 370	1 380	DC	1.04	430	0.05	0.36	1.40	0.41	0.12	35	135		
	1 390	1 400	DC	0.83	433	0.04	0.27	1.13	0.31	0.13	33	136		
	2 395	2 410	DC	0.83	437	0.24	2.04	0.45	2.28	0.11	246	54	Woodada Formation	
	2 510	2 515	DC	0.53	433	0.16	1.77	0.44	1.93	0.08	334	83	Kockatea Shale	shale
	2 545	2 550	DC	0.50	433	0.22	2.38	0.55	2.60	0.08	476	110		shale
	2 765	2 768	DC	1.01	433	2.13	2.60	3.57	4.73	0.45	257	353		bulk sample
	2 765	2 768	DC	0.93	436	1.19	2.04	2.66	3.23	0.37	219	286		
	2 765	2 770	DC	2.11	436	0.76	1.66	2.29	2.42	0.31	79	109		
	2 825	2 828	DC	0.64	439	0.34	1.23	1.65	1.57	0.22	192	258		
	2 828	2 831	DC	1.73	428	0.73	2.66	2.13	3.39	0.22	154	123		shale
	2 828	2 831	DC	1.85	428	0.77	3.07	1.98	3.84	0.20	166	107		
	2 838	2 831	DC	1.77	438	0.56	1.73	1.74	2.29	0.24	98	98	Caryngínia Formation	
	2 831	2 834	DC	1.72	434	0.75	4.38	1.37	5.13	0.15	255	80		shale
	2 831	2 834	DC	1.45	434	0.57	3.95	1.67	4.52	0.13	272	115		
	2 831	2 834	DC	1.34	440	0.45	1.87	1.01	2.32	0.19	140	75		
	2 834	2 837	DC	2.48	435	0.45	3.82	1.53	4.27	0.11	154	62		shale
	2 834	2 837	DC	1.70	442	0.31	2.12	1.38	2.43	0.13	125	81		
	2 951	2 954	DC	1.06	425	0.17	0.39	1.47	0.56	0.30	37	139		
	2 972	2 975	DC	1.34	441	0.28	0.75	1.46	1.03	0.27	56	109		
	2 996	2 999	DC	1.09	433	0.34	0.67	1.82	1.01	0.34	61	167		
	3 050	3 053	DC	0.88	446	0.20	0.75	0.64	0.95	0.21	85	73		
	3 113	3 116	DC	1.45	449	0.35	0.73	1.06	1.08	0.32	50	73		
	3 137	3 140	DC	1.70	447	0.48	0.76	0.93	1.24	0.39	45	55		
	3 145	3 152	DC	1.27	443	0.30	0.60	0.87	0.90	0.33	47	69		
	3 170	3 173	DC	1.05	449	0.20	0.43	0.82	0.63	0.32	41	78	Irwin River Coal Measures	
	3 185	3 188	DC	3.88	455	0.54	2.00	0.79	2.54	0.21	52	20		
	3 188	3 191	DC	3.75	462	0.55	1.48	0.67	2.03	0.27	39	18		
	3 200	3 203	DC	4.02	459	0.53	2.15	0.75	2.68	0.20	53	19		
	3 209	3 212	DC	3.53	464	0.62	1.72	0.68	2.34	0.26	49	19		
	3 227	3 230	DC	2.39	458	0.41	0.99	0.75	1.40	0.29	41	31		
Livet 1	837	837	SWC	0.81	404	1.08	2.10	0.22	3.18	0.34	259	27	base Winning Group	
	848	–	SWC	1.73	420	0.74	3.19	0.50	3.93	0.19	184	29		
	1 176	–	SWC	1.64	425	0.20	2.78	9.16	2.98	0.07	170	559	Kockatea Shale	
	1 231	–	SWC	0.93	430	0.20	3.38	3.98	3.58	0.06	363	428		
	1 295	–	SWC	0.88	428	0.10	1.79	1.14	1.89	0.05	203	130		
	1 640	–	SWC	0.50	436	0.09	1.43	0.98	1.52	0.06	286	196		

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	T_{max} (°C)	S_1	S_2	S_3	$S_1 + S_2$	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
South Turtle Dove 1B	375	–		0.31	–	–	–	–	–	–	–	–	unnamed	
	870	–		0.64	–	–	–	–	–	–	–	–	Lesueur Sandstone	
	990	–		0.62	–	–	–	–	–	–	–	–	Kockatea Shale	
	1 010	–	DC	0.50	437	0.18	1.04	0.45	1.22	0.15	208	90		shale
	1 140	–	DC	0.56	440	0.09	0.56	0.65	0.65	0.14	100	116		shale
	1 160	–	DC	0.61	–	–	–	–	–	–	–	–		shale
	1 100	–		0.59	473	0.09	1.00	–	1.09	0.08	169	–		
	1 150	–		0.65	442	0.15	0.62	1.33	0.77	0.19	95	205		
	1 155	–		0.53	440	0.15	0.33	0.77	0.48	0.31	62	145		
	1 160	–		0.56	438	0.10	0.37	0.78	0.47	0.21	66	139		
	1 160	–	DC	0.61	436	0.12	0.56	0.56	0.68	0.18	92	92		
	1 165	–		0.63	440	0.10	0.43	0.77	0.53	0.19	68	122		
	1 170	–		0.61	439	0.15	0.49	0.90	0.64	0.23	80	148		
	1 170	–	DC	0.69	427	0.16	0.55	0.53	0.71	0.23	80	77		shale
	1 175	–	DC	0.83	428	0.14	0.71	0.96	0.85	0.16	86	116	Beekeeper Formation	shale
	1 175	–		0.64	435	0.18	0.63	0.79	0.81	0.22	98	123		
	1 180	–		0.69	435	0.14	0.46	0.91	0.60	0.23	67	132		
	1 185	–		1.89	433	0.23	0.47	1.00	0.70	0.33	25	53		
	1 185	–		1.90	–	0.26	0.60	–	0.86	0.30	32	–		
	1 190	–		2.24	462	0.20	0.40	0.94	0.60	0.33	18	42		
	1 195	–		2.46	448	0.26	0.69	1.24	0.95	0.27	28	50		
	1 200	–		2.59	440	0.30	0.71	1.45	1.01	0.30	27	56		
	1 205	–		3.46	434	0.39	0.89	1.49	1.28	0.30	26	43		
	1 210	–		2.90	471	0.24	0.65	1.33	0.89	0.27	22	46		
	1 215	–		2.77	473	0.31	0.75	1.75	1.06	0.29	27	63		
	1 220	–		3.43	492	0.32	0.74	1.62	1.06	0.30	22	47		
	1 225	–		3.30	510	0.20	0.57	1.75	0.77	0.26	17	53		
	1 235	–		2.77	428	0.40	2.70	–	3.10	0.13	97	–		
	1 325	–		3.52	–	0.27	0.60	–	0.87	0.31	17	–		
	1 445	–		3.19	–	0.24	0.40	–	0.64	0.38	13	–		
	1 540	–		2.96	–	0.19	0.30	–	0.49	0.39	10	–		
	1 635	–		2.83	–	0.16	0.20	–	0.36	0.44	7	–		
	1 850	–		3.37	–	0.17	0.30	–	0.47	0.36	9	–		
Wittecarra 1	921	923	DC	0.68	350	0.04	0.20	0.33	0.24	0.17	29	49	Lesueur Sandstone	
	1 365	1 389	DC	1.03	452	0.32	1.29	1.93	1.61	0.20	125	187		
	1 923	1 926	DC	1.86	427	0.08	2.94	0.25	3.02	0.03	158	13	Woodada Formation	
	1 932	1 926	DC	1.17	430	0.05	1.53	0.15	1.58	0.03	131	13		
	1 980	1 983	DC	1.05	430	0.07	1.71	0.18	1.78	0.04	163	17		
	1 980	1 983	DC	1.60	429	0.14	3.60	5.10	3.74	0.04	225	319		shale
	1 986	1 989	DC	2.03	428	0.17	3.90	5.46	4.07	0.04	192	269		shale

Appendix 4 (continued)

Well	*Depth from (m)*	*Depth to (m)*	*Sample type*	*TOC (%)*	*T_{max} (°C)*	*S_1*	*S_2*	*S_3*	*$S_1 + S_2$*	*PI*	*HI*	*OI*	*Formation*	*Lithology selected (if indicated)*
Wittecarra 1 (continued)	1 986	1 989	DC	1.38	432	0.11	2.03	0.22	2.14	0.05	147	16		
	2 076	2 079	DC	2.92	427	0.20	6.51	3.37	6.71	0.03	223	115		shale
	2 076	2 079	DC	1.15	432	0.16	1.74	0.21	1.90	0.08	151	18		
	2 088	2 091	DC	3.47	423	0.38	9.98	1.81	10.36	0.04	288	52		shale
	2 088	2 091	DC	2.80	425	0.33	5.91	0.31	6.24	0.05	211	11		
	2 106	2 109	DC	1.72	429	0.19	4.74	6.02	4.93	0.04	276	350		shale
	2 106	2 109	DC	1.21	431	0.15	2.29	0.18	2.44	0.06	189	15		
	2 121	2 124	DC	1.23	432	0.12	3.50	4.98	3.62	0.03	285	405		shale
	2 121	2 124	DC	0.98	432	0.16	1.88	0.14	2.04	0.08	192	14		
	2 133	2 135	DC	1.80	432	0.17	5.98	6.27	6.15	0.03	332	348		shale
	2 133	2 136	DC	1.29	432	0.21	3.23	0.22	3.44	0.06	250	17		
	2 163	2 175	DC	1.30	433	0.23	4.04	6.77	4.27	0.05	311	521		
	2 199	2 205	DC	0.84	432	0.14	2.60	5.50	2.74	0.05	310	655		
	2 205	2 211	DC	0.82	434	0.20	3.13	4.31	3.33	0.06	382	526		
	2 274	2 280	DC	1.14	432	0.31	3.77	2.17	4.08	0.08	331	190		
	2 301	2 304	DC	0.71	434	0.19	1.54	0.13	1.73	0.11	217	18		
	2 319	2 325	DC	1.08	432	0.28	3.66	1.88	3.94	0.07	339	174		
	2 325	2 331	DC	1.20	431	0.36	4.25	2.42	4.61	0.08	354	202		
	2 342	2 345	DC	0.80	433	0.46	1.40	0.19	1.86	0.25	175	24		
	2 349	2 397	DC	0.86	434	0.25	1.70	0.17	1.95	0.13	198	20		
	2 394	2 403	DC	1.12	435	0.32	3.65	2.88	3.97	0.08	326	257		
	2 400	2 403	DC	0.76	434	0.16	1.56	0.13	1.72	0.09	205	17		
	2 406	2 412	DC	1.06	434	0.41	4.73	3.15	5.14	0.08	446	297		
	2 442	2 445	DC	0.68	436	0.30	0.89	5.55	1.19	0.25	131	816		shale + siltstone
	2 448	2 451	DC	0.75	435	0.19	3.71	2.60	3.90	0.05	495	347		siltstone + shale
	2 451	2 454	DC	0.39	436	0.12	1.31	0.09	1.43	0.08	336	23		
	2 451	2 454	DC	0.70	436	0.25	4.50	1.94	4.75	0.05	643	277		siltstone + shale
	2 457	2 460	DC	0.71	435	0.21	4.57	2.02	4.78	0.04	644	285		siltstone
	2 460	2 463	DC	0.68	436	0.19	4.48	2.28	4.67	0.04	659	335		siltstone
	2 466	2 469	DC	0.64	437	0.18	4.24	1.38	4.42	0.04	663	216	Kockatea Shale	shale
	2 472	2 475	DC	0.61	439	0.14	3.35	1.07	3.49	0.04	549	175		shale
	2 624	–	SWC	0.41	442	0.05	0.72	0.14	0.77	0.06	176	34		
	2 747	–	SWC	0.50	447	0.09	0.35	0.15	0.44	0.20	70	30		
	2 812	–	SWC	0.49	447	0.06	0.08	0.19	0.14	0.43	16	39		
	2 838	–	SWC	1.14	383	0.14	0.28	0.24	0.42	0.33	25	21	Carynginia Formation	
	2 848	–	SWC	1.37	400	0.11	0.26	0.21	0.37	0.30	19	15		
	2 858	–	SWC	1.42	446	0.21	0.33	0.04	0.54	0.39	23	3		
	2 873	–	SWC	1.07	457	0.09	0.26	0.01	0.35	0.26	24	1		

NOTES:
HI: hydrogen index
OI: oxygen index
PI: production index
S_1: existing hydrocarbons (HC)
S_2: pyrolytic yield (HC)
S_3: organic carbon dioxide
$S_1 + S_2$: potential yield
T_{max}: temperature of maximum pyrolytic yield (S_2)
TOC: total organic carbon
DC: Ditch cutting
SWC: Sidewall core

Appendix 5

Vitrinite reflectance data from Abrolhos Sub-basin petroleum exploration wells

Formation	Depth (m)	Sample type	Mean Ro (%)
Batavia 1			
Yarragadee Formation	405	?cuttings	0.41
	415	?cuttings	0.42
Cattamarra Coal Measures	755	?cuttings	0.40
	770	?SWC	0.36
	930	?cuttings	0.21
	1 000	?cuttings	0.37
	1 050	?cuttings	0.20
Lesueur Sandstone	2 057.5	?SWC	0.46
	2 171	?SWC	0.52
	2 235 – 2 250	?cuttings	0.64
	2 250	?cuttings	0.63
	2 255	?cuttings	0.69
	2 275	?SWC	0.61
	2 305	?cuttings	0.58
	2 310	?cuttings	0.65
Kockatea Shale	2 325	?cuttings	0.62
	2 370	?cuttings	0.60
	2 395	?cuttings	0.68
	2 445 – 2 447	?cuttings	0.63
	2 554	?SWC	0.75
	2 580	?SWC	0.61
	2 610	?SWC	0.97
	2 623	?SWC	0.90
	2 635	?cuttings	1.12
	2 640	?cuttings	1.15
	2 650.6	?	1.10
	2 721	?SWC	1.10
Wittecarra Sandstone	2 766	?SWC	1.43
	2 775	?cuttings	1.70
	2 795.9	core 1	2.13
Carynginia Formation	2 822.8	?SWC	1.43
	2 829.5	?SWC	?1.4
	2 830.4	?	1.13
Irwin River Coal Measures	2 855.6	?	1.27
	2 865.7	?	1.10
	2 893.5	?SWC	1.28
	2 905 – 2 910	?cuttings	1.51
	2 912	?cuttings	1.62
Geelvink 1A			
Yarragadee Formation	490	cuttings	0.43
	500	cuttings	0.33
	600	cuttings	0.37
	685	cuttings	0.44
	700	cuttings	0.38
	795	cuttings	0.38
	800	cuttings	0.38
Cadda Formation	900	cuttings	0.38
	1 000	cuttings	0.45
	1 020	cuttings	0.48
Cattamarra Coal Measures	1 100	cuttings	0.45
	1 200	cuttings	0.49
	1 300	cuttings	0.45
	1 310	cuttings	0.47
	1 360	cuttings	0.52
	1 400	cuttings	0.50
Eneabba Formation	1 500	cuttings	0.47
	1 600	cuttings	0.50
	1 600	cuttings	0.58
	1 630	cuttings	0.53
Eneabba Formation (cont.)	1 700	cuttings	0.49
	1 900	cuttings	0.55
	2 000	cuttings	0.61
	2 100	cuttings	0.63
	2 165	cuttings	0.61
Lesueur Sandstone	2 200	cuttings	0.61
	2 300	cuttings	0.65
	2 305	cuttings	0.76
	2 400	cuttings	0.63
Kockatea Shale	2 700	cuttings	0.65
	2 720	cuttings	0.67
	2 800	cuttings	0.65
	2 800	cuttings	0.67
	2 900	cuttings	0.69
	2 940	cuttings	0.96
Carynginia Formation	3 000	cuttings	1.31
	3 005	cuttings	1.10
	3 022	cuttings	?1.02
	3 030	cuttings	1.10
	3 053	cuttings	1.42
Gun Island 1			
Winning Group	884–887	cuttings	0.32
Yarragadee Formation	911–914	cuttings	0.43
	954–957	cuttings	0.53
	975–978	cuttings	0.47
	1 018 – 1 021	cuttings	0.48
	1 173 – 1 177	cuttings	0.56
	1 240 – 1 244	cuttings	0.45
	1 265 – 1 268	cuttings	0.51
	1 314 – 1 317	cuttings	0.48
	1 369 – 1 372	cuttings	0.46
	1 375 – 1 378	cuttings	0.43
	1 466 – 1 469	cuttings	0.46
	1 521 – 1 524	cuttings	0.44
	1 792 – 1 795	cuttings	0.45
	1 838 – 1 841	cuttings	0.46
	1 893 – 1 896	cuttings	0.45
	2 044 – 2 045	cuttings	0.50
	2 097 – 2 100	cuttings	0.56
Cadda Formation	2 356.9	core 17	0.56
Cattanarra Coal Measures	2 648 – 2 652	cuttings	0.56
	2 662	core 19	0.57
	2 673 – 2 676	cuttings	0.58
	2 969 – 2 975	cuttings	0.56
	3 158 – 3 167	cuttings	0.61
Eneabba Formation	3 251	core 20	0.59
	3 371 – 3 380	cuttings	0.84
	3 392 – 3 395	cuttings	0.77
Houtman 1			
Yarragadee Formation	765–770	cuttings	0.41
	850–855	cut tings	0.23
	900–905	cuttings	0.40
	1 648	SWC	0.41
	1 800 – 1 805	cuttings	0.43
	1 810 – 1 820	cuttings	0.45
	2 395 – 2 400	cuttings	0.42
	2 531 – 2 536	cuttings	0.43
	2 535	SWC	0.46

Appendix 5 (continued)

Formation	*Depth (m)*	*Sample type*	*Mean Ro (%)*
Yarragadee Formation (cont.)	2 603	SWC	0.56
	2 620 – 2 630	cuttings	0.49
	2 630 – 2 635	cuttings	0.47
	2 650 – 2 665	cutti ngs	0.54
	2 690 – 2 700	cuttings	0.59
	2 855	cuttings	0.58
	2 870 – 2 875	cuttings	0.62
	2 915	cuttings	0.60
	2 920 – 2 935	cuttings	0.58
	2 930 – 2 935	cuttings	0.65
	2 940 – 2 945	cuttings	0.61
	2 940 – 2 950	cuttings	0.70
Cadda Formation	3 076.1	core 1	0.58
	3 084.4	cuttings	0.56
	3 159.4	cuttings	0.60
	3 166.1 – 3 166.4	core 2	0.58
	3 280 – 3 285	cuttings	0.61
Cattamarra Coal Measures	3 345 – 3 350	cuttings	0.73
	3 362.4	core	0.67
	3 389.2	core 4	0.60
	3 392.7	cuttings	0.70
	3 440.5	SWC	0.62
	3 445.5	SWC	0.66
	3 485A	cuttings	0.95
	3 485B–D	cuttings	0.73
	3 470	cuttings	0.73
	3 520	cuttings	0.69
	3 660 – 3 670	cuttings	0.82
	3 740 – 3 745	cuttings	0.95
	3 845	cuttings	1.06
	3 855 – 3 860	cuttings	1.03

Formation	*Depth (m)*	*Sample type*	*Mean Ro (%)*
Wittecarra 1			
Lesueur Sandstone	907.7	?SWC	0.35
	921	?cuttings	0.31
	1 023	?cuttings	0.4
	1 230	?cuttings	0.31
	1 287	?cuttings	0.35
	1 350.5	?SWC	0.48
	1 416	?cuttings	0.44
	1 611.4	?SWC	0.44
	1 698	?SWC	0.48
Woodada Formation	1 852	?SWC	0.66
	1 976	?SWC	0.62
	2 108	?SWC	0.63
	2 133	?cuttings	0.49
	2 172	?cuttings	0.52
	2 199	?cuttings	0.56
	2 250	?cuttings	0.57
	2 331	?cuttings	0.69
	2 331(A)	?cuttings	0.56
	2 400	?cuttings	0.76
Kockatea Shale	2 475	?cuttings	0.59
	2 497.5	?SWC	0.7
	2 500	?SWC	0.66
	2 598	?cuttings	0.87
	2 649	?cuttings	0.75
	2 709	?cuttings	0.82
	2 748	?cuttings	0.85
	2 799	?cuttings	0.9
Carynginia Formation	2 883	?cuttings	0.79

NOTE: SWC: sidewall core

Appendix 6

Palynology of an Upper Permian interval in South Turtle Dove 1B

by

J. Backhouse*

Introduction

Slides were examined from 18 sidewall core samples and 18 cuttings samples prepared by West Australian Petroleum Pty Ltd (WAPET) from the interval 1164.5 to 1785–1800 m. Sidewall core (SWC) slides were examined over the interval 1164.5 to 1320 m to determine the age of the highest Permian strata and the nature of the Permian–Triassic boundary. Below 1320 m, only slides from cuttings samples are available down to 1785–1800 m, and presumably much of the palynomorph content of these slides is the result of downhole caving. One slide from each of these cuttings samples was examined for this report.

A range chart of identifiable palynomorphs set against depth is presented in Table 6.1.

Palynostratigraphy

The suggestions on stratigraphic units (formations) are made in the context of the northern Perth Basin. Because formations are essentially lithostratigraphic units, these comments are not considered to be definitive. Zonal schemes referred to are published in Helby et al. (1987), Foster (1982) and Backhouse (1991, 1993).

Protohaploxypinus samoilovichii / *Lunatisporites pellucides* Zone (1 SWC: 1164.5 m)

Yield: Low.

Preservation: Poor.

Assemblage: A number of spinose acritarchs and rare spores were located on this slide. The infrequent spores and the nature of the spinose acritarchs suggest that this sample is from the lowest unequivocal Triassic zones.

Environment: The abundance of spinose acritarchs indicates a marine environment of deposition.

Age: Early Scythian (Early Triassic).

Formation: Kockatea Shale, and judging from the acritarch assemblage, it is in the lowest interval of the Kockatea Shale.

Protohaploxypinus microcorpus Zone? (1 SWC: 1164.5 m)

Yield: Low.

Preservation: Poor.

Assemblage: There is probably some contamination in the slides from this sample. Certainly there are Permian spores present (possibly reworked), and some acritarchs may be caved from the overlying units. The assemblage also contains elements of the *P. microcorpus* Zone, of basal Triassic or uppermost Permian age (described by Foster, 1982). The present material is not good enough (it is both sparse and quite thermally mature) to determine conclusively whether this zone is present.

Environment: Probably marine.

Age: Early Scythian (Early Triassic), or latest Permian.

Formation: Indeterminate.

Latest Permian? (1 SWC: 1175 m)

Yield: Very low.

Preservation: Extremely poor.

Assemblage: The only pollen grains present are *Weylandites lucifer* and *Vitreisporites signatus.* Some of the acritarchs look rather like Triassic forms and are assumed to be contamination. An assemblage with common *Weylandites* is at the top of the Permian interval in Sue 1 in the southern Perth Basin. The present assemblage is much less well preserved, and there is no certainty that it correlates with the one in Sue 1.

Environment: ?Marine

Age: ?Latest Permian

Formation: Indeterminate.

Didecitriletes ericianus Zone or higher (15 SWCs: 1187 to 1320 m)

Yield: Very low.

Preservation: Extremely poor.

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* Backhouse Biostrat Pty Ltd

Assemblage: Because of the high thermal maturity through this interval, most spores and pollen are impossible to identify to species level, and they are also extremely few in number. *D. ericianus* is present in nearly every sample and is readily distinguished even at these high maturity levels by the characteristically spinose outline. Several specimens can be seen in some samples. The few other forms that are tentatively identified to species level are consistent with a position in the *D. ericianus* Zone or higher. It is possible that some or all of this interval is within the *Dulhuntyispora parvithola* Zone, as this species is not particularly common within its nominate zone in the Perth Basin. However, there is no direct evidence for the *D. parvithola* Zone. The frequency of *D. ericianus* suggests that this interval is some way above the base of the *D. ericianus* Zone.

Environment: Spinose acritarchs, indicating marine deposition, are present in most samples and show that this is a largely marine sequence. These acritarchs display a level of thermal maturity commensurate with this level in the well, and are not considered to be contaminants from the overlying Triassic strata.

Age: Late Permian.

Formation: There is a possibility that this interval correlates with the Wagina Sandstone (*D. parvithola* Zone) (see comments above), but it is probably safer to assume that it correlates with some unit below the Wagina Sandstone, possibly the Beekeeper Formation or an equivalent unit.

Indeterminate, but probably *Didecitriletes ericianus* Zone or higher (17 ditch cuttings, DCs: 1395–1410 m to 1725–1740 m)

The cuttings samples through this interval contain similar assemblages to the ones in the overlying Permian interval. *D. ericianus* is present in several samples and *Dulhuntyispora* (probably *D. dulhuntyi*) is also recorded. If these sparse assemblages are approximately in situ then the Permian interval must extend down to at least 1695–1710 m, and probably down to 1725–1740 m. Spinose acritarchs and Triassic spores and pollen are present through this interval, but they show low maturity and are assumed to be caved from the Triassic section. It is possible that a few mature *Micrhystridium* spp. are present, and the whole interval may be marine or non-marine.

Indeterminate (1 DC: 1785–1800 m)

The one small slide available from this depth contains opaque rounded grains and finely disseminated material. It is devoid of any trace of spore, pollen or acritarch, and lacks the structured inertinite that is a feature of the overlying cuttings samples. It may represent a unit different from those represented by the samples above.

Maturation

All samples examined are thermally mature or overmature for hydrocarbon generation. Estimated thermal alteration index (TAI) values are:

1164.5 – 1175 m: TAI 3+ (c. Ro 1.3%)
1187 – 1725–1740 m: TAI 4- to 4 (c. Ro 1.5 to 2.5%)

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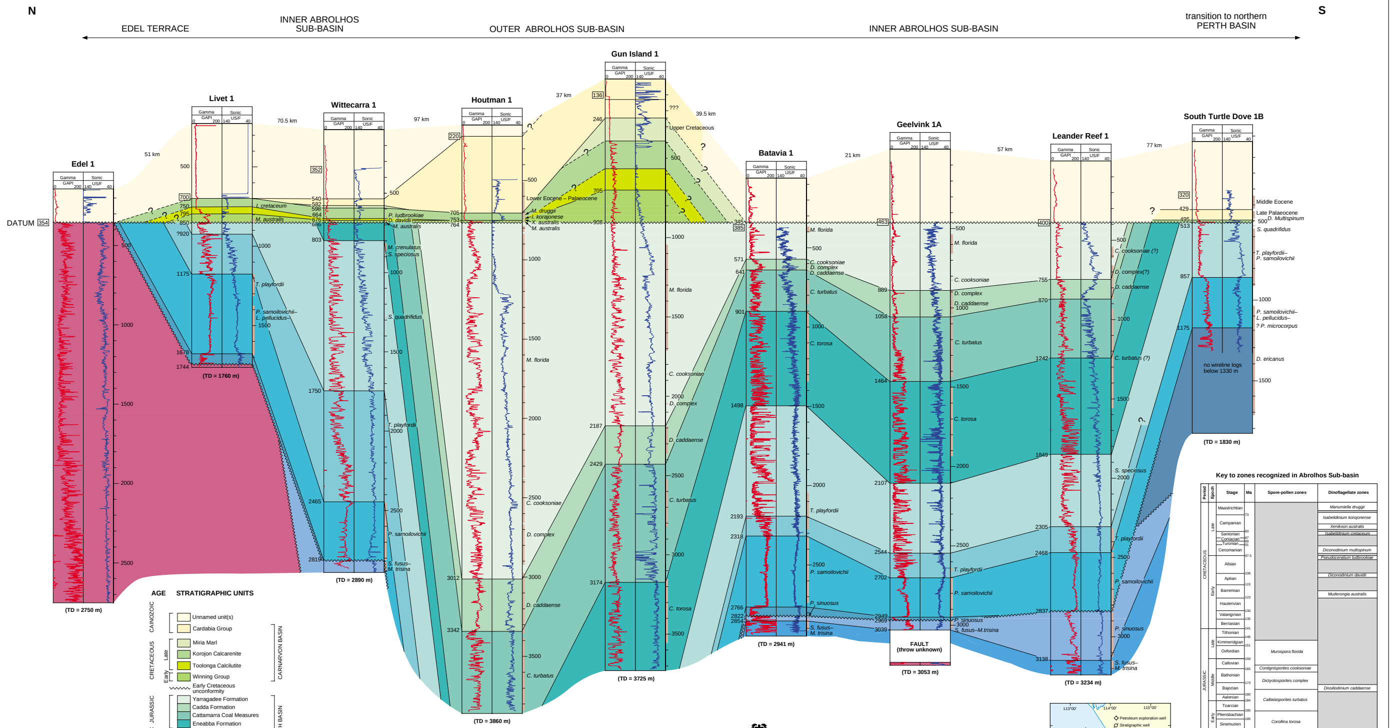
Table 6.1. Distribution of selected palynomorphs from South Turtle Dove 1B

Selected species	*Depth in metres*																	
	1 164.5	*1 170*	*1 175*	*1 187*	*1 192*	*1 204*	*1 210*	*1 217*	*1 227*	*1 244*	*1 256*	*1 268*	*1 274*	*1 281*	*1 297*	*1 305*	*1 312*	*1 320*
Spore pollen																		
Densoisporites playfordii	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Indotriradites splendens/niger	–	P	–	–	P	–	P	–	–	–	P	–	–	–	–	–	–	P
Kraeuselisporites sp.	–	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Limatulasporites limatulus	–	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Marsupipollenites striatus	–	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Microbaculispora trisina	–	P	–	–	–	–	–	–	–	–	–	–	P	–	–	–	–	P
Phidaesporites fosteri	–	?P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Playfordiaspora velata	–	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Protohalploxypinus amplus	–	P	–	–	–	–	–	–	P	–	–	–	P	–	–	–	–	–
Weylandites lucifer	–	P	C	–	–	P	–	–	–	–	–	–	–	–	–	–	–	–
Vitreisporites signatus	–	–	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Horriditriletes spp.	–	–	–	P	P	–	–	P	–	–	–	P	–	–	–	P	–	–
Bisaccate pollen indet.	–	–	–	–	P	–	P	–	–	–	–	–	–	–	–	–	–	–
Didecitriletes ericianus	–	–	–	–	P	C	C	P	P	P	P	P	P	–	P	–	P	P
Microbaculispora micronodosa	–	–	–	–	P	–	P	–	P	–	–	–	–	–	–	–	P	–
Microbaculispora villosa	–	–	–	–	P	–	–	–	P	–	–	–	–	–	P	–	–	–
Praecolpatites sinuosus	–	–	–	–	?P	–	–	–	–	–	–	–	?P	–	–	–	–	–
Dictyotriletes aules	–	–	–	–	–	–	–	–	P	–	–	–	–	–	–	–	–	–
Dulhuntyispora sp.	–	–	–	–	–	–	–	–	–	–	–	?P	–	–	–	–	–	–
Microbaculispora tentula	–	–	–	–	–	–	–	–	–	–	–	P	–	–	–	–	–	–
Vittatina sp.	–	–	–	–	–	–	–	–	–	–	–	–	P	–	–	–	–	–
Protohaploxypinus limpidus	–	–	–	–	–	–	–	–	–	–	–	–	–	P	–	–	–	–
Striatopodocarpites fusus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Microplankton																		
Veryhachium cf. *triqueter*	–	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Micrhystridium 'Reticulate' type	P	?P	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Micrhystridium spp.	–	P	P	P	P	–	–	P	P	C	–	C	P	P	–	–	C	P
Micrhystridium	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Veryhachium spp.	–	P	P	–	–	P	–	–	–	–	–	–	–	–	–	–	–	–
Other																		
Chordecysta chalasta	–	P	?P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 6.1. (continued)

Selected species	*Depth in metres* 1 395 – 1 410	1 410 – 1 425	1 440 – 1 455	1 455 – 1 470	1 470 – 1 485	1 485 – 1 500	1 575 – 1 590	1 590 – 1 605	1 605 – 1 620	1 620 – 1 635	1635 – 1 650	1 650 – 1 665	1 665 – 1 680	1 680 – 1 695	1 695 – 1 710	1 710 – 1 725	1 725 – 1 740	1 785 – 1 800
Spore pollen																		
Densoisporites playfordii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Indotriradites splendens/niger	–	–	–	–	–	–	–	–	–	–	–	P	–	P	–	–	–	–
Kraeuselisporites sp.	–	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Limatulasporites limatulus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Marsupipollenites striatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Microbaculispora trisina	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Phidaesporites fosteri	–	–	–	–	P	–	–	–	–	–	–	–	–	–	–	–	–	–
Playfordiaspora velata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Protohalploxypinus amplus	–	–	–	–	–	–	–	–	–	–	–	–	–	P	–	–	–	–
Weylandites lucifer	–	–	–	–	–	–	–	–	–	–	–	–	–	–	P	?P	–	–
Vitreisporites signatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Horriditriletes spp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	P	–	–
Bisaccate pollen indet.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Didecitriletes ericianus	–	P	–	–	–	–	–	–	–	P	–	–	P	–	P	?P	?P	?P
Microbaculispora micronodosa	–	P	?P	P	–	P	P	–	–	–	–	–	–	–	–	–	–	–
Microbaculispora villosa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Praecolpatites sinuosus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dictyotriletes aules	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dulhuntyispora sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Microbaculispora tentula	–	–	–	–	–	P	–	–	–	–	–	–	–	–	P	–	–	–
Vittatina sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Protohaploxypinus limpidus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Striatopodocarpites fusus	–	–	P	–	–	–	–	P	–	–	–	–	–	P	–	–	P	P
Microplankton																		
Veryhachium cf. *triqueter*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Micrhystridium 'Reticulate' type	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Micrhystridium spp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Micrhystridium	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Veryhachium spp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Other																		
Chordecysta chalasta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

NOTES: P: present
C: more common than in other samples



AGE STRATIGRAPHIC UNITS

- CAINOZOIC: Unnamed unit(s); Cardabia Group
- CRETACEOUS Late: Miria Marl; Korojon Calcarenite; Toolonga Calcilutite
- CRETACEOUS Early: Winning Group — CARNARVON BASIN
- Early Cretaceous unconformity
- JURASSIC / TRIASSIC: Yarragadee Formation; Cadda Formation; Cattamarra Coal Measures; Eneabba Formation; Lesueur Sandstone; Woodada Formation; Kockatea Shale — PERTH BASIN

MAIN ABROLHOS SUB-BASIN

- TRIASSIC Early: Wittecarra Sandstone — PERTH BASIN
- Basal Triassic unconformity
- PERMIAN Early: Carynginia Formation; Irwin River Coal Measures
- Early Permian unconformity
- ORDOVICIAN: Tumblagooda Sandstone — CARNARVON BASIN

SOUTH TURTLE DOVE AREA

- PERMIAN Late: Beekeeper Formation — PERTH BASIN

354 Depth of highest sample collected

GOVERNMENT OF WESTERN AUSTRALIA
HON. NORMAN MOORE, M.L.C.
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DEPARTMENT OF MINERALS AND ENERGY
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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
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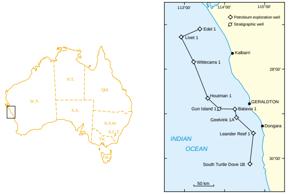

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 75 PLATE 1

NORTH–SOUTH WELL LOG CORRELATION EDEL 1 – SOUTH TURTLE DOVE 1B

Key to zones recognized in Abrolhos Sub-basin

Period	Epoch	Stage	Ma	Spore-pollen zones	Dinoflagellate zones
CRETACEOUS	Late	Maastrichtian			*Manumiella druggii*
		Campanian	73		*Isabelidinium korojonense*
					Xenikoon australis
		Santonian	83		*Isabelidinium cretaceum*
		Coniacian	87		
		Turonian	89		
		Cenomanian	91		*Diconodinium multispinum*
	Early	Albian	97.5		*Pseudoceratium ludbrookiae*
		Aptian	108		*Diconodinium davidii*
		Barremian	115		*Muderongia australis*
		Hauterivian	123		
		Valanginian	130		
		Berriasian	135		
JURASSIC	Late	Tithonian	141		
		Kimmeridgian	146		
		Oxfordian	151	*Murospora florida*	
	Middle	Callovian	159		
		Bathonian	165	*Contignisporites cooksoniae*	
				Dictyotosporites complex	
		Bajocian	173		*Dissiliodinium caddaense*
		Aalenian	180	*Callialasporites turbatus*	
	Early	Toarcian	184		
		Pliensbachian	190	*Corollina torosa*	
		Sinemurien	195		
		Hettangian	202		
TRIASSIC	Late	Rhaetian	205		
		Norian	207	*Minutosaccus crenulatus*	no zones erected
		Carnian	220	*Samaropollenites speciosus*	
	Middle	Ladinian	230	*Staurosaccites quadrifidus*	
		Anisian	235	*Triplexisporites playfordii*	
	Early	Spathian	241		
		Nammalian	244	*Protohaploxypinus samoilovichii*	
		Griesbachian	247	*Lunatisporites pellucidus* / *Protohaploxypinus microcorpus*	
PERMIAN	Late	Tatarian: Dorashamian	251	*zones undifferentiated*	
		Tatarian: Dzhulfian	255		
		Tatarian: Midian	259		
		Kazanian	263	*Didecitriletes ericianus*	
		Ufimian	267		
	Early	Kungurian	270	*Praecolpatites sinuosus*	
		Artinskian	274	*Microbaculisporites trisina*	
			285	*Striatopodocarpites fusus*	
		Sakmarian			
		Asselian	293		
			298		