Government of Western Australia

Department of **Mines, Industry Regulation and Safety**

REPORT 174

A REVIEW OF PALYNOLOGY FROM THE HARVEY REGION, SOUTHERN PERTH BASIN, WESTERN AUSTRALIA

by SK Martin

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Perth 2018

Geological Survey of Western Australia

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Cover photograph: Drill rods used for core recovery, DMP Harvey 3, southern Perth Basin. DMP Harvey 3, drilled to investigate potential carbon-dioxide sequestration in the area, was later sampled for palynological studies

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A review of palynology from the Harvey region, southern Perth Basin, Western Australia

by

SK Martin

Abstract

This Report modernizes and collates all of the legacy biostratigraphic information for a portion of the southern Perth Basin, Western Australia, from Mandurah in the north to Bunbury in the south, including the southern part of the Mandurah Terrace and a small part of the northern Bunbury Trough. The dataset consists of six wells, one geothermal borehole, 195 water bores, and 10 miscellaneous sites (mineral bores and surface samples), with much of the biostratigraphic information obtained from Geological Survey of Western Australia (GSWA) Paleontology Reports, well completion reports, and consultant reports. The palynological dataset covers the Early Triassic through to Holocene, with no Permian biostratigraphic assemblages identified with certainty. Spores and pollen are the dominant palynomorphs recovered due to the terrestrial nature of the sedimentary sequences within the southern Perth Basin, particularly during the early Mesozoic. Spore-pollen assemblages covering the Lower Triassic *Kraeuslisporites saeptatus* (= *Lunatisporites pellucidus*) Zone through to the Lower Cretaceous *Balmeiopsis limbata* (= *Ruffordiaspora australiensis*) Zone are recorded in this part of the basin; Cenozoic spore-pollen assemblages are also noted, although these are difficult to place within zones due to poor knowledge of these assemblages within Western Australia. Of these zones, the Lower Cretaceous (*B. limbata*) and Lower Jurassic (*Corollina torosa* and *Callialasporites turbatus*) zones are the most commonly recorded, with Triassic zones observed only in the deeper petroleum wells, and Upper Jurassic and Upper Cretaceous zones being rare to absent. Marine microplankton-bearing assemblages are restricted to post-breakup (post-Valanginian) Cretaceous and Cenozoic units, and include examples of the *Kaiwaradinium scrutillinum* (= *Senoniasphaera tabulata*) through to the *Xenascus asperatus* Zones. This summary highlights a number of features previously noted in the assemblages of the southern Perth Basin, including: the presence of Aptian–Albian assemblages; the identification of a possible 'transitional *Biretisporites eneabbaensis* – *B. limbata* Zone' biounit in the Early Cretaceous; the distinctive nature of Early Triassic assemblages; and the difficulties in separating the low-diversity, poor-yielding *C. torosa* and *C. turbatus* Zones. These features are not documented in the northern Perth Basin, and constitute key differences between the two parts of the basin. Although stratigraphy is not the focus of this Report, the biostratigraphic data have highlighted issues with the stratigraphic units used in the southern Perth Basin, likely due to past authors' focus on lithostratigraphy — that focus has created confusion about the ages of certain units and how these units correlate to one another. Therefore, the stratigraphy in this part of the basin should be re-examined independently of the better-known northern Perth Basin successions, taking into account the critical age data provided by palynology. This stratigraphic revision would also be aided by additional palynological studies, including reassessment of existing slides or preparation of new samples, from a number of key boreholes.

KEYWORDS: biostratigraphic zone, biostratigraphy, Cenozoic, lithologic correlation, Mesozoic, palynology, Permian, reviews

Introduction

Recent research into the carbon dioxide geosequestration potential of the Harvey area by the then Department of Mines and Petroleum (DMP; now Department of Mines, Industry Regulation and Safety [DMIRS]) has generated new datasets, including new boreholes (GSWA Harvey 1, DMP Harvey 2–4) and associated seismic studies. However, that project also highlighted a number of issues with the currently published stratigraphy of the southern Perth Basin (Fig. 1), particularly the definition, differentiation, and ages of Mesozoic units in the Harvey Ridge area (Millar and Reeve, 2014; Zhan, 2014). Although some of these uncertainties may be a reflection of basin geology, attempts to understand the sedimentary succession of the southern Perth Basin have also been hampered by the paucity of recent research and mapping in the area. This is mainly due to conflicting land use issues and a perceived lack of petroleum prospectivity.

Much of the confusion that surrounds the southern Perth Basin's Mesozoic units relates to the timing of depositional cycles, and therefore the correlation of geological units between the poorly understood southern portion of the basin and better-known northern successions. Past correlative work has relied almost entirely on lithological comparisons, without much reference to biostratigraphic information (e.g. Crostella and Backhouse, 2000). Therefore, a better understanding of the biostratigraphy of the southern Perth Basin is required before the stratigraphy of this region can be adequately reassessed.

This Report collates, reviews and re-evaluates all historic biostratigraphic information within the southern Perth Basin, as an important first step to reassessing stratigraphy. As this region is geographically extensive, the decision was made to focus the initial work on the Harvey Ridge area, with the intent of expanding this assessment farther

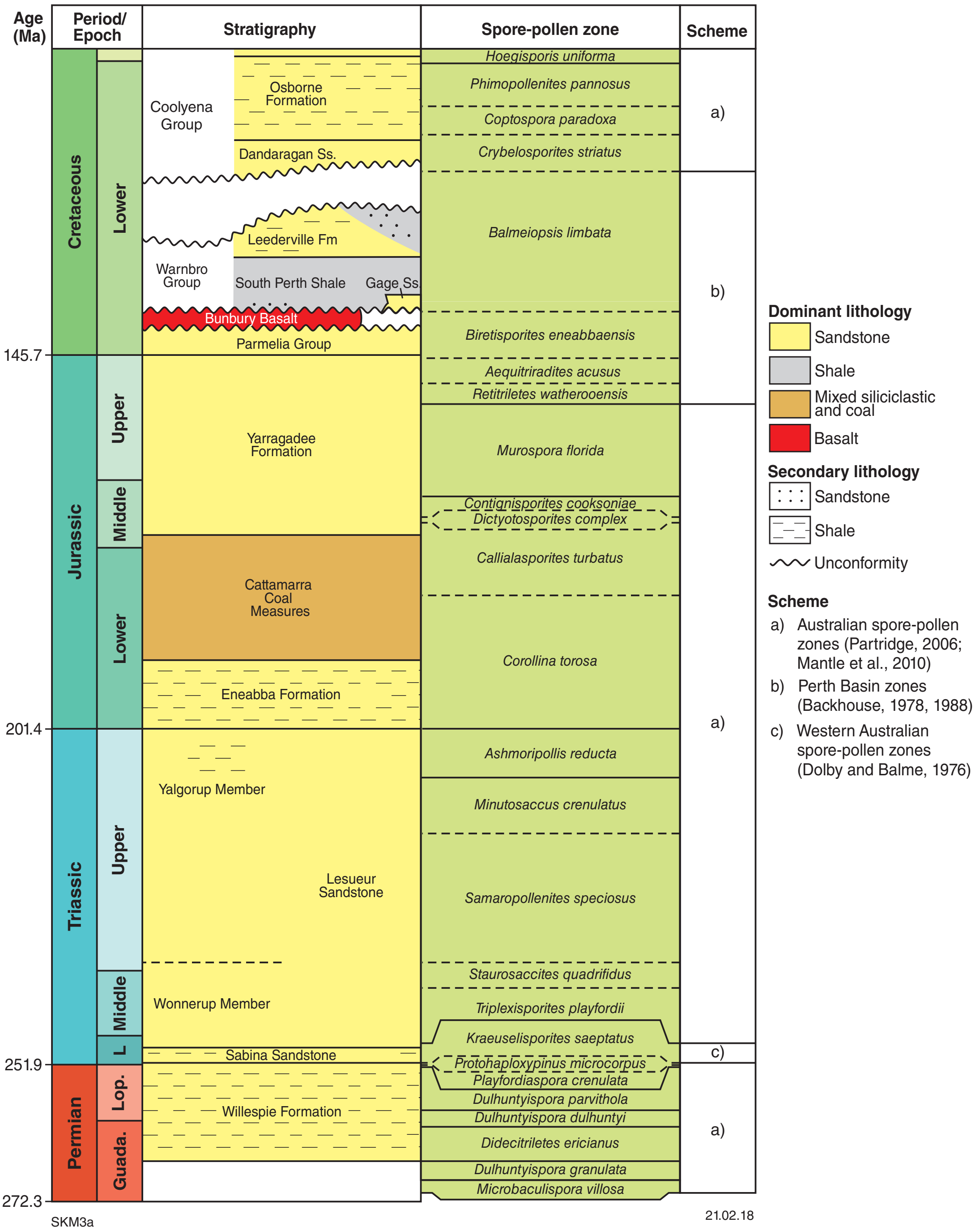


Figure 1. Current stratigraphy of the southern Perth Basin compared to the spore-pollen zones used in this Report; biostratigraphic data modified from Geoscience Australia's Australian biozonation schemes and basin lithostratigraphy datapack for TimeScale Creator (Geoscience Australia, 2016)

south in the near future. This area was selected due to the new biostratigraphic information obtained from the recent drilling of GSWA Harvey 1 and DMP Harvey 2–4, and related interest in the area as a possible carbon dioxide sequestration hub.

Data from this review will be incorporated into a future re-evaluation of the stratigraphy of the southern Perth Basin. Previous Geological Survey of Western Australia (GSWA) Records related to this project have included a reassessment of seismic data in the Harvey area (Zhan, 2014), and a review of the structural architecture of the entire Perth Basin, focused particularly on sub-basin boundaries and definitions (Thomas, 2014).

Previous work

The Perth Basin is a Phanerozoic, polycyclic, intracontinental to rift basin, extending roughly 900 km along the Western Australian coast in a near north–south orientation. Despite its extensive latitudinal range, the basin is relatively narrow in an east–west direction, being about 90 km wide at its broadest point onshore. The eastern margin of the basin is delineated by the Darling Fault. Offshore, the basin extends offshore west to the edge of the continental shelf. The onshore southern Perth Basin is classically divided into four onshore sub-basins — from north to south these are the Mandurah Terrace, the Bunbury Trough, the Treeton Terrace, and the Vasse Shelf (Fig. 2a). All except the Treeton Terrace extend offshore; a fifth sub-basin of the southern Perth Basin, the Vlaming Sub-basin, is entirely offshore. The regional geology of this basin and its structural subdivisions are well known, and have been summarized in numerous GSWA publications (Playford et al., 1976; Cockbain, 1990; Mory and Iasky, 1996; Crostella and Backhouse, 2000; Thomas, 2014).

The most recent in-depth assessment of the geology and petroleum prospectivity of the southern and central Perth Basin was published by Crostella and Backhouse (2000). That review summarized the basin structure and stratigraphy, and discussed the drilling results for each of the petroleum wells in the region. Their report also presented an in-depth history of geological investigations into the southern Perth Basin up to the year 2000.

Although Crostella and Backhouse's (2000) work remains the best introduction to the regional structure and history of the southern Perth Basin, the lithostratigraphic approach to the stratigraphy is problematic, particularly for the Mesozoic units (see Zhan [2014] for a comprehensive list of issues). Of particular concern is the extrapolation of the Mesozoic units and concepts from the northern Perth Basin into the central and southern parts of the basin, despite the large geographic separation, and evidence for different lithologies and depositional environments. Over such large geographic distances, purely lithostratigraphic units tend to become time transgressive, making it difficult to reconcile units with seismic data. In Crostella and Backhouse (2000), this approach resulted in Upper Triassic to Upper Jurassic successions of the southern Perth Basin assigned to lithologically similar, pre-existing northern Perth Basin units without considering age information, leading to later basinwide inconsistencies in stratigraphic usage. An example is the use of Eneabba Formation and Cattamarra Coal Measures, which appear to be of doubtful applicability within the southern part of the basin; Crostella and Backhouse (2000) applied these unit names somewhat inconsistently when compared to biostratigraphic information. Similarly, Crostella and Backhouse (2000) regarded their Myalup Member (later renamed the Yalgorup Member; Millar and Reeve, 2014) and Wonnerup Member to be parts of the Lesueur Sandstone, although this is uncertain without firm biostratigraphic data from these members. However, this treatment was not attempted for the Permian, Lower Triassic, or parts of the Cretaceous successions, in which separate time-equivalent units were used for the northern and southern basin areas.

This approach of assigning southern basin successions to northern Perth Basin nomenclature based on lithology pre-dates Crostella and Backhouse's (2000) review, and reflects the long history of research within the basin (see McWhae et al., 1956; Playford et al., 1976). However, this purely lithostratigraphic approach should be avoided wherever possible as it continues to cause issues with the identification, correlation, and interpretation of these units.

Materials and methods

Methods and scope

The current review reassesses and collates all biostratigraphic studies previously conducted within an area extending between the latitudes of 32°29'30"S and 33°22'30"S (Fig. 2). Only the onshore portions of the central and southern Perth Basin are included in this assessment, specifically the Mandurah Terrace and Bunbury Trough subdivisions.

The study area was chosen to extend between the cities of Mandurah and Bunbury, to take advantage of recent drilling in the area and to break the southern Perth Basin reassessment into more manageable portions; also included in this region are the major towns of Pinjarra, Harvey, Brunswick Junction, and Waroona. The southern boundary was extended slightly south of Bunbury to include the deeper Picton Line of water bores, although the numerous Bunbury Shallow water bores are still excluded. To the north, the boundary was set slightly north of Mandurah to include recent water bores drilled by the then Western Australian Department of Water (DoW; now Department of Water and Environmental Regulation [DWER]) and a few key Artesian Monitoring water bores.

There are no major pre-Quaternary macrofauna or macroflora localities recorded within the region, and only rare records of Cretaceous and older microfossils and macroinvertebrates have been noted in boreholes (e.g. Grey and Cockbain, 1975). Quaternary coastal limestone and cave deposits, and Holocene lake and beach deposits, are excluded from this study as they provide no relevant biostratigraphic information. A lack of pre-

Valanginian (Fig. 1) open-marine units in the southern Perth Basin means there has been little paleontological research in the area besides palynology; as a result, southern Perth Basin biostratigraphy relies exclusively on palynological studies of subsurface well and bore samples.

For this Report, all known palynological studies were collated, overall patterns were determined, and gaps in knowledge regarding the biostratigraphy of the region identified. Wells and water bores drilled prior to 1987 required standardization against the current Australia-wide palynological scheme (see 'Biostratigraphic data' section below for details) to make them comparable to other results; for key sections, GSWA commissioned reviews to facilitate this standardization, with the unpublished reports added to various GSWA's online databases for future reference. With the exception of Lake Preston 1, Pinjarra 1 and DMP Harvey 2, the present work was based entirely on unpublished palynological reports without reference to the original samples or slides, and the new interpretations assume that the assemblage was completely described and constituent species correctly identified in the original report. Any discrepancies identified in this review are noted for future investigation.

As the emphasis of this review is on biostratigraphic data, this Report does not provide a strict review or reassessment of the area's stratigraphy. However, some discussion on the implications of palynology on interpretation of the area's stratigraphy is provided for context. Greatest attention was paid to assemblages from the problematic Middle Triassic to Upper Jurassic portion of the succession; less attention was given to the Cretaceous interval, which is widely distributed at shallow depths throughout the Perth Basin, and the biostratigraphy of which has been extensively studied (Backhouse, 1978, 1984, 1988a).

Well and bore data

The dataset used here (Table 1; Appendix 1, 2) consists of six petroleum wells, 194 water bores comprising 27 lines (some private water bores are treated together, rather than being assigned to separate lines), one geothermal bore, and 10 miscellaneous samples (including mineral bores, outcrop samples, and boreholes of unknown purpose). Well and bore summaries were written for boreholes with evidence for pre-Cretaceous palynomorphs as an aid for discussion. These summaries are given in Appendix 2, and cover the history of study, palynological results, and interpretations of data robustness for each borehole.

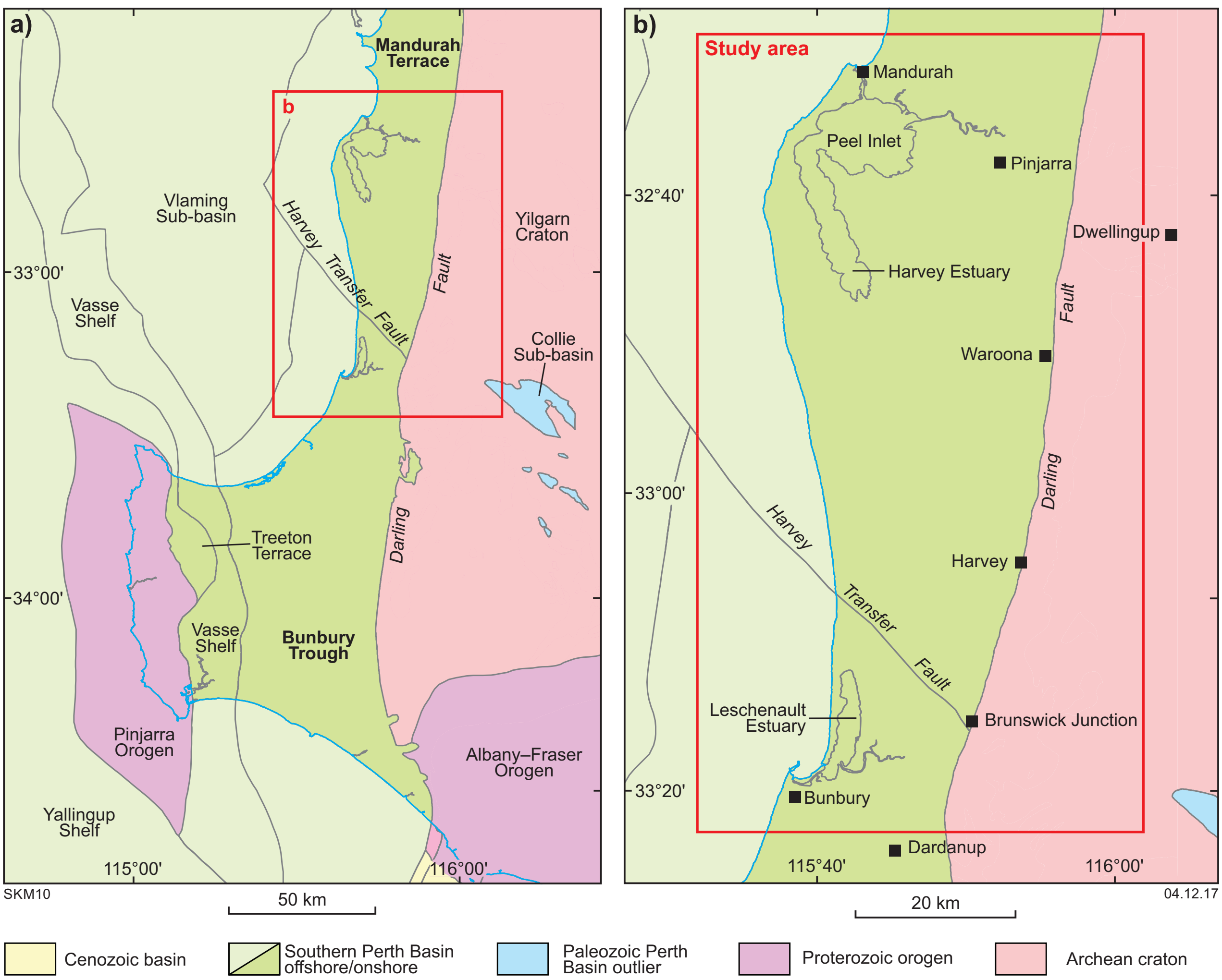


Figure 2. **Southwestern Australia showing features mentioned in this Report: a) tectonic subdivisions of the southern Perth Basin; and b) study area extent and geographic features**

Table 1. List of petroleum wells, boreholes, and miscellaneous samples used in this study. Site identifier refers to Figure 3 and Appendix 1; lettered sites are petroleum wells. Site abbreviations are also used in well sheets and well sheet figures in Appendix 2

Site identifier	*Site name*	*Site abbreviation*	*Site identifier*	*Site name*	*Site abbreviation*
A	Pinjarra 1	PJ1	42	Harvey Irrigation A	HIA
B	Lake Preston 1	LK1	43	Harvey Irrigation B	HIB
C	Preston 1	PR1	44	Harvey Irrigation C	HIC
D	GSWA Harvey 1	HV1	45	Harvey Irrigation D	HID
E	DMP Harvey 2	HV2	46	Harvey Irrigation F	HIF
F	DMP Harvey 3/A	HV3	47	Harvey Irrigation G	HIG
			48	Harvey Irrigation H	HIH
1	Alcoa Pinjarra E1	AE1	49	Harvey Shallow 1A	HS1A
2	Alcoa Pinjarra E2	AE2	50	Harvey Shallow 2A	HS2A
3	Alcoa Pinjarra E3	AE3	51	Harvey Shallow 3A	HS3A
4	Alcoa Pinjarra E4	AE4	52	Harvey Shallow 4A	HS4A
5	Alcoa Pinjarra E5	AE5	53	Harvey Shallow 5A	HS5A
6	Alcoa Pinjarra E6	AE6	54	Harvey Shallow 6A	HS6A
7	Alcoa Pinjarra E7	AE7	55	Harvey Shallow 7A	HS7A
8	Alcoa Pinjarra E8	AE8	56	Harvey Shallow 8A	HS8A
9	Alcoa Pinjarra O1	AO1	57	Harvey Shallow 9A	HS9A
10	Alcoa Pinjarra O2	AO2	58	Harvey Shallow 10A	HS10A
11	Alcoa Pinjarra O3	AO3	59	Harvey Shallow 11A	HS11A
12	Alcoa Pinjarra O8	AO8	60	Harvey Shallow 12A	HS12A
13	Alcoa Pinjarra O9	AO9	61	Harvey Shallow 13A	HS13A
14	Alcoa Pinjarra O10	AO10	62	Harvey Shallow 14A	HS14A
15	Alcoa Pinjarra O11	AO11	63	Harvey Shallow 15A	HS15A
16	Alcoa Pinjarra O12	AO12	64	Harvey Shallow 16A	HS16A
17	Artesian Monitoring 65	AM65	65	Harvey Shallow 17A	HS17A
18	Artesian Monitoring 66	AM66	66	Harvey Shallow 18A	HS18A
19	Artesian Monitoring 67	AM67	67	Harvey Shallow 19A	HS19A
20	Artesian Monitoring 68	AM68	68	Harvey Shallow 20A	HS20A
21	Binningup Line 1A	BPL1A	69	Harvey Shallow 21A	HS21A
22	Binningup Line 2A	BPL2A	70	Harvey Shallow 22A	HS22A
23	Binningup Line 3A	BPL3A	71	Harvey Shallow 23A	HS23A
24	Binningup Line 4A	BPL4A	72	Harvey Shallow 24A	HS24A
25	Binningup Estate 2	BPE2	73	Harvey Shallow 25A	HS25A
26	Carey Park Primary 1	CPPS1	74	Harvey Shallow 26A	HS26A
27	South Bunbury Primary 1	SBPS1	75	Harvey Shallow 27A	HS27A
28	Bunbury (Laporte) Inlet 1	BI1	76	Harvey Shallow 28B	HS28B
29	Bunbury (Laporte) Inlet 2	BI2	77	Harvey Shallow 29A	HS29A
30	Bunbury (Laporte) Inlet 3	BI3	78	Harvey Shallow 31A	HS31A
31	Bunbury (Laporte) Inlet 4	BI4	79	Harvey Shallow 33A	HS33A
32	Eaton Line 1	EA1	80	Harvey Shallow 34A	HS34A
33	Eaton Line 2	EA2	81	Harvey Shallow 35A	HS35A
34	Eaton Line 3	EA3	82	Harvey Shallow 36A	HS36A
35	Harvey Line 1B	HL1B	83	Harvey Shallow 37B	HS37B
36	Harvey Line 2A	HL2A	84	Harvey Shallow 39A	HS39A
37	Harvey Line 3A	HL3A	85	Harvey Shallow 40A	HS40A
38	Harvey Line 4A	HL4A	86	Harvey Shallow 41A	HS41A
39	Harvey Water Table 1.5/75	HWT1.5	87	Harvey Shallow 42A	HS42A
40	Harvey Water Table 1.6/75	HWT1.6	88	Harvey Shallow 43A	HS43A
41	Harvey Water Table 1.9/75	HWT1.9	89	Harvey Shallow 45A	HS45A

Table 1. continued

Site identifier	Site name	Site abbreviation	Site identifier	Site name	Site abbreviation
90	Harvey Shallow 46A	HS46A	138	Bunbury Laporte Line 1	LP1
91	Harvey Shallow 47C	HS47C	139	Bunbury Laporte Line 2	LP2
92	Harvey Shallow 48A	HS48A	140	Bunbury Laporte Line 3	LP3
93	Harvey Shallow 49A	HS49A	141	Bunbury Laporte Line 4	LP4
94	Harvey Shallow 50A	HS50A	142	Bunbury Laporte Line 5	LP5
95	Harvey Shallow 51A	HS51A	143	Bunbury Laporte Line 7	LP7
96	Harvey Shallow 52A	HS52A	144	Bunbury Laporte Line F4DB	LPF4DB
97	Harvey Shallow 53A	HS53A	145	Mandurah Aquatic and Recreation Centre 1	MARC01
98	Harvey Shallow 54A	HS54A	146	Mandurah Golf Course 1	MGC
99	Harvey Shallow 55A	HS55A	147	Mandurah Line 1	MH1
100	Harvey Shallow 56A	HS56A	148	Mandurah Line 2	MH2
101	Harvey Shallow 57A	HS57A	149	Mandurah Line 3	MH3
102	Harvey Shallow 58A	HS58A	150	Mandurah Line 4	MH4
103	Harvey Shallow 59A	HS59A	151	Mandurah Line 5	MH5
104	Harvey Shallow 60A	HS60A	152	Mandurah Line 6	MH6
105	Harvey Shallow 61A	HS61A	153	Mandurah Line 7	MH7
106	Harvey Shallow 62B	HS62A/B	154	Mandurah Line 8	MH8
107	Harvey Shallow 63A	HS63A	155	Mandurah Line 9	MH9
108	Harvey Shallow 64A	HS64A	156	Mandurah Line 10	MH10
109	Harvey Shallow 65A	HS65A	157	Mandurah Line 11	MH11
110	Harvey Shallow 66A	HS66A	158	Mandurah Line 12	MH12
111	Harvey Shallow 67A	HS67A	159	Mandurah Line 13	MH13
112	Harvey Shallow 68A	HS68A	160	Mandurah Line 14	MH14
113	Harvey Shallow 69A	HS69A	161	Mandurah Line 15	MH15
114	Harvey Shallow 70A	HS70A	162	Mandurah Line 16	MH16
115	Harvey Shallow 71A	HS71A	163	Mandurah Line 17	MH17
116	Harvey Shallow 72A	HS72A	164	Mandurah Line 18	MH18
117	Harvey Shallow 73A	HS73A	165	Mandurah Shire 1	MS1
118	Harvey Shallow 74A	HS74A	166	PWD Miami 1/80	MI1/80
119	Kemerton Line 1D	KE1D	167	Murray–Peel Leedervile 1A	MPL1A
120	Kemerton Line 2D	KE2D	168	Murray–Peel Leedervile 1B	MPL1B
121	Kemerton 4	KW4	169	Murray–Peel Leedervile 2A	MPL2A
122	Kemerton–Wellesley 1	KEML1	170	Murray–Peel Leedervile 3A	MPL3A
123	Kemerton–Wellesley 2	KEML2	171	Murray–Peel Leedervile 4A	MPL4A
124	Lake Clifton Shallow A1	LCA1	172	Murray–Peel Leedervile 5A	MPL5A
125	Lake Clifton Shallow A2	LCA2	173	Murray–Peel Leedervile 6A	MPL6A
126	Lake Clifton Shallow A4	LCA4	174	Murray–Peel Leedervile 6B	MPL6B
127	Lake Clifton Shallow A5	LCA5	175	Murray–Peel Leedervile 7A	MPL7A
128	Lake Clifton Shallow B1	LCB1	176	Murray–Peel Leedervile 8A	MPL8A
129	Lake Clifton Shallow B3	LCB3	177	Murray DWMP 080-2B	HS080
130	Lake Clifton Shallow C1	LCC1	178	Murray DWMP 096-1A	HS096
131	Lake Clifton Shallow C2	LCC2	179	Murray DWMP 104-1A	HS104
132	Lake Clifton Shallow C4	LCC4	180	Murray DWMP 108-1A	HS108
133	Lake Clifton Shallow C5	LCC5	181	Park Ridge Estate 1	PRE1
134	Lake Clifton Shallow C6A	LCC6A	182	Picton Line 1	PL1
135	Lake Clifton Shallow E8	LCE8	183	Picton Line 2A	PL2A
136	Lake Clifton Shallow F6	LCF6	184	Picton Line 3A	PL3A
137	Lake Clifton Shallow G7	LCG7	185	Picton Line 3B	PL3B

Table 1. continued

Site identifier	*Site name*	*Site abbreviation*	*Site identifier*	*Site name*	*Site abbreviation*
186	Picton Line 4A	PL4A	196	Burekup, mineral hole 8	BKP8
187	Preston Beach 1	PB1	197	Burekup, mineral hole 10	BKP10
188	Waroona Junior High School 1	WJHS1	198	Coastal Property 1	COASTAL1
189	Waroona Junior High School 3	WJHS3	199	GSWA14332	GSWA14332
190	PWD Yunderup 3	YN3	200	Leschenault Inlet bore A	LESCH A
191	Coolup, Brownes dairy bore	BROWNES	201	Leschenault Inlet bore B(i)	LESCH B(i)
192	Burekup, Edwards bore	EDWARDS	202	Alcoa Pinjarra Mud Lake 3	MUDLAKE 3
193	Halls Head, ED2	HH ED2	203	Wagerup A bore	WAGERUP A
194	Yunderup, Hills bore	HILLS	204	Wagerup B bore	WAGERUP B
195	North Dandalup, Runcimans bore	RUNCIMAN	205	Alcoa Wagerup bore	ALCOA WAG

Although many water bores have been drilled within the study area, most are shallow, or were drilled expressly for residential or agricultural purposes, and have not been actively sampled or rigorously assessed geologically. These bores have little or no value for lithological or biostratigraphic studies at present and were not used in this project. Furthermore, no coal and mineral boreholes drilled within the region have had samples studied for biostratigraphy, and these were also excluded from this study. However, some of these boreholes may be of future interest for lithological, structural, or biostratigraphic studies if they are sufficiently deep and if samples are available for examination.

The majority of wells included in this review are on the Mandurah Terrace, with only 39 water bores and miscellaneous sites (Fig. 3 and Table 1; Appendix 1) within the Bunbury Trough. The Bunbury Trough samples were included to assess the degree of stratigraphic discontinuity, if any, across the Harvey Transfer Fault, which is interpreted as the boundary between the Mandurah Terrace and Bunbury Trough (Crostella and Backhouse, 2000; Thomas, 2014).

Petroleum and stratigraphic wells

The dataset examined here includes seven deep wells distributed across the Mandurah Terrace. Petroleum well Pinjarra 1 is the most northerly, with petroleum wells Lake Preston 1 and Preston 1, and the stratigraphic wells GSWA Harvey 1 and DMP Harvey 2, 3/3A and 4 clustered towards the centre of the study area; no petroleum wells fall within the southern portion of the region of interest. As no palynological studies have been conducted on DMP Harvey 4, and DMP Harvey 3/3A yielded no usable biostratigraphic results, these wells do not contribute materially to the Report's conclusions, but are commented on in 'Barren and indeterminate sections.'

GSWA Harvey 1 and DMP Harvey 2–4 were not drilled under the State Mining or Petroleum Acts, and therefore are not technically petroleum wells. However, in this Report, they are grouped with company-drilled petroleum exploration holes due to similarities in construction and analysis, and the whole group is referred to as 'petroleum wells' in the generic sense. All of these wells were drilled more deeply and are more thoroughly sampled than water, coal, and mineral bores, and therefore form more valuable datapoints for biostratigraphic studies. Unfortunately, the small number of petroleum wells in the study area means they provide only rare, although important, insights into the deeper parts of the succession.

Reports relating to petroleum wells are held in the DMIRS Western Australian Petroleum and Geothermal Information Management System (WAPIMS) database, which is freely accessible through the DMIRS website <www.dmp.wa.gov.au/wapims>.

Water boreholes

Due to the paucity of petroleum wells in the area, water bores provide the largest set of subsurface geological data from the Harvey region. Despite their increased density, these wells are mostly shallow, rarely exceeding 100 m total depth (TD).

Many of the older water bores used in this review were drilled by GSWA's Hydrogeology Section (now part of DWER), and the reports and samples relating to these bores are held by GSWA, accessible through the Geoscience Publications database (<www.dmp.wa.gov.au/GSWApublications>). The majority of palynology studies from the 1960s to the 1980s were conducted by palynologists working for GSWA. The results were captured in informal Paleontology Reports, which are also publicly accessible via the Paleontology Reports cabinet of the Geoscience Publications database <www.dmp.wa.gov.au/GSWApublications> (under 'Using online catalogue' section). GSWA palynologists also worked on samples from a variety of miscellaneous water bores, such as private bores and holes drilled by other government departments or industry, where the sites were of interest to GSWA for hydrogeological or stratigraphic studies; these results are also available as GSWA Paleontology Reports. Palynology slides relating to petroleum wells and GSWA-drilled water bores are also held by GSWA and catalogued in WAPIMS.

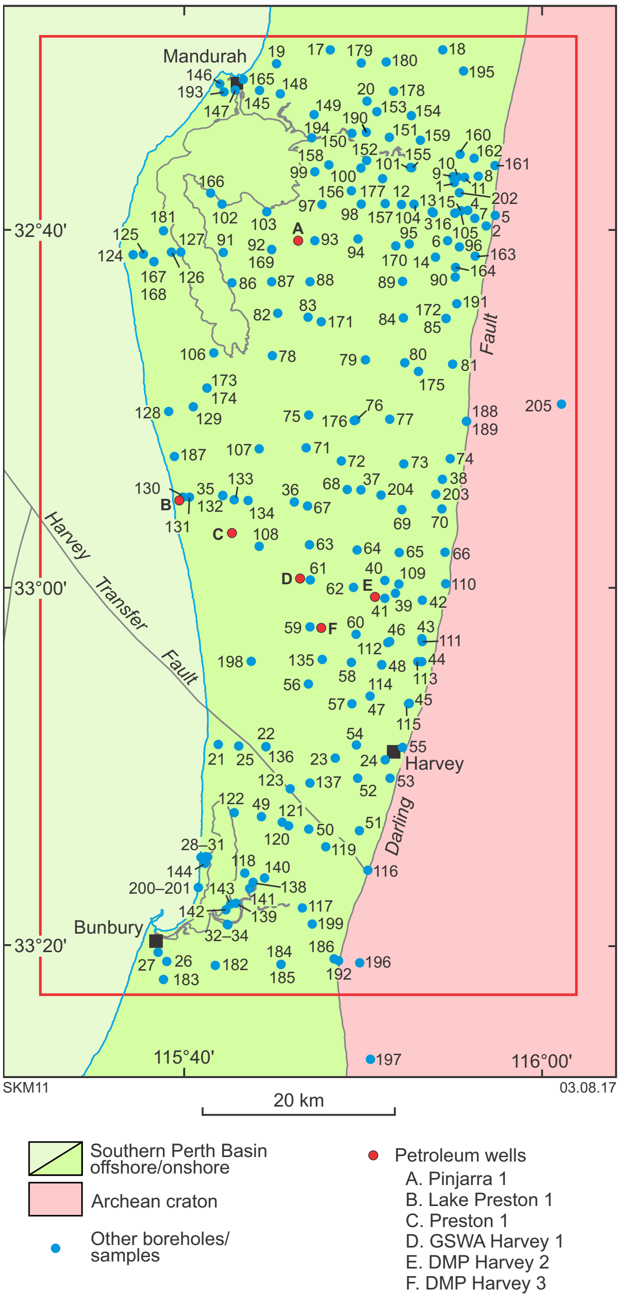


Figure 3. **Map of the boreholes used in this Report; red points indicate petroleum wells, blue dots are water and geothermal bores and miscellaneous samples. See Table 1 for the key to waterbore and miscellaneous sample abbreviations**

Borehole information is also held by DWER. These location and drilling data can be accessed using DWER's Water Information Reporting (WIR) application (<http://wir.water.wa.gov.au/>), which was used wherever possible to confirm relevant bore details. Australian Water Resource Council (AWRC) numbers for each bore are listed in Appendix 1. These unique identifiers are useful as water bore names were not formally regulated, and some bores have accumulated a variety of names and designations over time.

A recent round of investigative drilling conducted in the Mandurah area by the then DoW in 2012 and 2013 also included palynological studies; permission to use these wells and the related reports was kindly provided in 2015 by the then DoW.

Geothermal boreholes

Geothermal boreholes are usually drilled more deeply than water bores, making them useful data points for biostratigraphic studies. There is only one geothermal borehole (MARC01) within the study area for which palynological studies have been conducted. This borehole was drilled for the Mandurah Aquatic and Recreation Centre in 2015; permission to include this information was kindly provided by the City of Mandurah.

Miscellaneous sites

There are an additional 10 sites assessed in this Report. One site represents a surface sample collected by GSWA geologists as part of mapping or project work, and two others are from shallow mineral bores submitted for study by industry geologists. The remaining seven miscellaneous sites are boreholes of unknown location and purpose, which could not be correlated with any known water, mineral or petroleum bore records.

As core or hand samples, and the resulting slides and residues, are unlikely to have been kept from any of these miscellaneous sites, it is difficult to review the biostratigraphic data if required at a later stage. Therefore, these sites should be treated as problematic, and have only been included in this review for the sake of data completeness.

Biostratigraphic data

Figure 4 presents a summary of the biostratigraphic schemes used in this Report, and includes the present calibrations to global chronostratigraphic ages (GTS2016 International Time Scale; Geoscience Australia, 2016). Biostratigraphic zones quoted in this Report primarily refer to the standard Australian scheme, herein collectively referred to as the Australian Palynological Zonations. Established as Australia-wide, Mesozoic-only spore-pollen and dinocyst schemes by Helby et al. (1987), both palynological schemes were later modified, expanded, and recalibrated by other workers such as Foster (2001), Helby et al. (2004), and Partridge (2006). The Partridge (2006) version of these zonations was more recently integrated with Cenozoic and Paleozoic schemes (Mantle et al., 2010) to create the overarching Australian Spore-Pollen Zonation (extending from the Quaternary to the Devonian) and Australian Dinocyst Zonation (extending from the Quaternary to the Triassic). These palynological zonation schemes were initially calibrated to the GTS2004 International Time Scale (Monteil, 2006; Mantle et al., 2010), and later recalibrated to the GTS2012 and GTS2016 time scales as part of the Geoscience Australia Biozonation Datapack for TimeScale Creator (Geoscience Australia, 2016).

It should be noted that although superficially similar, some of the zone definitions differ between Partridge (2006) and Helby et al. (1987); that is, some zone boundaries are defined using different taxon first appearances or last appearances, and therefore a zone identification made under the Helby et al. (1987) definitions may not match a zone identified using later schemes. For the current study, these issues only apply to the Cretaceous *Phoberocysta burgeri*, *Odontochitina operculata*, and *Xenascus asperatus* Australian Dinocyst Zones (Fig. 4b), with the definitions changed Australia-wide for the *P. burgeri* and *X. asperatus* Zones (Foster, 2001), and a seemingly more localized zone definition change based on the North West Shelf (Carnarvon Basin) for *O. operculata* Zone by Helby et al. (2004). Of these definitions, the changed definition for the base of the *P. burgeri* Zone has the greatest effect on the present work. *P. burgeri* assemblages described post-2001 are now possibly equivalent to the *Kaiwaradinium scrutillinum* Perth Basin Zone (previously only correlatable to the *Phoberocysta lowryi* Perth Basin Zone), and any assemblage assigned to the *K. scrutillinum* Zone pre-2001 is possibly now correlatable to the *P. burgeri* Zone (previously only correlated to the *Senoniasphaera tabulata* Australian Zone). Where possible, this ambiguity has been taken into account in the reassessed assemblage zones, although assemblages assigned directly to the *K. scrutillinum* Zone are uncommon in the boreholes re-examined here.

Although the Australian Spore-Pollen and Dinocyst Zonations are useful frameworks for biostratigraphic zonation, a continent-wide scheme cannot be fully representative of every basin in every time period. Therefore, a number of zonation schemes specific to the Perth Basin are also used in this Report, principally where the local zones better represent the observed palynomorph assemblages. This approach is used for the Early Cretaceous, where the spore-pollen and dinocyst schemes devised for the basin by Backhouse (1978, 1984, 1988a) are used in preference to the equivalent Australian Palynological biozones (Fig. 4b). Also used is the Lower Triassic *Kraeuselisporites saeptatus* Spore-Pollen Zone, devised for the Carnarvon Basin by Dolby and Balme (1976) and extensively applied to Early Triassic assemblages in the Perth Basin and in Western Australia as a whole (Fig. 4a). Other, older zonation schemes, such as Filatoff's (1975) key work on the Jurassic of the Perth Basin, are referred to in a general sense, but are now superseded by the Australian Palynological Zonation scheme.

The most recent Geoscience Australia Biozonation Datapack for TimeScale Creator (Geoscience Australia, 2016) provides correlations between Backhouse's (1988a) local Perth Basin zones and those of the Australian Spore-Pollen and Dinocyst Zonations. As this is the most recently published dataset, those correlations are mostly followed here. However, some of the correlations presented in this dataset appear to require revision. In particular, the Biozonation Datapack correlates the boundary between the *Biretisporites eneabbaensis* and *Balmeiopsis limbata* Perth Basin Spore-Pollen Zones to a level within the *Fusifomacysta tumida* Perth Basin Dinocyst Zone, even though Backhouse (1988a) specifically stated that the *F. tumida* Zone is correlated in its entirety with the *B. eneabbaensis* Zone. Therefore this Report follows Backhouse (1988a) in equating the base of the *B. limbata* Zone with the base of the *Gagiella mutabilis* Perth Basin Dinocyst Zone, although this association is still tentative. The correlation of the base of the *G. mutabilis* Zone to a position within the *Systematophora areolata* Australian Dinocyst Zone (Partridge, 2006) seems reasonable given the present data.

The projected top of the *B. limbata* Zone is somewhat more difficult to constrain in the Perth Basin. Backhouse (1988) stated that the top of this zone coincided with the boundary between the *Microcachryidites* and *Hoegisporis* Microfloras of Balme (1964), and equated this to the top of Dettmann and Playford's (1969) *Cyclosporites hughesii* Spore-Pollen Zone. This boundary was considered equivalent to the top of the *C. hughesii* Zone of Helby et al. (1987), and is still maintained as such (Partridge, 2006). Although the top of the *C. hughesii* Spore-Pollen Zone is presently correlated with the middle of the *Diconodinium davidii* Dinocyst Zone, the top of the *B. limbata* Spore-Pollen Zone has more recently been thought to correlate to the base of the *Canninginopsis denticulata* Australian Dinocyst Zone (J Backhouse, 2017, written comm., 23 May; currently correlated to a level within lower *Coptospora paradoxa* Australian Spore-Pollen Zone by Partridge [2006]). As this latter correlation is not officially published, the present Report follows the Geoscience Australia Biozonation Datapack correlation, although noting that there may be some issues with this part of the zonations.

No correlation is provided between the Dolby and Balme (1976) zones and the Australian Spore-Pollen Zonation in the Geoscience Australia Biozonation Datapack for TimeScale Creator (Geoscience Australia, 2016); however, Helby et al. (1987) regarded Dolby and Balme's (1976) *K. saeptatus* Zone to correspond to the whole *Protohaploxypinus samoilovichii* and uppermost *Lunatisporites pellucidus* Zones. As the zone definitions for these two Australia-wide zones do not seem to have changed since that time, the same correlation is used here.

Despite the long history of study within Australia, few of the local palynological zones are strongly tied to international chronostratigraphic units, and zone diachroneity is of particular concern for this continent-wide zonation scheme. The issue is exacerbated in the Perth Basin due to the dominantly continental depositional environments, the relative paucity of sediments suitable for palynomorph preservation, and the small number of palynological zone ties established directly within the basin. This is much less of an issue for the Cretaceous, due to the regular presence of dinoflagellates, and is also less problematic for particular points in the Mesozoic where marine sediments are recorded (specifically the Induan/Olenekian and Bajocian) in the northern portion of the basin, but is a very serious concern for much of the section under discussion. For this reason, this Report refrains from associating palynology zones with specific chronostratigraphic units or absolute ages, particularly for the terrestrial spore-pollen zones, which are more difficult to correlate and more prone to diachroneity and environmental influences. Brief notes on the zone ties as they pertain to the southern Perth Basin, and on global floral trends as they affect biostratigraphy as a whole, are presented in Appendix 2.

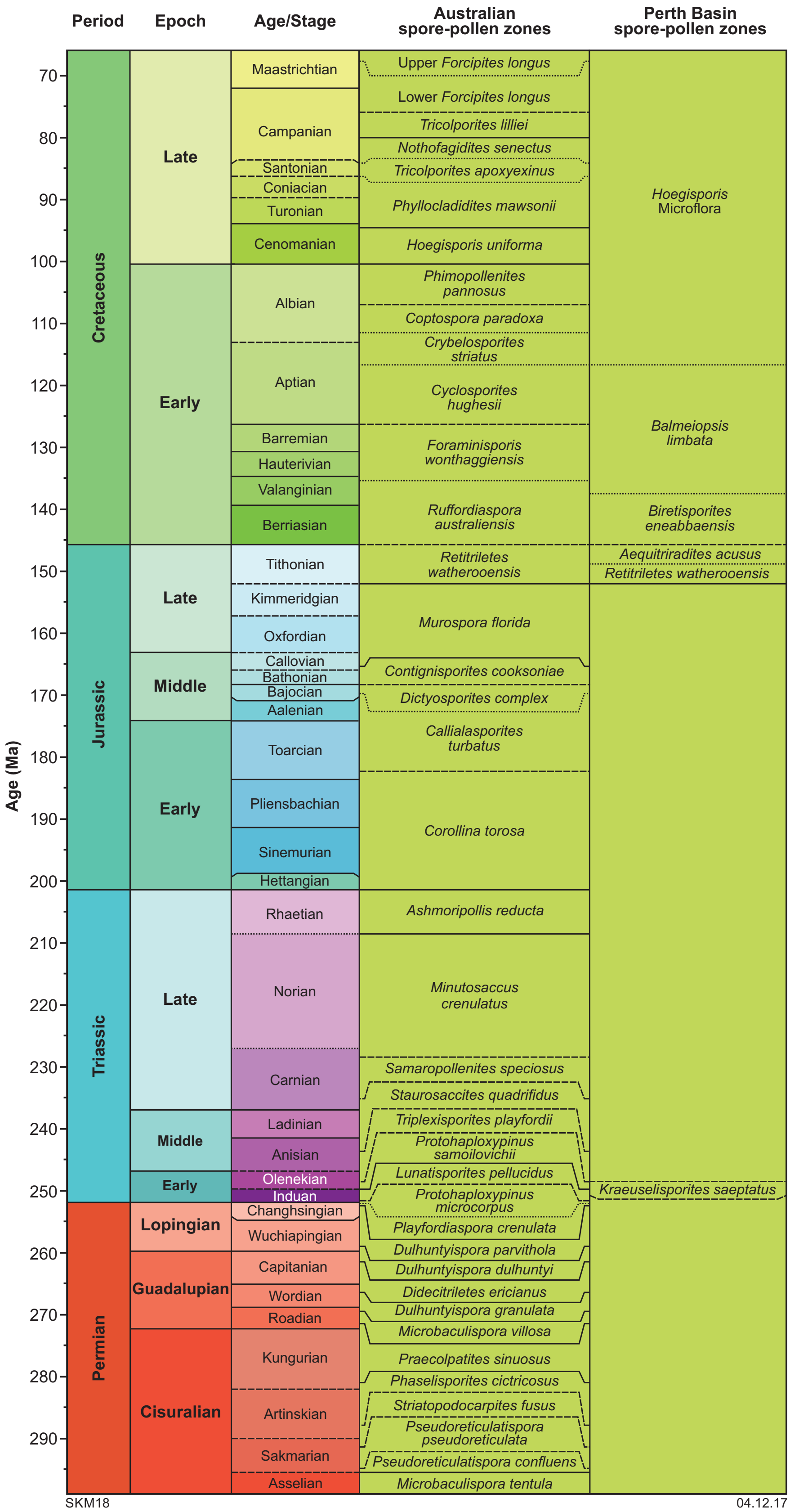


Figure 4. Summary of the spore-pollen and dinocyst zonation schemes referenced in this Report, correlated to the 2016 Global Time Scale: a) comparison of Australian (Partridge, 2006; Mantle et al., 2010) and Perth Basin (Backhouse, 1988a) spore-pollen zones from the Permian through to the end of the Cretaceous; b) comparison of Australian (Partridge, 2006) and Perth Basin (Backhouse, 1988a) spore-pollen and dinocyst schemes for the Cretaceous only. Data modified from Geoscience Australia's Australian biozonation schemes and basin lithostratigraphy datapack for TimeScale Creator (Geoscience Australia, 2016)

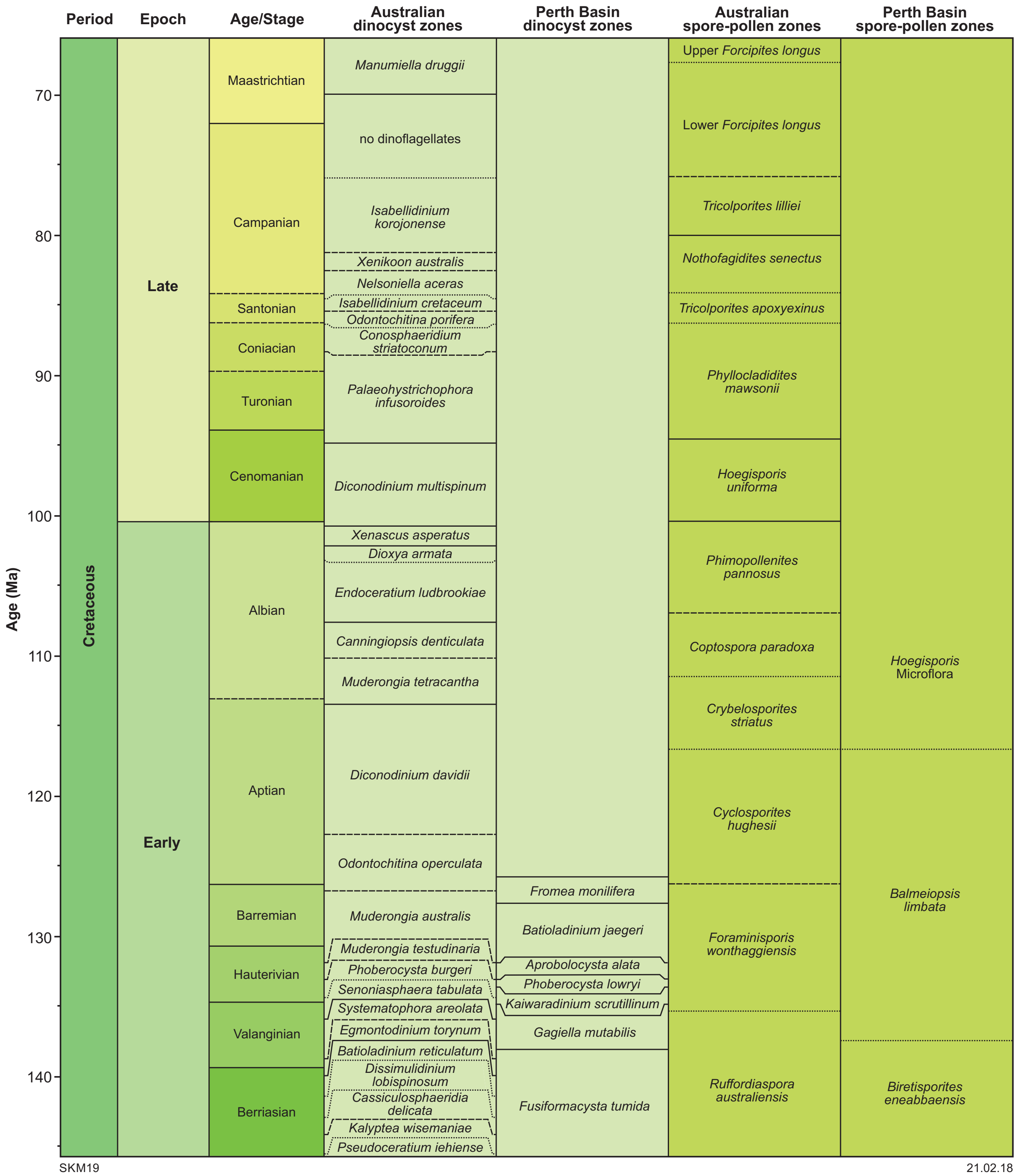


Figure 4. continued

Data limitations

Historical reports provide a useful dataset for regional-scale studies of this kind, but can also present a number of issues and limitations to interpretation. Most of these limitations — distribution and extent of previous sampling and study, data and sample access, changes in taxonomy and zonation schemes through time, sampling issues — relate to the process of palynological study itself and the era in which samples were analysed. These limitations can be partly ameliorated by bringing all of the report interpretations into line with the modern nomenclature and zonation schemes or by restudying the original samples, as attempted in this Report. Of particular interest in this regard is the relative paucity of well and bore data in the project area in comparison to the well-studied northern Perth Basin, and the disconnect between northern and southern Perth Basin studies caused by the Perth Metropolitan region, which lacks deep boreholes and therefore clear stratigraphic data for pre-Cretaceous units. As most of these process issues relate to specific wells or boreholes, they are discussed in more depth in Appendix 2.

This study has also highlighted that the southern Perth Basin is affected by regional geological limitations relating to conditions at the time of fossilization. Outcrops of pre-Cretaceous units are rare within the southern Perth Basin, and where they do exist, exposures are typically low, isolated, weathered, and therefore difficult to compare and obtain robust data from. The deep weathering profile across the southern Perth Basin causes considerable issues for biostratigraphic studies of outcrop and shallow well samples because oxidization renders samples unsuitable for the recovery of palynomorphs. Extensive pre-diagenetic oxidation of the Triassic and Jurassic rocks, likely during subaerial exposure or soil-forming periods (e.g. see the discussion on paleosols in GSWA Harvey 1; Millar and Reeve, 2014), further exacerbates palynomorph degradation. This oxidation can be unevenly developed, and is probably related to the highly variable channelized fluvial depositional environments at this time. The dominance of sandstone and rarity of intercalated organic-rich fine-grained lithologies in the Mesozoic of the Perth Basin causes considerable difficulties in correlating units both at the surface and in the subsurface. In the subsurface, the similar lithological and geophysical signatures of these sand-rich units can make it difficult to differentiate sandstone units of different ages when in direct contact.

Although none of these limitations individually precludes the usefulness of legacy datasets, all must be carefully considered when building models and regional interpretations.

Results

Due to the large number of shallow water-bores in the present dataset, there is proportionally less age information available for older time periods. Of the examined holes, only the petroleum wells yielded pre-Jurassic assemblages, and only one petroleum well, Lake Preston 1, provides an insight into Early Triassic and older palynofloras. As a result, the Cretaceous is well studied in this region, with far less known about the distribution and nature of pre-Cretaceous units. The following section provides a summary of what can be interpreted about each biostratigraphic zone or time slice based on the studied data; the time divisions used are reflections of the natural breaks or groupings in the palynoflora seen within the dataset.

Cenozoic

Apart from Quaternary rocks and surficial deposits, which are widespread, Cenozoic units are rare onshore in the Perth Basin, recorded mainly in the Perth Metropolitan region (northernmost Mandurah Terrace) and farther north (Davidson, 1995). No Paleogene or Neogene units are presently known from the Bunbury Trough or farther south (Cockbain, 1990; Crostella and Backhouse, 2000; Mory et al., 2015). This is in contrast to the widespread development of Paleogene (late Paleocene to late Eocene) and Neogene (mostly Miocene) marine units in the adjacent Eucla and Carnarvon Basins.

Although Quaternary units blanket most of the area, they are rarely cored, and are more rarely sampled for palynology. Cenozoic palynofloral assemblages have been noted in only 21 boreholes (and one outcrop sample) in the region (Fig. 5). Despite the small biostratigraphic dataset, the surficial Cenozoic units are considered distinctive on lithological grounds alone. Based on sample (typically ditch cuttings) descriptions, surficial sediments across the region are dominated by Quaternary unconsolidated sands and calcareous units, lithologies generally unsuitable for palynomorph preservation. Where recovered, palynomorph assemblages from these Quaternary sediments are commonly low yielding and of low diversity.

All recorded Cenozoic assemblages are Neogene or younger and there is no evidence for Paleogene palynomorph assemblages within the study area. The deepest Cenozoic palynological record is in Mandurah Line 3 (MH3), where a sample at 180 ft (54.86 m) yielded an assemblage interpreted as Quaternary in age (with Early Cretaceous pollen worked in). This depth seems unusual compared with the adjacent Mandurah Line 1 and 2, where the deepest Cenozoic samples were recovered at 70 ft (21.34 m, MH1; Plate 2) and 30 ft (9.14 m, MH2) and certainly Early Cretaceous assemblages have been recovered from as shallow as 25 m depth. This thickening of the Cenozoic succession in MH3 has been attributed to the development of a channel in the area, an interpretation supported by the high permeability of the Cenozoic rocks in this bore compared with the more clay-rich rocks recorded in other Mandurah bores (Emmenegger, 1964). Elsewhere in the project area, the maximum depth at which there is evidence for Cenozoic palynomorphs ranges from 6 to 36 m. For some of these bores (BI3, CPPS1, HS4A, HS5A, HS18A HS27A, HS31A, HS49A, HS71A, GSWA 14332), the only samples that yielded palynomorphs are Cenozoic in age; for the remaining holes (AO8, EA1, HWT1.5, HWT1.6, HWT1.9, HS16A, HS65A, LP5, MH1–3, MPL7A), Lower Cretaceous rocks of the *B. limbata* Spore-Pollen Zone were interpreted beneath the Cenozoic succession.

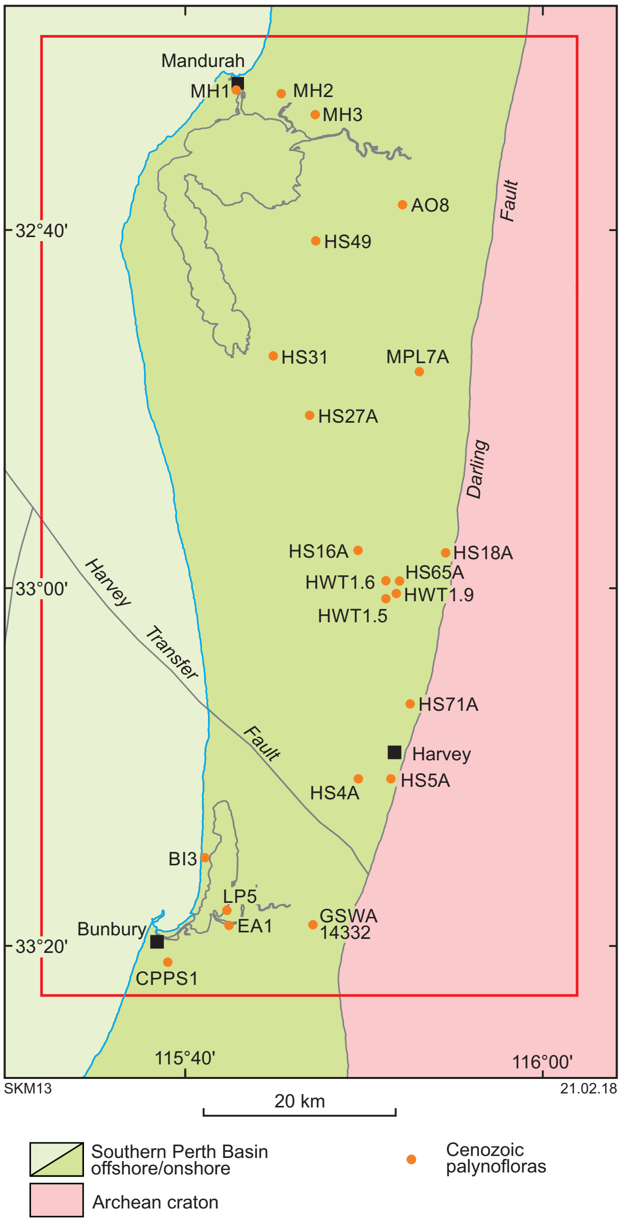


Figure 5. Distribution of boreholes with Cenozoic palynofloras within the study area. See Table 1 or Appendix 1 for a list of the borehole name abbreviations

Cenozoic palynological assemblages in Western Australia are poorly studied, with palynofloras normally compared to better-studied assemblages in eastern Australia. This uncertainty in zone identification, coupled with the low yields of palynomorphs recorded in most samples within the southern Perth Basin, results in low-precision age determinations. Assemblages from HS5A and HS31 have the lowest precision determinations in the re-examined dataset, being ‘Miocene to Recent’ in age. ‘Pliocene to Recent’ (also known as ‘Late Tertiary to Holocene’) assemblages are also common, recorded in AO8, CPPS1, HWT1.5, HWT1.6, HS13A, HS14A, HS16A, HS18A and MPL7A, as are ‘Quaternary’ or ‘Pleistocene to Recent’ assemblages seen in GSWA 14332, EA1, BI3, HS27A, LP5, MH2, MH3 and some samples in MH1. Only five determinations are more precise — samples from HS4A and HWT1.9 are identified as Holocene or near Holocene, whereas samples from HS65A, HS71A, plus the deepest Cenozoic sample in MH1 (70 ft; 21.3 m), are all Plio–Pleistocene. This last determination suggests that the Cenozoic succession in MH1, at its deepest point (approximately 21 m) is older than that in both MH2 and MH3, even though the Cenozoic succession is thicker in MH3 (at least 55 m thick). Compared to other boreholes in the area, a relatively thick Holocene succession is also suggested for HS4A, with a palynology assemblage of this age interpreted at a depth of 27 m.

In the northern and central part of the area, a few Pliocene to Quaternary assemblages (AO8, MH1, MH3, and HS31A) included rare microplankton, indicating a slight marine influence. Other Quaternary or Holocene samples (BI3, CPPS1, EA1, HWT bores, HS4A, HS16A, HS18A, HS27A, HS65A, HS71A, Laporte 5, MPL7A, and GSWA 14332) contain entirely nonmarine palynofloral assemblages, heavily dominated by Myrtaceae (mostly eucalypt) pollen. Within the Mandurah Line, there is a distinct difference in environment between boreholes, with the thicker succession in MH3 only weakly marine or paralic, and the shallower and possibly older succession in MH1 indicating nearshore to marine conditions; the sample from MH2 shows no evidence of marine influence. This suggests some variability in local environments throughout the late Neogene and Quaternary, and decreasing marine influence to the south during the later Cenozoic.

Cretaceous

The Cretaceous biostratigraphy of the Perth Basin has been monographed a number of times (Backhouse, 1978, 1984, 1988a), and units of this age are well understood compared to other parts of the stratigraphy. Cretaceous biostratigraphy in the southern Perth Basin has been aided by the presence of marine palynomorphs, which generally permit higher biostratigraphic precision than the terrestrial spores and pollen when recorded. An additional benefit is improved correlation between the Perth Basin and other parts of the state, particularly the Northern Carnarvon Basin, where more extensive geological and biostratigraphic work has been conducted (e.g. Foster, 2001; Monteil, 2006).

Late Cretaceous assemblages are rare in the study area, and the majority of palynological samples reassessed for this project are of Early Cretaceous age (Figs 6, 7). Although the *B. limbata* Zone is currently correlated to the *S. areolata* to middle *D. davidii* (or *?Muderongia tetracantha*) Australian Dinocyst Zones (Geoscience Australia, 2016), in this Report marine assemblages of the *D. davidii* Zone and younger are considered separately from those assemblages assigned generally to the nonmarine *B. limbata* Spore-Pollen Zone or Perth Basin Dinocyst Zones, which are generally associated with sediments of the Warnbro Group (Backhouse, 1988a).

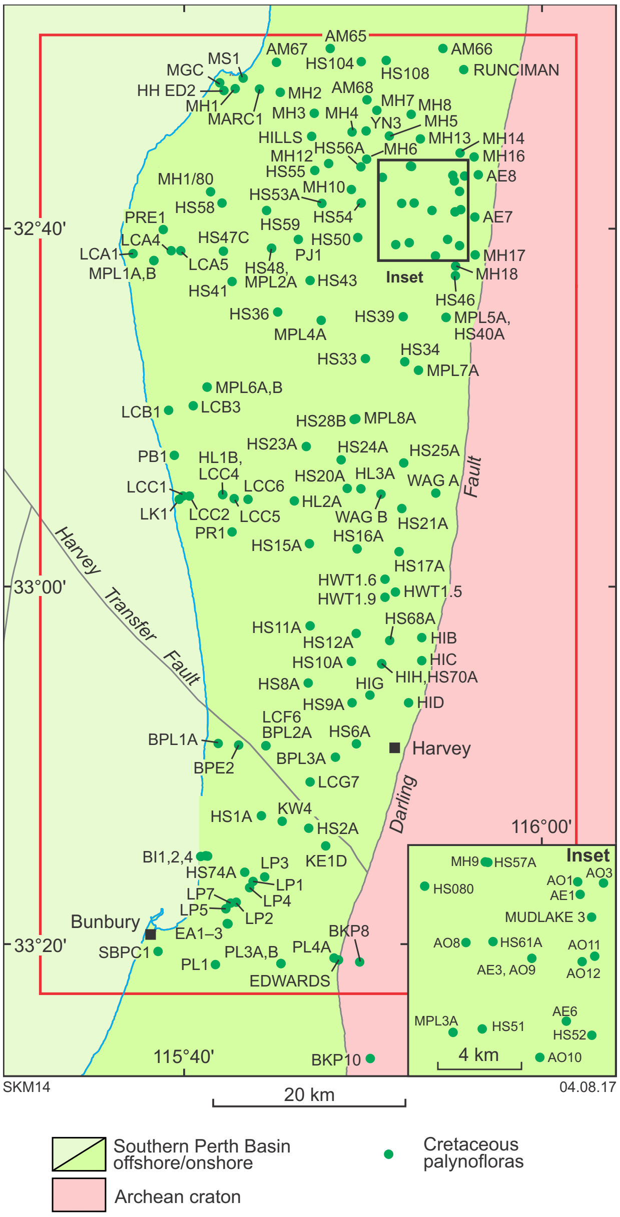


Figure 6. **Distribution of boreholes with Cretaceous palynofloras within the study area. See Table 1 or Appendix 1 for a list of the borehole name abbreviations**

Late Early Cretaceous — *D. davidii* Dinocyst Zone and younger

Distribution

Palynological assemblages of the late Early Cretaceous were noted in six boreholes (Figs 6, 7), namely Miami 1/80 (MI1/80), Lake Clifton Shallow A1 (LCA1), A4 (LCA4) and A5 (LCA5), and Murray–Peel Leederville bores 1A (MPL1A) and 1B (MPL1B), with additional possible records in Lake Clifton Shallow B1 (LCB1) and B3 (LCB3), and Park Ridge Estate 1 (PRE1). With one exception, these boreholes are close to the coast within the Mandurah Terrace, directly west of the Harvey Estuary and north of Lake Clifton; only MI1/80 is sited just east of the Harvey Estuary. The LCB bores are the most southern sections with doubtful later Cretaceous assemblages. Although also drilled within this general area west of the Harvey Estuary, the single processed sample (at 29 m) from Lake Clifton Shallow A2 (LCA2) contained an assemblage too sparse for age interpretation, possibly due to sediment oxidation (Backhouse, 1980b).

Palynological assemblages in all boreholes are low in yield and diversity, and are difficult to assign to specific biostratigraphic zones; the low level of confidence in the assemblages is made worse because samples were obtained exclusively from ditch cuttings, making assemblages vulnerable to mixing and contamination. In addition, the Miami and Lake Clifton Shallow assemblages are only reported on very briefly (Backhouse, 1980a,b), making comparison between holes difficult.

MPL1A presents the best view of the late Early Cretaceous succession in this area, due to its greater depth and more comprehensive sampling (Plate 3). The three shallowest samples in MPL1A (34–35 m, 53–54 m and 116–117 m) are interpreted as late Early Cretaceous in age, with dinoflagellates and nondiagnostic spore-pollen assemblages recorded in all three samples. The very low palynomorph yield in the shallowest sample makes it difficult to assign to a specific zone, although the dinoflagellates are consistent with the *X. asperatus* to *Endoceratium ludbrookiae* Australian Dinocyst Zones (Fig. 4b). This interpretation is supported by the next deepest sample (53–54 m), which contained a low to medium yield and higher diversity assemblage, assignable to the *E. ludbrookiae* or perhaps *C. denticulata* Dinocyst Zone. The deepest MPL1A sample contains a more diagnostic assemblage clearly assignable to the *D. davidii* Dinocyst Zone. Therefore, late Early Cretaceous rocks in MPL1A extend at least from 34–117 m and cover a range of dinocyst zones from *X. asperatus* to *D. davidii*, although it is difficult to assess whether these zones are represented in whole.

A single sample assessed from MPL1B (a sidetrack drilled at the same site as MPL1A), from a depth of 33–34 m, contains a poor assemblage with nondiagnostic spores and pollen, and rare dinoflagellates that are similar to those from the MPL1A sample at 53–54 m. This suggests a similar succession in both holes, although the assemblage in MPL1B appears older than material at the equivalent depth in MPL1A. The palynological information in MPL1A and MPL1B partly contradicts the formation tops for these holes, with the boundary between the Quaternary Tamala Limestone and Cretaceous Osborne Formation picked at 51 m (based on the basic well datasheet available via the DWER website). As the palynological samples are from ditch cuttings, it is possible that these late Early Cretaceous palynomorphs have been reworked into the Cenozoic succession, or that there was a discrepancy in the recorded sample depths. The formation boundary is not obvious from the MPL1A lithology or gamma ray logs.

Despite poor reporting, the Lake Clifton Shallow Line A, Miami, and Park Ridge assemblages share some similarities to those seen in MPL1A, including:

- *Cribroperidinium* cf. *C. edwardsii*[1], seen at 27 m in LCA4, 21 m in MI1/80, and 154 m in PRE1 (cf. 53–54 m in MPL1A)
- *Chlamydophorella nyei* seen at 27 m in LCA4 (cf. 53–54 m in MPL1A)
- *Endoceratium turneri* seen at 21 m in MI1/80 (cf. 53–54 m in MPL1A)
- *Discorsia nannus* seen possibly at 21 m in MI1/80 (cf. 116–117 m in MPL1A).

Therefore, the LCA samples appear to correlate with the shallower two assemblages seen in MPL1A, somewhere within the *X. asperatus* to *C. denticulata* Zones, whereas MI1/80 best resembles the *D. davidii* to *E. ludbrookiae* Zone assemblages in MPL1A, and the PRE1 sample is likely *D. davidii* Zone or younger. This palynological information agrees well with previous lithostratigraphic assessments of the Lake Clifton Shallow boreholes (Commander, 1988, 1990), which interpreted Line A boreholes as reaching TD within the Osborne Formation. The Lake Clifton Shallow Line B boreholes share no species with the assemblages mentioned above, although like Line A, the samples are poorly reported, with only a single species, *Perotriletes majus*, mentioned (in LCB1). This species is regarded as indicative of the upper *Crybelosporites striatus* Zone or younger (i.e. younger than the *B. limbata* Perth Basin Spore-Pollen Zone) in much of Australia (Wagstaff et al., 2012), although a lack of corroborating evidence means that this identification is extremely tentative. Lithologically, the bores in Line B were previously interpreted to have reached TD in the Leederville Formation with no younger Cretaceous units intersected (Commander, 1988, 1990), which conflicts with the palynological data seen here.

Absent sections

There is no evidence in the present dataset for palynozones younger than the late Albian *X. asperatus* Dinocyst Zone (that is, younger than the *Phimopollenites pannosus* Australian Spore-Pollen Zone). As a result, a hiatus or erosional period is interpreted for the Harvey Ridge area and northern Bunbury Trough, beginning in the ?Cenomanian and extending through the Late Cretaceous and Paleogene.

Also lacking is evidence for the *M. tetracantha* Dinocyst Zone, which falls between the *D. davidii* and *C. denticulata* Zones. However, this is a very thin zone and is seldom firmly identified because it is difficult to separate from the *D. davidii* Zone (the top boundary of which relies on identifying the last appearance of *Diconodinium davidii*). The small number of boreholes preserving late Early Cretaceous assemblages in the area means it is possible the zone is present but has not yet been intersected or sampled.

Comparison to other parts of the Perth Basin

In the Perth Basin, upper Lower to Upper Cretaceous rocks are grouped into the dominantly marine Coolyena Group, consisting, from oldest to youngest, of the lowermost Dandaragan Sandstone, the Osborne Formation, the Molecap Greensand, Gingin Chalk, the Poison Hill Greensand and likely equivalent, the Lancelin Formation (see Millar and Reeve [2014] for a chart showing the stratigraphy of the entire Perth Basin). In the northern Mandurah Terrace, specifically the southern part of the Perth Metropolitan region, the Osborne Formation is the only recorded Coolyena Group unit; these Mandurah Terrace records (including those noted in this Report) are also the only recorded upper Lower to Upper Cretaceous rocks in the southern Perth Basin (Davidson, 1995).

The Osborne Formation was divided into three members — the basal Henley Sand Member, Kardinya Shale Member, and Mirrabooka Member (Davidson, 1995) — based on work within the Perth Metropolitan region, and the type sections for all of these units (AM36A, AM11, AM42 and AM30Z for the Osborne Formation, Henley Sand Member, Kardinya Shale Member and Mirrabooka Member, respectively) are similarly located in this area. Unfortunately, palynological assemblages are poorly diversified in all of these type sections — a review (Backhouse, 1982) of the palynology from the Osborne Formation type section (AM36A, 37–133 m) recorded an assemblage assigned to *E. ludbrookiae* C Subzone (of Morgan, 1980; equivalent to the *Diconodinium multispinum* Dinocyst Zone of Helby et al., 2004) at 85 m, and an assemblage clearly assignable to the *B. limbata* Spore-Pollen Zone and *Batioladinium jaegeri* Dinocyst Zone (of Backhouse, 1988a; equivalent to the *Muderongia australis* Dinocyst Zone of Helby et al., 2004; Fig. 4b) at 119 m. However, both the *B. limbata* and *B. jaegeri* Zones are considered indicative of the Warnbro Group (as per Backhouse, 1988a) not the Coolyena Group, which somewhat confuses the definition of the Osborne Formation. As the assemblages are processed from sidewall cores, caving is unlikely for this sample, and the alternative possibilities are that either the Osborne Formation extends into the top of the *B. limbata* Zone, or the Osborne Formation section in this borehole is thinner than noted by Davidson (1995). Given that lithostratigraphic units can be time transgressive, neither possibility can be excluded.

Across the Perth Basin, assemblages of the *Endoceratium turneri* Subzone A (of Morgan, 1980; equivalent to the *D. davidii* Zone of Helby et al., 1987) to the *Conosphaeridium striatoconum* Zones have all been described from sediments assigned to the Osborne Formation (e.g. Marshall, 1984). However, Backhouse (2013) commented that although *D. davidii* Zone assemblages have been included in the Osborne Formation in the past, it is uncertain whether rocks of this zone, and possibly those containing the younger *M. tetracantha* and older *O. operculata* Zones, should be ascribed to this unit, or would better be regarded as part of a separate Aptian-aged unit. The existence of this potential unit, which has not been confirmed or formally defined, is based on the regular observation of a sequence break between the Aptian (*D. davidii* ± *M. tetracantha* Zones) and

1 All genus and species authorities are listed in Appendix 3 to prevent confusion with in-text references.

Albian–Cenomanian sections (*C. denticulata* and younger Zones) in better preserved well sections farther north in the Perth Basin. Separation of this potential unit from the underlying Warnbro Group is more uncertain, as in the past the *B. limbata* Spore-Pollen Zone (the top of which is normally correlated within the *D. davidii* Dinocyst Zone; Geoscience Australia, 2016) was correlated with the Warnbro Group wherever it was recorded (Backhouse, 1988a). Whether there is a stratigraphic break between the top of the *Fromea monilifera* Perth Basin Dinocyst Zone (= lower *O. operculata* Australian Zone) and the *D. davidii* Australian Dinocyst Zone assemblages in the present project area is difficult to determine with the current material.

Aptian and younger dinocyst zones are commonly observed and well recorded in the Vlaming Sub-basin, such as petroleum wells Araucaria 1, Sugarloaf 1, Challenger 1, Parmelia 1 and Warnbro 1, and it is likely that the mid-Cretaceous succession in the Lake Clifton area is a localized onshore extension of this thicker offshore succession. The succession in the Vlaming Sub-basin wells also extends more-or-less continuously from at least the *S. areolata* Dinocyst Zone through to the *O. operculata* Zone.

Early Cretaceous — *B. limbata* Spore-Pollen Zone (Backhouse, 1988a)

Distribution

Based on the information collated in Appendix 2, palynomorphs of the *B. limbata* Zone and equivalent dinocyst zones (*G. mutabilis* to *F. monilifera* Perth Basin Dinocyst Zones of Backhouse [1988a], or *S. areolata* to *D. davidii* [or *M. tetracantha*?] Australian Dinocyst Zones of Partridge [2006]) are the dominant assemblages recorded, noted in three of the petroleum wells, the single geothermal bore, and 103 of the 204 water or other bores (Figs 6, 7). An additional 45 water bores contain generic 'Early Cretaceous' assemblages that are too poorly preserved or incompletely reported, and cannot be assigned to a zone; those samples are not considered further here. *B. limbata* Zone assemblages are absent from wells GSWA Harvey 1 and DMP Harvey 2 as these wells began their coring and/or palynological sampling within the Lower Jurassic succession; however, both were interpreted as intersecting the Leederville Formation at shallower depths, and therefore this zone would likely have been recorded if sampled (Plates 1A, 1B and 4). As the *B. limbata* Zone is currently correlated to the *S. areolata* to *D. davidii* Australian Dinocyst Zones (Geoscience Australia, 2016), the marine *D. davidii* Zone assemblages (i.e. in MPL1A; Plate 3) discussed above may be the same age as some nonmarine *B. limbata* Zone or generic Early Cretaceous assemblages. However, this is difficult to determine without stronger stratigraphic data and palynological evidence.

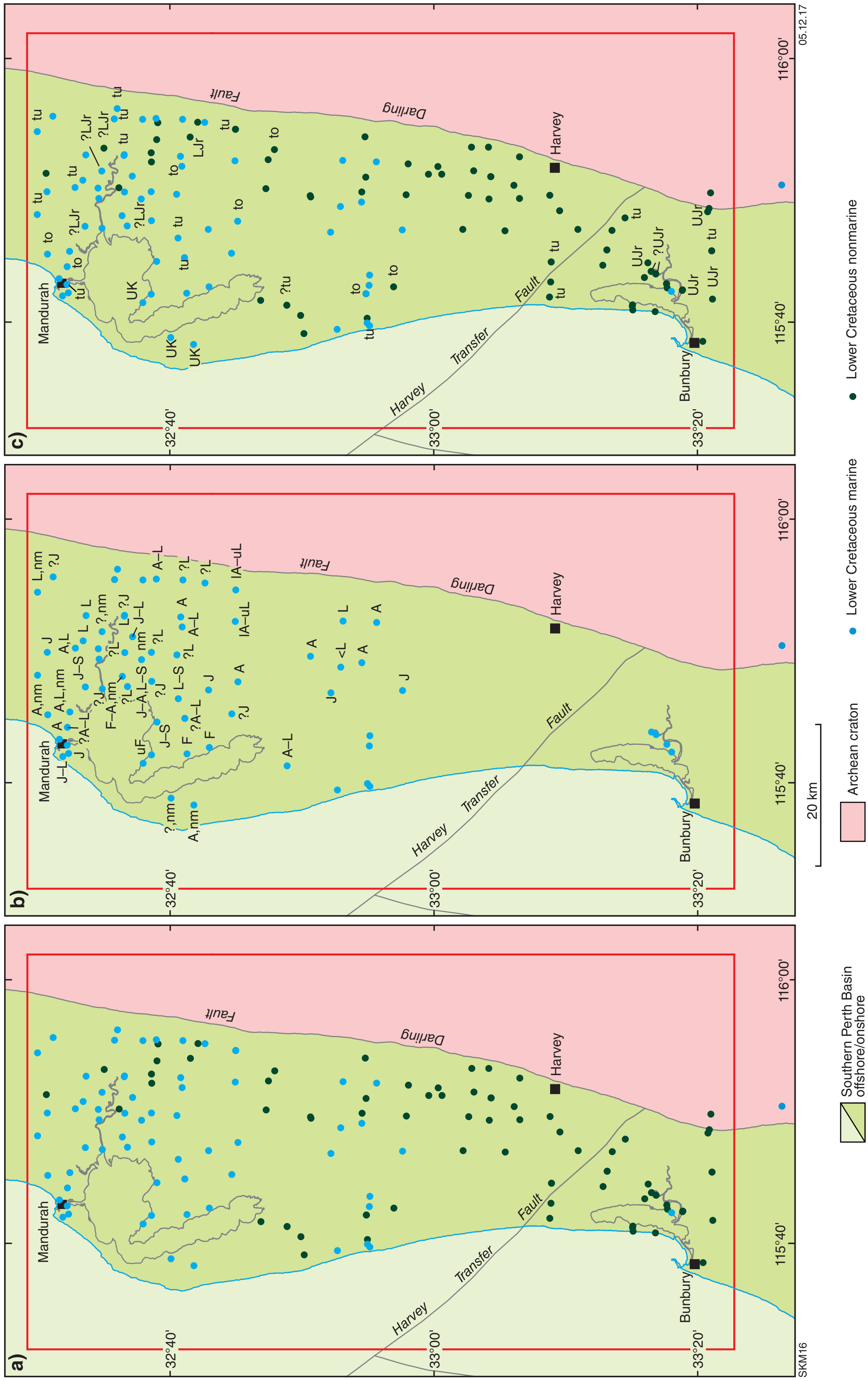
Of the 62 water bores and miscellaneous sites across the study area that lack evidence for the *B. limbata* Zone or equivalent dinocyst zone assemblages, 26 consisted of indeterminate or barren assemblages; five had no reported age data (Harvey Shallow boreholes, which appear to have been erroneously excluded from reporting); 16 recorded Quaternary or late Early Cretaceous ages in their deepest samples (i.e. apparently did not reach the *B. limbata* Zone); two holes (HL2A and KW4) preserved enigmatic Early Cretaceous assemblages that appear to be older than the *B. limbata* Zone; and 13 had Early Jurassic ages in their shallowest samples (i.e. Cretaceous succession either removed or not sampled). Sites lacking *B. limbata* Zone assemblages are distributed throughout the entire project region and do not display any particular pattern in their geographic distribution.

Within the group of boreholes with *B. limbata* Zone or equivalent assemblages, marine influence was recorded in about half; specifically Lake Preston 1, Pinjarra 1, MARC01, and 47 of the 103 water bores (Fig. 7a). Marine assemblages decrease in number to the south of the study area; relatively few marine records are seen south of the Harvey township, although a small group of sites was recorded around the Bunbury township. Not all marine assemblages could be assigned to a dinocyst zone using only the legacy reports, and several assemblages (such as in Lake Preston 1; Backhouse, 2016a) were of low diversity and could not be clearly zoned even on reanalysis of the original slides. None of the marine assemblages in the Bunbury area could be assigned to a dinocyst zone, making it difficult to compare these samples to assemblages further north in the Mandurah Terrace.

Those samples that could be assigned a zone ranged from the *?K. scrutillinum* (= *S. tabulata* Australian Dinocyst Zone; Geoscience Australia, 2016) to upper *F. monilifera* (= lower *O. operculata* Australian Dinocyst Zone; Geoscience Australia, 2016) Perth Basin Dinocyst Zones (Fig. 7b). The youngest assemblages in this set, assigned to the *F. monilifera* Zone, are recorded on the eastern margin of the Harvey Estuary (HS41, HS47C, HS58), geographically close to a set of boreholes recording late Early Cretaceous (*D. davidii* to possible *X. asperatus* Zone) assemblages.

Figure 7. **(page 17) Distribution of *Balmeiopsis limbata* Zone or equivalent assemblages (excluding transitional or generic Lower Cretaceous assemblages): a) grouped by environment, with nonmarine samples marked in green and marine samples in blue; b) marine assemblages showing distribution of dinocyst zones, where unlabelled boreholes cannot be assigned to any particular zone; c) map showing the boreholes where the *B. limbata* Zone assemblages are overlain or underlain by assemblages of other ages, with only the immediately under- or overlying assemblage indicated.**

ABBREVIATIONS: u, upper; l, lower; <, younger than; ?, uncertain assemblage
Dinocyst Zones: F, *Fromea monilifera*; J, *Batioladinium jaegeri*; A, *Aprobolocysta alata*; L, *Phoberocysta lowryi*; S, *Kaiwaradinium scrutillinum*; UK, Upper Cretaceous
Spore-Pollen Zones: nm, *B. limbata*; UJr, Upper Jurassic; to, *Corollina torosa*; tu, *Callialasporites turbatus*; LJr, Lower Jurassic
Borehole name abbreviations: see Table 1 or Appendix 1


a)
b)
c)
Mandurah
Harvey
Bunbury
Darling Fault
Harvey Transfer Fault
32°40'
33°00'
33°20'
115°40'
116°00'
20 km
Southern Perth Basin offshore/onshore
Archean craton
Lower Cretaceous marine
Lower Cretaceous nonmarine
SKM16
05.12.17

The oldest assemblages, recorded southeast of Peel Inlet in Pinjarra 1 and MH10 can be assigned to the *K. scrutillinum* to *P. lowryi* Perth Basin Dinocyst Zones, although these are low confidence assemblages and therefore difficult to assess relative to other better-determined samples. Assemblages of the *B. jaegeri* (roughly equivalent to the *M. australis* Australian Dinocyst Zone), *Aprobolocysta alata (= Muderongia testudinaria* Australian Dinocyst Zone) and *P. lowryi* (= upper *P. burgeri* Australian Dinocyst Zone) Dinocyst Zones are roughly equal in numbers within the dataset, although the *P. lowryi* Zone is common towards the east of the study area, *B. jaegeri* Zone is commonly recorded in the centre, and *A. alata* Zone is recorded throughout the area. Therefore, although there is no clear overall age-related directional trend for these assemblages, there is some degree of regionalization. The presence of younger assemblages towards the west may be a reflection of increased accommodation space in that area during breakup.

Although all 'marine' samples listed above contain spore-pollen assemblages of the *B. limbata* Zone, only a small number of sites in the present dataset — PB1, LP1, LP2, LP4, MPL1A, AM65, AM66, AM67, MH5, MH10, MH12 and Runcimans bore — contain samples with marine influence intercalated with samples that show no evidence of marine influence within the same borehole (Plates 2, 3). In these boreholes, marine and nonmarine assemblages appear equally interspersed, with no clear pattern. In MH5, MH12 and Runcimans bore, the nonmarine assemblages are associated with dinoflagellates typically indicative of the *F. monilifera* to *A. alata* Zones. Slightly older *A. alata* and *P. lowryi* Zone assemblages are interspersed with nonmarine *B. limbata* Zone assemblages in the Artesian Monitoring and MPL bores (e.g. Plate 3). MH10 appears to preserve the oldest section in this set, with a single nonmarine assemblage below a sample likely assignable to the *K. scrutillinum* Zone. Together, this suggests sporadic pulses of marine influence during the time period represented by the *B. limbata* Zone.

A large number of sites assessed as part of this review have only had single palynology samples analysed, or else were shallow and bottomed within the Early Cretaceous succession. Therefore, only 30 boreholes with Early Cretaceous records also recorded palynological assemblages older than the *B. limbata* Zone, and most of these sites are located in the north (Fig. 7c). Of this set, the underlying samples in four sites yielded Upper Jurassic zones, 15 sites showed *B. limbata* Zone overlying *Callialasporites turbatus* Spore-Pollen Zone assemblages, six sites yielded earliest Jurassic *Corollina torosa*[1] Spore-Pollen Zone assemblages beneath the Early Cretaceous, with generic Early Jurassic assemblages beneath the Cretaceous in five sites. Those boreholes where the *C. turbatus* Zone is absent or unsampled below the Cretaceous unconformity are widely spaced across the Mandurah Terrace, and none is located in the Bunbury Trough.

Determining the thickness of the *B. limbata* Zone and equivalents across the study area is difficult due to the number of single-sample sites, and boreholes that reach TD within the *B. limbata* Zone. Even for sites that do extend into the Jurassic, the regular presence of barren or low-yield assemblages around the Jurassic–Cretaceous unconformity hampers the depth estimation of that boundary. Mandurah Line 1 contains the thickest succession that can be confidently assigned to the *B. limbata* Zone — at least 343 m thick (9.14 – 352.0 m) — although an additional 62 m of the section below this contains no biostratigraphic data. The Lower Cretaceous successions in MPL1A and MPL6A are also thick (at least 238 m and 247 m, respectively) relative to other boreholes in the dataset (Plate 3); however, these boreholes bottom in the Cretaceous and there are no firm constraints on the true thickness of the *B. limbata* Zone in either. The borehole intersections re-examined here suggest that sediments containing the *B. limbata* Zone are thinner to the east, although this is somewhat uncertain due to the issues discussed above.

Absent sections

There are no obvious lacunae within the *B. limbata* Zone spore-pollen assemblages in the study area. However, this spore-pollen zone covers a long time period and is without subdivisions, and time gaps are difficult to identify without reference to the equivalent marine zonation.

There is no record in this area of the *F. tumida* or *G. mutabilis* Perth Basin Dinocyst Zones, or any of the older Australia-wide Valanginian to Berriasian dinocyst zones (lower *S. areolata* to *Pseudoceratium iehiense* Dinocyst Zones; Geoscience Australia, 2016). As Backhouse (1988a) observed that the *K. scrutillinum* Zone is the earliest period in the Cretaceous in which marine influence was widespread across the Perth Basin, it is likely that this absence is normal for the Perth Basin as a whole, and that deposition, if occurring, was entirely nonmarine in the southern Perth Basin prior to this time.

There is also no robust evidence for the *O. operculata* Australian Dinocyst Zone, the upper portion of which is considered younger than the uppermost (*F. monilifera*) Zone of Backhouse's (1988a) Perth Basin dinoflagellate scheme. Unfortunately, as only one borehole within the dataset — MPL1A — preserves both Early (*A. alata* Perth Basin Zone = *M. testudinaria* Australian Zone) and mid (*D. davidii* Australian Zone) Cretaceous palynofloras, it is uncertain whether the succession is conformable but incompletely sampled (i.e. *M. australis* and *O. operculata* Zones are present but unrecorded), or whether there is an unconformity or hiatus at this level (see 'late Early Cretaceous' section above for further discussion).

Comparison to other parts of the Perth Basin

In the Perth Basin, the *B. limbata* Zone and its dinocyst zone equivalents are the only palynological zones recorded within the Warnbro Group (Fig. 1; previously known as the South Perth Formation; Cockbain and Playford, 1973). Backhouse (1988a) demonstrated that assemblages of this zone (and its dinocyst zone equivalents) are well

1 Although the correct taxonomic name for this species has been changed to *Classopollis torosus*, the zone name does not appear to have been officially revised as of 2017; therefore it was decided to retain the original zone name proposed in Helby et al. (1987). See Appendix 3 for further discussion on this taxonomic nomenclature.

distributed across the central Perth Basin, although his report included boreholes from a geographic area wider than the present study, and lacked borehole sections between the Peel Inlet and north of Bunbury.

In the central and southern part of the Perth Basin, the Warnbro Group consists of three formations — the Gage Sandstone, South Perth Shale and Leederville Formation — although only the Leederville Formation is recorded in the Bunbury Trough (Backhouse, 1988a; Davidson, 1995). The poorly sorted sandstone of the Leederville Formation is thought to have been deposited within a fluvio-deltaic setting, and the siltstone, claystone and shale of the South Perth Shale is interpreted as deposited in inner-shelf marine conditions. The fine-grained Gage Sandstone is interpreted as a marine or restricted marine deposit. Based on Backhouse (1988a), the Gage Sandstone extends over the *G. mutabilis* to *P. lowryi* Zones, the South Perth Shale covers the *K. scrutillinum* to *A. alata* Zones, and the Leederville Formation ranges from the *A. alata* to the *F. monilifera* Zones in the Mandurah Terrace (listed as the 'southern Dandaragan Trough' in Backhouse [1988a]). This contrasts with the present study area, where all of zones *K. scrutillinum* to *F. monilifera* are recorded within sediments attributed almost entirely to the Leederville Formation. In the Perth area, Davidson (1995) estimated that the Gage Sandstone is up to 350 m thick onshore, the South Perth Shale up to 300 m thick, and the Leederville Formation up to 600 m thick. Due to the somewhat diachronous nature of these units across the basin, these Warnbro Group units are interpreted using a combination of lithology, geophysical log characteristics, and biostratigraphy (Davidson, 1995). Rocks of this group (and the *B. limbata* Zone assemblages) are truncated by a distinct Aptian-aged unconformity, and are generally overlain by rocks of the Osborne Formation (Backhouse, 1988a; Davidson, 1995).

Earliest Cretaceous — *B. eneabbaensis* Spore-Pollen Zone (Backhouse, 1988a)

Distribution

Unlike post-breakup *B. limbata* Zone assemblages, evidence for pre-breakup Cretaceous successions is rare in the boreholes reassessed here. Only a single borehole, PWD D12, has reported a palynological assemblage that could belong to the *B. eneabbaensis* Zone, collected from between two flows of the Bunbury Basalt (Burgess, 1978). Although Backhouse (1988a) appeared to confirm the zone identification of this sample in his monograph on Early Cretaceous palynofloras, the assemblage is unusual in that it includes a number of species thought to have become extinct within the *B. eneabbaensis* Zone (*Aequitriradites hispidus* and *Concavissimisporites variverrucatus*) and some species thought to first appear in the *B. limbata* Zone (*Foveosporites canalis*). Therefore, although this present Report follows Burgess (1978) and Backhouse (1988a) in regarding the sample representative of the *B. eneabbaensis* Zone, this sample should be re-examined to clarify its identity. Because the location details for this borehole are presently imprecise, the assemblage was not studied with the other assemblages and should be considered with caution until the location and sample identification can be verified. Therefore, this borehole is not discussed further here, and it is not included in this Report's appendices.

Other unusual assemblages, intermediate between the *B. eneabbaensis* and *B. limbata* Zones, have been noted in a small number of boreholes along the Harvey (HL1B, HL2A, and HL3A; Plate 1A) and Kemerton (KE1D; Plate 1B) Lines (Backhouse, 2012a), with other potential examples of this assemblage identified in boreholes such as KW4 and SBPS1. As described using the Harvey Line boreholes, this intermediate microfloral assemblage contains both nonmarine *Moorodinium* dinoflagellate cysts that had otherwise only been recorded in the Parmelia Formation farther north (Backhouse, 1988a; Backhouse, 2012a), and spores and pollen previously only recorded in the *B. limbata* and younger zones (but excluding the index taxa *Balmeiopsis limbata* and *Balmeiopsis robusta*). These taxa are associated with species typical of the *B. eneabbaensis* Zone (e.g. *A. hispidus* and *Januasporites multispinus*), and other long-ranging Early Cretaceous forms. Backhouse (2012a) informally named this characteristic assemblage the 'transitional *B. eneabbaensis* – *B. limbata* Zone', noting that it did not appear to be the result of assemblage mixing or downhole contamination; he also noted that similar assemblages were observed in other boreholes in the Bunbury Trough, particularly between flows of the Bunbury Basalt (perhaps referring to the PWD D12 assemblage). For simplicity, this Report treats the assemblage, named using the informal term coined by Backhouse (2012a), as separate from both the *B. eneabbaensis* and *B. limbata* Zones. However, it is noted that the unit may simply be an unusual phase of the *B. eneabbaensis* Zone with restricted geographic (and possibly biostratigraphic) distribution. Regardless, this unusual microflora, and the sedimentary sections within which they are recorded, requires additional research.

Although initially listed as belonging to the *B. limbata* Zone (Backhouse, 1988b, 1989), a set of samples from Kemerton 1D and a single sample from KW4 were also noted as unusual. They contain many of the taxa recorded in the *B. limbata* Zone, with the addition of *B. eneabbaensis* Zone *Moorodinium* cysts, as seen in the Harvey boreholes. However, as these reports do not provide species lists or mention other taxa in the descriptions, it is difficult to determine whether the assemblages contain a mixed *B. limbata* and *B. eneabbaensis* Zone, if the initial reports misidentified the biostratigraphic zone, or if there is evidence for assemblage contamination or reworking. Further work will be required to clarify the identity of these samples. Evidence for this same transitional assemblage was also seen in the shallowest palynological sample from GSWA Harvey 1 (795–825 m depth). However, this sample contained a mixture of drilling mud and cuttings, and the assemblage included Cretaceous, Jurassic and Triassic palynomorphs, making the age of the sample indeterminate. To date, all of the potential transitional samples are restricted to the central and southern portions of the study area, although this distribution may be a reflection of incomplete study.

No other assemblages reviewed here contained solid evidence for the *B. eneabbaensis* Spore-Pollen Zone or equivalent *F. tumida* Dinocyst Zone (Backhouse, 1988a), although there are a number of generic nonmarine Late Jurassic to Early Cretaceous spore-pollen assemblages (in AO12, AM66, HIG, HIH, LP1, Brownes bore, and Coastal Property 1), which may fall within this time span. However, based on the prevalence of *B. limbata* Zone and equivalent assemblages, these poorly reported assemblages are more likely to belong to the post-breakup palynology zones.

A few boreholes examined in this project intersected the Bunbury Basalt, specifically PWD D12, LP5 and EA1, although the palynological data are not robust in these boreholes (Edgell, 1962a,b, 1963; Backhouse, 1972). Engineering bores from the Bunbury Port area recently obtained by GSWA, many of which intersected multiple basalt flows, are currently under palynological and sedimentological study with the aim of better aligning the age of the basalt flows to the palynological zonation.

Comparison to other parts of the Perth Basin

Throughout the Perth Basin, *B. eneabbaensis* Zone assemblages are recorded only in the Parmelia Group; similarly, only this spore-pollen zone is recorded in this stratigraphic unit. As suggested by the eponymous spore's specific epithet, this zone was first identified in the Eneabba area of the Dandaragan Trough, and it is also commonly recognized within the northern Mandurah Trough (Perth area and surroundings). The *F. tumida* Dinocyst Zone is recorded in a number of wells in the central and southern part of the offshore Vlaming Sub-basin, including Bouvard 1, Charlotte 1, Gage Roads 1 and 2, Marri 1, Minder Reef 1, Mullaloo 1, Parmelia 1, Peel 1, and Roe 1 (Backhouse, 1988a; various well completion reports). Backhouse (1988a) noted that this dinocyst zone is dominated by nonmarine (lacustrine) forms, with the earliest truly marine form, *Gagiella mutabilis*, marking the top of this zone and the transition into the Warnbro Group. Offshore, the *B. eneabbaensis* and overlying *B. limbata* Zones (and corresponding dinocyst zones) are represented by thick sedimentary packages, reflecting rapid subsidence not seen onshore (Backhouse, 1988a).

The informally identified 'transitional *B. eneabbaensis* – *B. limbata* Zone' biostratigraphic unit is presently only recorded in the southern Perth Basin and has no clear equivalent in the offshore Vlaming Sub-basin, or onshore central or northern Perth Basin. Its distribution is uncertain due to the low numbers of analysed palynology samples and the fairly recent recognition of the assemblage. Due to its unusual nature, the unit has been variously placed at the base of the Warnbro Group, top of the Parmelia Group, or even considered representative of a separate stratigraphic unit known as 'young Parmelia'. Therefore, the Cretaceous succession of the southern Perth Basin, previously assumed to be identical to that of the central and northern basin, requires additional work to clarify biostratigraphic relationships to units farther north.

Jurassic

Five of the petroleum wells and 50 of the 205 water and geothermal bores studied yielded Jurassic-aged assemblages (Fig. 8a).

Middle to Late Jurassic — *D. complex* to *R. watherooensis* Spore-Pollen Zones

Distribution

All confirmed Late Jurassic assemblages in the dataset are within the Bunbury Trough close to the city of Bunbury, specifically within boreholes of the Picton (PL1 and PL4A), Laporte (LP1, LP3 and LP4), and Eaton (EA3) lines (Fig. 8b; Plates 1B, 5). Three possible Late Jurassic records from the Mandurah Terrace — recorded in Alcoa Pinjarra bore AO12, Harvey Irrigation bore HIG, and Brownes bore — are low-yielding assemblages heavily dominated by long-ranging Late Jurassic to Early Cretaceous spores and pollen, and there is a similarly indeterminate Late Jurassic to Early Cretaceous assemblage in the Bunbury Trough, in the Coastal Property 1 borehole. The ages of these assemblages are better considered indeterminate until the boreholes can be resampled or the ages clarified. Based on the current dataset, there is no solid evidence for Upper Jurassic successions on the Harvey Ridge, which agrees with previous interpretations that rocks equivalent in age to the Bajocian Cadda Formation (only recorded in the northern Perth Basin) and Bathonian–Tithonian Yarragadee Formation are absent from this area (Crostella and Backhouse, 2000; Thomas, 2014).

In the Bunbury Trough, only the three *Murospora florida* Australian Spore-Pollen Zone samples in EA3 have been placed with any precision within a zone. Of the other boreholes, the samples from LP1, LP3, LP4 and PL1 can only be placed somewhere between the *Dictyosporites complex* and *M. florida* Zones, whereas the PL4A samples are slightly more constrained, linked to either the *Contignisporites cooksoniae* or *M. florida* Australian Spore-Pollen Zone. The relatively low resolution of these assemblages is mostly due to the difficulties inherent in differentiating the *C. cooksoniae* and *D. complex* Zones from the *M. florida* Zone within the Perth Basin. Unlike the latter zone, the *C. cooksoniae* and *D. complex* Zones are defined principally by abundance changes, with relatively few index taxa, and are dominated by long-ranging species (Filatoff, 1975; Backhouse, 1978). None of the Late Jurassic assemblages of the Bunbury Trough includes in situ marine elements or taxa suggesting unusual marginal environments, thereby agreeing with the interpretation of strongly terrestrial, dominantly fluvial, conditions throughout the Perth Basin during the Middle to Late Jurassic (Backhouse, 1984; Mory and Iasky, 1996).

In EA3, Upper Jurassic rocks are at least 25 m thick and may be thicker, as the deepest sample containing *M. florida* Zone assemblages is at TD, and the boundary between Late Jurassic and overlying *B. limbata* Zone

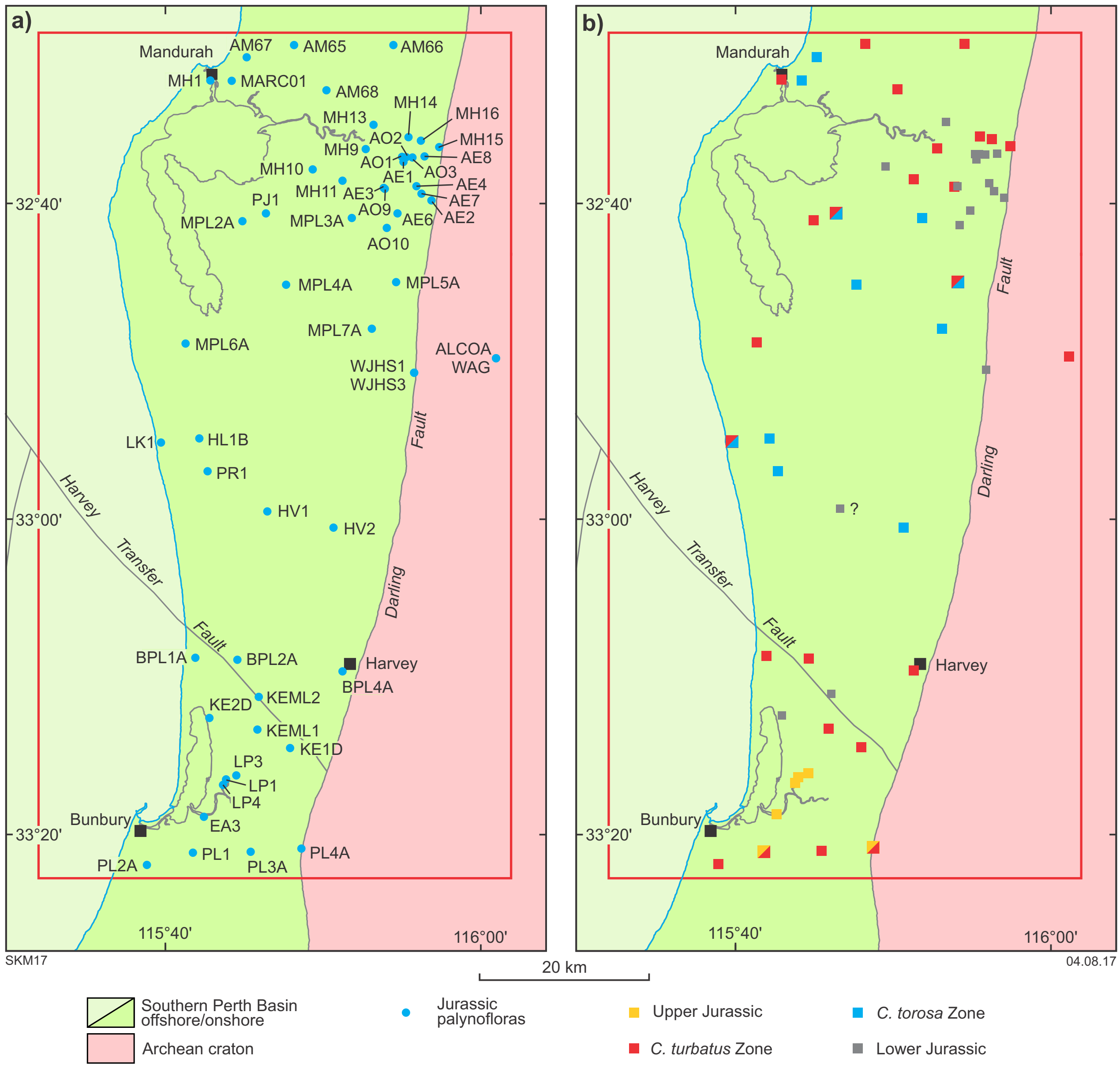


Figure 8. **a) Distribution of boreholes with Jurassic palynofloras within the study area; b) map illustrating the distribution of later Jurassic (*Murospora florida* to *Dictyotosporites complex* Zones), *Callialasporites turbatus* Zone, *Corollina torosa* Zone, and generalized or indeterminate Lower Jurassic assemblages. See Table 1 or Appendix 1 for a list of the borehole name abbreviations**

assemblages lies within a 317 m segment of the borehole with no biostratigraphic data (176.78 – 493.78 m; Plate 1B). Based primarily on unpublished lithology logs, the top of the Yarragadee Formation was placed at 202 m, which agrees with the available palynological data, although the Yarragadee Formation in this borehole may include palynofloras of multiple biostratigraphic zones (other than *M. florida* Zone).

In LP3, Late Jurassic assemblages extend from 710 ft (216.41 m) to borehole TD, and the boundary with overlying Lower Cretaceous (likely *B. limbata* Zone) rocks is somewhere between 552 and 710 ft (168.25 – 216.41 m; Balme, 1962; Backhouse, 2015c). Based on this information, the boundary between the Yarragadee Formation and overlying units can be assumed to fall somewhere within the same span. A similar succession is also seen in LP1; the boundary between Late Jurassic (*?M. florida* to *D. complex* Zone) and Early Cretaceous (*?B. limbata* Zone) assemblages is somewhere between 630 and 690 ft (192.02 – 210.31 m). Interestingly, although only 1.7 km southwest of LP3 and 0.7 km northeast of LP1, LP4 has its deepest Early Cretaceous palynology assemblages at 930 ft (283.46 m), far deeper than the shallowest Late Jurassic samples in either neighbouring hole, suggesting a localized thickening of at least 67 m in the Lower Cretaceous succession. Only a single Late Jurassic sample was recorded from LP4 at 1045 ft (318.52 m, close to TD), with the Jurassic–Cretaceous boundary falling somewhere between

930 and 1045 ft in this borehole. Unfortunately, the use of ditch cuttings for palynological analyses in the Laporte Line makes the assemblage depths somewhat suspect for all of the Laporte holes, and these boundary depths are even more uncertain as a result. No formal formation boundaries are available to allow correlation to biostratigraphy, and it appears that no wireline logs were run in Laporte Line bores 1–4.

Of the six boreholes with reasonable Late Jurassic assemblage data, PL1 and PL4A are the only boreholes for which the zone thickness can be estimated (Plate 5). Furthermore, greater confidence is placed on the depths of the zone boundaries in these boreholes due to the use of sidewall cores for palynological sampling. Biostratigraphic data from PL1 suggest at least 267 m of Upper Jurassic rocks unconformably sandwiched between samples containing the Lower Cretaceous *?B. limbata* and Lower–Middle Jurassic *C. turbatus* Zones. Although Wharton (1981) originally picked the base of the Cretaceous at 280 m depth, palynological evidence from this borehole instead indicates that the boundary is between 201 and 242.5 m. The boundary between Upper Jurassic and underlying Lower–Middle Jurassic rocks in PL1 is interpreted to be between 516 and 664.3 m based on palynological results summarized here, supporting Wharton's (1981) tentative pick of 566 m.

At least 58 m of Upper Jurassic rocks are preserved in PL4A, placed between Early Cretaceous assemblages and those of the Lower Jurassic *C. turbatus* Zone. The Cretaceous unconformity in this borehole falls between 69 and 198 m depth, although the palynological sample from 69 m is now lost and its age cannot be confirmed. Wharton (1981) placed this boundary at 104 m depth, noting that the unconformity was difficult to identify using lithology and wireline data alone. A recent restudy of the slides (Backhouse, 2011) identified the *C. turbatus* Zone in the deepest sample from PL4A, placing the boundary between Late Jurassic and Early–Middle Jurassic assemblages between 256 and 314 m; however, Wharton (1981) interpreted the Upper Jurassic rocks to extend through to TD. The new data suggest a thinner Upper Jurassic succession in the easternmost borehole of the Picton Line (PL4A; Plate 5) than previously assumed, perhaps indicating thinning (less deposition or greater erosion) towards the basin margin at the Darling Fault, similar to the trend seen in the Lower Cretaceous rocks.

Absent sections

There are presently no records in the project area of the Tithonian *Retitriletes watherooensis* Australian Spore-Pollen Zone (as defined by Helby et al. [1987], equivalent to the *R. watherooensis* plus *Aequitriradites acusus* Perth Basin Spore-Pollen Zones in Backhouse [1988a]). Combined with the absence of *B. eneabbaensis* Zone assemblages, this indicates a depositional break over the Jurassic–Cretaceous boundary in this part of the basin. *R. watherooensis* Zone assemblages have been noted in water and coal bores farther south in the Bunbury Trough, are present within petroleum well Rockingham 1 on the Mandurah Terrace to the north of Mandurah, and are recorded in offshore wells within the Vlaming Sub-basin (such as Sugarloaf 1 and Peel 1). The *R. watherooensis* Zone is also commonly recorded in the central and northern Perth Basin (Backhouse, 1978; Backhouse, 1988a); therefore, its absence in the southern Perth Basin appears to be a local feature, possibly due to the formation of the Harvey Ridge.

Comparison to other parts of the Perth Basin

Throughout the Perth Basin, the Yarragadee Formation extends from the upper *D. complex* Zone through to the top of the *R. watherooensis* Zone (or the top of *A. acusus* Zone in the Backhouse [1988a] scheme). Deposition of this unit is interpreted to have lasted at least 25 million years, from the Bajocian to the Jurassic–Cretaceous boundary, based on the current correlation of these palynology zones with the international time scale.

The Yarragadee Formation is a fluvial unit dominated by sand, with few finer-grained or carbonaceous layers. The unit is extensively developed in the subsurface throughout the Perth Basin, and the unit's only formal subsurface reference section (in petroleum well Gingin 1) is interpreted to be 2959 m thick (Backhouse, 1984; Mory and Iasky, 1996). Crostella and Backhouse (2000) indicated the unit's thickest section in the southern Perth Basin is 712 m in Karridale Line 6, noting no difference in lithology or biostratigraphy from records in the northern Perth Basin. Therefore, the paucity of sediments equivalent to the Yarragadee Formation in the study area is unusual compared to the northern Perth Basin and other parts of the southern Perth Basin. This is likely a result of exposure and weathering of this package around the edges of the Harvey Ridge prior to widespread post-breakup sedimentation in the area.

Underlying the Yarragadee Formation in the northern Perth Basin is the distinctively marine Cadda Formation, which contains palynomorph assemblages of the *Dissiliodinium caddaense* Dinocyst and lower *D. complex* to uppermost *C. turbatus* Spore-Pollen Zones. This Bajocian marine unit is interpreted to be absent across the study area, despite the presence of some Late Jurassic samples of ambiguous ages that may belong to the *D. complex* Zone (LP1, LP3, LP4 and PL1), and the numerous *C. turbatus* Zone assemblages (see section on the 'Early to Middle Jurassic', below). The only assemblage previously noted to be 'Cadda-equivalent' in age, within Mandurah Line 11, was later reassessed to be more indicative of the *C. turbatus* Zone. The southern boundary of Middle Jurassic marine influence lies close to the Perth Metropolitan area (Mory and Iasky, 1996), with the southernmost record of the *D. caddaense* Zone noted in Cockburn 1 in the offshore Mandurah Terrace. There is presently no evidence for marine conditions in the onshore central and southern Perth Basin during the Jurassic.

Early to Middle Jurassic — *C. torosa* and *C. turbatus* Spore-Pollen Zones

Distribution

Apart from the Early Cretaceous *B. limbata* Zone (Warnbro Group equivalent assemblages), the Early to Middle Jurassic *C. torosa* and *C. turbatus* Zones are the most widespread and most common palynological zones within the dataset (Fig. 8b). Assemblages from one or both of these Jurassic zones are recorded in four of the area's petroleum wells. In DMP Harvey 2, earlier Jurassic assemblages were the shallowest sampled biozones, although the overlying Cretaceous rocks were also sampled in Pinjarra 1, Preston 1 and Lake Preston 1 (Plates 1A, 4). The geothermal borehole MARC01, and 28 other bores also contain either the *C. torosa* or *C. turbatus* (or both) Zones.

Early or Early–Middle Jurassic assemblages that cannot be placed with certainty into either zone are recorded in 17 additional bores. A lack of complete species lists in legacy reports for 11 of the Alcoa Pinjarra boreholes (AE1–4, AE6–8, AO1–3, AO10) makes reassessment uncertain, although it may be possible to improve the biostratigraphic resolution by re-examining existing slides or resampling cores and cuttings, if samples are available. For KEML2, MH10, MH13, WHS1 and WHS3, the assemblages themselves are too poorly preserved or too low in diversity to allow adequate zone identification, and it is unlikely that these samples will ever provide clear biostratigraphic data. The final sample in this set of indeterminate samples is the shallowest assemblage from GSWA Harvey 1, which was a combination of drilling mud and drill chips collected from 795 to 825 m depth. The mud portion of this sample contains a mixed palynomorph assemblage including possibly Late Triassic (*Minutosaccus crenulatus* or *Samaropollenites speciosus* Zone), Early Jurassic (*C. torosa* or *C. turbatus* Zones) and Early Cretaceous ('transitional *B. eneabbaensis* – *B. limbata* Zone') forms, whereas the drill chips appear barren. As a result, it is difficult to determine which, if any, of the assemblage elements are in situ, and which elements are contaminants. Thus, the rocks at this depth are interpreted to be barren of palynomorphs, with the Triassic, Jurassic and Cretaceous palynomorphs either introduced in the drilling mud or from shallower in the borehole (Backhouse, 2014). As these poorly constrained Early Jurassic assemblages are difficult to assess, they are not considered in the following discussions, although they do provide additional support for the widespread distribution of Lower Jurassic sedimentary rocks, and the difficulties inherent in identifying these zones.

All of the Early Jurassic assemblages in the study area are nonmarine, with no acritarchs or other taxa that would indicate marine influence. However, the assemblages of this age in MARC01, HL1B, MPL3A, MPL4A, MPL5A, MPL7A and WHS1 are closely associated with coaly or carbonaceous lithologies, which suggest localized swamps or lakes.

Only three holes — Lake Preston 1, Pinjarra 1 and MPL5A — yielded assemblages of both the *C. torosa* and *C. turbatus* Zones (Plates 1A, 3 and 4). In Pinjarra 1, the palynological evidence indicates at least 130 m of *C. turbatus* Zone rocks, whereas the *C. turbatus* Zone in Lake Preston 1 is at least 76 m thick (121.9 – 198.1 m). Only a single *C. turbatus* Zone sample was seen in MPL5A, at 156–157 m depth, although this assemblage was considered both high yielding and well preserved in comparison to the poorer yielding samples from the two petroleum wells. In both petroleum wells, the *C. torosa* Zone samples are widely scattered and surrounded by numerous barren samples. In Pinjarra 1, this zone extends over at least 1980 m, although no slides from the two deepest *C. torosa* Zone assemblages reported by Balme (1966) could be found in the GSWA Relinquishment collection, reducing confidence in these records (Backhouse, 2016b). Only a single sample is clearly assignable to the *C. torosa* Zone (670.6 m) in Lake Preston 1, with no solid palynological data for 472 m below and at least 301 m above the sample. As a result, the boundary between the *C. torosa* and *C. turbatus* Zones, and the bottom boundary of the *C. torosa* Zone, are poorly constrained. In MPL5A, there is only 41 m between the single *C. turbatus* and shallowest *C. torosa* Zone samples, thereby providing far better control on the boundary between those zones; however, the two *C. torosa* Zone samples are low yielding and low in diversity in comparison to the well-preserved *C. turbatus* Zone assemblage seen in the same water bore. Although the *C. torosa* Zone assemblages in MPL5A are the deepest palynology samples in the borehole, there is 20 m below these samples (to TD) for which there are no age data, and the complete thickness of this zone is unknown (Plate 3).

In the remaining 33 boreholes, *C. turbatus* Zone assemblages are more numerous, recorded in 22 water bores, whereas *C. torosa* Zone assemblages are recorded in eight bores, including two petroleum wells and the single geothermal borehole. The *C. turbatus* Zone assemblages appear to be absent from the central Mandurah Terrace roughly coinciding with the Harvey Ridge, thereby confirming the absence of Middle and Upper Jurassic units in this area, with erosion bringing the older *C. torosa* Zone assemblages closer to the surface. An example is seen in the two petroleum wells in the centre of the Harvey Ridge, DMP Harvey 2 and Preston 1, which contain *C. torosa* Zone assemblages without evidence for the *C. turbatus* Zone, unlike the more marginal Lake Preston 1 where both zones are recorded (Plate 4). *C. turbatus* Zone assemblages also appear to be absent just east of Mandurah, as only *C. torosa* Zone assemblages are recorded in both MARC01 (Plates 1A, 2) and AM67. The more localized absence in this area seems more likely a result of nondeposition than regional erosion. However, because the two boreholes to the southeast, MH2 and MH3, were not drilled deep enough to intersect the Jurassic succession, the total areal extent of this *C. turbatus* Zone absence is unknown.

Within the study area, the Lower Jurassic succession directly underlies, or is assumed to directly underlie, the Cretaceous breakup unconformity, with two exceptions. In the southern part of the area, within the Bunbury Trough, two boreholes (Picton Line bores 1 and 4A; Plate 5) preserve Upper Jurassic rocks over Lower Jurassic successions; specifically, the *M. florida* to *D. complex* Zones in PL1, and the *M. florida* to *C. cooksoniae* Zones in PL4A (see 'Bajocian to Tithonian' section, above). Therefore, the Jurassic–Cretaceous unconformity appears to be a far shorter lacuna in the Bunbury Trough (covering perhaps the *R. watherooensis* through to *B. eneabbaensis* Zones) than on the Harvey Ridge, where this gap extends from at least the *D. complex* Zone through to the *B. eneabbaensis* Zone. On occasion, the gap extends from the *C. turbatus* Zone to the *B. eneabbaensis* Zone, particularly in areas where the *C. torosa* Zone is the shallowest Jurassic zone intersected. The second exception is in the far east of the Mandurah Terrace, along the boundary with the Yilgarn Craton (and more rarely in remnant sedimentary rocks on top of the Craton), where Early Cretaceous assemblages appear absent and Early Jurassic assemblages are encountered at very shallow depths. The best examples of this are seen in the Alcoa Wagerup (*C. turbatus* Zone at 28.6 m), Waroona Junior High School 1 (*?C. torosa* Zone at 15.2 m), Mandurah Line 15 (*C. turbatus* Zone at 15.2 m, see Plate 2), and Alcoa Pinjarra E2 ('Early Jurassic' assemblages at 58.6 m) boreholes, where the Jurassic succession appears to directly underlie Quaternary rocks. This agrees with previous interpretations of an uplifted sliver of Lower Jurassic sedimentary rocks lying alongside the Darling Fault (e.g. Commander, 1975; Playford et al., 1976; Davidson, 1995).

None of the water and geothermal boreholes with Early–Middle Jurassic assemblages contains evidence for Triassic palynomorphs, although a number of boreholes have barren or indeterminate assemblages at TD that might mask older (Triassic) units; for example, the bottom 100 m of MARC01 has no biostratigraphic information, although the top of the Lesueur Sandstone is interpreted close to TD (based on geophysical logging and lithology). The same is true for the shallow petroleum well Preston 1 — although this well was interpreted to have reached TD within the Lower Jurassic Eneabba Formation based primarily on lithology (Crostella and Backhouse, 2000), samples from 2210 ft (673.6 m) to TD were barren and could be Triassic in age (Plate 4).

Only the three deepest petroleum wells record Triassic assemblages below the Jurassic. DMP Harvey 2 has Upper Triassic *Ashmoripollis reducta* Spore-Pollen Zone assemblages directly underlying Lower Jurassic samples (Plates 1A, 1B and 4); for Pinjarra 1, the *M. crenulatus* or upper *S. speciosus* Spore-Pollen Zones are identified below the deepest Early Jurassic assemblage (Plate 1A). Underlying the deepest Early Jurassic assemblages in Lake Preston 1 is a 1325 m long section of poorly yielding samples tentatively Triassic in age, with the next deepest identifiable assemblage only generally attributable to a Middle to Late Triassic age (Plate 4).

Comparison to other parts of the Perth Basin

In the northern Perth Basin, the *C. torosa* Zone is recorded mainly in the Eneabba Formation, although the uppermost *C. torosa* Zone has been noted in the lowermost Cattamarra Coal Measures; similarly, the *C. turbatus* Zone is typically associated with the Cattamarra Coal Measures, although the uppermost part of the zone is thought to extend into the overlying Cadda Formation in some locations (e.g. Mory and Iasky, 1996; Mory et al., 2015). The poor yields and low diversity of these two Lower Jurassic zones mean that the boundary between them is imprecisely known in the Perth Basin. Of the two zones, the top of *C. turbatus* Zone is clearly recorded in the basin, as successions of this age commonly contain marine taxa, such as dinoflagellates and ammonoids (normally in the Cadda Formation), which can be used for age correlation. The base of the *C. torosa* Zone, which is thought to coincide with the transition from a *Dicroidium*-dominated to pteridosperm–conifer flora and seen as a change from *Falcisporites*- to araucariacean-dominated palynoassemblages (see the 'Biological and ecological controls' section of Appendix 2), is considered a key palynostratigraphic level Australia-wide (Helby et al., 1987; McLoughlin, 2001). However, this boundary is rarely seen clearly in the Perth Basin due to the strongly oxidized or sandstone-dominated Eneabba and Lesueur Formations and equivalent units, which rarely yield diverse palynofloras.

Although typically correlated to the *C. torosa* and *C. turbatus* Zones, respectively, the type and reference sections for both the Eneabba Formation and Cattamarra Coal Measures have poor biostratigraphic control, and few of the palynology samples originally described by Balme (1961) from Eneabba 1 (which contains the type section for both units) have been subsequently reviewed (Backhouse, 1992). Unsurprisingly for lithostratigraphically defined units, some age variability has been noted in both formations across the northern part of the basin. For example, Mory and Iasky (1996) noted that the Eneabba Formation seems to extend into the Late Triassic in some wells south of Woodada, suggesting that the lower contact of the unit may be diachronous across the Triassic–Jurassic boundary.

In the northern Perth Basin, the Eneabba Formation is a terrigenous redbed unit, consisting of interbedded sandstone and multicoloured, fine-grained lithologies, although Mory and Iasky (1996, p. 25) also noted the presence of 'minor carbonaceous shale and thin coal' in the unit. The Cattamarra Coal Measures is also an interbedded unit, containing sandstone and carbonaceous mudstones, with thicker coaly or coal-bearing layers throughout. In outcrop, the boundary between these two units has long been considered problematic (Playford and Cope, 1971; Playford and Low, 1972; Filatoff, 1975), although later workers (Mory, 1994a,b; Mory and Iasky, 1996) described log and lithological characters that allow separation of the formations in the northern Perth Basin. Historically, a very simplistic approach was used to identify these units, with multicoloured sedimentary rocks interpreted as part of the Eneabba Formation, and coaly or carbonaceous lithologies belonging to the Cattamarra Coal Measures. These criteria were also applied in the southern Perth Basin, including by Crostella and Backhouse (2000); however, this purely lithostratigraphic approach is of questionable usefulness for the Triassic and Jurassic units of the southern Perth Basin, where oxidation is extensive and extends throughout the Triassic and Jurassic (based on sparse palynology), coals are relatively rare, and marine pulses are absent. This has led to considerable confusion over the definition and age of the early Mesozoic stratigraphy south of Perth.

Zonal issues

A unique combination of Early Jurassic phytoevolution, climate, and geology in the Perth Basin makes the *C. torosa* and *C. turbatus* Zones difficult to identify and interpret, particularly in the southern part of the basin. Phytoevolutionary stasis, noted in the later Triassic and Early Jurassic worldwide, and encouraged by low climatic gradients from equator to pole and relative environmental stability, have resulted in fewer distinctive bioevents recognized across this interval, and therefore few opportunities to separate assemblages into zones. As a result, both of these Lower Jurassic spore-pollen zones are long-ranging, with the *C. torosa* Zone currently interpreted as extending 20 Ma (201–181 Ma) and the *C. turbatus* Zone ranging 11 Ma (181–170 Ma). Along with the Upper Triassic *M. crenulatus* Zone, *C. torosa* is the longest spore-pollen zone in the Mesozoic Australian palynology scheme.

Although considered moderately diverse Australia-wide by Helby et al. (1987), the *C. torosa* Zone in the Perth Basin is characteristically exceptionally low yielding and low in diversity, dominated by common, long-lived taxa and few index taxa. Filatoff's (1975) discussion of his lower *Classopollis chateaunovi* Assemblage-subzone (not including the *Classopollis anasillos* Range-Zone), which is considered equivalent to the whole of the *C. torosa* Australian Spore-Pollen Zone, is particularly useful in describing the features of this zone within the Perth Basin. In the southern Perth Basin, these assemblages appear to consist dominantly to almost exclusively (50% of yield up to 95% or more) of *Classopollis* spp., with rarer secondary taxa dominated by araucariaceans and ferns.

Overall, the *C. turbatus* Zone is regarded as higher in diversity and better yielding than the *C. torosa* Zone. Again, Filatoff's (1975) discussion of his *C. anasillos* Range-Zone to *Dictyophyllidites harrisii* Assemblage-subzone, which together are considered equivalent to the *C. turbatus* Australian Zone, are instructive when considering the Perth Basin specifically. However, in the majority of southern Perth Basin assemblages reviewed here, the increase in diversity and yield between zones is relatively small. The *C. turbatus* Zone is commonly identified based on lower proportions of *Classopollis* spp., and increased proportions of *Exesipollenites tumulus* and *Callialasporites* spp. (especially *Callialasporites turbatus* and *Callialasporites dampieri*; Filatoff, 1975; Helby et al., 1987).

As a direct result of these low-diversity palynofloras, attempts to assign Early–Middle Jurassic assemblages to either of these two zones relies heavily on taxon absences, and the relative abundances of taxa such as *Classopollis* spp., *Cyathidites* spp., and *Callialasporites* spp. Assemblages of exceptionally low yield and diversity, consisting almost entirely of *Classopollis* spp., are commonly placed within the *C. torosa* Zone, whereas slightly richer assemblages, with increased numbers of *C. turbatus* and *C. dampieri* are commonly placed in *C. turbatus* Zone (Filatoff, 1975; Helby et al., 1987). Of the other identified index taxa, only *E. tumulus* is commonly recovered in the Perth Basin. Although Filatoff (1975) noted that this species was present sporadically throughout the whole of his *Exesipollenites tumulus* Assemblage-zone (equivalent to both the *C. torosa* and *C. turbatus* Australian Spore-Pollen Zones), he also noted that records of the species become 'almost negligible' in the south. Helby et al. (1987) considered this (almost exclusively Western Australian) species dominant in the lower *C. turbatus* Zone, with a possible extension into the upper *C. torosa* Zone in the northern part of the basin.

The low diversity and yield of the Early Jurassic assemblages, and reliance on negative evidence, reduces confidence in zone identifications in the southern Perth Basin. Without one of the rare index taxa as support, differentiating a typical *C. torosa* Zone assemblage from an unusual, depleted, or poorly preserved *C. turbatus* Zone assemblage (i.e. an assemblage abnormally high in *Classopollis* spp. or low in diversity) is difficult. An example of this can be seen in BPL4A, which is a low-diversity *C. turbatus* Zone assemblage with *Classopollis torosus* as the co-dominant taxon; similarly, in a review of palynology slides from HL1B, Backhouse (2012a) noted that one low-diversity sample is difficult to place, suggesting it could belong in *C. torosa* Zone, or could be a *Classopollis*-rich interval of the *C. turbatus* Zone. This uncertainty is apparently reflected in the high number of reports where 'Early Jurassic' is the greatest level of biostratigraphic precision the palynologist was able to reach. These issues must be considered carefully in this region, due to confusion over the applicability and usage of the Lower Jurassic stratigraphic units.

Triassic

Only four of the petroleum wells (Pinjarra 1, Lake Preston 1, GSWA Harvey 1 and DMP Harvey 2) in the region are deep enough to yield palynofloras older than Jurassic (Fig. 9; Plates 1A, 1B and 4). Due to the highly reduced dataset, it is difficult to extrapolate successions and zones across the entire study area, and the following discussions are therefore localized.

Unlike the Permian, Jurassic and Cretaceous, the Triassic assemblages of the Perth Basin have never been formally studied or monographed, and much of the work on these zones within Western Australia has been conducted in the Carnarvon Basin (e.g. Dolby and Balme, 1976; Backhouse et al., 2002). The exception is the Early Triassic assemblages of the Kockatea Shale (a unit only recorded in the northern Perth Basin), which were initially studied by Balme (1963) and later used by Dolby and Balme (1976) to establish their *K. saeptatus* Zone. Therefore, it is presently unclear whether Triassic Perth Basin palynofloras are particularly different, localized or specialized in comparison to northwestern or eastern Australia. This is important as the Triassic paleoenvironment in the Perth Basin, and particularly in the south of that basin, was clearly different from other parts of Western Australia where the palynology has been well studied, such as the fluvio-deltaic to shallow-marine successions of the North West Shelf, offshore Canning Basin, and Bonaparte Basin (e.g. Riding et al., 2010).

Latest Triassic — *M. crenulatus* and *A. reducta* Spore-Pollen Zones

Distribution

DMP Harvey 2 and Pinjarra 1 are the only boreholes in the dataset to yield Late Triassic palynomorph assemblages; specifically two samples assigned tentatively to the *A. reducta* Spore-Pollen Zone from DMP Harvey 2, and a single sample from the lower *M. crenulatus* or *S. speciosus* Zone in Pinjarra 1 (Plates 1A, 1B and 4).

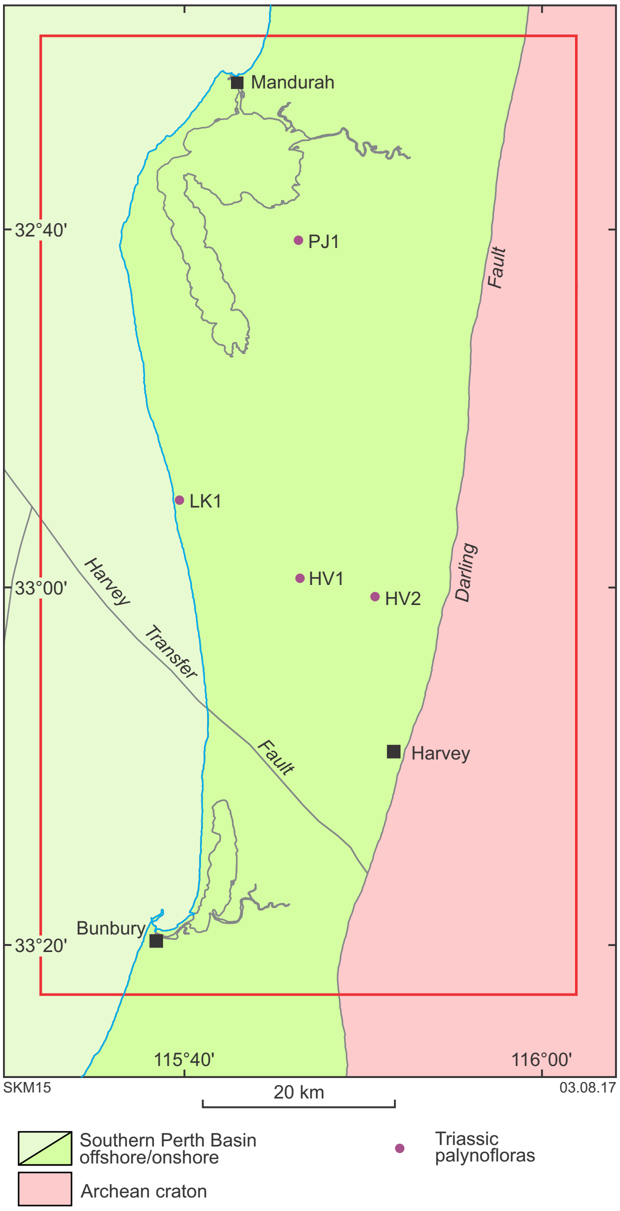


Figure 9. Distribution of boreholes with Triassic palynofloras recorded within the study area. See Table 1 or Appendix 1 for a list of the borehole name abbreviations

Both of the DMP Harvey 2 samples (at 732.5 and 793.10 m) are relatively low yielding and the assemblages lack many of the key index taxa seen farther north in the Carnarvon Basin. This decreases confidence in the zone identification, although the presence of both the nominate species and ubiquitous Triassic spore *Falcisporites australis,* and lack of evidence for older zones, makes the *A. reducta* Zone most likely. The samples also contained a number of acritarch species, specifically the brackish- or freshwater forms *Bartenia communis*, *Lecaniella* spp. and *Pilasporites crateriformis*, and were interpreted as nonmarine. Therefore, the difference in zone diversity and preserved assemblage between the Northern Carnarvon and southern Perth Basins appears to reflect differences in depositional environments — rocks containing the *A. reducta* Zone are mostly marginal marine on the North West Shelf (Backhouse et al., 2002), compared to the terrestrial, sandstone-dominated sedimentary units of the Late Triassic in the southern Perth Basin. Formation picks for DMP Harvey 2 place both of these samples in the centre of the Yalgorup Member of the Lesueur Sandstone (Plates 1A, 1B and 4), which agrees with previous interpretations that this unit is Late Triassic in age. The *A. reducta* Zone is of biostratigraphic interest as the top of the zone (and therefore the base of the *C. torosa* Zone) is correlated to the Triassic–Jurassic boundary based on work in the North West Shelf, and the zone is relatively short in chronostratigraphic terms, covering the Rhaetian. Therefore, a relatively precise age constraint can be applied to these two samples in DMP Harvey 2, assuming that the *A. reducta* Zone is correlatable between the Northern Carnarvon and Perth Basins.

In Pinjarra 1, the single low-yielding lower *M. crenulatus* or *S. speciosus* Zone (Norian–Carnian) sample at 8800 ft (2682.24 m) indicates an older section than that intersected in DMP Harvey 2. The sample is moderately diverse, although much of the material is poorly preserved, making identifications difficult. The presence of *Camerosporites secatus* is used as evidence that the sample is not from the upper *M. crenulatus* Zone, although the other taxa seen in the assemblage are typical of both the lower *M. crenulatus* and *S. speciosus* Zones, reducing the precision of the age determination. An algal form seen in this sample, *Plaesiodictyon mosellanum*, is an indicator of brackish to freshwater environments, and there is no evidence for marine influence at this level. The *M. crenulatus* Zone is typically considered late Carnian to late Norian in age and the *S. speciosus* Zone is normally correlated to the middle to late Carnian (Fig. 4), making the Pinjarra 1 sample middle Carnian to late Norian in age. Based on Crostella and Backhouse's (2000) formation picks for Pinjarra 1, this sample falls in the middle of the Yalgorup Member (Plate 1A), but is underlain by a section of poor palynological assemblages that make the interpretation of later Triassic floras very difficult in the Pinjarra area.

Although indications of similarly aged Late Triassic assemblages (*M. crenulatus* or *S. speciosus* Zones) are also seen in the shallowest, heavily mixed and likely contaminated palynological sample from GSWA Harvey 1 (at 795–825 m), the dubious nature of that sample makes the apparent similarity difficult to interpret.

Lake Preston 1 also contains likely Upper Triassic assemblages of low yield and poor preservation, which cannot be assigned to any particular zone. The top of this data-poor section consists of a set of barren samples that extends for 1270 m below the deepest record of the *C. torosa* Zone (670.56 – 1943.4 m). These samples are interpreted as possibly Triassic based on a comparison of organic matter in these samples with material in deeper assemblages that are confidently dated as Triassic. This is followed at a deeper level by a section of vaguely Middle to Late Triassic palynomorphs and barren samples, until the first likely *T. playfordii* Spore-Pollen Zone samples are finally recovered at 2585.01 m depth. Therefore, although there is no direct evidence for the *A. reducta* to *Staurosaccites quadrifidus* Spore-Pollen Zones in Lake Preston 1, no break in deposition is interpreted for this portion of the well. If Crostella and Backhouse's (2000) formation tops for Lake Preston 1 are accepted, this interval of no or poor biostratigraphic data extends across the deepest 500 m of the Eneabba Formation, throughout the entire Yalgorup Member and about 500 m into the Wonnerup Member (Plate 4); this is somewhat surprising as the Eneabba Formation is generally thought to be Early Jurassic in age. This barren segment appears to be a product of the dominantly sandy and heavily oxidized lithologies that characterize the Early Jurassic and later Triassic in the southern Perth Basin.

Absent sections

There is no firm evidence for assemblages of the upper *M. crenulatus* Zone. Furthermore, if the sample from Pinjarra 1 belongs in the *S. speciosus* Zone, then there is no evidence for the *M. crenulatus* Zone at all in the study area. However, this absence does not necessarily suggest a depositional hiatus during the Late Triassic. The *A. reducta* and *M. crenulatus* Zones are clearly irregularly preserved in the Perth Basin, and are here associated with a heavily oxidized (Yalgorup Member) and sandstone-dominated (Wonnerup Member) sedimentary succession that rarely preserves good palynomorph assemblages; therefore, it is as likely that environmental influences are masking the presence of the zones.

Comparison to other parts of the Perth Basin

The record of *A. reducta* Zone within DMP Harvey 2 is unexpected, as this zone has not been previously recorded within the southern Perth Basin and is rare in the northern Perth Basin; however, the zone is well defined within the Carnarvon Basin (Backhouse et al., 2002). Like the *A. reducta* Zone, the *M. crenulatus* Zone is not commonly recorded within the Perth Basin; in the Northern Carnarvon Basin, the *M. crenulatus* Zone is well defined and it is recorded within the Mungaroo Formation (Backhouse et al., 2002). Conversely, *S. speciosus* Zone assemblages are relatively common within the Lesueur Sandstone in the Perth Basin (see 'Middle to Late Triassic' section).

In the northern Perth Basin, the *A. reducta* and *M. crenulatus* Zones are recorded only in the Lesueur Sandstone, with this formation correlating to the *A. reducta* – *T. playfordii* Zones (Fig. 1; Mory and Iasky, 1996). However, as assemblages of the *A. reducta* Zone are rarely observed or preserved, *M. crenulatus* to *T. playfordii* Zone assemblages are more commonly recovered from this unit. Similar to the assemblages recorded here, biostratigraphic data are relatively patchy for the Lesueur Sandstone in the northern Perth Basin, which is a reflection of the dominantly coarse-grained lithologies in the unit.

In the northern Perth Basin, the Lesueur Sandstone is generally a coarse to very coarse feldspathic and pebbly sandstone, with minor siltstone and conglomerate. The ratio of fine-grained lithologies was noted to increase towards the north of the basin (north of Eneabba), whereas the overall unit thickness is noted to increase considerably (up to 3000 m) to the southeast (Mory and Iasky, 1996). Interpreted as deposited under fluvial conditions, perhaps trending to alluvial fan settings towards the current Perth Metropolitan region, the Lesueur Sandstone is entirely terrestrial in nature, and in this regard the northern and southern records are similar. The unit has been noted as difficult to separate from the overlying Eneabba Formation and some authors have suggested that the units interfinger (Balme, 1969).

Middle to Late Triassic — *T. playfordii* to *S. speciosus* Spore-Pollen Zones

Distribution

Four of the petroleum wells re-examined include Middle to Late Triassic palynological assemblages covering the *T. playfordii* to *S. speciosus* Zones. Due to their greater depths, Lake Preston 1 and Pinjarra 1 intersected older zones than the Harvey wells, extending down to the *T. playfordii* Zone; GSWA Harvey 1 and DMP Harvey 2 only extend as far as the *S. quadrifidus* Zone before reaching TD (Plates 1A, 1B and 4).

GSWA Harvey 1 has more certainly identified samples within its Middle Triassic succession compared to DMP Harvey 2, which has the more comprehensively preserved Upper Triassic to Lower Jurassic succession (discussed in sections above). The shallowest samples with robust palynological data in GSWA Harvey 1 (at 901.75 and 903.6 m) contain broadly similar, moderate-yield and moderate-diversity assemblages considered typical of the *S. speciosus* Zone, and specifically within the lower *S. speciosus* Zone based on the combination of rare *Ephedripites macistriatus* and *Staurosaccites quadrificus*, plus the likely absence of the freshwater acritarch *B. communis*. The deepest productive palynological sample in this well is at 2514.4 m, with a sample tentatively identified as the *S. quadrifidus* Zone. However, the low diversity and poor preservation of the spores and pollen in this sample make the zone difficult to identify confidently, and it is possible that the sample instead belongs to the *S. speciosus* or *T. playfordii* Zones. Between 903.6 and 2514.4 m is a long interval of barren samples, with an additional 400 m below 2514.4 m for which there are no biostratigraphic data. Using the formation tops presented in the well completion report (Millar and Reeve, 2014), the two shallowest palynological samples are within the Yalgorup Member, whereas the deepest sample falls into the Wonnerup Member.

DMP Harvey 2 (Plates 1A, 1B and 4) has four low-yield, moderate-diversity samples, from 1111.9 to 1348.25 m, all assigned to the lower *S. speciosus* or *S. quadrifidus* Zones; as the deepest of these four samples is very close to TD it is likely that no older biostratigraphic zone was intersected in this borehole. Using the formation tops from the DMP Harvey 2 well completion report, these lower *S. speciosus* to *S. quadrifidus* Zone samples were collected within the lowermost Yalgorup Member and into the Wonnerup Member. Although this seems to suggest an age similarity between these two stratigraphic units, the zones and any potential boundaries cannot be precisely identified within this four-sample set. Between these Middle Triassic samples and the deepest *?A. reducta* Zone sample at 793.10 m is approximately 300 m of well without robust biostratigraphic control — the two samples within this segment are unusual, low-yielding, low-diversity assemblages, which could not be assigned to any known spore-pollen zone. If the Middle–Upper Triassic succession within DMP Harvey 2 is continuous and conformable, this 300 m gap may cover the entire *M. crenulatus* and upper portion of the *S. speciosus* Zones. Backhouse (2015a) suggested the presence of a time break somewhere within this succession, perhaps reflecting the normal fault intersected by this well, or else indicating a period of nondeposition or condensed section.

Assemblages of the *T. playfordii* Zone are the only Middle–Late Triassic zones recorded with certainty in both Pinjarra 1 and Lake Preston 1. In Pinjarra 1, a single sample at 14 820 – 15 000 ft (4517.14 – 4572.0 m), close to TD, was tentatively assigned to this zone, although it is possible that some of the shallower, more generically Middle–Late Triassic samples encountered between 8970 and 14690 ft (2734.06 – 4477.51 m; Plate 1A) may also belong to this zone. Similar low-diversity *?T. playfordii* Zone assemblages are recorded in Lake Preston 1, at depths of 8481, 9000 and 10 150 ft (2585.0, 2743.2 and 3093.7 m; Plate 4). Like the sample from Pinjarra 1, the deepest of these samples is dominated by *Aratrisporites tenuispinosus* (a typical *T. playfordii* Zone form), with few other taxa; the shallower sample from that set is higher in diversity, but lacks any index taxa. The single *T. playfordii* Zone sample in Pinjarra 1 (at 14 820–15 000 ft; 4517.1 – 4572.0 m) has been correlated to the sample from 10 150 ft (3093.7 m) in Lake Preston 1 (Backhouse, 2016b), with the considerably deeper record in the more northerly well likely due to the thicker Jurassic succession in this area.

Lake Preston 1 also has three cuttings samples, at 10 800, 10 850 and 10 900 ft (3291.8, 3307.1 and 3322.32 m), with unusual palynomorph assemblages reminiscent of both the *T. playfordii* and *K. saeptatus* Zones. Although this assemblage contains some of the elements of the older *K. saeptatus* Zone, the overall assemblage is similar to the younger *T. playfordii* Zone. This may reflect a local variation in the vegetation, poor preservation of palynomorphs at depth, or caving in these lower cutting samples.

Absent sections

There is no robust evidence for the upper part of the *S. speciosus* Zone within the study area. However, like the *A. reducta* and *M. crenulatus* Zones, it is likely that evidence for this zone is obnubilated by the pervasive oxidation and rarity of fine-grained lithologies common in the Middle–Upper Triassic succession.

Comparison to other parts of the Perth Basin

The Middle Triassic *S. speciosus* to *T. playfordii* Zones are all recorded within the Lesueur Sandstone within the northern Perth Basin, with the *T. playfordii* Zone also recorded within the Woodada Formation, a relatively thin subsurface unit seen north of Jurien Bay. The Woodada Formation is interpreted as an intermediate unit between the marine, dominantly fine-grained Kockatea Shale, and the fluvial, dominantly coarse-grained Lesueur Sandstone, indicating deposition in a deltaic environment (Mory and Iasky, 1996). The Woodada Formation is not recorded in the central or southern Perth Basins, and is likely age equivalent to the lower part of the Wonnerup Member (Mory and Iasky, 1996; Crostella and Backhouse, 2000). This interpretation is based primarily on the recognition of *T. playfordii* Zone assemblages within the interpreted Wonnerup Member within Lake Preston 1, and is supported by the fact that no Middle Triassic zones (i.e. *T. playfordii* Zone or younger) have yet been recorded in the Sabina Sandstone, which underlies the Wonnerup Member (Fig. 1). The interpreted depositional environment of the Middle Triassic Woodada Formation is similar to the Lower Triassic Sabina Sandstone, which appears deltaic to fluvial in nature, as opposed to the fluvial sandstones of the Wonnerup Member. This difference reflects the change in relative position of the Early and Middle Triassic shoreline, which was retreating northwards throughout the Triassic.

Earliest Triassic — *P. crenulata* to *P. samoilovichii* Spore-Pollen Zones

Distribution

Lake Preston 1 is the only well in the Harvey area containing Early Triassic palynological assemblages, although GSWA Harvey 1 was interpreted to reach TD within the Sabina Sandstone, no palynological samples were obtained that confirm the age of this section (Plate 4).

In Lake Preston 1, Early Triassic assemblages were identified in 31 samples, mainly ditch cuttings, extending from 11 150 to 12 828 ft (3398.5 – 3910.0 m). All of these samples are assigned to the *K. saeptatus* Zone as per Dolby and Balme (1976); however, Backhouse (2016a) noted that these assemblages were different in overall character to equivalent zone assemblages recorded in the northern Perth Basin. The Western Australian *K. saeptatus* Zone is interpreted as equivalent to the Australian upper *L. pellucidus* Spore-Pollen Zone and the whole of the *P. samoilovichii* Spore-Pollen Zone (Helby et al., 1987). These Australian Spore-Pollen Zones are considered difficult to apply in Western Australia, which is likely why usage of the *K. saeptatus* Zone continues locally.

The Lower Triassic rocks in this well are at least 511 m thick, although a small number of samples above this contain species characteristic of both

T. playfordii and *K. saeptatus* Zones, and a number of underlying samples are identified as '*K. saeptatus* Zone or older', suggesting the actual thickness may be closer to 700 m (Plate 4). Unfortunately, the overall poor preservation of palynomorphs within these deep samples makes it difficult to identify many of the species, although Backhouse (2016a) noted some variation in the assemblage with depth. The shallowest samples, including those of the '*T. playfordii* to *K. saeptatus* Zone', contain abundant *Densoisporites* spp. from 11 238 to 11 450 ft (3425.3 – 3490.0 m) depth; assemblages from 11 750 to 12 766 ft (3581.4 – 3891.1 m) contain monosaccate pollen; large, dark *Rugulatisporites/Verrucosisporites* specimens are noted from 12 016 to 12 828 ft (3662.5 – 3910.0); and the nominative species, *Kraeuselisporites saeptatus*, is recorded from 11 238 to 12 766 ft (3425.3 – 3891.1 m). The *K. saeptatus* Zone appears conformable with the overlying *T. playfordii* Zone in Lake Preston 1, based on samples confidently assigned to both zones and the intermediate assemblages seen between. The transition between the *K. saeptatus* Zone and the underlying (presumed Permian) biostratigraphic units cannot be determined due to the poor preservation of palynomorphs.

This interpretation differs from that of the original well completion report (Dolby and Williams, 1973), where the Permian–Triassic boundary was considered to lie between 11 800 and 11 850 ft (3596.6 – 3611.9 m), although all samples from 11 700 to 13 150 ft (3566.2 – 4008.1 m) were noted as containing a mixed assemblage of Permian and Triassic forms, compared to similar assemblages in the Wonnerup 1 and Whicher Range 1 petroleum wells further south in the Bunbury Trough. Crostella and Backhouse (2000) later recorded these 'mixed samples' as evidence for the *?Protohaploxypinus microcorpus* Spore-Pollen Zone, although no evidence for this questionably earliest Triassic zone was recorded during the slide redescription. Conversely, the recent slide redescription (Backhouse, 2016a) suggested that the Permian–Triassic boundary is likely deeper, perhaps below 13 150 ft (4008.1 m), a depth at which Dolby and Williams (1973) also noted a distinct change in the palynoflora. This depth is close to the estimated top Willespie Formation (Fig. 1; top of the Sue Group) selected by Crostella and Backhouse (2000) at 4035 m, suggesting (extremely tentatively) that the Sabina Sandstone does not extend into the Permian in this well.

In the original well completion report, the Sabina Sandstone was interpreted as extending from 11 399 to 13 239 (3474–4035 m); although Crostella and Backhouse (2000) retained the bottom pick, they revised the top of the Sabina Sandstone to 3511 m depth. Based on this interpretation, the *K. saeptatus* Zone appears to extend throughout the Sabina Sandstone and into the overlying unit (interpreted as the Wonnerup Member based on Crostella and Backhouse [2000]). From these interpretations, the whole of the Sabina Sandstone and the lowermost Wonnerup Member (Lesueur Sandstone) is Early Triassic in age in Lake Preston 1 (Plate 4). This interpretation, if correct, has implications for the age control and definition of the Wonnerup Member, which is poorly defined at present.

Absent sections

There is no evidence for the transitional Permian–Triassic *Playfordiaspora crenulata* and *P. microcorpus* Spore-Pollen Zones within the study area. However, these short-ranging zones are rarely preserved Australia-wide, and are difficult to distinguish from each other, to the extent that the two are combined into a larger *P. crenulata* Zone in MGPalaeo's 2014 zonation scheme (Geoscience Australia, 2016). The placement of these zones at the Permian–Triassic boundary suggests that these low-diversity assemblages are disaster floras, with mass-extinction recovery beginning during the more distinctive *K. saeptatus* Zone. The rarity of these zone assemblages in the Perth Basin may indicate that this era boundary corresponds to a basinwide period of erosion or depositional hiatus, or may simply appear absent due to their low diversity.

Comparison to other parts of the Perth Basin

In the northern Perth Basin, deposition of the Kockatea Shale extends from the ?earliest Triassic *P. microcorpus* to *T. playfordii* Australian Spore-Pollen Zones, including the locally preferred Lower Triassic *K. saeptatus* Western Australian Spore-pollen Zone (Mory and Iasky, 1996). This marine transgressional unit onlaps the Northampton Inlier, with the maximum age of the succession becoming younger towards the southeast. The Kockatea Shale outcrops only rarely, but is thickly developed and widespread in the subsurface. In the southern Perth Basin, the Sabina Sandstone is interpreted as the lateral equivalent to the Kockatea Shale, and similarly extends through the *P. microcorpus* to *P. samoilovichii* Zones (including the local *K. saeptatus* Zone). However, the earliest assemblages of the Sabina Sandstone — the *P. microcorpus/P. crenulata* Zone(s) — have only been recorded in Whicher Range 2 and are therefore rare in the southern part of the basin (Crostella and Backhouse, 2000). Unlike the Kockatea Shale, there have been no records of Middle Triassic (*T. playfordii* Zone) assemblages within the Sabina Sandstone.

In the northern Perth Basin, *K. saeptatus* Zone palynofloras contain strong marine indicators, particularly acritarchs; however, no marine indicators are seen within the Sabina Sandstone, and the unit is considered wholly continental. Therefore, during the Early Triassic the paleoshoreline lay north of the Harvey area, likely in line with the present Perth Metropolitan region. Lake Preston 1 is identified as containing the thickest section of Sabina Sandstone anywhere in the southern Perth Basin (Crostella and Backhouse, 2000). Crostella and Backhouse (2000) also noted that the unit thins towards the west, suggesting that the basin's depositional edge was within the Vasse Shelf during the Early Triassic.

Permian

Lake Preston 1 is the only well or borehole re-examined that was interpreted to reach Permian units, although palynomorphs are poorly preserved towards the bottom of this well due to strong thermal alteration of the sediments at depth.

Dolby and Williams (1973) originally considered the samples from 11 850 to 13 150 ft (3611.9 – 4008.12 m) as latest Permian in age, based on the identification of *Kraeuselisporites rallus*, a species initially described from the latest Permian of Salt Range, Pakistan, and which had been described as part of Zone VIII (very latest Permian) of Kemp et al.'s (1977) Permian Canning Basin biostratigraphic zonation. A revision of the Lake Preston 1 palynology slides (Backhouse, 2016a) considered that the specimens previously identified as *K. rallus* are more likely to be *Kraeuselisporites cuspidus*, a form common in the Lower Triassic Kockatea Shale; as a result, the section down to at least 13 200 ft (4023.4 m) is reinterpreted as Early Triassic in age. Below this depth, age evidence is sparse, with numerous barren samples and the few productive samples preserving very lean assemblages dominated by Triassic (possibly caved) taxa, and a small number of possible Permian taxa. Therefore, although deep Permian units are still a possibility, there is no firm evidence for palynoassemblages of this age within Lake Preston 1, hampering comparisons between this succession and others within the southern Perth Basin, such as in Sue 1 and Whicher Range 1.

Lake Preston 1 was interpreted to reach TD within the Sue Coal Measures (now the Sue Group), with the boundary between it and the overlying Sabina Sandstone placed at 13 239 ft (4035.2 m) in the original well completion report (Young and Johanson, 1973). This depth is similar to the new top Permian pick (Plate 4). Elsewhere in the southern Perth Basin, the Sue Group has been noted to extend from the Sakmarian *Pseudoreticulatispora confluens* Zone through to the uppermost Permian – lowermost Triassic *P. microcorpus* Zone (e.g. Backhouse, 1993).

Barren and indeterminate sections

Barren and indeterminate sections are common and widespread across the study area (Fig. 10), a result of the dominance of coarse-grained lithologies and extensive oxidation of the nonmarine pre-Cretaceous succession. Aside from isolated unproductive or low-yield samples, barren sections are common at two particular levels: around and below the Cretaceous unconformity; and within the Early Jurassic and Late Triassic assemblages, particularly assemblages of the *C. torosa* to *T. playfordii* Zones.

Short barren sections are regularly developed between Cretaceous (normally the *B. limbata* Zone or equivalent dinocyst zones, and also generic 'Neocomian–Aptian' assemblages likely ascribable to this zone) and underlying, normally Lower Jurassic, zones. These barren samples appear related to the Cretaceous breakup unconformity, with the Jurassic sediments underlying the unconformity likely affected by erosion thereby destroying palynomorphs, an influence that may be compounded by the naturally low-yielding nature of the Lower Jurassic palynomorph assemblages. Barren samples above the unconformity are more difficult to explain, but may reflect transitional or disturbed environments unsuited to the accumulation and preservation of palynomorphs. Of the petroleum wells re-examined, Preston 1 has barren and indeterminate samples between ?*B. limbata* (at 181.1 m) and ?*C. torosa* (at 374 m) Zone samples, and Lake Preston 1 has two barren samples tentatively allied (using palynofacies data) to the Cretaceous between 76.2 and 121.9 m (Plate 4). Similar situations, with very low-yielding, indeterminate, barren, or questionably Cretaceous (possibly caved) samples between more certain Early Cretaceous and Early Jurassic assemblages, are also seen in a number of water and geothermal bores, including Artesian Monitoring bores AM66 and AM68, a number of Alcoa Pinjarra bores, Mandurah Line MH10, Mandurah Aquatic and Recreation Centre bore MARC01, Mandurah Peel Leederville bore MPL5, Binningup Line BPL1A and BPL2A, Kemerton Deep KE1D, and Picton Line PL3A and PL4A. In these boreholes, the Cretaceous

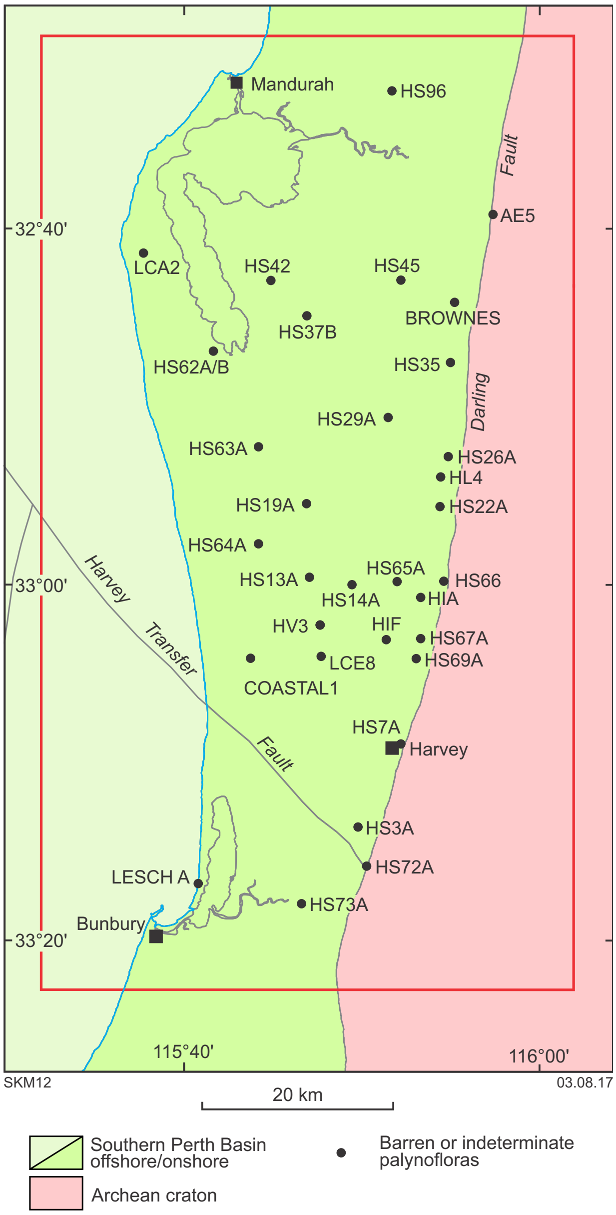


Figure 10. Distribution of boreholes with barren samples or indeterminate palynofloras within the study area. See Table 1 or Appendix 1 for a list of the borehole name abbreviations

palynomorphs are probably downhole contaminants overprinting barren or low-yield assemblages (e.g. Ingram, 1969), although whether these barren sections are in fact below the unconformity cannot be confirmed using palynomorphs alone.

The long barren intervals associated with the Triassic–Jurassic boundary are only observed in petroleum wells, although sporadic barren samples are seen within Early Jurassic assemblages in many shallower boreholes. GSWA Harvey 1 has over 1000 m (903.6 – 2514.4 m depth) of barren section within the Middle and Upper Triassic succession (Plate 4), and Pinjarra 1 has over 1500 m of barren section within the *C. torosa* Zone (469.39 – 2077.2 m depth), with a shorter barren section (2225.34 – 2585.3 m) within the Upper Triassic to Lower Jurassic succession (Plate 1A). Lake Preston 1 contains an approximately 1000 m long barren section (972.3 – 1943.4 m) within the same Upper Triassic to Lower Jurassic succession. Preston 1 was not deep enough to extend into the Triassic (or, at least, there is no biostratigraphic evidence of Triassic palynomorph assemblages), although there is a short (~200 m) barren section extending to TD beneath a set of samples assigned to the *C. torosa* Zone. Barren sections in all of these wells are dominated by sandstones, associated with minor fine-grained lithologies typically described as 'varicoloured', 'multicoloured', or 'mottled'. These barren intervals often span zone boundaries, particularly the base of the *C. torosa* Zone, and may conceal entire zones; for example, the uppermost Triassic spore-pollen zones are rarely seen in the area, despite an assumption that the Upper Triassic – Lower Jurassic units are broadly conformable in both the southern and northern Perth Basin (Mory and Iasky, 1996; Crostella and Backhouse, 2000).

An interesting example of barren assemblages can also be seen in DMP Harvey 3/3A, drilled in 2015. This well was fully cored, and 14 samples from throughout the hole were processed for palynology, all of which proved barren (Backhouse, 2015b). To check against processing errors, two of the more promising samples were reprocessed at a different laboratory, with the same results; this suggests that the palynomorphs are poorly preserved or absent throughout the entire well. Similar palynological studies planned for interval-cored Harvey 4 were abandoned after examination of the available cores identified strong oxidation in all of the fine-grained lithologies. In both cases, fine-grained lithologies were relatively uncommon and, where noted, many of these lithologies were clearly oxidized, displaying mottled reddish or brownish hues. A similar range of unpromising-looking (both sand-dominated and heavily oxidized) lithologies were also seen in the fully cored DMP Harvey 2, although nearly all of the samples from this well yielded adequate palynomorph assemblages. The rocks in Harvey 3/3A may have been affected by a localized environmental or diagenetic effect which destroyed in situ palynomorphs, but which did not affect nearby GSWA Harvey 1 or DMP Harvey 2 to the same degree. The variability in palynomorph yield between adjacent wells may partly be a reflection of the highly discontinuous nature of oxidation in the Harvey area lithologies, which consist of an interwoven series of paleosols and discontinuous fluvial and floodplain facies.

Discussion

Implications for stratigraphy

Although stratigraphy is not the focus of this Report, reviewing the palynological data has highlighted a number of issues that are particular to the study area or to the southern Perth Basin as a whole. Due to the small number of robust assemblages in the dataset used here, many of these conclusions are poorly resolved at present and will require additional work. The Perth Metropolitan region, lying across the northern Mandurah Terrace in the central Perth Basin, forms a considerable barrier to understanding the stratigraphy of the southern Perth Basin, as its infrastructure hampers geophysical and drilling exploration of the transition between the well-studied northern and understudied southern Perth Basin.

Importantly, this region's stratigraphy has previously been defined from a wholly lithostratigraphic perspective, and some of these units are likely time transgressive. Time transgressive units covering large geographic regions and lacking adequate borehole ties are difficult to link to seismic data, and therefore easier to miscorrelate or misinterpret. Re-evaluating the stratigraphy of the southern Perth Basin in a way that encompasses both lithology and age data should improve some of the issues identified here.

Cretaceous

Within the study area, the Osborne Formation is only recorded within a small coastal part of the Mandurah Terrace west of the Harvey Estuary. As numerous boreholes in the examined dataset intersected the Cretaceous–Cenozoic boundary but showed only Early Cretaceous assemblages under the unconformity, this restricted distribution is interpreted as a true absence, not a reflection of sampling biases. These upper Lower Cretaceous sedimentary rocks likely extend across the *X. asperatus* to *D. davidii* Dinocyst Zones, although poor preservation in some of these assemblages makes it uncertain whether the section is complete and conformable. As the *M. tetracantha* Zone is difficult to identify even in well-diversified assemblages, its absence in this region may not be significant; regardless, the best later Cretaceous assemblages, from MPL1A, suggest a depositional break between the Aptian *D. davidii* and mid-Albian *C. denticulata* Zones (Plate 3). Although all of the zones from *X. asperatus* to *D. davidii* have been previously associated with the Osborne Formation (e.g. Davidson, 1995), other workers (Mory and Iasky, 1996; Crostella and Backhouse, 2000) interpreted the Osborne Formation (and the Coolyena Group, of which the Osborne is the basal unit) as exclusively Albian in age, with a distinct stratigraphic break between *D. davidii* Zone and the oldest Albian samples generally of the *C. denticulata* Zone. Similarly, Backhouse (2012b, 2013) considered the *D. davidii* Zone assemblage in MPL1A to belong to a geological unit he informally termed the 'Aptian unit', separating it from the younger Osborne Formation. The stratigraphic relationship of this potential 'Aptian unit' to the Osborne Formation and Warnbro

Group is unknown; therefore, further work is required to establish its distribution and characteristics.

The current review adds little to the understanding of the Warnbro Group, although the group is extensively developed across the study area. As noted in Backhouse (1988a), marine influence varies considerably throughout much of the Warnbro Group, with marine and nonmarine assemblages regularly interspersed within a single borehole. The lack of marine Warnbro Group assemblages in the south of the study area, with only a handful of marine records in the Bunbury Trough (in LP1, LP2, LP4, LP5), suggests that marine influence was either restricted to the north of Harvey during the deposition of the Warnbro Group, or that the coastline was farther to the west, in an area now offshore, in the southern part of the area. The latter interpretation better fits the evidence of rare marine assemblages in the Laporte area, and the thick Lower Cretaceous succession seen in the offshore Vlaming Sub-basin wells. The rough geographic groupings observed in the distribution of dinocyst zones might reflect variable paleogeographic influences on each marine incursion, or patterns of erosion.

All of the Cretaceous assemblages older than the *B. limbata* Zone within the study area are unusual assemblages referred to here as the 'transitional *B. eneabbaensis* – *B. limbata* Zone' (Backhouse, 2012a), recorded in scattered boreholes in the Bunbury area and possibly in GSWA Harvey 1. These poorly known assemblages may represent a new biostratigraphic unit or may be a distinctive local phase of the *B. eneabbaensis* Zone. Whether this biostratigraphic unit coincides with deposition of the lowermost part of the Warnbro Group, the uppermost part of the Parmelia Group, or some previously unrecorded intervening unit, is also uncertain. The identity and distribution of this new biostratigraphic unit has implications for the correlation of the Bunbury Basalt to sedimentary units in the area, as previously the Parmelia Group was interpreted to underlie, and the Warnbro Group to overlie, the Bunbury Basalt, although palynological data around and between the basalt flows are rare and poorly constrained. Further work is required to clarify this potential new biostratigraphic unit and its associated stratigraphy.

The apparent absence of the Parmelia Group around the Harvey Ridge agrees well with both Davidson (1995) and Crostella and Backhouse (2000), who both considered the group to have been deposited widely across the Perth Basin, and later eroded from much of the onshore area during the Early Cretaceous breakup event. In the central Perth Basin, the Parmelia Group is only recorded in the Gingin area north of Perth (Davidson, 1995), whereas in the southern Perth Basin it is also recorded in the southernmost Bunbury Trough (Crostella and Backhouse, 2000). No assemblages assignable to the *F. tumida* Dinocyst Zone of Backhouse (1988a) have been recorded in the study area, indicating entirely nonmarine deposition during the earliest part of the Cretaceous.

Middle to Late Jurassic

There is no evidence for the Yarragadee Formation or rocks of equivalent age in the southern Mandurah Terrace (Harvey Ridge), with the only records of generalized *D. complex* to *M. florida* Zone assemblages examined during this project found within the Bunbury Trough. The uppermost part of the Yarragadee Formation appears to be absent across the entire project area as the *R. watherooensis* Zone is not recorded. This and the (partial?) absence of Parmelia Group assemblages suggests an extensive period of erosion or nondeposition in the northernmost southern Perth Basin during the Late Jurassic; if erosional, this may be related to the Valanginian breakup event.

Crostella and Backhouse (2000) considered rocks equivalent in age to the Cadda Formation (upper *C. turbatus* and lower *D. complex* Zones) to be absent from both the Mandurah Terrace and Bunbury Trough. Although there are four potential *D. complex* Zone assemblages in the Bunbury Trough (LP1, LP3, LP4, and PL1), these samples are equally likely to belong within the *C. cooksoniae* or *M. florida* Zones, due to the difficulties inherent in separating the three zones using isolated assemblages. *C. turbatus* Zone assemblages are far more common throughout the study area, although the generally poor-yielding and poorly diversified assemblages mean that the upper and lower subzones are difficult to identify. However, the lack of evidence for the *D. caddaense* Dinocyst Zone in the study area indicates that, for the present-day onshore area at least, the marine incursion that characterizes the Cadda Formation in the northern Perth Basin did not extend farther south than the Perth Metropolitan region. As a result, any Cadda Formation time-equivalent sedimentary rocks in the area would be nonmarine and therefore difficult to distinguish from underlying interbedded fluvial and paleosol, Cattamarra-aged, or overlying sandstone-dominated, Yarragadee-equivalent, units.

Middle Triassic to Early Jurassic

The Lower Jurassic and Upper Triassic succession in the southern Perth Basin has historically been defined using northern Perth Basin stratigraphic units, despite growing evidence of lithological and biostratigraphic differences between the two regions. Previous identification of these units has been based mainly on lithology, with coal-bearing or strongly carbonaceous lithologies designated part of the Cattamarra Coal Measures, multicoloured sandy lithologies interpreted as part of the Eneabba Formation, and clean sandy successions placed within the Lesueur Sandstone, in many instances without reference to biostratigraphic data (e.g. Deeney, 1989a,b; Crostella and Backhouse, 2000, Plate 1A). The reliance on lithostratigraphy led to a number of internal inconsistencies within Crostella and Backhouse's (2000) review of the southern Perth Basin, such as sedimentary units of *C. torosa* Zone age in the Bunbury Trough (in Chapman Hill 1) being assigned to the Cattamarra Coal Measures because they lacked multicoloured fine-grained sedimentary rocks. The suggestion by Crostella and Backhouse (2000) that the Cattamarra Coal Measures in the southern part of the basin is the time-equivalent of the Eneabba Formation in the northern Perth Basin, implying both units are time transgressive from north to south within the basin, also appears symptomatic of the lithostratigraphic approach taken in defining these units.

The 2016 restudy of the palynology slides from Lake Preston 1 identified assemblages of the *C. turbatus* Zone in this well for the first time. Therefore, rocks equivalent in age to the Cattamarra Coal Measures directly underlie the Cretaceous unconformity in this well (Plate 4), rather than the Eneabba Formation age-equivalent unit suggested by the original well completion report and Crostella and Backhouse (2000). By including this new palynological evidence, the Jurassic stratigraphy in Lake Preston 1 and Pinjarra 1 can be correlated with greater confidence. This new interpretation implies that the uplift and erosion of Middle Jurassic and younger units was not equally developed across the central Harvey Ridge, with the area around Lake Preston 1 experiencing less erosion than previously suggested. The eastern side of the Harvey Ridge, along the Darling Fault as far south as MPL5A, also preserves rocks of both the *C. turbatus* and *C. torosa* Zones and therefore also experienced less erosion than the main part of the ridge. Along the edge of the Yilgarn Craton south of MPL5A, around the latitude of Waroona township, *C. turbatus* Zone assemblages are also absent, suggesting conditions more similar to the main part of the ridge, where the *C. turbatus* Zone is absent and the Cretaceous unconformity overlies sediments of the *C. torosa* Zone.

The reassessment of biostratigraphic data in the study area highlights the issues caused by defining the Jurassic stratigraphy of the southern Perth Basin using only lithology. Rocks of both the *C. turbatus* and *C. torosa* Zones are broadly similar in lithology across the region, with carbonaceous and coaly lithologies and multicoloured sedimentary rocks seen throughout. In borehole MPL5A, where both the Cattamarra Coal Measures and Eneabba Formation were identified, there is no clear justification for the formation boundary picks as the lithologies are fairly consistent throughout both Early Jurassic zones. Elsewhere, *C. torosa* Zone assemblages in boreholes MARC01, HL1B, MPL3A, 4A and7A, and WHS1 are strongly associated with coaly or carbonaceous layers considered more typical of the *C. turbatus* Zone in the northern Perth Basin. *C. turbatus* Zone assemblages in AE4, AE6, BPL1A, 2A and 4A, MH15, and MPL2A occur in strongly coloured or mottled lithologies, which are more usual in the *C. torosa* Zone in the northern part of the basin. Therefore, these two palynology zones cannot be predicted based on lithology alone. Using simplified biostratigraphic cues to identify units (e.g. *C. torosa* Zone = Eneabba Formation and *C. turbatus* Zone = Cattamara Coal Measures) can also be as problematic as using purely lithological characters, particularly for poorly preserved and poorly diversified assemblages. The stratigraphy in the southern Perth Basin needs to be revised to include clear unit definitions using both age and lithological information.

Clarifying the age and definition of the Yalgorup and Wonnerup Members of the Lesueur Sandstone is also an issue in the Harvey area. Both units have historically poor biostratigraphic control, being defined primarily using lithology and geophysical log character (Crostella and Backhouse, 2000). A review of the palynological slides from the Yalgorup Member type section, designated as the 1219–2045 m interval in Lake Preston 1 by Crostella and Backhouse (2000), reveals that all samples are barren of palynomorphs, apart from the deepest sample, which was low yielding and considered only possibly Middle to Late Triassic in age (Backhouse, 2016a). Palynological data from the Wonnerup Member type section, designated as the 2640–3644 m interval in Wonnerup 1 (Crostella and Backhouse, 2000), is similarly vague, with a recent informal review of the well completion report (without reference to the slides) only able to date these assemblages as ‘probably Late to Middle Triassic’ (J Backhouse, 2014, written comm., 31 March). It is uncertain whether the Lesueur Sandstone is laterally continuous between the northern and southern Perth Basin, as the formation has not been intersected within the central Perth Basin (which lacks deep wells or boreholes).

New palynological data from the Harvey wells and the recent review of palynological slides from Pinjarra 1 provides additional age control for these Triassic units. Based on palynological assemblages in DMP Harvey 2 and Pinjarra 1, the Yalgorup Member appears to include part of the lower *C. torosa* Zone, all of the *A. reducta* Zone, much or all of the *S. speciosus* Zone, and possibly the upper *S. quadrifidus* Zone (Plate 1A), therefore potentially extending from the Early Jurassic through to the Carnian or Ladinian. Palynological evidence from the Wonnerup Member in GSWA Harvey 1 and DMP Harvey 2 suggests the unit top is within the uppermost *S. quadrifidus* or lower *S. speciosus* Zones, with data from Lake Preston 1 suggesting that the unit extends through the *T. playfordii* Zone and into the uppermost *K. saeptatus* Zone (Plate 4), therefore approximately covering the Ladinian to Olenekian. These interpretations rely heavily on the assumption that the formation tops are correctly defined. The formation boundaries used here for Lake Preston 1 and Pinjarra 1 are those selected by Crostella and Backhouse (2000) who originally defined the members, and therefore the unit identifications in these wells are assumed to be consistent. The formation tops for the Wonnerup Member in the Harvey wells are also likely to be consistent, as the top boundary of this sandstone-dominated unit is distinct in seismic data, geophysical logs, and in core (Zhan, 2014). However, the top of the Yalgorup Member is difficult to identify because the unit is lithologically similar to the overlying Eneabba Formation and is challenging to differentiate in seismic data (Zhan, 2014), at least in the Harvey area.

Based on the new biostratigraphic data from the Harvey wells and the newly reviewed data from older wells and water bores, and supported by the difficulties inherent in separating the Yalgorup Member, Eneabba Formation, and Cattamarra Coal Measures in the Harvey area (Zhan, 2014), the Lower Jurassic and Upper Triassic succession is interpreted to represent a long-lived, continuous system of strongly localized, fluvial, paludal, and perhaps alluvial-plain deposits, including numerous paleosols. The definitions for northern Perth Basin units of equivalent age, the Cattamarra Coal Measures and Eneabba Sandstone, do not accurately reflect the lithologies seen in the southern Perth Basin and therefore likely do not apply in the study region. The entire succession may be better redefined as a single extensive formation, akin to the original 'Cockleshell Gully Formation' (abandoned when the Cattamarra and Eaneabba Members were raised to formations [Mory, 1994a,b]).

Although the Yalgorup Member is currently defined as belonging within the Lesueur Sandstone, the member is lithologically distinct from both its parent unit as seen in the northern Perth Basin and the underlying Wonnerup Member. This difference was also identified by Crostella and Backhouse (2000, p. 16) who stated '…the Wonnerup Member is lithologically closer to the Lesueur Sandstone, and the Myalup [now Yalgorup] Member represents a transitional environment between the underlying Wonnerup Member and the overlying Cattamarra Coal Measures.' Therefore, these authors imply that the Yalgorup Member would be better regarded as part of the same formation as rocks previously described in the southern Perth Basin as the 'Eneabba Formation', rather than being grouped with the Wonnerup Member or Lesueur Sandstone. This idea is supported by the palynological data presented here, which suggest that the Yalgorup Member is laterally equivalent to the lowermost Eneabba Formation and upper part of the Lesueur Sandstone in the northern Perth Basin, with the Wonnerup Member equivalent to part of the Lesueur Sandstone, the Woodada Formation, and part of the Kockatea Shale. However, additional biostratigraphic information and geological studies of borehole sections of this age are needed before any of these stratigraphic units can be formally redefined.

Regardless of the stratigraphic subdivisions, the extensive paleosol development within this Upper Triassic to Lower Jurassic succession suggests long periods of environmental stability without regular inundation or rapid subsidence. This in turn indicates both a relatively quiescent tectonic regime and that the region remained a considerable distance from the coastline throughout this time period. That is, the area was far enough from the paleoshoreline that no expression of the marine transgression, which forms the main differentiation between the Eneabba Formation and Cattamarra Coal Measures in the northern Perth Basin, is evident. A wide, low-gradient, continental river valley with multiple streams and transient lakes or ponds is the interpreted setting for this succession.

Permian to Middle Triassic

Based on the succession preserved in Lake Preston 1, the Sabina Sandstone can be interpreted as entirely Early Triassic in age in this area (Plate 4). A distinct microfloral change noted towards the base of the Sabina Sandstone suggests that the boundary with the Willespie Formation (part of the Sue Group) lies close to, or coincides with, a biostratigraphic zone boundary, perhaps the base of the *K. saeptatus* Zone and top of the *P. microcorpus* or *P. crenulata* Zone(s). Unfortunately, this cannot be confirmed as all palynological samples below 13 200 ft in this well, including all of the potentially Permian assemblages, are too poorly preserved for adequate age identification. The top of the Sabina Sandstone falls within the *K. saeptatus* Zone, although this zone is also recorded in sections ascribed by Crostella and Backhouse (2000) to the Wonnerup Member. Therefore, the Sabina Sandstone appears to not be age equivalent to the northern Perth Basin's Kockatea Shale in its entirety, with this latter unit recorded as extending throughout the *K. saeptatus* Zone and into the *T. playfordii* Zone. Unlike the Kockatea Shale, the Sabina Sandstone is completely terrestrial (Crostella and Backhouse, 2000), as confirmed by the lack of marine palynomorphs recorded in Lake Preston 1. Despite this, the Early Triassic assemblages seen in Lake Preston 1 are unusual when compared to assemblages of similar age farther north (Backhouse, 2016a), which may indicate a different depositional environment in the Harvey area at this time.

Due to the strongly degraded nature of the palynomorphs within the deepest section of Lake Preston 1, no statement can be made about the Permian units within the study area. No other boreholes or wells in this area were interpreted to intersect Permian units or yielded Permian palynoassemblages.

Environment

Although the main aim of this Report is to review biostratigraphic or age data from the southern Perth Basin, the palynological studies discussed here also provide insights into the region's depositional environment. Many previous reviews of Perth Basin palynological assemblages — especially Backhouse (1988a) for the Early Cretaceous, and Filatoff (1975) for the Jurassic — have discussed the paleoenvironment of the whole Perth Basin, and the data presented here broadly agree with those interpretations.

The Early Triassic microflora of the southern Perth Basin differs from other contemporaneous assemblages statewide in being entirely nonmarine. Marine *K. saeptatus* Zone assemblages have previously been described as containing a low diversity of miospores (Dolby and Balme, 1976); conversely, the miospores seen in assemblages of this age in Lake Preston 1 were considerably more diverse, and include megaspores and large lycophyte spores.

This difference in diversity probably reflects a shorter transport window between these dominantly continental plants and their depositional environments. Backhouse (2016a) also noted that this assemblage was different in character compared with equivalent-aged miospore assemblages in the central and northern Perth Basins, although these differences in microflora may also reflect differences in depositional environments. The Early Triassic palynomorph assemblages from Lake Preston 1 are not well preserved, and environmental signals are difficult to identify based purely on this material.

Like the rest of the Perth Basin, Middle–Late Triassic microfloras re-examined here are of the 'Ipswich' style, which are relatively low-diversity assemblages dominated by *Falcisporites* spp. and *Aratrisporites* spp. Ipswich-type floras are dominated by lycophytes, ferns, and gymnosperms, and are considered indicative of moist climates, likely related to higher paleolatitudes (Dolby and Balme, 1976). The rapid increase in cheirolepidacean pollen (and associated decrease in *Falcisporites* pollen) worldwide at the start of the Jurassic has been interpreted as indicative of a change to drier conditions. This event is seen distinctly in the Perth Basin, and is also evidenced in the area's relatively low-diversity assemblages, and the dominant paleosols and redbed lithologies (Filatoff, 1975; Helby et al., 1987). Conversely, the increase in floral diversity and shifting dominance to araucariacean and fern taxa within the *C. turbatus* Zone Australia-wide suggests less strenuous environmental conditions towards the Middle Jurassic, with an interpreted shift to higher rainfall conditions supported by the increase in swampy coastal (coal) deposits towards the top of the Cattamarra Coal Measures in the northern Perth Basin.

In the Perth Basin, the dominance of araucariacean and fern taxa continues into the Late Jurassic and Early Cretaceous, with a particular increase in the proportions of hydrophilic lycopod, fern, and dinoflagellate cyst taxa (such as *Moorodinium*) characterizing the pre-breakup *B. eneabbaensis* Zone. This suggests widespread lacustrine or lagoonal deposits (essentially nonmarine or brackish shallow-water bodies) within the Perth Basin at this time, probably formed as a precursor to continental breakup (Backhouse, 1988a). There is little evidence for the *B. eneabbaensis* Zone in the study area, although the 'transitional *B. eneabbaensis* to *B. limbata* Zone' assemblages include *Moorodinium*, and therefore may represent a distal (more continental?) variant of the *B. eneabbaensis* Zone flora.

The overall reduction of fern and lycopod miospores and associated increase of araucariaceans seen in the *B. limbata* Zone, coupled with the pulses of marine assemblages interspersed between the more terrestrial floras, was interpreted to represent the destruction of these shallow-water pool environments at breakup, and a return to more classic fluvio-deltaic environments with periodic marine inundation (Backhouse, 1988a). The Cretaceous palynomorph assemblages re-examined here support these interpretations, with the apparent decrease in marine assemblages towards the south of the study area suggesting that the shoreline was to the north or west during this period. Late Cretaceous assemblages, although rare within the study area, suggest an influx of shallow-marine conditions at least over the Harvey Estuary area during the Aptian and Albian, which may have been a single event or two separate pulses. Despite this increase in marine influence, the associated miospore assemblages are overall similar to that of the *B. limbata* Zone, indicating no major shift in continental environments or flora.

The most iconic and unusual assemblages in the dataset are within the Early Jurassic (*C. torosa* and *C. turbatus* Zone assemblages). These assemblages are characterized by the extreme dominance of *Classopollis* and very low diversity of other forms, which could indicate an unusual low-diversity local flora, strongly dominated by cheirolepidaceans. An example of this can be seen in one sample from BPL4A, which, although interpreted as a *C. turbatus* Zone assemblage, completely lacks araucariacean taxa (such as *Callialasporites* spp.) and is dominated by equal proportions of *C. torosus* pollen and *Trilobosporites antiquus* (fern spores), with few other taxa. The dominance of *Classopollis* pollen in particular points to difficult local environmental conditions, as the cheirolepidaceans are considered to have been particularly hardy, salt- and drought-tolerant conifers (Filatoff, 1975; Backhouse, 1988a). However, Filatoff (1975) stated that the interpretation of a warm to hot and arid Perth Basin in the Early Jurassic as indicated by the palynoflora was at odds with the high latitude of the Perth Basin during this period, and indicated that macrofossil assemblages from the Perth Basin are more dominated by cycadophytes than cheirolepidaceans. This suggests the preserved microflora is not representative of the overall flora. As a result, it is possible that the preserved microfloral assemblages record a strong taphonomic bias, resulting from the prevalence of environments unsuitable for palynomorph accumulation and preservation.

Due to the chemical stability of sporopollenin, palynomorphs are mostly inert, and are able to be transported long distances and reworked without destruction. Despite this, palynomorphs are susceptible to both strongly oxidizing and high-temperature and pressure environments, rapidly degrading under those conditions (Traverse, 2008). The mottled and multicoloured fine-grained lithologies within the Lower Jurassic succession in the study area indicates that these rocks were oxidized during deposition or diagenesis, resulting in the removal of most or all of the palynomorphs within these successions. The few spores and pollen that survived the oxidation process are likely to be morphologically robust (perhaps due to a thick exine), represent taxa that were abundant in the original rock, or are very easy to recognize and identify, even in a degraded state. *Classopollis* is a small pollen with simple morphology, derived from a wind-pollinated conifer (Filatoff, 1975; Backhouse, 1988a); consequently, these pollen grains would be very tough, easily transported in both water and air, and were likely produced in huge quantities by a single plant — all of which are characteristics advantageous for preservation.

Therefore, the dominance of *Classopollis* in Early Jurassic assemblages in the study area may be due to the original large volumes of pollen available for burial, and the taphonomic robustness of the pollen itself, rather than any particular abundance of its source plant. Although the genus declines rapidly in importance from the Middle Jurassic onwards, a slight increase of *Classopollis* is also recorded within the *B. limbata* Zone in the Perth Basin. Backhouse (1988a) attributed this increase to a taphonomic bias, caused by the ease in transporting this small pollen downriver for vast distances, before accumulating in shallow-marine settings. This inclusion of *Classopollis* pollen within marine *B. limbata* Zone assemblages is also seen within the current dataset.

Conclusions and recommendations

This Report details the available biostratigraphic data for the southern Perth Basin between the cities of Mandurah and Bunbury; however, the dataset is hampered by a series of issues that makes it difficult to correlate between boreholes with reasonable resolution. A lack of data in the study area and the era of study for some samples provide serious constraints, as do the low diversity and low yield of palynofloras in the Late Triassic and Early Jurassic, and the dominance of environments unsuitable for palynomorph accumulation and preservation in the southern Perth Basin during this same period. Together, these factors conspire to reduce the usefulness of palynofloral data in this region, and are unlikely to be improved or mitigated by increased data collection or analysis techniques. The lack of marine influence and volcanic input in the region negates other traditional avenues for age control — specifically micropaleontology and isotope geochronology — making the relationships of the Jurassic and older units in the southern Perth Basin a challenge to unravel. Other techniques, such as chemostratigraphy, should be investigated as a possible aid to traditional biostratigraphic and geochronological information.

This study highlights a number of remaining issues to be addressed.

- Is there a continuous palynological succession throughout the early Late Cretaceous in the southern Perth Basin? Are the Aptian-age samples attributable to the Osborne Formation, Warnbro Group, or neither?
- What is the nature of the ‘transitional *B. eneabbaensis* to *B. limbata* Zone’ assemblages identified in the Harvey Line water bores? Is this a real zone, or a local effect caused by drilling contamination or other influences?
- What age is the breakup unconformity in the Harvey area? Does the *B. eneabbaensis* Zone precede the entire breakup succession? What age are rocks between flows of the Bunbury Basalt?
- Can the *C. turbatus* and *C. torosa* Zones be differentiated with certainty in the southern Perth Basin?
- Should the Lower Jurassic rocks in this area be assigned to formations established in the northern Perth Basin?
- What age are the Yalgorup and Wonnerup Members? Did deposition of the Yalgorup Member extend into the Early Jurassic? Are they really best described as members of the Lesueur Sandstone or should they be independent formations? Are these units strictly conformable or do they overlap or interfinger?
- Can the Upper Triassic and Lower Jurassic successions be separated into multiple formations, or should they be defined as one long succession?
- What is the nature of the Lower Triassic succession in the Harvey area? Is it as thick as suggested by the biostratigraphic data from Lake Preston 1? If so, why, and what implications does this have for petroleum resources and carbon storage?
- What is the identity and distribution of Permian rocks in the Harvey area?

Based on the collation of historic biostratigraphic data presented here, a number of future projects are recommended to help answer some of these issues.

- Redescription of existing slides, or resampling and reanalysis of key deep water bores, particularly the Mandurah Line, Picton Line, Laporte Line and Alcoa Pinjarra boreholes.
- Sampling and analysis of ditch cuttings from DMP Harvey 4 with the aim of supporting age data obtained from GSWA Harvey 1 and DMP Harvey 2.
- In-depth taxonomic and biostratigraphic study of the ‘transitional *B. eneabbaensis – B. limbata* Zone’ palynoflora, incorporating sub- and intra-basalt assemblages to assess their position relative to the Lower Cretaceous palynozones.
- In-depth taxonomic study of Early Triassic palynomorph assemblages of the southern Perth Basin, as a baseline for comparison to more comprehensively studied northern Perth Basin assemblages.
- Comprehensive sampling and study of the Wonnerup Member and Yalgorup Member (currently assigned to the Lesueur Sandstone) to determine the specific age controls on these units.

A similar review of biostratigraphic data is planned to cover the region from Bunbury to the south coast of Western Australia. Integration of this more detailed and comprehensive dataset with the present results may clarify some of the gaps in knowledge identified here.

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Appendix 1

Wells and bores index

	Bore/well	ID[a]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[b]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
Petroleum wells												
A	Pinjarra 1	W000127	MT	–32.676	115.771	1965	4572.3	BE Balme, J Backhouse	1966, 1997, 2016	16 CC; 7 SWC; 8 DC	(Balme, 1966a; Backhouse, 1997, 2016b,c)	K, Jr, Tr
B	Lake Preston 1	W000862	MT	–32.949	115.711	1972	4571.1	G Dolby and AJ Williams, J Backhouse	1973, 2016	19 SWC; 73 DC	(Dolby and Williams, 1973; Backhouse, 2016a)	K, Jr, Tr, ?P
C	Preston 1	W000163	MT	–32.919	115.662	1966	765.4	BE Balme	1966	2 CC; 5 SWC; 2 DC	(Balme, 1966b)	K, Jr
D	GSWA Harvey 1	W003619	MT	–32.992	115.774	2012	2945	J Backhouse	2014	14 CC; 2 DC	(Backhouse, 2014)	Jr, Tr
E	DMP Harvey 2	W005822	MT	–33.009	115.844	2015	1351	J Backhouse	2015	22 CC	(Backhouse, 2015a)	Jr, Tr
F	DMP Harvey 3/A	W005860/A	MT	–33.0376	115.7941	2015	1550	J Backhouse	2015	14 CC	(Backhouse, 2015b)	x
Alcoa Pinjarra water bores												
1	AE1	61400066	MT	–32.62225	115.918148	1969	316.99	BS Ingram	1969	6 DC	(Ingram, 1969e)	K, Jr
2	AE2	61400067	MT	–32.622314	115.948003	1969	303.89	BS Ingram	1969	3 DC	(Ingram, 1969e)	Jr
3	AE3	61400909	MT	–32.65081	115.898655	1969	271.27	BS Ingram	1969	5 DC	(Ingram, 1969e)	?, ?Jr
4	AE4	61400910	MT	–32.647962	115.932265	1969	292.61	BS Ingram	1969	7 DC	(Ingram, 1969e)	K, Jr
5	AE5	61400911	MT	–32.653018	115.956451	1969	147.83	BS Ingram	1969	2 DC	(Ingram, 1969e)	x
6	AE6	61400912	MT	–32.676555	115.912226	1969	304.8	BS Ingram	1969	4 DC	(Ingram, 1969e)	K, Jr
7	AE7	61400913	MT	–32.655997	115.937362	1969	217.32	BS Ingram	1969	6 DC	(Ingram, 1969e)	K, Jr
8	AE8	61400070	MT	–32.61636	115.940399	1969	207.87	BS Ingram	1969	2 CC, 1 DC	(Ingram, 1969e)	K, Jr
9	AO1	61400071	MT	–32.616829	115.917105	1969	231.65	BS Ingram	1969	3 DC	(Ingram, 1969e)	K, ?Jr
10	AO2	61400072	MT	–32.61719	115.921268	1969	179.83	BS Ingram	1969	2 DC	(Ingram, 1969e)	?Jr
11	AO3	61400073	MT	–32.617465	115.928097	1969	179.83	BS Ingram	1969	5 DC	(Ingram, 1969e)	K, ?Jr
12	AO8	61419321	MT	–32.642854	115.869264	1972	243.8	J Backhouse	1972	3 DC	(Backhouse, 1972d)	Cz, K
13	AO9	61400921	MT	–32.649618	115.897454	1972	214.5	J Backhouse	1972, 2015	2 DC	(Backhouse, 1972a, 2015d)	?K, Jr
14	AO10	61400922	MT	–32.692007	115.900913	1972	274.32	J Backhouse	1972, 1973, 2015	4 DC	(Backhouse, 1972b, 1973, 2015d)	K, Jr
15	AO11	61400923	MT	–32.651032	115.918964	1972	93.5	K Grey	1972	3 DC	(Grey, 1972b)	K
16	AO12	61400924	MT	–32.651032	115.918953	1972	93.5	J Backhouse	1972, 2015	5 DC	(Backhouse, 1972c,d, 2015d)	?K, ?Jr
Artesian Monitoring water bores												
17	AM65	61415009	MT	–32.498518	115.802716	1980	363	J Backhouse	1980, 2015	14 SWC	(Backhouse, 1980b, 2015d)	K, Jr
18	AM66	61415027	MT	–32.49859	115.907455	1981	384	J Backhouse	1981, 2011	15 SWC	(Backhouse, 1981b, 2011a)	K, Jr
19	AM67	61415004	MT	–32.51149	115.752638	1980	375.5	J Backhouse	1980, 2015	16 SWC	(Backhouse, 1980c, 2015d)	K, Jr

	Bore/well	ID[(a)]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[(b)]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
20	AM68	61415016	MT	–32.546294	115.83679	1980	327	J Backhouse	1980, 2015	16 SWC	(Backhouse, 1980d, 2015d)	K, Jr
Binningup Line water bores												
21	BPL1A	61230101–3	BT	–33.146389	115.698333	1984	806.5	J Backhouse	1984, 2015	19 SWC, 11 DC	(Backhouse, 1984, 2015d)	K, Jr
22	BPL2A	61330126–8	MT	–33.148335	115.742782	1984	600	J Backhouse	1985, 2015	17 SWC, 1 DC	(Backhouse, 1985a, 2015d)	K, Jr
23	BPL3A	61230105,6,9	MT	–33.159163	115.807502	1984	800.5	J Backhouse	1986	22 SWC/DC, 2 DC	(Backhouse, 1986a)	K
24	BPL4A	61230107,08,11	MT	–33.160833	115.853889	1984	802.6	J Backhouse	1986, 2015	21 SWC	(Backhouse, 1986b, 2015d)	Jr
Binningup Estate water bores												
25	BPE2	61210697	BT	–33.147858	115.717493	1976	150.3	J Backhouse	1977	4 DC	(Backhouse, 1977b, 1981c)	K
Bunbury area primary school water bores												
26	CPPS1	61110636	BT	–33.348682	115.6506587	1974	45.11	J Backhouse	1974	2 DC	(Backhouse, 1974a,b)	Cz
27	SBPS1	61110635	BT	–33.340313	115.6424173	1974	44.5	J Backhouse	1974	2 DC	(Backhouse, 1974c,h)	K
Bunbury (Laporte) Inlet water bores												
28	BI1	61210463	BT	–33.251306	115.688794	1973	24.1	J Backhouse	1974	1 DC	(Backhouse, 1974g)	K
29	BI2	61210464	BT	–33.251132	115.68681	1973	39	J Backhouse	1974	1 DC	(Backhouse, 1974g)	K
30	BI3	61210465	BT	–33.251519	115.684991	1973	33.13	J Backhouse	1974	1 DC	(Backhouse, 1974g)	Cz
31	BI4	61210466	BT	–33.251697	115.682218	1973	29.6	J Backhouse	1974	1 DC	(Backhouse, 1974g)	K
Eaton Line water bores												
32	EA1	61210396	BT	–33.314543	115.707248	1963	228.6	HS Edgell	1963	6 DC?	(Edgell, 1963o)	Cz, K
33	EA2	61210409	BT	–33.314250	115.706844	1967	213.4	BS Ingram	1967	2 DC	(Ingram, 1967a)	K
34	EA3	61211444	BT	–33.314561	115.707247	1972	518.2	K Grey, J Backhouse	1972, 2015	5 DC	(Grey, 1972a,c; Backhouse, 1972f, 2015d)	K, Jr
Harvey Line water bores												
35	HL1B	61330145, 29, 30	MT	–32.914446	115.702502	1983	605	J Backhouse	1983, 2012	19 SWC	(Backhouse, 1983a, 2012a)	K, Jr
36	HL2A	61330132–4	MT	–32.920278	115.769444	1983	810	J Backhouse	1983, 2012	16 SWC	(Backhouse, 1983b, 2012a)	K
37	HL3A	61330136–8	MT	–32.909167	115.831389	1983	602.5	J Backhouse	1983, 2012	27 SWC	(Backhouse, 1983c, 2012a)	K
38	HL4A	61330140	MT	–32.899167	115.9057222	1984	600	J Backhouse	1985	26 SWC	(Backhouse, 1985b)	–

	Bore/well	ID[a]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[b]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
Harvey Water Table water bores												
39	HWT1.5	61318010	MT	–33.005188	115.863443	1975	24.67	J Backhouse	1975	3 CC	(Backhouse, 1975c)	Cz, K
40	HWT1.6	61318014	MT	–32.993517	115.853713	1975	29.71	J Backhouse	1975	5 CC	(Backhouse, 1975d)	Cz, K
41	HWT1.9	61318020	MT	–33.010186	115.853712	1975	29.36	J Backhouse	1975	5 CC	(Backhouse, 1975b)	Cz, K
Harvey Irrigation water bores												
42	HIA	61300276	MT	–33.011947	115.888611	1980	122	J Backhouse	1980	2 DC	(Backhouse, 1980e)	x
43	HIB	61300277	MT	–33.047775	115.887776	1980	122	J Backhouse	1980	4 SWC, 2 DC	(Backhouse, 1980e)	K
44	HIC	61300278	MT	–33.069443	115.889163	1980	104	J Backhouse	1980	4 SWC, 2 DC	(Backhouse, 1980e)	K
45	HID	61300279	MT	–33.108333	115.875835	1980	88	J Backhouse	1980	2 SWC	(Backhouse, 1980e)	K
46	HIF	61300281	MT	–33.051388	115.856392	1980	81	J Backhouse	1980	4 SWC	(Backhouse, 1980e)	–, x
47	HIG	61300280	MT	–33.101112	115.839717	1980	107	J Backhouse	1980	3 SWC	(Backhouse, 1980e)	?Jr–K
48	HIH	61300282	MT	–33.072781	115.849441	1980	119	J Backhouse	1980	3 SWC	(Backhouse, 1980e)	?K
Harvey Shallow water bores												
49	HS1A	61230001	BT	–33.213611	115.738611	1983	54	J Backhouse	1983	1 DC	(Backhouse, 1983f)	K
50	HS2A	61230003	BT	–33.225278	115.782778	1983	27	J Backhouse	1983	1 DC	(Backhouse, 1983f)	K
51	HS3A	61230007	MT	–33.226944	115.829722	1982	33	J Backhouse	1983	1 DC	(Backhouse, 1983d)	x
52	HS4A	61230008	MT	–33.177778	115.828056	1983	27	J Backhouse	1983	2 DC	(Backhouse, 1983f)	Cz
53	HS5A	61230010	MT	–33.177778	115.858611	1983	30	J Backhouse	1983	1 DC	(Backhouse, 1983d)	Cz
54	HS6A	61230012	MT	–33.146667	115.827222	1982	30	J Backhouse	1983	1 DC	(Backhouse, 1983d)	K
55	HS7A	61230014	MT	–33.149167	115.870278	1983	30	J Backhouse	1983	1 DC	(Backhouse, 1983d)	x
56	HS8A	61330001	MT	–33.0900	115.782222	1982	39	J Backhouse	1983	1 DC	(Backhouse, 1983d)	K
57	HS9A	61330004	MT	–33.108333	115.823056	1982	33	J Backhouse	1983	1 DC	(Backhouse, 1983d)	K
58	HS10A	61330007	MT	–33.0700	115.8225	1982	36	J Backhouse	1983	1 DC	(Backhouse, 1983d)	K
59	HS11A	61330009	MT	–33.036667	115.783889	1982	39	J Backhouse	1982	1 DC	(Backhouse, 1982c)	?K
60	HS12A	61330011	MT	–33.043611	115.826944	1982	39	J Backhouse	1982	1 DC	(Backhouse, 1982c)	?K
61	HS13A	61330013	MT	–32.993056	115.784167	1982	39	J Backhouse	1982	1 DC	(Backhouse, 1982c)	ind.
62	HS14A	61330015	MT	–32.999722	115.824167	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982c)	ind.
63	HS15A	61330017	MT	–32.9600	115.783333	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982c)	K
64	HS16A	61330020	MT	–32.9650	115.827778	1982	36	J Backhouse	1982	2 DC	(Backhouse, 1982c)	Cz, K

	Bore/well	ID[a]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[b]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
65	HS17A	61330022	MT	–32.9675	115.866944	1982	30	J Backhouse	1982	1 DC	(Backhouse, 1982c)	K
66	HS18A	61330024	MT	–32.967222	115.909444	1982	33	J Backhouse	1982	1 DC	(Backhouse, 1982c)	Cz
67	HS19A	61330026	MT	–32.923889	115.781667	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982c)	x
68	HS20A	61330028	MT	–32.908889	115.818333	1982	27	J Backhouse	1982	1 DC	(Backhouse, 1982c)	K
69	HS21A	61330030	MT	–32.9275	115.869444	1982	27	J Backhouse	1982	1 DC	(Backhouse, 1982d)	K
70	HS22A	61330032	MT	–32.926944	115.906667	1982	45	J Backhouse	1982	2 DC	(Backhouse, 1982d)	ind.
71	HS23A	61330034	MT	–32.869722	115.780278	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982e)	K
72	HS24A	61330036	MT	–32.881944	115.813056	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982e)	K
73	HS25A	61330038	MT	–32.884722	115.871111	1982	33	J Backhouse	1982	1 DC	(Backhouse, 1982e)	K
74	HS26A	61330040	MT	–32.879867	115.914303	1982	27	J Backhouse	1982	1 DC	(Backhouse, 1982d)	ind.
75	HS27A	61330042	MT	–32.839269	115.782565	1982	30	J Backhouse	1982	2 DC	(Backhouse, 1982e)	Cz
76	HS28B	61330044	MT	–32.843889	115.826667	1982	45	J Backhouse	1982	2 DC	(Backhouse, 1982e)	K
77	HS29A	61330046	MT	–32.843056	115.858333	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982e)	x
78	HS31A	61330050	MT	–32.78.3889	115.748611	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982f)	Cz
79	HS33A	61330055	MT	–32.7875	115.835556	1982	33	J Backhouse	1982	1 DC	(Backhouse, 1982f)	K
80	HS34A	61330057	MT	–32.790556	115.872222	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982f)	K
81	HS35A	61330059	MT	–32.791944	115.916667	1982	33	J Backhouse	1982	1 DC	(Backhouse, 1982f)	x
82	HS36A	61330061	MT	–32.744444	115.753889	1982	30	J Backhouse	1982	1 DC	(Backhouse, 1982f)	K
83	HS37B	61330063	MT	–32.748056	115.781944	1982	36	J Backhouse	1982	1 DC	(Backhouse, 1982f)	x
84	HS39A	61330068	MT	–32.748611	115.870833	1981	38	J Backhouse	1982	1 DC	(Backhouse, 1982f)	K
85	HS40A	61430001	MT	–32.749167	115.910556	1981	30	J Backhouse	1982	2 DC	(Backhouse, 1982f)	K
86	HS41A	61330070	MT	–32.716111	115.711389	1981	30	J Backhouse	1982	1 DC	(Backhouse, 1982g)	K
87	HS42A	61330072	MT	–32.7150	115.748056	1982	42	J Backhouse	1982	1 DC	(Backhouse, 1982g)	x
88	HS43A	61330074	MT	–32.71500	115.783889	1981	30	J Backhouse	1982	1 DC	(Backhouse, 1982g)	K
89	HS45A	61330079	MT	–32.714722	115.8700	1982	28	J Backhouse	1982	1 DC	(Backhouse, 1982g)	x
90	HS46A	61430003	MT	–32.710556	115.919167	1981	30	J Backhouse	1982	1 DC	(Backhouse, 1982g)	K
91	HS47C	61330081	MT	–32.687500	115.703056	1982	22	J Backhouse	1982	1 DC	(Backhouse, 1982g)	K
92	HS48A	61330083	MT	–32.684906	115.748091	1981	42	J Backhouse	1982	1 DC	(Backhouse, 1982g)	?K
93	HS49A	61330087	MT	–32.676667	115.788333	1981	30	J Backhouse	1982	1 DC	(Backhouse, 1982g)	Cz
94	HS50A	61330089	MT	–32.6750	115.828611	1981	30	J Backhouse	1981	1 DC	(Backhouse, 1981d)	K
95	HS51A	61430005	MT	–32.679827	115.876199	1981	30	J Backhouse	1982	1 DC	(Backhouse, 1982b)	K

	Bore/well	ID[a]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[b]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
96	HS52A	61430006	MT	–32.6825	115.923056	1981	30	J Backhouse	1981	1 DC	(Backhouse, 1981d)	K
97	HS53A	61330091	MT	–32.643056	115.7950	1981	30	J Backhouse	1981	2 DC	(Backhouse, 1981d)	K
98	HS54A	61330094	MT	–32.6425	115.831667	1981	30	J Backhouse	1981	2 DC	(Backhouse, 1981d)	K
99	HS55A	61330096	MT	–32.612222	115.788333	1981	30	J Backhouse	1981	1 DC	(Backhouse, 1981d)	?K
100	HS56A	61430008	MT	–32.609167	115.831389	1981	26	J Backhouse	1981	2 DC	(Backhouse, 1981d)	?K
101	HS57A	61430010	MT	–32.608333	115.8775	1981	30	J Backhouse	1981	1 DC	(Backhouse, 1981d)	K
102	HS58A	61330098	MT	–32.642778	115.701944	1982	18	J Backhouse	1983	1 DC	(Backhouse, 1983e)	K[c]
103	HS59A	61330100	MT	–32.649884	115.743406	1982	18	J Backhouse	1983	1 DC	(Backhouse, 1983e)	K
104	HS60A	61430013	MT	–32.6425	115.880833	1982	21	J Backhouse	1983	1 DC	(Backhouse, 1983e)	K
105	HS61A	61430015	MT	–32.648786	115.924269	1982	27	J Backhouse	1983	1 DC	(Backhouse, 1983e)	K
106	HS62A/B	61330102	MT	–32.781111	115.694167	1982	33	J Backhouse	1983	3 DC?	(Backhouse, 1983e)	?[c]
107	HS63A	61330104	MT	–32.870556	115.736389	1982	33	J Backhouse	1983	1 DC	(Backhouse, 1983e)	?[c]
108	HS64A	61330108	MT	–32.961667	115.736389	1982	42	J Backhouse	1983	1 DC	(Backhouse, 1983e)	?[c]
109	HS65A	61330112	MT	–32.996944	115.866667	1982	30	J Backhouse	1983	2 DC	(Backhouse, 1983e)	Cz, ?K
110	HS66A	61330113	MT	–32.996667	115.910278	1982	28	J Backhouse	1983	1 DC	(Backhouse, 1983e)	?[c]
111	HS67A	61330114	MT	–33.050657	115.888648	1982	33	J Backhouse	1983	1 DC	(Backhouse, 1983e)	x
112	HS68A	61330118	MT	–33.050556	115.858333	1982	42	J Backhouse	1983	1 DC	(Backhouse, 1983e)	K
113	HS69A	61330120	MT	–33.069444	115.884444	1983	30	J Backhouse	1983	1 DC	(Backhouse, 1983f)	x
114	HS70A	61330121	MT	–33.072222	115.850833	1982	51	J Backhouse	1983	1 DC	(Backhouse, 1983e)	K
115	HS71A	61330124	MT	–33.108056	115.876389	1982	36	J Backhouse	1983	1 DC	(Backhouse, 1983e)	Cz
116	HS72A	61230016	MT	–33.263611	115.837778	1982	27	J Backhouse	1983	1 DC	(Backhouse, 1983e)	x
117	HS73A	61230018	BT	–33.298889	115.776667	1983	31.5	J Backhouse	1983	1 DC	(Backhouse, 1983f)	x
118	HS74A	61230020	BT	–33.266389	115.723333	1983	33	J Backhouse	1983	1 DC	(Backhouse, 1983f)	K
Kemerton Line water bores												
119	KE1D	61218500	BT	–33.2419	115.7986	1989	474	J Backhouse	1989	2 SWC, 9 DC	(Backhouse, 1989a)	K, Jr
120	KE2D	61218502	BT	–33.2100	115.7133333	1989	501	J Backhouse	1989	7 SWC	(Backhouse, 1989b)	Jr
121	KW4	61200454	BT	–33.218974	115.7581252	1987	239 (?)	J Backhouse	1988	1 DC	(Backhouse, 1988)	K
Kemerton–Wellesley water bores												
122	KEML1	61200125	BT	–33.22235069	115.7639151	2001	208	J Backhouse	2001	3 DC	(Backhouse, 2001)	Jr
123	KEML2	61200127	BT	–33.18784116	115.7655371	2001	222.6	J Backhouse	2001	3 DC	(Backhouse, 2001)	Jr

	Bore/well	ID[a]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[b]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
Lake Clifton Shallow water bores												
124	LCA1	61319123	MT	–32.689722	115.689722	1979	36	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
125	LCA2	61319124	MT	–32.689317	115.628616	1979	30	J Backhouse	1980	1 DC	(Backhouse, 1980h)	ind.
126	LCA4	61319127	MT	–32.687222	115.654722	1979	27	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
127	LCA5	61319128	MT	–32.687211	115.663313	1979	21	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
128	LCB1	61319129	MT	–32.8359	115.652000	1979	28	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
129	LCB3	61319131	MT	–32.831652	115.675042	1979	26.5	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
130	LCC1	61319136	MT	–32.915886	115.665768	1979	30	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
131	LCC2	61319137	MT	–32.915949	115.671648	1979	27	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
132	LCC4	61319138	MT	–32.914167	115.702500	1979	26	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
133	LCC5	61319139	MT	–32.918056	115.713056	1979	24	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
134	LCC6A	61319140	MT	–32.918889	115.726111	1979	39	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
135	LCE8	61319164	MT	–33.066927	115.795248	1979	36	J Backhouse	1980	1 DC	(Backhouse, 1980h)	x
136	LCF6	61319171	MT	–33.148333	115.742778	1979	31.2	J Backhouse	1980	1 DC	(Backhouse, 1980h)	K
137	LCG7[d]	61319182	MT	–33.1791879	115.7606174	1979	33	J Backhouse	1979	1 DC	(Backhouse, 1979)	K
Bunbury Laporte Line water bores												
138	LP1	61210392	BT	–33.27507	115.730982	1962	229.82	BE Balme, HS Edgell	1962	1 DC	(Balme, 1962; Edgell, 1962a)	K, ?Jr
139	LP2	n.d.	BT	–33.2944	115.7153	1962	274.32	BE Bame, HS Edgell	1962	1 DC	(Balme, 1962; Edgell, 1962a)	K
140	LP3	61118004	BT	–33.270833	115.741667	1962	321.56	BE Balme, HS Edgell, J Backhouse	1962, 2015	2 DC	(Balme, 1962; Edgell, 1962a; Backhouse, 2015d)	K, Jr
141	LP4	61210394	BT	–33.280744	115.727794	1962	336.65	BE Balme, HS Edgell	1962	2 DC	(Balme, 1962; Edgell, 1962a)	K, Jr
142	LP5	61210395	BT	–33.300374	115.705534	1962	213.36	HS Edgell	1962	10 DC	(Edgell, 1962c,d)	Cz, K
143	LP7	61211445	BT	–33.295064	115.710059	1973	231	J Backhouse	1974	2 DC	(Backhouse, 1974e)	K
144	LPF4DB[e]	61219904	BT	–33.252341	15.686868	1976	20.5	J Backhouse	1977	1 DC	(Backhouse, 1977c)	K
Mandurah Aquatic and Recreation Centre geothermal bore												
145	MARC01	n/a	MT	–32.5360	115.7141	2015	1502.4	J Backhouse	2015	9 DC	(Backhouse, 2015c)	K, Jr
Mandurah Golf Course bore												
146	MGC	61401397	MT	–32.530712	115.7000495	1963	213.36	HS Edgell	1963	9 DC	(Edgell, 1963d–f,i,m)	K

	Bore/well	ID(a)	Sub-basin	Latitude	Longitude	Year drilled	TD (m)(b)	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
Mandurah Line water bores												
147	MH1	61401396	MT	–32.535961	115.714094	1962	611.12	HS Edgell, BS Ingram, J Backhouse	1962, 1967, 2011	10 CC; 16 DC	(Edgell, 1962b,e–h; Ingram, 1967d; Backhouse, 2011c)	Cz, K, Jr
148	MH2	61400236	MT	–32.537127	115.753711	1963	174.04	HS Edgell, J Backhouse	1963, 2011	9 DC	(Edgell, 1963a; Backhouse, 2011c)	Cz, K
149	MH3	61400235	MT	–32.559145	115.7877885	1963	208.48	HS Edgell, J Backhouse	1963, 2011	9 DC	(Edgell, 1963b,g,j; Backhouse, 2011c)	Cz, K
150	MH4	61419303	MT	–32.576389	115.823056	1963	153.62	HS Edgell, J Backhouse	1963, 2011	4 DC	(Edgell, 1963n; Backhouse, 2011c)	K
151	MH5	61400237	MT	–32.58017807	115.8578736	1963	255.12	HS Edgell, J Backhouse	1963, 1964, 2011	8 DC	(Edgell, 1963h,l, 1964a; Backhouse, 2011c)	K, ?Jr
152	MH6	61400241	MT	–32.60962	115.838157	1966	165.2	BS Ingram, J Backhouse	1966, 2011	2 DC	(Ingram, 1966e; Backhouse, 2011c)	?K
153	MH7	61400240	MT	–32.55640271	115.8462458	1965	201.47	BS Ingram, K Hooper, J Backhouse	1965; 1972, 2011	5 DC	(Ingram, 1965a; Hooper, 1972; Backhouse, 2011c)	K
154	MH8	61400063	MT	–32.56002929	115.8781645	1965	173.74	HS Edgell, BS Ingram, J Backhouse	1965, 2011	3 DC	(Edgell, 1965; Ingram, 1965a; Backhouse, 2011c)	K
155	MH9	61419305	MT	–32.608611	115.878611	1965	221.59	HS Edgell, BS Ingram, J Backhouse	1964, 1965, 2011	5 DC	(Edgell, 1964b; Ingram, 1965b; Backhouse, 2011c)	K, Jr
156	MH10	61419307	MT	–32.6300	115.822222	1966	286.82	BS Ingram, J Backhouse	1967, 2011	8 CC, 4 DC	(Ingram, 1967c; Backhouse, 2011c)	K, ?Jr
157	MH11	61401089	MT	–32.64188698	115.8540942	1966	291.08	BS Ingram, J Backhouse	1966, 2011	4 CC, 1 DC	(Ingram, 1966a; Backhouse, 2011c)	Jr
158	MH12	61400239	MT	–32.6057832	115.8013769	1966	290.47	BS Ingram, J Backhouse	1966, 1977, 2011	5 CC	(Ingram, 1966b; Backhouse, 1977a, 2011c)	K
159	MH13	61419306	MT	–32.58296	115.886487	1966	217.63	BS Ingram, J Backhouse	1966, 2011	3 CC	(Ingram, 1966c; Backhouse, 2011c)	K, Jr
160	MH14	61419310	MT	–32.5960	115.9237	1967	206.35	BS Ingram, J Backhouse	1967, 2011	9 DC	(Ingram, 1967b; Backhouse, 2011c)	K, Jr
161	MH15	61400068	MT	–32.60639661	115.955937	1969	95.1	BS Ingram, J Backhouse	1969, 2011	2 DC	(Ingram, 1969d; Backhouse, 2011c)	Jr
162	MH16	61419300	MT	–32.5998	115.9367	1969	130.45	BS Ingram, J Backhouse	1969, 2011	4 DC	(Ingram, 1969a; Backhouse, 2011c)	K, Jr
163	MH17	61419331	MT	–32.69117693	115.9375427	1969	106.98	BS Ingram, J Backhouse	1969, 2011	3 DC	(Ingram, 1969b; Backhouse, 2011c)	K
164	MH18	61400915	MT	–32.70138853	115.9196697	1969	152.4	BS Ingram, J Backhouse	1969, 2011	1 CC, 2 DC	(Ingram, 1969c; Backhouse, 2011c)	K

	Bore/well	ID[a]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[b]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
Mandurah Shire (Mandurah Shire Offices) water bore												
165	MS1	61401414	MT	–32.526323	115.721631	1980	191.72	J Backhouse	1980	4 SWC	(Backhouse, 1980f)	K
Miami PWD water bore												
166	MI1/80	61411060	MT	–32.632219	115.6912733	1980	313	J Backhouse	1980	2 DC, 3 SWC	(Backhouse, 1980g)	K
Murray–Peel Leederville water bores												
167	MPL1A	61300134	MT	–32.696332	115.638720	2012	354	J Backhouse	2012, 2013	8 DC	(Backhouse, 2012b, 2013h)	K
168	MPL1B	61300135	MT	–32.696377	115.638719	2012	238	J Backhouse	2012	1 DC	(Backhouse, 2012b)	K
169	MPL2A	61300140	MT	–32.684915	115.748048	2012	366	J Backhouse	2013	14 DC	(Backhouse, 2013a)	K, Jr
170	MPL3A	61407116	MT	–32.681299	115.863725	2013	192	J Backhouse	2013	5 DC	(Backhouse, 2013b)	K, Jr
171	MPL4A	61300142	MT	–32.752207	115.794372	2013	253	J Backhouse	2013	8 DC	(Backhouse, 2013c)	K, Jr
172	MPL5A	61407118	MT	–32.749166	115.910555	2013	300	J Backhouse	2013	6 DC	(Backhouse, 2013d)	K, Jr
173	MPL6A	61300137	MT	–32.814283	115.687863	2012	288	J Backhouse	2013	5 DC	(Backhouse, 2013e)	K, ?Jr
174	MPL6B	61300138	MT	–32.814284	115.687916	2012	150	J Backhouse	2012	1 DC	(Backhouse, 2012b)	K
175	MPL7A	61300145	MT	–32.798650	115.884972	2012	210	J Backhouse	2013	6 DC	(Backhouse, 2013f)	Cz, K, Jr
176	MPL8A	61300148	MT	–32.844411	115.825075	2012	217	J Backhouse	2013	6 DC	(Backhouse, 2013g)	K
Murray DWMP water bores												
177	HS080[f]	61410657	MT	–32.618804	115.851536	2009	n.d.	J Backhouse	2009	2 CC	(Backhouse, 2009)	K
178	HS096	61410664	MT	–32.537404	115.861904	2009	n.d.	J Backhouse	2009	1 CC	(Backhouse, 2009)	x
179	HS104[g]	61410669	MT	–32.510837	115.831876	2009	n.d.	J Backhouse	2009	1 CC	(Backhouse, 2009)	K
180	HS108	61410675	MT	–32.5100	115.854991	2009	n.d.	J Backhouse	2009	1 CC	(Backhouse, 2009)	K
Park Ridge Estate water bore												
181	PRE1[h]	61311038	MT	–32.6674	115.6473	1976	194	J Backhouse	1976, 1977	2 DC	(Backhouse, 1976, 1977d)	K
Picton Line water bores												
182	PL1[i]	61118047	BT	–33.3525	115.6958	1974	1200.1	J Backhouse	1974, 1975, 2015	17 SWC, 6 DC	(Backhouse, 1974f, 1975a, 2015d)	K, Jr
183	PL2A	61118048	BT	–33.3656	115.6472	1978	772	J Backhouse	1978, 2015	7 SWC	(Backhouse, 1978c, 2015d)	Jr

	Bore/well	ID[a]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[b]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
184	PL3A	61118051/61118052	BT	–33.3514	115.7569	1978	794.33	J Backhouse	1978, 2011	18 SWC	(Backhouse, 1978d, 2011b)	K, Jr
185	PL3B	61118053	BT	–33.3514	115.7569	1978	228	J Backhouse	1978	7 SWC, 1 DC	(Backhouse, 1978b)	K
186	PL4A	61118054/ 61118055	BT	–33.3481	115.8103	1978	823	J Backhouse	1978, 2011	12 SWC, 2 DC	(Backhouse, 1978a,e, 2011b)	K, Jr
Preston Beach water bore												
187	PB1	61319001	MT	–32.877729	115.657788	1972	77.1	J Backhouse	1972	2 DC	(Backhouse, 1972e)	K
Waroona Junior High School water bore												
188	WJHS1[j]	61311392	MT	–32.845028	115.929537	1974	132	J Backhouse	1975, 2015	4 DC	(Backhouse, 1975e,g, 2015d)	Jr
189	WJHS3	61311394	MT	–32.845028	115.929537	1974	230.4	J Backhouse	1975, 2015	2 DC	(Backhouse, 1975f, 2015d)	Jr
PWD Yunderup water bore												
190	YN3	61419311	MT	–32.575578	115.8362844	1973	114.3	K Grey	1973	8 DC	(Grey, 1973)	K
Private water bores												
191	BROWNES	61400905	MT	–32.735293	115.9204561	1965	132.28	BS Ingram	1966	3 DC	(Ingram, 1966d)	?Jr–K
192	EDWARDS	61210233	BT	–33.346297	115.8061581	1963	42.67	HS Edgell	1964	1 DC	(Edgell, 1964c)	K
193	HH ED2	61402191	MT	–32.5379	115.7037	1981	30	J Backhouse	1981	1 CC	(Backhouse, 1981a)	K
194	HILLS	61400238	MT	–32.580611	115.7856884	1958	54.56	HS Edgell	1963	1 DC	(Edgell, 1963k)	K
195	RUNCIMAN	61400061	MT	–32.518348	115.926879	1963	73.15	HS Edgell	1963	3 DC	(Edgell, 1963c)	K
Miscellaneous mineral bores, quarry sites and field sites[k]												
196	BKP8	n/a	BT	–33.3500	115.8300	1982?	n.d.	J Backhouse	1982	1 CC	(Backhouse, 1982h)	K
197	BKP10	n/a	BT	–33.4400	115.8400	1982?	n.d.	J Backhouse	1982	3 CC	(Backhouse, 1982h)	K
198	COASTAL1	n/a	BT	–33.0690	115.7290	1974?	n.d.	J Backhouse	1974	2 DC	(Backhouse, 1974d)	?Jr–K
199	GSWA14332	n/a	BT	–33.313889	115.785833	1964	n.d.	HS Edgell	1964	1 HS	(Edgell, 1964c)	Cz
200	LESCH A	n/a	BT	–33.2800	115.6800	1982?	n.d.	J Backhouse	1982	1 CC	(Backhouse, 1982i)	ind.
201	LESCH B(i)	n/a	BT	–33.2800	115.6800	1982?	n.d.	J Backhouse	1982	1 CC	(Backhouse, 1982i)	K
202	MUDLAKE 3	n/a	MT	–32.6320	115.9230	n.d.	n.d.	J Backhouse	1982	1 CC	(Backhouse, 1982a)	K
203	WAGERUP A	n/a	MT	–32.9130	115.9010	n.d.	n.d.	J Backhouse	1980	3 SWC	(Backhouse, 1980i)	K

	Bore/well	ID[(a)]	Sub-basin	Latitude	Longitude	Year drilled	TD (m)[(b)]	Palynologist	Year analysed	Samples analysed	Palynology Report	Reported age
204	WAGERUP B	n/a	MT	–32.9140	115.8500	n.d.	n.d.	J Backhouse	1980	4 SWC	(Backhouse, 1980i)	K
205	ALCOA WAG	n/a	MT	–32.8290	116.0180	n.d.	n.d.	J Backhouse	1980	4 CC	(Backhouse, 1980a)	Jr

Data source: Petroleum wells: DMIRS WAPIMS database (www.dmp.wa.gov.au/wapims); water bores: Department of Water and Environmental Regulation (DWER) WIR database (refer to www.water.wa.gov.au for more information), or GSWA legacy reports and records (for water bores without an AWRC number)

NOTES: 'n.d.' indicates data that could not be determined with certainty.

(a) ID for petroleum wells is UWI (Unique Well Indicator) used in DMIRS WAPIMS database; for water bores, ID is AWRC (Australian Water Resources Council) reference number as designated by DWER.

(b) Total depth measured in metres; where original metrics were in feet, this has been converted to metres.

(c) Report 1983/2 does not describe the results from HS63A, HS64A and HS66 in the main text, despite quoting these bores in the introductory material list; this appears to be an error in reporting that was never corrected. Samples quoted as HS64A in text appear to instead represent those of HS65A based on sample depths. One of the samples stated as from HS61A (identified as F46352) more likely represents the sample from HS58A, although in the sample list the HS58 sample is erroneously identified as F46325. Additionally, no samples are mentioned for HS62B, with two samples mentioned for HS62A instead; it is possible that one or both of these samples was derived from HS62B and mislabelled in the report.

(d) Erroneously listed as Lake Clifton G8 in this report.

(e) This borehole, mentioned in GSWA Hydrogeology Report 1397 and other unpublished GSWA documents, is assumed to correspond to Laporte Tamala Lime – F4.5 listed on DWER databases.

(f) In the palynology report, the AWRC number for this bore is listed as 61410660; however, according to the DWER database, the correct reference number is 61410657 as used here.

(g) Although labelled as 'HS104-4' in the report, there is no borehole with that name in the DWER database, and the AWRC no. quoted in the text refers to HS104-1A.

(h) The borehole in this report is named 'Park Ridge 1', which is assumed to be a misspelling of 'Park Ridge Estate 1'.

(i) Mistakenly listed as 'Picton Junction 1' in Paleontology Reports.

(j) One sample, described in PalRept 1975/8, was originally described as from 'Waroona High School 1' bore; however, as there is no record of such a bore in the DWER databases, it is assumed that this is a sample from the Waroona Junior High School 1 bore, mislabelled in the report.

(k) These boreholes lack strong location and sample collection information as they likely represent ad hoc samples taken by DMIRS officers during project work; in most cases the locations have been estimated using information presented in the Paleontology Reports. Further work to locate and verify these legacy sites is required if the results are to be used in the future.

Abbreviations: TD, total depth

Sub-basin column: MT, Mandurah Terrace; BT, Bunbury Trough

Sample type column: CC, conventional core; SWC, sidewall core; DC, ditch cutting (includes bit samples, bailed samples, sludge samples); HS, hand sample

Palynology Report column: WCR, well completion report; PalRept, GSWA unpublished Paleontology Report

Reported age column: P, Permian; Tr, Triassic; Jr, Jurassic; K, Cretaceous; Cz, Cenozoic (incl. Quaternary); –, not processed; x, barren; ind., indeterminate

All columns: ?, uncertain; n/a, not applicable

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Appendix 2

Borehole summaries and palynological data

This appendix collates the basic sample and palynological information for all wells and boreholes in the study area, including the history of study and data robustness for each borehole or well line examined. In order to present this data with geographic context, the individual reports can be reached via hyperlinks in Figure 2.1. Clicking on the marked site of interest on the map links to the well summary related to that point. Six correlation panels are also provided for this Report and can be accessed by clicking on the correlation lines on the map.

As the focus of this report is the pre-Cretaceous succession, only boreholes yielding Jurassic or older palynofloras are treated individually; boreholes with indeterminate or Cretaceous or younger palynofloras are grouped together by line. The reader should refer to the original reports listed in Appendix 1 and the reference list in the main section of this Report for more information on these shallow boreholes. For many of the individually treated boreholes, charts are provided comparing the palynological data with the lithology (based on the most recent stratigraphic picks) and gamma ray data; if geophysical logs are not available, lithology logs are used instead.

All well revisions undertaken for this data summary were conducted using previous reports without reference to the original slides, with the exception of a recent review of Lake Preston 1 (Backhouse, 2016a) and Pinjarra 1 (Backhouse, 2016b). The original slides were also examined in some externally commissioned well or sample reviews. It is hoped that future projects will include slide restudy and perhaps resampling of key sections and boreholes for those critical sections identified in this literature collation.

Authorship details for all species mentioned in these summaries can be found in Appendix 3; a chart comparing the various zonation schemes is included in the main text as Figure 4.

Dataset limitations

As the result of reassessing legacy data, the biostratigraphic results contained in this dataset are affected by the usual issues of process, analysis, and data access. As most of these problems are common to all wells in the dataset, or are typical for palynological studies, they are only briefly discussed here. Where issues affect individual wells or bore lines, these are discussed further in the relevant well summaries.

Collection issues

Under Western Australia's *Petroleum and Geothermal Resources Act 1967* and *Petroleum (Submerged Lands) Act 1982* — specifically within the Petroleum and Geothermal Resources (Resource Management and Administration) Regulations 2015, Part 8, Divisions 3 and 4 — all data and samples from petroleum wells must be submitted to the Geological Survey of Western Australia (GSWA; on behalf of the Department of Mines, Industry Regulation and Safety) for permanent storage and curation. As for reports, a searchable database of all available physical assets relating to petroleum wells is stored within the Department's WAPIMS system <www.dmp.wa.gov.au/wapims>. However, the history of petroleum exploration in the state pre-dates the Act, and submitted data and assets may not be complete for those wells drilled prior to the Act's establishment, especially where data were curated long after collection.

This problem is more pronounced for mineral holes (e.g. coal and mineral sands), water bores and geothermal holes, where there is no firm legislation requiring the submission and storage of data or samples. There are no requirements to submit samples taken from mineral cores, and therefore few palynological slides from such holes have been submitted and catalogued in centralized collections, such as GSWA or Geoscience Australia, resulting in a depleted physical asset dataset from which to reassess biozonation results.

Although many of the water bores in the southern Perth Basin with palynology results were drilled under supervision of GSWA, not all of the well samples from every borehole were stored. In general, only selected 'representative' palynological slides appear to have been kept from water bores, thereby reducing the available dataset, and decreasing the chance of recognizing subtle assemblage changes. In addition, for many of the water bores reviewed in this Report, no well samples (ditch cuttings or core samples) were apparently retained, further hampering efforts to clarify ambiguous, poorly processed, or lost analyses. Even where well samples were retained, conventional cores were rarely collected in water bores, and sidewall cores were routinely consumed during sample processing, with only ditch cuttings stored for future study.

Where assets such as palynology slides are available, some of the oldest palynology slides in the collection are becoming brittle and breakages are increasingly common. Separation of coverslips from the glass backing slides, and degradation of the mounting medium with time can also reduce the usefulness of these slides. Finally, palynological processing techniques have improved extensively in the past 60 years. Imprecise processing can make a low-yielding sample appear barren, accidently skew the proportions of taxa within an assemblage, or introduce sample contaminants in a way that makes biases difficult to identify.

Sample selection and limitations

Due to the chemical robustness of sporopollenin, palynomorph reworking and assemblage contamination are an issue in palynological studies. This can result in multiple age populations within a single sample, or discordance between a palynomorph assemblage and surrounding lithology or fossil assemblages. The most common form of discordant palynological assemblage is the reworking of older palynomorphs into younger samples, which is usually due to normal sedimentary processes. These reworked palynomorphs may be identified by greater amounts of abrasion, degradation or alteration (indicated by colour) seen on the grains compared with palynomorphs of other age populations. However, palynomorph degradation can be formed by in situ taphonomic effects, and degradation by itself is not an indication of reworked palynomorphs.

Downhole contamination from overlying or younger units, also termed ‘stratigraphic leak’, is typically a result of drilling processes rather than of geology (Traverse, 2008). The two main sources of artificial contamination are drilling mud composition and drilling processes, making the sample types selected for analysis important for the accuracy of palynological analyses. Drilling muds can include sediments or sedimentary products that may incorporate palynomorphs, so understanding the composition of drilling muds used in a well can also be important to understanding the degree and type of contamination. The increased use of synthetic drilling muds and more careful application of drilling methodologies in recent times have decreased the negative effects of artificial contamination. However, palynology samples taken from conventional cores (CC) are still the least likely to be contaminated by mud and downhole sediments, and are therefore considered to provide the most reliable results.

The high cost of conventional coring means that samples of this type are rarely collected in water or geothermal boreholes, and cored intervals are typically short, requiring a combination of samples from cores and other sample types (normally sidewall cores [SWC] or ditch cuttings [DC]) to allow the broadest coverage of a borehole. In the dataset used here, all of the petroleum wells except Lake Preston 1 recovered some cores, which were used preferentially for palynological analysis. A small number of water bores — a few of the deeper exploration holes on the Mandurah line, a single Alcoa Pinjarra Observation borehole, and the Murray DWMP and Harvey Water Table boreholes — have also had cores cut and sampled for palynology. Sidewall cores have less contamination compared to cuttings and are useful samples for palynological studies; however, small sample sizes mean there is rarely an opportunity for resampling or reprocessing if the original slides are lost, degraded or poorly prepared. Sidewall cores were commonly collected from deeper exploratory water bores, such as the Harvey, Binningup and Picton lines, and the three older petroleum wells recovered sidewall cores in addition to conventional cores.

Ditch cuttings — also known as bit, sludge, or bailed samples — are recovered during the drilling process or from materials that are open to contamination during drilling. Palynological results from these samples are accorded the lowest confidence, although age uncertainty can be reduced where samples are submitted in association with more robust sample types, such as conventional or sidewall cores. The majority of the shallow water bores drilled in the study area collected only ditch cuttings with no other sample types for reference. Where these are the only sample types available for palynological analysis, it can be difficult to precisely and accurately determine assemblage zones and the depth of zone boundaries because the zones intermingle and blur downhole. There are additional interpretation problems where downhole contamination overprints sedimentary successions that are naturally lean or barren of palynomorphs; in these cases, only the contaminant assemblage is seen and the sample can be misinterpreted as younger than it actually is.

Taxonomic and biostratigraphic issues

Palynological research on the wells and bores reviewed here was conducted over a wide time period, from the mid-1960s, when Australian palynological studies were still in their infancy, through to the present, where the discipline is well-developed and more mature. Through this period both species and assemblage (and therefore biostratigraphic) interpretations have changed. A concern with reassessing legacy reports is the potential change through time of taxonomic concepts or diagnoses for key biostratigraphic taxa. Aside from shifting taxon names or evolutionary lineages, this redefinition can also change the range and biogeographic distributions of specific taxa, thereby changing the biostratigraphic value of particular species, and complicating the process of bringing these historic studies into line with the modern zonation scheme.

An example of taxonomic uncertainties can be seen in the key Early Jurassic pollen genus *Classopollis* and the three main species placed within this genus complex, which have been separated, recombined, and synonymized multiple times. This uncertainty causes considerable problems when attempting to bring historic palynological studies up to the modern zone and taxonomic usage without reference to the original slides. For a summary on the issues relating to the taxonomy of *Classopollis* and its species, including the usage of this taxon within the current report, see the relevant sections in Appendix 3.

Many of the boreholes examined herein were drilled prior to the establishment of Australia-wide biostratigraphic zonation proposed by Helby et al. (1987), and the key index taxa and boundary events used to define the ages of these samples are likely different from zone concepts used currently. This, combined with subsequent refinements of zone resolution and distribution, can further complicate comparisons between older assemblages; where possible, this Report aimed to update these historical palynological interpretations using published reports alone. However, it was eventually decided to completely reassess the original palynological slides from Lake Preston 1 and Pinjarra 1 due to the age of the original palynological studies, and the importance of these two sections in understanding the Triassic succession in the study area.

Zone ties

As marine organisms, dinoflagellates are more useful for intercontinental correlation than terrestrial spores and pollens, and the local record of these marine palynomorphs have proved critical for tying Australian palynological zones to international chronostratigraphic stratotypes, particularly where used in conjunction with foraminifera, calcareous nannofossil, and macrofossil data (Riding et al., 2010a). As not all of the Australian palynology zones are adequately tied to absolute ages at present, work is continuing to pin down zone boundaries, with current efforts focused on isotope dissolution thermal ionization mass spectrometry (ID-TIMS) dating of Permian and Triassic ash beds in coal-rich basins in the eastern states of Australia (Laurie et al., 2015). Results to date (Smith and Mantle, 2013; Nicoll et al., 2014; Metcalfe et al., 2015; Laurie et al., 2016) have suggested that the application of this method changes the interpreted age of some zones considerably, particularly in the Permian.

Few palynological zone ties have been directly established within the southern Perth Basin due to the region's poor outcrop, dominantly continental sediments, and rare volcanic rocks. Therefore, all links between zones and absolute ages in this area are extrapolated from the northern Perth Basin, or farther afield in Western Australia (particularly from the well-studied North West Shelf). Care must therefore be taken when comparing zones identified in this basin to absolute ages, particularly for the terrestrial spore-pollen zones. Although the zone ties for the Australian Middle Triassic to Upper Jurassic dinocyst zones were recently comprehensively reviewed by Riding et al. (2010a), discussions of zone ties as they relate directly to the Perth Basin are only recorded in basin-specific palynological reviews, such as Backhouse (1988) or Filatoff (1975). Therefore, a brief discussion of the relevant periods and zone ties are presented here as background on the uncertainties of individual zone ages.

A combination of foraminifera and calcareous nannofossils are preferentially used as the global standard for the definition and division of the Aptian and Albian (Gradstein et al., 2012). Extensive work has been conducted internationally to correlate these marine microfossil zones to absolute ages based primarily on radiometric dating (see Gradstein et al., 2012 for a list of radiometric dates and their biostratigraphic ties), making this scheme both robust and high-resolution globally. Foraminifera and calcareous nannofossil records have also been used to tie the Aptian and Albian spore-pollen and dinocyst zones to the global chronostratigraphic record within Australia, primarily based on work in the North West Shelf (e.g. Wright and Apthorpe, 1976; Apthorpe, 1979). Therefore, as the foraminiferal data from the North West Shelf is linked directly to the official chronostratigraphy, the correlation between the Australian middle Cretaceous dinocyst zones and the global stratotypes can be considered relatively robust. Within the Perth Basin, foraminifera and nannofossils are presently unknown from onshore Aptian and Albian units, although upper Cretaceous marine rocks of the Coolyena Group (particularly the Santonian Gingin Chalk) have yielded both foraminifera and calcareous nannofossils (e.g. Belford, 1959, 1960; Shafik, 1990), providing local ties for the Late Cretaceous and minimum age constraints for mid-Cretaceous units such as the Osborne Formation.

As for the mid-Cretaceous, correlation between different geographic regions is difficult for the Early Cretaceous and Late Jurassic due to regionalization in the marine faunas and a lack of global biotic events (Gradstein et al., 2012). Within Australia, this issue makes correlating between basins, and from marine to nonmarine successions, problematic during this period (Turner et al., 2009), and as a result ties are not particularly robust. The primary Middle–Late Jurassic tie in Western Australia comes from a set of lower Bajocian marine successions from the Perth (Newmarracarra Limestone and Cadda Formation) and Northern Carnarvon (Athol Formation) Basins. All three units preserve spore-pollen assemblages of the earliest *Dictyotosporites complex* and uppermost *Callialasporites turbatus* Spore-Pollen Zones in association with dinoflagellates of the *Dissilodinium caddaense* Dinocyst Zone. This co-occurrence of marine and nonmarine assemblages provides a link between the higher resolution dinoflagellate palynology and the broader spore-pollen schemes. In addition, both units also preserve marine macroinvertebrate assemblages, including ammonoids, which are the global biostratigraphic standard for this geological time period (Arkell and Playford, 1954; Coleman and Skwarko, 1967; Westermann and Wang, 1988; Hall, 1989; Riding et al., 2010a,b). However, the high-resolution European ammonoid-based chronozonation — the zonation scheme formally tied to absolute ages, and therefore critical to global correlations — is considered difficult to apply outside of that continent (Arkell and Playford, 1954; Hall, 1989; Gradstein et al., 2012) due to a disconnect between the traditional Tethyan (i.e. western European) forms and circum-Pacific faunas. As a result, dinoflagellate, foraminiferal, calcareous nannofossil, and isotope chemostratigraphy data (e.g. Apthorpe and Heath, 1981; Riding et al., 2010b; Mantle and Riding, 2012) are all used to both support and confirm the robustness of this important tie point. Unfortunately, Jurassic zones older than this Bajocian tie are only poorly constrained due partly to the rarity of dinoflagellates and other marine taxa in Australia during this period, although some foraminiferal work in the North West Shelf has permitted general links.

A variety of marine fossils, including ammonoids and conodonts, from the Kockatea Shale (northern Perth Basin) and Locker Shale (Northern Carnarvon Basin) provide the primary zone ties for the Lower Triassic and Anisian spore-pollen zones in Western Australia (McTavish, 1973; McTavish and Dickins, 1974; Skwarko and Kummel, 1974; Heath and Apthorpe, 1986; Helby et al., 1987; Gorter, 1994; Nicoll and Foster, 1998; Nicoll, 2002; Apthorpe, 2003). The widespread nature of this marine incursion, coupled with the broad range of taxa that can be used for biostratigraphy, has resulted in a number of robust ties, although linking these tied zones to geological successions in eastern Australia has had variable success due to the dominantly nonmarine nature of these rocks. For the Ladinian and later Triassic, ammonoids are unknown in Australia, and a combination of conodonts, foraminifera, and dinocysts are used to tie local zones to the global stratotypes (e.g. Apthorpe and Heath, 1981; Helby et al., 1987; Gorter, 1994; Nicoll and Foster, 1998; Nicoll, 2002; Riding et al., 2010a), primarily using successions of the North West Shelf.

Ammonoids form the primary tie for early Permian (Cisuralian) palynology zones, with other marine taxa such as brachiopods, bivalves, and gastropods used to support international correlations (Archbold et al., 1990). Within the Perth Basin, the Holmwood Shale (Irwin Terrace) contains numerous fossiliferous layers with distinctive Sakmarian ammonoids and other marine fossils, thereby providing zone ties for the upper 'Stage 2' to *Pseudoreticulatispora pseudoreticulata* Spore-Pollen Zones (Glenister and Furnish, 1961; Archbold, 1982; Foster et al., 1985; Glenister et al., 1990; Backhouse, 1991, 1993). Ammonoid-bearing fossil assemblages in the Canning Basin similarly provide age constraints for later early Permian palynozones (Foster and Waterhouse, 1988), although some of these ties could benefit from re-examination. As upper Permian deposits in the Perth Basin are restricted to the Bunbury Trough and are entirely terrestrial in nature, no palynology zone ties of this age have been established in southern Western Australia (Backhouse, 1993).

Biological and ecological controls

Global floral evolution patterns strongly influence the robustness of palynological schemes as zone definitions are best defined using numerous and observable taxon changes. Terrestrial plants in particular are strongly influenced by a range of environmental factors that influence the diversity and richness of assemblages, and the range of individual taxa (Helby et al., 1987).

Although broadly similar across the Gondwanan supercontinent, Gondwanan terrestrial floras from the Permian through to the Cretaceous are considerably different from those of the northern hemisphere; this separation of Gondwanan and Laurasian floras creates difficulties in correlating local microfloral zones to global schemes. Marine floras (dinoflagellates are only recorded from the Triassic onwards) are considered more comparable between the northern and southern hemispheres throughout the Mesozoic, due to the easier dispersal of taxa in oceans. However, there are still times of notable provincialism in marine faunas and floras, although these periods may vary between different fossil groups (Archbold, 2000; Grant-Mackie et al., 2000; Henderson et al., 2000; Gradstein et al., 2012).

Reflecting the patterns seen in Gondwana as a whole, strong and fairly complex floral provincialism has been noted in Australia for the Triassic, with lesser provincialism in the Permian (primarily in macroflora) and Cretaceous. This trend is seen in macro- and microfloras, and in both marine and nonmarine assemblages (Dolby and Balme, 1976; Helby et al., 1987; McLoughlin et al., 1997; Grant-Mackie et al., 2000; Archbold, 2000; McLoughlin, 2001). Controls on floral provincialism vary according to time period; for the early Permian floras, provincialism is considered a product of the strong global climatic gradient of the time, which was linked to glaciation, although little obvious provincialism is seen within Australian Permian terrestrial microfloras (Balme and Backhouse *in* Skwarko, 1993). In the Triassic, microfloras show a clear division between northern 'Onslow' (North West Shelf, Bonaparte Basin, India, Madagascar and east Africa) and higher latitude 'Ipswich' palynofloras (Perth Basin, eastern Australia, Antarctica, southern Africa, South America), with a narrow intermediate palynoflora. Controls on Triassic microfloral provincialism are still mostly unknown, although the moderating influence of the Tethys on the northern Gondwanan coastline likely had an effect (McLoughlin, 2001). Unlike the microfloras, Triassic macrofloras show strong facies control, with similar macroplant suites recorded in similar depositional settings across Gondwana (McLoughlin, 2001).

Early Cretaceous floras are also considered to demonstrate moderate levels of provincialism across Gondwana, and this is likely due to the large range of latitudes, and therefore climatic zones, covered by the continents at that time. McLoughlin (2001) considered that Australia included two separate subprovinces, or areas of endemism, in the Early Cretaceous: Indo-Eromanga (India and northern Australia) and Tasman (southeastern Australia and Zealandia). Late Cretaceous floras are also moderately provincialized across Gondwana, which is classically attributed to the geographically separate state of Gondwanan continental fragments at this time, and resultant evolutionary drift due to assemblage isolation. However, other effects such as regional extinction events, or current or climatic conditions, may also have been an influence (McLoughlin, 2001).

In comparison to the Permian, Triassic and Early Cretaceous, the Jurassic flora shows less marked provincialism, and there are strong floral (and faunal) connections globally, as a result of both stable and relatively equatable climates from pole to pole (Grant-Mackie et al., 2000; McLoughlin, 2001). This environmental stability resulted in many Jurassic species (e.g. *Classopollis torosus*) having cosmopolitan distributions across both Laurasia and Gondwana during this period, although these distributions were not necessarily strictly time-equivalent. In addition to high proportions of cosmopolitan taxa, many of the Jurassic palynomorphs seen in Australia show remarkable conservatism over long periods of time, persisting well into the Cretaceous (McLoughlin, 2001). Although cosmopolitan floras can aid intrabasinal biostratigraphic correlations, floral conservatism reduces the number of easily identifiable bioevents, making it difficult to split floral assemblages into easily identifiable zones. This results in long-ranging zones with indistinct boundaries, as seen in the Upper Triassic and Lower Jurassic Australian palynofloral zones.

In their proposal for a continent-wide palynological scheme, Helby et al. (1987) acknowledged the importance of floral provincialism between the western and eastern portions of the continent by proposing parallel 'western' and 'eastern' zones for some parts of the Mesozoic; this is also seen in the persistence of use of the localized Lower Cretaceous palynological schemes devised for the Perth Basin (Backhouse, 1978, 1988). The difference in floras from west to east and from north to south is related to both global (and Gondwanan) floral patterns of extinction and stasis, and latitudinal differences across the Australian landmass at the time of deposition. For much of the Mesozoic, Australia was oriented with the Western Australian coast at lower latitudes than parts of the east coast, resulting in strong climatic variation between the eastern and western portions of the Australian landmass (Smith et al., 1994; Veevers, 2006; Metcalfe, 2006). As the continent was not strictly perpendicular to latitudinal lines, there were similar latitudinal and paleobiogeographic variations along the Western Australian coast, with the current northern basins at lower latitudes and with better connection to the Meso-Tethys coast than basins farther to the south. As a result, many of the palynological events, zone definitions, and absolute age ties have been defined in the higher diversity and better studied northern basins (especially the Northern Carnarvon Basin). The resulting extrapolation of zone definitions into the Perth Basin is fraught with uncertainties due to the application of these definitions to geographically separated assemblages accumulated under different climatic and environmental conditions. Floral disconnect has led to concerns of zone diachroneity between basins, even within Western Australia; i.e. suggestions that the similarity in floras does not necessarily indicate simultaneity. For example, there is some evidence that the floral turnover between the Permian glossopteroid and Triassic *Dicroidium* macrofloras was diachronous across Gondwana, with the changeover likely initiated later (in the Early Triassic) at higher paleolatitudes (McLoughlin et al., 1997). Similarly, a number of Early Cretaceous palynomorph species appear in the fossil record slightly earlier in northwestern deposits as compared to southeastern Australia, suggesting a poleward migration for a number of taxa at this time (Helby et al., 1987; McLoughlin, 2001). This potential for diachroneity is of particular concern when interpreting the pre-breakup Mesozoic succession in the southern Perth Basin, where data quality is poor or absent for portions of the time scale, and for time periods where absolute age zone ties are poor or lacking.

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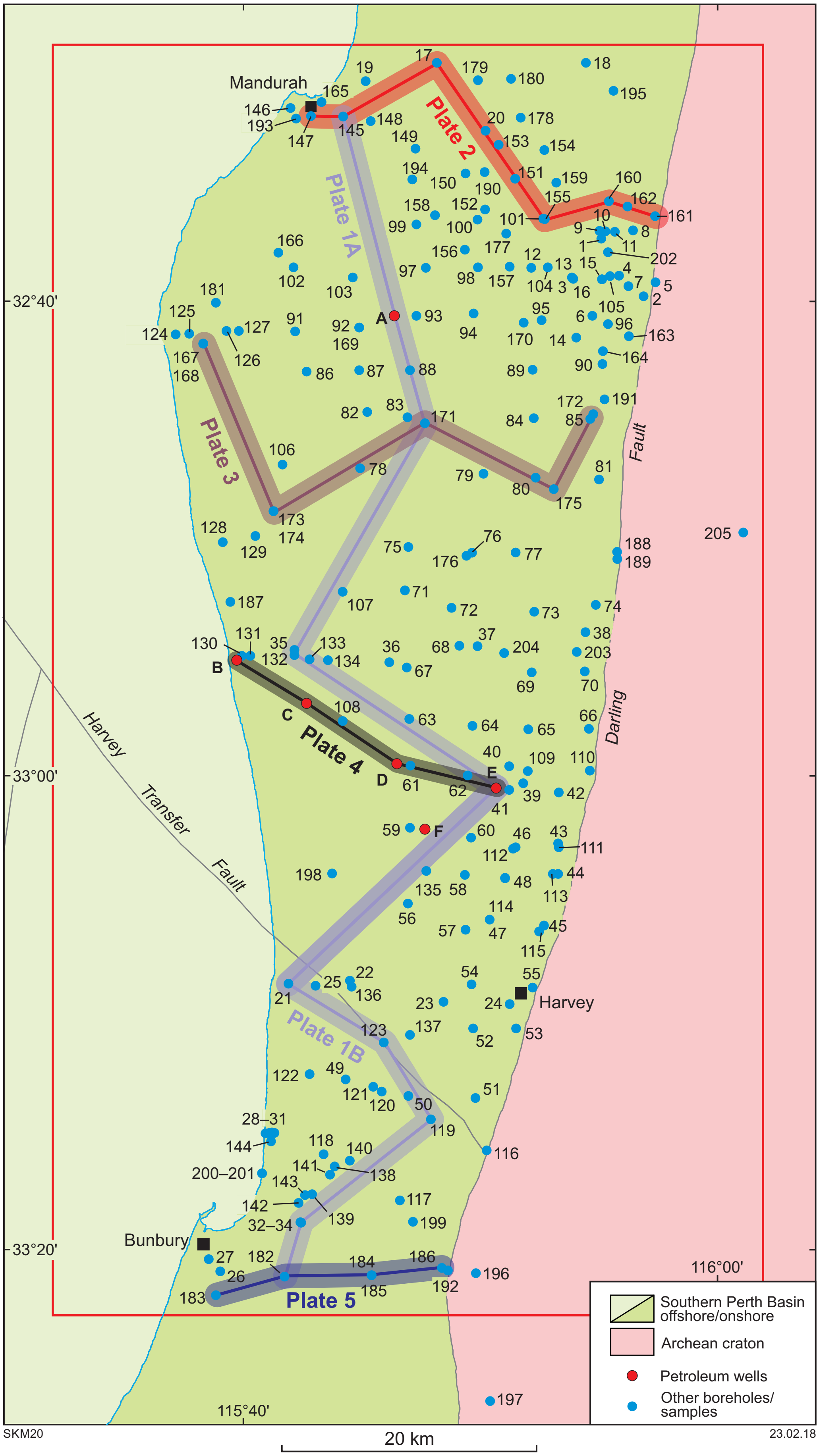
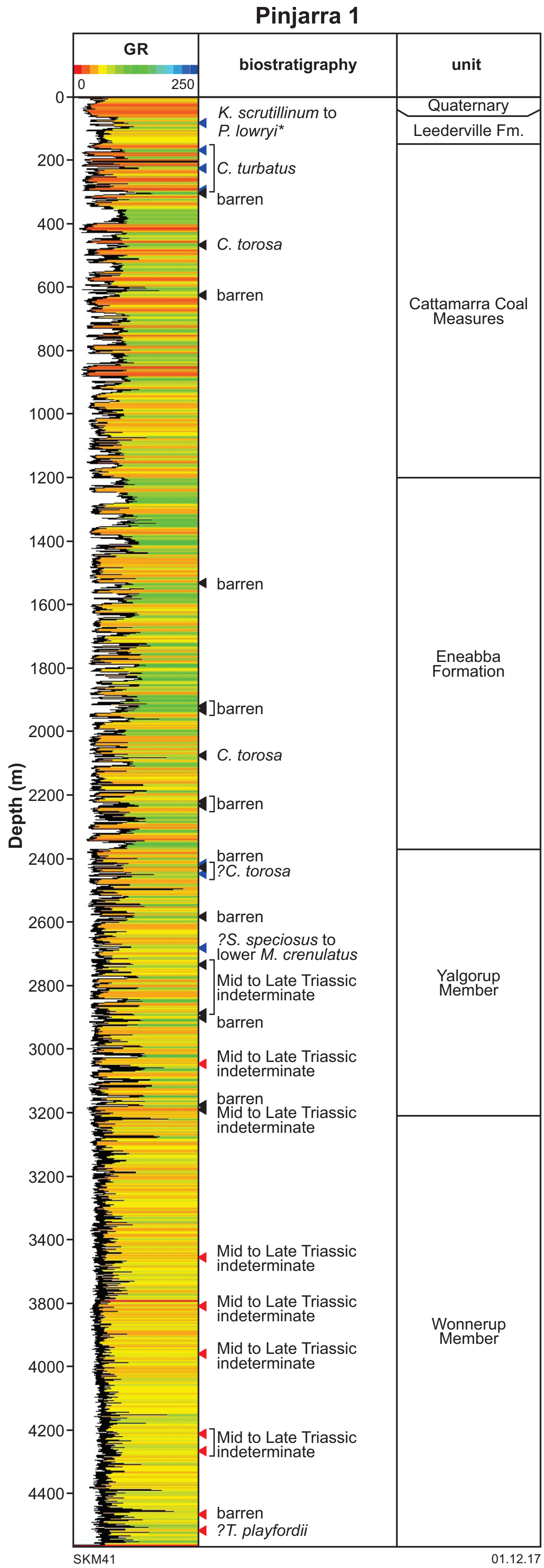

Mandurah
Harvey
Bunbury
Plate 1A
Plate 1B
Plate 2
Plate 3
Plate 4
Plate 5
Darling Fault
Harvey Transfer Fault
32°40'
33°00'
33°20'
115°40'
116°00'
Southern Perth Basin offshore/onshore
Archean craton
Petroleum wells
Other boreholes/ samples
SKM20
23.02.18
20 km

Figure 2.1

Pinjarra 1

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(a)]	*Report*
275	83.82	SWC	*K. scrutillinum* to *P. lowryi*#	(Backhouse, 2016a)
553	168.6	SWC	*C. turbatus*^	(Backhouse, 2016a)
747	227.7	SWC	*C. turbatus*^	(Backhouse, 2016a)
980	298.7	SWC	*C. turbatus*^	(Backhouse, 2016a)
992	302.36	CC	barren	(Backhouse, 2016a)
1530–1540	466.3 – 469.4	CC	*C. torosa*^	(Backhouse, 2016a)
2050	624.8	CC	barren	(Backhouse, 2016a)
5028	1532.5	CC	barren	(Backhouse, 2016a)
6319–6326	1926.0 – 1928.2	CC	barren	(Backhouse, 2016a)
6325	1927.9	CC	barren	(Backhouse, 2016a)
6815–6825	2077.2 – 2080.3	CC	*C. torosa*^	(Backhouse, 2016a)
7301	2225.3	CC	barren	(Backhouse, 2016a)
7301–7311	2225.3 – 2228.4	CC	barren	(Backhouse, 2016a)
7927	2416.1	SWC	barren	(Backhouse, 2016a)
7956	2425.0	CC	*?C. torosa*^	(Backhouse, 2016a)
8025	2446.0	SWC	*?C. torosa*^	(Backhouse, 2016a)
8482	2585.3	CC	barren	(Backhouse, 2016a)
8800	2682.24	SWC	*S. speciosus*^ to lower *M. crenulatus*^	(Backhouse, 2016a)
8970–8980	2734.1 – 2737.1	CC	Middle–Late Triassic indet.	(Backhouse, 2016a)
9487–9497	2891.6 – 2894.7	CC	Middle–Late Triassic indet.	(Backhouse, 2016a)
9492	2893.2	CC	barren	(Backhouse, 2016a)
10 000–10 100	3048.0 – 3078.5	DC	Middle–Late Triassic indet.	(Backhouse, 2016a)
10436	3180.9	CC	barren	(Backhouse, 2016a)
10 436–10 446	3180.9 –3183.9	CC	Middle–Late Triassic indet.	(Backhouse, 2016a)
12 000–12 100	3657.6 – 3688.1	DC	Middle–Late Triassic indet.	(Backhouse, 2016a)
12 500–12 600	3810.0 – 3840.5	DC	Middle–Late Triassic indet.	(Backhouse, 2016a)
13 000–13 500	3962.4 – 4114.8	DC	Middle–Late Triassic indet.	(Backhouse, 2016a)
13 810–13 860	4209.3 – 4224.5	DC	Middle–Late Triassic indet.	(Backhouse, 2016a)
14 000–14 500	4467.2 – 4419.6	DC	Middle–Late Triassic indet.	(Backhouse, 2016a)
14650–14690	4465.3 –4477.5	DC	barren	(Backhouse, 2016a)
14 820–15 000	4517.1 – 4572.0	DC	*?T. playfordii*^	(Backhouse, 2016a)

NOTES:
(a) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Dinocyst Zone



Pinjarra 1 is the most northerly and easterly of the six petroleum wells examined in the study area, and is also the oldest and deepest well within the set; drilled in 1965, this well extended to a total depth (TD) of 15 001 ft (4572.3 m). The well was drilled on the crest of a prominent structure, both as a stratigraphic well and to test the hydrocarbon potential of a then untested region. It was eventually plugged and abandoned without intersecting any hydrocarbon indicators. A full set of samples was collected from this well, including ditch cuttings, conventional cores, and sidewall cores. Ditch cuttings were collected at 5 ft intervals during coring, and at 10 ft intervals at other times. In addition, 28 sidewall cores were recovered, along with 28 conventional cores totalling 287 ft (87.48 m) with 200.5 ft (61.11 m) recovery (Jones and Nicholls, 1966).

The first palynological study of samples from this well was included within the well-completion report and was conducted by Balme (1966). Balme examined 27 samples, including six sidewall core samples, one ditch cutting sample, and 20 samples from conventional cores. Unfortunately, only nine of those samples, five from cores and four from sidewall cores, yielded any palynomorphs. An additional three samples were processed and analysed in 1997 in an attempt to confirm the sediment ages at the bottom of the well (Backhouse, 1997). Although Balme (1966) described the lithology of a number of the barren samples in the centre of the well as 'black shale' and 'black claystone', recent examination of the core (this review) has shown that most of the fine-grained lithologies in this section are strongly oxidized. One sample from Core 9 (1533.75 m) was selected to test for potential palynomorphs, but was found to be barren (Backhouse, 2016b), and no more samples were taken. In 2016, J Backhouse reviewed all previous Pinjarra 1 palynology results (based on the WCR) and re-examined all of the slides held by GSWA in the petroleum relinquishment collection (Backhouse, 2016a); the results of this reinterpretation are also included here.

The shallowest sample analysed from Pinjarra 1 is a sidewall core from 275 ft, which yielded the only Cretaceous assemblage analysed from the well. Although relatively sparse, the assemblage included a small number of dinoflagellates, indicating marine conditions at this level. The set of dinoflagellates observed indicated a palynology zone older than the *Muderongia australis* Dinocyst Zone, and most likely an affinity with the *Phoberocysta burgeri* or *Senoniasphaera tabulata* Australian Dinocyst Zones (*Kaiwaradinium scrutillinum* to *Phoberocysta lowryi* Perth Basin Dinocyst Zones; Backhouse, 1988).

NOTES: **TD = 4572.3 m; lithostratigraphy based on Crostella and Backhouse (2000); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores; black, conventional cores**

The next three samples, sidewall cores from 553 ft (168.55 m), 747 ft (227.69 m) and 980 ft (298.70 m), all preserve similar assemblages, although the shallower sample is far more diverse and therefore easier to place in a biostratigraphic context. Balme considered two of these samples to be Lower or Middle Jurassic in age and equivalent to the 'Cockleshell Gully Formation' (likely equating to the Cattamarra Coal Measures of the northern Perth Basin). The recent re-evaluation places them within the *Callialasporites turbatus* Spore-Pollen Zone (and probably the lower part of this zone) based on the overall assemblage, and combined presence of *Callialasporites turbatus* and *Exesipollenites tumulus* associated with common, but not overwhelmingly abundant, *Classopollis torosus*.

The next two palynomorph-yielding samples are from conventional cores, but are widely separated in the well, with a sample from Core 2 at 1530–1540 ft (466.34 – 469.39 m) and the other from Core 14 at 6815–6825 ft (2077.21 – 2080.26 m). Between these two samples are four barren core samples, with other barren samples both above and below. Although potential reasons for this barren section were not provided in the original report, observation of the core from this part of the well (this review) indicates highly oxidized sediments unsuitable for palynology; an additional sample collected for palynology in 2015, from a depth of 5032 ft, also proved to be barren after processing (Backhouse, 2016b). Again, these two samples yielded similar low-diversity assemblages, although heavily dominated by *C. torosus* and associated pollen. Balme considered these samples as Lower Jurassic or uppermost Triassic in age, and suggested equivalence to the lower portion of the 'Cockleshell Gully Formation' (likely equating to the Eneabba Formation in current nomenclature); this assessment is supported by the recent reassessment, which places these samples within the *Corollina torosa* Spore-Pollen Zone. Other than *C. torosus*, the other taxa described from these samples — *Cyathidites minor*, *Vitreisporites pallidus*, and *'Pityosporites'*, '*Circulina*' (now *Classopollis*), and cf. *Osmundacidites* species — are long-ranging through the Jurassic but are all common elements within the *C. torosa* Zone.

The next two samples — from Core 16 at 7956 ft (2424.99 m) and a sidewall core at 8025 ft (2446.02 m) — are barren of palynomorphs, but contain common spheroidal bodies of possibly fungal or algal affinity. Balme noted that these spheroidal bodies are similar to those seen in the Hill River area, within the lower part of the 'Cockleshell Gully Formation'. On this basis, he proposed a tentative link to the Lower Jurassic for those samples. Unfortunately, these slides were not available for re-examination during 2016, although the very tentative link to the *C. torosa* Zone is maintained based on the description in the well-completion report.

A sidewall core from 8800 ft (2682.24 m) not previously reported in palynology reports on this well, was found in the recent review to contain a low yielding, partially diagnostic assemblage dominated by pollen of the *Minutosaccus crenulatus – Samaropollenites speciosus* complex. This dominance indicates assignment to a zone younger than *Staurosaccites quadrifidus*, with the abundance of *Camerosporites secatus* suggesting a zone older than the upper *Minutosaccus crenulatus* Zone. As a result, an assignment to the upper *M. crenulatus* or *Samaropollenites speciosus* Spore-Pollen Zone is preferred, thereby indicating a Late Triassic age.

Below this sample, from 8970 – 14 690 ft (2734.06 – 4477.51 m) is a set of nine samples with extremely low yields, interspersed with three barren samples. These samples include five conventional core samples first discussed by Balme (1966), and a set of samples taken from ditch cuttings at a later date (Backhouse, 1997). These samples are all poorly diversified, and heavily dominated by *Falcisporites australis*, although the dominance of this taxon becomes less with increased depth. Overall, the assemblages are more indicative of the Triassic, and likely the Late Triassic, although the deeper samples probably range into the Middle Triassic. However, caving of Lower Cretaceous and Lower Jurassic palynomorphs is also common in these samples, highlighting the possibility that all of these samples are in fact barren, and all observed palynomorphs are introduced from elsewhere in the section.

The deepest sample in Pinjarra 1 for which there are extant slides comes from 14 820 – 15 000 ft (4517.14 – 4572.0 m) and is derived from ditch cuttings. This sample is distinct from overlying samples, in that it is heavily dominated by *Aratrisporites tenuispinosus*, but is otherwise of low diversity and yield. The poor yield and diversity, plus poor preservation of the palynomorphs and derivation of the sample from ditch cuttings, makes it difficult to firmly assign this sample to any particular zone, but the assemblage is broadly similar to a pair of samples within Lake Preston 1 (at 9000 ft and 10 150 ft), and is tentatively considered to belong to the *Triplexisporites playfordii* Spore-Pollen Zone.

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Lake Preston 1

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(a)]	*Report*
200	61.0	DC	*B. limbata*#	(Backhouse, 2016)
250	76.2	DC	*?B. limbata*#	(Backhouse, 2016)
300	91.4	DC	indeterminate	(Backhouse, 2016)
350	106.7	DC	indeterminate	(Backhouse, 2016)
400	121.92	DC	*?C. turbatus*^	(Backhouse, 2016)
450	137.16	DC	*C. turbatus*^	(Backhouse, 2016)
500	152.4	DC	*C. turbatus*^	(Backhouse, 2016)
550	167.64	DC	*C. turbatus*^	(Backhouse, 2016)
600	182.9	DC	barren	(Backhouse, 2016)
650	198.12	DC	*C. turbatus*^	(Backhouse, 2016)
700	213.4	DC	barren	(Backhouse, 2016)
750	228.6	DC	barren	(Backhouse, 2016)
1050	320.0	DC	indeterminate	(Backhouse, 2016)
1550	472.4	DC	indeterminate	(Backhouse, 2016)
2200	670.56	DC	*C. torosa*^	(Backhouse, 2016)
3190	972.31	DC	?Triassic indeterminate	(Backhouse, 2016)
3200	975.36	DC	?Triassic indeterminate	(Backhouse, 2016)
3200	975.36	DC	?Triassic indeterminate	(Backhouse, 2016)
3270	996.70	DC	?Triassic indeterminate	(Backhouse, 2016)
3300	1005.84	DC	?Triassic indeterminate	(Backhouse, 2016)
3362	1024.74	SWC	?Triassic indeterminate	(Backhouse, 2016)
3652	1113.13	SWC	?Triassic indeterminate	(Backhouse, 2016)
3750	1143.00	DC	?Triassic indeterminate	(Backhouse, 2016)
3990	1216.15	DC	?Triassic indeterminate	(Backhouse, 2016)
4000	1219.20	DC	?Triassic indeterminate	(Backhouse, 2016)
4226	1288.08	SWC	?Triassic indeterminate	(Backhouse, 2016)
4560	1389.89	SWC	?Triassic indeterminate	(Backhouse, 2016)
4700	1432.56	DC	?Triassic indeterminate	(Backhouse, 2016)
5000	1524.00	DC	?Triassic indeterminate	(Backhouse, 2016)
5235	1592.63	SWC	?Triassic indeterminate	(Backhouse, 2016)
5250	1600.20	DC	?Triassic indeterminate	(Backhouse, 2016)
5563	1695.60	SWC	?Triassic indeterminate	(Backhouse, 2016)
6000	1828.80	DC	?Triassic indeterminate	(Backhouse, 2016)
6376	1943.40	SWC	?Triassic indeterminate	(Backhouse, 2016)
6550	1996.44	DC	Mid–Late Triassic	(Backhouse, 2016)
6893	2100.99	SWC	Mid–Late Triassic	(Backhouse, 2016)
6900	2103.12	DC	Mid–Late Triassic	(Backhouse, 2016)
7000	2133.60	DC	Mid–Late Triassic	(Backhouse, 2016)
7700	2346.96	SWC	barren	(Backhouse, 2016)
8000	2438.40	DC	barren	(Backhouse, 2016)
8089	2465.53	SWC	barren	(Backhouse, 2016)
8481	2585.01	SWC	*?T. playfordii*^	(Backhouse, 2016)
8811	2685.59	SWC	barren	(Backhouse, 2016)
9000	2743.2	DC	*?T. playfordii*^	(Backhouse, 2016)
9109	2776.42	SWC	barren	(Backhouse, 2016)

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(a)]	*Report*
10000	3048.00	DC	barren	(Backhouse, 2016)
10150	3093.72	DC	*?T. playfordii*^	(Backhouse, 2016)
10200	3108.96	DC	barren	(Backhouse, 2016)
10250	3124.20	DC	barren	(Backhouse, 2016)
10300	3139.44	DC	barren	(Backhouse, 2016)
10350	3154.68	DC	indeterminate	(Backhouse, 2016)
10450	3185.16	DC	barren	(Backhouse, 2016)
10500	3200.40	DC	barren	(Backhouse, 2016)
10600	3230.88	DC	barren	(Backhouse, 2016)
10700	3261.36	DC	barren	(Backhouse, 2016)
10800	3291.84	DC	*K. saeptatus*[%] or *T. playfordii*^	(Backhouse, 2016)
10850	3307.08	DC	*K. saeptatus*[%] or *T. playfordii*^	(Backhouse, 2016)
10900	3322.32	DC	*K. saeptatus*[%] or *T. playfordii*^	(Backhouse, 2016)
10928	3330.85	DC	barren	(Backhouse, 2016)
11087	3379.32	DC	barren	(Backhouse, 2016)
11150	3398.52	DC	*K. saeptatus*[%]	(Backhouse, 2016)
11238	3425.34	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
11300	3444.24	DC	*K. saeptatus*[%]	(Backhouse, 2016)
11450	3489.96	DC	*K. saeptatus*[%]	(Backhouse, 2016)
11750	3581.40	DC	*K. saeptatus*[%]	(Backhouse, 2016)
11758	3583.84	SWC	barren	(Backhouse, 2016)
11800	3596.64	DC	*K. saeptatus*[%]	(Backhouse, 2016)
11863	3615.84	SWC	barren	(Backhouse, 2016)
11900	3627.12	DC	*K. saeptatus*[%]	(Backhouse, 2016)
11950	3642.36	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12000	3657.60	SWC	barren	(Backhouse, 2016)
12016	3662.48	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
12050	3672.84	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12066	3677.72	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
12150	3703.32	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12194	3716.73	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
12200	3718.56	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12250	3733.80	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12260	3736.85	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12300	3749.04	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12350	3764.28	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12364	3768.55	SWC	barren	(Backhouse, 2016)
12400	3779.52	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12409	3782.26	SWC	barren	(Backhouse, 2016)
12450	3794.76	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12462	3798.42	SWC	barren	(Backhouse, 2016)
12504	3811.22	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
12550	3825.24	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12560	3828.29	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
12573	3832.25	SWC	barren	(Backhouse, 2016)
12600	3840.48	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12608	3842.92	SWC	barren	(Backhouse, 2016)
12614	3844.75	SWC	barren	(Backhouse, 2016)

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(a)]	*Report*
12650	3855.72	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12686	3866.69	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12700	3870.96	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12750	3886.20	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12766	3891.08	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
12800	3901.44	DC	*K. saeptatus*[%]	(Backhouse, 2016)
12828	3909.97	SWC	*K. saeptatus*[%]	(Backhouse, 2016)
12850	3916.68	DC	*K. saeptatus*[%] or older	(Backhouse, 2016)
12900	3931.92	DC	*K. saeptatus*[%] or older	(Backhouse, 2016)
12932	3941.67	SWC	barren	(Backhouse, 2016)
12948	3946.55	SWC	barren	(Backhouse, 2016)
12950	3947.16	DC	*K. saeptatus*[%] or older	(Backhouse, 2016)
12953	3948.07	SWC	barren	(Backhouse, 2016)
13000	3962.4	DC	*K. saeptatus*[%] or older	(Backhouse, 2016)
13050	3977.64	DC	*K. saeptatus*[%] or older	(Backhouse, 2016)
13100	3992.88	DC	*K. saeptatus*[%] or older	(Backhouse, 2016)
13150	4008.12	DC	*K. saeptatus*[%] or older	(Backhouse, 2016)
13200	4023.36	DC	Permian–Triassic	(Backhouse, 2016)
13250	4038.60	DC	Permian–Triassic	(Backhouse, 2016)
13255	4040.12	SWC	Permian–Triassic	(Backhouse, 2016)
13300	4053.84	DC	Permian–Triassic	(Backhouse, 2016)
13350	4069.08	DC	Permian–Triassic	(Backhouse, 2016)
13400	4084.32	DC	Permian–Triassic	(Backhouse, 2016)
13450	4099.56	DC	Permian–Triassic	(Backhouse, 2016)
13500	4114.80	DC	Permian–Triassic	(Backhouse, 2016)
13512	4118.46	SWC	Permian–Triassic	(Backhouse, 2016)
13550	4130.04	DC	barren	(Backhouse, 2016)
13589	4141.93	SWC	barren	(Backhouse, 2016)
13600	4145.28	DC	Permian–Triassic	(Backhouse, 2016)
13650	4160.52	DC	barren	(Backhouse, 2016)
13700	4175.76	DC	barren	(Backhouse, 2016)
13750	4191.00	DC	barren	(Backhouse, 2016)
13800	4206.24	DC	indeterminate	(Backhouse, 2016)
13850	4221.48	DC	barren	(Backhouse, 2016)
13891	4233.98	SWC	barren	(Backhouse, 2016)
13900	4236.72	DC	indeterminate	(Backhouse, 2016)
13950	4251.96	DC	barren	(Backhouse, 2016)
14000	4267.20	DC	indeterminate	(Backhouse, 2016)
14050	4282.44	DC	indeterminate	(Backhouse, 2016)
14100	4297.68	DC	indeterminate	(Backhouse, 2016)
14150	4312.92	DC	indeterminate	(Backhouse, 2016)
14200	4328.16	DC	indeterminate	(Backhouse, 2016)
14250	4343.40	DC	indeterminate	(Backhouse, 2016)
14300	4358.64	DC	indeterminate	(Backhouse, 2016)
14350	4373.88	DC	indeterminate	(Backhouse, 2016)
14400	4389.12	DC	indeterminate	(Backhouse, 2016)
14450	4404.36	DC	indeterminate	(Backhouse, 2016)
14463	4408.32	SWC	barren	(Backhouse, 2016)

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(a)]	*Report*
14500	4419.60	DC	indeterminate	(Backhouse, 2016)
14550	4434.84	DC	indeterminate	(Backhouse, 2016)
14600	4450.08	DC	indeterminate	(Backhouse, 2016)
14650	4465.32	DC	indeterminate	(Backhouse, 2016)
14700	4480.56	DC	indeterminate	(Backhouse, 2016)
14750	4495.80	DC	indeterminate	(Backhouse, 2016)
14757	4497.93	SWC	indeterminate	(Backhouse, 2016)
14800	4511.04	DC	indeterminate	(Backhouse, 2016)
14850	4526.28	DC	barren	(Backhouse, 2016)
14900	4541.52	DC	indeterminate	(Backhouse, 2016)
14950	4556.76	DC	barren	(Backhouse, 2016)
14977	4564.99	DC	indeterminate	(Backhouse, 2016)

NOTES:
(a) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [%] Dolby and Balme (1976) Spore-Pollen Zone; ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone

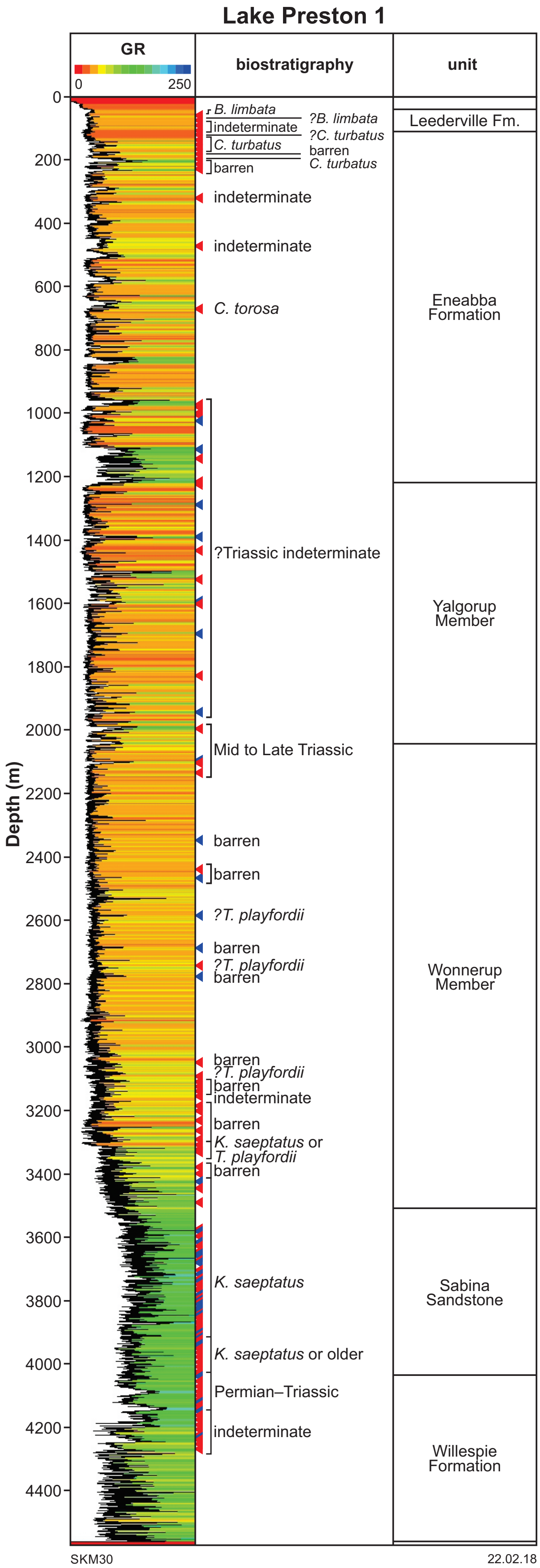
Lake Preston 1 was drilled by WAPET in late 1972 and early 1973, extending to a TD of 14 977 ft (4565 m). The well was planned as a wildcat test, but was plugged and abandoned at TD after encountering no unexpected geology and no significant hydrocarbon shows. As no suitable reservoirs were intersected in the target Sabina Sandstone and Sue Coal Measures, no conventional cores were cut in this well, although 46 sidewall cores were recovered and a complete set of ditch cuttings sampled at 10 ft (3 m) intervals (Young and Johanson, 1973).

The original palynological study on this well was included as part of the well-completion report (Young and Johanson, 1973). This study, conducted by G Dolby and AJ Williams, examined 25 samples (15 cuttings samples and 10 sidewall cores) extending to 14 950 ft (4556.8 m), and interpreted a sequence for this well extending from the Early Cretaceous through to the Late Permian (Dolby and Williams, 1973). None of the samples in the original report was linked to any particular zone or zonation scheme, and the report only provides partial microfloral listings and no range chart.

An informal review of this palynology report (J Backhouse, 2014, written comm., 4 January) conducted at the start of this project suggested that a number of additional palynological slides existed beyond the material described by Dolby and Williams (1973). These undescribed samples — at least nine additional SWC and 15 samples from DC — are predominantly from the deeper portion of the well. Backhouse (2016) later conducted a preliminary study of one set of the historic Lake Preston slides in the GSWA Petroleum Relinquishment collection (GSWA holds two sets of slides from the same depths), including these slides not previously described in the WCR. Unfortunately, many of the slides were found to be barren or extremely low yielding, and as species counts were considered unlikely to add to the discussion, only a basic reassessment was conducted on the material. However, this preliminary re-examination still provided useful information on the Jurassic to Permian section of the well, and the results are therefore included in the following discussion.

As noted elsewhere, the use of ditch cuttings for palynological analyses is not considered ideal due to the high chance of sample contamination either from muds or from overlying formations. However, in this well, ditch cuttings and sidewall cores are interspersed throughout the deeper part of the drilled section, with sidewall-core samples able to provide a partial check on the fidelity of analyses taken from ditch cuttings. Overall, the results from the cuttings closely match those obtained from sidewall cores, particularly deeper than 11 000 ft, where closely spaced samples of both types yielded similar assemblages interpreted as equal in age. Unfortunately, the shallowest sidewall core is at 4226 ft (1288.1 m), meaning that there is no check on the accuracy of ditch cuttings within the Jurassic and Cretaceous portions of the well sequence.

According to Dolby and Williams (1973), only the very shallowest sample — cuttings from 150 to 200 ft (45.7 – 61.0 m) — preserved any dinoflagellates. A single dinoflagellate was also observed (at 200 ft) during the recent slide reassessment (Backhouse, 2016), thereby confirming the interpreted slight marine influence at this depth. This cutting sits within sediments later assigned to the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 2016). Aside from dinoflagellates, which are common components of the Early Cretaceous palynoflora in the Perth Basin, Dolby and Williams (1973) noted a number of spore-pollen taxa considered typical for the *B. limbata* Zone in the two shallowest well samples (150–200 and 300–350 ft), such as *Balmeiopsis limbata*, *Cicatricosisporites hughesi* and *Cyathidites concavus*.



The slide reassessment confirms this zone for the 200 ft slide, although the index species *B. limbata* was not recorded. Although the recent slide reassessment found the following three slides in the set (250, 300 and 350 ft) to be barren or low yielding, with none able to be placed firmly within any particular zone, Backhouse (2016) considered these samples to be Early Cretaceous in age, based on the comparable organic matter preserved within the samples. He also noted a distinct change in organic matter and palynofacies in the 400 ft sample, thereby suggesting that the Jurassic–Cretaceous unconformity falls somewhere between 350 and 400 ft.

This result agrees well with Dolby and Williams' (1973) assessment, who interpreted an unconformity separating the Lower Cretaceous (*B. limbata* Zone) and Lower Jurassic (*Callialasporites turbatus* Spore-Pollen Zone) sediments between 350 and 450 ft. Using the original palynology report, the 450–500 ft sample, the highest below this unconformity, was reassessed as belonging to the *C. turbatus* Zone, based on the co-occurrence of *Callialasporites turbatus*, *Classopollis classoides* and *Callialasporites dampieri*, with samples at 600–650 ft and 1000–1050 ft also tentatively allied to this zone (J Backhouse, 2014, written comm.). However, the recent reassessment of slides suggests that a number of samples between 400 and 650 ft (400, 450, 500, 550 and 650 ft) are assignable to this Lower Jurassic zone, with the following four slides, from 700 to 1550 ft either age indeterminate or barren (Backhouse, 2016).

The next diverse sample after this — labelled as from 2150–2200 ft (655.3 – 670.6 m) in Dolby and Williams (1973), and 2200 ft in the slide redescription — has an assemblage clearly assignable to the underlying *Corollina torosa* Spore-Pollen Zone (Backhouse, 2016). Unfortunately, the thick section of sediments above this depth without available samples makes it difficult to interpret or approximate the boundary between the *C. turbatus* and *C. torosa* Zones. The same is true below the *C. torosa* Zone sample, for which Dolby and Williams (1973) noted that the 19 analysed samples between 2200 and 8481 ft (670.6 – 2585.0 m) were either barren or nearly so, with only rare *Falcisporites* sp. palynomorphs recovered from a few sidewall-core samples in this section. The slide reassessment noted a long set of age-indeterminate samples extending from 3190 to 6376 ft, where all of the slides were barren of palynomorphs. However, Backhouse (2016) noted that these samples yielded organic matter more similar to the underlying Triassic samples than to the overlying Jurassic samples, thereby suggesting that much of this sequence is in fact Triassic in age.

Notes: TD = 4571.1 m; lithostratigraphy based on Crostella and Backhouse (2000); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores

If this interpretation is correct, the Triassic–Jurassic boundary may lie closer to 2200 ft (the depth of the deepest unequivocal Jurassic assemblage) than 6500 ft (the depth of the shallowest unequivocal Triassic assemblage).

This reassessment is the first time the *C. turbatus* Zone has been identified within Lake Preston 1 — the original well-completion report assigned a late Early to early Middle Jurassic age to these samples and associated the entire section as the 'Eneabba Member of the Cockleshell Gully Formation.' Crostella and Backhouse (2000) specifically assigned this entire section of the well to the *C. torosa* Zone (Crostella and Backhouse, 2000, plate 1), thereby implying that the Cretaceous unconformity in this well had removed all of the *C. turbatus* and younger Jurassic zones. In truth, there is firmer evidence for a thick *C. turbatus* Zone than *C. torosa* Zone, although this is likely a factor of the notoriously low-yielding and low-diversity nature of the *C. torosa* Zone assemblages in the Perth Basin.

The slide reassessment identified four slides — from 6550, 6893, 6900 and 7000 ft — as containing the shallowest certainly Triassic assemblages (Backhouse, 2016). This determination is based on the almost exclusive presence of small forms of Triassic taxon *Falcisporites australis*. It has been suggested that these samples are Middle to Late Triassic in age, although this cannot be proven based on these assemblages alone, but is an estimate based on the age of underlying samples, and the noted low yield and low-diversity floras of the later Triassic in the Perth Basin (i.e. Lesueur Formation). If this assumption of a Middle to Late Triassic age is correct for these samples, a small set of deeper barren samples (7700, 8000 and 8089 ft) are also likely Middle Triassic in age.

A diverse assemblage recovered at 8481 ft was considered ?Middle–Late Triassic in age based on restudy of the original palynological report (J Backhouse, 2014, written comm.). Crostella and Backhouse (2000) considered this sample to belong to the *Triplexisporites playfordii* Zone, with the recent slide reassessment tentatively agreeing with the identification of this zone (Backhouse, 2016). Interestingly, a number of species within this assemblage appear endemic, indicating a slightly different flora when compared to the northern Perth Basin or farther north into the Carnarvon and Canning Basins. This endemism makes it difficult to firmly assign this and similar assemblages (at 9000 and 10 150 ft) to any particular zone, although the preserved palynoflora is roundly reminiscent of the *T. playfordii* Zone and lacks index species from any of the younger (*Staurosaccites quadrifidus*, *Samaropollenites speciosus*, or *Minutosaccus crenulatus* Zones) or older (*Kraeuselisporites saeptatus* Zone of Dolby and Balme [1976] = *Lunatisporites pellucidus and Protohaploxypinus samoilovichii* Zones of Helby et al. [1987]) spore-pollen zones. The presence of *Aratrisporites tenuispinosus* in the 10150 ft sample is thought to support this zone assignment. Dolby and Williams (1973) compared the 10100 – 10150 ft (3124.2 – 3139.4 m) sample to palynofloras from the Woodada Formation of the northern Perth Basin. An assemblage similar to these ?*T. playfordii* Zone samples is also observed in the nearby Pinjarra 1 well (at 14820 ft).

Following another set of barren samples, likely Middle Triassic in age, are three unusual assemblages (at 10800, 10850, 10900 ft), which contain some, but not all, of the characteristics of both the *T. playfordii* and *K. saeptatus* Zones. As the assemblages are not particularly consistent with either zone, they are considered somewhat indeterminate between the two (Backhouse, 2016).

The next diverse set of samples recognized by Dolby and Williams (1973) lies between 11150 and 11450 ft (3398.5 – 3490.0 m), and are Early Triassic in age. A recent review of this legacy report assigns these samples somewhat tentatively to the *K. saeptatus* Zone, and therefore this part of the well can be considered an age equivalent of the Kockatea Shale of the northern Perth Basin (J Backhouse, 2014, written comm.). The assignment of these samples to the *K. saeptatus* Zone was confirmed during the slide reassessment in 2016, although that review found this zone assemblage in 31 separate samples between 11150 and 12828 ft (Backhouse, 2016). This differs from Dolby and Williams (1973) interpretation, which considered samples from 11700 – 13150 ft (3566.2 – 4008.1 m) to contain a mixture of Permian and Triassic forms. Overall, Dolby and Williams designated the shallowest two samples of this set transitional Permo–Triassic floras, and the deepest five samples late Upper Permian in age based on the identification of *Kraeuselisporites rallus*, previously recorded from the latest Permian of Salt Range, Pakistan. These samples were noted by Dolby and Williams (1973) to resemble similarly mixed assemblages in the Wonnerup 1 (at 13316 and 13380 ft) and Whicher Range 1 (at 12269.5 and 12560–70 ft) petroleum wells further south in the basin.

This set is closely followed by two final sidewall-core samples (at 13255 and 13512 ft) interpreted by Dolby and Williams (1973) as Upper Permian and considered most likely Permian when that report was reviewed in 2014. Conversely, the slide reassessment found no obvious change in palynoflora at the shallower depth of 11 750 ft, apparent from the appearance of monosaccate pollens at this depth which are noted to be dissimilar from most Permian monosaccate forms and similar in preservation to other, likely Early Triassic spores and pollens from similar depths. Furthermore, it was noted that *K. rallus* is similar to *Kraeuselisporites cuspidus*, an Early Triassic form commonly recorded in the Kockatea Shale. Therefore, there is no firm palynological evidence for Permian sediments within this section.

Between 12850 and 13150 ft, samples generally yielded assemblages similar to those above assigned to the *K. saeptatus* Zone. However, this is only true for the slides from ditch cuttings as all sidewall-core samples were barren. Having barren sidewall cores within a set of ditch cuttings that yield palynoflora is usually considered an indicator that assemblages within the cuttings are caved, and do not represent the true age of sediments at that depth; however, in these cases, caved assemblages tend to be low yield, whereas the samples seen here are moderately yielding. Nevertheless, this difference adds uncertainty to these assemblages, and as a result samples from this section are considered *K. saeptatus* Zone or older.

From 13 200 to 13 600 ft are a set of low-yielding to barren samples. The poor assemblages in this section contain a number of Triassic spore-pollen species, plus a small number of Permian taxa, including possible *Striatopodocarpites fusus*, *Protohaploxypinus microcorpus* and *Acanthotriletes tereteangulatus*. If the Triassic palynomorphs are caved, it is possible that this section is Late Permian in age, although the data are far too sparse to confirm this interpretation. Therefore, while Dolby and Williams (1973) would have considered the top Permian in Lake Preston 1 to fall between 11 800 and 11 850 ft, recent reassessment suggests the top Permian in fact lies farther down the hole, perhaps around 13 250 ft. Based on the stratigraphic determinations published in the original well-completion report for Lake Preston 1, Dolby and William's (1973) interpretation for the system boundary lies within sediments of the Sabina Sandstone, which was considered to extend from 11 399 – 13 239 ft (3474–4035 m), whereas the revised palynology (Backhouse, 2016) would place the Permian–Triassic boundary closer to, or coincident with, the boundary between the Sabina Formation and Sue Group. Interestingly, Dolby and Williams (1973) noted a strong change in palynofauna, both in composition and preservation, between 13 150 and 13 255 ft, which they correlated to a formation boundary between the Sabina Sandstone and underlying Sue Group, which would also agree with this reinterpretation.

Dolby and Williams (1973) observed that although the samples themselves remained organic rich, palynomorphs rapidly degraded below depths of 13 500 ft (4114.8 m), and they could not determine the age of the sediments at TD. This is supported by the recent slide redescription, which found a continuous sequence of 34 barren samples between 13 650 and 14 977 ft (Backhouse, 2016). This degradation is likely taphonomic, relating to the deep burial, and therefore thermal destruction, of palynomorphs.

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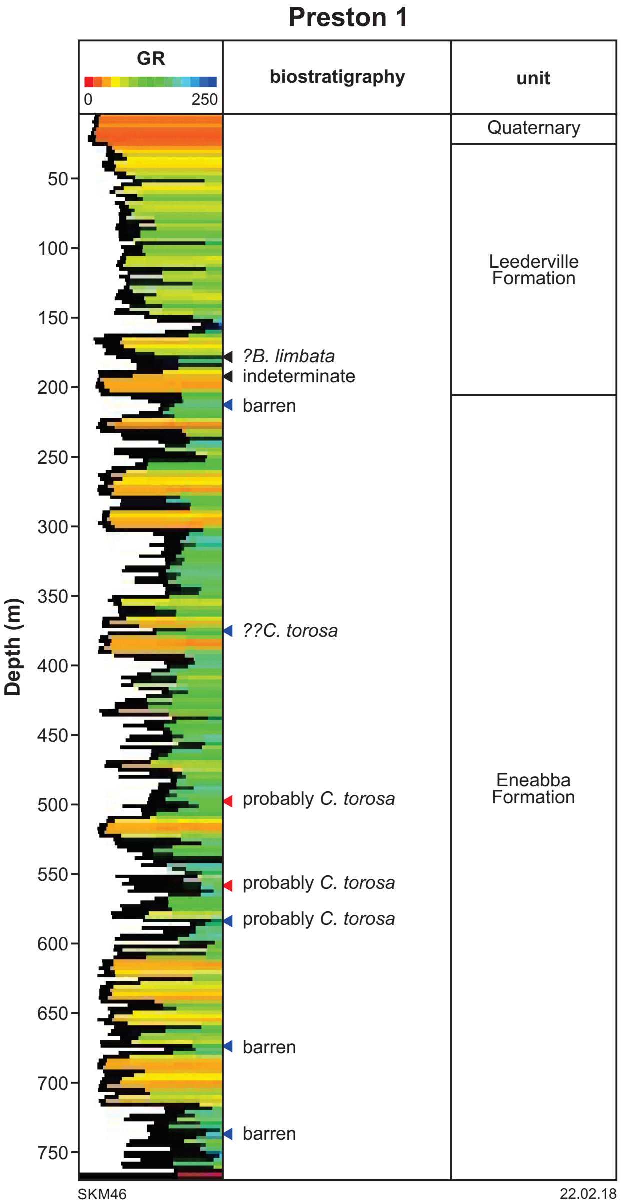
Preston 1

Depth (feet)	Depth (metres)	Sample type	Zone/age[(a)]	Report
594	181.1	CC	*?B. limbata*[#]	(J Backhouse, 2014, written comm., 29 March)
597	182.0	CC	indeterminate	(J Backhouse, 2014, written comm., 29 March)
696	212.1	SWC	barren	(J Backhouse, 2014, written comm., 29 March)
1227	374.0	SWC	*??C. torosa*^	(J Backhouse, 2014, written comm., 29 March)
1630	496.8	DC	Probably *C. torosa*^	(J Backhouse, 2014, written comm., 29 March)
1830	557.8	DC	Probably *C. torosa*^	(J Backhouse, 2014, written comm., 29 March)
1914	583.4	SWC	Probably *C. torosa*^	(J Backhouse, 2014, written comm., 29 March)
2210	673.6	SWC	barren	(J Backhouse, 2014, written comm., 29 March)
2412	735.2	SWC	barren	(J Backhouse, 2014, written comm., 29 March)

NOTES:
(a) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone



Notes: **TD = 765.4 m; lithostratigraphy based on Crostella and Backhouse (2000); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores; black, conventional cores**

Preston 1 is the closest borehole to the current GSWA Harvey 1 well, and was drilled by WAPET to a TD of 2511 ft (765.4 m) in 1966. Drilled as a shallow stratigraphic test, the well encountered no signs of hydrocarbons and was abandoned at a TD slightly deeper than originally planned. A complete set of samples were collected from this well, comprising ditch cuttings, conventional cores, and sidewall cores. Three 10 ft lengths of core were intended to be cut over the course of the well, although only the uppermost core, from 593–603 ft (180.75 – 183.79 m) recovered any samples; attempts to cut core from 2270–2280 ft (691.90 – 694.94 m) and 2410–2420 ft (734.57 – 737.62 m) failed. Of the 20 sidewall cores shot, 17 were recovered and 15 of those were obtained by WAPET for sampling. Ditch cuttings were collected at 10 ft intervals down to 2450 ft, but at 5 ft intervals during coring depths. The well-completion report noted that these ditch cuttings are highly contaminated from 80–290 ft (24.38 – 88.39 m), and poor mud conditions meant that little material was recovered from shallow claystones to 1200 ft (365.76 m) (Lehmann, 1966).

Only a single formal palynological study has been conducted on the Preston 1 samples, conducted by BE Balme in 1966, with the results included as part of the well-completion report (Balme, 1966). Only eight samples were analysed as part of this study; as only one of these samples was from ditch cuttings and none from the highly contaminated shallower portion of the well, it is suggested that the recovered results are representative, or close to representative, of the well palynoflora at each of the sampled depths. None of the samples in the original report was linked to any particular zone or zonation scheme, and the report provided no range chart, making the report results difficult to assess without re-examining the slides or taking new samples. Despite this, J Backhouse (2014, written comm., 29 March) informally reviewed all the palynology known from this well for GSWA, based entirely on Balme's (1966) published report.

The two deepest samples examined by Balme were barren — specifically sidewall cores at 2110 and 2412 ft (643.13 and 735.18 m) — resulting in a lack of age control in the deepest 600 ft (~182 m) of section, between 1914 ft and the TD of 2511 ft. In addition, a core sample at 597 ft (181.97 m) and a sidewall core sample at 696 ft (212.14 m) were also considered age indeterminate, despite the sidewall core containing only rare disaccate pollen and the core sample containing ?fungal spheroidal bodies that Balme (1966, p. 17) compared to similar features in 'early Jurassic "red beds" in the Hill River area' (assumed here to equate to the Eneabba Formation).

As a result, only four of the palynological samples gave some age indications. None of these samples preserved any dinoflagellates, and all are considered to have been deposited under nonmarine conditions. The shallowest sample from Preston 1 was taken from Core 1, at 594 ft (181.05 m). This sample, with uncommon but well-preserved spores and pollen was considered by Balme (1966) to be Neocomian or Late Jurassic in age. Recent reassessment of this sample suggests assignation to the *Balmeiopsis limbata* Spore-Pollen Zone, although the association is considered untrustworthy due to the few spore and pollen species noted in this sample and the drilling issues noted in this section of the well (J Backhouse, 2014, written comm., 29 March). As a result, it is recommended that this core is resampled and reassessed to clarify the age of this section.

The remaining three samples consist of two sidewall cores at 1227 and 1914 ft (373.99 and 538.39 m), bracketing a set of ditch cuttings from 1630–1830 ft (496.82 – 557.78 m). The uppermost sample in this set yielded only rare specimens of the pollen *Classopollis torosus*, which by itself is not sufficient evidence to suggest an age. However, the slightly expanded assemblages preserved in the other two samples suggest that all three belong to the same interval. Balme (1966) considered these samples to be Lower Jurassic in age and equivalent to the lower part of the 'Cockleshell Gully Formation' (possibly Eneabba Formation?), and the report reassessment placed all three probably within the *Corollina torosa* Spore-Pollen Zone (J Backhouse, 2014, written comm., 29 March).

As a result, there appears to be a change from Lower Cretaceous to Lower Jurassic sediments somewhere between 594 and 1227 ft, although there is presently no palynological evidence suggesting where this unconformity lies, or whether there are other age units within this gap in the data. Interestingly, the original study of these samples suggested this unconformity was within Core 1, due to the assignation of this upper sample (at 594 ft) to the Early Cretaceous and comparison (albeit highly tentatively) of the underlying sample (at 597 ft) with Early Jurassic sediments of the northern Perth Basin (Balme, 1966). This interpretation was not followed in the well-completion report as a whole, which considered the unconformity between Lower Cretaceous and Lower Jurassic units to be much further down the well, at 672 ft (204.83 m). Similarly, there is no palynological evidence of the age at TD, or whether there is an unconformity below the Lower Jurassic sediments at 1914 ft.

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GSWA Harvey 1

Depth (feet)	Depth (metres)	Sample type[(a)]	Zone/age[(b)]	Report
–	795–825 (mud)	DC	?*C. torosa* / *C. turbatus* to *M. crenulatus* or younger^	(Backhouse, 2014)
–	795–825 (chips)	DC	Indeterminate	(Backhouse, 2014)
–	901.75	CC	upper *S. quadrifidus* to lower *S. speciosus*^	(Backhouse, 2014)
–	903.6	CC	*S. speciosus* or older^	(Backhouse, 2014)
–	923.5	CC	barren	(Backhouse, 2014)
–	924.0	CC	indeterminate	(Backhouse, 2014)
–	924.6	CC	barren	(Backhouse, 2014)
–	1268.8	CC	barren	(Backhouse, 2014)
–	1270.0	CC	indeterminate	(Backhouse, 2014)
–	1302.5	CC	indeterminate	(Backhouse, 2014)
–	1914.7	CC	barren	(Backhouse, 2014)
–	2510.9	CC	barren	(Backhouse, 2014)
–	2514.3	CC	barren	(Backhouse, 2014)
–	2514.4	CC	?*S. quadrifidus* or slightly younger^	(Backhouse, 2014)
–	2514.55	CC	barren	(Backhouse, 2014)
–	2514.7	CC	barren	(Backhouse, 2014)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone;

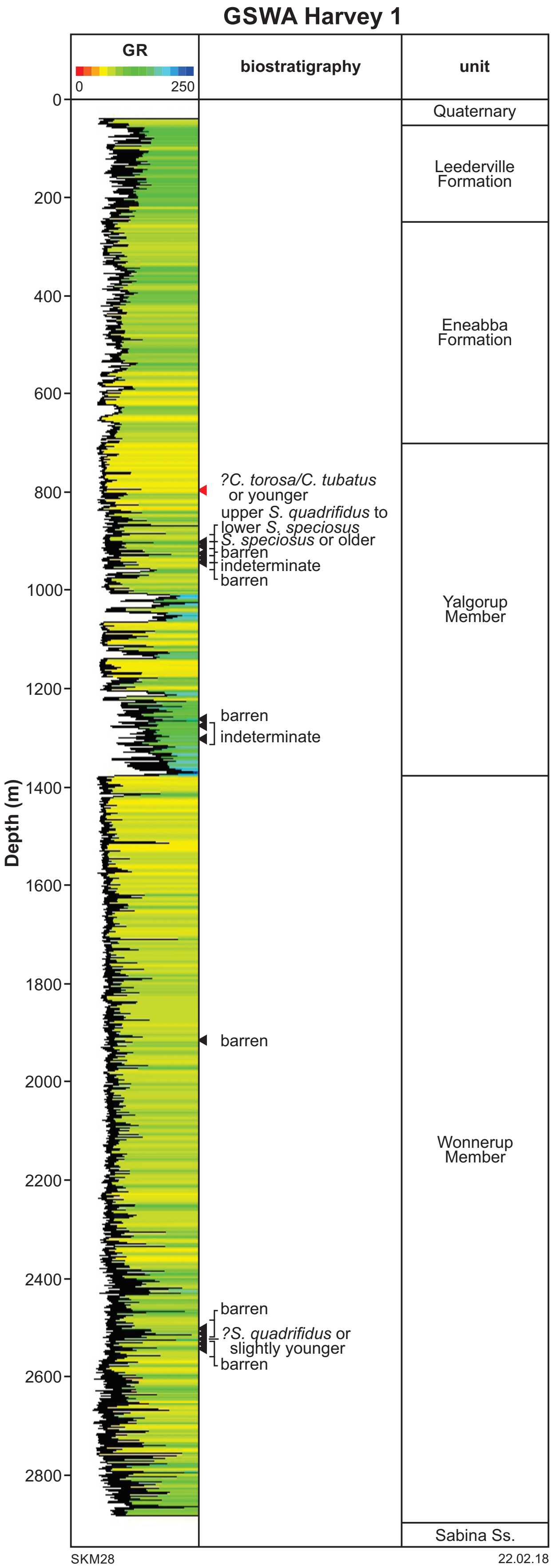
Located northwest of the Harvey township, GSWA Harvey 1 was drilled by GSWA in 2012 to assess the stratigraphy and carbon-dioxide sequestration potential of the Harvey Ridge area. The well was plugged and abandoned at a TD of 2945 m. Samples from the well included ditch cuttings cut at 15 m intervals from 60–840 m and at 5 m intervals from 840–2945 m, and six conventional cores cut over four intervals (Millar and Reeve, 2014).

Palynological analysis was conducted by J Backhouse in 2014; 16 samples were selected for analysis, 14 of which were sampled from the core post-drilling, plus a mud sample and a sample of selected drill chips from the same depth that were submitted during drilling of the well. Unfortunately, due to the highly oxidized nature of the sediments within the cored well sections, few sections of these cores were considered suitable for palynology, and 11 of the submitted core samples were barren, including the two deepest samples from 2514.55 and 2514.7 m (Backhouse, 2014).

The shallowest samples collected from this well were the mud and drill chips samples taken from the depth interval 795–825 m during drilling. The mud sample yielded a small collection of palynomorphs representing three distinct assemblages — elements of a 'transitional *Biretisporites eneabbaensis – Balmeiopsis limbata* Zone' spore-pollen assemblage previously noted in the Harvey area (Backhouse, 2012); Lower Jurassic taxa possibly representing the *Corollina torosa* or *Callialasporites turbatus* Spore-Pollen Zones; and Triassic taxa possibly suggesting the *Minutosaccus crenulatus* or *Samaropollenites speciosus* Spore-Pollen Zones. However, the equivalent drill chips sample was completely barren, suggesting in fact the palynomorphs obtained at this depth are derived from the mud or represent downhole contamination. Therefore, it is still possible that Lower Cretaceous, Lower Jurassic, and Upper Triassic units are present in the stratigraphy intersected by this well, but these units are likely to be present at unknown depths above 795 m.

Of the three remaining samples that yielded palynomorphs, two adjacent samples at 901.75 m and 903.6 m preserve similar assemblages. The dominance of *Falcisporites australis*, presence of *Samaropollenites speciosus*, rarity of *Staurosaccites quadrifidus*, and possible absence of the acritarchs *Bartenia communis* and *Thymospora ipsviciensis*, suggest placement of these samples within the *S. speciosus* Spore-Pollen Zone, and likely the lower part of this zone, which is considered latest Ladinian to early Carnian in age. The final sample, from 2514.4 m, is not particularly diverse and the palynomorphs not well preserved, which hampers the age determination. However, the assemblage was noted as most closely resembling the *Staurosaccites quadrifidus* Spore-Pollen Zone, although the lower *S. speciosus* Zone or *Triplexisporites playfordii* Spore-Pollen Zones could not be ruled out.

Based on this work, therefore, much of the section intersected by the Harvey 1 well is Middle or Late Triassic in age, although it is possible that Lower Cretaceous, Lower Jurassic, and Lower Triassic units are also present in the well or nearby.



Notes: **TD = 2945 m; lithostratigraphy based on Millar and Reeve (2014); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; black, conventional cores**

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DMP Harvey 2

Depth (feet)	Depth (metres)	Sample type	Zone/age[(a)]	Report
–	213.9	CC	*C. torosa*^	(Backhouse, 2015)
–	219.3	CC	*C. torosa*^	(Backhouse, 2015)
–	248.95	CC	*C. torosa*^	(Backhouse, 2015)
–	283.1	CC	*C. torosa*^	(Backhouse, 2015)
–	344.75	CC	barren	(Backhouse, 2015)
–	377.0	CC	*C. torosa*^	(Backhouse, 2015)
–	450.9	CC	*C. torosa*^	(Backhouse, 2015)
–	552.2	CC	*C. torosa*^	(Backhouse, 2015)
–	610.95	CC	*C. torosa*^	(Backhouse, 2015)
–	644.9	CC	barren	(Backhouse, 2015)
–	686.9	CC	barren	(Backhouse, 2015)
–	732.5	CC	*?A. reducta*^	(Backhouse, 2015)
–	793.1	CC	*?A. reducta*^	(Backhouse, 2015)
–	821.2	CC	indeterminate (contaminated)	(Backhouse, 2015)
–	821.25	CC	?Triassic indet.	(Backhouse, 2015)
–	908.25	CC	indeterminate (contaminated)	(Backhouse, 2015)
–	908.26	CC	?Triassic indet.	(Backhouse, 2015)
–	1006.95	CC	barren	(Backhouse, 2015)
–	1111.9	CC	*S. quadrifidus* to ?lower *S. speciosus*^	(Backhouse, 2015)
–	1242.5	CC	*S. quadrifidus* to ?lower *S. speciosus*^	(Backhouse, 2015)
–	1315.7	CC	*S. quadrifidus* to ?lower *S. speciosus*^	(Backhouse, 2015)
–	1348.25	CC	*S. quadrifidus* to ?lower *S. speciosus*^	(Backhouse, 2015)

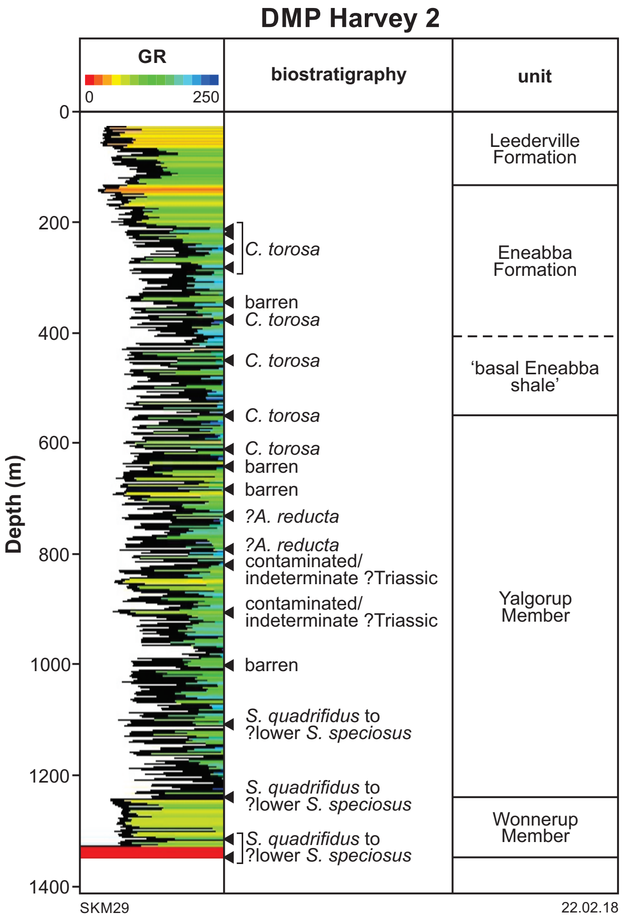
NOTES:
(a) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone

DMP Harvey 2 is the most southerly located and most recently drilled of all petroleum wells assessed in this Report. Located near GSWA Harvey 1, northwest of the Harvey township, DMP Harvey 2 was drilled in 2015 as part of a larger project to assess the stratigraphy and carbon-dioxide sequestration potential of the Harvey Ridge area. The well was plugged and abandoned at a TD of 1351 m. The well was fully cored from 207.7 m through to TD, and ditch cuttings were also collected at 3 m intervals from 0 to 207.7 m (Stelfox, 2018).

Palynological studies were completed by Backhouse (2015). Originally, 20 samples were selected from throughout the cored section, but two of these samples (821.2 and 908.25 m) were found to be heavily contaminated by drilling mud, with two new samples subsequently collected close to the original depths to compensate (Backhouse, 2015). Due to the extensive core available from this well, palynology samples could be carefully selected, resulting in only four of these 20 samples being barren (344.75, 644.9, 686.9 and 1006.95 m). Although the samples were selected to maximize coverage, a number of extensive sections of sandy or strongly oxidized lithologies were observed throughout the cored section, and this is reflected in the sample spacing.

The remaining 16 samples identified four zone populations. The shallowest palynological sample (213.90 m) is Early Jurassic in age, assigned to the *Corollina torosa* Zone. There is no direct evidence for the age of the upper section in this well, beyond the assumption that the Cretaceous–Jurassic unconformity is shallower than 213.90 m.

The *C. torosa* Zone was confidently identified for the section from 213.9 to at least 610.95 m depth, with eight samples yielding similar assemblages that indicate this zone. Only one sample within this set (at 344.75 m) was barren, but as it is bracketed by well-preserved assemblages of the same zone, it can be assumed to represent an unsuitable lithology, or highly oxidized section, within the same sequence. Although these assemblages are of variable diversity and yield, a number of samples (especially 248.95, 552.2 and 610.95 m) were impressively high yielding and diverse compared to other records of this zone within the southern Perth Basin, and this zone identification is therefore robust. Overall, the



Notes: TD = 1351 m; lithostratigraphy based on Stelfox (2018); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: black, conventional cores

samples were dominated by *Classopollis torosus* (greater than 65% and up to 93% of the assemblage yield). Other key zone indicator species were also present, including *Anapiculatisporites dawsonensis*.

Two barren samples between 610.95 and 732.5 m indicate a long section of core for which no ages can be obtained. Looking at the lithology logs, this section appears to be dominated by sandstones and sandy lithologies, with mudstones that are mottled, red-brown, or purple in colour, indicating strong oxidization of the sediments. Unfortunately, the transition from the *C. torosa* Zone to the underlying *Ashmoripollis reducta* Spore-Pollen Zone appears to fall somewhere in this barren section, and it is therefore uncertain at what depth the transition occurs, and whether the boundary is conformable or otherwise.

Two samples at 732.5 and 793.1 m depth are tentatively assigned to the *A. reducta* Zone. This is a relatively narrow spore-pollen zone which is rarely identified in the Perth Basin. The deeper of these two samples (793.1 m) contains specimens of index species *A. reducta*, but cannot be firmly placed in this zone because this species occasionally appears in older zones, and the samples do not preserve the other index species used to confirm the zone identification. However, index species of older zones are not preserved either, so assignation to *A. reducta* Zone is most likely for these samples.

Below 793.1 m there is another section of barren or poorly yielding sediments, extending down to 1111.9 m. This section is noted on the lithology logs as dominated by sandy lithologies, and by mottled, purple and red mudstones, which are unsuitable for the preservation of palynomorphs. The two samples that did yield noncontaminated palynofloras (at 821.25 and 908.26 m) within this lean section had low-yield and low-diversity assemblages of long-ranging or age nondiagnostic species and were assigned an indeterminate Triassic age based on the overlying *?A. reducta* Zone samples and the lack of *Classopollis* pollen (a taxon used to indicate Jurassic or younger palynofloras). Again, this barren section obscures a biostratigraphic zone boundary. If the identification of *A. reducta* Zone is correct for the overlying samples, and *Samaropollenites speciosus* to *Staurosaccites quadrifidus* Spore-Pollen Zone identification is correct for the underlying samples, then the entire *Minutosaccus crenulatus* Spore-Pollen Zone, and the boundaries between that and surrounding zones, fall within this section. Whether the *M. crenulatus* Zone is missing due to unconformities or disconformities, or if the entire section is conformable but hidden within this barren zone, is uncertain.

Between 1111.9 and 1348.25 m are four samples assigned to either the lower *S. speciosus* or *S. quadrifidus* Zones. *Staurosaccites quadrifidus* is seen in the 111.9 m sample, which suggests either this or the lower *S. speciosus* Zone, although no other index species of either zone are seen, limiting the certainty of this zone identification. However, no index species for older zones are noted either, which suggests these samples are *S. quadrifidus* Zone at their oldest. Unfortunately, some of the palynomorphs in these samples were noted to be very dark, which hampers species identification. As the deepest sample analysed, at 1348.25 m, lies close to TD (1351.15 m), these Middle–Late Triassic sediments are thought to extend to the base of the well section.

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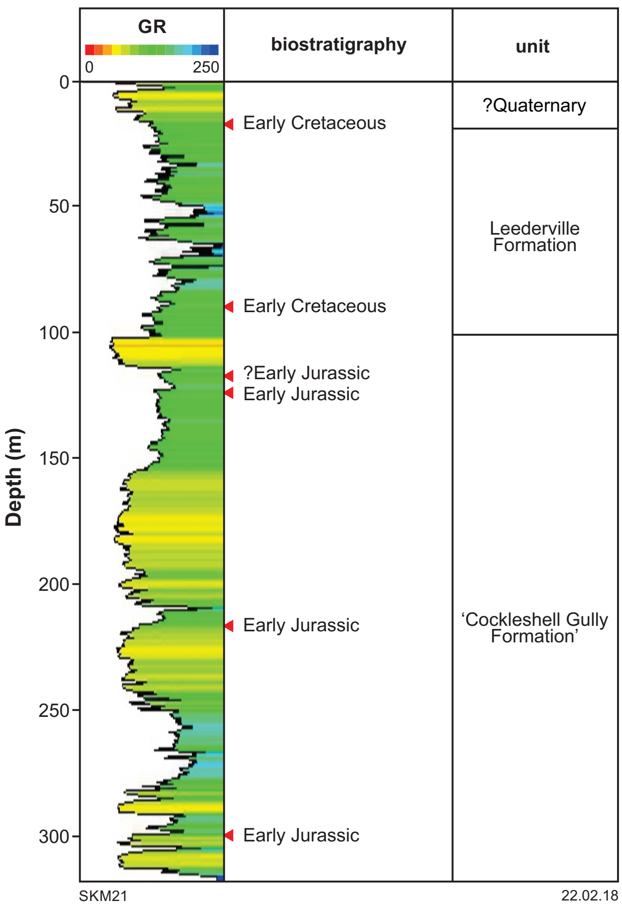
Alcoa Pinjarra E1–8 and O1–3

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
AE1[(a)]				
55	17.0	DC	Early Cretaceous	(Ingram, 1969)
290	89.4	DC	Early Cretaceous	(Ingram, 1969)
380	117.2	DC	?Early Jurassic	(Ingram, 1969)
400	123.4	DC	Early Jurassic	(Ingram, 1969)
700	215.9	DC	Early Jurassic	(Ingram, 1969)
970	299.2	DC	Early Jurassic	(Ingram, 1969)
AE2				
190	58.6	DC	Early Jurassic	(Ingram, 1969)
350	107.9	DC	Early Jurassic	(Ingram, 1969)
720	222.1	DC	Early Jurassic	(Ingram, 1969)
AE3				
370	114.1	DC	?Early Jurassic	(Ingram, 1969)
380	117.2	DC	indeterminate (caved?)	(Ingram, 1969)
400	123.4	DC	indeterminate (caved?)	(Ingram, 1969)
430	132.6	DC	indeterminate (caved?)	(Ingram, 1969)
450	138.8	DC	?Early Jurassic	(Ingram, 1969)
AE4				
80	24.7	DC	Early Cretaceous	(Ingram, 1969)
210	64.8	DC	Early Cretaceous	(Ingram, 1969)
310	95.6	DC	Early Cretaceous	(Ingram, 1969)
340	104.9	DC	?Early Jurassic	(Ingram, 1969)
500	154.2	DC	Early Jurassic	(Ingram, 1969)
620	191.2	DC	Early Jurassic	(Ingram, 1969)
940	289.9	DC	Early Jurassic	(Ingram, 1969)
AE5				
210	64.8	DC	barren	(Ingram, 1969)
430	132.61	DC	barren	(Ingram, 1969)
AE6				
270	83.3	DC	Early Cretaceous	(Ingram, 1969)
380	117.2	DC	?Early Jurassic	(Ingram, 1969)
610	188.1	DC	Early Jurassic	(Ingram, 1969)
790	243.6	DC	Early Jurassic	(Ingram, 1969)
AE7				
130	40.1	DC	Early Cretaceous	(Ingram, 1969)
250	77.1	DC	Early Cretaceous	(Ingram, 1969)
330	101.8	DC	Early Cretaceous	(Ingram, 1969)
390	120.3	DC	Early Cretaceous	(Ingram, 1969)
430	132.6	DC	Early Cretaceous	(Ingram, 1969)
530	163.5	DC	?Early Jurassic	(Ingram, 1969)
AE8				
89–109	24.5 – 33.6	CC	Early Cretaceous	(Ingram, 1969)
160	49.3	DC	?Early Jurassic	(Ingram, 1969)

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age[(b)]*	*Report*
612–620	188.7 – 191.2	CC	Early Jurassic	(Ingram, 1969)
AO1				
340	104.9	DC	Early Cretaceous	(Ingram, 1969)
390	120.3	DC	?Early Jurassic	(Ingram, 1969)
440	135.7	DC	?Early Jurassic	(Ingram, 1969)
AO2				
360	111.0	DC	?Early Jurassic	(Ingram, 1969)
370	114.1	DC	?Early Jurassic	(Ingram, 1969)
AO3				
300	92.5	DC	Early Cretaceous	(Ingram, 1969)
340	104.9	DC	Early Cretaceous	(Ingram, 1969)
370	114.1	DC	Early Cretaceous	(Ingram, 1969)
440	135.7	DC	Early Cretaceous	(Ingram, 1969)
500	154.2	DC	?Early Jurassic	(Ingram, 1969)

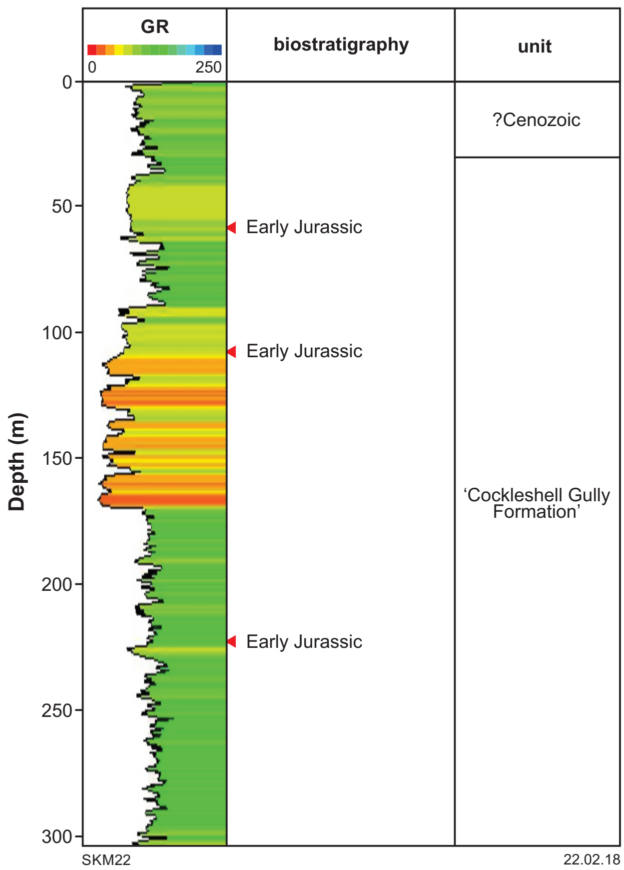
NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples)

AE1



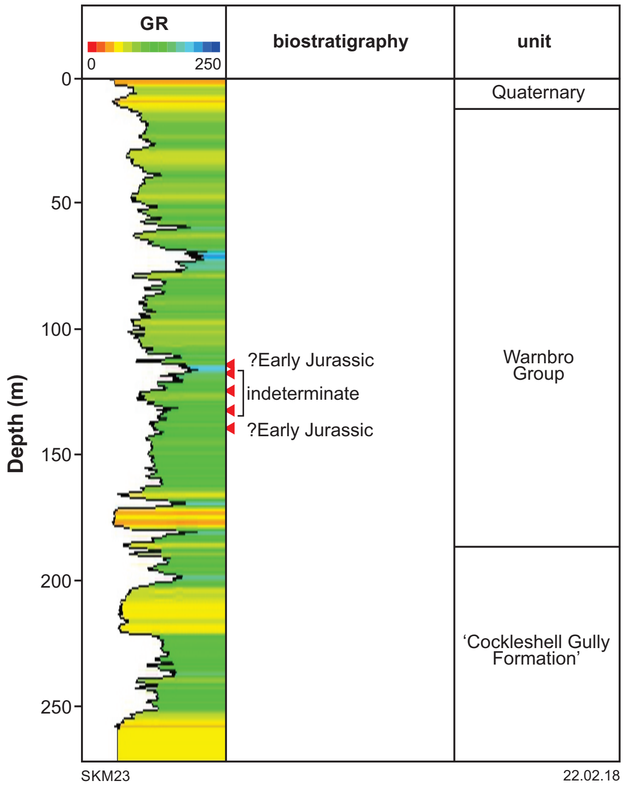
Notes: TD = 316.99 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings

AE2



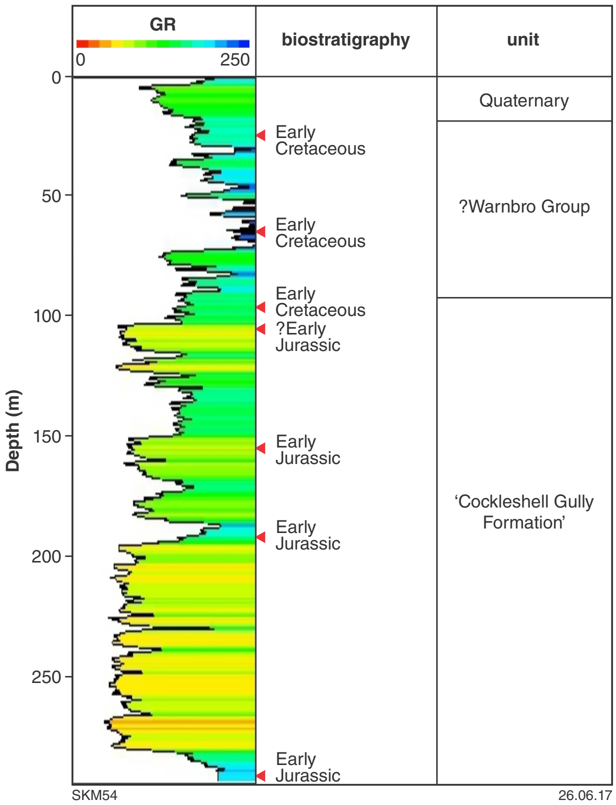
Notes: TD = 303.89 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings

AE3

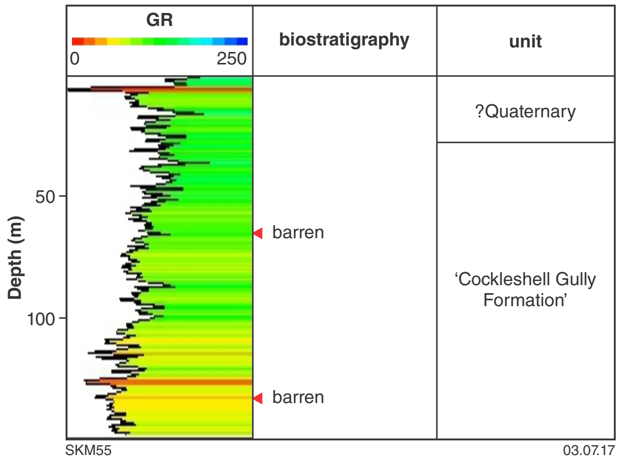


Notes: **TD = 271.27 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings**

AE4

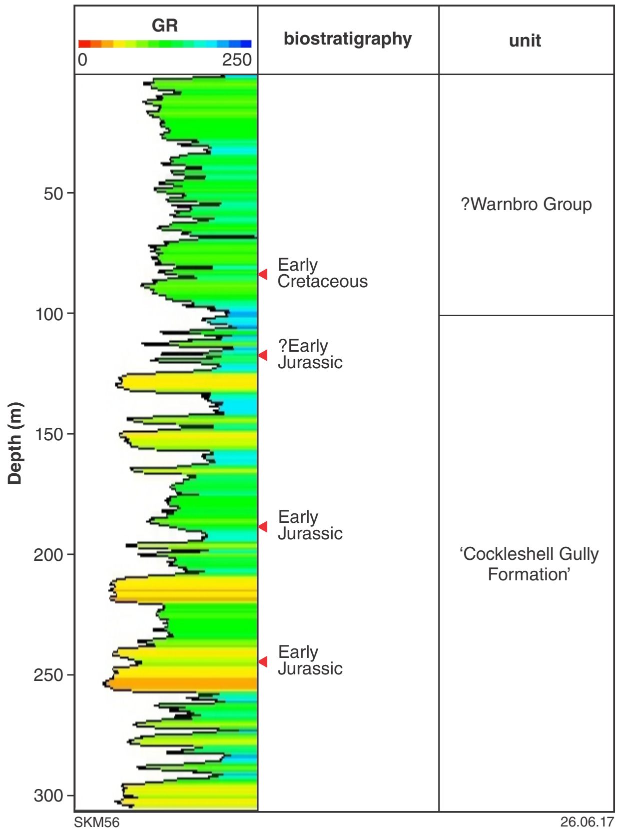


AE5



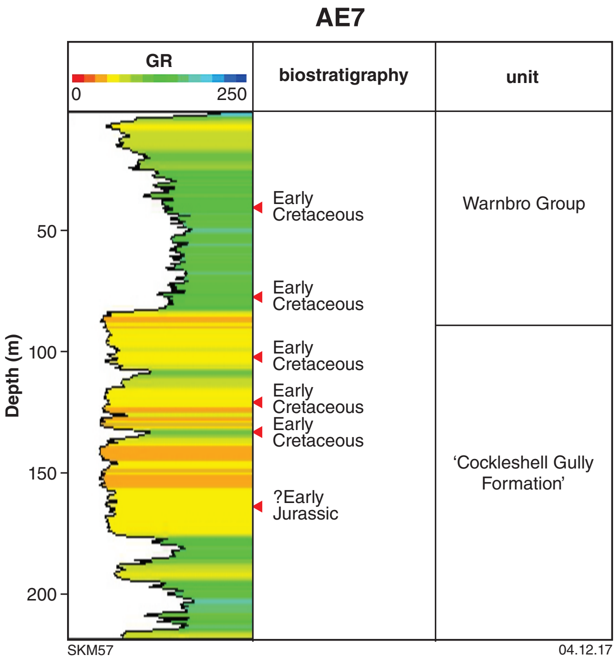
Notes: **TD = 147.83 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings**

AE6

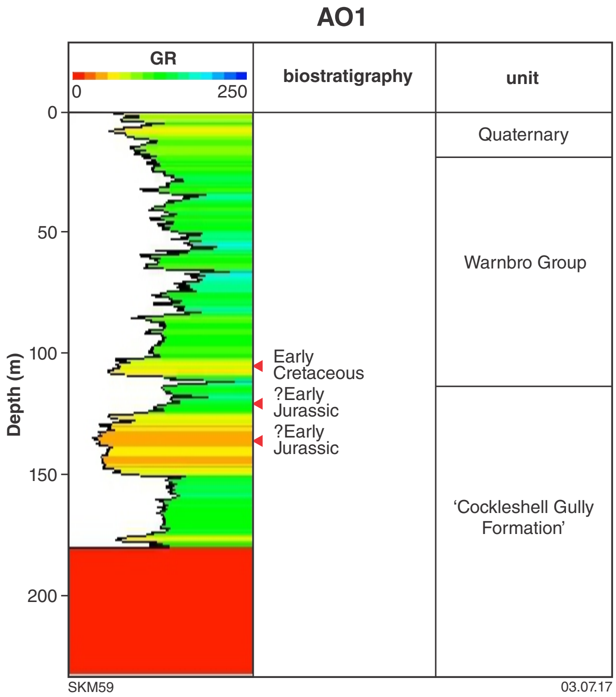


Notes: **TD = 304.8 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings**

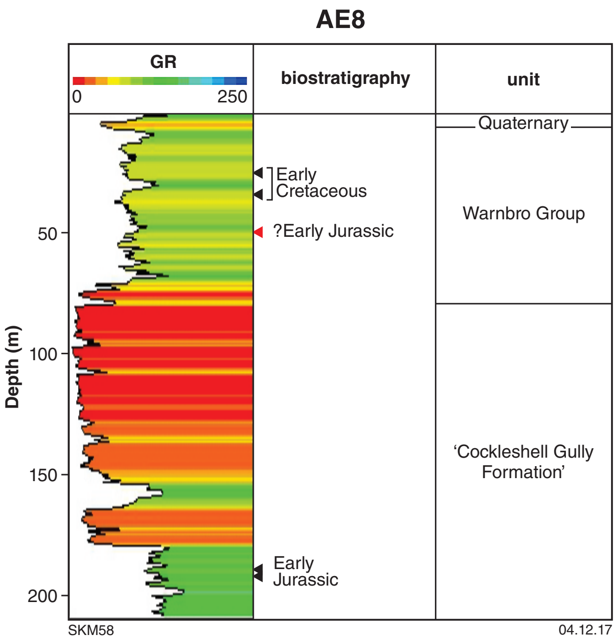
Notes: **(AE4) TD = 292.61 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings**



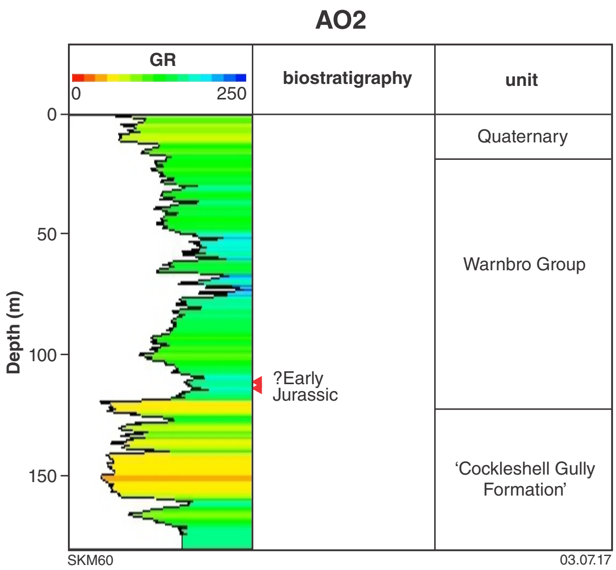
Notes: TD = 217.32 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings



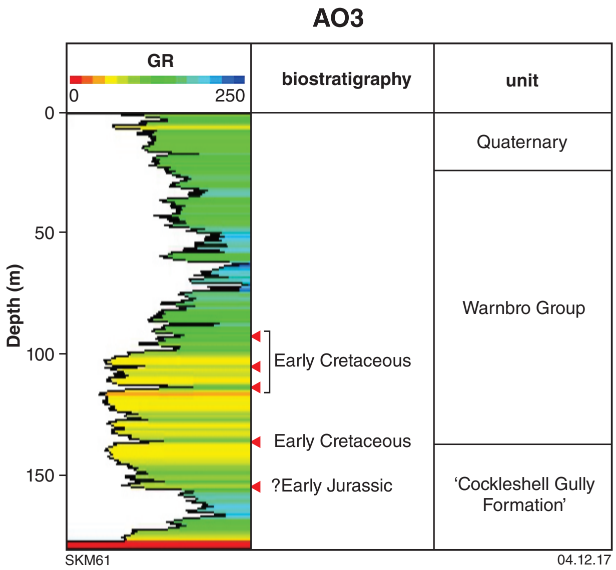
Notes: TD = 231.65 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings



Notes: TD = 207.87 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings; black, conventional cores



Notes: TD = 179.83 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings



Notes: TD = 179.83 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

In 1969, Alcoa Australia drilled a series of 16 water bores on and around the site of its alumina refinery east of Pinjarra, with further seven holes drilled in 1972. The boreholes, drilled to aid in the discovery and extraction of groundwater for use in the refinery, were divided into three types — exploratory (AE), observation (AO), and production (AP) holes. Although drilled by industry, GSWA hydrologists sampled a number of these boreholes to aid regional groundwater studies, including a set of samples submitted for palynological study. In total, eight exploratory (AE1–8) and eight observation (AO1–3, 8–12) boreholes were studied for palynology by GSWA paleontologists, and all except three preserve evidence of Jurassic palynofloras. Only samples from holes AO9, AO10, and AO12 have been reviewed formally since they were originally studied.

AE1–8 and AO1–3

The original set of boreholes in this series was drilled in 1969, with eleven of the boreholes having samples submitted for palynological study. The deepest of these eleven boreholes was AE1, drilled to a TD of 316.99 m, and the shallowest was AE5 at 147.83 m (Commander, 1975). Between two and seven ditch cutting samples were submitted from each of the boreholes for study, except for AE8, where two core samples and one cutting sample were used. The two ditch cuttings (from 210 and 430 ft) submitted from the shallowest exploratory borehole, AE5 (147.83 m TD), did not yield palynomorphs and therefore no age data exists for this hole (Ingram, 1969).

The remaining ten boreholes all yielded palynomorphs, with the samples reported in a single informal GSWA Paleontology Report (Ingram, 1969). Unfortunately, Ingram reported on all of the different boreholes together, with the palynofloras generalized into three main types — 'Lower Cretaceous', '?Lower Jurassic', and 'Lower Jurassic'. For this reason, the boreholes are not discussed individually here, but are grouped together, as in the original report. There is a further issue in that Ingram (1969) noted that many of the samples suffered from severe downhole contamination, making the results difficult to interpret and of dubious accuracy. In particular, he noted that many of the samples listed as Early Cretaceous may in fact be older assemblages completely overprinted by assemblages from higher in the hole.

Ingram's 'Lower Cretaceous' grouping consisted of a set of samples dominated by typical Late Jurassic to Early Cretaceous species including *Contignisporites cooksoniae*, *Staplinisporites telatus*, *Ischyosporites crateris*, and *Murospora florida*, but also includes *Cicatricosisporites hughesi*, which has been recorded in the *Balmeiopsis limbata* Spore-Pollen Zone and only rarely in the upper *Biretisporites eneabbaensis* Spore-Pollen Zone (Backhouse, 1988). In addition, some samples of this type were noted to preserve rare dinoflagellates, including Edgell's Neocomian to Aptian index taxa *Muderongia mcwhaei* and *Phoberocysta neocomica*. Assuming these species are correctly identified, samples bearing a combination of these dinoflagellates suggests the *Phoberocysta burgeri* Dinocyst Zone of Helby et al. (1987), which equates to part of the *Phoberocysta lowryi* Dinocyst Zone of Backhouse (1988). Unfortunately, the report does not indicate which of the samples in each of described boreholes contains marine taxa, and it is uncertain if all of the samples preserve similar spore-pollen assemblages. Therefore, these samples are suspected to represent the *B. limbata* Zone and dinoflagellate zone equivalents, although re-examination of the slides is required to confirm this.

The 'Lower Jurassic' grouping consists of samples with entirely nonmarine spores and pollen dominated by *Classopollis torosus*, with other distinctly Early Jurassic taxa, including *Callialasporites turbatus, Callialasporites dampieri* and *Exesipollenites tumulus*. Assuming that the assemblages are similar in all samples, the combination of these taxa, and the probable moderate proportions of *C. torosus* (as it seems likely that such a strong dominance of a single species would be mentioned in the report, if it were the case), suggests that these assemblages belong in the *Callialasporites turbatus* Spore-Pollen Zone. But again, as the report does not indicate which taxa are recorded in which samples, it is uncertain if all of the samples preserve similar spore-pollen assemblages. Until the assemblages can be re-examined, the entire group are here considered generically Early Jurassic in age.

The '?Lower Jurassic' grouping consists of mixed assemblages generally dominated by Early Cretaceous taxa, but also including Early Jurassic forms such as *E. tumulus*. Therefore, these samples represent two possibilities — downhole contamination of Early Cretaceous forms into (perhaps naturally low-yielding) Lower Jurassic sediments, or reworking of Early Jurassic forms into Lower Cretaceous sediments. Remanié palynomorphs of a range of ages are recorded commonly in the Warnbro Group (e.g. Backhouse, 1988) making this a real possibility; however, the use of ditch cuttings makes downhole contamination extremely likely, and this was the preferred interpretation for these mixed assemblages (Ingram, 1969). Based on this, Ingram (1969) considered these mixed assemblages as likely Lower Jurassic in age, perhaps located just below the Jurassic–Cretaceous unconformity.

Of the ten boreholes, AE1, AE4, AE6, and AE8 all yielded sample sets that transitioned from Lower Cretaceous to a single ?Lower Jurassic sample, and finally into Lower Jurassic samples. AE1 yielded its deepest Lower Cretaceous sample at 290 ft and its first true Lower Jurassic sample at 400 ft, with a mixed sample at 380 ft. AE4 yielded a similar range of depths with Lower Cretaceous extending to 310 ft, a mixed sample at 340 ft, and Lower Jurassic from 500 ft. AE6 was similar with Lower Cretaceous extending to 270 ft, a mixed sample at 380 ft, and Lower Jurassic from 610 ft. In all three cases, the Jurassic–Cretaceous unconformity sits between 100 and 150 m depth, although the uncertainty surrounding this depth is high. In comparison, all three cuttings samples from AE2, from 190 to 720 ft all yielded Early Jurassic samples, suggesting a much shallower Jurassic–Cretaceous unconformity in that area.

All of the remaining boreholes — AE3, AE7, AO1, AO2 and AO3 — bottomed out in mixed assemblages, making the depth of the Jurassic–Cretaceous unconformity ambiguous. Of these holes, AE3 and AO2 yielded only mixed assemblages, although AE7, AO1 and AO3 preserved Lower Cretaceous samples in the shallower portions of the boreholes (Ingram, 1969).

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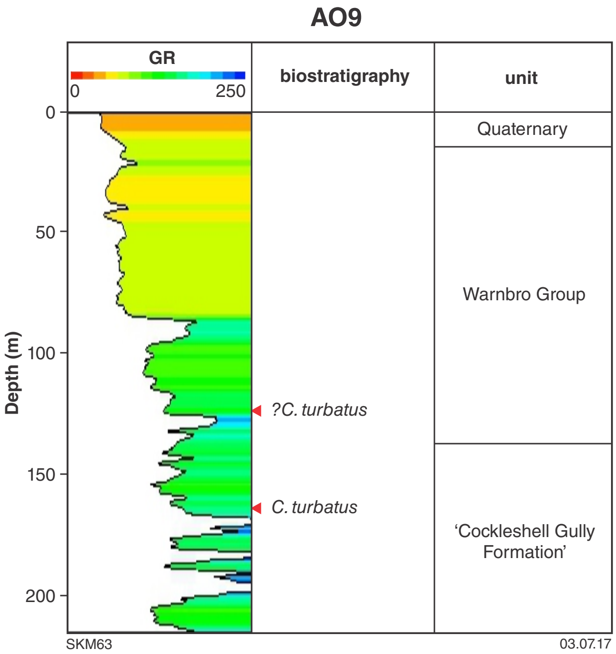
Alcoa Pinjarra O9

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
AO9[(a)]				
400–410	123.4 – 126.4	DC	?*C. turbatus*^	(Backhouse, 2015)
530–540	163.5 – 166.5	DC	*C. turbatus*^	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone



Notes: TD = 214.5 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*), indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

In 1969, Alcoa Australia drilled a series of 16 water bores on and around the site of its alumina refinery east of Pinjarra, with further seven holes drilled in 1972. The boreholes, drilled to aid in the discovery and extraction of groundwater for use in the refinery, were divided into three types — exploratory (AE), observation (AO), and production (AP) holes. Although drilled by industry, GSWA hydrologists sampled a number of these boreholes to aid regional groundwater studies, including a set of samples submitted for palynological study. In total, eight exploratory (AE1–8) and eight observation (AO1–3, 8–12) boreholes were studied for palynology by GSWA paleontologists, and all except three preserve evidence of Jurassic palynofloras. Only samples from holes AO9, AO10 and AO12 have been reviewed formally since they were originally studied.

AO9

Drilled in 1972 to a TD of 214.5 m, AO9 had a total of two ditch cuttings (400–410 ft, 530–540 ft) submitted for palynological analysis, the results of which were reported in a single informal GSWA Paleontology Report (Backhouse, 1972). Both samples yielded palynofloras with no evidence of marine influence. That report was recently reviewed without reference to the original slides or samples, with the aim to bring the zone identifications up to current usage (Backhouse, 2015).

The deepest sample in the borehole yielded a single assemblage clearly of Early Jurassic age, dominated by *Classopollis* pollen, and containing both *Callialasporites turbatus* and *Exesipollenites tumulus*. Although this sample was not assigned to any particular biostratigraphic zone — the report pre-dates both Filatoff's (1975) work on the Jurassic of the Perth Basin and the Helby et al. (1987) biostratigraphic scheme for the Mesozoic — this combination of species is considered indicative of Helby et al.'s (1987) *Callialasporites turbatus* Zone (Backhouse, 2015).

Unlike the deeper material, that from 400–410 ft proved to be a mixed assemblage. Most of the spores and pollen indicate an Early Cretaceous age, including *Acanthotriletes levidensis* and common *Microcachryidites antarcticus* and *Murospora florida*, with *A. levidensis* in particular indicating the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988). However, the sample also has very high proportions of *Classopollis* pollen and common *E. tumulus*, features most often associated with Early Jurassic palynofloras, particularly the uppermost *Corollina torosa* or lower *Callialasporites turbatus* Spore-Pollen Zones. As a result, one or other of the assemblages is a contaminant, although the author of the original report did not speculate on which is more likely to have been introduced. A review of this report (Backhouse, 2015) considered the most likely scenario to be that both of these samples are assignable to the *C. turbatus* Zone, and that the shallower sample is heavily contaminated with Cretaceous spores and pollen, likely derived from overlying (unsampled) lithologies.

Therefore, these samples together suggest that both Early Cretaceous (*B. limbata* Zone) and Early Jurassic (likely *C. turbatus* Zone) sections are present in this borehole, although the depth of the unconformity between them is difficult to constrain using only palynology. Based on lithological and geophysical cues, the boundary between the Lower Cretaceous Warnbro Group and Lower Jurassic 'Cockleshell Gully Formation' has previously been placed at 360 ft (Commander, 1975); the palynology data neither contradict nor support this interpretation.

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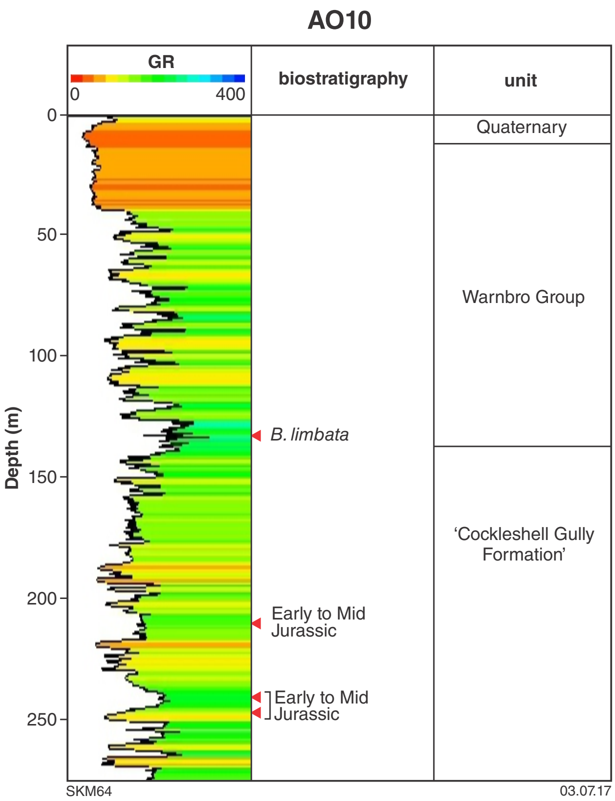
Alcoa Pinjarra O10

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
AO10[(a)]				
430–440	132.6 – 135.7	DC	*B. limbata*[#]	(Backhouse, 2015)
680–690	209.7 – 212.8	DC	Early–Mid Jurassic	(Backhouse, 2015)
780–790	240.6 – 243.6	DC	Early–Mid Jurassic	(Backhouse, 2015)
800–810	246.7 – 249.8	DC	Early–Mid Jurassic	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone



Notes: TD = 274.32 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

In 1969, Alcoa Australia drilled a series of 16 water bores on and around the site of its alumina refinery east of Pinjarra, with further seven holes drilled in 1972. The boreholes, drilled to aid in the discovery and extraction of groundwater for use in the refinery, were divided into three types — exploratory (AE), observation (AO), and production (AP) holes. Although drilled by industry, GSWA hydrologists sampled a number of these boreholes to aid regional groundwater studies, including a set of samples submitted for palynological study. In total, eight exploratory (AE1–8) and eight observation (AO1–3, 8–12) boreholes were studied for palynology by GSWA paleontologists, and all except three preserve evidence of Jurassic palynofloras. Only samples from holes AO9, AO10, and AO12 have been reviewed formally since they were originally studied.

AO10

AO10 was drilled in 1972 to a TD of 274.32 m. A total of four ditch cuttings from this borehole were submitted for palynological study — from depths of 430–440 ft, 680–690 ft, 780–790 ft, and 800–810 ft — with the results reported in two informal GSWA Paleontology Reports (Backhouse, 1972, 1973). These reports were reviewed in 2015, to bring the biostratigraphic information in line with current usage (Backhouse, 2015).

The shallowest sample, from 430–440 ft, contained only a sparse assemblage of nonmarine palynomorphs, dominated by long ranging Late Jurassic – Early Cretaceous forms, such as *Murospora florida*, *Contignisporites cooksoniae* and *Podocarpidites ellipticus*. As a result, Backhouse (1972) originally suggested an Early Cretaceous age based on the absence of inaperturate pollen, but did not assign a specific zone. The recent review suggests that this combination of species is most indicative of the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 2015).

The remaining three samples were all considered Early Jurassic in age, although the 780–790 ft sample yielded only a very sparse assemblage of *Classopollis* pollen grains, and was only assigned an age based on the bracketing samples. Strong down-hole contamination by Early Cretaceous palynomorphs was noted in the two richer assemblages, and most of the named taxa are long-ranging Jurassic and Cretaceous forms. Besides the dominance of *Classopollis*, no Early Jurassic index taxa are recorded in either sample, making it difficult to place in any particular zone. The report review concurred with the interpretation of an Early–Middle Jurassic age for this sample, but also noted that the original slides would need to be reviewed in order to place the samples within a specific zone (Backhouse, 2015).

These palynological results agree well with the borehole's formation picks, which were made using lithological and geophysical data. In the borehole completion report, a thin Quaternary section (to ~45 ft) is underlain by sediments interpreted as the Warnbro Group; the unconformity between these Lower Cretaceous sediments and the underlying Lower Jurassic 'Cockleshell Gully Formation' is placed at roughly 670 ft (Commander, 1975).

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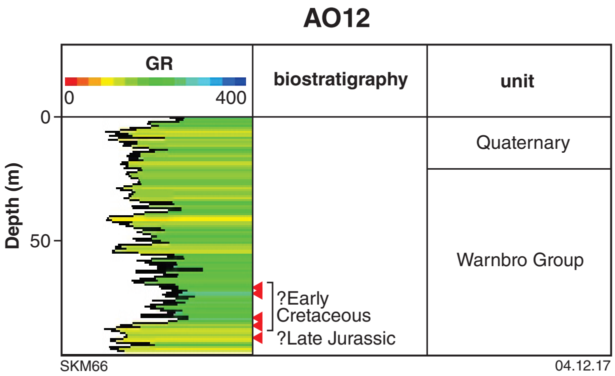
Alcoa Pinjarra O12

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
AO12[(a)]				
220–230	67.9 – 70.9	DC	?Early Cretaceous	(Backhouse, 2015)
230–240	70.9 – 74.0	DC	?Early Cretaceous	(Backhouse, 2015)
260–270	80.2 – 83.3	DC	?Early Cretaceous	(Backhouse, 2015)
270–280	83.3 – 86.4	DC	?Early Cretaceous	(Backhouse, 2015)
–	88.0 – 91.0	DC	?Late Jurassic	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)



Notes: TD = 93.5 m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

In 1969, Alcoa Australia drilled a series of 16 water bores on and around the site of its alumina refinery east of Pinjarra, with further seven holes drilled in 1972. The boreholes, drilled to aid in the discovery and extraction of groundwater for use in the refinery, were divided into three types — exploratory (AE), observation (AO), and production (AP) holes. Although drilled by industry, GSWA hydrologists sampled a number of these boreholes to aid regional groundwater studies, including a set of samples submitted for palynological study. In total, eight exploratory (AE1–8) and eight observation (AO1–3, 8–12) boreholes were studied for palynology by GSWA paleontologists, and all except three preserve evidence of Jurassic palynofloras. Only samples from holes AO9, AO10, and AO12 have been reviewed formally since they were originally studied.

AO12

Observation bore AO12 was a shallow borehole, drilled in 1972 to a TD of 93.5 m. Five ditch cuttings were submitted for palynological study from this borehole (220–230, 230–240, 260–270, 270–280 ft, and 88–91 m), which were reported upon in two informal GSWA Paleontology Reports (Backhouse, 1972a,b). These reports were reviewed in 2015, to bring the biostratigraphic information in line with current usage (Backhouse, 2015).

The deepest sample, from 88–91 m, contains a number of standard Late Jurassic – Early Cretaceous forms, including *Araucariacites australis, Callialasporites dampieri*, and *Foraminisporis* sp. cf. *dailyi*. The assemblage was considered more indicative of the Late Jurassic, rather than the Early Cretaceous, although specific reasons for this interpretation were not provided. The recent review of the results also considered the assemblage very difficult to assign a specific zone to without reference to the original slides, and therefore defaulted to following the original interpretation that the sample is of Late Jurassic age (Backhouse, 2015).

The remaining four samples all yielded similar, but poorly preserved, assemblages of nonmarine spores and pollen. Common to all samples were common *Classopollis classoides* and *Microcachryidites antarcticus*, with other typical Jurassic–Cretaceous taxa such as *Contignisporites cooksoniae*, *Murospora florida*, *C. dampieri*, and *Rogalskaisporites canaliculus*, also recorded from particular samples. Generally, high proportions of *M. antarcticus* are used to indicate Early Cretaceous as opposed to Late Jurassic assemblages. Although common to abundant *Classopollis* is normally an indicator of Jurassic floras, this genus can also be common within the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988). However, on the balance of evidence, Backhouse assigned these assemblages to the Early Cretaceous, particularly the Neocomian to Aptian. The more recent review also considered the samples to be Early Cretaceous (likely *B. limbata* Zone) in age based on the presence of *Laevigatosporites* and common *Podocarpidites* spp. (Backhouse, 2015). Like *Classopollis*, common *Cyathidites* is somewhat unusual in Early Cretaceous assemblages, but can be locally common in Warnbro Group assemblages.

This description of potential Late Jurassic samples at the base of the borehole is poorly constrained and requires additional work to clarify the age of assemblages. Based on lithology and geophysical data, this borehole had previously been interpreted to intersect only Early Cretaceous (Warnbro Group) sediments, with no interpreted Quaternary or pre-Cretaceous units (Commander, 1975). Furthermore, no record of Late Jurassic assemblages is seen elsewhere on the Harvey Ridge, with all of the nearby Mandurah Line and Alcoa Pinjarra boreholes passing directly from Lower Cretaceous to Lower Jurassic assemblages.

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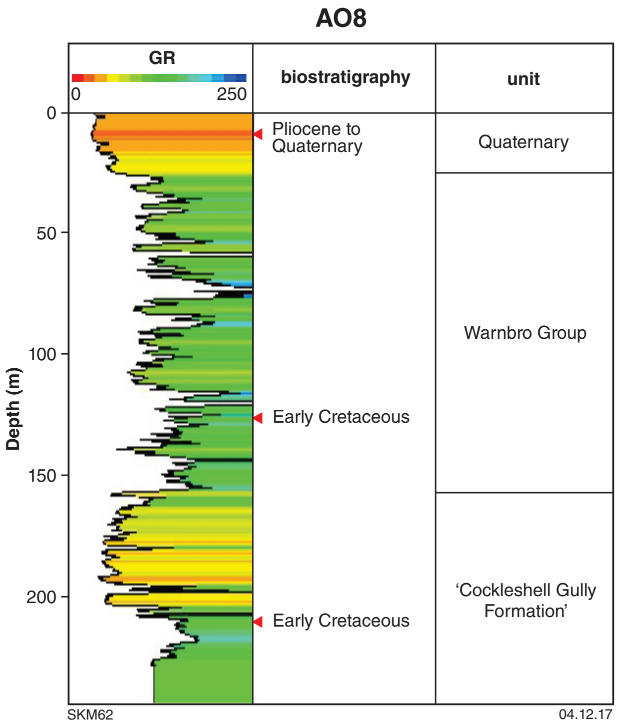
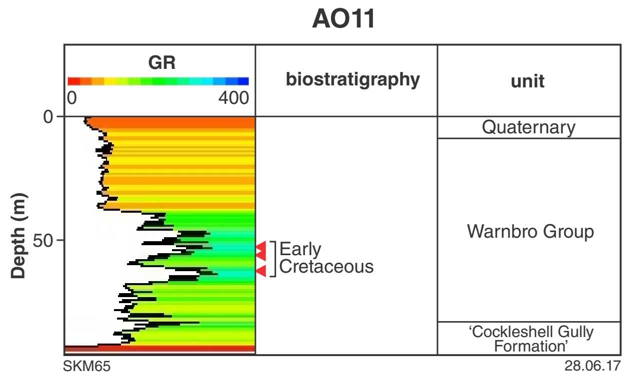
Alcoa Pinjarra other samples

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
AO8[(a)]				
–	9–12	DC	Pliocene to Quaternary	(Backhouse, 1972)
–	126–129	DC	Early Cretaceous	(Backhouse, 1972)
–	210–221	DC	Early Cretaceous	(Backhouse, 1972)
AO11				
170–180	52.4 – 55.5	DC	Early Cretaceous	(Grey, 1972)
180–190	55.5 – 58.6	DC	Early Cretaceous	(Grey, 1972)
200–210	61.7 – 64.8	DC	Early Cretaceous	(Grey, 1972)
MUDLAKE 3				
–	34.6 – 34.83	CC	*B. limbata*[#]	(Backhouse, 1982)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone





Notes: **TD = 243.8 (AO8) and 93.5 (AO11) m; lithostratigraphy based on Commander (1975); arrows indicate sample type used for palynology: red, ditch cuttings**

Line summary

In 1969, Alcoa Australia drilled a series of 16 water bores on and around the site of its alumina refinery east of Pinjarra, with further seven holes drilled in 1972. The boreholes, drilled to aid in the discovery and extraction of groundwater for use in the refinery, were divided into three types — exploratory (AE), observation (AO), and production (AP) holes. Although drilled by industry, GSWA hydrologists sampled a number of these boreholes to aid regional groundwater studies, including a set of samples submitted for palynological study. In total, eight exploratory (AE1–8) and eight observation (AO1–3, 8–12) boreholes were studied for palynology by GSWA paleontologists, and all except three preserve evidence of Jurassic palynofloras. Only samples from holes AO9, AO10, and AO12 have been reviewed formally since they were originally studied.

In 1982, a single sample from Alcoa Pinjarra Mud Lake No. 3 (also known as H1A-SA No. 18) was also submitted for palynological assement by GSWA geologist RP Mather. This short borehole was likely drilled by Alcoa for engineering purposes, as no record of the hole can be found on the DWER Water Information Reporting database. Due to this, the location information used here is an estimate, based on details provided in the Paleontology Report (Backhouse, 1982) and cross-checked using aerial imagery.

AO8 and AO11

In total, three ditch cuttings from AO8 were submitted for palynological analyses, from depths of 9–12, 126–129, and 210–221 m (Backhouse, 1972). The shallowest sample yielded pollen and spores indicating a Pliocene to Recent age, but included no evidence of marine influence. The two deeper samples yielded entirely nonmarine assemblages of Early Cretaceous (Neocomian) spores and pollen, including *Cicatricosisporites hughesi*, which is mostly commonly seen in the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988). As for the AE1–8 and AO1–3 samples, this zones is most likely, but should be confirmed by re-examination of the slides.

Like AO12, AO11 was a shallow borehole, reaching a TD of 93.5 m. All three cuttings from this borehole (170–180, 180–190, 200–210 m) yielded similar, nonmarine, Early Cretaceous assemblages of spores and pollen. Unfortunately, none of the samples yielded index species, although the high proportions of *Microcachryidites antarcticus*, *Murospora florida*, and *Contignisporites* spp. were suggested to indicate a Neocomian to Aptian age and correlation with the South Perth Shale (Grey, 1972).

Alcoa Pinjarra Mud Lake 3

A single core sample from Alcoa Pinjarra Mud Lake 3, from a depth of 34.6 – 34.83 m, was assessed palynologically in 1982 (Backhouse, 1982). This sample yielded a fair assemblage of palynomorphs, including typical Early Cretaceous spores and pollen, and a small number of dinoflagellates. The spore-pollen taxa are all too generic to assign to one particular Early Cretaceous zone, although the dinoflagellate *Cassiculosphaeridia magna* is recorded within the *Gagiella mutabilis* to *Fromea monilifera* Dinocyst Zones, therefore suggesting a link to the *B. limbata* Zone (Backhouse, 1988). Unfortunately, the low diversity of this dinoflagellate assemblage means that no greater precision can be achieved for this sample.

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Artesian Monitoring 65

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age[(b)]*	*Report*
AM65[(a)]				
–	101	SWC	indeterminate	(Backhouse, 2015)
–	155	SWC	indeterminate	(Backhouse, 2015)
–	163	SWC	*?A. alata*‡	(Backhouse, 2015)
–	169	SWC	*B. limbata*#	(Backhouse, 2015)
–	198	SWC	indeterminate	(Backhouse, 2015)
–	207	SWC	indeterminate	(Backhouse, 2015)
–	215	SWC	*C. turbatus*^	(Backhouse, 2015)
–	242	SWC	*C. turbatus*^	(Backhouse, 2015)
–	259	SWC	*?C. turbatus*^	(Backhouse, 2015)
–	277	SWC	indeterminate	(Backhouse, 2015)
–	286	SWC	indeterminate	(Backhouse, 2015)
–	308	SWC	indeterminate	(Backhouse, 2015)
–	345	SWC	indeterminate	(Backhouse, 2015)
–	360	SWC	indeterminate	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

Line summary

The Artesian Monitoring drilling program is a long-lived project, designed to test the distribution of artesian water and pumping potential of groundwater. There have been at least 70 bores drilled as part of this program in the Perth Basin, starting in 1977 and extending through to 1986. Most of these boreholes were drilled relatively deeply, greater than 200 m, but few of them have associated palynological studies. As monitoring bores, most of these holes are currently actively producing, or were active in the past.

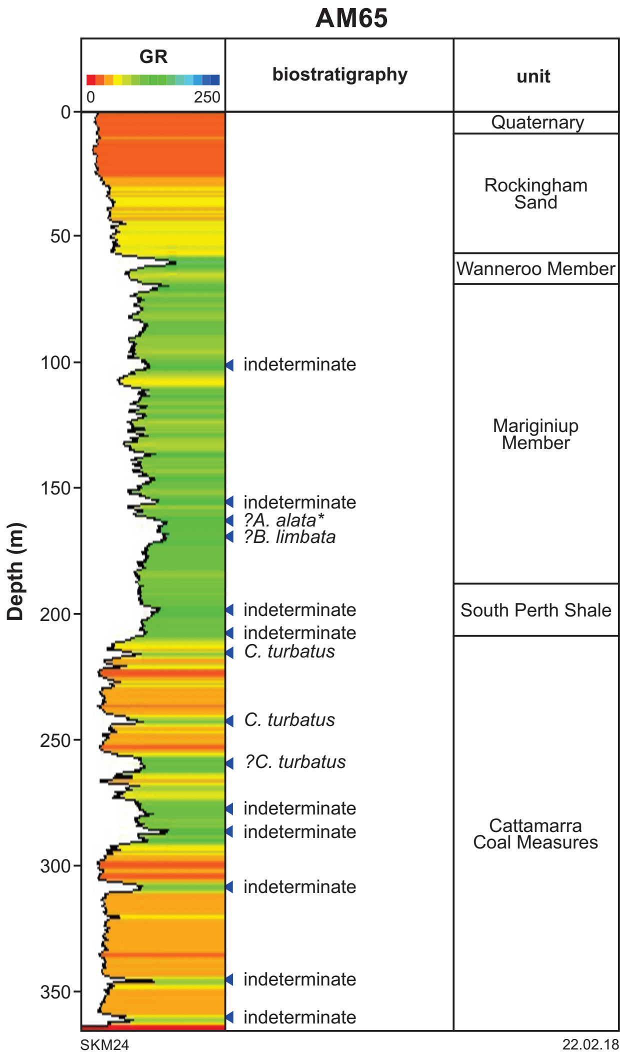
Only four of the Artesian Monitoring boreholes in the study area have had palynological analyses conducted — AM65, AM66, AM67 and AM68. Three of these bores, AM65, AM66 and AM67, lie just north of Mandurah, whereas AM68 is to the east of this city. All except AM66 were drilled in 1980, and each reached a total depth greater than 300 m (363, 384, 375.5 and 327 m, respectively). For each well, a single palynological review was conducted in 1980 or 1981 by then-GSWA staff palynologist, J Backhouse, with the assemblages from AM66 later reviewed by the same author in 2011. The original palynology reports for the remaining three boreholes were recently reassessed, without reference to the original slides (Backhouse, 2015), in preparation for this Report.

AM65

The palynology of this borehole was originally assessed by Backhouse (1980). Although the material from this well has not been formally restudied, a review of the report, to bring the zone identifications up to the current zonation schema, was conducted in 2015 (Backhouse, 2015).

In total, 14 sidewall cores were selected for the original palynological study, and all were processed and yielded palynomorphs. Unfortunately, nine of these samples yielded mixed Jurassic and Cretaceous palynofloras and were interpreted to have been contaminated by drilling muds. The remaining five samples yielded palynofloras apparently uncontaminated by drilling mud, and these can divided into two separate assemblages.

The shallowest two samples, from 163 and 169 m, yielded moderately diverse assemblages of Early Cretaceous spore and pollen, and were originally considered late Neocomian to early Aptian in age. The sample from 163 m also yielded a single dinoflagellate and two acritarch specimens, which suggest a slight marine influence at the time these rocks were deposited. The other sample contains no microplankton or acritarchs and can therefore be considered entirely nonmarine. The reassessment of this report considered both of these samples as assignable to the *Balmeiopsis limbata* Spore-Pollen Zone, and possibly also the *Aprobolocysta alata* Dinocyst Zone, although the low numbers of microplankton seen in the sample makes this latter assignation somewhat uncertain (Backhouse, 2015).



Notes: TD = 363 m; lithostratigraphy based on Davidson (1995); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores

The deeper three samples, from 215, 242 and 259 m, all yielded sparse palynofloras of Early Jurassic age. The shallowest of these three samples contained *Exesipollenites tumulus*, *Classopollis* spp., and *Alisporites* spp., whereas the deeper samples contained dominant *Classopollis* spp. with *Callialasporites turbatus* and *Araucariacites australis*. Despite the low diversity of this assemblage, the author assigned the initial sample to Filatoff's (1975) *Classopollis chateaunovi* Spore-Pollen Zone. *E. tumulus*, in particular, has a short range and according to Helby et al. (1987), is most common in the lower *Callialasporites turbatus* Spore-Pollen Zone, and is present more rarely in the upper *Corollina torosa* Spore-Pollen Zone, although both *C. turbatus* and *A. australis* are relatively long ranging. The recent review of this material suggested a high probability that these samples can all be assigned to the *C. turbatus* Zone.

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Artesian Monitoring 66

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
AM66[a]				
–	40	SWC	contaminated with drilling mud	(Backhouse, 1981)
–	53	SWC	barren	(Backhouse, 1981)
–	86	SWC	not processed	(Backhouse, 1981)
–	119	SWC	*P. lowryi*‡	(Backhouse, 2011)
–	138	SWC	Cretaceous indeterminate	(Backhouse, 2011)
–	144	SWC	contaminated with drilling mud	(Backhouse, 1981)
–	192	SWC	contaminated with drilling mud	(Backhouse, 1981)
–	201	SWC	Cretaceous indeterminate	(Backhouse, 2011)
–	214	SWC	not processed	(Backhouse, 1981)
–	242	SWC	not processed	(Backhouse, 1981)
–	275	SWC	*C. turbatus*^	(Backhouse, 2011)
–	300	SWC	*C. turbatus*^	(Backhouse, 2011)
–	329	SWC	barren	(Backhouse, 1981)
–	338	SWC	barren	(Backhouse, 1981)
–	370	SWC	not processed	(Backhouse, 1981)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

Line summary

The Artesian Monitoring drilling program is a long-lived project, designed to test the distribution of artesian water and pumping potential of groundwater. There have been at least 70 bores drilled as part of this program in the Perth Basin, starting in 1977 and extending through to 1986. Most of these boreholes were drilled relatively deeply, greater than 200 m, but few of them have associated palynological studies. As monitoring bores, most of these holes are currently actively producing, or were active in the past.

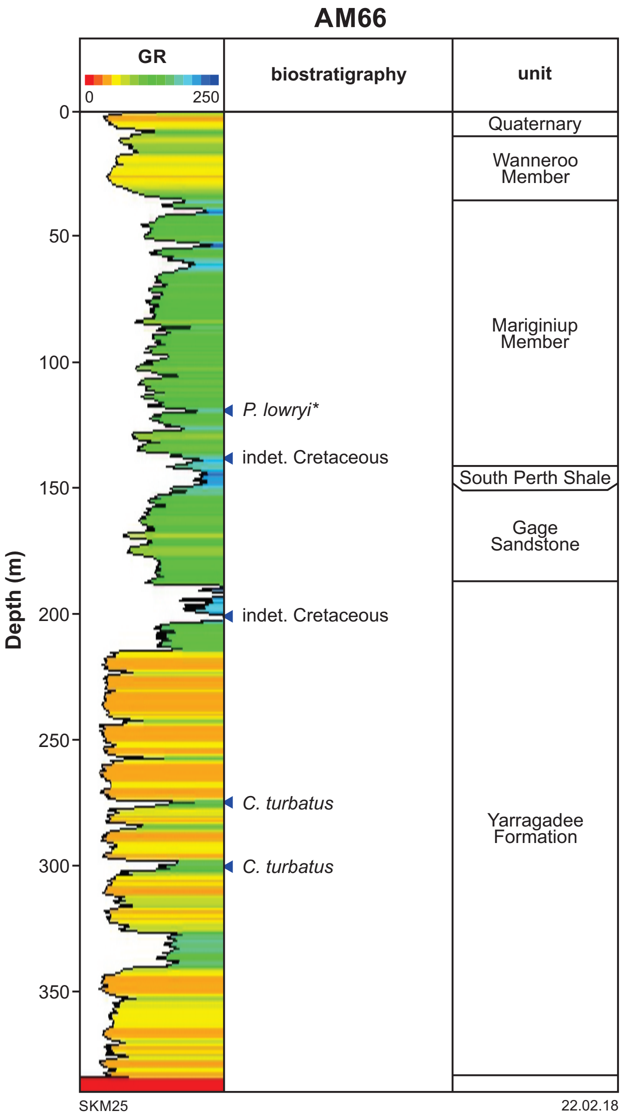
Only four of the Artesian Monitoring boreholes in the study area have had palynological analyses conducted — AM65, AM66, AM67 and AM68. Three of these bores, AM65, AM66 and AM67, lie just north of Mandurah, whereas AM68 is to the east of this city. All except AM66 were drilled in 1980, and each reached a total depth greater than 300 m (363, 384, 375.5 and 327 m, respectively). For each well, a single palynological review was conducted in 1980 or 1981 by then-GSWA staff palynologist, J Backhouse, with the assemblages from AM66 later reviewed by the same author in 2011. The original palynology reports for the remaining three boreholes were recently reassessed, without reference to the original slides (Backhouse, 2015), in preparation for this Report.

AM66

AM66 was drilled in 1981 to a TD of 384 m, and the palynology of this well was assessed by J Backhouse the same year (Backhouse, 1981). The slides from this well were restudied by this same author in 2011, on behalf of the then Department of Water (Backhouse, 2011).

For the original report in 1981, 15 sidewall cores were examined from this borehole. Of these, four samples (86, 214, 242 and 370 m) were considered unsuitable for palynological studies and not processed. Of the 11 samples that were processed, three samples (53, 329 and 338 m) were found to be barren of palynomorphs and three other assemblages (40, 144 and 192 m) were too contaminated with drilling mud to be assessed with confidence.

The remaining five samples can be divided into two age groups: the shallowest three (119, 138 and 201 m) are considered to be Early Cretaceous in age, and the deepest two samples (275 and 300 m) are Early Jurassic age. Of the Cretaceous samples, only the shallowest preserves dinoflagellates, and the remaining two samples have low-diversity and low-yielding, nonmarine assemblages. Backhouse (1981) suggested assignment of the deepest Cretaceous assemblage to Filatoff's (1975) *Klukisporites scaberis* Spore-Pollen Zone (Late Jurassic; taxa now *Ischyosporites scaberis*), although



Notes: TD = 384 m; lithostratigraphy based on Davidson (1995); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores

noting that the assemblage may be late Neocomian like the overlying sample. In the 2011 review, both of these low-yielding assemblages were considered indeterminate, but probably Cretaceous in age, and Backhouse noted that both the palynomorph and palynodebris assemblages were distinctive enough from the underlying Jurassic assemblages to suggest that they were this age. Only the shallowest, marine Cretaceous sample is sufficiently diverse and and yielded sufficient palynomorphs to allow its placement in the *Phoberocysta lowryi* Dinocyst Zone (Backhouse, 2011).

Like the shallower Early Cretaceous assemblages, neither of the deeper Early Jurassic samples in AM66 yielded specimen-rich, diverse palynological assemblages. Despite this, in his original report, Backhouse (1981) considered both assemblages to be clearly assignable to either the *Dictyotosporites complex* or *Dictyophyllidites harrisii* Assemblage Zones (of Filatoff, 1975), based on the dominance of *Classopollis* spp., and the presence of *Exesipollenites tumulus* in the 275 m sample and *Callialasporites turbatus* in the 300 m sample. Backhouse's (2011) review agreed with this interpretation, considering both assemblages assignable to the *Callialasporites turbatus* Spore-Pollen Zone. Therefore, it has been interpreted that the Jurassic–Cretaceous unconformity in AM66 lies somewhere between 210 and 275 m depth. This disagrees with previously assessed formation tops for this well (taken from DWER's Water Information Reporting [WIR] database), which interpreted a boundary between the Leederville Formation and underlying Yarragadee Formation at 137 m. In addition, the interpretation of *C. turbatus* Zone assemblages makes it unlikely the Yarragadee Formation is present in this well, and the section at 275 m and below is better regarded as equivalent in age to the Cattamarra Coal Measures in the northern Perth Basin.

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Artesian Monitoring 67

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
AM67[(a)]				
–	56	SWC	*B. limbata*[#]	(Backhouse, 2015)
–	68	SWC	*B. limbata*[#]	(Backhouse, 2015)
–	122	SWC	*A. alata*[‡]	(Backhouse, 2015)
–	162	SWC	indeterminate	(Backhouse, 2015)
–	172	SWC	indeterminate	(Backhouse, 2015)
–	183	SWC	indeterminate	(Backhouse, 2015)
–	189	SWC	indeterminate	(Backhouse, 2015)
–	220	SWC	indeterminate	(Backhouse, 2015)
–	242	SWC	probably *P. lowryi*[‡]	(Backhouse, 2015)
–	253	SWC	not older than *P. lowryi*[‡]	(Backhouse, 2015)
–	281	SWC	probably *C. torosa*^	(Backhouse, 2015)
–	297	SWC	barren	(Backhouse, 1980)
–	318	SWC	barren	(Backhouse, 1980)
–	340	SWC	barren	(Backhouse, 1980)
–	349	SWC	barren	(Backhouse, 1980)
–	353	SWC	barren	(Backhouse, 1980)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone; [‡]Backhouse (1988) Dinocyst Zone

Line summary

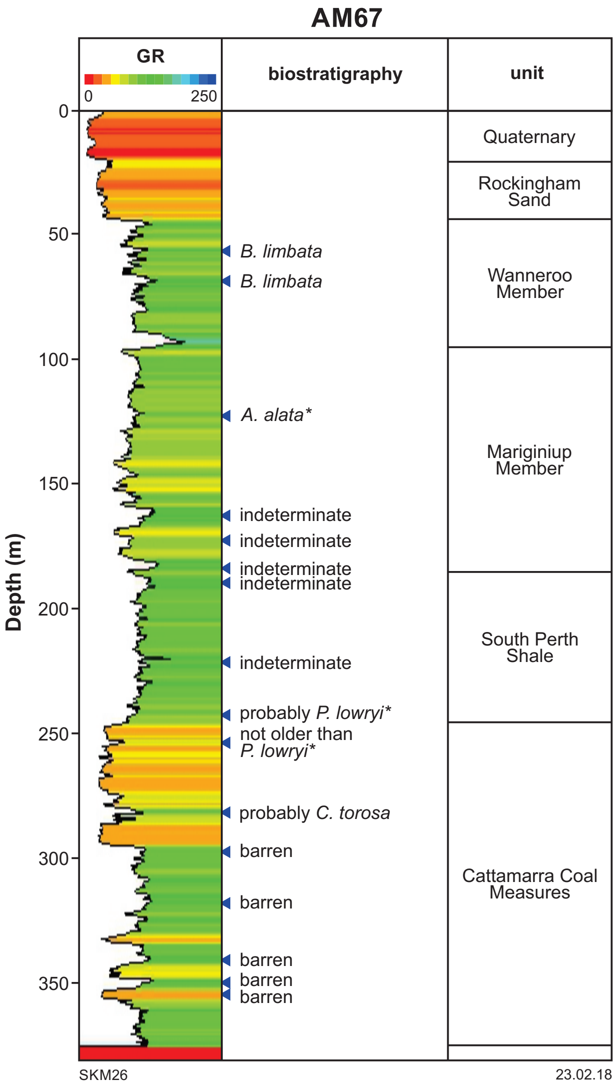
The Artesian Monitoring drilling program is a long-lived project, designed to test the distribution of artesian water and pumping potential of groundwater. There have been at least 70 bores drilled as part of this program in the Perth Basin, starting in 1977 and extending through to 1986. Most of these boreholes were drilled relatively deeply, greater than 200 m, but few of them have associated palynological studies. As monitoring bores, most of these holes are currently actively producing, or were active in the past.

Only four of the Artesian Monitoring boreholes in the study area have had palynological analyses conducted — AM65, AM66, AM67 and AM68. Three of these bores, AM65, AM66 and AM67, lie just north of Mandurah, whereas AM68 is to the east of this city. All except AM66 were drilled in 1980, and each reached a total depth greater than 300 m (363, 384, 375.5 and 327 m, respectively). For each well, a single palynological review was conducted in 1980 or 1981 by then-GSWA staff palynologist, J Backhouse, with the assemblages from AM66 later reviewed by the same author in 2011. The original palynology reports for the remaining three boreholes were recently reassessed, without reference to the original slides (Backhouse, 2015), in preparation for this Report.

AM67

Only one palynological assessment has been conducted on samples from AM67 to date, by then-GSWA staff palynologist J Backhouse (Backhouse, 1980). The interpretations of that report were reviewed and modernized in 2015 (Backhouse, 2015). Sixteen sidewall-core samples were processed from AM67, none of which showed evidence of obvious oxidation. Although the shallowest 11 samples yielded palynomorphs, the deepest four samples, from 297–363 m, were barren of palynomorphs, and the age at TD is unknown for this borehole.

The shallowest two samples in AM67 all yielded sparse assemblages of typically Early Cretaceous palynomorphs, including the zone indicator *Balmeiopsis limbata*, and therefore can be assigned to that spore-pollen zone. In addition, samples at 122 m, 172 m, 220 m, 242 m and 253 m all yielded marine dinoflagellates, suggesting marine pulses into this part of the Perth Basin during the Early Cretaceous. Of these samples, the assemblage at 122 m was referred to ‘Zone 4’ of Late Barremian age which, according to Backhouse (2015), equates roughly to the *Aprobolocysta alata* Zone of Backhouse (1988), and the sample at 242 m was assigned to ‘Zone 2’ or ‘Zone 3’ which is equivalent to the *Kaiwaradinium scrutillinum* or *Phoberocysta lowryi* Dinocyst Zones of Backhouse



Notes: **TD = 375.5 m; lithostratigraphy based on Davidson (1995); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**

(1988). Although the samples at 172 m and 220 m also yielded marine dinoflagellates, the author noted that the samples are contaminated with drilling mud, casting doubt on whether these marine indicators are introduced at this depth. The same doubt exists at 253 m, where the assemblage looks similar to that at 242 m, but which also seems to be heavily contaminated by drilling mud.

The deepest sample yielding palynomorphs, at 281 m, contains a sparse palynoflora strongly dominated by *Classopollis* spp. with supporting *Exesipollenites tumulus*. This sample was considered Early Jurassic (Hettangian or Sinemurian) at the time of this original assessment, and was correlated to the lower part of Filatoff's (1975) *Classopollis chateaunovi* Spore-Pollen Zone, which Helby et al. (1987) considered equivalent to the *Classopollis torosa* Spore-Pollen Zone. The recent reassessment supports this association with the *C. torosa* Zone, although attribution of that assemblage to the overlying *Callialasporites turbatus* Spore-Pollen Zone cannot be ruled out. Regardless, there is a clear microfloral break between 242 m (or possibly 253 m) and 281 m, jumping from the Early Cretaceous to the Early Jurassic. As Lower Jurassic palynological assemblages tend to be very lean in the southern Perth Basin, it is possible that some or all of the barren samples recorded below 281 m are of similar age, although this suggestion is untestable without additional samples from this section.

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Artesian Monitoring 68

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
AM68[(a)]				
–	36	SWC	barren	(Backhouse, 1980)
–	45	SWC	barren	(Backhouse, 1980)
–	60	SWC	probably *A. alata*‡	(Backhouse, 2015)
–	78	SWC	barren	(Backhouse, 1980)
–	110	SWC	barren	(Backhouse, 1980)
–	143	SWC	barren	(Backhouse, 1980)
–	157	SWC	barren	(Backhouse, 1980)
–	169	SWC	probably *A. alata*‡	(Backhouse, 2015)
–	174	SWC	*P. lowryi*‡	(Backhouse, 2015)
–	188	SWC	barren	(Backhouse, 1980)
–	194	SWC	barren	(Backhouse, 1980)
–	225	SWC	barren	(Backhouse, 1980)
–	253	SWC	indeterminate	(Backhouse, 2015)
–	268	SWC	indeterminate	(Backhouse, 2015)
–	279	SWC	barren	(Backhouse, 1980)
–	308	SWC	probably *C. turbatus*^	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

Line summary

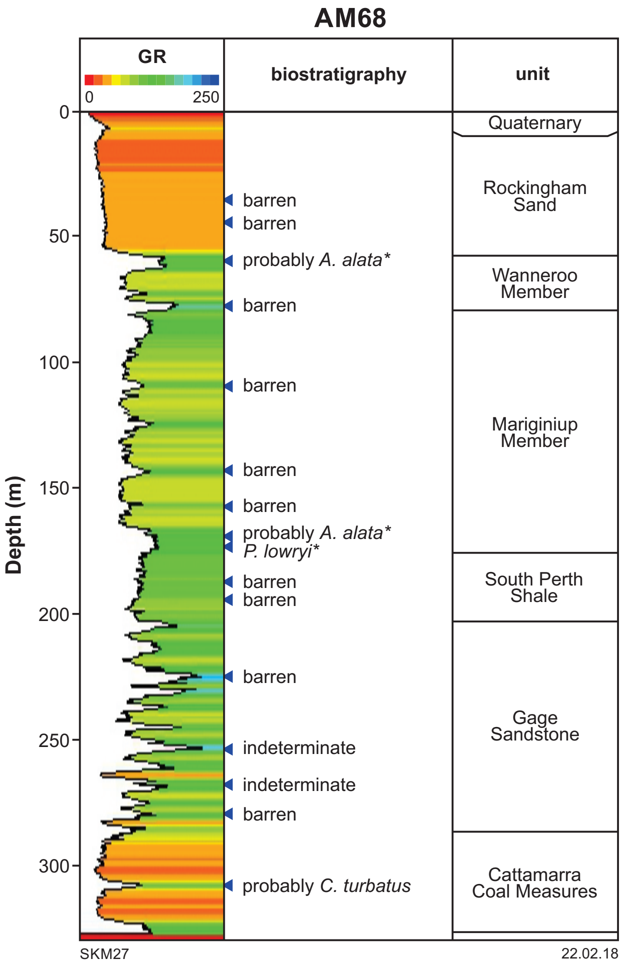
The Artesian Monitoring drilling program is a long-lived project, designed to test the distribution of artesian water and pumping potential of groundwater. There have been at least 70 bores drilled as part of this program in the Perth Basin, starting in 1977 and extending through to 1986. Most of these boreholes were drilled relatively deeply, greater than 200 m, but few of them have associated palynological studies. As monitoring bores, most of these holes are currently actively producing, or were active in the past.

Only four of the Artesian Monitoring boreholes in the study area have had palynological analyses conducted — AM65, AM66, AM67 and AM68. Three of these bores, AM65, AM66 and AM67, lie just north of Mandurah, whereas AM68 is to the east of this city. All except AM66 were drilled in 1980, and each reached a total depth greater than 300 m (363, 384, 375.5 and 327 m, respectively). For each well, a single palynological review was conducted in 1980 or 1981 by then-GSWA staff palynologist, J Backhouse, with the assemblages from AM66 later reviewed by the same author in 2011. The original palynology reports for the remaining three boreholes were recently reassessed, without reference to the original slides (Backhouse, 2015), in preparation for this Report.

AM68

The palynology of this borehole was assessed by Backhouse (1980), and has not been formally reviewed since. In 2015, a review of the report findings was undertaken to bring the zone identifications up to current usage (Backhouse, 2015), although the original samples and slides were not re-evaluated at the same time. In the original palynological study, 16 sidewall cores were selected for processing, although eight of these samples were either heavily contaminated sandstones or drilling mud and were therefore not processed. Of the remaining eight samples processed, two — at 225 and 279 m — were barren of palynomorphs.

The six samples yielding palynomorphs can be divided into three distinct assemblages. The three shallowest samples (60, 169 and 174 m) are clearly Early Cretaceous in age and each contain dinoflagellates in addition to spores and pollen, indicating a marine depositional environment. The shallowest sample was noted to include species that suggest assignation to either ‘Zone 4’ or ‘Zone 5’, considered equivalent to Backhouse’s (1988) *Aprobolocysta alata* and *Batioladinium jaegeri* Dinocyst Zones, respectively; whereas, the middle sample was linked only to ‘Zone 4’, and therefore considered equivalent to *A. alata* Zone. The sample from 174 m was considered to belong to ‘Zone 3’, which is linked to



Notes: TD = 327 m; lithostratigraphy based on Davidson (1995); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores

Backhouse's (1988) *Phoberocysta lowryi* Dinocyst Zone (Backhouse, 2015). A recent reassessment (Backhouse, 2015) of the original palynology report suggests a similar interpretation — with samples at 60 and 169 m assigned to the *A. alata* (or perhaps slightly younger) Zone, and the 174 m sample assigned to the *P. lowryi* Zone.

The middle two samples, at 253 and 268 m, yielded sparse assemblages that contained a mixture of Early and Late Jurassic palynomorphs. No purely Cretaceous forms or microplankton were preserved within the assemblages, but these samples were considered to represent Jurassic sediments reworked during the earliest Cretaceous (pre-Hauterivian; Backhouse, 1980). This section was also considered equivalent in age to the Gage Sandstone (then a member of the South Perth Shale), although the reasons for this particular association were not made entirely clear in Backhouse's (1980) report. However, later work (Backhouse, 2015) noted that these two samples are in fact heavily contaminated, and their age is therefore uncertain.

The deepest sample submitted from this bore, at 308 m, contains no dinoflagellates, but does contain a diverse assemblage of spores and pollen dominated by *Classopollis chateaunovi* (more than 50% of the assemblage) and other typically Early Jurassic taxa, including *Dictyophyllidites harrisii*, *Vitreisporites pallidus, Staplinisporites caminus*, *Duplexisporites problematicus*, *Antulsporites saevus* and *Alisporites grandis*. This assemblage suggests association with the uppermost part of Filatoff's (1975) *Classopollis chateaunovi* Spore-Pollen Zone, considered equivalent to the middle of Helby et al.'s (1987) *Callialasporites turbatus* Spore-Pollen Zone. The recent review (Backhouse, 2015) supports this interpretation and was echoed during a recent reassessment of the original report made for the present Report, with the sample considered to be more likely assignable to the *C. turbatus* Zone than the *Corollina torosa* Spore-Pollen Zone. Therefore, there is a distinct microfloral break within the borehole, although the lack of age control on the central ?Early Cretaceous samples make it difficult to determine the depth of this break.

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Binningup Line 1A

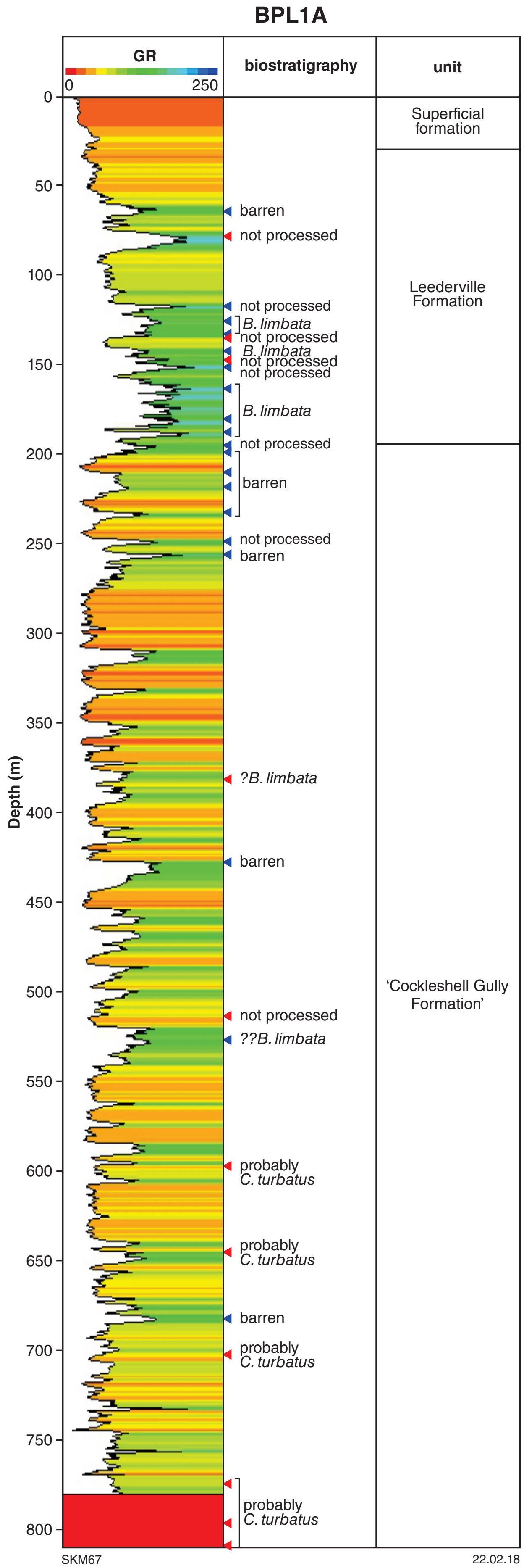
Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
BPL1A[(a)]				
–	64.5	SWC	barren	(Backhouse, 1984)
–	78–81	DC	not processed	(Backhouse, 1984)
–	117	SWC	not processed	(Backhouse, 1984)
–	125.5	SWC	*B. limbata*#	(Backhouse, 2015)
–	133	SWC	*B. limbata*#	(Backhouse, 2015)
–	135–138	DC	not processed	(Backhouse, 1984)
–	142	SWC	*B. limbata*#	(Backhouse, 2015)
–	147–150	DC	not processed	(Backhouse, 1984)
–	151	SWC	not processed	(Backhouse, 1984)
–	163	SWC	*B. limbata*#	(Backhouse, 2015)
–	180	SWC	*B. limbata*#	(Backhouse, 2015)
–	187.5	SWC	*B. limbata*#	(Backhouse, 2015)
–	194.5	SWC	not processed	(Backhouse, 1984)
–	198	SWC	barren	(Backhouse, 1984)
–	210	SWC	barren	(Backhouse, 1984)
–	218	SWC	barren	(Backhouse, 1984)
–	232	SWC	barren	(Backhouse, 1984)
–	248	SWC	not processed	(Backhouse, 1984)
–	255.5	SWC	barren	(Backhouse, 1984)
–	381	DC	*?B. limbata*#	(Backhouse, 2015)
–	427.5	SWC	barren	(Backhouse, 1984)
–	513–516	DC	not processed	(Backhouse, 1984)
–	526.5	SWC	*??B. limbata*#	(Backhouse, 2015)
–	597–600	DC	probably *C. turbatus*^	(Backhouse, 2015)
–	645–648	DC	probably *C. turbatus*^	(Backhouse, 2015)
–	682	SWC	barren	(Backhouse, 1984)
–	702–705	DC	probably *C. turbatus*^	(Backhouse, 2015)
–	774–777	DC	probably *C. turbatus*^	(Backhouse, 2015)
–	795–798	DC	probably *C. turbatus*^	(Backhouse, 2015)
–	810	DC	probably *C. turbatus*^	(Backhouse, 2015)

NOTES:

(a) Well or bore name abbreviations taken from Appendix 1

(b) Age or zone taken from most recent study or review

Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone



Line summary

The Binningup Line is a set of six water bores drilled on four sites (BPL1–4). The initial set of four wells, designated with an 'A' suffix, was drilled as deep exploratory holes. Shallow water-supply holes, suffixed 'W', were later completed at sites 1 and 3. Drilled in 1984 by GSWA's hydrogeology division, but funded jointly by the State and Commonwealth Governments, the bore sites were oriented from west to east, extending across the onshore part of the basin from Binningup township (Deeney, 1989).

The four exploratory holes reached TD of 806.5 m (BPL1A), 600 m (BPL2A), 800.5 m (BPL3A), and 802.6 m (BPL4A), respectively. Sampling in the four exploratory bores included a full set of ditch cuttings taken every 3 m, and roughly 20 sidewall cores in each hole; a suite of geophysical tools were also run in each hole including gamma ray and resistivity logging. The two shallower water-supply holes reached TD of 18 m (BPL1W) and 33 m (BPL3W), but no samples were collected from these boreholes and therefore no palynology analyses conducted. Samples from all four exploration boreholes were initially analysed by GSWA palynologist J Backhouse between 1984 and 1986, with results reported informally in a series of GSWA Paleontology Reports. These slides have not been reviewed since.

BPL1A

A total of 19 sidewall cores and 11 ditch cuttings were submitted for palynology from BPL1A, and these samples were described in a single, unpublished GSWA Paleontology Report (Backhouse, 1984). This report was reviewed in 2015, with the aim to clarify and modernize the biostratigraphic interpretations (Backhouse, 2015).

Of these samples, the four shallowest ditch cuttings and four of the sidewall cores were not processed due to unsuitable lithology or oxidization, and eight sidewall cores were barren after processing. Signs of oxidation were particularly common between the depths of 187.5 m and 526.5 m, with nearly all samples between those two depths barren or unprocessed.

In the initial reports, productive samples down to 526.5 m were noted to be particularly diverse and rich in palynomorphs, with the uppermost five sidewall-core samples (125.5, 133, 142, 163, 180 and 187.5 m) and one of the ditch cuttings (381 m) considered Early Cretaceous in age. The recent review of this report assigned these samples to the *Balmeiopsis limbata* Spore-Pollen Zone,

Notes: **TD = 806.5 m; lithostratigraphy based on Deeney (1989); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores**

although this interpretation is somewhat uncertain for the unreliable cuttings sample (Backhouse, 2015). The single sidewall core at 526.5 m yielded a surprisingly diverse assemblage of long-ranging latest Jurassic or Early Cretaceous taxa; however, Backhouse confessed uncertainty as to whether this sample was correctly labelled, based on its position within a long section of oxidized and barren lithologies more typical of the Early Jurassic units of the Perth Basin. Although the review considered this assemblage to also be assignable to the *B. limbata* Zone, the surrounding barren samples were also noted, and it is speculated that the sample is actually a barren Early Jurassic sample heavily contaminated with Early Cretaceous caving.

Below this set of Cretaceous samples, six ditch cuttings (597–600, 645–648, 702–705, 774–777, 795–798, and 810 m [= TD]) yielded sparse, low-diversity assemblages commonly dominated by *Classopollis* pollen, with minor occurrences of other palynomorphs. Based on the dominance of *Classopollis* and the low diversity of the assemblage, Backhouse assigned the section to the Lower Jurassic, despite some of the taxa, such as *Contignisporites cooksoniae* (at 645–648 m), *Dictyophyllidites equiexinus* (at 702–705 m and 810 m), and *Microcachryidites antarcticus* (at 597–600 m), being more indicative of the Late Jurassic and Early Cretaceous than the Early Jurassic. However, the inconsistent distribution and rarity of these forms suggests that they may be downhole contamination — all of the species in these deeper samples are present and common in the overlying assemblages. Deeney (1989) interpreted the Lower Jurassic sediments in this borehole as belonging to the ‘Eneabba Member of the Cockleshell Gully Formation’, and this, plus the low-diversity nature of these assemblages, suggests a possible link to the *Corollina torosa* Spore-Pollen Zone. However, the recent review in fact suggests that these samples are probably attributable to the *Callialasporites turbatus* Spore-Pollen Zone (Backhouse, 2015), and therefore more likely equivalent to the Cattamarra Coal Measures than to the older Eneabba Formation.

Taking the palynological results at face value, the Jurassic–Cretaceous unconformity in BPL1A would be placed somewhere between 381 and 597 m depth. However, Deeney (1989) placed this unconformity at a depth of 194 m, suggesting a possible disconnect between lithological and biostratigraphic data. Given that ditch cuttings are prone to contamination, the cuttings sample at 381 m can be considered suspect — possibly representing Early Cretaceous contamination printed onto a barren or near barren sample, as suggested for the 526.5 m sample. Therefore, there is little solid information as to the age of the section between 187.5 and 597 m in BPL1A, although most or all of the section may be Early Jurassic in age.

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Binningup Line 2A

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
BPL2A[(a)]				
–	62	SWC	*B. limbata*[#]	(Backhouse, 2015)
–	95	SWC	*B. limbata*[#]	(Backhouse, 2015)
–	118.5	SWC	*B. limbata*[#]	(Backhouse, 2015)
–	149	SWC	*B. limbata*[#]	(Backhouse, 2015)
–	160	SWC	not processed	(Backhouse, 1985)
–	168.5	SWC	barren	(Backhouse, 1985)
–	188.5	SWC	not processed	(Backhouse, 1985)
–	255	SWC	barren	(Backhouse, 1985)
–	287	SWC	barren	(Backhouse, 1985)
–	305	SWC	*C. turbatus*^	(Backhouse, 2015)
–	365.5	SWC	not processed	(Backhouse, 1985)
–	382.5	SWC	not processed	(Backhouse, 1985)
–	386.5	SWC	barren	(Backhouse, 1985)
–	395	SWC	barren	(Backhouse, 1985)
–	415	SWC	barren	(Backhouse, 1985)
–	514.5	SWC	barren	(Backhouse, 1985)
–	594	SWC	barren	(Backhouse, 1985)
–	603	DC	not processed	(Backhouse, 1985)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone

Line summary

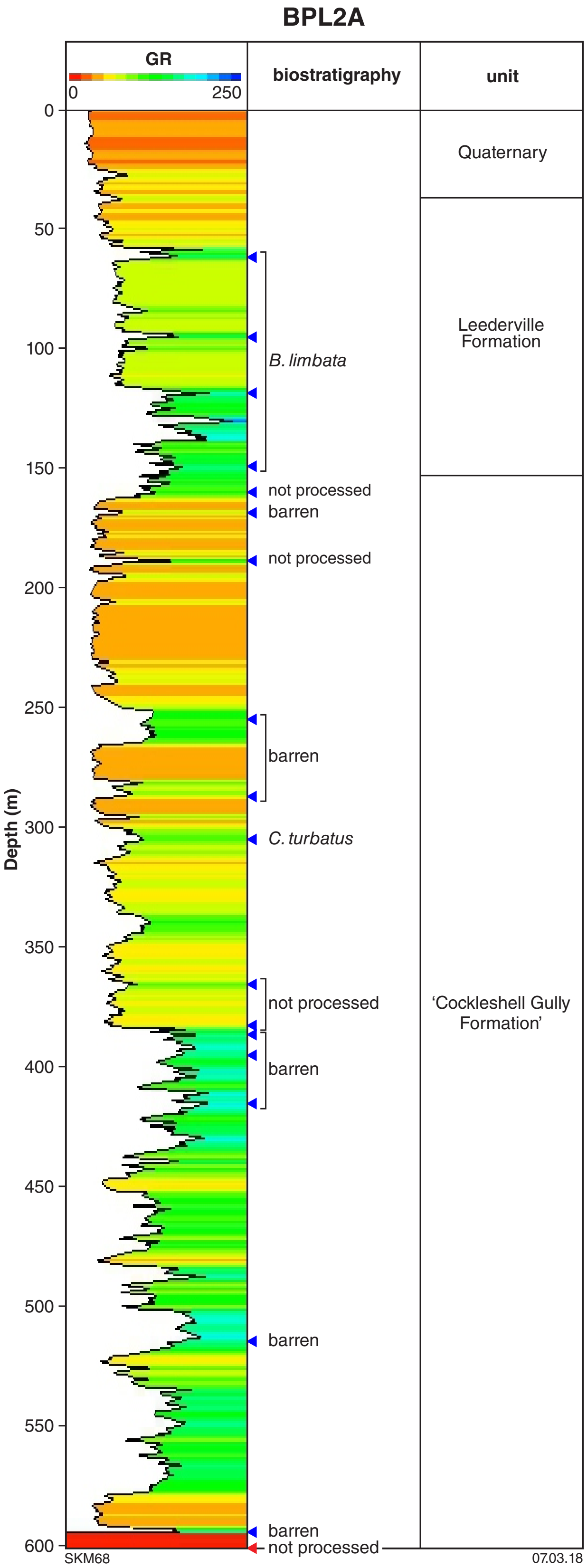
The Binningup Line is a set of six water bores drilled on four sites (BPL1–4). The initial set of four wells, designated with an ‘A’ suffix, was drilled as deep exploratory holes. Shallow water-supply holes, suffixed ‘W’, were later completed at sites 1 and 3. Drilled in 1984 by GSWA’s hydrogeology division, but funded jointly by the State and Commonwealth Governments, the bore sites were oriented from west to east, extending across the onshore part of the basin from Binningup township (Deeney, 1989).

The four exploratory holes reached TD of 806.5 m (BPL1A), 600 m (BPL2A), 800.5 m (BPL3A), and 802.6 m (BPL4A), respectively. Sampling in the four exploratory bores included a full set of ditch cuttings taken every 3 m, and roughly 20 sidewall cores in each hole; a suite of geophysical tools were also run in each hole including gamma ray and resistivity logging. The two shallower water-supply holes reached TD of 18 m (BPL1W) and 33 m (BPL3W), but no samples were collected from these boreholes and therefore no palynology analyses conducted. Samples from all four exploration boreholes were initially analysed by GSWA palynologist J Backhouse between 1984 and 1986, with results reported informally in a series of GSWA Paleontology Reports. These slides have not been reviewed since.

BPL2A

A total of 17 sidewall cores and three ditch cuttings from BPL2A were submitted for palynological analysis, but two of the ditch cuttings and four sidewall-core samples were not considered suitable for palynological analyses and were not processed (Backhouse, 1985). Of the remaining 14 samples, eight sidewall cores were found to be barren upon processing. Although the report on this material lists one of the ditch cutting samples (603 m) as both processed and yielding, there is no mention of the palynomorphs derived from this sample, and its age is presently unknown. The report was reviewed in 2015, with the aim of clarifying and modernizing the biostratigraphic interpretations (Backhouse, 2015).

Four of the five sidewall cores yielding palynomorphs (62, 95, 118.5 and 149 m) are from the shallowest part of the bore; these four samples yielded similar assemblages that place them within the *Balmeiopsis limbata* Spore-Pollen Zone and are Berriasian to Aptian in age. The final sidewall core at 305 m is noted as having yielded a rich assemblage of distinctly Early Jurassic aspect, and was considered by Backhouse (1985) to fall within the lower part of Filatoff’s (1975) *Dictyophyllidites harrisii* Assemblage Zone. This zone is generally equated to the upper *Callialasporites turbatus* Spore-Pollen Zone of Helby et al. (1987), and is correlated to the Toarcian to Bajocian. Both of these interpretations (*B. limbata* and



Notes: **TD = 600 m; lithostratigraphy based on Deeney (1989); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores**

C. turbatus Zones) are supported in the recent report review (Backhouse, 2015).

Palynological evidence indicates that the Jurassic–Cretaceous unconformity falls somewhere between 149 and 305 m depth; furthermore, the recent review notes that the entire section between 160 m to at least 603 m consists of sandstones or oxidized sediments, and on this basis (Backhouse, 2015) concluded that the Early Jurassic sediments extend throughout this range. Deeney (1989) placed the unconformity at 153 m depth, likely on the basis of supporting geophysical log data and lithological characters. Although Deeney (1989) considered the Early Jurassic section below the unconformity to belong to the 'Eneabba Member' of the 'Cockleshell Gully Formation', the interpretation of this section as belonging to the *C. turbatus* Zone suggests a unit more likely equivalent to the Cattamarra Coal Measures, at least at about 305 m depth. However, a lack of palynological data means that the age of the borehole at TD is unknown, and it is possible that sedimentary units equivalent in age to Eneabba Formation exist deeper in the borehole. Interestingly, Deeney (1989) suggested a difference in the nature of the Lower Jurassic rocks between the west (BPL1A and BPL2A) and east (BPL3A and BPL4A) of the line based on lithology and geophysical log data, although there is no appreciable difference between the palynological assemblages seen in BPL2A and BPL4A.

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Binningup Line 4A

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
BPL4A[a]				
–	143	SWC	*C. turbatus*^	(Backhouse, 2015)
–	various depths	SWC (x 20)	Not processed	(Backhouse, 1986)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone

Line summary

The Binningup Line is a set of six water bores drilled on four sites (BPL1–4). The initial set of four wells, designated with an 'A' suffix, was drilled as deep exploratory holes. Shallow water-supply holes, suffixed 'W', were later completed at sites 1 and 3. Drilled in 1984 by GSWA's hydrogeology division, but funded jointly by the State and Commonwealth Governments, the bore sites were oriented from west to east, extending across the onshore part of the basin from Binningup township (Deeney, 1989).

The four exploratory holes reached TD of 806.5 m (BPL1A), 600 m (BPL2A), 800.5 m (BPL3A), and 802.6 m (BPL4A), respectively. Sampling in the four exploratory bores included a full set of ditch cuttings taken every 3 m, and roughly 20 sidewall cores in each hole; a suite of geophysical tools were also run in each hole including gamma ray and resistivity logging. The two shallower water-supply holes reached TD of 18 m (BPL1W) and 33 m (BPL3W), but no samples were collected from these boreholes and therefore no palynology analyses conducted. Samples from all four exploration boreholes were initially analysed by GSWA palynologist J Backhouse between 1984 and 1986, with results reported informally in a series of GSWA Paleontology Reports. These slides have not been reviewed since.

BPL4A

Although 21 sidewall cores were collected in this well, all but one showed signs of intense oxidization and were not considered suitable for palynological analysis (Backhouse, 1986). The single unoxidized sidewall core, from a depth of 143 m, yielded a low-diversity assemblage strongly dominated by *Classopollis ?torosus* and *Trilobosporites antiquus*, and was assigned to Filatoff's (1975) *Dictyophyllidites harrisii* Assemblage Zone. This zone is equated to the *Callialasporites turbatus* Spore-Pollen Zone of Helby et al. (1987), and is considered to be Toarcian to Bajocian in age. A recent review of the Backhouse (1986) report, compiled without examining the original samples, confirms the assignation of this sample to the *C. turbatus* Zone (Backhouse, 2015).

Like other boreholes on the Binningup Line, Deeney (1989) considered the Lower Jurassic strata in this bore to belong to 'Eneabba Member' of the 'Cockleshell Gully Formation', although like BPL2A, the presence of *C. turbatus* Zone palynomorphs at 143 m suggests a unit more likely equivalent to the Cattamarra Coal Measures. As more than half of the deepest part of this borehole (from 143 to the TD of 803 m) has no biostratigraphic control, it is possible that the section passes into sediments of the *Corollina torosa* Zone further down the borehole in BPL4A, although palynology data would be needed to confirm this.

As with BPL 1–3, other features of this borehole interpreted by Deeney (1989), including the presence and depth of the Jurassic–Cretaceous unconformity (at 99 m), also cannot be confirmed due to a lack of biostratigraphic data.

References

Backhouse, J 1986, Biostratigraphy of Binningup Line 4 based on palynology: Geological Survey of Western Australia, Paleontology Report 1986/06, 3p.

Backhouse, J 2015, Review of old palynology reports for 15 boreholes in the southern Perth Basin 1: Backhouse Biostrat Pty Ltd, Perth, Western Australia, Report BB499, 6p. (unpublished).

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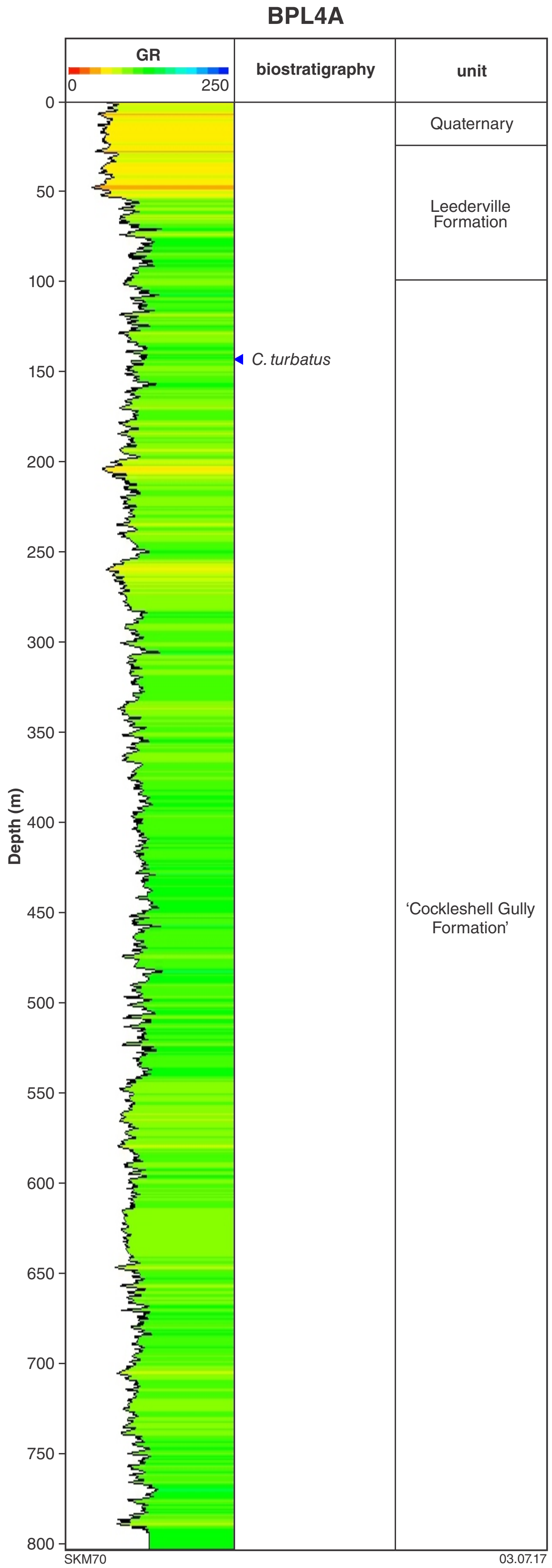
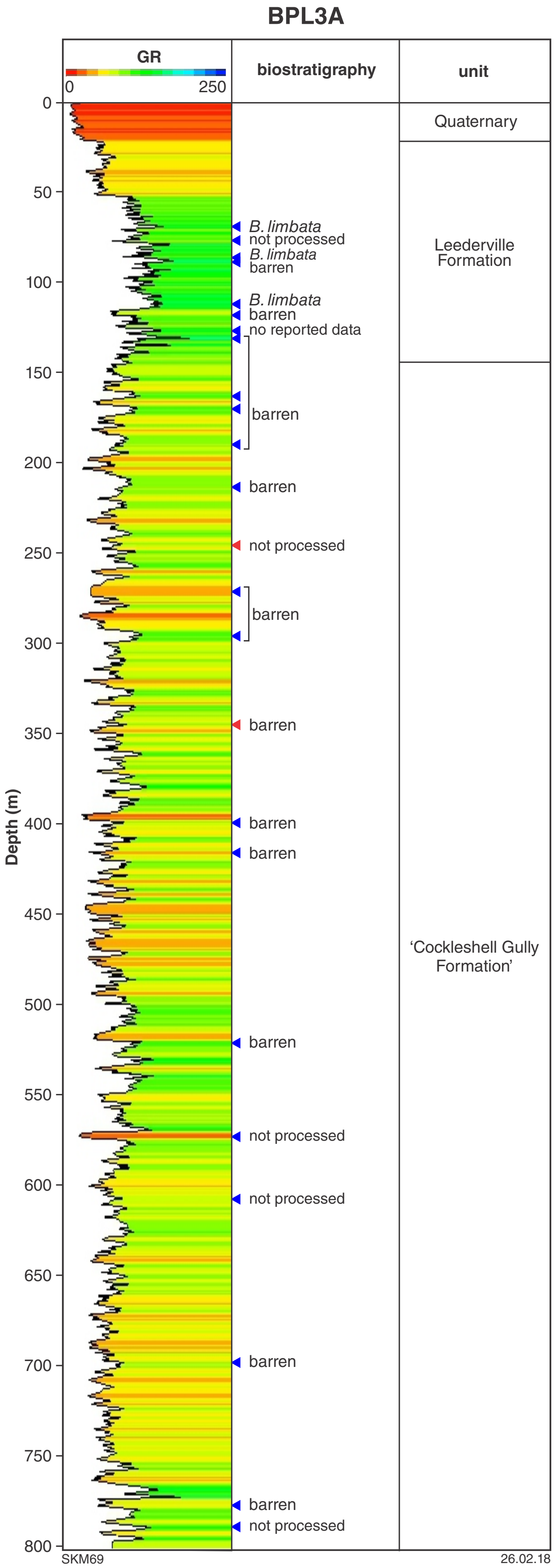


Notes: **TD = 802.6 m; lithostratigraphy based on Deeney (1989); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**

Binningup Line 3A and Binningup Estate 2

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
BPL3A[(a)]				
–	69	DC/SWC	*B. limbata*[#]	(Backhouse, 1986)
–	77	DC/SWC	not processed	(Backhouse, 1986)
–	87	DC/SWC	*B. limbata*[#]	(Backhouse, 1986)
–	88	DC/SWC	barren	(Backhouse, 1986)
–	112	DC/SWC	*B. limbata*[#]	(Backhouse, 1986)
–	118	DC/SWC	barren	(Backhouse, 1986)
–	127	DC/SWC	[no report]	(Backhouse, 1986)
–	131	DC/SWC	barren	(Backhouse, 1986)
–	163	DC/SWC	barren	(Backhouse, 1986)
–	170	DC/SWC	barren	(Backhouse, 1986)
–	189.5	DC/SWC	barren	(Backhouse, 1986)
–	213	DC/SWC	barren	(Backhouse, 1986)
–	246–249	DC	not processed	(Backhouse, 1986)
–	271	DC/SWC	barren	(Backhouse, 1986)
–	295.5	DC/SWC	barren	(Backhouse, 1986)
–	345–348	DC	barren	(Backhouse, 1986)
–	399	DC/SWC	barren	(Backhouse, 1986)
–	416	DC/SWC	barren	(Backhouse, 1986)
–	521	DC/SWC	barren	(Backhouse, 1986)
–	573	DC/SWC	not processed	(Backhouse, 1986)
–	607.5	DC/SWC	not processed	(Backhouse, 1986)
–	698	DC/SWC	barren	(Backhouse, 1986)
–	777	DC/SWC	barren	(Backhouse, 1986)
–	789	DC/SWC	not processed	(Backhouse, 1986)
BPE2				
–	27–29	DC	barren	(Backhouse, 1977)
–	59–60	DC	*?B. limbata*[#]	(Backhouse, 1977)
–	142–148	DC	*?B. limbata*[#]	(Backhouse, 1981)
–	148–150	DC	*?B. limbata*[#]	(Backhouse, 1977)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples); HS, hand sample
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone



Line summary

The Binningup Line is a set of six water bores drilled on four sites (BPL1–4). The initial set of four wells, designated with an 'A' suffix, was drilled as deep exploratory holes. Shallow water-supply holes, suffixed 'W', were later completed at sites 1 and 3. Drilled in 1984 by GSWA's hydrogeology division, but funded jointly by the State and Commonwealth Governments, the bore sites were oriented from west to east, extending across the onshore part of the basin from Binningup township (Deeney, 1989).

The four exploratory holes reached TD of 806.5 m (BPL1A), 600 m (BPL2A), 800.5 m (BPL3A), and 802.6 m (BPL4A), respectively. Sampling in the four exploratory bores included a full set of ditch cuttings taken every 3 m, and roughly 20 sidewall cores in each hole; a suite of geophysical tools were also run in each hole including gamma ray and resistivity logging. The two shallower water-supply holes reached TD of 18 m (BPL1W) and 33 m (BPL3W), but no samples were collected from these boreholes and therefore no palynology analyses conducted. Samples from all four exploration boreholes were initially analysed by GSWA palynologist J Backhouse between 1984 and 1986, with results reported informally in a series of GSWA Paleontology Reports. These slides have not been reviewed since.

BPL3A

At least four BPL3A samples yielded palynomorphs upon processing (Backhouse, 1986), with the three reported samples (69, 87, 112 m) containing assemblages indicating the *Balmeiopsis limbata* Spore-Pollen Zone of Early Cretaceous age. The deepest sample yielding palynomorphs in this borehole (at 127 m) was not included in the report and its age is unknown; therefore, there is no biostratigraphic evidence that this borehole intersected strata older than Cretaceous. Despite the lack of age control for more than half the deepest section of this borehole (from 127–789 m), it is possible that some of the barren, oxidized sequence is Early Jurassic in age. Deeney (1989) interpreted an unconformity between Lower Cretaceous sedimentary rocks and underlying Lower Jurassic rocks of the 'Cockleshell Gully Formation' at 145 m depth in this borehole, and assigned the Lower

Notes: **TD = 800.5 m; lithostratigraphy based on Deeney (1989); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores**

Jurassic strata to the 'Eneabba Member' of this formation based on the 'multicoloured' sediments and lack of coal sequences. However, *Callialasporites turbatus* Spore-Pollen Zone assemblages, and therefore sediments equivalent in age to the Cattamarra Coal Measures, seem more likely, based on the sequences intersected in the closest two deep boreholes BPL2A and BPL4A.

Binningup Estate 2

The final borehole in the Binningup area with palynological data is BPE2. This bore is relatively shallow (TD 150 m), with three of the four samples recovered yielding nonmarine Early Cretaceous palynological assemblages, strongly resembling those obtained from sediments of the Warnbro Group seen elsewhere in the area (Backhouse, 1977; 1981). On this basis, these samples are tentatively associated with the *B. limbata* Zone.

References

Backhouse, J 1977, Palynology of Binningup Estate No.2 borehole: Geological Survey of Western Australia, Paleontology Report 1977/79, 2p.

Backhouse, J 1981, Palynology of Binningup Estate 2 borehole: Geological Survey of Western Australia, Paleontology Report 1981/43, 1p.

Backhouse, J 1986, Biostratigraphy of Binningup Line 3A based on palynology: Geological Survey of Western Australia, Paleontology Report 1986/04, 4p.

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Deeney, AC 1989, Hydrogeology of the Binningup borehole line, Perth Basin, in Professional papers: Geological Survey of Western Australia, Report 25, p. 7–16.

Bunbury area primary school bores

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
CPPS1[(a)]				
–	8.8 – 12.2	DC	barren	(Backhouse, 1974a)
–	17.1 – 36.6	DC	Late Tertiary or Quaternary	(Backhouse, 1974b)
SBPS1				
–	13.2 – 15.8	DC	Early Cretaceous	(Backhouse, 1974d)
–	40.8 – 44.5	DC	indeterminate	(Backhouse, 1974c)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)

Carey Park Primary No. 1 (CPPS1)

Drilled in 1974 to provide water to the Carey Park Primary School, this borehole reached a TD of 45.11 m. Only two ditch cuttings from this borehole were submitted for palynological assessment, with each sample studied by J Backhouse in 1974 and discussed in its own report. The first of these samples, from 8.8 – 12.2 m depth, proved to be entirely barren of palynomorphs (Backhouse, 1974a). The second sample, from 17.1 – 36.6 m, contained only a few angiosperm pollen that were considered late Cenozoic in age (Backhouse, 1974b).

South Bunbury Primary School, bore no. 1 (SBPS1)

Like Carey Park Primary No. 1 bore, the South Bunbury Primary School no. 1 bore was drilled in 1974, and reached a TD of 44.5 m. Again, only two ditch cuttings from this well were assessed palynologically in 1974 by J Backhouse, with each sample discussed in a separate report. The shallowest of these samples, from 13.2 – 15.8 m (Backhouse, 1974d), yielded a relatively diverse assemblage of Early Cretaceous taxa, with the presence of *Ceratosporites equalis* restricting the assemblage to either the *Biretisporites eneabbaensis* or *Balmeiopsis limbata* Spore-Pollen Zones. However, key index taxa such as *Biretisporites eneabbaensis*, *Balmeiopsis limbata* and *Balmeiopsis robusta* are absent from this sample, and the remaining spores provide a mixed signal, with *Contignisporites multimuratus* more regularly considered indicative of the *B. eneabbaensis* Zone, and *Cicatricosisporites* sp. cf. *C. hughesi* found more commonly in the *B. limbata* Zone (Backhouse, 1988). Although this might suggest this assemblage belongs to the enigmatic 'transitional *B. eneabbaensis* – *B. limbata* Zone' biostratigraphic unit seen elsewhere in the study area, it is equally likely that the assemblage can be assigned to a single zone, more likely the *B. limbata* Zone. A reassessment of the slide should be attempted to clarify the age of this sample.

The deepest sample, from 40.8 – 44.5 m, yielded only a small number of fungal spores and a single specimen of spore *C. multimuratus*; as a result, this low yielding assemblage is considered indeterminate (Backhouse, 1974c).

References

Backhouse, J 1974a, A barren sample from Carey Park Primary School borehole — Bunbury: Geological Survey of Western Australia, Paleontology Report 1974/43, 1p.

Backhouse, J 1974b, A further sample from Carey Park Primary School borehole, Bunbury: Geological Survey of Western Australia, Paleontology Report 1974/74, 1p.

Backhouse, J 1974c, Further palynology of South Bunbury Primary School borehole: Geological Survey of Western Australia, Paleontology Report 1974/73, 1p.

Backhouse, J 1974d, Palynology of the South Bunbury Primary School borehole: Geological Survey of Western Australia, Paleontology Report 1974/18, 1p.

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Bunbury (Laporte) Inlet 1–4

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
BI1[(a)]				
–	24	DC	Early Cretaceous	(Backhouse, 1974)
BI2				
–	39	DC	Early Cretaceous	(Backhouse, 1974)
BI3				
–	29.5	DC	Quaternary or Recent	(Backhouse, 1974)
BI4				
–	24.3	DC	Early Cretaceous	(Backhouse, 1974)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)

Line summary

A set of four boreholes was drilled on the western side of the Leschenault Inlet in 1973. These Bunbury (Laporte) Inlet bores were shallow, with TD of 24.1 (BI1), 39 (BI2), 33.1 (BI3), and 29.6 (BI4) m, and all four were completed as observation bores. One ditch cutting, from the base of the hole, was submitted for palynological assessment from each of the Bunbury Inlet boreholes, and the results were reported in a single GSWA Paleontology Report (Backhouse, 1974).

Bunbury (Laporte) Inlet boreholes

None of the Bunbury (Laporte) Inlet boreholes yielded palynological assemblages older than Early Cretaceous. The sample from BI3, at 29.5 m depth, only contained Quaternary pollen, despite being deeper than two of the adjacent holes (BI1 and BI4). This suggests either a thicker surficial unit in that area, or downhole contamination by surface pollen (Backhouse, 1974).

The remaining samples from Bunbury (Laporte) Inlet bores 1, 2 and 4 were considered to be Early Cretaceous in age; however, the report provides few details beyond stating that the assemblages were similar to one another. Presumably, these assemblages are assignable to the *Balmeiopsis limbata* Spore-Pollen Zone, although the slides would need to be re-examined to confirm this. Like many of the Bunbury Trough boreholes, none of these Cretaceous records contains evidence for marine influence.

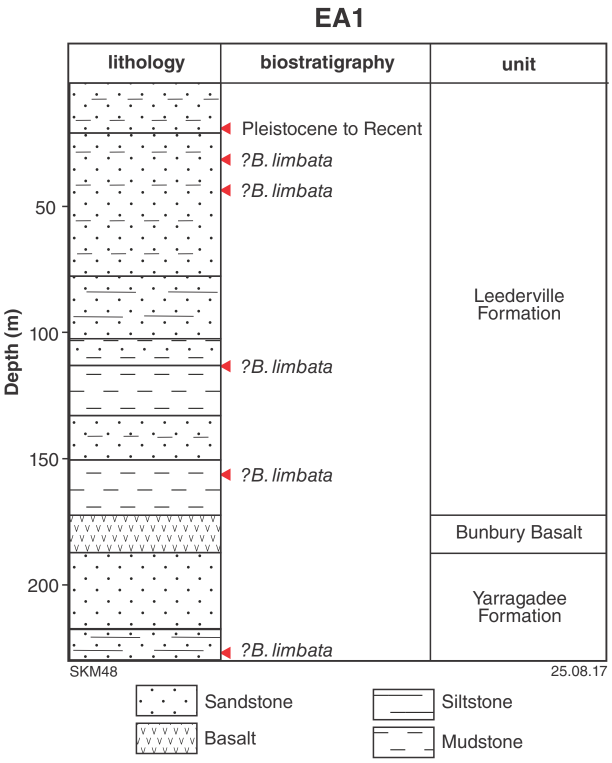
Reference

Backhouse, J 1974, Palynology of the Bunbury Inlet boreholes Nos. 1 to 4: Geological Survey of Western Australia, Paleontology Report 1974/19, 1p.

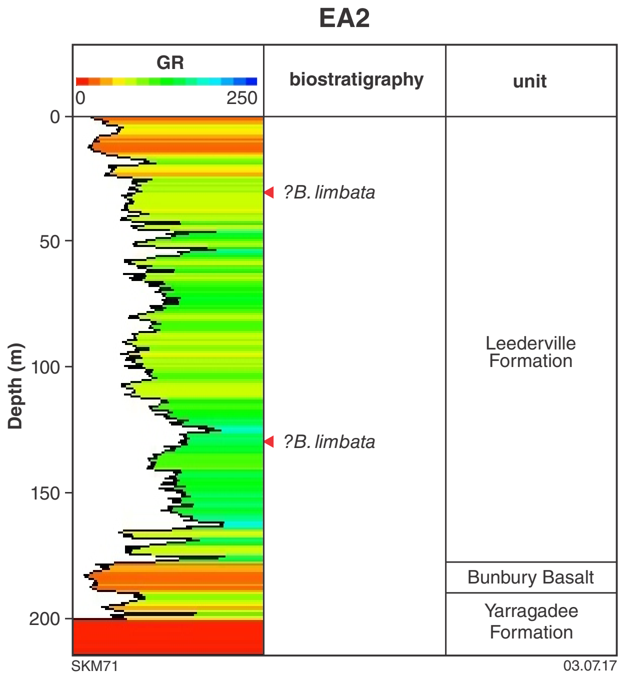
Eaton Line 1 and 2

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
EA1[(a)]				
60	18.3	DC?	Pleistocene to Recent	(Edgell, 1963)
100	30.5	DC?	?*B. limbata*[#]	(Edgell, 1963)
140	42.7	DC?	?*B. limbata*[#]	(Edgell, 1963)
370	112.8	DC?	?*B. limbata*[#]	(Edgell, 1963)
510	155.5	DC?	?*B. limbata*[#]	(Backhouse, 1972)
750	228.6	DC?	?*B. limbata*[#]	(Backhouse, 1972)
EA2				
100–103	30.5 – 31.4	DC	?*B. limbata*[#]	(Ingram, 1967)
425	129.5	DC	?*B. limbata*[#]	(Ingram, 1967)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone



Notes: TD = 228.6 m; lithostratigraphy based on DWER WIR data (AWRC = 61210396); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings



Notes: TD = 213.4 m; lithostratigraphy based on DWER WIR data (AWRC = 61210409); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Eaton line of water bores were drilled progressively over ten years, beginning with EA1 in 1963, followed by EA2 in 1967, and finally EA3 in 1972. Drilled for the State Public Works Department to provide a town water supply for Eaton, just north of Bunbury, EA1 and EA2 were terminated early upon reaching higher-salinity waters below aquifers of suitable water quality.

EA1 and EA2

Eaton Line boreholes 1 and 2 were considerably shallower than EA3, and therefore did not penetrate sediments older than Cretaceous. The shallowest sample from EA1, at 60 ft, contained an assemblage of angiosperm pollen considered Pleistocene to Recent in age (Edgell, 1963); all of the remaining Cretaceous palynofloras intersected in both boreholes were considered Neocomian to Aptian in age, and likely fall within the *Balmeiopsis limbata* Spore-Pollen Zone (Edgell, 1963; Ingram, 1967; Backhouse, 1972). However, although EA1 samples extended to the bottom of the borehole, providing some certainty that no Jurassic section was intersected at all by this water bore, the deepest sample from EA2 was at 425 ft, well short of the 700 ft TD.

References

Backhouse, J 1972, Palynological evidence for the age of the Bunbury Basalt: Geological Survey of Western Australia, Paleontology Report 1972/04, 3p.

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Edgell, HS 1963, Stratigraphic succession in Eaton No. 1 water bore based on palynology: Geological Survey of Western Australia, Paleontology Report 1963/03, 1p.

Ingram, BS 1967, Palynology of Eaton 2: Geological Survey of Western Australia, Paleontology Report 1967/47, 1p.

Eaton Line 3

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
EA3[(a)]				
500	152.4	DC	?*B. limbata*[#]	(Backhouse, 2015)
580	176.8	DC	?*B. limbata*[#]	(Backhouse, 2015)
1620	493.8	DC	*M. florida*^	(Backhouse, 2015)
1680	512.1	DC	*M. florida*^	(Backhouse, 2015)
1700	518.2	DC	*M. florida*^	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone

Line summary

The Eaton line of water bores were drilled progressively over 10 years, beginning with EA1 in 1963, followed by EA2 in 1967, and finally EA3 in 1972. Drilled for the State Public Works Department to provide a town water supply for Eaton, just north of Bunbury, EA1 and EA2 were terminated early upon reaching higher-salinity waters below aquifers of suitable water quality.

EA3

A total of five ditch cuttings from this well were submitted for palynological analysis, from the following depths: 500 ft (152.4 m), 580 ft (176.8 m), 1620 ft (493.8 m), 1680 ft (512.1 m), and 1700 ft (518.2 m). These results were reported in a set of three GSWA Paleontology Reports, with the first two reports by GSWA paleontologist K Grey covering four of the five samples (Grey, 1972a,b). These results were revised and the final sample described by Backhouse (1972). A recent review of these reports was conducted by Backhouse (2015), with the aim of clarifying and modernizing the biostratigraphic interpretations.

Backhouse (1980) considered the samples to fall into three separate groups. The shallowest two samples, from 500 and 580 ft were considered definitely Early Cretaceous in age. Although no zone was formally assigned in the recent review, the observation that the samples are probably from the Warnbro Group suggests a correlation with the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 2015). Both the original description and review noted that the samples represent somewhat unusual Warnbro Group assemblages, with the plentiful coal fragments seen in the coarse fraction suggesting a coal-swamp depositional environment.

The deepest sample, from 1700 ft, was originally considered of 'undoubted Late Jurassic' age. Two other samples from 1620 and 1680 ft contain a mixture of Late Jurassic to Early Cretaceous forms, suggesting the possibility of contamination. The determination of a Late Jurassic, as opposed to Early Cretaceous, age for the deepest sample was based on relative abundances, particularly of inaperturate pollen and the species *Microcachryidites antarcticus*, and on the form of *M. antarcticus* specimens, which are apparently larger than the normal Cretaceous representatives (Backhouse, 1972). Otherwise, the taxa preserved in these sediments are broadly similar, and all are considered to be Late Jurassic to Early Cretaceous forms. The recent review agrees with this interpretation, assigning all three the samples to the *Murospora florida* Spore-Pollen Zone based on the abundance of *Callialasporites dampieri* and presence of (possibly caved) *Murospora florida* (Backhouse, 2015).

References

Backhouse, J 1972, Re-assessment of the palynological results from Eaton No.3: Geological Survey of Western Australia, Paleontology Report 1972/80, 2p.

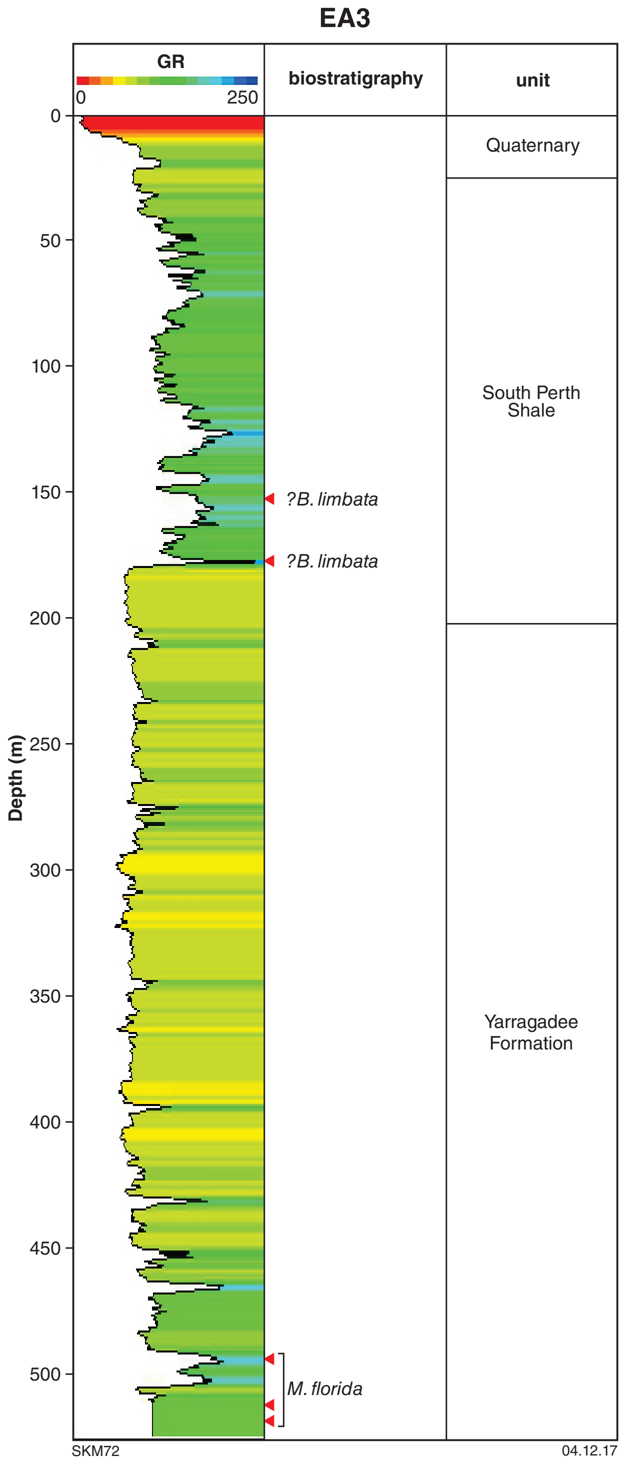
Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Backhouse, J 2015, Review of old palynology reports for 15 boreholes in the southern Perth Basin 1: Backhouse Biostrat Pty Ltd, Perth, Western Australia, Report BB499, 6p. (unpublished).

Grey, K 1972a, Further palynology of Eaton No. 3: Geological Survey of Western Australia, Paleontology Report 1972/65, 3p.

Grey, K 1972b, Palynology of Eaton Bore No. 3: Geological Survey of Western Australia, Paleontology Report 1972/64, 3p.

Helby, R, Morgan, R and Partridge, AP 1987, A palynological zonation of the Australian Mesozoic: Association of Australasian Palaeontologists, Memoir 4, p. 1–94.



Notes: **TD = 518.2 m; lithostratigraphy based on DWER WIR data (AWRC = 61211444); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

Harvey Line 1B

Depth (feet)	Depth (metres)	Sample type	Zone/age(b)	Report
HL1B(a)				
–	89	SWC	?*B. limbata*# or 'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	112	SWC	not processed	(Backhouse, 1983)
–	146	SWC	not processed	(Backhouse, 1983)
–	166	SWC	'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	174	SWC	'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	189	SWC	not processed	(Backhouse, 1983)
–	194	SWC	not processed	(Backhouse, 1983)
–	225	SWC	not processed	(Backhouse, 1983)
–	249	SWC	?upper *C. torosa*^	(Backhouse, 2012)
–	288	SWC	barren	(Backhouse, 1983)
–	347	SWC	?upper *C. torosa*^	(Backhouse, 2012)
–	362	SWC	barren	(Backhouse, 1983)
–	423	SWC	?upper *C. torosa*^	(Backhouse, 2012)
–	450	SWC	not processed	(Backhouse, 1983)
–	486	SWC	?upper *C. torosa*^	(Backhouse, 2012)
–	512	SWC	indeterminate	(Backhouse, 2012)
–	548	SWC	not processed	(Backhouse, 1983)
–	561	SWC	?upper *C. torosa*^	(Backhouse, 2012)
–	590	SWC	?upper *C. torosa*^	(Backhouse, 2012)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone

Line summary

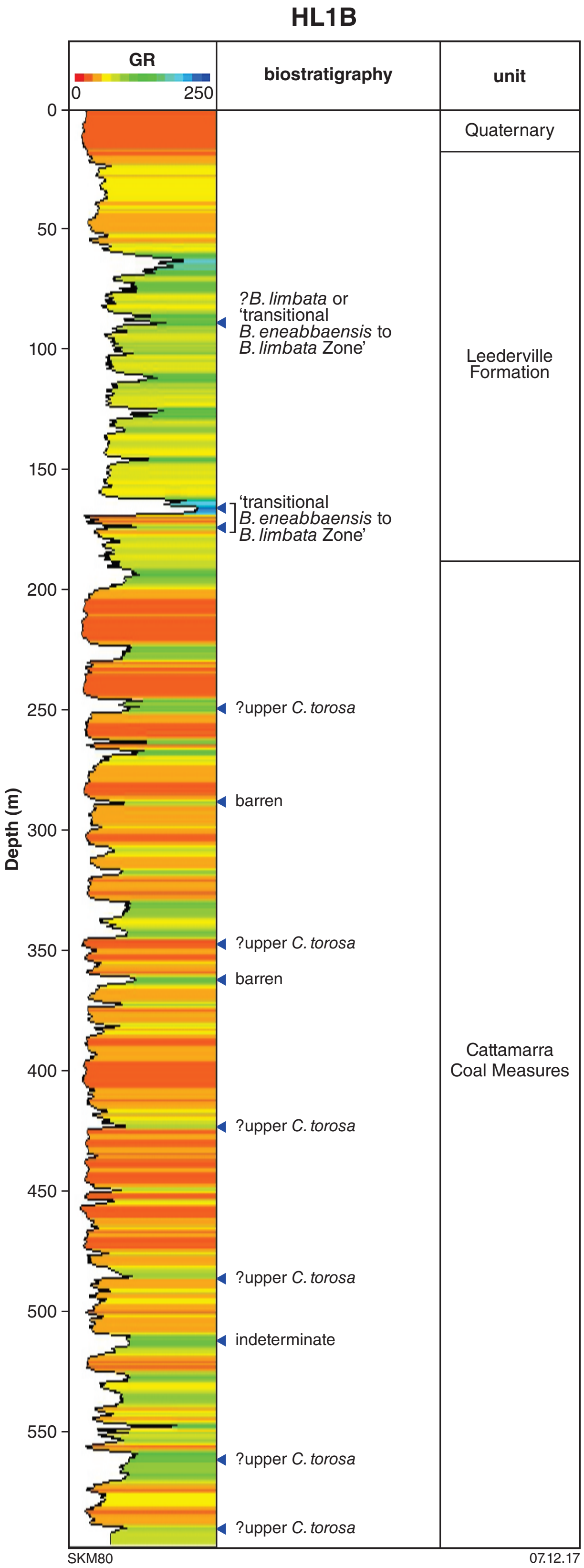
The Harvey Line is a set of eight water bores drilled on four sites (HL1–4). Drilled between 1982 and 1985 by GSWA's hydrogeology division, the well sites extend in an west–east direction across the onshore part of the basin east from Lake Preston 1 and just north of Preston 1 (Deeney, 1989). The initial set of holes on these sites, designated a 'W' suffix, were drilled as water-supply bores, whereas the later holes, suffixed 'A', were drilled for exploratory purposes. Two additional exploratory bores were drilled to solve specific borehole issues: HL1B was constructed after HL1A encountered severe drilling difficulties and became the main exploration section at this site, whereas HL4B was a short bore drilled to provide additional monitoring.

The four primary exploratory holes reached TD of 605 m (HL1B), 810 m (HL2A), 602.5 m (HL3A) and 600 m (HL4A), respectively. In each hole, ditch cuttings were collected at 3 m intervals, and roughly 20 sidewall cores were obtained from each bore; a suite of geophysical wireline logs (including gamma ray and resistivity logs) was also obtained in each hole. Samples from all four exploration boreholes were initially analysed between 1983 and 1985, with results reported informally in a series of GSWA Paleontology Reports. The slides from HL1–3 stored in the GSWA palynology collection were later reviewed in 2012 as part of preparations to drill the GSWA Harvey 1 well (Backhouse, 2012).

HL1B

A total of 21 sidewall cores from HL1B was initially submitted for palynological analysis (Backhouse, 1983). Of these, seven samples were considered lithologically unsuitable, and an additional two samples were found to be barren after processing. Two samples cannot be accounted for, as they are mentioned neither in the initial informal paleontology report, nor in any later palynological reviews; therefore, the depths and ages of these samples are unknown.

In the original sample review, the 14 sidewall cores were divided palynologically into two distinct assemblages. Samples from 89, 166 and 174 m preserve palynomorph assemblages containing taxa typical of both the *Balmeiopsis limbata* and *Biretisporites eneabbaensis* Spore-Pollen Zones, although the 166 and 174 m samples are far more diverse and therefore more easily defined than the shallowest sample. The two deeper samples also preserved a number of dinoflagellates of the genus *Moorodinium*, most species of which were considered by Backhouse (1988) to belong to the *Fusiformacysta tumida* Dinocyst Zone, which was correlated with the older *B. eneabbaensis* Zone. However, Backhouse (1988) did not consider these dinoflagellates particularly age diagnostic, and they are of greater interest as environmental indicators because they are considered indicative of freshwater or brackish aquatic (lacustrine or lagoonal) environments. In his later review of the HL1B samples, Backhouse



Notes: TD = 605 m; lithostratigraphy based on Deeney (1989); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores

(2012) considered these three samples as representative of the 'transitional*B. eneabbaensis – B. limbata* Zone' assemblage commonly recorded in the southern Perth Basin.

The remaining samples, covering the interval from 249 to 590 m, yielded low-diversity assemblages dominated by *Classopollis* pollen and containing no dinoflagellates. In the original description, these assemblages were assigned to the upper part of Filatoff's (1975) *Classopollis chateaunovi* Assemblage Zone based on the presence of *Nevesisporites vallatus* and *Ischyosporites variegatus*, both of which first appear in this part of the *C. chateaunovi* Zone; Helby et al. (1987) equated this part of Filatoff's (1975) zone to their *Callialasporites turbatus* Spore-Pollen Zone. However, the 2012 reassessment of these samples instead suggested an affiliation to the upper *Corollina torosa* Spore-Pollen Zone based predominantly on the extremely high percentages of *Classopollis* spp. pollen in the samples (67–94%), although it was also considered that the section could represent a *Classopollis*-rich horizon within the *C. turbatus* Zone specific to the southern Perth Basin.

Based on the palynological studies, the Jurassic–Cretaceous unconformity falls somewhere between 174 and 249 m in HL1B. This inference is also followed in hydrogeological studies of this borehole, as Deeney (1989) placed the unconformity at 188 m depth. Deeney interpreted the Jurassic section below this unconformity to correspond to the 'Cattamarra Member of the Cockleshell Gully Formation' (now the Cattamarra Coal Measures) based on both palynological and lithological features. However, the *C. torosa* Zone is not thought to coincide with deposition of the Cattamarra Coal Measures in the northern Perth Basin, and this zone normally coincides with deposition of the Eneabba Formation. Interestingly, both carbonaceous shales and coal were recovered in cuttings in HL1B, even though such organic-rich lithologies are rare in the Eneabba Formation within the northern Perth Basin. The same association of coaly lithologies with *C. torosa* Zone assemblages can also be seen in the MARC01 borehole between 410 and 1410 m.

References

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Harvey Line 2–4

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
HL2A[(a)]				
–	97.5	SWC	'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	115.5	SWC	'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	146	SWC	'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	233	SWC	barren	(Backhouse, 1983a)
–	254.5	SWC	barren	(Backhouse, 1983a)
–	268.25	SWC	barren	(Backhouse, 1983a)
–	305.5	SWC	not processed	(Backhouse, 1983a)
–	473	SWC	barren	(Backhouse, 1983a)
–	584	SWC	not processed	(Backhouse, 1983a)
–	594	SWC	barren	(Backhouse, 1983a)
–	606.5	SWC	barren	(Backhouse, 1983a)
–	697.5	SWC	not processed	(Backhouse, 1983a)
–	708.5	SWC	not processed	(Backhouse, 1983a)
–	734.5	SWC	not processed	(Backhouse, 1983a)
–	755.5	SWC	not processed	(Backhouse, 1983a)
–	801	SWC	barren	(Backhouse, 1983a)
HL3A				
–	61	SWC	?*B. limbata*[#] or 'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	66	SWC	barren	(Backhouse, 1983b)
–	78.5	SWC	?*B. limbata*[#] or 'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	97.5	SWC	not processed	(Backhouse, 1983b)
–	130.5	SWC	?*B. limbata*[#] or 'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	145	SWC	?*B. limbata*[#] or 'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	150.5	SWC	not processed	(Backhouse, 1983b)
–	182	SWC	?*B. limbata*[#] or 'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	193	SWC	not processed	(Backhouse, 1983b)
–	193.5	SWC	probably 'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 2012)
–	204	SWC	not processed	(Backhouse, 1983b)
–	228.5	SWC	not processed	(Backhouse, 1983b)
–	257	SWC	not processed	(Backhouse, 1983b)
–	271	SWC	not processed	(Backhouse, 1983b)
–	292	SWC	not processed	(Backhouse, 1983b)
–	321.5	SWC	not processed	(Backhouse, 1983b)
–	358	SWC	not processed	(Backhouse, 1983b)
–	397.5	SWC	not processed	(Backhouse, 1983b)
–	437	SWC	not processed	(Backhouse, 1983b)
–	456	SWC	not processed	(Backhouse, 1983b)
–	483.5	SWC	not processed	(Backhouse, 1983b)
–	582.5	SWC	not processed	(Backhouse, 1983b)
–	583	SWC	not processed	(Backhouse, 1983b)
–	593	SWC	not processed	(Backhouse, 1983b)
–	593.5	SWC	not processed	(Backhouse, 1983b)
–	594	SWC	not processed	(Backhouse, 1983b)

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
–	598.5	SWC	not processed	(Backhouse, 1983b)
HL4A				
–	11.0 – 86.5	SWC (x 26)	not processed	(Backhouse, 1985)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: #Backhouse (1988) Spore–Pollen Zone

Line summary

The Harvey Line is a set of eight water bores drilled on four sites (HL1–4). Drilled between 1982 and 1985 by GSWA's hydrogeology division, the well sites extend in an west–east direction across the onshore part of the basin east from Lake Preston 1 and just north of Preston 1 (Deeney, 1989). The initial set of holes on these sites, designated a 'W' suffix, were drilled as water–supply bores, whereas the later holes, suffixed 'A', were drilled for exploratory purposes. Two additional exploratory bores were drilled to solve specific borehole issues: HL1B was constructed after HL1A encountered severe drilling difficulties and became the main exploration section at this site, whereas HL4B was a short bore drilled to provide additional monitoring.

The four primary exploratory holes reached TD of 605 m (HL1B), 810 m (HL2A), 602.5 m (HL3A) and 600 m (HL4A), respectively. In each hole, ditch cuttings were collected at 3 m intervals, and roughly 20 sidewall cores were obtained from each bore; a suite of geophysical wireline logs (including gamma ray and resistivity logs) was also obtained in each hole. Samples from all four exploration boreholes were initially analysed between 1983 and 1985, with results reported informally in a series of GSWA Paleontology Reports. The slides from HL1–3 stored in the GSWA palynology collection were later reviewed in 2012 as part of preparations to drill the GSWA Harvey 1 well (Backhouse, 2012).

HL2A, HL3A and HL4

Unfortunately, all 26 of the sidewall cores submitted for palynological analysis from HL4A were considered too oxidized to process, and as a result no age data have been obtained from this borehole (Backhouse, 1985).

HL2A and HL3A both yielded palynomorphs and all samples were Early Cretaceous in age; specifically, assemblages of the 'transitional *Biretisporites eneabbaensis – Balmeoipsis limbata* Zone' also seen in HL1A (Backhouse, 2012). Although no Jurassic assemblages or indications of such assemblages were obtained, for both holes more than half of the deepest section contained only barren samples and therefore have no biostratigraphic control — this includes sections from 146 m through to 810 m (TD) for HL2A, and 193.5 m to 603 m (TD) in HL3A. Therefore, it seems possible that both bores intersected Jurassic (probably Early Jurassic) sediments, but there is no evidence to support this assumption.

In the case of HL2A, Deeney (1989) considered the Jurassic–Cretaceous unconformity to lie at 203 m depth, likely based on lithological descriptions and geophysical well logs. Interestingly, Deeney (1989) interpreted both the presence of both the 'Cattamarra Member' and 'Eneabba Member' (both now raised to formation status) of the 'Cockleshell Gully Formation' present in this hole, with the 'Cattamarra Member' extending from 203 to 241 m depth, and the 'Eneabba Member' extending throughout the rest of the borehole. For HL3A, Deeney (1989) interpreted the Jurassic–Cretaceous unconformity at 204 m depth, with only the 'Eneabba Member' (interpreted here as a succession equivalent to the Eneabba Formation) beneath this break. Deeney (1989) interpreted the section in HL4A to pass from the Lower Cretaceous Leederville Formation into an equivalent of the Lower Jurassic Eneabba Formation, with this unconformity inferred at 24 m depth based entirely on a combination of intersected lithology and geophysical log interpretations. Considering the lack of biostratigraphic information in these borehole sections, such interpretations are unproven but possible, with additional sampling likely required to clarify the stratigraphy in this borehole and along the Harvey Line in general.

References

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Backhouse, J 1983b, Palynology of Harvey Line 3A: Geological Survey of Western Australia, Paleontology Report 1983/19, 3p.

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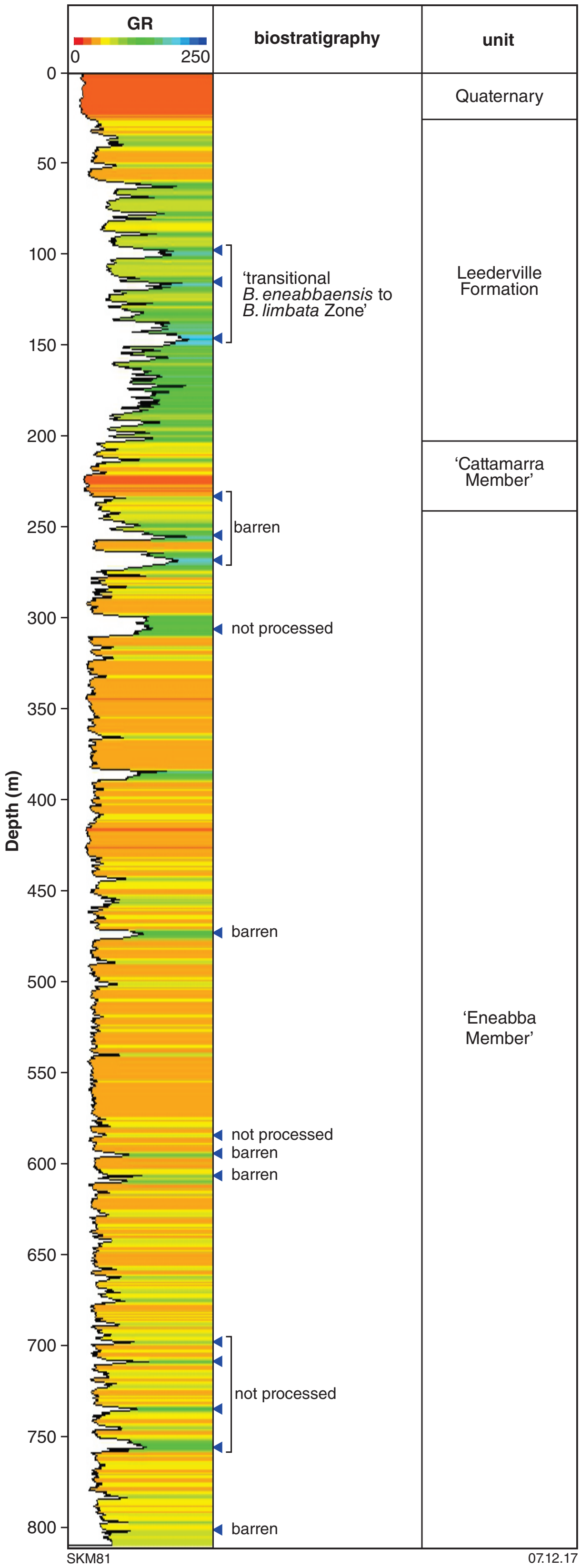
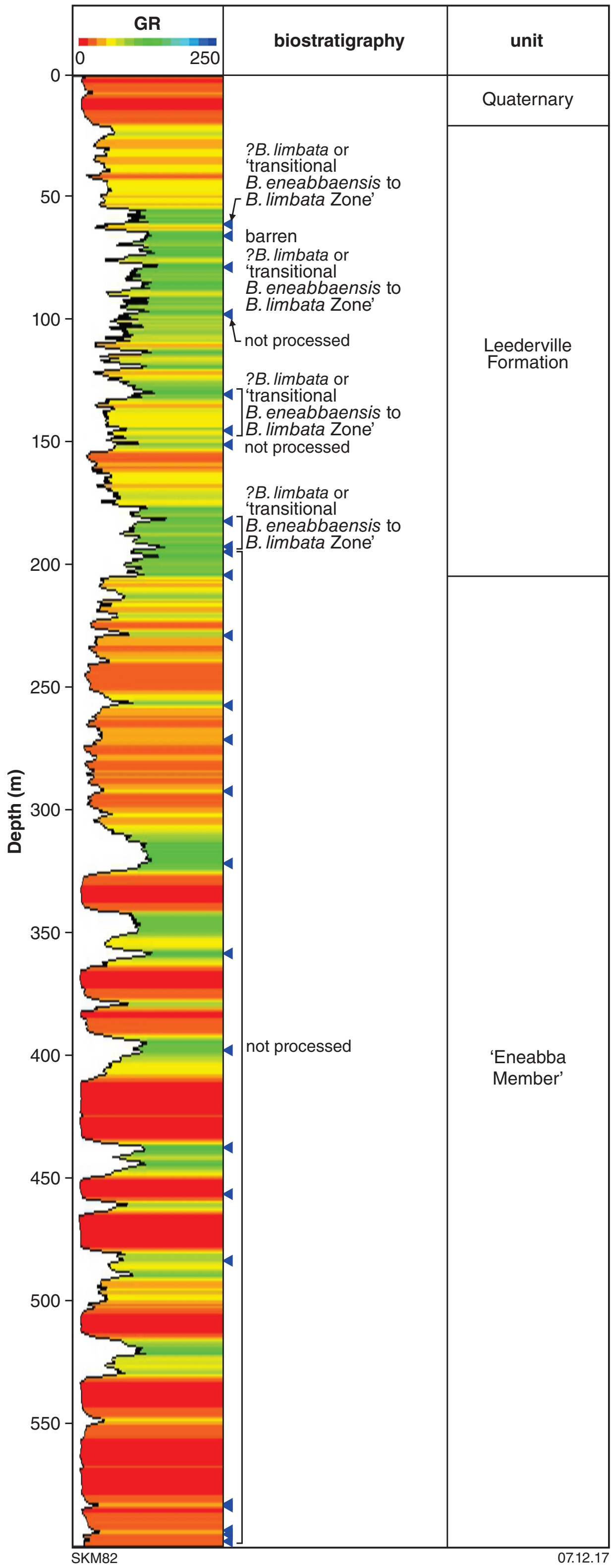
Deeney, AC 1989, Hydrogeology of the Harvey Borehole Line, Perth Basin, *in* Professional papers: Geological Survey of Western Australia, Report 26, p. 59–68.

HL2A



Notes: **TD = 810 m; lithostratigraphy based on Deeney (1989); quoted biostratigraphic units are spore–pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**

HL3A



Notes: **TD = 602.5 m; lithostratigraphy based on Deeney (1989); quoted biostratigraphic units are spore–pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**

Harvey Water Table boreholes

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
HWT1.5[(a)]				
–	11.42 – 12.19	CC	Late Tertiary or Holocene	(Backhouse, 1975b)
–	16.76 – 17.52	CC	barren	(Backhouse, 1975b)
–	22.09 – 22.86	CC	Early Cretaceous	(Backhouse, 1975b)
HWT1.6				
–	9.14 – 9.9	CC	barren	(Backhouse, 1975c)
–	16.0 – 16.76	CC	Late Tertiary or Holocene	(Backhouse, 1975c)
–	25.9 – 26.66	CC	Early Cretaceous	(Backhouse, 1975c)
–	27.42 – 28.18	CC	Early Cretaceous	(Backhouse, 1975c)
–	28.95 – 29.75	CC	barren	(Backhouse, 1975c)
HWT1.9				
–	8.38 – 9.14	CC	barren	(Backhouse, 1975a)
–	11.42 – 12.11	CC	Holocene or near Holocene	(Backhouse, 1975a)
–	15.24 – 16.0	CC	Holocene or near Holocene	(Backhouse, 1975a)
–	26	CC	Early Cretaceous	(Backhouse, 1975a)
–	29	CC	*?B. limbata*[#]	(Backhouse, 1975a)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone

Harvey Water Table boreholes

Three Harvey Water Table boreholes (officially known as HWT 1.5/75, HWT 1.6/75 and HWT 1.9/75) were drilled in 1975, each less than 30 m deep. Interestingly for shallow boreholes, all three have conventional core in addition to cuttings, making the palynological results from these bores more robust than those from other shallow water bores. Three core samples from HWT 1.5/75, and five each from HWT 1.6/75 and HWT 1.9/75, were submitted for palynological analysis, with the results reported in three separate GSWA Paleontology Reports (Backhouse, 1975a–c). All three boreholes have late Neogene or Quaternary assemblages overlying Early Cretaceous assemblages, and none of the bores appears to have penetrated into Jurassic or older strata. None of the Cretaceous assemblages shows evidence for marine influence, and only one, the 29 m sample from HWT1.9, could be linked to the *Balmeiopsis limbata* Spore-Pollen Zone, albeit tentatively. The Quaternary assemblage seen in HWT1.9 has the most tightly constrained age, and is interpreted as Holocene or near Holocene. The assemblages from HWT1.5 and 1.6 were stated to be 'late Tertiary to Quaternary', which is here interpreted to equate to Pliocene to Recent. For each of the three boreholes, an unconformity between Quaternary surficial sediments and underlying Cretaceous section falls at around 20 m depth — between 12.2 and 22.1 m in HWT 1.5/75, between 16.8 and 25.9 m in HWT 1.6/75, and between 16.0 and 26.0 m in HWT 1.9/75.

References

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Backhouse, J 1975b, Palynology of Harvey Water Table borehole No. 1.5/75: Geological Survey of Western Australia, Paleontology Report 1975/48, 1p.

Backhouse, J 1975c, Palynology of Harvey Water Table borehole No. 1.6/75: Geological Survey of Western Australia, Paleontology Report 1975/47, 1p.

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Harvey Irrigation A–H

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age[(b)]*	*Report*
HIA[(a)]				
–	36	DC	barren	(Backhouse, 1980)
–	39	DC	barren	(Backhouse, 1980)
HIB				
–	18	SWC	barren	(Backhouse, 1980)
–	22	SWC	barren	(Backhouse, 1980)
–	25	SWC	barren	(Backhouse, 1980)
–	31.8	SWC	Early Cretaceous	(Backhouse, 1980)
–	33–36	DC	Early Cretaceous	(Backhouse, 1980)
–	111–114	DC	barren	(Backhouse, 1980)
HIC				
–	25	SWC	barren	(Backhouse, 1980)
–	33–36	DC	barren	(Backhouse, 1980)
–	39	SWC	barren	(Backhouse, 1980)
–	86	SWC	?Early Cretaceous	(Backhouse, 1980)
–	94.5	SWC	Late Jurassic to Early Cretaceous	(Backhouse, 1980)
–	93–96	DC	*B. limbata*[#]	(Backhouse, 1980)
HID				
–	37.5	SWC	Early Cretaceous	(Backhouse, 1980)
–	81	SWC	barren	(Backhouse, 1980)
HIF				
–	21	SWC	barren	(Backhouse, 1980)
–	37.5	SWC	not processed	(Backhouse, 1980)
–	42	SWC	not processed	(Backhouse, 1980)
–	61.5	SWC	barren	(Backhouse, 1980)
HIG				
–	35	SWC	Early Cretaceous	(Backhouse, 1980)
–	47	SWC	indeterminate	(Backhouse, 1980)
–	93	SWC	?Late Jurassic to Early Cretaceous	(Backhouse, 1980)
HIH				
–	48	SWC	?Early Cretaceous	(Backhouse, 1980)
–	61.5	SWC	?Early Cretaceous	(Backhouse, 1980)
–	79.5	SWC	?Early Cretaceous	(Backhouse, 1980)

NOTES:

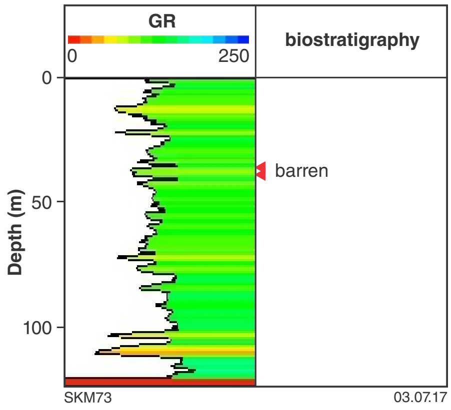
(a) Well or bore name abbreviations taken from Appendix 1

(b) Age or zone taken from most recent study or review

Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)

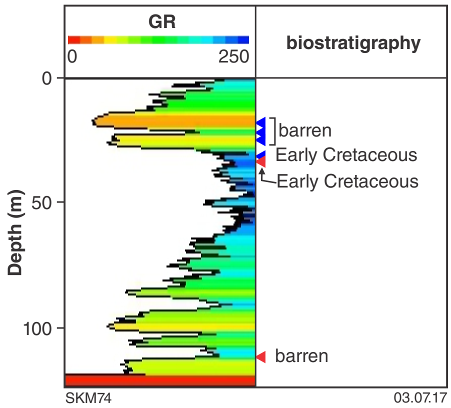
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone

HIA



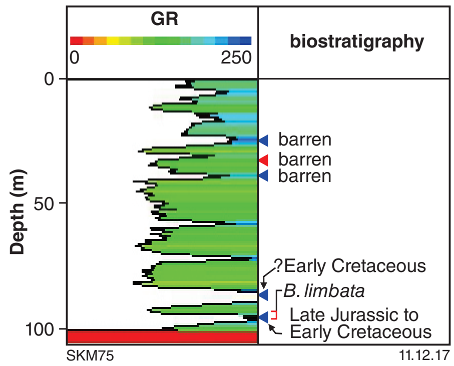
Notes: **TD = 122 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

HIB



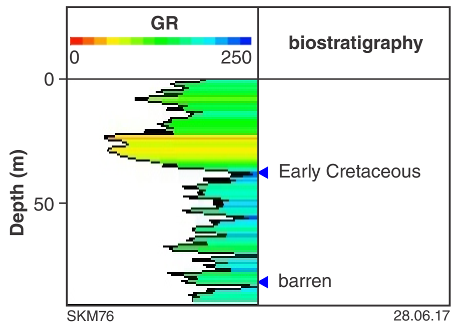
Notes: **TD = 122 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores**

HIC



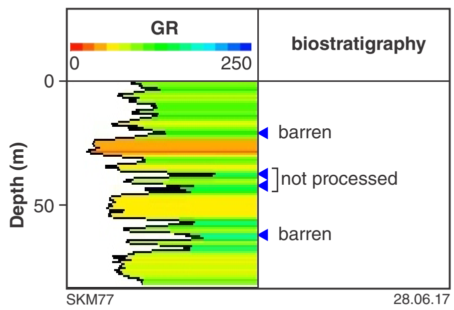
Notes: **TD = 104 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores**

HID

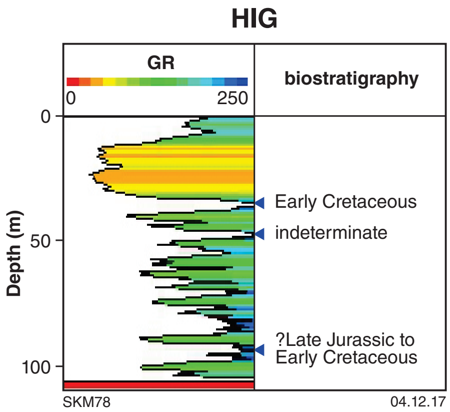


Notes: **TD = 88 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**

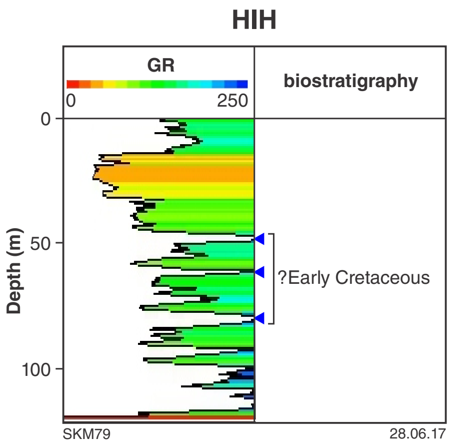
HIF



Notes: **TD = 81 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**



Notes: **TD = 107 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**



Notes: **TD = 119 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores**

Harvey Irrigation bores

The Harvey Irrigation water bore line comprises seven boreholes drilled in 1980. Samples submitted for palynological analyses were a mixture of sidewall cores and ditch cuttings, and all results were reported in a single GSWA Paleontology Report (Backhouse, 1980). Although bores A and F contained only barren samples, the other bores in this line yielded Early Cretaceous palynomorphs, with no indications of younger (Quaternary) strata, and no evidence for marine influence in the assemblages. All of these Early Cretaceous assemblages were considered to be Late Neocomian to Aptian in age, and therefore most likely represent the *Balmeiopsis limbata* Spore-Pollen Zone, although the slides would need to be reassessed to confirm this.

The original report gave a generalized Late Jurassic to Early Cretaceous age for samples in bores G and H due to the nondiagnostic nature of the individual species preserved. However, the assemblages preserved in the HIH samples as a whole were considered reminiscent of the Warnbro Group, thereby suggesting an Early Cretaceous age for the succession in this borehole. The same Early Cretaceous age is also likely for the samples from HIG, especially based on the recorded presence of *Reticuloidosporites arcus* at 35 m. Backhouse (1988) later considered this species to only occur within his Early Cretaceous *Biretisporites eneabbaensis* and *B. limbata* Spore-Pollen Zones, although a Late Jurassic age is still possible for the deeper samples.

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Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Harvey Shallow boreholes

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
HS1A[(a)]				
–	54	DC	Early Cretaceous	(Backhouse, 1983c)
HS2A				
–	27	DC	Early Cretaceous	(Backhouse, 1983c)
HS3A				
–	24–27	DC	barren	(Backhouse, 1983a)
HS4A				
–	0–3	DC	Holocene	(Backhouse, 1983c)
–	27	DC	Holocene	(Backhouse, 1983c)
HS5A				
–	27–30	DC	Miocene to Recent	(Backhouse, 1983a)
HS6A				
–	30	DC	*B. limbata*[#]	(Backhouse, 1983a)
HS7A				
–	30	DC	barren	(Backhouse, 1983a)
HS8A				
–	38	DC	Early Cretaceous	(Backhouse, 1983a)
HS9A				
–	33	DC	*B. limbata*[#]	(Backhouse, 1983a)
HS10A				
–	33–36	DC	*B. limbata*[#]	(Backhouse, 1983a)
HS11A				
–	34–36	DC	*B. limbata*[#]	(Backhouse, 1982b)
HS12A				
–	36–39	DC	*?B. limbata*[#]	(Backhouse, 1982b)
HS13A				
–	36–39	DC	indeterminate	(Backhouse, 1982b)
HS14A				
–	30–33	DC	indeterminate	(Backhouse, 1982b)
HS15A				
–	33–36	DC	*B. limbata*[#] / *B. jaegeri*[‡]	(Backhouse, 1982b)

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age(b)*	*Report*
HS16A				
–	24–27	DC	Pliocene to Quaternary	(Backhouse, 1982b)
–	33–36	DC	*?B. limbata*#	(Backhouse, 1982b)
HS17A				
–	27–30	DC	Early Cretaceous	(Backhouse, 1982b)
HS18A				
–	30–33	DC	Pliocene or more probably Quaternary	(Backhouse, 1982b)
HS19A				
–	33–36	DC	barren	(Backhouse, 1982b)
HS20A				
–	24–27	DC	*?A. alata*‡	(Backhouse, 1982b)
HS21A				
–	24–27	DC	*B. limbata*# / *A. alata*‡	(Backhouse, 1982c)
HS22A				
–	18–21	DC	almost barren	(Backhouse, 1982c)
–	42–45	DC	almost barren	(Backhouse, 1982c)
HS23A				
–	30–35.6	DC	*B. jaegeri*‡	(Backhouse, 1982d)
HS24A				
–	33–36	DC	no older than *P. lowryi*‡	(Backhouse, 1982d)
HS25A				
–	30–33	DC	*?P. lowryi*‡	(Backhouse, 1982d)
HS26A				
–	24–27	DC	indeterminate	(Backhouse, 1982c)
HS27A				
–	18–21	DC	Pleistocene or Recent	(Backhouse, 1982d)
–	27–30	DC	indeterminate	(Backhouse, 1982d)
HS28B				
–	36–39	DC	*A. alata*‡	(Backhouse, 1982d)
–	42–45	DC	*?B. limbata*#	(Backhouse, 1982d)
HS29A				
–	33–36	DC	barren	(Backhouse, 1982d)
HS31A				
–	30–33	DC	Miocene or younger	(Backhouse, 1982e)

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
HS33A				
–	30–33	DC	*B. limbata*[#]	(Backhouse, 1982e)
HS34A				
–	33–36	DC	*B. limbata*[#]	(Backhouse, 1982e)
HS35A				
–	30–33	DC	barren	(Backhouse, 1982e)
HS36A				
–	27–30	DC	*B. limbata*[#] / ?*B. jaegeri*[‡]	(Backhouse, 1982e)
HS37B				
–	33–36	DC	barren	(Backhouse, 1982e)
HS39A				
–	36–38	DC	upper *P. lowryi*[‡] or lower *A. alata*[‡]	(Backhouse, 1982e)
HS40A				
–	24–27	DC	upper *P. lowryi*[‡] or lower *A. alata*[‡]	(Backhouse, 1982e)
–	27–30	DC	upper *P. lowryi*[‡] or lower *A. alata*[‡]	(Backhouse, 1982e)
HS41A				
–	27–30	DC	*F. monilifera*[‡]	(Backhouse, 1982f)
HS42A				
–	39–42	DC	barren	(Backhouse, 1982f)
HS43A				
–	27–30	DC	*B. jaegeri*[‡]	(Backhouse, 1982f)
HS45A				
–	27–30	DC	barren	(Backhouse, 1982f)
HS46A				
–	27–30	DC	?*P. lowryi*[‡]	(Backhouse, 1982f)
HS47C				
–	18–22	DC	*F. monilifera*[‡]	(Backhouse, 1982f)
HS48A				
–	30–42	DC	Early Cretaceous	(Backhouse, 1982f)
HS49A				
–	15–18	DC	Late Tertiary to Quaternary	(Backhouse, 1982f)
HS50A				
–	24–30	DC	?*P. lowryi*[‡]	(Backhouse, 1981)

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
HS51A				
–	17–30	DC	*A. alata*‡	(Backhouse, 1982a)
HS52A				
–	27–30	DC	?*P. lowryi*‡	(Backhouse, 1981)
HS53A				
–	24–27	DC	Mesozoic indeterminate	(Backhouse, 1981)
–	27–30	DC	*B. jaegeri*‡ or possibly ?*P. lowryi*‡	(Backhouse, 1981)
HS54				
–	21–24	DC	?*P. lowryi*‡	(Backhouse, 1981)
–	24–30	DC	?*P. lowryi*‡	(Backhouse, 1981)
HS55A				
–	24–30	DC	?*P. lowryi*‡	(Backhouse, 1981)
HS56A				
–	24–26	DC	?*P. lowryi*‡	(Backhouse, 1981)
–	27–28	DC	?*P. lowryi*‡	(Backhouse, 1981)
HS57A				
–	27–30	DC	*B. jaegeri*‡ or possibly ?*P. lowryi*‡	(Backhouse, 1981)
HS58A				
–	15–18	DC	upper *F. monilifera*‡ (or *D. davidii*†?)	(Backhouse, 1983b)
HS59A				
–	15–18	DC	*B. limbata*# / *K. scrutillinum*‡ to *B. jaegeri*‡	(Backhouse, 1983b)
HS60A				
–	15–21	DC	?Early Cretaceous	(Backhouse, 1983b)
HS61A				
–	24–27	DC	*B. limbata*# / *P. lowryi*‡ to *A. alata*‡	(Backhouse, 1983b)
HS62A/B				
–	24–27	DC	[no / confused data presented in report]	(Backhouse, 1983b)
–	27–30	DC	[no / confused data presented in report]	(Backhouse, 1983b)
–	30–33	DC	[no / confused data presented in report]	(Backhouse, 1983b)
HS63A				
–	30–33	DC	[no / confused data presented in report]	(Backhouse, 1983b)
HS64A				
–	39.0 – 41.5	DC	[no / confused data presented in report]	(Backhouse, 1983b)

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*(b)	*Report*
HS65A				
–	12	DC	Pliocene–Pleistocene	(Backhouse, 1983b)
–	30	DC	indeterminate	(Backhouse, 1983b)
HS66A				
–	27–30	DC	[no / confused data presented in report]	(Backhouse, 1983b)
HS67A				
–	31–33	DC	barren	(Backhouse, 1983b)
HS68A				
–	39–42	DC	*?B. limbata*#	(Backhouse, 1983b)
HS69A				
–	24–27	DC	barren	(Backhouse, 1983c)
HS70A				
–	51	DC	?Early Cretaceous	(Backhouse, 1983b)
HS71A				
–	33–36	DC	Pliocene–Pleistocene	(Backhouse, 1983b)
HS72A				
–	27	DC	barren	(Backhouse, 1983b)
HS73A				
–	27–30	DC	barren	(Backhouse, 1983c)
HS74A				
–	33	DC	Early Cretaceous	(Backhouse, 1983c)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: †Helby et al. (1987) Dinocyst Zone; #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

Harvey Shallow boreholes

Seventy Harvey Shallow boreholes, drilled in the Harvey area between 1981 and 1983, had ditch cuttings submitted for palynological analyses. In most of these bores, only a single ditch cutting was submitted for study, although a handful of bores had two or three ditch cuttings analysed. The results were reported in a series of 10 informal GSWA Paleontology Reports (Backhouse, 1981, 1982a–f, 1983a–c). For 12 of these bores, submitted samples yielded no palynomorphs and no age data were therefore obtained; the results for two boreholes were erroneously excluded from the reports and it is unclear whether these samples were barren or if any age data were obtained. A further 11 boreholes yielded only Quaternary palynomorphs and appear to not have penetrated through surficial cover, and the remaining 45 boreholes yielded only Cretaceous assemblages and appear not to have penetrated below Cretaceous strata. The lack of assemblages older than the Cretaceous is not surprising for this set of boreholes as none is deeper than 55 m, and most are less than 40 m deep. Within the boreholes that reached Cretaceous strata, around two-thirds showed evidence for marine conditions during deposition, although a small number (HS11, 34, 59A) also show evidence for lagoonal or backswamp conditions.

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Kemerton Line 1D

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
KE1D[(a)]				
–	66	DC	*B. limbata*[#] (transitional?)	(Backhouse, 1989a)
–	115	SWC	*B. limbata*[#]	(Backhouse, 1989a)
–	120	DC	*B. limbata*[#]	(Backhouse, 1989a)
–	152	SWC	*B. limbata*[#] (transitional?)	(Backhouse, 1989a)
–	201	DC	?*C. turbatus*^	(Backhouse, 1989a)
–	243	DC	?*C. turbatus*^	(Backhouse, 1989a)
–	345	DC	*C. turbatus*^	(Backhouse, 1989a)
–	360	DC	*C. turbatus*^	(Backhouse, 1989a)
–	399	DC	*C. turbatus*^	(Backhouse, 1989a)
–	426	DC	*C. turbatus*^	(Backhouse, 1989a)
–	471	DC	*C. turbatus*^	(Backhouse, 1989a)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone

Line summary

The Kemerton Line consists of four exploratory boreholes on two sites, drilled in June–July 1989 to augment knowledge of deep groundwater resources in the Kemerton–Australind area (Commander, 1989). Shallow (name suffixed ‘S’) and deep (name suffixed ‘D’) holes were drilled at each site, but palynological analyses were only conducted on samples from the deep drilling. Both deep boreholes were drilled using a mud rotary rig, with KE1D drilled to a TD of 474 m and KE2D drilled to a TD of 501 m; both were completed after drilling and are presently operating as water bores. Ditch cuttings were collected at 3 m intervals from each of the deep bores, and sidewall cores were also cut, although KE1D had poor core recovery due to the loss of the sidewall-core gun during drilling.

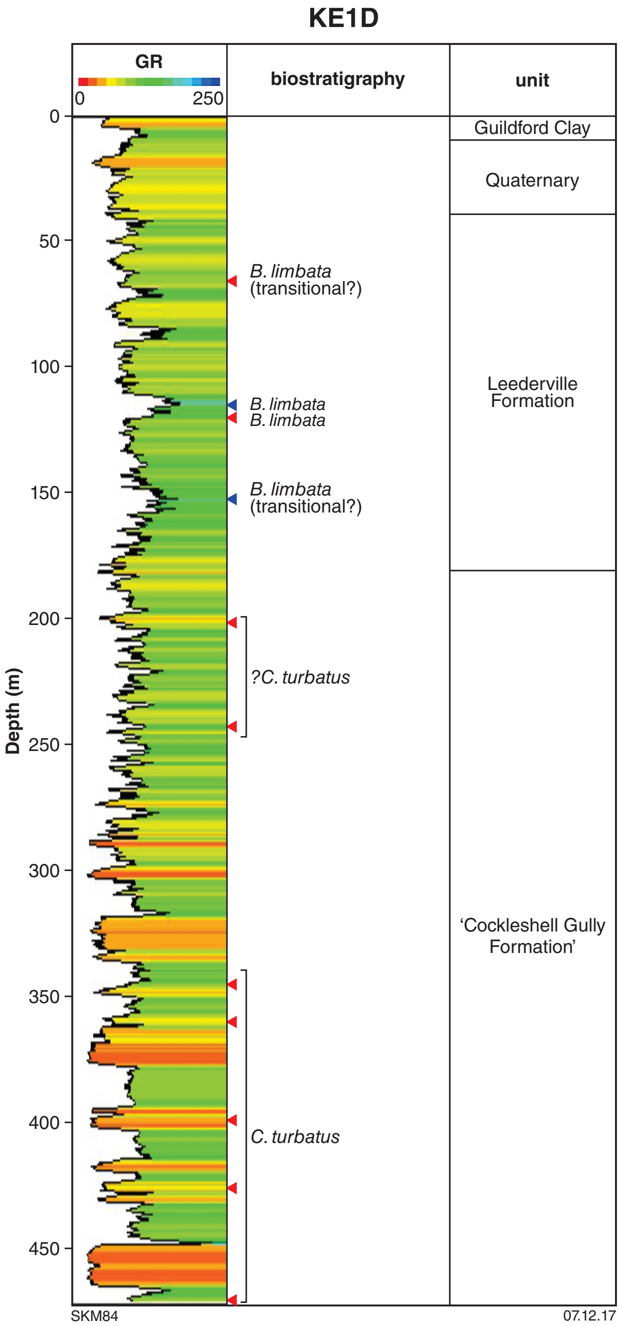
Only a single palynological study has been conducted on each of the Kemerton wells, with samples (both ditch cuttings and sidewall cores) submitted for analysis by then-GSWA palynologist J Backhouse soon after the boreholes were drilled, with a single GSWA Paleontology Report written for each of the holes (Backhouse, 1989a,b). In both cases, the results were assigned to the current Australian zonation scheme — Helby et al. (1987) zones for the Jurassic, and Backhouse (1988) for the Cretaceous — and therefore, these results do not require translation or in-depth reassessment.

KE1D

A total of 15 ditch cuttings (at depths between 18 and 471 m) and two sidewall cores (from 115 and 152 m) were submitted for palynological analysis, although three cuttings were not processed due to unsuitable lithologies. All of the remaining samples yielded palynomorphs. Overall, Backhouse (1989a) considered the samples assignable to three separate groups — Early Cretaceous, probably Early Jurassic, and Early Jurassic.

All samples between 66 and 152 m (including the two sidewall cores) were considered Early Cretaceous in age, and specifically assignable to Backhouse’s (1988) *Balmeiopsis limbata* Spore-Pollen Zone. Although the assemblages contain no certainly marine dinoflagellates and are considered to represent nonmarine depositional environments, Backhouse (1989a) noted the presence of a number of *Moorodinium*-type dinoflagellates, generally interpreted as occurring in freshwater or brackish aquatic (lacustrine or lagoonal) environments (Backhouse, 1988). Although generally thought to be of uncertain biostratigraphic value, Backhouse (1989a) noted that these dinocysts are most commonly found in the Parmelia Group in the Dandaragan Trough, but have been recorded from the lowermost part of the Warnbro Group in the Bunbury Trough, which would agree with other data obtained from the spore-pollen assemblage in KE1D. Backhouse (1989a) was initially uncertain whether the record of *Moorodinium* in the Bunbury Trough was a reflection of Parmelia Group reworking into the lower Warnbro Group in this region, or a localized extension of the species’ age range (perhaps due to favourable environmental conditions). However, in a later review of the Harvey Line water bores, an assemblage similar to this was identified as a new ‘transitional *Biretisporites eneabbaensis* – *B. limbata* Zone’ spore-pollen biostratigraphic unit (Backhouse, 2012). The full extent and age of this biostratigraphic unit is presently unknown.

Samples from 345 m to the deepest sample at 471 m were unequivocally assigned to the *Callialasporites turbatus* Spore-Pollen Zone by Backhouse (1989a). The basis for



Notes: TD = 474 m; lithostratigraphy based on Commander (1989); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores

this zone determination was not explained in detail in the report and cannot be reassessed without re-examining the original slides.

The two intermediate ditch cuttings, from 201 and 243 m, contain somewhat mixed assemblages, including forms that are certainly Cretaceous and forms that are certainly Jurassic in age, plus a number of long-ranging taxa. In his report, Backhouse (1989a) suggested that these samples were mixed but probably Early Jurassic in age based on the dominance of *Callialasporites turbatus*, and would therefore consider the Jurassic–Cretaceous unconformity to fall between 152 and 201 m. In a report on these wells, Commander (1989) placed the Jurassic–Cretaceous unconformity between the 'Cockleshell Gully Formation' and Leederville Sandstone at roughly 180 m, based on palynological, lithological and geophysical information.

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Kemerton Line 2D

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
KE2D[(a)]				
–	215	SWC	upper *C. torosa*^ or lower *C. turbatus*^	(Backhouse, 1989b)
–	293	SWC	upper *C. torosa*^ or lower *C. turbatus*^	(Backhouse, 1989b)
–	325	SWC	upper *C. torosa*^ or lower *C. turbatus*^	(Backhouse, 1989b)
–	335	SWC	upper *C. torosa*^ or lower *C. turbatus*^	(Backhouse, 1989b)
–	368	SWC	upper *C. torosa*^ or lower *C. turbatus*^	(Backhouse, 1989b)
–	405	SWC	upper *C. torosa*^ or lower *C. turbatus*^	(Backhouse, 1989b)
–	442.5	SWC	upper *C. torosa*^ or lower *C. turbatus*^	(Backhouse, 1989b)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone

Line summary

The Kemerton Line consists of four exploratory boreholes on two sites, drilled in June–July 1989 to augment knowledge of deep groundwater resources in the Kemerton–Australind area (Commander, 1989). Shallow (name suffixed ‘S’) and deep (name suffixed ‘D’) holes were drilled at each site, but palynological analyses were only conducted on samples from the deep drilling. Both deep boreholes were drilled using a mud rotary rig, with KE1D drilled to a TD of 474 m and KE2D drilled to a TD of 501 m; both were completed after drilling and are presently operating as water bores. Ditch cuttings were collected at 3 m intervals from each of the deep bores, and sidewall cores were also cut, although KE1D had poor core recovery due to the loss of the sidewall-core gun during drilling.

Only a single palynological study has been conducted on each of the Kemerton wells, with samples (both ditch cuttings and sidewall cores) submitted for analysis by then-GSWA palynologist J. Backhouse soon after the boreholes were drilled, with a single GSWA Paleontology Report written for each of the holes (Backhouse, 1989a,b). In both cases, the results were assigned to the current Australian zonation scheme — Helby et al. (1987) zones for the Jurassic, and Backhouse (1988) for the Cretaceous — and therefore, these results do not require translation or in-depth reassessment.

KE2D

A total of seven sidewall cores from 215 to 442.5 m (Backhouse, 1989b) were submitted for palynology from this borehole. Of these, the sidewall core from 293 m was too oxidized to process and the 405 m sidewall core was mostly sandstone and therefore unsuitable for palynology; the sidewall-core sample from 335 m was found to yield a very poor assemblage and may also have been oxidized to some degree. The remaining samples all yielded assemblages of nonmarine Early Jurassic palynomorphs. The obtained assemblages, although relatively high yielding, were noted to be very low in diversity and strongly dominated by *Classopollis torosus*, with this low diversity hampering the assignment of the assemblages to any particular spore-pollen zone. In the end, Backhouse (1989b) described all of the samples as either upper *Corollina torosa* or lower *Callialasporites turbatus* Spore-Pollen Zones, with the likelihood of upper *C. torosa* Zone increasing downhole. Therefore, the Lower Jurassic section seen in this bore is considered older than at the equivalent depths in KE1D, although there are no precise constraints on the maximum and minimum age of the section in KE2D.

As in KE1D, it is assumed that this Lower Jurassic unit is directly overlain by Lower Cretaceous sediments of the Warnbro Group. Commander (1989) interpreted this boundary to be between the ‘Cockleshell Gully Formation’ and the Leederville Formation at 210 m. Although the obtained palynology results do not contradict this interpretation, the depth of the unconformity and nature of the overlying sediments cannot be confirmed based on this data.

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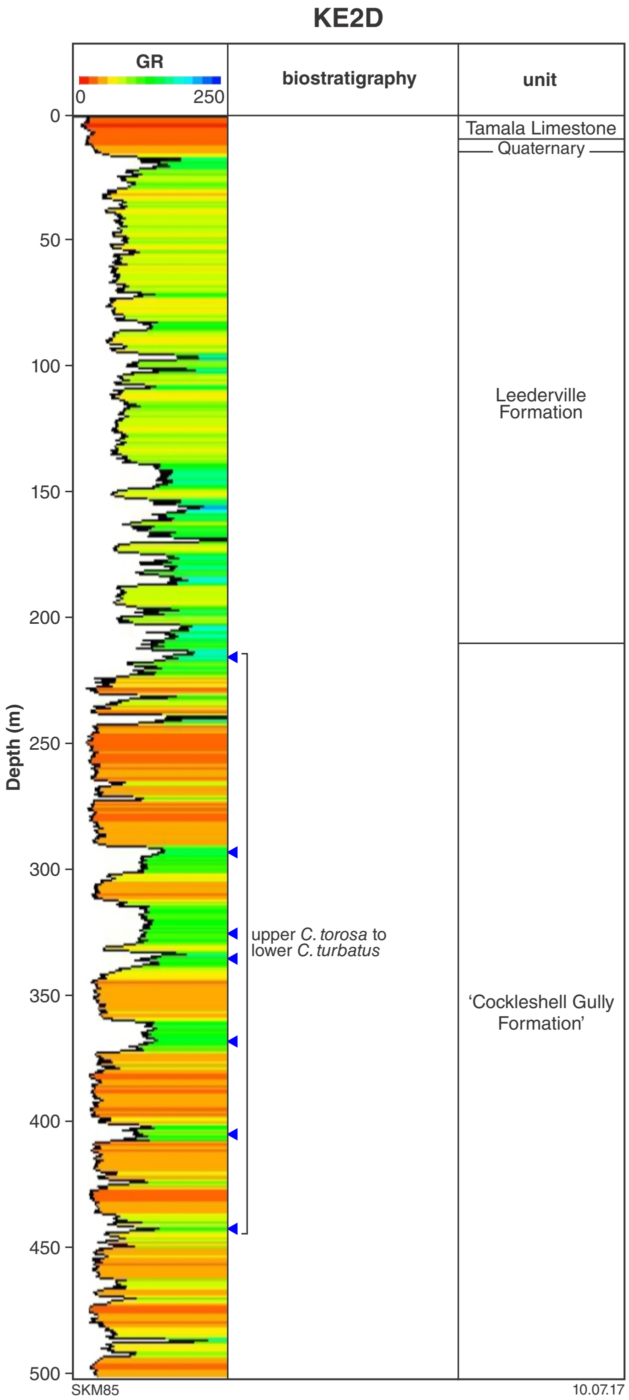
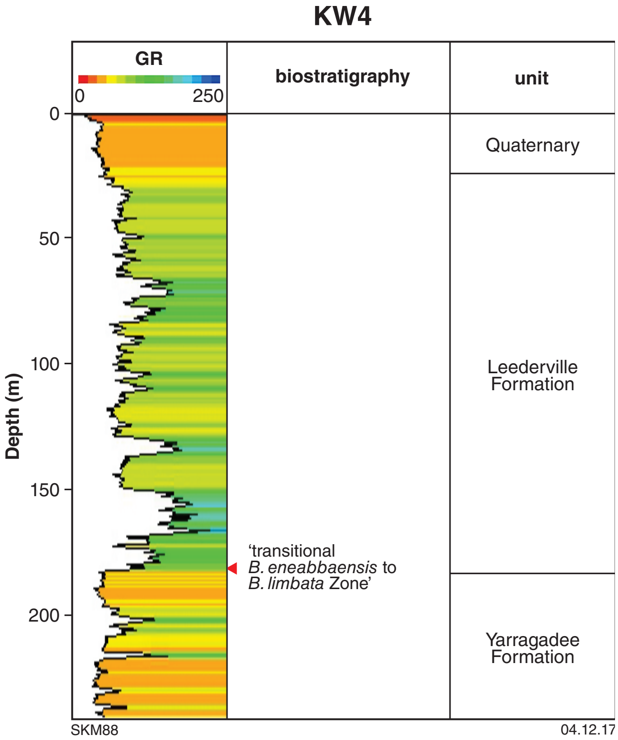


Notes: TD = 501 m; lithostratigraphy based on Commander (1989); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores

Kemerton bore KW4

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
KW4[a]				
–	181–184	DC	'transitional *B. eneabbaensis* – *B. limbata* Zone'	(Backhouse, 1988)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)



Notes: TD = ?239 m; lithostratigraphy based on Commander (1989b); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

KW4

Drilled in 1988, Kemerton KW4 was one of three boreholes drilled within the then newly developed Kemerton Industrial Park to provide water resources for the SCM titanium refinery (Commander, 1989a). The borehole TD is uncertain, but seems to have been greater than 239 m. Only a single sample from KW4, a ditch cutting from 181 to 184 m, was submitted for palynological analysis, and was reported in a single Paleontology Report (Backhouse, 1988). This sample has not been reviewed since its original description.

Although this report presents no species list, Backhouse noted that the assemblage is somewhat unusual, containing common *Classopollis* spp., *Balmeiopsis limbata*, and other taxa typical of the Warnbro Group (and therefore of the *Balmeiopsis limbata* Spore-Pollen Zone), associated with numerous specimens of the dinocyst *Moorodinium*, generally considered indicative of the *Biretisporites eneabbaensis* Spore-Pollen Zone. As such, this sample appears to contain an example of the enigmatic 'transitional *B. eneabbaensis* – *B. limbata* Zone' assemblage, subsequently identified informally in the Harvey Line water bores, and suspected in other boreholes within the region (Backhouse, 2012). However, the existence and nature of this biounit is as yet unconfirmed, and a review of this slide would be required to verify this identification.

Using Commander's (1989b) formation picks, the palynology sample falls within the Leederville Formation, close to an unconformity with the underlying Yarragadee Formation. However, if this sample is assignable to the 'transitional *B. eneabbaensis* – *B. limbata* Zone' biounit, it is possible that the base of the Warnbro Group lies at a level shallower than 181 m in this borehole. The current palynological data present no evidence for Late Jurassic sediments.

References

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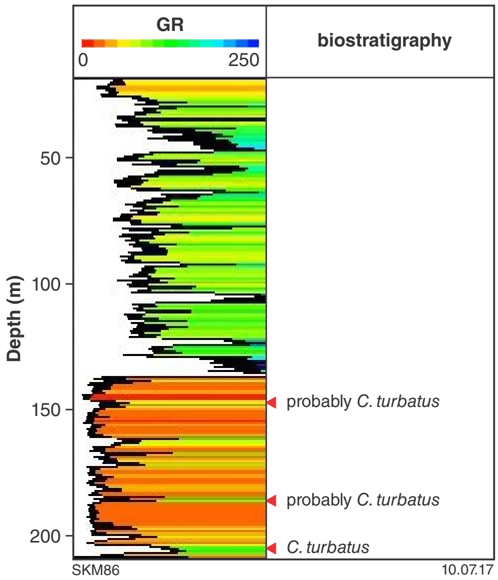
Kemerton–Wellesley 1

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
KEML1[(a)]				
–	147–150	DC	probably *C. turbatus*^	(Backhouse, 2001)
–	186–189	DC	probably *C. turbatus*^	(Backhouse, 2001)
–	205–208	DC	*C. turbatus*^	(Backhouse, 2001)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone

KEML1



Notes: TD = 208 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The two Kemerton–Wellesley boreholes were drilled in the Kemerton Industrial Park, located between Bunbury and Australind. Drilled to TD of 208 m (KEML1) and 222.6 m (KEML2) by the Bunbury Drilling Company, technical reports on the project were provided to the Kemerton Technical Working Group by Aquaterra Consulting Pty Ltd. As part of the geological investigations, three ditch cuttings were assessed from each borehole by J Backhouse; these results were reported in a single report (Backhouse, 2001).

KEML1

Three ditch cuttings from KEML1 were submitted from depths of 147–150, 186–189 and 205–208 m. Although the lithology of the shallowest sample was predominantly sandstone, all three samples had high yields of well-preserved spores and pollen (Backhouse, 2001). The deepest sample, at 205–208 m, yielded a fairly typical *Callialasporites turbatus* Spore-Pollen Zone assemblage, dominated by the eponymous species, plus *Classopollis torosus*, *Araucariacites australis* and *Baculatisporites* spp., and is therefore assigned to that Early Jurassic zone. The two shallower samples contained similar Early Jurassic palynomorphs, but with the presence of additional unequivocal Cretaceous forms, including dinoflagellates. These Cretaceous species are assumed to represent cavings from overlying sequences, but their presence introduces some uncertainty into the age of the samples. Backhouse (2001) therefore noted that these two shallower samples may still fall within the upper part of the *C. turbatus* Zone, or within the lower part of the overlying *Dictyosporites complex* or *Contignisporites cooksoniae* Spore-Pollen Zones.

Although all of the palynological data from this borehole indicate an Early–Middle Jurassic age for the sequence, there are no age data from the shallowest 140 m. Circumstantial evidence indicates the presence of Cretaceous sediments higher in the section, likely Lower Cretaceous sediments directly overlying the Lower Jurassic sequence, but direct evidence for the depth of this unconformity or the nature of these shallower sediments is lacking.

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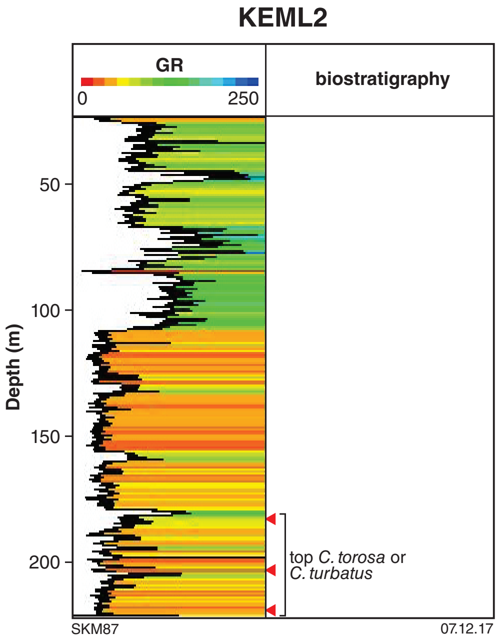
Kemerton–Wellesley 2

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
KEML2[a]				
–	183–186	DC	top *C. torosa*^ or *C. turbatus*^	(Backhouse, 2001)
–	203–206	DC	top *C. torosa*^ or *C. turbatus*^	(Backhouse, 2001)
–	219–222	DC	top *C. torosa*^ or *C. turbatus*^	(Backhouse, 2001)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone



Notes: **TD = 222.6 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

Line summary

The two Kemerton–Wellesley boreholes were drilled in the Kemerton Industrial Park, located between Bunbury and Australind. Drilled to TD of 208 m (KEML1) and 222.6 m (KEML2) by the Bunbury Drilling Company, technical reports on the project were provided to the Kemerton Technical Working Group by Aquaterra Consulting Pty Ltd. As part of the geological investigations, three ditch cuttings were assessed from each borehole by J Backhouse; these results were reported in a single report (Backhouse, 2001).

KEML2

Three ditch cuttings from KEML2 were submitted for palynological analysis, from depths of 183–186, 203–206, and 219–222 m (Backhouse, 2001). All three samples consisted of sandy claystones, and yielded high numbers of well-preserved spores and pollen, with no marine microplankton recovered. All three samples presented very similar assemblages, dominated by *Classopollis torosus*, with remaining taxa contributing only a small proportion of the assemblage. As the shallowest sample yielded *Callialasporites turbatus* and possible *Exesipollenites tumulus*, it was suggested that all three samples could be placed within the lower part of the *Callialasporites turbatus* Spore-Pollen Zone of Helby et al. (1987), although there is a possibility that the samples belong in, or extend into, the upper *Corollina torosa* Spore-Pollen Zone.

Based on this interpretation, it was considered that the section in KEML2 is older than that intersected in KEML1, although again there is no direct evidence of the age and nature of the section from the upper 180 m of the borehole. As with KEML1, a Cretaceous – Early Jurassic unconformity is expected in this section, although its nature and depth is completely unknown at present.

References

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Lake Clifton Shallow boreholes

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
LCA1[(a)]				
–	36	DC	?Albian	(Backhouse, 1980)
LCA2				
–	29	DC	indeterminate	(Backhouse, 1980)
LCA4				
–	27	DC	?Albian	(Backhouse, 1980)
LCA5				
–	18–21	DC	?Albian	(Backhouse, 1980)
LCB1				
–	28	DC	?Albian	(Backhouse, 1980)
LCB3				
–	26	DC	Aptian or Albian	(Backhouse, 1980)
LCC1				
–	27–30	DC	?*B. limbata*[#]	(Backhouse, 1980)
LCC2				
–	24–27	DC	Early Cretaceous	(Backhouse, 1980)
LCC4				
–	24–26	DC	?*B. limbata*[#]	(Backhouse, 1980)
LCC5				
–	21–24	DC	*A. alata*[‡] to *F. monilifera*[‡]	(Backhouse, 1980)
LCC6A				
–	39	DC	?*B. limbata*[#]	(Backhouse, 1980)
LCE8				
–	33–36	DC	barren	(Backhouse, 1980)
LCF6				
–	37	DC	Early Cretaceous	(Backhouse, 1980)
LCG7				
–	30–33	DC	Early Cretaceous	(Backhouse, 1979)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone; [‡]Backhouse (1988) Dinocyst Zone

The Lake Clifton Shallow boreholes were drilled in 1979 to assess the shallow water resources, and lake levels and balances, of the South West Coastal Groundwater Area, and were all completed for monitoring purposes. The bores were drilled along seven west–east oriented lines, with between five and nine holes drilled on each line, to a total of 50 boreholes (Commander, 1988). Of these, 14 boreholes were assessed palynologically, with one ditch cutting sample submitted from each, collected from near TD (Backhouse, 1979, 1980). Unfortunately, full species listings for these samples are not provided in the report, which makes subsequent reassessment difficult without re-examining the original slides.

Although the deepest bore in this project (C7) reached a TD of 61 m, the deepest of the studied boreholes (C6A) has a TD of only 39 m and none intersected units older than the Early Cretaceous. Two of the 14 boreholes (A2 and E8) yielded barren, or nearly barren, samples and did not provide any age data. Samples from LCC2 and LCG7 were very lean and could only be identified as generally Early Cretaceous in age; neither of these samples contained dinoflagellates or other marine indicators.

Of the remaining 10 samples, all three A-line boreholes (A1, A4, A5) yielded sparse, marine assemblages, and were associated with the lower Osborne Formation or equivalent based on the presence of dinoflagellates *Chlamydophorella nyei* and *Cribroperidinium edwardsii*.

The two B-line samples (B1, B3) were noted to yield nonmarine assemblages described as Aptian or Albian in age, but are now considered more likely to belong in the Albian (this Report). The single species mentioned for this line, *Perotriletes majus* (in LCB1), is generally considered to extend from the upper *Crybelosporites striatus* to the lower *Phimopollenites pannosus* Spore-Pollen Zones, but has occasionally been recorded in zones as old as the *Foraminisporis wonthaggiensis* Spore-Pollen Zones (in the Surat and Eromanga Basins). Therefore this species is mostly indicative of the *Coptospora paradoxa* Spore-Pollen Zone Australia-wide, and is better considered Albian–Cenomanian in age (Wagstaff et al., 2012). In the Perth Basin, the species is only known from successions above the Leederville Formation, suggesting that the succession in these boreholes has more in common with the A line (clearly Osborne Formation) than the C line (clearly Warnbro Group).

Many of the samples from the C-line boreholes (C1, C4, C5, C6) showed evidence of marine influence, and were considered to be slightly older than the B-line bores; that is, Barremian to Aptian in age. Again, the lack of species lists in the report makes assigning the assemblages to particular zones difficult, although the noted presence of *Cyclonephelium attadalicum* in LCC5 suggests a link to the *Aprobolocysta alata* to *Fromea monilifera* Dinocyst Zones and therefore the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988). On this basis, it is likely that the other C-line borehole samples and the single F-line sample (F6, nonmarine) are also assignable to this spore-pollen zone, although the slides would need to be reviewed for certainty.

In general, the assemblages become progressively older from north to south, although none of the boreholes provides evidence for Jurassic or older sediments.

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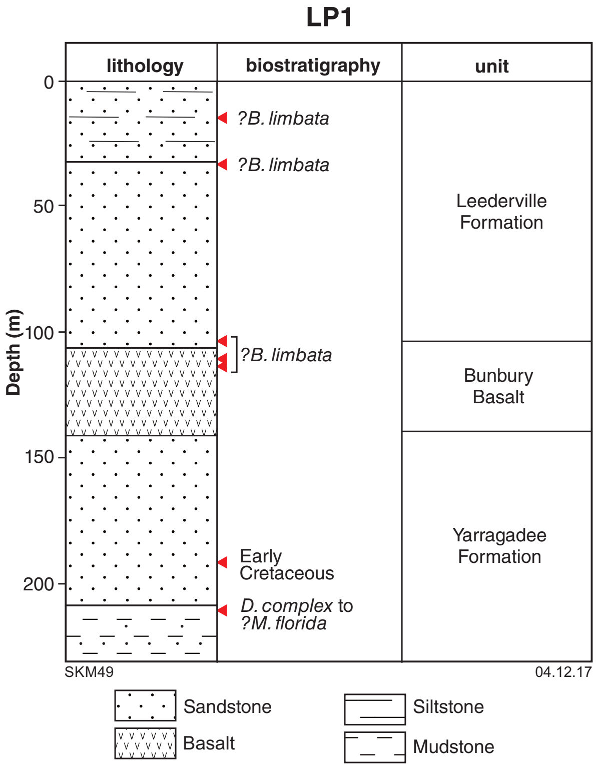
Laporte Line 1

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
LP1[(a)]				
50	15.2	DC	?B. limbata[#]	(Balme, 1962)
110	33.5	DC	?B. limbata[#]	(Balme, 1962)
340	103.6	DC	?B. limbata[#]	(Balme, 1962)
360	109.7	DC	?B. limbata[#]	(Balme, 1962)
370	112.8	DC	?B. limbata[#]	(Balme, 1962)
620–630	191.2 – 194.3	DC	Early Cretaceous	(Edgell, 1962a)
690	210.3	DC	D. complex^ to ?M. florida^	(Balme, 1962)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone



Notes: **TD = 229.82 m; lithostratigraphy based on DWER WIR data (AWRC = 61210392); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

Line summary

The Bunbury Laporte Line of bores (also known as the La Porte Line of bores) is one of the oldest set of water bores in the study area, with Laporte Line Nos 1–5 drilled by the then Mines Department in 1961 and 1962. Additional boreholes were drilled as part of this line in the late 1960s (LP6 in 1968) and 1970s (LP7 in 1973, LP8 in 1976). All bores in this line are moderately deep; the shallowest is LP5 with a TD of 213.4 m and the deepest is LP4 at 336.7 m TD. The main line of Laporte water bores was later followed by multiple rounds of shallow drilling across the Leschenault Peninsula, including LPF4DB, drilled in 1977.

The first palynological work on the Laporte water bores was an unpublished report on LP1–4, written by University of Western Australia palynologist BE Balme (1962). These ditch cutting samples (six from LP1, five from LP2, five from LP3, and three from LP4) were selected by GSWA hydrogeologists during drilling and later sent for analysis. Additional ditch cutting samples from these boreholes were studied later by GSWA palynologist HS Edgell, and reported in well completion summaries and a single GSWA Paleontology Report (Edgell, 1962a). For the other Laporte boreholes, only two ditch cuttings were submitted from LP7 (Backhouse, 1974), and a single ditch cutting was analysed from LPF4DB (Backhouse, 1977). The greatest amount of work was conducted on LP5, with 10 ditch cuttings submitted for analysis, reported in two Paleontology Reports (Edgell, 1962b,c). None of these results has been reviewed after its initial reporting.

LP1

Laporte Line No. 1 was drilled in 1962 to a TD of 754 ft (229.82 m), with a total of seven ditch cuttings submitted for palynological analysis. Of these samples, all but one (620–630 ft) were studied by Balme (1962), and the remaining sample was studied by and reported in a single Paleontology Report (Edgell, 1962a).

The shallowest sample at 50 ft contains a mixed Quaternary – Early Cretaceous assemblage. Balme (1962) noted that both age components were equally well preserved and he could not determine whether the Cretaceous forms were reworked or if the Quaternary component was downhole contamination. Considering the contamination potential of ditch cuttings, the latter interpretation is preferred, and the sample is tentatively considered Early Cretaceous in age. Balme (1962) assigned the Cretaceous portion of the assemblage to his 'Assemblage D' of 'Neocomian to lower Aptian age'. The inclusion of *Foveosporites canalis*, a spore generally restricted to the Early Cretaceous *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988), tentatively suggests assignment to this modern zone, with this interpretation supported by the broader assemblage. Although deeper palynomorph-rich samples (at 110 and 370 ft) lack any taxa specifically linked to the *B. limbata* Zone, Balme considered the samples to be of the same or similar age (Balme's [1962] Assemblages C and D, where D is marine and C is nonmarine), and all are similarly assigned tentatively to the same zone. Two intervening samples at 340 and 360 ft were very poorly yielding, containing only long-ranging Jurassic–Cretaceous taxa; their age and assignment is therefore assumed based on surrounding samples.

Edgell (1962a) considered a sample from 620–630 ft depth to be slightly older (Lower Neocomian) than Balme's (1962) set of samples, belonging to an assemblage (Balme's [1962] Assemblage B) intermediate between the putatively Late Jurassic assemblage seen deeper in the hole (Assemblage A) and the main set of Neocomian–Aptian samples (Microfossil Assemblage C and D) seen at shallower levels. Unfortunately, the samples assigned to Assemblage B are of low diversity and yield, and their age is difficult to interpret without reference to the original slides. However, as Assemblages C and D seem attributable to the *B. limbata* Zone, and Assemblage A is probably akin to the *Murospora florida* Spore-Pollen Zone or slightly older, Assemblage B appears to fall somewhere within the *Retitriletes watherooensis* to *Biretisporites eneabbaensis* Spore-Pollen Zones (Backhouse, 1988), and may correlate to any or all of these of these zones.

The final sample within the collection described by Balme (1962) (at 690 ft) was also low yielding and was considered too low in diversity to confidently appraise. However, the sample was tentatively associated with his Late Jurassic Assemblage A, mostly based on the lack of distinctly Cretaceous taxa and the relative abundance of *Callialasporites dampieri* and *Araucariacites australis*, the latter of which appears in the Late Jurassic. Based on the composition of richer assemblages in other Laporte bores (particularly in Laporte No. 3), Assemblage A is most likely equivalent to the *M. florida* Zone, but may be slightly older, perhaps as old as the *Dictyotosporites complex* Spore-Pollen Zone (Helby et al., 1987).

Interestingly, one of the shallowest samples in LP1 (at 110 ft) was noted to contain a small number of microplankton, indicating estuarine or shallow marine conditions (Balme, 1962). Unfortunately, none of these microplankton assemblages was diverse enough to be associated with any zone, and therefore do not help or increase biostratigraphic precision. Other than this single sample, the remaining assemblages lack marine indicators and are considered terrestrial in origin.

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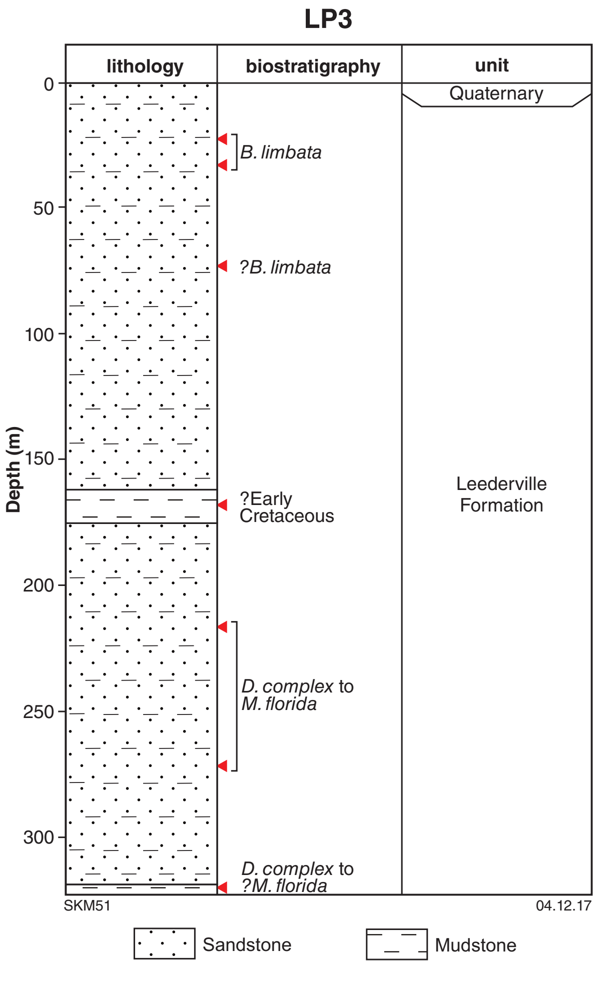
Laporte Line 3

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
LP3[(a)]				
74–77	22.55 – 23.5	DC	*B. limbata*[#]	(Balme, 1962)
108	32.9	DC	*B. limbata*[#]	(Balme, 1962)
240	73.15	DC	*?B. limbata*	(Balme, 1962)
551–552	167.9 – 168.2	DC	?Early Cretaceous	(Balme, 1962)
710	216.4	DC	*D. complex*^ to *M. florida*^	(Backhouse, 2015)
890	271.3	DC	*D. complex*^ to *M. florida*^	(Backhouse, 2015)
1050	320.0	DC	*D. complex*^ to ?*M. florida*^	(Balme, 1962)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone



Notes: TD = 321.56 m; lithostratigraphy based on DWER WIR data (AWRC = 61118004); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Bunbury Laporte Line of bores (also known as the La Porte Line of bores) is one of the oldest set of water bores in the study area, with Laporte Line Nos 1–5 drilled by the then Mines Department in 1961 and 1962. Additional boreholes were drilled as part of this line in the late 1960s (LP6 in 1968) and 1970s (LP7 in 1973, LP8 in 1976). All bores in this line are moderately deep; the shallowest is LP5 with a TD of 213.4 m and the deepest is LP4 at 336.7 m TD. The main line of Laporte water bores was later followed by multiple rounds of shallow drilling across the Leschenault Peninsula, including LPF4DB, drilled in 1977.

The first palynological work on the Laporte water bores was an unpublished report on LP1–4, written by University of Western Australia palynologist BE Balme (1962). These ditch cutting samples (six from LP1, five from LP2, five from LP3, and three from LP4) were selected by GSWA hydrogeologists during drilling and later sent for analysis. Additional ditch cutting samples from these boreholes were studied later by GSWA palynologist HS Edgell, and reported in well completion summaries and a single GSWA Paleontology Report (Edgell, 1962a). For the other Laporte boreholes, only two ditch cuttings were submitted from LP7 (Backhouse, 1974), and a single ditch cutting was analysed from LPF4DB (Backhouse, 1977). The greatest amount of work was conducted on LP5, with 10 ditch cuttings submitted for analysis, reported in two Paleontology Reports (Edgell, 1962b,c). None of these results has been reviewed after its initial reporting.

LP3

LP3 was drilled to a TD of 1055 ft (321.6 m) in 1962, with seven ditch cuttings submitted for palynological analysis. Five of these ditch cuttings at 74–77 ft (22.55 – 23.5 m), 108 ft (32.9 m), 240 ft (73.15 m), 551–552 ft (167.9 – 168.2 m) and 1050 ft (320.0 m) were studied by Balme (1962), with an additional two samples at 710 ft (216.41 m) and 890 ft (271.27 m) studied later by Edgell (1962a). As none of these assemblages included microplankton, all are considered to represent terrestrial deposition.

The shallowest two samples in this set contain rich assemblages of Early Cretaceous spores and pollen, including the index species *Balmeiopsis limbata*, thereby indicating assignment to the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988). Although the underlying sample (at 240 ft) was considered by Balme (1962) to be equivalent in age, this assemblage lacks *B. limbata*, and there is a slim possibility that the assemblage belongs to the 'transitional *Biretisporites eneabbaensis* – *B. limbata* Zone' biounit rather than the *B. limbata* Zone (J Backhouse, 2017, written comm., 23 February).

The next sample, at 551–552 ft, yielded a moderately rich palynomorph assemblage of biostratigraphically indistinct, long-ranging Late Jurassic and Early Cretaceous taxa. Although acknowledging the difficulties in assigning the sample to a particular assemblage or zone, Balme (1962) considered it most likely Early Cretaceous in age. However, as the overlying sample is likely from the *B. limbata* Zone, and the underlying sample is *Murospora florida* Spore-Pollen Zone or younger, this sample could be equivalent in age to either of these zones or anywhere between.

The remaining three samples yielded Jurassic palynomorph assemblages that, despite sharing only a single species — *Callialasporites dampieri* — were all considered to fall within Balme's (1957) Microfloral Assemblage IIa (Balme, 1962; Edgell, 1962a). Helby et al. (1987) later equated this assemblage to their *Dictyotosporites complex* to *M. florida* Spore-Pollen Zones, of Late Jurassic age. However, the shallowest of these three samples contains only long ranging Jurassic–Cretaceous taxa, poorly indicative of age, although the relative rarity of *Classopollis* spp. and *Callialasporites turbatus*, and presence of rare *Microcachryidites antarcticus* and *C. dampieri*, does suggest a Late Jurassic to Early Cretaceous age. The middle and deepest samples contain similarly long-ranging species, with a small number of unusual taxa. The presence of *M. antarcticus*, seen only in the middle LP3 sample (551–552 ft), was used by Filatoff (1975) to mark the end of his *M. florida* Microflora and therefore the start of Balme's *Microcachryidites* Assemblage, and Backhouse (1988) noted its presence in the *Retitriletes watherooensis* Spore-Pollen Zone and younger, suggesting assignment of this sample to these later Jurassic or Early Cretaceous zones. *Acanthotriletes levidensis* was also recorded exclusively in the middle LP3 sample and was considered by Filatoff (1975) to occur in his *Contignisporites cooksoniae* to *M. florida* Zones (*M. florida* being the top of his zonation scheme), although Backhouse (1988) mentioned this species only within his *B. limbata* Zone (again the top of his scheme). It is uncertain whether this indicates that Filatoff (1975) misidentified or had a different interpretation of this species, or whether the species became very rare (or cryptic) between the *M. florida* and *B. limbata* Zones. As a result, this taxon, which seemed at first to be a useful index species, has a somewhat opaque zonal range. *Mantonisporites crassiangulatus* is another taxon with a confused history. Filatoff (1975) recorded the species in his upper *Classopollis chateaunovi* to *D. complex* Zones, noting that it is also reworked into the *M. florida* Zone, whereas Backhouse (1988) listed the species occurring throughout his zones, from *R. watherooensis* to *B. limbata*. Again, one can only conclude that the overall assemblage points to the Late Jurassic to Early Cretaceous. However, *Reticuloidosporites arcus* (called *Polypodiidites arcus* in Balme's [1962] report), which is seen in the deepest sample of this set, has been considered restricted to the Cretaceous *Biretisporites eneabbaensis* and *B. limbata* Spore-Pollen Zones (Backhouse, 1988), further confusing the age of these samples.

A review of Edgell's (1962a) report, without re-examination of the slides, was conducted in 2015, in order to clarify the biostratigraphic interpretation (Backhouse, 2015). That review concluded that these two LP3 samples fall somewhere within the *M. florida* to *D. complex* Zones of Helby et al. (1987), based primarily on the rarity of *Classopollis* spp. spores and abundance of *C. dampieri*, thereby indicating a Late Jurassic age for these samples. The underlying sample (at 1050 ft) is also considered to fall into the same zone range due to overall similarities in the assemblages, with *R. arcus* likely present as a downhole contaminant. No further refinement of this age is possible without additional sampling or re-examination of the slides.

Based on this sequence and nearby Laporte boreholes, the base of the Quaternary can be presumed to be shallower than 20 m depth (base of the Quaternary in LP5 is between 18.5 and 20.05 m; Edgell, 1962c), with Lower Cretaceous sediments of the Warnbro Group almost certainly intersected by 22 m depth. The Jurassic–Cretaceous boundary likely falls somewhere between 168 and 219 m, although the uncertain nature of the sample at 167.9 – 168.2 m allows for the possibility that the Jurassic boundary is shallower than this. In nearby LP4, Cretaceous palynomorph assemblages are recovered to at least 285 m depth (Edgell, 1962a), suggesting a shallower Cretaceous unconformity in LP3 compared to more westerly boreholes. Unfortunately, the use of ditch cuttings in these boreholes severely reduces the precision of biostratigraphic boundary depths and correlations are therefore uncertain.

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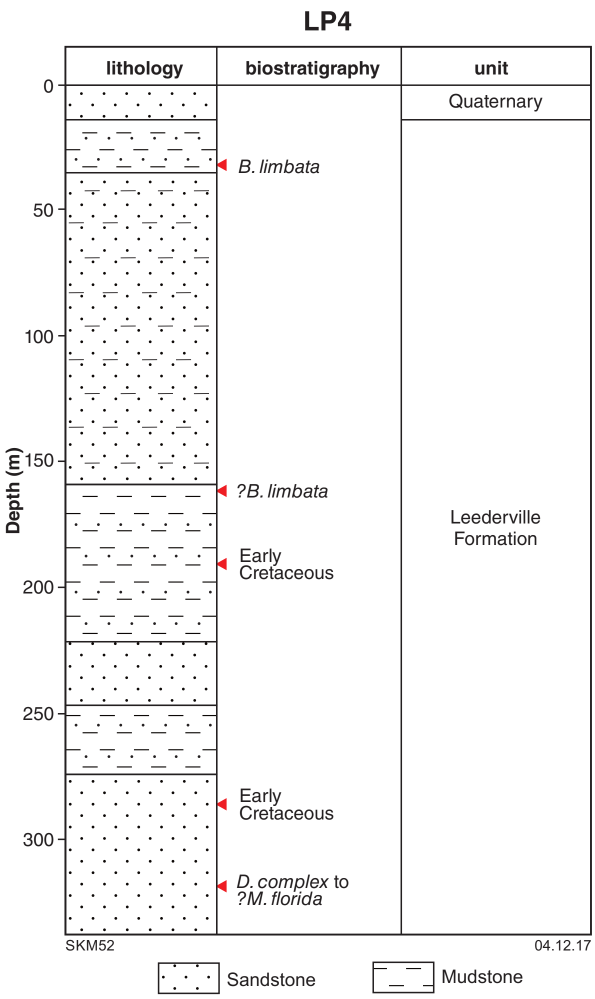
Laporte Line 4

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
LP4[(a)]				
105	32.0	DC	*B. limbata*#	(Balme, 1962)
530	161.5	DC	*?B. limbata*#	(Balme, 1962)
620	190.6	DC	Early Cretaceous	(Edgell, 1962a)
930	285.9	DC	Early Cretaceous	(Edgell, 1962a)
1045	318.5	DC	*D. complex*^ to *?M. florida*^	(Balme, 1962)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone



Notes: **TD = 336.65 m; lithostratigraphy based on DWER WIR data (AWRC = 61210394); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

Line summary

The Bunbury Laporte Line of bores (also known as the La Porte Line of bores) is one of the oldest set of water bores in the study area, with Laporte Line Nos 1–5 drilled by the then Mines Department in 1961 and 1962. Additional boreholes were drilled as part of this line in the late 1960s (LP6 in 1968) and 1970s (LP7 in 1973, LP8 in 1976). All bores in this line are moderately deep; the shallowest is LP5 with a TD of 213.4 m and the deepest is LP4 at 336.7 m TD. The main line of Laporte water bores was later followed by multiple rounds of shallow drilling across the Leschenault Peninsula, including LPF4DB, drilled in 1977.

The first palynological work on the Laporte water bores was an unpublished report on LP1–4, written by University of Western Australia palynologist BE Balme (1962). These ditch cutting samples (six from LP1, five from LP2, five from LP3, and three from LP4) were selected by GSWA hydrogeologists during drilling and later sent for analysis. Additional ditch cutting samples from these boreholes were studied later by GSWA palynologist HS Edgell, and reported in well completion summaries and a single GSWA Paleontology Report (Edgell, 1962a). For the other Laporte boreholes, only two ditch cuttings were submitted from LP7 (Backhouse, 1974), and a single ditch cutting was analysed from LPF4DB (Backhouse, 1977). The greatest amount of work was conducted on LP5, with 10 ditch cuttings submitted for analysis, reported in two Paleontology Reports (Edgell, 1962b,c). None of these results has been reviewed after its initial reporting.

LP4

The four shallowest samples from LP4 yielded Early Cretaceous palynomorphs. However, only the shallowest of these, from 105 ft (32.0 m), contains index taxa, specifically *Balmeiopsis limbata*, which strongly suggests assignment to the *Balmeiopsis limbata* Spore-Pollen Zone of Backhouse (1988). Other taxa within the assemblage also broadly support this interpretation. Although the remaining samples from 530 ft (161.54 m), 620 ft

(188.98 m) and 930 ft (283.46 m) are broadly similar, they are lower in diversity and dominated by long-ranging Jurassic–Cretaceous taxa. Balme (1962) assigned his samples to Assemblage C, an interpretation followed later for the material examined by Edgell (1962a). If the assemblage assignment is correct, then a link to the *B. limbata* Zone can also be tentatively assumed. However, as it is also possible that the samples are assignable to the *Biretisporites enebbaensis* Spore-Pollen Zone, or 'transitional *B. eneabbaensis – B. limbata'* biozone, it is preferred at present to simply consider the samples Early Cretaceous in age.

The deepest sample from LP4 at 1045 ft (318.5 m) was assigned by Balme (1962) to his Assemblage A, based on the absence of characteristically Cretaceous forms and high proportions of *Callialasporites dampieri*. More characteristic material of this assemblage recorded from Laporte Line No. 3 (LP3) indicates that Balme's zone is most likely correlatable to the Late Jurassic *Murospora florida* Spore-Pollen Zone (Helby et al., 1987), although there is a potential that the material is slightly older, perhaps extending back as far as the *Dictoytosporites complex* Spore-Pollen Zone. The same interpretation is therefore tentatively applied to this sample from LP4.

Interestingly, the shallowest sample in LP4 at 105 ft contains small numbers of microplankton, indicating estuarine or shallow marine conditions (Balme, 1962), although none of these microplankton assemblages was diverse enough to be associated with any zone, and cannot be used to increase the biostratigraphic precision. Other than this sample, the remaining assemblages lack marine indicators and are considered terrestrial in origin.

References

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Backhouse, J 1977, Palynology of Laporte No.F4DB borehole: Geological Survey of Western Australia, Paleontology Report 1977/11, 1p.

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Other Laporte Line boreholes

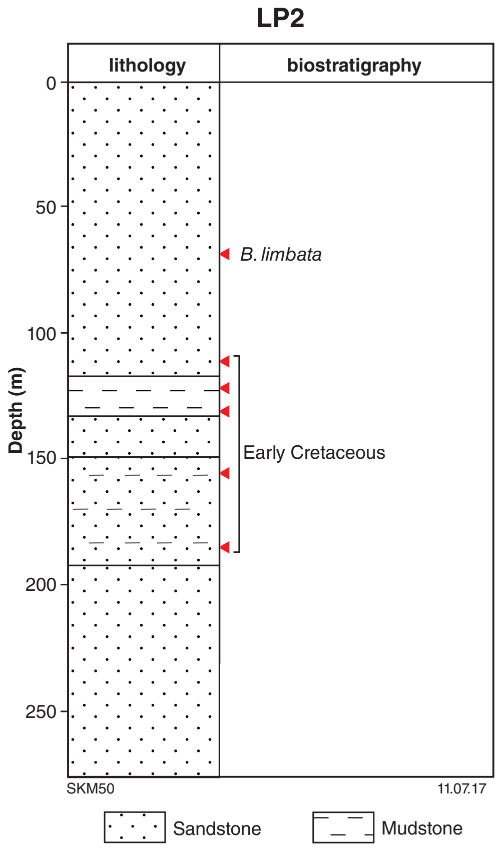
Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
LP2[(a)]				
225–226	68.6 – 68.9	DC	*B. limbata*[#]	(Balme, 1962)
365	111.25	DC	Early Cretaceous	(Balme, 1962)
400	121.9	DC	Early Cretaceous	(Balme, 1962)
430	131.1	DC	Early Cretaceous	(Balme, 1962)
510	155.45	DC	Early Cretaceous	(Balme, 1962)
600	185.0	DC	Early Cretaceous	(Edgell, 1962a)
LP5				
30	9.3	DC	Pleistocene	(Edgell, 1962c)
60	18.5	DC	Pleistocene	(Edgell, 1962c)
65	20.1	DC	Early Cretaceous	(Edgell, 1962b)
180	55.5	DC	Early Cretaceous	(Edgell, 1962c)
230	70.9	DC	Early Cretaceous	(Edgell, 1962c)
300	92.5	DC	Early Cretaceous	(Edgell, 1962c)
350	107.9	DC	Early Cretaceous	(Edgell, 1962b)
450	138.8	DC	Early Cretaceous	(Edgell, 1962b)
570	175.8	DC	Early Cretaceous	(Edgell, 1962b)
690	212.8	DC	Early Cretaceous	(Edgell, 1962b)
LP7				
–	90–93	DC	*B. limbata*[#]	(Backhouse, 1974)
–	159–162	DC	*?B. limbata*[#]	(Backhouse, 1974)
LPF4DB				
–	20.5	DC	*?B. limbata*[#]	(Backhouse, 1977)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone

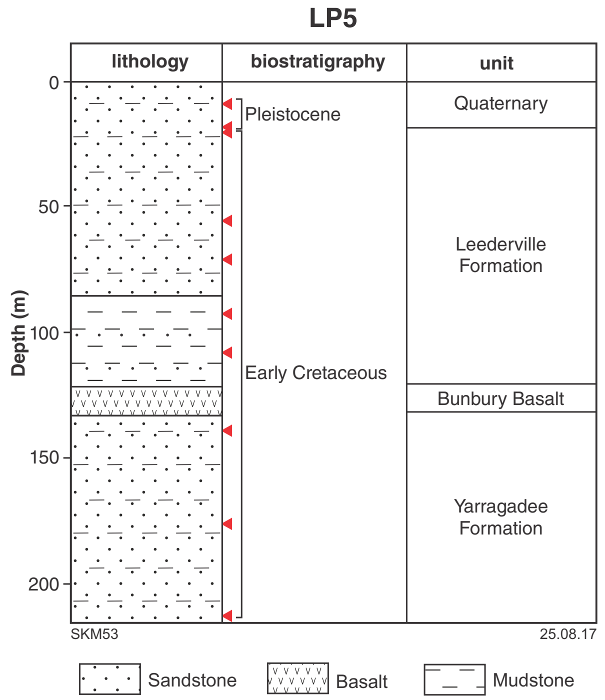
Line summary

The Bunbury Laporte Line of bores (also known as the La Porte Line of bores) is one of the oldest set of water bores in the study area, with Laporte Line Nos 1–5 drilled by the then Mines Department in 1961 and 1962. Additional boreholes were drilled as part of this line in the late 1960s (LP6 in 1968) and 1970s (LP7 in 1973, LP8 in 1976). All bores in this line are moderately deep; the shallowest is LP5 with a TD of 213.4 m and the deepest is LP4 at 336.7 m TD. The main line of Laporte water bores was later followed by multiple rounds of shallow drilling across the Leschenault Peninsula, including LPF4DB, drilled in 1977.

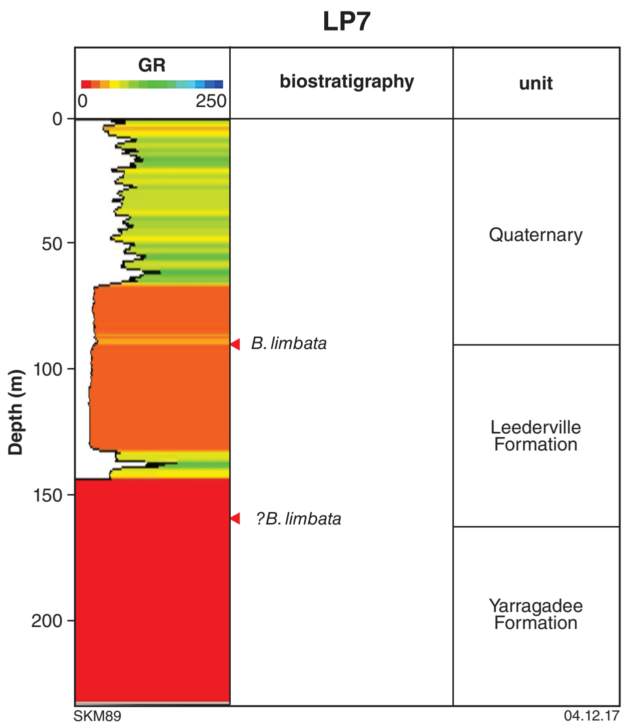
The first palynological work on the Laporte water bores was an unpublished report on LP1–4, written by University of Western Australia palynologist BE Balme (1962). These ditch cutting samples (six from LP1, five from LP2, five from LP3, and three from LP4) were selected by GSWA hydrogeologists during drilling and later sent for analysis. Additional ditch cutting samples from these boreholes were studied later by GSWA palynologist HS Edgell, and reported in well completion summaries and a single GSWA Paleontology Report (Edgell, 1962a). For the other Laporte boreholes, only two ditch cuttings were submitted from LP7 (Backhouse, 1974), and a single ditch cutting was analysed from LPF4DB (Backhouse, 1977). The greatest amount of work was conducted on LP5, with 10 ditch cuttings submitted for analysis, reported in two Paleontology Reports (Edgell, 1962b,c). None of these results has been reviewed after its initial reporting.



Notes: **TD = 274.32 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

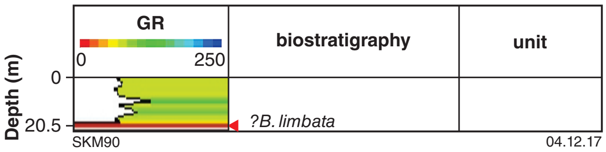


Notes: **TD = 213.36 m; lithostratigraphy based on DWER WIR data (AWRC = 61210395); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**



Notes: **(LP7) TD = 231 m; lithostratigraphy based on DWER WIR data (AWRC = 61211445); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

LPF4DB



Notes: TD = 20.5 m; lithostratigraphy based on DWER WIR data (AWRC = 61219904); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

LP2, LP5, LP7 and LPF4DB

None of the Bunbury Laporte boreholes listed here yielded palynological assemblages older than Early Cretaceous. The two shallowest samples from Bunbury Laporte 5 (at 30 and 60 ft) yielded Quaternary palynomorph assemblages, and the palynological evidence suggests that the Quaternary – Early Cretaceous unconformity in this borehole lies between 60 and 65 ft depth (Edgell, 1962b,c). Most of the Cretaceous samples from these remaining Bunbury Laporte bores were considered to be Early Cretaceous, specifically Neocomian–Aptian, in age (Balme, 1962; Edgell, 1962a–c; Backhouse, 1974, 1977). Although all of these Early Cretaceous assemblages strongly suggest the *Balmeiopsis limbata* Spore-Pollen Zone of Backhouse (1988), only samples where the index taxon *Balmeiopsis limbata* is recorded have been directly allied to that biozone. The other samples are not associated with any particular zone as there is a small chance that the assemblages are instead derived from the transitional *Biretisporites eneabbaensis – B. limbata* Spore-Pollen biozone (J. Backhouse, 2017, written comm., 23 February).

Samples in LP2 (225–226 ft) and LP5 (300, 570, and 690 ft) were noted to contain small numbers of microplankton, indicating estuarine or shallow marine depositional conditions (Balme, 1962; Edgell, 1962b,c). Unfortunately, none of these microplankton assemblages were diverse enough to be associated with any zone, and do not help improve the biostratigraphic precision of either well. Other than these four samples, the remaining assemblages lack marine indicators and are considered terrestrial in origin.

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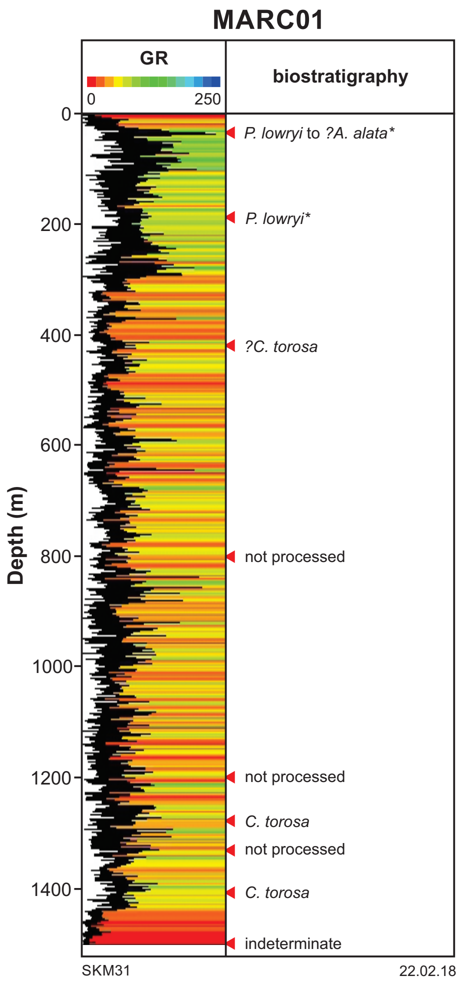
Mandurah Aquatic and Recreation Centre 01

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MARC01[(a)]				
–	36–39	DC	*P. lowryi*‡ to ?*A. alata*‡	(Backhouse, 2015)
–	189–195	DC	*P. lowryi*‡	(Backhouse, 2015)
–	420	DC	?*C. torosa*^	(Backhouse, 2015)
–	800	DC	not processed	(Backhouse, 2015)
–	1200	DC	not processed	(Backhouse, 2015)
–	1278	DC	*C. torosa*^	(Backhouse, 2015)
–	1330	DC	not processed	(Backhouse, 2015)
–	1407–1410	DC	*C. torosa*^	(Backhouse, 2015)
–	1500	DC	indeterminate	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone



Notes: TD = 1502.4 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

This is a recently drilled borehole, completed in 2015 to at least 1500 m depth. Only cuttings samples were obtained from this well, nine of which were submitted for palynological assessment. A report was prepared by Backhouse (2015), the results of which are only briefly summarized here due to their recent study. Three of the cuttings samples from the centre of the hole (800, 1200, 1330 m depth) were not analysed as the samples consisted of coal, which is unsuitable for palynological analyses. The remaining six samples yielded palynomorphs.

A sample at 189–195 m contained a diverse high-yielding assemblage including numerous dinoflagellates. Based on the co-occurrence of *Phoberocysta lowryi* and *Senoniasphaera tabulata*, the sample is clearly placed within the *Phoberocysta lowryi* Australian Dinocyst Zone and the spore-pollen indicate placement within the *Balmeiopsis limbata* Perth Basin Spore-Pollen Zone. An overlying sample, at 36–39 m, contained a similarly high-yielding diverse assemblage including dinoflagellates, with the spore-pollen again indicating the *B. limbata* Zone. However, the microplankton assemblage includes no index taxa and is a little more difficult to place within a zone. The sample must belong to the *P. lowryi* Zone or younger based on the underlying sample, and Backhouse considered the lack of *Muderongia australis* and other *Batioladinium jaegeri* Dinocyst Zone species an indication that the sample is older than these two roughly age-equivalent zones. As a result, the sample probably falls within the *Aprobolocysta alata* or *P. lowryi* Dinocyst Zones of Backhouse (1988). The unusual dinoflagellate assemblage seen in this shallower sample also indicates an increasing marine influence downhole within the Warnbro Group sediments.

The next three samples, from 420, 1278, and 1407–410 m, all contain Early Jurassic palynomorphs. The two shallowest samples in this set yielded a rich assemblage of spore-pollen, although many of the palynomorphs in the assemblage are clearly caved from overlying Cretaceous sediments. The deepest sample, which contains no evidence of caved palynomorphs, is relatively low yielding in comparison. Excluding the caved palynomorphs (which were noted to be paler in colour than the assumed in situ components), all three assemblages are dominated by *Classopollis torosus*, with this pollen comprising 95% of the palynomorphs recovered from the 1407–1410 m sample. This dominance of *C. torosus*, the few *Callialasporites turbatus* seen in the 420 m sample, and absence of *Exesipollenites tumulus*, suggest that all three samples fall into the *Corollina torosa* Spore-Pollen Zone. This further suggests that that the *Callialasporites turbatus* Spore-Pollen Zone was not encountered in this borehole. As Backhouse (2015) noted, this is counterintuitive due to the presence of coal within these samples, a feature almost always associated with the Cattamarra Coal Measures and therefore the *C. turbatus* Zone in the northern Perth Basin, although rare coaly beds are also noted within the Eneabba Formation (and therefore the *C. torosa* Zone) in this part of the basin (Mory and Iasky, 1996).

The deepest sample from the borehole, from 1500 m, yielded only Early Cretaceous palynomorphs, and is similarly interpreted as heavily contaminated, although the sediments at this depth appear to have been originally barren or very nearly so. Therefore, the age of the sediments at TD within this borehole is uncertain, but is possibly Early Jurassic.

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Shallow Mandurah region boreholes

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[b]	*Report*
MGC[a]				
65	19.8	DC	*B. limbata*[#] / ?*B. jaegeri*[‡] (*M. australis*[†])	(Edgell, 1963e)
90	27.4	DC	*B. jaegeri*[‡] (*M. australis*[†])	(Edgell, 1963d)
150	45.7	DC	*B. limbata*[#] / ?*B. jaegeri*[‡] (*M. australis*[†])	(Edgell, 1963a)
200	61.0	DC	*B. jaegeri*[‡] (*M. australis*[†])	(Edgell, 1963e)
240	73.2	DC	*B. jaegeri*[‡] (*M. australis*[†])	(Edgell, 1963e)
310	94.5	DC	*B. limbata*[#] / ?*B. jaegeri*[‡] (*M. australis*[†])	(Edgell, 1963e)
410	125.0	DC	*B. limbata*[#] / ?*B. jaegeri*[‡] (*M. australis*[†])	(Edgell, 1963b)
630	192.0	DC	*B. limbata*[#] / *P. lowryi*[‡] to *B. jaegeri*[‡]	(Edgell, 1963c)
700	213.6	DC	barren	(Edgell, 1963c)
MS1				
–	122	SWC	not processed	(Backhouse, 1980a)
–	128	SWC	*B. limbata*[#] / ?*P. lowryi*[‡]	(Backhouse, 1980a)
–	180	SWC	Early Cretaceous?	(Backhouse, 1980a)
–	210	SWC	*B. limbata*[#] / *P. lowryi*[‡]	(Backhouse, 1980a)
MI1/80				
–	21	DC	*D. davidii*[†] to *X. asperatus*[†]	(Backhouse, 1980b)
–	82	SWC	Early Cretaceous	(Backhouse, 1980b)
–	145	SWC	Early Cretaceous	(Backhouse, 1980b)
–	236	SWC	Early Cretaceous	(Backhouse, 1980b)
–	282	DC	Early Cretaceous	(Backhouse, 1980b)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [†]Helby et al. (1987) Dinocyst Zone; [#]Backhouse (1988) Spore-Pollen Zone; [‡]Backhouse (1988) Dinocyst Zone

Mandurah Golf Course bore 1 (MGC)

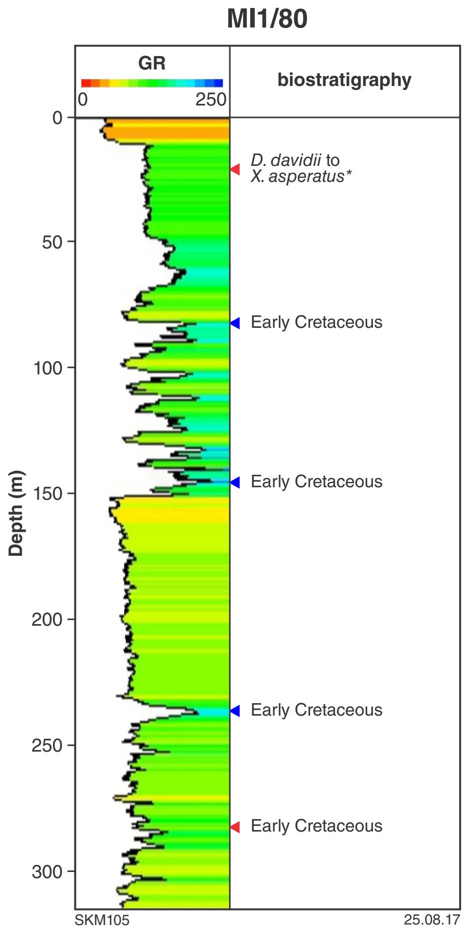
One of the earliest water bores in the Mandurah area, Mandurah Golf Course bore No. 1 was drilled in 1963 by the Mandurah Shire to provide adequate water for the golf course and its grounds (Emmenegger, 1964; Commander, 1975). The borehole reached a TD of 213.4 m. In total, nine ditch cutting samples were collected from this borehole for palynological assessment, from 65, 90, 150, 200, 240, 310, 410, 630 and 700 ft. These samples were described by HS Edgell in 1963, in five separate Paleontology Reports (Edgell, 1963a–e). In all, only the deepest sample, from 700 ft, was barren, with Edgell noting that the sample's sandy lithology was unsuitable for the preservation of palynomorphs.

The remaining samples were all considered Early Cretaceous in age, and all contained both miospores and dinocysts in their assemblages. The diversity and number of dinocysts varies between the samples, indicating variations in the amount of marine influence. Samples at 65, 150 and 310 ft had low yields of microplankton and were considered to represent only weakly marine sequences. Edgell (1963a–e) considered all of the samples to contain miospore assemblages typical of Balme's (1964) *Microcachryidites* Assemblage; the species lists provided for each sample suggest that all can be correlated with Backhouse's (1988) *Balmeiopsis limbata* Spore-Pollen Zone, based on the presence of species such as *Acanthotriletes levidensis*, *Balmeiopsis limbata* and common *Podocarpidites ellipticus*.

For the microplankton assemblages, Edgell (1963a–e) compared them to the sequence in MH1, which was the deepest and most complete sequence through the Early Cretaceous in that area at the time. Based on this, he considered samples from 90, 200 and 240 ft as belonging in his *Dingodinium cerviculum* Dinocyst Zone (Edgell, 1964), which Helby et al. (1987) equated to their *Muderongia australis* Dinocyst Zone. In the current Report, these samples are equated to the *Batioladinium jaegeri* Dinocyst Zone of Backhouse (1988). Due to general assemblage similarities, the poorer samples between these more diverse assemblages are also tentatively linked to that same dinocyst zone, although a review of the original slides would be required to clarify this. The deepest yielding sample in this set, at 630 ft, is not a very diverse assemblage, although the presence of *Cyclonephelium hystrix*, *Oligosphaeridium complex*, and *Dingodinium cerviculum* generally suggests the sample is younger than Backhouse's (1988) *Phoberocysta lowryi* Dinocyst Zone.

Mandurah Shire bore 1 (MS1)

Mandurah Shire No. 1 (also known as the Mandurah Shire Offices bore) was drilled by the City of Mandurah in 1980 to a TD of 191.72 m. A total of four sidewall cores were submitted for palynological assessment from this borehole, with all studied by J Backhouse in 1980, and reported in a single Paleontology Report (Backhouse, 1980a). As the shallowest sample at 122 m contained only drilling mud, this sample was not processed. The remaining three samples were all considered Early Cretaceous in age, although the sample from 180 m was almost barren and contained no dinoflagellates. Both samples from 128 and 210 m contained dinoflagellates and were interpreted to represent nearshore environments. Unfortunately, the report does not provide a complete species list for these samples, although Backhouse (1980a) noted the presence of *Phoberocysta* sp. A in the deepest sample, and on that basis assigned this sample to 'Warnbro Group Zone 3'. Based on his later monograph on Late Jurassic and Early Cretaceous palynomorphs (Backhouse, 1988), this species is indicative of either the *Kaiwaradinium scrutillinum* or *P. lowryi* Dinocyst Zones, although the informal 'Zone 3' is normally correlated to the *P. lowryi* Zone (Backhouse, 2015). Although the dinoflagellate assemblage from the 128 m sample was less distinctive, Backhouse considered this sample to also belong to his 'Warnbro Group Zone 3', although slightly younger than the deeper 210 m sample (Backhouse, 1980a). In the current Report, the sample is tentatively assigned to the *P. lowryi* Zone.



Notes: TD = 313 m; no lithostratigraphic picks available for this borehole; quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings, blue, sidewall cores

PWD Miami 1/80

PWD Miami 1/80 (also known as 'Grey Point bore') was drilled in 1980 by the Public Works Department in the Miami area of Mandurah, finishing at a TD of 313 m. Two ditch cuttings (at 21 and 282 m) and three sidewall cores (at 82, 145 and 236 m) were submitted for palynological analysis, with all samples reported on in a single GSWA Paleontology Report (Backhouse, 1980b).

Of the five samples, all except one (at 82 m) was noted to contain marine elements, although no taxa were listed for the deepest four assemblages. For the shallowest sample, the presence of *Endoceratium turneri* suggests correlation to the *Diconodinium davidii* to *Xenascus asperatus* Dinocyst Zones, and therefore an Aptian to Albian age, although both *E. turneri* and *Cribroperidinium edwardsii* are noted to occasionally extend into the Cenomanian (Helby et al., 1987). For the deeper samples, Backhouse (1980b) considered the assemblages to be Aptian or Barremian in age, which would suggest an association with the *Balmeiopsis limbata* Spore-Pollen Zone and associated dinocyst zones (Backhouse, 1988), although this is difficult to confirm without a species list or reference to the original slides. As such, this Record treats these deeper assemblages as generically Early Cretaceous in age.

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Mandurah Line 1

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
MH1[a]				
30	9.1	DC	Pleistocene to Recent	(Edgell, 1962c)
50	15.2	DC	Pleistocene to Recent	(Edgell, 1962c)
70	21.3	DC	Plio–Pleistocene	(Edgell, 1962c)
80	24.4	DC	*B. limbata*#	(Backhouse, 2011)
100	30.5	DC	*B. limbata*#	(Backhouse, 2011)
140	42.7	DC	*B. limbata*#	(Backhouse, 2011)
151	46.0	DC	*B. limbata*#	(Backhouse, 2011)
300	91.4	DC	*B. limbata*#	(Backhouse, 2011)
460	140.2	DC	*B. limbata*#	(Backhouse, 2011)
480	146.3	DC	*B. limbata*#	(Backhouse, 2011)
490	149.4	DC	*B. limbata*#	(Backhouse, 2011)
560	170.7	DC	*B. limbata*#	(Backhouse, 2011)
610	185.9	DC	*B. limbata*#	(Backhouse, 2011)
660	201.2	DC	*B. limbata*#	(Backhouse, 2011)
928	282.9	CC	*B. limbata*#	(Backhouse, 2011)
929	283.2	CC	*B. limbata*#	(Edgell, 1962a)
990	301.8	DC	Early to Middle Jurassic??	(Backhouse, 2011)
1006	306.6	CC	Early to Middle Jurassic??	(Backhouse, 2011)
1150	350.5	CC	Early to Middle Jurassic?	(Ingram, 1967)
1153	351.4	CC	Early to Middle Jurassic?	(Edgell, 1962a)
1155	352.0	CC	Early to Middle Jurassic?	(Backhouse, 2011)
1230	374.9	DC	Early to Middle Jurassic?	(Backhouse, 2011)
1350	411.5	CC	*?C. turbatus*^	(Backhouse, 2011)
1355	413.0	CC	*C. turbatus*^	(Backhouse, 2011)
1590	484.6	CC	barren	(Backhouse, 2011)
1594	485.9	CC	*C. turbatus*^ (small possibility of *C. torosa*^)	(Backhouse, 2011)

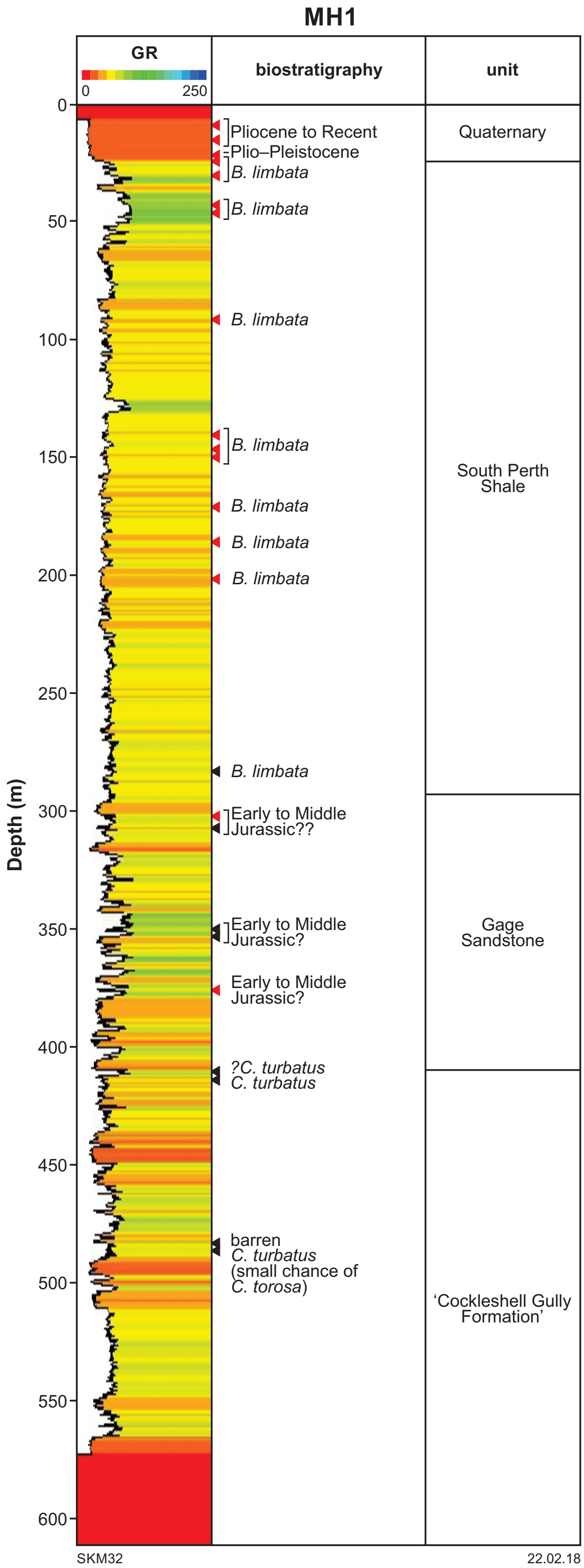
NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH1

MH1 is the oldest and deepest borehole in the Mandurah Line, spudded in 1962 and extending to a TD of 2005 ft (611.12 m). Located in Mandurah city on the western side of the estuary, the borehole was drilled to explore the stratigraphy and hydrology of this region of the Perth Basin, but found only poor-quality water. A full set of samples was collected from this bore, including ditch cuttings collected at 5 ft intervals, and 16 cores collected at different depths from 142 ft through to 1913 ft. Of these cores, only Core 12 from 1438 to1451 ft had no recovery (Passmore, 1962).



Notes: TD = 611.12 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; black, conventional cores

The initial palynological study on this borehole was reported in a set of five GSWA Paleontology Reports (Edgell, 1962a–e); this information was reviewed in a later GSWA Paleontology Report (Ingram, 1967). All this work was again reviewed by Backhouse (2011) at the behest of DoW (now DWER), as part of a project to reassess the hydrogeological potential of the Mandurah area. Only the earlier reports, not the slides themselves, were reviewed in the 2011 report, relying heavily on accurate taxonomic reporting of past studies.

Edgell's (1962a–e) original reports examined 15 ditch cutting samples (at 30, 50, 70, 80, 100, 140, 300, 460, 480, 490, 560, 610, 660, 990 and 1230 ft), and three core samples (from Core 1 at 151 ft, Core 8 at 929 ft, and Core 10 at 1153 ft). Interestingly, a brief report by Edgell included as Appendix 2 of Passmore (1962) suggested that further samples, extending from 1230 ft to TD, were also assessed by Edgell, although the reports describing these samples appear to be lost. Edgell (1963, 1964) used this work on MH1 to establish his Perth Basin microplankton zonation, which continued to be used in studies of the region until the establishment of Backhouse's (1988) and Helby et al.'s (1987) schemes in the late 1980s. For his later review, Ingram (1967) reassessed several samples derived from Cores 8 (928 ft), 9 (1006 ft), 10 (1150 and 1155 ft), 11 (1350 and 1355 ft) and 14 (1590 and 1594 ft). Ingram did not reassess the shallower samples as he was aiming to clarify the age of the unit underlying the Lower Cretaceous strata and the position of any age breaks.

The shallowest three samples from MH1 yielded diverse palynomorph assemblages that Edgell (1962c) considered Quaternary in age, specifically Pliocene or Pleistocene. The assemblages are relatively similar, dominated by pollen of the Myrtaceae and pollen aligned with the halophytic taxon *Salicornia*, although the identity of the rarer taxa varies from sample to sample. In all three samples, the assemblage included microplankton, suggesting marine influence throughout the interval, although the diversity and number of microplankton appears to increase with depth.

In his Paleontology Reports, Edgell (1962a–e) recorded all the remaining samples (down to 1230 ft) as containing distinctly Early Cretaceous palynomorph assemblages, including microplankton. Based on the cuttings samples, all were considered specifically Neocomian or Aptian in age, using spore or pollen species such as *Acanthotriletes levidensis*, *Contignisporites cooksoniae* and *Murospora florida* as indicators and confirmed using microplankton such as *Dingodinium cerviculum*. In the report included in Passmore's (1962) discussion of MH1, Edgell considered this Lower Cretaceous section to extend down to 1674 ft, with samples below this assigned to the Upper Jurassic 'Claremont Sandstone' (now considered part of the Yarragadee Formation). As there appear to be no reports from Edgell describing MH1 samples below 1230 ft, it is unclear why the unconformity was interpreted at this depth, particularly as Passmore (1962) noted that the unconformity is difficult to pick using lithology alone. In a later report establishing a microplankton biostratigraphic scheme for the Perth Basin, Edgell (1964) presented MH1 as a representative example, dividing the section into several zones: his 'Frequent *Deflandrea cincta*' Zone (equivalent to Helby et al.'s [1987] *Ascodinium cinctum* Dinocyst Zone) from 75 to 145 ft; *Dingodinium cerviculum* Zone (equivalent to Helby et al.'s [1987] *Muderongia australis* Dinocyst Zone) from 145 to 580 ft; *Muderongia mcwhaei* Zone (equivalent to Helby et al.'s [1987] *Muderongia testudinaria* to upper *Phoberocysta burgeri* Dinocyst Zones) from 580 to 780 ft; *Wetzeliella? neocomica* Zone (equivalent to Helby et al.'s [1987] *P. burgeri* to upper *Senoniasphaera tabulata* Dinocyst Zones) from 780 to 1150 ft; and *Deflandrea* sp. nov. Zone (equivalent to Helby et al.'s [1987] lower *S. tabulata* Zone) extends from 1150 to 1675 ft, with no microplankton recorded below 1675 ft.

Ingram's (1967) review of core material broadly supports Edgell's identifications, particularly as Core 8 was noted to contain the Neocomian–Aptian dinoflagellate *Muderongia mcwhaei*, and Cores 9 and 10 were noted by Ingram (1967) as containing poorly diversified assemblages giving an unresolved Late Jurassic to Early Cretaceous age. However, unlike Edgell, Ingram (1967) considered Core 11 to contain a low-diversity, 'mixed' assemblage with both Early Cretaceous and Early Jurassic palynomorphs, and Core 14 was considered 'likely Early Jurassic' in age based on the predominance of *Classopollis* and *Exesipollenites* specimens within a low-diversity assemblage. Therefore, the Jurassic/Cretaceous unconformity was thought to lie between 1150 and 1350 ft, assuming that the Early Cretaceous palynomorphs seen in Core 11 are contaminants. However, Ingram (1967) also discussed two other interpretations for the position of the unconformity; specifically, between 1350 and 1590 ft if the Early Jurassic palynomorphs in Core 11 are remanié, or even as shallow as 970 ft based on the well logs and assuming that all the low-diversity Cretaceous assemblages below Core 8 are the result of downhole contamination. Regardless, all three interpretations are much shallower than the 1674 ft depth proposed by Edgell (1963, 1964) for this boundary.

On the whole, Backhouse (2011) agreed with Ingram (1967) that the most likely pick for this boundary falls between 1150 and 1350 ft. However, he also noted that the Jurassic–Cretaceous unconformity is relatively shallow in the nearby Pinjarra 1 petroleum well, and therefore that Ingram's (1967) suggestion that the Early to Middle Jurassic strata may extend up to 970 ft is a distinct possibility. Based on the presence of *Classopollis* sp. and *Exesipollenites tumulus* in Core 14, Backhouse assigned the Jurassic palynology assemblages to the *Callialasporites turbatus* Zone, and likely the lower subzone.

Within the pre-Quaternary section of MH1, Lower Cretaceous dinoflagellates are recorded by both Edgell (1962a–e) and Ingram (1967) in all samples to at least 1230 ft depth. However, because the dinoflagellates seen below 929 ft may be downhole contamination, the age of the samples between 929 and 1590 ft requires clarification. Despite this, it seems clear that the entire Cretaceous deposition event in this borehole was under marine influence, which constitutes an unusual thickness of marine sediments for the southern Perth Basin. The two shallowest samples within the Lower Cretaceous section, at 80 and 100 ft were considered only weakly marine, and probably representative of brackish littoral setting, but from 140–1230 ft the samples are all considered marine nearshore or neritic. This interpretation is also confirmed by shallow-water foraminifera recorded at 480 ft (Edgell, 1962e). If Edgell's zone assignments for assemblages shallower than 929 ft are accurate, then the marine MH1 assemblages appear to cover the *Muderongia australis* to *S. tabulata* Zones; however, the slides will need to be reviewed to confirm this assignment.

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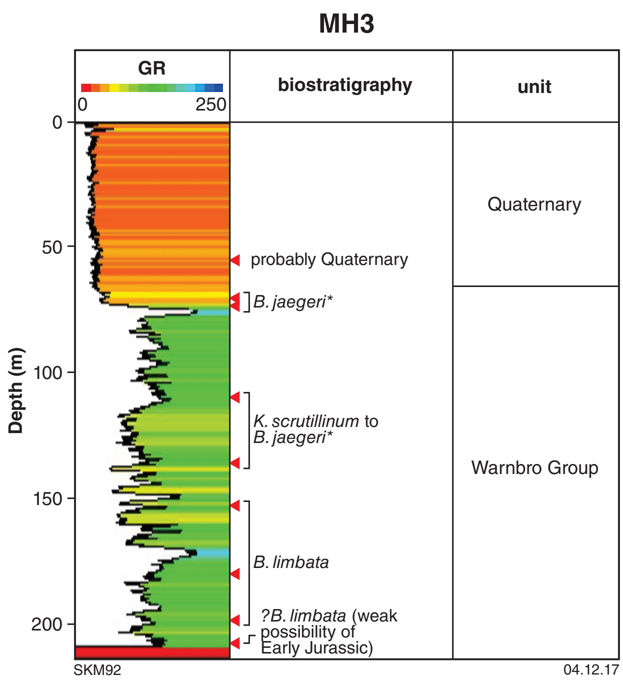
Mandurah Line 3

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH3[(a)]				
180	54.9	DC	probably Quaternary	(Backhouse, 2011)
230	70.1	DC	*B. jaegeri*‡	(Backhouse, 2011)
240	73.2	DC	*B. jaegeri*‡	(Backhouse, 2011)
360	109.7	DC	*K. scrutillinum*‡ to *B. jaegeri*‡	(Backhouse, 2011)
445	135.6	DC	*K. scrutillinum*‡ to *B. jaegeri*‡	(Backhouse, 2011)
500	152.4	DC	*B. limbata*#	(Backhouse, 2011)
590	179.8	DC	*B. limbata*#	(Backhouse, 2011)
650	198.1	DC	*B. limbata*#	(Backhouse, 2011)
680	207.3	DC	?*B. limbata*# (weak possibility of Early Jurassic)	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone



Notes: TD = 208.48 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH3

Located to the southeast of MH2, MH3 was drilled in July–August 1963 to a TD of 684 ft (208.48 m), before it was plugged and abandoned. As for MH2, no conventional or sidewall cores were collected from MH3, but ditch cuttings were collected every 5 ft and samples were retained every 10 ft (Emmenegger, 1964).

The initial palynology from MH3 was described in a set of three Paleontology Reports (Edgell, 1963a–c). This work was not reviewed until 2011, when the palynology of the Mandurah Line was reassessed for DoW (now DWER) by Backhouse (2011).

Edgell (1963a–c) conducted routine analyses on nine ditch cutting samples in this well from the following depths: 180 ft (54.9 m), 230 ft (70.1 m), 240 ft (73.2 m), 360 ft (109.7 m), 445 ft (135.6 m), 500 ft (152.4 m), 590 ft (179.8 m), 650 ft (198.1 m) and 680 ft (207.3 m; TD). The shallowest sample analysed, from 180 ft, yielded a sparse palynomorph assemblage dominated by eucalypt pollen, mixed with typical late Mesozoic spore-pollen taxa. Edgell considered the rare older microfloral taxa to be reworked and therefore considered the sample to be Quaternary in age. This agrees with the original formation picks from MH3, which placed the Quaternary – Late Cretaceous boundary at about 215 ft depth (Commander, 1975).

The remaining samples were all considered Early Cretaceous in age. All were assigned by Edgell (1963a–c) to the *Microcachryidites* Assemblage of Balme (1964), which corresponds to Helby et al.'s (1987) *Retitriletes watherooensis*, *Biretisporites eneabbaensis* and *Cicatricosisporites hughesi* western Spore-Pollen Zones, and Backhouse's (1988) *R. watherooensis* to *Balmeiopsis limbata* Spore-Pollen Zones. The shallowest sample in the Cretaceous section (230 ft) yielded low-diversity spore-pollen assemblages, although the underlying samples (240–445 ft) yielded diverse assemblages including the rare species *Acanthotriletes levidensis* and zone indicator *Balmeiopsis limbata* at 240 ft, and *Foveosporites canalis* at 445 ft; on this basis, this set of samples can be assigned to Backhouse's (1988) *B. limbata* Zone. Interestingly, the samples in the centre of the borehole (500–650 ft) are also of low palynomorph diversity, although all three still retain taxa typical of the *B. limbata* Zone, including *F. canalis* at 500 ft. The deepest sample, at 680 ft, yielded a diverse assemblage, similar to the shallower Cretaceous samples, including the *B. limbata* Zone indicators *A. levidensis* and *F. canalis*. For this reason, Edgell considered this sample Early Cretaceous, and specifically Neocomian, in age, although Backhouse (2011) stated there is a 'slight possibility' that this sample is in fact Jurassic, based on the abundance of *Classopollis* pollen. No Jurassic section had previously been recorded for the MH3 borehole, with the borehole originally interpreted as reaching TD within the Lower Cretaceous Warnbro Group (Commander, 1975).

Of the Cretaceous samples recovered from MH3, all showed marine influence on the depositional environment, except the sample at 500 ft which lacked microplankton and contained an abundance of plant material. Edgell (1963a–c) specifically considered the samples from 230 and 240 ft to be strongly marine, followed by marine samples at 360 and 445 ft, nonmarine at 500 ft, and weakly marine from 590 ft to TD. Therefore, this borehole shows a progressive reduction in marine influence downhole, with a brief nonmarine interlude in the centre of the section. The two shallowest of these samples contain a diverse microplankton assemblage, which was ascribed to Edgell's (1964) *Dingodinium cerviculum* Dinocyst Zone (Edgell, 1963c). This zone has been correlated to the Helby et al. (1987) *Muderongia australis* Dinocyst Zone, and thereby to the *Batioladinium jaegeri* Dinocyst Zone of Backhouse (1988). Although Edgell (1963c) considered this zone to be Aptian in age, Helby et al. (1987) regarded this zone as Barremian, and subsequent updates to the microplankton zone scheme (e.g. Partridge, 2006) place the zone from the late Hauterivian to the end Barremian. Therefore, it seems unlikely that the shallowest sediments in this borehole were Aptian in age and most can be considered Neocomian. Although the microplankton assemblages were of low diversity, the assemblages from 360 and 445 ft contain a number of species that generally suggest placement somewhere between the *B. jaegeri* and *K. scrutillinum* Dinocyst Zones, particularly *Oligosphaeridium complex* and *Pterospermella aureolata* (Backhouse, 1988). Edgell (1963c) assigned the deeper marine assemblages to *Wetzelliella neocomica* Dinocyst Zone (Edgell, 1964), which was later correlated to the Helby et al. (1987) upper *Senoniasphaera tabulata* to *Phoberocysta burgeri* Dinocyst Zones, and thereby to the *Kaiwaradinium scrutillinum* to *Phoberocysta lowryii* Dinocyst Zones of Backhouse (1988).

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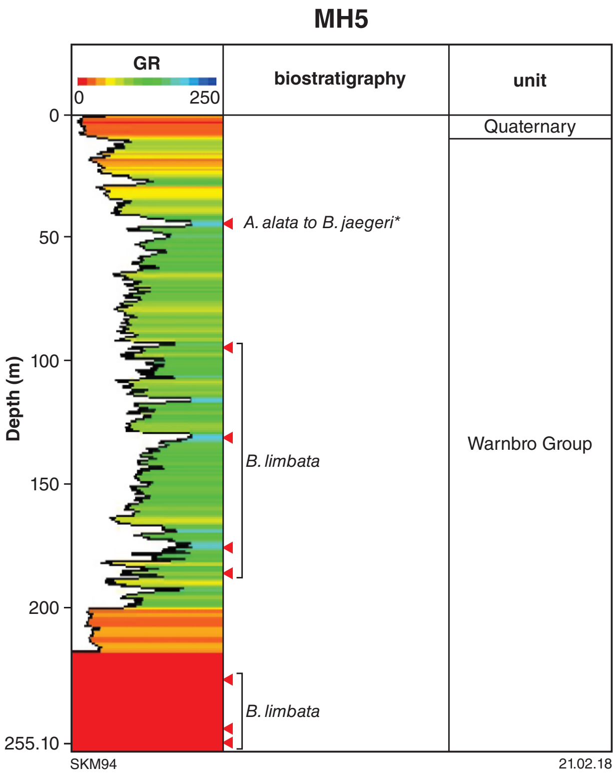
Mandurah Line 5

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH5[(a)]				
145	44.2	DC	*A. alata*‡ to *B. jaegeri*‡	(Backhouse, 2011)
310	94.5	DC	*B. limbata*#	(Backhouse, 2011)
430	131.1	DC	*B. limbata*#	(Backhouse, 2011)
575	175.3	DC	*B. limbata*#	(Backhouse, 2011)
610	185.9	DC	*B. limbata*#	(Backhouse, 2011)
785	239.3	DC	*B. limbata*#	(Backhouse, 2011)
820	249.9	DC	*B. limbata*#	(Backhouse, 2011)
837	255.1	DC	?*B. limbata*# (suspicion of Early Jurassic)	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone



Notes: **TD = 255.12 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH5

Drilled in November and December 1963, MH5 was the last of the first wave of Mandurah Line water bores. This borehole was drilled to a TD of 837 ft (255.12 m) and was handed over to the landowner for irrigation purposes at the end of the drilling program. As with previous bores in this line, MH5 recovered no conventional or sidewall cores, and ditch cuttings were retained every 10 ft (Emmenegger, 1964).

The initial palynology study from MH5 was described in a set of three Paleontology Reports (Edgell, 1963a,b, 1964). This work was not reviewed until 2011, when the palynology of the Mandurah Line was reassessed for DoW (now DWER) by Backhouse (2011).

Eight ditch cuttings were submitted for palynological analysis from this borehole, from depths of 145 ft (44.20 m), 310 ft (94.49 m), 430 ft (131.06 m), 575 ft (175.26 m), 610 ft (185.93 m), 785 ft (239.27 m), 820 ft (249.94 m) and 837 ft (255.12 m). All were considered by Edgell (1963a,b, 1964) to be Early Cretaceous in age, and assigned to Balme's (1964) *Microcachryidites* Assemblage. Backhouse (2011) later considered the deepest sample at 837 ft to perhaps fall into the Jurassic, but also stated that the section would require resampling to confirm this idea. Like MH3, this borehole had not previously been interpreted to include Jurassic sediments, with the original composite log indicating that the borehole reached TD within the Lower Cretaceous Warnbro Group (Commander, 1975).

Samples from 145 and 310 ft both yielded diverse microplankton cysts alongside the spore-pollen assemblage, and are considered to represent a littoral marine depositional environment. Below this point, marine influence appears to vary, with samples from 430 and 785 ft yielding rare microplankton and therefore considered paralic or weakly marine, and samples from 575, 610 and 837 ft all lacking microplankton and therefore considered nonmarine. The sample at 820 ft is considered littoral marine, although the diversity of microplankton is not as high as the shallowest samples. With regard to age, the presence of *Dingodinium cerviculum* and '*Gonyaulax diaphanis*' (species now considered a junior synonym of *Cribroperidinium muderongense*) seen in the shallowest sample was used by Edgell to interpret an Aptian age for the uppermost portion of MH5, and *Phoberocysta neocomica* in many of the deeper microplankton assemblages was used to assign a Neocomian age. Most microplankton-bearing samples fall somewhere within the *Kaiwaradinium scrutillinum* to *Fromea monilifera* Dinocyst Zones using Backhouse's (1988) scheme. However, the shallowest sample appears to be restricted to the *Aprobolocysta alata* to lower *Batioladinium jaegeri* Dinocyst Zones (Backhouse, 1988) based on the co-appearance of *Scriniodinium attadalense* and *Coronifera oceanica*.

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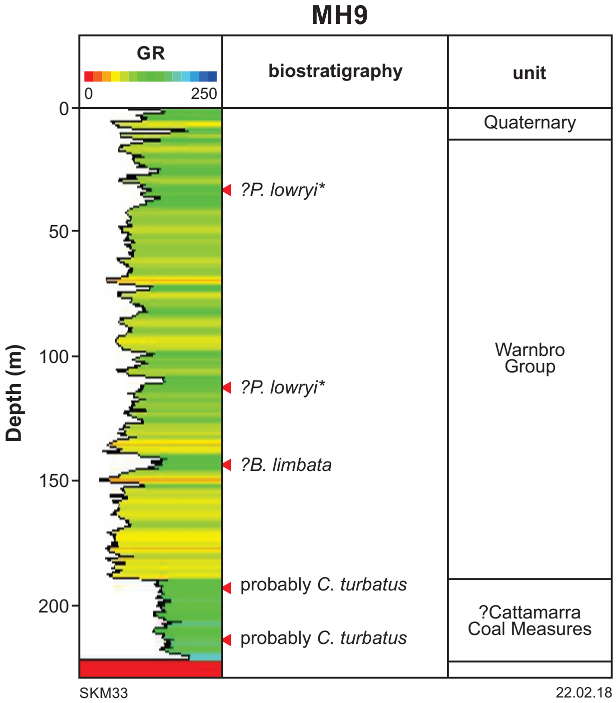
Mandurah Line 9

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH9[(a)]				
110–120	33.5 – 36.6	DC	?*P. lowryi*‡	(Backhouse, 2011)
368	112.2	DC	?*P. lowryi*‡	(Backhouse, 2011)
470	143.3	DC	?*B. limbata*#	(Backhouse, 2011)
630	192.0	DC	probably *C. turbatus*^	(Backhouse, 2011)
700	213.4	DC	probably *C. turbatus*^	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone



Notes: TD = 221.59 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region’s stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH9

MH9 was drilled in 1964 and 1965, to a TD of 727 ft (221.6 m). As for many Mandurah Line bores, no conventional or sidewall cores were recovered from this borehole, and ditch cuttings were collected and retained every 10 ft (Commander, 1975).

Samples from this borehole were studied by HS Edgell and BS Ingram, both of whom described their results in Paleontology Reports (Edgell, 1964; Ingram, 1965). This work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

In total, five ditch cuttings were submitted from this borehole — Edgell (1964) reported on a single sample from 110–120 ft (33.5 – 36.6 m), and Ingram (1965) described samples from 368 ft (112.2 m), 470 ft (143.3 m), 630 ft (192.0 m), and 700 ft (213.4 m). The shallowest three samples in that set were described as containing typically Early Cretaceous spore-pollen assemblages. Edgell (1964) considered the shallowest sample to contain ‘abundant’ spores, and described a relatively high diversity of taxa; whereas Ingram (1965) considered the deeper two samples as relatively poor in diversity and yield. Overall, Edgell (1964) considered the spore-pollen assemblage from 110–120 ft to be Aptian in age, correlating the samples with the upper part of the South Perth Formation.

Of these three Early Cretaceous samples, only those from 110–120 ft and 368 ft contained microplankton; the sample from 470 ft contained no microplankton and was therefore considered nonmarine. Like the spore-pollen assemblages, Edgell (1964) noted that microplankton were 'frequent' in the shallower sample, whereas Ingram (1965) considered the microplankton assemblage from 327 ft to be poor. Despite this, Ingram (1965) identified *Wetzeliella? neocomica* (now combined as *Phoberocysta neocomica*) in this assemblage, and thereby assigned the sample to Edgell's Neocomian *Wetzeliella? neocomica* Dinocyst Zone. Helby et al. (1987) considered this zone to correlate with their upper *Senoniasphaera tabulata* and lower *Phoberocysta burgeri* Dinocyst Zones. Backhouse's (2011) review considered this sample to belong to the *Phoberocysta lowryi* Dinocyst Zone of Backhouse (1988), which Helby et al. (1987) regarded as equivalent to their *P. burgeri* and lower *Muderongia testudinaria* Dinocyst Zones. Therefore, a correlation to the *P. burgeri* Zone of Helby et al. (1987) seems most likely for this sample. Edgell (1964) also considered that MH9 could be correlated with other Mandurah Line boreholes on the presence of index microplankton *Dingodinium cerviculum*, and using this he suggested a shallow westerly dip of the Early Cretaceous units from MH9 to MH1.

The deepest two samples from this borehole preserve a different, Early Jurassic palynoflora, lacking microplankton. Ingram (1965) noted that in both cases, the palynomorph yield was rich, but not particularly diverse, although the deepest sample at 700 ft was slightly richer than that at 630 ft. Ingram (1965) considered the assemblage, which contains abundant *Classopollis torosus* and *Callialasporites turbatus*, and frequent *Exesipollenites tumulus* among other taxa, to be entirely typical of the Early Jurassic, particularly as seen in the 'Byford beds', and compared the assemblage to that seen below 1670 ft in MH1. Based on this report, Backhouse (2011) considered these samples to likely fall within *Callialasporites turbatus* Spore-Pollen Zone.

The Jurassic–Cretaceous boundary likely falls somewhere between 470 and 630 ft in MH9, although issues with relating ditch cutting assemblages to depths may mean that boundary is slightly deeper than indicated. On the original MH9 well composite log, this unconformity was picked at 620 ft based on gamma ray logs, supporting the palynological data (Commander, 1975).

References

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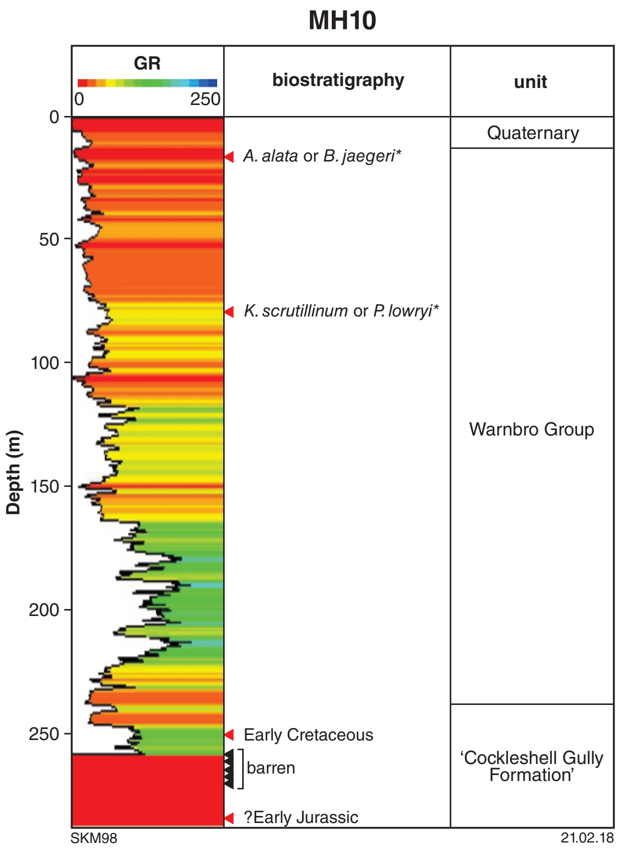
Mandurah Line 10

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH10[(a)]				
54–60	16.5 – 18.3	DC	*A. alata*‡ or *B. jaegeri*‡	(Ingram, 1967)
260–280	79.3 – 85.3	DC	*K. scrutillinum*‡ or *P. lowryi*‡	(Ingram, 1967)
820	249.9	DC	Early Cretaceous	(Ingram, 1967)
846	257.9	CC	barren	(Ingram, 1967)
850	259.1	CC	barren	(Ingram, 1967)
854	260.3	CC	barren	(Ingram, 1967)
855	260.6	CC	barren	(Ingram, 1967)
867	264.3	CC	barren	(Ingram, 1967)
875	266.7	CC	barren	(Ingram, 1967)
883	269.1	CC	barren	(Ingram, 1967)
885	269.8	CC	barren	(Ingram, 1967)
931–941	283.8 – 286.8	DC	?Early Jurassic	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ‡Backhouse (1988) Dinocyst Zone



Notes: TD = 286.82 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; black, conventional cores

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH10

MH10 was drilled in 1966 to a TD of 941 ft (286.8 m). As this borehole was drilled using a cable-tool and rotary plant, cores were collected in addition to the standard set of ditch cuttings collected every 10 ft (~3 m; Commander, 1975).

All samples submitted for palynology were studied by BS Ingram in 1967, with the information reported in a single Paleontology Report (Ingram, 1967). This work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

In total 12 samples from this borehole were submitted, consisting of four ditch cuttings at 54–60 ft (16.5 – 18.3 m), 260–280 ft (79.3 – 85.3 m), 820 ft (249.9 m) and 931–941 ft (283.8 – 286.8 m), and eight core samples from 846 to 885 ft (257.9 – 269.8 m).

Unfortunately, all eight core samples were taken from fine-grained, reddish-hued rocks, and all were found to be barren of palynomorphs. Therefore, only the remaining four cuttings samples were analysed for palynology.

The three shallowest samples in this set yielded Early Cretaceous spore-pollen assemblages, and were considered by Ingram (1967) to be Neocomian in age. The palynomorph assemblage yielded in the central sample (260–280 ft) was poorer than the other two samples; however, Ingram (1967) did not list the spores or pollen recorded from any of the samples, and the assemblages cannot be related to known spore-pollen zones without re-examination of the original slides. Microplankton were not recovered from the deepest of these three samples (at 820 ft), and the depositional environment is considered nonmarine. The poorer central sample yielded few and mostly fragmentary microplankton, with only a single species recognized — *Phoberocysta neocomica*. Conversely, the shallowest sample contains multiple species of microplankton, although Ingram (1967) noted that two of Edgell's (1964) index species (*Muderongia mcwhaei* and *Dingodinium cerviculum*) were found together, making the sample relatively difficult to link to a zone. Overall, the species are reminiscent of the late *Phoberocysta lowryi* to *Batioladinium jaegeri* Dinocyst Zones (Backhouse, 1988). Therefore, these three samples suggest decreasing marine influence down the section in MH10.

The deepest cuttings sample from this borehole only yielded only a poor assemblage of palynomorphs, with *Araucariacites australis* and *Classopollis* sp. the only identifiable taxa. Although these are long-ranging forms, Ingram (1967) considered that the sample composition, the paucity of palynomorphs, and observed lithologies suggest an Early Jurassic assemblage, although Backhouse (2011) agreed with Ingram that this assignation is extremely tentative and without real support. Using geophysical logs, the boundary between the Early Cretaceous (Warnbro Group) and Early Jurassic ('Cockleshell Gully Formation') was placed at roughly 830 ft, which agrees very broadly with this palynological data (Commander, 1975).

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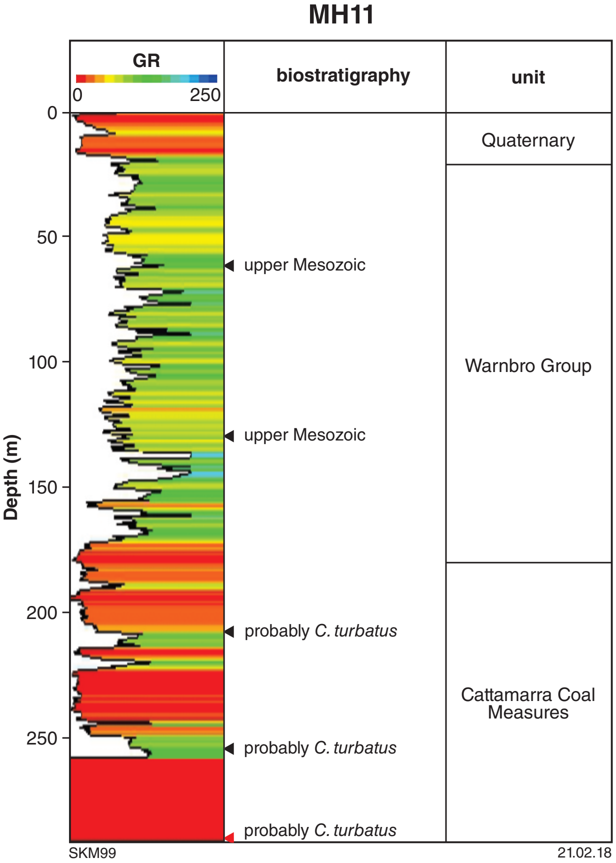
Mandurah Line 11

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
MH11[(a)]				
202–212	61.6 – 64.6	CC	upper Mesozoic	(Backhouse, 2011)
425–435	129.5 – 132.6	CC	upper Mesozoic	(Backhouse, 2011)
680–690	207.3 – 210.3	CC	probably *C. turbatus*^	(Backhouse, 2011)
833–843	253.9 – 257.0	CC	probably *C. turbatus*^	(Backhouse, 2011)
950	289.6	DC	probably *C. turbatus*^	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone



Notes: TD = 291.08 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; black, conventional cores

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH11

MH11 was drilled in 1966 to a TD of 955 ft (291.1 m). Although this borehole was drilled using a rotary plant, four cores were collected in addition to the standard set of ditch cuttings collected every 10 ft (~3 m; Commander, 1975).

All samples submitted for palynology were studied by BS Ingram in 1966, with the information reported in a single Paleontology Report (Ingram, 1966). Ingram did not list any of the taxa recovered from the samples, making his work difficult to reassess based only on his report. However, this work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

A total of four core samples were submitted for analysis (202–212, 425–435, 680–690 and 833–843 ft), plus one ditch cutting from the bottom of the borehole (950 ft). The two shallowest core samples, although containing considerable plant fragments, yielded very few palynomorphs, and Ingram (1966) considered that the age of these samples could not be determined more precisely than late Mesozoic.

The remaining core and cuttings samples all yielded richer palynomorph assemblages, although Ingram (1966) noted that the proportions of taxa change down the hole. Overall, the Core 3 sample was considered to be 'Middle Jurassic (Bajocian)' in age, the cutting sample 'definitely Lower Jurassic', and the Core 4 sample as transitional between those two samples (Ingram, 1966). The two taxa suggested as Bajocian indicators, *Callialasporites turbatus* and *Exesipollenites tumulus*, are now considered indicative of the lower part of the Helby et al. (1987) *Callialasporites turbatus* Spore-Pollen Zone when found together in the Perth Basin. Therefore, although the Bajocian sample was originally suggested to indicate the Cadda Formation (Ingram, 1966), the later review considered the occurrence of Cadda Formation within this borehole unproven due to a lack of marine palynomorphs (Backhouse, 2011). A more likely scenario is that MH11 preserves a transition from sediments of the lower *C. turbatus* Zone into the upper *Corollina torosa* Spore-Pollen Zone. Ingram (1966) noted that similar strata were observed within Pinjarra 1, and a recent review of the same petroleum well also identified *C. turbatus* Zone assemblages transitioning into assemblages of the *C. torosa* Zone.

Using geophysical and lithological cues, the Jurassic–Cretaceous unconformity (between the Lower Cretaceous Warnbro Group and Lower Jurassic 'Cockleshell Gully Formation') in this borehole has been interpreted at roughly 560 ft (Commander, 1975). Although the palynological data obtained to date does not contradict this interpretation, it does not help to support or constrain this depth either.

References

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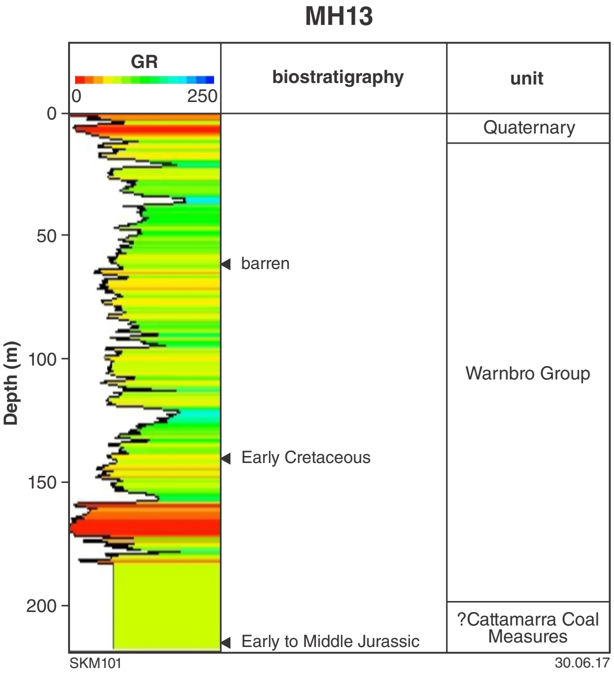
Mandurah Line 13

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH13[(a)]				
202–212	61.6 – 64.6	CC	barren	(Ingram, 1966)
460–470	140.2 – 143.3	CC	Early Cretaceous	(Ingram, 1966)
704–714	214.6 – 217.6	CC	Early to Middle Jurassic	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core



Notes: **TD = 217.63 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: black, conventional cores**

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region’s stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH13

MH13 was drilled in 1966 to a TD of 714 ft (217.63 m). Although this borehole was drilled using a rotary plant, three cores were collected in addition to the standard set of ditch cuttings collected every 10 ft (~3 m; Commander, 1975).

All samples submitted for palynology were studied by BS Ingram, with the information reported in a single Paleontology Report (Ingram, 1966). Ingram did not list any of the taxa recovered from the samples, making his work difficult to reassess based only on his report. However, this work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

Samples from each of the three conventional cores were submitted for palynological analyses. These are roughly equally spaced throughout the borehole section, at 202–212 ft (Core 1), 460–470 ft (Core 2), and 704–714 ft (Core 3). Despite all three samples having promising lithologies, Core 1 proved barren of spores and pollen.

Core 2 yielded a poor assemblage of Early Cretaceous taxa, including *Microcachryidites antarcticus*, which according to Backhouse (1988), first appears near the base of the *Retitriletes watherooensis* Spore-Pollen Zone. As Ingram (1966) only named *Contignisporites* sp. alongside this species, a more precise age cannot presently be determined for this sample. No mention of microplankton is made for this sample, so a nonmarine depositional environment is assumed at this depth.

Core 3 yielded a poor assemblage of Early Jurassic palynomorphs, specifically *Classopollis* and small *Cyathidites* grains. Although the sample was considered ‘similar to the poor assemblages obtained from the top of Lower Jurassic strata in other bores in this area’ (Ingram, 1966, p. 1), the description of a black mudstone lithology for this sample is somewhat anomalous for rocks of this age in this area. Backhouse (2011) agreed with Ingram that this sample is probably Middle or Early Jurassic in age, although noting that the assemblage was far from diagnostic. Based on this palynological data, the unconformity between Lower Cretaceous and Lower Jurassic strata must lie somewhere between 470 and

704 ft. Commander (1975) only tentatively placed this boundary at 650 ft depth, likely based on geophysical and lithological features.

References

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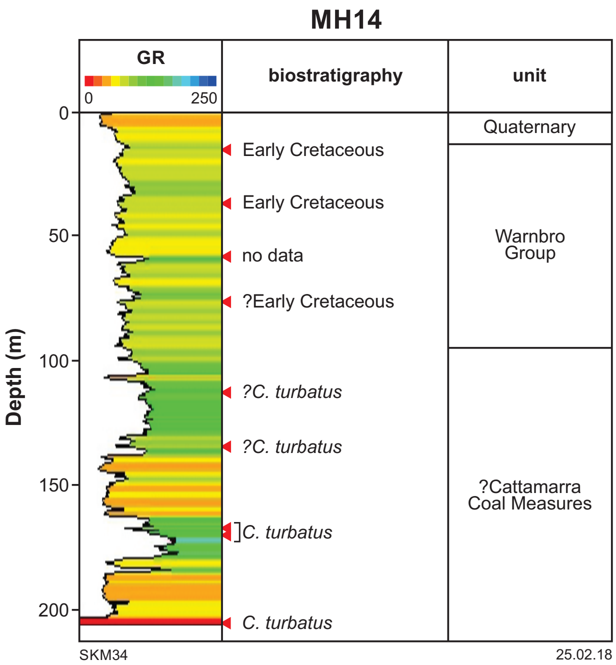
Mandurah Line 14

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH14[(a)]				
50	15.2	DC	Early Cretaceous	(Ingram, 1967)
120	36.6	DC	Early Cretaceous	(Ingram, 1967)
190	57.9	DC	[no data in report]	(Ingram, 1967)
250	76.2	DC	?Early Cretaceous	(Ingram, 1967)
370	112.8	DC	*?C. turbatus*^	(Backhouse, 2011)
440	134.1	DC	*?C. turbatus*^	(Backhouse, 2011)
548	167.0	DC	*C. turbatus*^	(Backhouse, 2011)
557	169.8	DC	*C. turbatus*^	(Backhouse, 2011)
674	205.4	DC	*C. turbatus*^	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone



Notes: TD = 206.35 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH14

MH14 was drilled in 1967 to a TD of 714 ft (206.35 m). This borehole was drilled using a cable-tool rig; no conventional or sidewall cores were collected, only a standard set of ditch cuttings were collected every 10 ft (~3 m; Commander, 1975).

All samples submitted for palynology were studied by BS Ingram in 1967, with the information reported in a single Paleontology Report (Ingram, 1967). This work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

In total, nine cutting samples were submitted for palynological analysis from the following depths: 50 ft (15.2 m), 120 ft (36.6 m), 190 ft (57.9 m), 250 ft (76.2 m), 370 ft (112.8 m), 440 ft (134.1 m), 548 ft (167.0 m), 557 ft (169.8 m) and 674 ft (205.4 m). All of these samples were processed and all yielded palynomorph assemblages.

Samples from 50 to 250 ft yielded Early Cretaceous spores, pollen and microplankton typical of the Warnbro Group. The shallowest of this set contained a poor miospore assemblage coupled with rare but clearly identifiable microplankton, whereas the sample from 120 ft preserved a similar assemblage with more diverse microplankton. The deepest sample of this trio contained only rare, poorly preserved microplankton with diverse miospores, suggesting nonmarine or paralic sediments of a similar age. Although the content of the 190 ft sample is not discussed in Ingram's report, it is assumed to have yielded similar Early Cretaceous palynomorphs.

The next two samples, from 370 and 440 ft, contained low-diversity, poorly preserved palynomorph assemblages of long-ranging late Mesozoic taxa, although Ingram reported the possible presence of *Exesipollenites tumulus*, which would suggest that these samples are Early or Middle Jurassic in age and assignable to either the *Corollina torosa* or *Callialasporites turbatus* Spore-Pollen Zones. The remaining three samples were considered Middle to Early Jurassic in age, based on the combined presence of *Classopollis torosus*, *Callialasporites turbatus*, *Staplinisporites caminus* and *Cibotiumspora jurienensis*. Because the proportions of *E. tumulus* and *Classopollis* spp. increase downhole, Ingram (1967) considered that the shallowest samples in this set are early Middle Jurassic in age and from the upper portions of the 'Cockleshell Gully Formation' (Cattamarra Coal Measures equivalent), whereas the deepest sample appears to be Early Jurassic in age. Backhouse's (2011) review considered this deeper portion of the borehole attributable to the *C. turbatus* Zone, with no mention of *C. torosa* Zone even in the deepest sample. Backhouse (2011) also agreed with Ingram that the Jurassic–Cretaceous unconformity falls somewhere between 250 and 548 ft, and most likely between 250 and 370 ft. This broadly agrees with the pick taken from lithological and geophysical data, which placed the unconformity at 310 ft depth (Commander, 1975).

References

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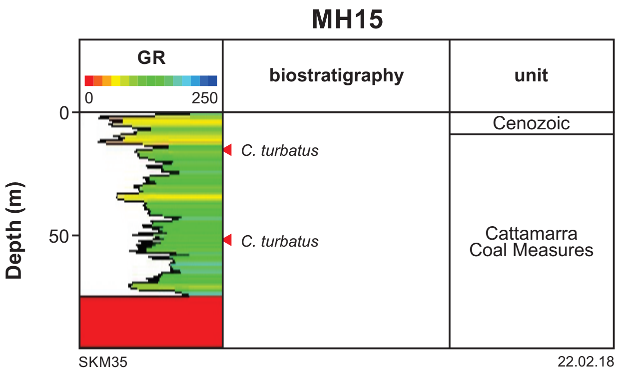
Mandurah Line 15

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
MH15[a]				
50	15.2	DC	*C. turbatus*^	(Backhouse, 2011)
170	51.8	DC	*C. turbatus*^	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone



Notes: TD = 95.1 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH15

MH15 was drilled in 1969 to a TD of 312 ft (95.10 m). This borehole was drilled using a cable-tool rig; no conventional or sidewall cores were collected, only a standard set of ditch cuttings were obtained every 10 ft (~3 m) (Commander, 1975).

All samples submitted for palynology were studied by BS Ingram in 1969, with the information reported in a single Paleontology Report (Ingram, 1969). This work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

Only two ditch cuttings, from 50 and 170 ft were submitted for palynological analysis. Both yielded similar assemblages which, although listed as 'limited' by Ingram (1969, p. 1), included taxa indicative of the Early to Middle Jurassic (*Classopollis torosus*, *Callialasporites turbatus* and *Callialasporites segmentatus*), long-ranging Jurassic–Cretaceous taxa (*Vitreisporites pallidus* and *Araucariacites australis*), and one form (*Microcachryidites antarcticus*) generally considered restricted to the Late Jurassic and Early Cretaceous (Filatoff, 1975; Helby et al., 1987; Backhouse, 1988). As the samples are cuttings, the broadly Jurassic–Cretaceous taxa may be a product of downhole contamination, and Backhouse (2011) considered both these samples to be assignable to the *Callialasporites turbatus* Spore-Pollen Zone. No samples were collected from the deeper half of this borehole, and as such it is presently uncertain whether MH15 bottomed within sediments of the *C. turbatus* Zone, or if it intersected older strata.

There is presently no evidence for sediments younger than Early Jurassic in age within this borehole. This interpretation agrees with the formation tops picked using geophysical and lithological data, which suggests that only sediments of the Lower Jurassic 'Cockleshell Gully Formation' were intersected in this borehole, and Quaternary or Cretaceous units are absent (Commander, 1975). Sections with thin or absent Cretaceous sediments are particularly common to the far east of the Perth Basin, close to the Darling Fault, where MH15 is located. A similar situation is seen in Alcoa Pinjarra borehole AE2, the Waroona Junior High School boreholes, and possibly also at MH17.

References

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

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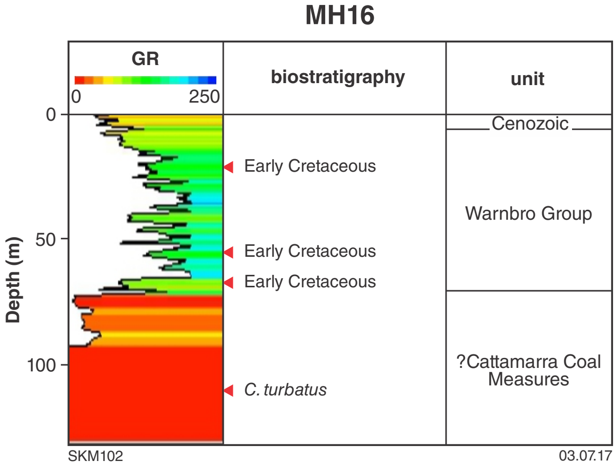
Mandurah Line 16

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH16[(a)]				
70	21.3	DC	Early Cretaceous	(Ingram, 1969)
180	54.9	DC	Early Cretaceous	(Ingram, 1969)
220	67.1	DC	Early Cretaceous	(Ingram, 1969)
360	109.7	DC	*C. turbatus*^	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone



Notes: TD = 130.45 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH16

MH16 was drilled in 1969 to a TD of 428 ft (130.45 m). This borehole was drilled using a cable-tool rig, no conventional or sidewall cores were collected, only a standard set of ditch cuttings were obtained every 10 ft (~ 3 m) (Commander, 1975).

All samples submitted for palynology were studied by BS Ingram in 1969, with the information reported in a single Paleontology Report (Ingram, 1969). This work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

A total of four ditch cuttings, from 70, 180, 220 and 360 ft, were submitted for palynological assessment. Of this set, the shallowest three samples yielded similar Early Cretaceous spore-pollen assemblages suggesting they belong in the Warnbro Group (and are therefore likely attributable to Backhouse's [1988] *Balmeiopsis limbata* Spore-Pollen Zone). As in other boreholes in the area, the shallowest of these three samples at 70 ft yielded microplankton, including *Dingodinium cerviculum*, used by Ingram (1969) to suggest a Neocomian to Aptian age at this depth. Microplankton are rare and indeterminate in the central sample, and the deepest sample lacks microplankton entirely, indicating a reduction in marine influence down the hole.

The final sample yielded a typical Early to Middle Jurassic spore-pollen assemblage, dominated by *Callialasporites turbatus* and *Araucariacites australis*, with *Exesipollenites tumulus*. Backhouse (2011) considered this assemblage assignable to the *Callialasporites turbatus* Spore-Pollen Zone, and probably the lower part of this zone. Although this would suggest that the Jurassic–Cretaceous unconformity in this borehole lies between 220 and 360 ft, the fact that only cuttings are analysed here means that the unconformity could be shallower in the hole, with any or all of the Cretaceous palynomorphs the result of downhole contamination (Backhouse, 2011). Despite this, Commander (1975) placed this boundary at approximately 230 ft depth, apparently on the basis of wireline logs and lithology.

References

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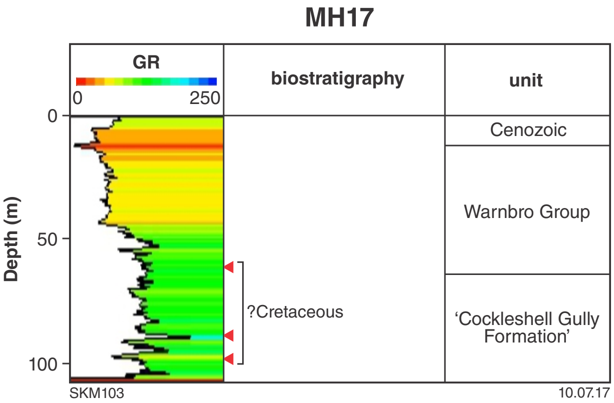
Mandurah Line 17

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MH17[(a)]				
200	61.0	DC	?Cretaceous	(Backhouse, 2011)
290	88.4	DC	?Cretaceous	(Backhouse, 2011)
320	97.5	DC	?Cretaceous	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)



Notes: TD = 106.98 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH17

MH17 was drilled in 1969 to a TD of 351 ft (106.98 m). This borehole was drilled using a cable-tool rig; no conventional or sidewall cores were collected, only a standard set of ditch cuttings were obtained every 10 ft (~3 m) (Commander, 1975).

All samples submitted for palynology were studied by BS Ingram in 1969, with the information reported in a single Paleontology Report (Ingram, 1969). This work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

Only three ditch cuttings, from 200, 290 and 320 ft, were submitted for palynological analysis from this borehole. Ingram (1969) noted that the assemblages obtained from the deeper two samples were essentially barren, with the sample at 320 ft yielding only a few modern pollen undoubtedly the result of downhole contamination. Therefore only the shallowest sample yielded useful palynomorphs, although even this sample was poor in its yield and diversity. Ingram (1969) noted only three identifiable taxa — *Murospora florida*, *Microcachryidites antarcticus* and *Classopollis torosus* — of which the first two were considered more suggestive of the Early Cretaceous. Backhouse (2011) agreed with Ingram that these three samples are 'probably Cretaceous'; however, in his review of the Mandurah region water bores, Commander (1975) placed a tentative boundary between Lower Cretaceous and Lower Jurassic strata at about 210 ft depth, suggesting that the two deeper barren samples were in fact derived from the 'Cockleshell Gully Formation' (either Cattamarra Coal Measures or Eneabba Formation in the northern Perth Basin). However, Commander noted that the presumed Lower Jurassic sediments in this well and MH18 were somewhat anomalous and could not easily be linked to other proven Lower Jurassic units known from Mandurah Line bores using either palynology or gamma ray log responses, and the true age of this section is therefore uncertain.

References

Backhouse, J 2011, Review of palynological data from Mandurah 1 borehole and some other Mandurah boreholes: Backhouse Biostrat Pty Ltd, Perth, Western Australia, Report BB349, 7p. (unpublished).

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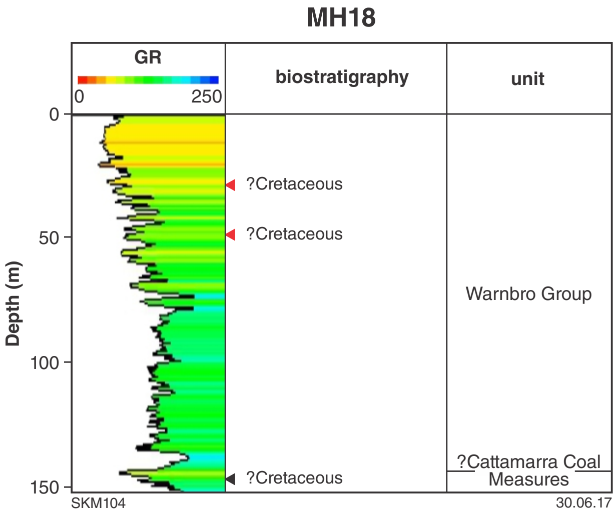
Mandurah Line 18

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
MH18[(a)]				
95	29.0	DC	?Cretaceous	(Backhouse, 2011)
160	48.8	DC	?Cretaceous	(Backhouse, 2011)
480–500	146.3 – 152.4	CC	?Cretaceous	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples



Notes: TD = 152.4 m; lithostratigraphy based on Commander (1975); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; black, conventional cores

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH18

MH18 was drilled in 1969 to a TD of 500 ft (152.40 m). This borehole was drilled using a cable-tool rig; a total of four conventional cores were collected from this hole, plus a standard set of ditch cuttings obtained every 10 ft (~3 m) (Commander, 1975).

All samples submitted for palynology were studied by BS Ingram in 1969, with the information reported in a single Paleontology Report (Ingram, 1969). This work was briefly reviewed by Backhouse (2011) as part of a reassessment of the palynology of the Mandurah Line for DoW (now DWER).

In total, four samples were submitted for palynology from this borehole; two ditch cuttings samples from 95 and 160 ft, and two samples from a single core at 480–500 ft depth. As in MH17, the two deepest samples from the core proved to be barren of palynomorphs, although plant tissues were recovered from the samples. The two shallowest samples contained poor spore-pollen assemblages of generally Early Cretaceous age, including taxa identified by Ingram (1969) as *Microcachryidites antarcticus*, *Contignisporites* spp., *Ischyosporites* spp., and *Tsugaepollenites* spp. Both samples lack microplankton and are therefore considered derived from a nonmarine facies, likely from the Warnbro Group. As with comparable samples in other Mandurah Line wells, Backhouse (2011) considered these shallower samples to be 'probably Cretaceous' and there is no direct palynological evidence that MH18 intersected strata older than Early Cretaceous. Despite this, Commander (1975) suggested the presence of 'Cockleshell Gully Formation' in the deeper part of this hole, including the barren core sections. However, no depth for the Jurassic–Cretaceous unconformity was estimated in this report, and it was noted that the lack of palynological evidence and unusual gamma ray logs for this bore and MH17 made the section difficult to correlate with other sections of presumably similar age in the area.

References

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Other Mandurah Line boreholes

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
MH2[(a)]				
30	9.1	DC	Quaternary	(Edgell, 1963a)
50	15.2	DC	Early Cretaceous	(Edgell, 1963a)
60	18.3	DC	Early Cretaceous	(Edgell, 1963a)
80	24.4	DC	Early Cretaceous	(Edgell, 1963a)
140	42.7	DC	Early Cretaceous	(Edgell, 1963a)
220	67.1	DC	Early Cretaceous	(Edgell, 1963a)
310	94.5	DC	Early Cretaceous	(Edgell, 1963a)
470	143.3	DC	Early Cretaceous	(Edgell, 1963a)
540	164.6	DC	Early Cretaceous	(Edgell, 1963a)
MH4				
110	33.5	DC	Early Cretaceous	(Edgell, 1963b)
215	65.5	DC	Early Cretaceous	(Edgell, 1963b)
320	97.5	DC	Early Cretaceous	(Edgell, 1963b)
460	140.2	DC	Early Cretaceous	(Edgell, 1963b)
MH6				
500–504	152.4 – 153.6	DC	Early Cretaceous	(Backhouse, 2011)
504–510	153.6 – 155.5	DC	Early Cretaceous	(Backhouse, 2011)
MH7				
138	42.1	DC	barren	(Ingram, 1965)
362	110.3	DC	Early Cretaceous	(Ingram, 1965)
482	146.9	DC	indeterminate	(Ingram, 1965)
616	187.8	DC	*P. lowryi*‡ or *A. alata*‡	(Ingram, 1965)
656	200.0	DC	*P. lowryi*‡	(Backhouse, 2011)
MH8				
327	99.7	DC	Early Cretaceous	(Ingram, 1965)
470	143.3	DC	Early Cretaceous	(Edgell, 1965)
500	152.4	DC	*P. lowryi*‡	(Backhouse, 2011)
MH12				
260–270	79.3 –82.3	CC	Early Cretaceous	(Backhouse, 2011)
439–449	133.8 – 136.9	CC	Early Cretaceous	(Backhouse, 2011)
660–670	201.2 – 204.2	CC	Early Cretaceous	(Backhouse, 2011)
762–772	232.3 – 235.3	CC	indeterminate	(Backhouse, 1977)
943–950	287.4 – 289.6	CC	*A. alata*‡ to *F. monilifera*‡	(Backhouse, 2011)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ‡Backhouse (1988) Dinocyst Zone

Line summary

The Mandurah Line (MH) water bores are one of the key hydrogeological exploration lines in the southern Perth Basin. Drilling of this line began at the request of the then Public Works Department (PWD) in 1962, with the aim of finding suitable water supplies for Mandurah and the surrounding area (Commander, 1975). A total of 18 wells was eventually drilled as part of this project, with the last (MH18) completed in 1969. As little was known of the region's stratigraphy at the time, a number of these bores were drilled deeper than 200 m, and palynological studies were conducted on all 18 bores at the time of drilling.

MH2, 4, 6, 7, 8, 12

None of the Mandurah Line boreholes listed here — MH2, 4, 6–8, 12 — show any indication of having penetrated below the Cretaceous sequence. Of these boreholes, only MH2 yielded Quaternary or Recent palynomorph assemblages, with the Quaternary – Early Cretaceous unconformity likely falling between 30 and 50 ft (9.1 – 15.2 m). The remaining samples from these holes are all considered Early Cretaceous in age, although the MH6 assemblages are so poor that no further biostratigraphic precision can be determined for this hole (Edgell, 1963a,b, 1965; Ingram, 1965, 1966a,b; Hooper, 1972; Backhouse, 1977, 2011).

Apart from the indeterminate MH6, the boreholes included marine palynomorph assemblages assigned to Backhouse's (1988) *Kaiwaradinium scrutilinium* to *Fromea monilifera* Dinocyst Zones, and are therefore equivalent to the *Balmeiopsis limbata* Spore-Pollen Zone. Most of the Cretaceous samples along this line have a distinct marine influence, although the amount of influence clearly waxes and wanes throughout the deposition of these sediments. In addition, Backhouse (2011) noted a distinct thinning of the Cretaceous section towards the east, likely explaining why the Jurassic section is almost always intersected in the eastern portion of the line, and only rarely in the deepest waterbores to the west (specifically MH1, which extends below 500 m depth).

Backhouse (1988) included the Mandurah Line boreholes in his seminal revision of Late Jurassic and Early Cretaceous in the Perth Basin, and more details on the late Mesozoic as seen in this borehole line are available there.

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Ingram, BS 1965, Palynology of samples from Mandurah No. 7 and No. 8 bores: Geological Survey of Western Australia, Paleontology Report 1965/21, 3p.

Ingram, BS 1966a, Five core samples from Mandurah No. 12 bore: Geological Survey of Western Australia, Paleontology Report 1966/35, 1p.

Ingram, BS 1966b, Two sludge samples from Mandurah No. 6 water bore: Geological Survey of Western Australia, Paleontology Report 1966/08, 1p.

Murray–Peel Leederville 2A

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
MPL2A[(a)]				
–	47–48	DC	upper *P. lowryi*‡ to *A. alata*‡	(Backhouse, 2013)
–	57–58	DC	upper *P. lowryi*‡ to *A. alata*‡	(Backhouse, 2013)
–	69–70	DC	upper *P. lowryi*‡ to *A. alata*‡	(Backhouse, 2013)
–	100–101	DC	*P. lowryi*‡ to *A. alata*‡	(Backhouse, 2013)
–	123–124	DC	*P. lowryi*‡ to *A. alata*‡	(Backhouse, 2013)
–	138–140	DC	*B. limbata*#	(Backhouse, 2013)
–	160–168	DC	*P. lowryi*‡	(Backhouse, 2013)
–	190–193	DC	*C. turbatus*^	(Backhouse, 2013)
–	220–224	DC	*C. turbatus*^	(Backhouse, 2013)
–	248–250	DC	*C. turbatus*^	(Backhouse, 2013)
–	289–293	DC	*C. turbatus*^	(Backhouse, 2013)
–	337–338	DC	*C. turbatus*^	(Backhouse, 2013)
–	343–344	DC	*C. turbatus*^	(Backhouse, 2013)
–	365–366	DC	*C. turbatus*^	(Backhouse, 2013)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

Line summary

The Department of Water (DoW, now DWER) drilled the Murray–Peel Leederville (MPL) line of bores in 2012 and 2013. As these samples were studied recently, with modern drilling and sample processing methods, the data can be considered to be relatively accurate and do not require translation from older taxonomic and biostratigraphic concepts. Basic well data for all of these holes can be found on DWER's Water Information Reporting (WIR) database.

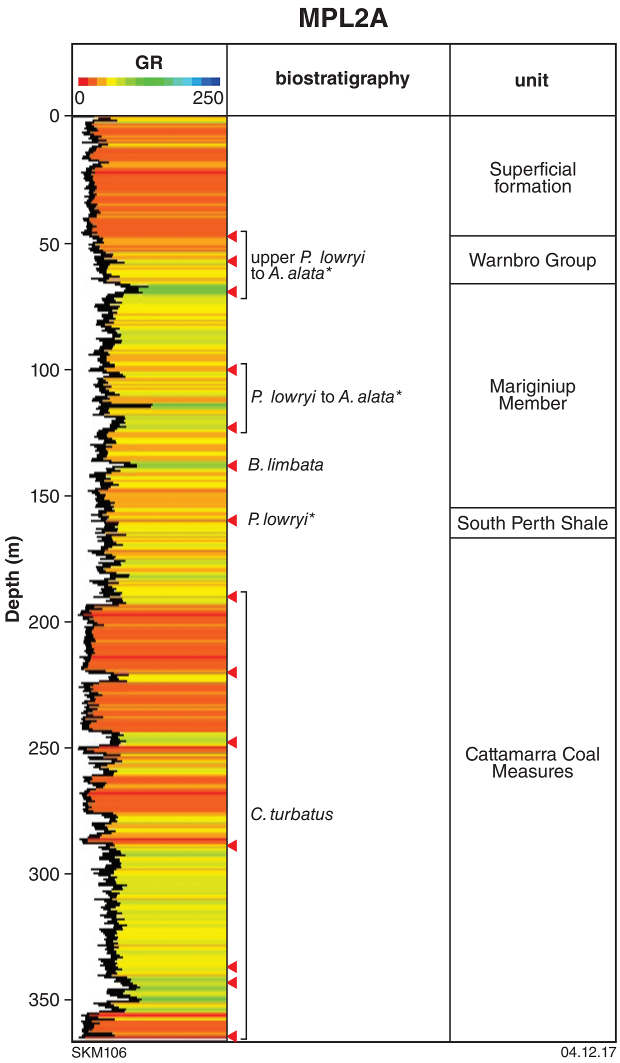
Altogether, the MPL line consists of sixteen boreholes drilled on eight separate sites; at each site, a deeper (with the 'A' suffix) and shallower (with the 'B' suffix) borehole were drilled alongside one another. All of these holes were deeper than 100 m TD — the shallowest being MPL6A (150 m TD) and the deepest MPL2A (366 m TD). Only ten of the sixteen MPL boreholes were assessed palynologically, and only five of these ten clearly penetrated the Cretaceous unconformity, with one additional bore tentatively considered to extend into the Jurassic section.

MPL2A

Drilled in 2013 to a TD of 366 m, MPL2A is the deepest borehole on the MPL line of water bores. A total of 12 ditch cuttings were submitted from this well for palynological analysis, extending from 47 to TD. The samples were studied by J Backhouse and presented in a report to DWER (then DoW) in 2013 (Backhouse, 2013). All samples from this borehole yielded palynomorphs, which could be broadly split into two major palynofloras.

The shallowest five samples (47–48, 57–58, 69–70, 100–101, and 123–124 m) yielded very similar palynomorph assemblages, including moderate numbers of dinoflagellates. Although the dinoflagellates were all of the 'Warnbro Group' type, none was considered biostratigraphically diagnostic, and the assemblages could not be placed more precisely than either the *Aprobolocysta alata* or *Phoberocysta lowryi* Dinocyst Zones. The presence of the dinoflagellate *Dingodinium cerviculum* in the 69–70 m sample indicates that this and the overlying samples are from the upper *P. lowryi* or *A. alata* Zones, but the two deeper samples cannot be assigned this slight zone refinement. The *P. lowryi and A. alata* Zones traditionally correlate to the centre of the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988), and the spore-pollen assemblages seen in these samples are typical for this zone.

The next deepest sample, from 138–140 m, contained only rare, fragmentary dinocysts assumed to be caved from higher in the borehole; the spore-pollen assemblage can be assigned to the *B. limbata* Zone, and does not appear vastly different in individual species distributions from the overlying sediments. As a result, this is considered to be a fluviatile part of the same sequence. This idea is supported by the palynoflora recovered from the 161–168 m sample, which contains rare *Phoberocysta lowryi*, and can therefore be assigned to the *P. lowryi* Zone. As with the overlying samples, the spore-pollen portion of this assemblage indicates an association to the *B. limbata* Zone, although a single specimen of *Callialasporites turbatus* was found. Although this species is normally considered evidence for a Jurassic age, the lack of other Jurassic forms (such as *Exesipollenites tumulus*) suggests



Notes: TD = 366 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

that the Jurassic section has not yet been reached at this depth.

At 190 m there is a distinct change in the palynoflora, from dominantly marine Early Cretaceous forms, to nonmarine Early Jurassic spores and pollen. The shallowest sample below this level, at 190–193 m, yielded a rich and diverse assemblage of well-preserved palynomorphs, dominated by *Classopollis torosus*, with common *C. turbatus* and *E. tumulus*, and consistent *Dictyophyllidites harrisii*. Together, these taxa place the sample firmly within the *Callialasporites turbatus* Spore-Pollen Zone, and likely within the lower part of that zone, based on the presence of relatively short-ranging form *E. tumulus*. The next three samples (220–224, 248–250, and 289–293 m) also yielded moderately rich assemblages of similar composition and can also be placed within this spore-pollen zone. Although the deepest three samples from this borehole (337–338, 343–344, 365–366 m) also yielded similar *C. turbatus* Zone assemblages, the extremely low yield of the assemblages suggests that these samples are in fact barren, and the few palynomorphs seen are caved from the richer overlying levels. Considering the low-yielding nature of the *Corollina torosa* Spore-Pollen Zone in the Perth Basin (Filatoff, 1975; Helby et al., 1987), it is possible that this zone was intersected in the deepest parts of MPL2A, although there is no solid evidence to support this at present.

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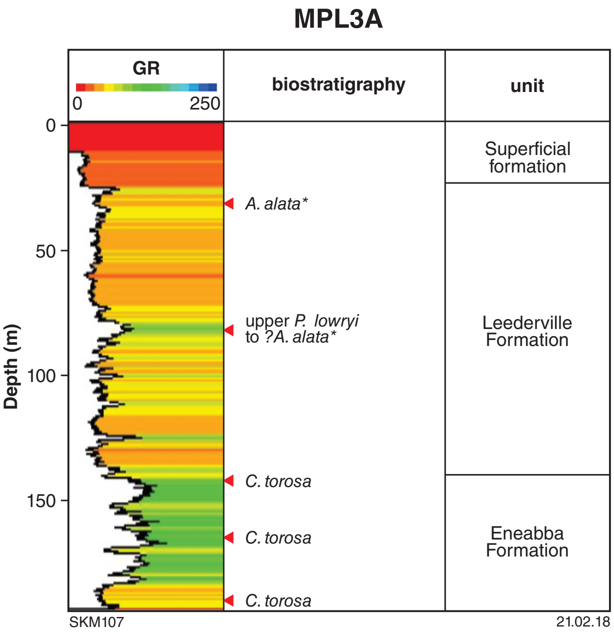
Murray–Peel Leederville 3A

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MPL3A[(a)]				
–	31–32	DC	*A. alata*‡	(Backhouse, 2013)
–	82–83	DC	upper *P. lowryi*‡ to *?A. alata*‡	(Backhouse, 2013)
–	142–143	DC	*C. torosa*^	(Backhouse, 2013)
–	165–166	DC	*C. torosa*^	(Backhouse, 2013)
–	190–192	DC	*C. torosa*^	(Backhouse, 2013)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone



Notes: TD = 192 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Department of Water (DoW, now DWER) drilled the Murray–Peel Leederville (MPL) line of bores in 2012 and 2013. As these samples were studied recently, with modern drilling and sample processing methods, the data can be considered to be relatively accurate and do not require translation from older taxonomic and biostratigraphic concepts. Basic well data for all of these holes can be found on DWER's Water Information Reporting (WIR) database.

Altogether, the MPL line consists of sixteen boreholes drilled on eight separate sites; at each site, a deeper (with the 'A' suffix) and shallower (with the 'B' suffix) borehole were drilled alongside one another. All of these holes were deeper than 100 m TD — the shallowest being MPL6A (150 m TD) and the deepest MPL2A (366 m TD). Only ten of the sixteen MPL boreholes were assessed palynologically, and only five of these ten clearly penetrated the Cretaceous unconformity, with one additional bore tentatively considered to extend into the Jurassic section.

MPL3A

MPL3A was drilled in 2013 to a TD of 192 m. Five ditch cuttings from this borehole were submitted for palynological studies, with the results presented in a single informal report (Backhouse, 2013). All the samples yielded palynofloras, although none was particularly rich in palynomorphs. Like MPL2A, the results from MPL3A indicate two separate palynofloras.

The two shallowest samples, ditch cuttings from 31–32 and 82–83 m depth, both yielded low numbers of dinoflagellates. Like MPL2A, most of these are generic 'Warnbro Group' forms of little biostratigraphic significance. However, the shallowest sample includes the dinoflagellate *Aprobolocysta alata* and shows no evidence of overlying zones, allowing this sample to be placed confidently within the *Aprobolocysta alata* Dinocyst Zone (Backhouse, 1988). The deeper sample, lacking index taxa for either higher or lower zones, can only be associated with either the *A. alata* or *Phoberocysta lowryi* Dinocyst Zones, although its low dinoflagellate yield makes this somewhat uncertain.

The deepest three samples from this borehole — 142–143, 165–166, and 190–192 m — contained low- to very low-yielding palynomorph assemblages strongly dominated by the pollen *Classopollis torosus*. This, plus the lack of common araucarian pollen in the assemblages, suggests assignment to the *Corollina torosa* Spore-Pollen Zone

(Filatoff, 1975; Helby et al., 1987). A small number of Cretaceous spore-pollen and dinoflagellates were also recovered from each of these samples, although these are presumed to be downhole contamination. The appearance of *C. torosa* Zone directly underlying the Cretaceous unconformity in this borehole is somewhat surprising, particularly when compared to the presence of the *Callialasporites turbatus* Spore-Pollen Zone at roughly the same level in nearby MPL2A. Unfortunately, the *C. torosa* Zone is poorly defined, and mostly defined by species absences in the Perth Basin, making it a difficult zone to identify with certainty. It is possible that an unusual, low-yielding *C. turbatus* Zone assemblage could resemble the older spore-pollen zone, and this may be the explanation here.

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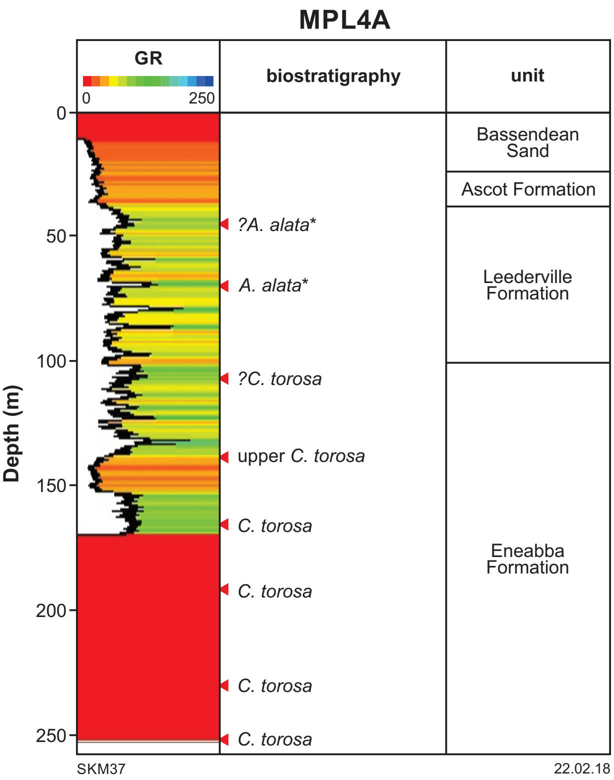
Murray–Peel Leederville 4A

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MPL4A[(a)]				
–	44–45	DC	?*A. alata*[‡]	(Backhouse, 2013)
–	69–70	DC	*A. alata*[‡]	(Backhouse, 2013)
–	106–107	DC	?*C. torosa*^	(Backhouse, 2013)
–	138–139	DC	upper *C. torosa*^	(Backhouse, 2013)
–	165–166	DC	*C. torosa*^	(Backhouse, 2013)
–	191–192	DC	*C. torosa*^	(Backhouse, 2013)
–	230–231	DC	*C. torosa*^	(Backhouse, 2013)
–	252–253	DC	*C. torosa*^	(Backhouse, 2013)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [‡]Backhouse (1988) Dinocyst Zone



Notes: TD = 253 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Department of Water (DoW, now DWER) drilled the Murray–Peel Leederville (MPL) line of bores in 2012 and 2013. As these samples were studied recently, with modern drilling and sample processing methods, the data can be considered to be relatively accurate and do not require translation from older taxonomic and biostratigraphic concepts. Basic well data for all of these holes can be found on DWER's Water Information Reporting (WIR) database.

Altogether, the MPL line consists of sixteen boreholes drilled on eight separate sites; at each site, a deeper (with the 'A' suffix) and shallower (with the 'B' suffix) borehole were drilled alongside one another. All of these holes were deeper than 100 m TD — the shallowest being MPL6A (150 m TD) and the deepest MPL2A (366 m TD). Only ten of the sixteen MPL boreholes were assessed palynologically, and only five of these ten clearly penetrated the Cretaceous unconformity, with one additional bore tentatively considered to extend into the Jurassic section.

MPL4A

Drilled in 2013 to a TD of 253 m, MPL4A had a total of eight ditch cutting samples submitted for palynological analyses. The results of this analysis were discussed in a single report by palynologist J Backhouse (Backhouse, 2013). Although palynomorphs were obtained from all samples, yields were low. Like other MPL boreholes, the results from MPL4A indicate two separate palynofloras.

The two shallowest samples (44–45 and 69–70 m) yielded typical 'Warnbro Group' assemblages, including dinoflagellates, indicating marine depositional conditions. The shallower sample contains *Dingodinium cerviculum* and *Phoberocysta neocomica*, which together indicates this sample falls somewhere between the uppermost

Phoberocysta lowryi and lowermost *Batioladinium jaegeri* Dinocyst Zones. The deepest sample yielded a similar assemblage, but includes *Phoberocysta burgeri*, which allows this range to be refined to the *Aprobolocysta alata* Dinocyst Zone (Backhouse, 1988).

The next deepest sample, from 106–107 m, is somewhat transitional, containing evidence of two separate palynofacies. Early Cretaceous spores, pollen and dinocysts similar to those obtained from the overlying samples are seen, alongside very common specimens of *Classopollis torosus* more similar to underlying samples. As the simplest explanation is to suggest that the Early Cretaceous forms are caved into a very low-yielding assemblage dominated by *C. torosus*, Backhouse tentatively assigned this sample to the *Corollina torosa* Spore-Pollen Zone, although there is very little evidence of this particular zone.

The deepest five samples (138–139, 165–166, 191–192, 230–231, 252–253 m) all had low or extremely low yields of spores and pollen, lacking dinoflagellates. There are a few obviously caved palynomorphs seen in the samples, but otherwise the assemblage contains Early Jurassic forms. The shallowest sample of this set is slightly richer than the other samples and contains very high percentages of *C. torosus*, associated with *Anapiculatisporites dawsonensis* and *Nevesisporites vallatus*, which together provide strong evidence for the upper *C. torosa* Zone for this sample (Filatoff, 1975; Helby et al., 1987). As the lower assemblages are relatively similar, particularly in the numbers of *C. torosus* pollen grains, and contain no evidence for older zones, they are all considered to fall into the *C. torosa* Zone.

References

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Murray–Peel Leederville 5A

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MPL5A[(a)]				
–	34–35	DC	*?B. limbata*[#]	(Backhouse, 2013)
–	74–75	DC	*?B. limbata*[#]	(Backhouse, 2013)
–	123–124	DC	indeterminate	(Backhouse, 2013)
–	156–157	DC	*C. turbatus*^	(Backhouse, 2013)
–	197–198	DC	*C. torosa*^	(Backhouse, 2013)
–	278–279	DC	*C. torosa*^	(Backhouse, 2013)

NOTES:
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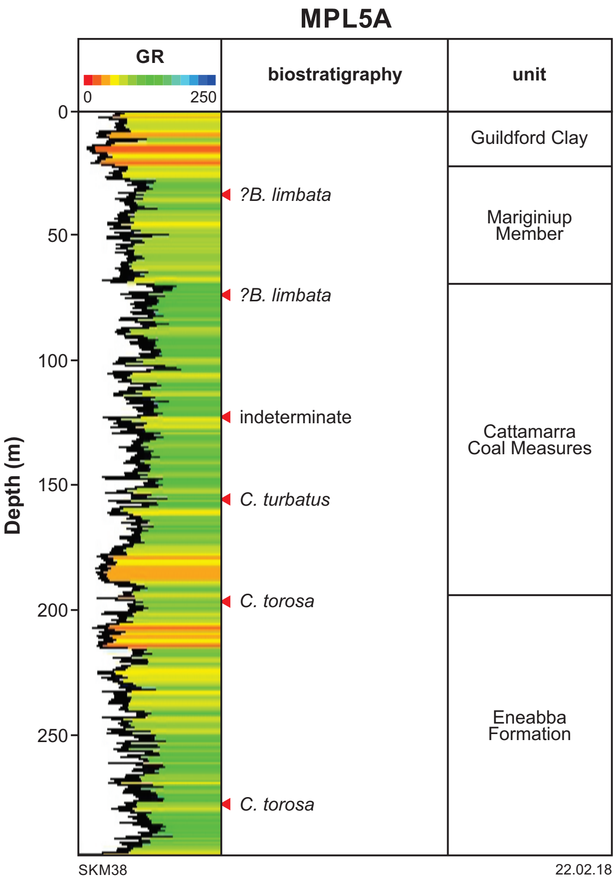
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone



Notes: TD = 300 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

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Altogether, the MPL line consists of sixteen boreholes drilled on eight separate sites; at each site, a deeper (with the 'A' suffix) and shallower (with the 'B' suffix) borehole were drilled alongside one another. All of these holes were deeper than 100 m TD — the shallowest being MPL6A (150 m TD) and the deepest MPL2A (366 m TD). Only ten of the sixteen MPL boreholes were assessed palynologically, and only five of these ten clearly penetrated the Cretaceous unconformity, with one additional bore tentatively considered to extend into the Jurassic section.

MPL5A

Drilled in 2013 to 300 m TD, MPL5A had a total of six ditch cuttings samples submitted for palynological analysis. These results were presented in a single informal report (Backhouse, 2013). Of the six samples, one (123–124 m) was effectively barren, yielding only two, almost certainly caved, palynomorphs; the lack of palynomorphs is not surprising considering the weathered nature of the claystone contained in this sample. The remaining samples all yielded palynomorphs, and could be divided into three palynofloras.

The two shallowest samples (34–35 and 74–75 m) both yielded similar, nonmarine Early Cretaceous assemblages, lacking dinoflagellates. The presence of *Balmeiopsis robusta* and lack of *Biretisporites eneabbaensis* Spore-Pollen Zone index taxa indicates assignment to the *Balmeiopsis limbata* Spore-Pollen Zone; assigning this sample more precisely within this very long ranging zone is difficult without dinoflagellates (Backhouse, 1988). The low diversity and unusual composition of the spores and pollen seen in this assemblage suggests an unusual depositional setting or restricted vegetation.

Below the low-diversity sample was a single sample (156–157 m) which yielded a rich, well-preserved assemblage of Early Jurassic spores and pollen. The sample is dominated by *Dictyophyllidites* spp., particularly a small form seen predominantly in the *Callialasporites turbatus* Spore-Pollen Zone, and contains common (but not abundant) *Classopollis torosus* and *Exesipollenites tumulus*, plus *Callialasporites turbatus* and other species consistent with the Early Jurassic. Together, this clearly indicates an association to the lower part of the *C. turbatus* Zone (Filatoff, 1975; Helby et al., 1987).

The two deepest samples (197–198 and 278–279 m) are both extremely low yielding and low diversity. The deepest sample contains common *C. torosus* as the only palynomorph, with the shallower sample dominated by *C. torosus* associated with other generic Early Jurassic forms. Based on the dominance of *C. torosus* and low diversity of the assemblages, these samples were both assigned to the *Corollina torosa* Spore-Pollen Zone, although the negative evidence used in this assignment is somewhat problematic.

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Murray–Peel Leederville 6A and 6B

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MPL6A[(a)]				
–	41–42	DC	*B. limbata*[#]	(Backhouse, 2013)
–	154–155	DC	*B. limbata*[#]	(Backhouse, 2013)
–	245–246	DC	*B. limbata*[#]	(Backhouse, 2013)
–	284–246	DC	*P. lowryi*[‡] to *A. alata*[‡]	(Backhouse, 2013)
–	284–285	DC	*P. lowryi*[‡] to *A. alata*[‡] (plus evidence for *C. turbatus*^)	(Backhouse, 2013)
MPL6B				
–	33–34	DC	probably *B. limbata*[#]	(Backhouse, 2012)

NOTES:
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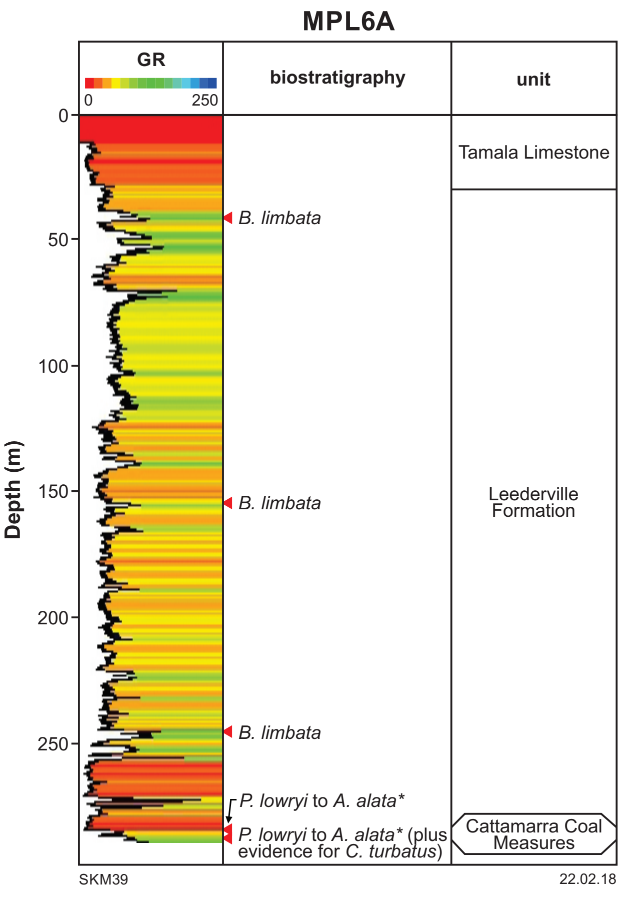
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; [#]Backhouse (1988) Spore-Pollen Zone; [‡]Backhouse (1988) Dinocyst Zone



Notes: TD = 288 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Department of Water (DoW, now DWER) drilled the Murray–Peel Leederville (MPL) line of bores in 2012 and 2013. As these samples were studied recently, with modern drilling and sample processing methods, the data can be considered to be relatively accurate and do not require translation from older taxonomic and biostratigraphic concepts. Basic well data for all of these holes can be found on DWER's Water Information Reporting (WIR) database.

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MPL6A

Drilled in 2012 to 288 m TD, five ditch cutting samples were submitted from MPL6A for palynological analyses. These results were presented in a single informal report (Backhouse, 2013). All samples yielded palynomorphs and could be divided into two palynofloras.

The three shallowest samples (41–42, 154–155, and 245–246 m) yielded similar nonmarine Early Cretaceous assemblages, lacking dinoflagellates. Although the shallowest of these samples was low yielding, it contained specimens of *Balmeiopsis limbata* alongside other typical Early Cretaceous forms, thereby indicating the *Balmeiopsis limbata* Spore-Pollen Zone. The two richer samples lacked this species, but contained *Balmeiopsis robusta*, another *B. limbata* Zone index species. As a result, all three samples are assigned to *B. limbata* Zone, although it is uncertain where in this broad zone the samples lie. A normally rare Early Cretaceous species, *Laevigatosporites belfordii*, seen in both the *Biretisporites eneabbaensis* and *B. limbata* Spore-Pollen Zones, is unusually common in the 245–246 m sample, which may indicate deposition within an unusual fern-rich environment.

The two deepest samples (284–285 and 287–288 m) yielded somewhat curious assemblages. Both samples contain dinoflagellates, and the presence of *Muderongia testudinaria*, *Senoniasphaera tabulata*, and *Dingodinium cerviculum* in the 284–285 m sample is strong evidence for the upper *Phoberocysta lowryi* or *Aprobolocysta alata* Dinocyst Zones. The deepest sample lacks these diagnostic taxa, but the dinocysts seen all agree with this interpretation. The samples also contain *B. limbata* and other spores and pollen found within the *B. limbata* Zone, overall suggesting an Early Cretaceous age. However, the samples also include a number of taxa more commonly associated with Early Jurassic zones, particularly the *Callialasporites turbatus* Spore-Pollen Zone. The 284–285 m sample contains two specimens of *Callialasporites turbatus*, and the 287–288 m sample contains both rare *C. turbatus* and *Exesipollenites tumulus*, which together are used to indicate the *C. turbatus* Zone (Helby et al., 1987). However, *C. turbatus* has been previously noted as a rare component of Early Cretaceous palynofloras (Backhouse, 1988), although predominantly as a reworked form in the *B. limbata* Zone, and its lone presence in the shallower of the two samples is no more than a suggestion that this sample is below the Jurassic–Cretaceous unconformity. The combination of *C. turbatus* and short-ranging *E. tumulus*, combined with the lower numbers of dinoflagellates, in the deepest sample is more robust evidence that this sample lies below the unconformity, and that the Early Cretaceous forms represent downhole contamination in a low-yielding Early Jurassic assemblage.

MPL6B

Drilled in 2012 to 150 m TD, only a single ditch cutting sample was submitted from MPL6B for palynological analyses. These results were presented in a single informal report (Backhouse, 2012). The sample contained a low-yielding palynological assemblage likely assignable to the *B. limbata* Zone. The sample lacks dinoflagellates or other marine indicators, but appears to have been deposited within an unusual depositional environment, probably a backswamp (Backhouse, 2012).

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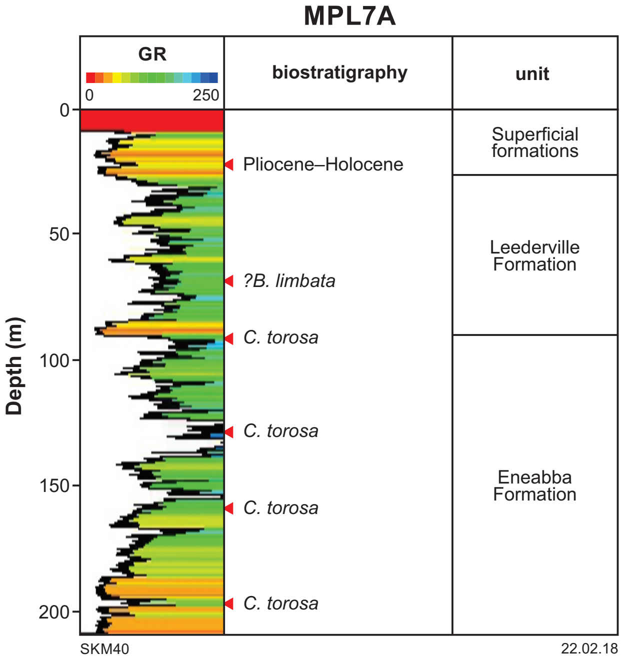
Murray–Peel Leederville 7A

Depth (feet)	Depth (metres)	Sample type	Zone/age(b)	Report
MPL7A(a)				
–	23–24	DC	Pliocene to Holocene	(Backhouse, 2013)
–	69–70	DC	?*B. limbata*#	(Backhouse, 2013)
–	92–93	DC	*C. torosa*^	(Backhouse, 2013)
–	129–130	DC	*C. torosa*^	(Backhouse, 2013)
–	159–160	DC	*C. torosa*^	(Backhouse, 2013)
–	197–198	DC	*C. torosa*^	(Backhouse, 2013)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone



Notes: TD = 210 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Line summary

The Department of Water (DoW, now DWER) drilled the Murray–Peel Leederville (MPL) line of bores in 2012 and 2013. As these samples were studied recently, with modern drilling and sample processing methods, the data can be considered to be relatively accurate and do not require translation from older taxonomic and biostratigraphic concepts. Basic well data for all of these holes can be found on DWER's Water Information Reporting (WIR) database.

Altogether, the MPL line consists of sixteen boreholes drilled on eight separate sites; at each site, a deeper (with the 'A' suffix) and shallower (with the 'B' suffix) borehole were drilled alongside one another. All of these holes were deeper than 100 m TD — the shallowest being MPL6A (150 m TD) and the deepest MPL2A (366 m TD). Only ten of the sixteen MPL boreholes were assessed palynologically, and only five of these ten clearly penetrated the Cretaceous unconformity, with one additional bore tentatively considered to extend into the Jurassic section.

MPL7A

MPL7A was drilled in 2012 to a TD of 210 m. In total, six ditch cuttings samples were submitted for palynological assessment, the results of which were presented in a single informal report to DWER (Backhouse, 2013). All of the samples yielded palynomorphs, which were divided into three separate assemblages.

The shallowest sample (23–24 m) yielded a sparse assemblage of angiosperm pollen of general Pliocene to Recent age. Unfortunately, little work has been done on Cenozoic palynology in Western Australia and the exact age of the sample cannot be further constrained without supporting research.

The underlying sample (69–70 m) also contains examples of these Cenozoic forms associated with clearly Early Cretaceous taxa; the Cenozoic forms are assumed to be caved from overlying sediments. No dinoflagellates were recorded, and the spores and pollen seen are generally undiagnostic biostratigraphically, with no recorded index species. As the assemblage contains no evidence for *Biretisporites eneabbaensis* or older (e.g. Early Jurassic) Spore-Pollen Zones, the sample is tentatively assigned to the *Balmeiopsis limbata* Spore-Pollen Zone, a reasonable interpretation if results from the surrounding MPL boreholes are considered.

The deepest four samples (92–93, 129–130, 159–160, and 197–198 m) were grouped together as Early Jurassic assemblages dominated by *Classopollis torosus*. The central two samples were noted as containing contamination from the overlying Early Cretaceous assemblage, making *C. torosus* appear less dominant. Overall, all three samples were assigned to the *Corollina torosa* Spore-Pollen Zone, despite the long ranging and caved Cretaceous taxa.

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Murray–Peel Leederville 1A, 1B, 8A

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
MPL1A[(a)]				
–	34–35	DC	?*E. ludbrookae*† to *X. asperatus*†	(Backhouse, 2012)
–	53–54	DC	?*E. ludbrookae*† or slightly older	(Backhouse, 2013b)
–	116–117	DC	*D. davidii*†	(Backhouse, 2013b)
–	209–210	DC	?*A. alata*‡	(Backhouse, 2013b)
–	298–299	DC	?*A. alata*‡	(Backhouse, 2013b)
–	341–342	DC	probably *A. alata*‡	(Backhouse, 2013b)
–	352–353	DC	?*B. limbata*#	(Backhouse, 2013b)
–	353–354	DC	?*B. limbata*#	(Backhouse, 2013b)
MPL1B				
–	32–33	DC	?Aptian to Albian	(Backhouse, 2012)
MPL8A				
–	41–42	DC	*B. limbata*#	(Backhouse, 2013a)
–	56–57	DC	*B. limbata*#	(Backhouse, 2013a)
–	101–102	DC	*B. limbata*#	(Backhouse, 2013a)
–	145–146	DC	*B. limbata*#	(Backhouse, 2013a)
–	157–158	DC	*B. limbata*#	(Backhouse, 2013a)
–	167–168	DC	?*B. limbata*#	(Backhouse, 2013a)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: †Helby et al. (1987) Dinocyst Zone; #Backhouse (1988) Spore–Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

Line summary

The Department of Water (DoW, now DWER) drilled the Murray–Peel Leederville (MPL) line of bores in 2012 and 2013. As these samples were studied recently, with modern drilling and sample processing methods, the data can be considered to be relatively accurate and do not require translation from older taxonomic and biostratigraphic concepts. Basic well data for all of these holes can be found on DWER's Water Information Reporting (WIR) database.

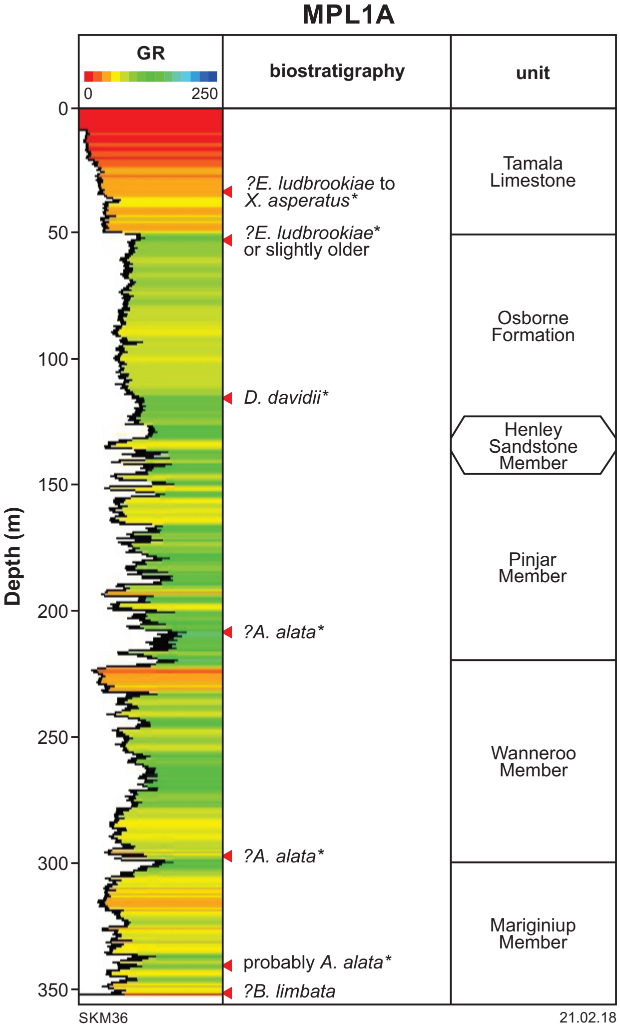
Altogether, the MPL line consists of sixteen boreholes drilled on eight separate sites; at each site, a deeper (with the 'A' suffix) and shallower (with the 'B' suffix) borehole were drilled alongside one another. All of these holes were deeper than 100 m TD — the shallowest being MPL6A (150 m TD) and the deepest MPL2A (366 m TD). Only ten of the sixteen MPL boreholes were assessed palynologically, and only five of these ten clearly penetrated the Cretaceous unconformity, with one additional bore tentatively considered to extend into the Jurassic section.

MPL1A, 1B, 8A

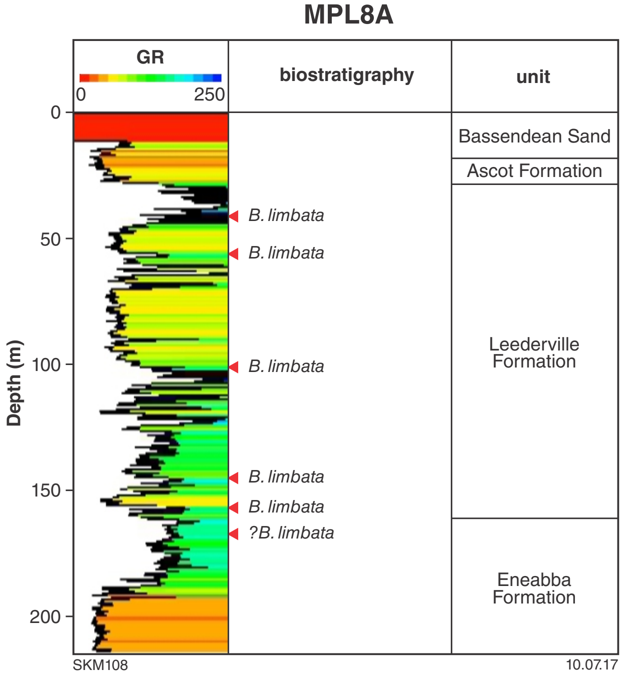
All of the MPL line boreholes listed here reached TD within the Cretaceous, and therefore demonstrate no evidence of older sediments in the area (Backhouse, 2012, 2013a,b). In addition, none of these assemblages indicated Quaternary samples, indicating that the surficial sediments are less than 32 m thick in MPL1B, and less than 41 m thick in MPL8A.

All samples from MPL8A yielded palynological assemblages assignable to the *Balmeiopsis limbata* Spore-Pollen Zone, thereby indicating nonmarine phases of the Warnbro Group. The samples from both of these boreholes had very low palynomorph yields, and this appears to indicate an unusual depositional environment, probably a backswamp (Backhouse, 2013a). Furthermore, the deepest sample from this set (167–168 m) shows evidence for oxidation, and therefore subaerial exposure, which is somewhat unusual for this zone, and perhaps tentatively suggests that in fact the bottom section of this borehole extends below the Jurassic–Cretaceous unconformity.

As the deepest of the Cretaceous-only boreholes in this line, MPL1A contains evidence of a range of different Cretaceous units. The shallowest samples are assigned to Helby et al. (1987) *?Endoceratium ludbrookiae* or



Notes: **TD = 354 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**



Notes: **TD = 217 m; lithostratigraphy based on Macaulay et al. (2016); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings**

Xenascus asperatus Dinocyst Zones, suggesting the Osborne Formation (Backhouse, 2012, 2013b). These are underlain by a single sample indicating the Aptian *Diconodinium davidii* Dinocyst Zone of Helby et al. (1987), which Backhouse (2013b) considered correlatable to a presently unnamed unit in the Perth Basin, relatively common in the central and southern portion of the basin. The deepest five samples are all considered referable to Warnbro Group, with marine assemblages of the *Aprobolocysta alata* Dinocyst Zone overlying nonmarine *B. limbata* Spore-Pollen Zone assemblages at the bottom of the hole (Backhouse, 2013b). Although the single sample studied from MPL1B could not be assigned to any particular dinocyst or spore–pollen zone, due to its sparsely yielding assemblage, the sample is considered Albian or slightly older in age, suggesting that it does not belong to the Warnbro Group, but is more likely correlatable to the unnamed Aptian unit (Backhouse, 2012).

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Murray DWMP bores

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
HS080-2B[(a)]				
–	14	CC	*B. jaegeri*‡ (*M. australis*†)	(Backhouse, 2009)
–	34.9	CC	*B. limbata*# / *P. lowryi*‡ to *B. jaegeri*‡ (*M. australis*†)	(Backhouse, 2009)
HS096-1A				
–	11.5	CC	barren	(Backhouse, 2009)
HS104-4				
–	59	CC	*B. jaegeri*‡ (*M. australis*†)	(Backhouse, 2009)
HS108-1A				
–	12.5	CC	*B. limbata*#	(Backhouse, 2009)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core
Zone/age column: †Helby et al. (1987) Dinocyst Zone; #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

The shallow Murray DWMP (or Murray Superficial) line is a set of greater than 70 boreholes drilled by DWER (then DoW) in 2009, spread across the Murray–Peel region between Mandurah and Harvey. Of these boreholes, only four have had palynological analyses conducted on them — HS080-2B, HS096-1A, HS104-4, and HS108-1A — none of which appears to be deeper than 60 m. Like the similar Harvey Shallow line, none of the assessed Murray DWMP samples yielded assemblages older than Early Cretaceous. Basic well data for all of these holes can be found on DWER's Water Information Reporting (WIR) database.

Due to their shallow depths, only a single sample was analysed palynologically from each of the four Murray DWMP boreholes, with the exception of HS080-2B, which had two samples analysed (Backhouse, 2009). Unfortunately, the single analysed sample from HS096-1A (from 11.5 m depth) yielded no palynomorphs, but one foraminiferal liner, which might suggest a marine depositional environment for the sample. The remaining samples all yielded spore-pollen assemblages indicating assignment to the *Balmeiopsis limbata* Spore-Pollen Zone, although the numbers of nonmarine palynomorphs is variable between holes. The sample from HS108-1A (12.5 m) yielded predominantly spore-pollen, and the few dinoflagellates obtained were insufficient to assign this sample to any particular dinocyst zone. At the other extreme, the sample from HS104-4 (59 m) yielded predominantly dinoflagellates with very few spores and pollen, although woody material was also very common in this assemblage. This sample from HS104-4 and the shallowest sample from HS080-2B (14 m) were both assigned to the *Muderongia australis* Dinocyst Zone (Helby et al., 1987), here considered equivalent to Backhouse (1988) *Batioladinium jaegeri* Dinocyst Zone. The deeper HS080-2B sample has a more ambiguous microplankton assemblage that may fall anywhere between the *Phoberocysta lowryi* and *B. jaegeri* Zones (of Backhouse, 1988).

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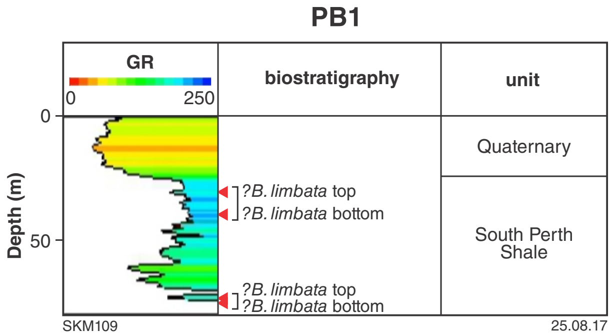
Other Lake Clifton area bores

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
PRE1[(a)]				
–	154	DC	*B. limbata*[#] or younger	(Backhouse, 1976)
–	192–194	DC	*?B. limbata*[#]	(Backhouse, 1977)
PB1				
100–130	30.5 – 39.6	DC	*?B. limbata*[#]	(Backhouse, 1972)
241–243	73.5 – 74.1	DC	*?B. limbata*[#]	(Backhouse, 1972)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone



Notes: TD = 77.1 m; lithostratigraphy based on Commander (1972); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings

Park Ridge Estate No. 1 (PRE1)

In 1976, Park Ridge Estate No. 1 was drilled as a private water bore in the Bouvard area (near Mandurah), to a TD of 194 m. Two ditch cuttings were submitted for palynological study from this borehole (Backhouse, 1976, 1977), from 154 m and 192–194 m, both of which recovered fair spore-pollen assemblages. The deepest assemblage is not well described, with only *Balmeiopsis limbata*, '*Inaperturopollenites* sp. B' (likely *B. robusta*) and indeterminate dinoflagellate plates directly mentioned (Backhouse, 1977). The combination of these two taxa suggests that the sample falls within Backhouse's (1988) *Balmeiopsis limbata* Spore-Pollen Zone, although this interpretation is only tentative without a more complete species listing.

The shallower sample seems at first glance to be similar, containing *B. limbata* and rare dinoflagellates with other common Early and mid-Cretaceous spores and pollen such as *Gleicheniidites senonicus* and *Stereisporites antiquasporites* (Backhouse, 1988). However, the dinoflagellate species mentioned, *Cribroperidinium edwardsii*, is more normally allied with post- *B. limbata* Zone assemblages in the Perth Basin (Edgell, 1964), and the assemblage may be more comparable to mid-Cretaceous assemblages seen in boreholes such as MPL1A. Therefore, this sample may belong to the *B. limbata* Zone or could be younger (Aptian or Albian).

Preston Beach No. 1 (PB1)

The Preston Beach 1 borehole was drilled south of Mandurah in 1972, lying between Lake Preston and the Indian Ocean (Commander, 1972). Drilled to a TD of 253 ft (77.1 m), three ditch cuttings were submitted for palynological assessment from this borehole, although only two, at 100–130 ft and 241–243 ft, were processed (Backhouse, 1972). Both samples yielded palynomorphs, although the shallower sample was poorer and included no marine palynomorphs. Overall, the spore and pollen assemblages of both samples were similar, dominated by long-ranging Late Jurassic to Early Cretaceous palynomorphs, including *Contignisporites cooksoniae*, *Araucariacites australis*, *Osmundacidites wellmanii*, *Microcachryidtes antarcticus* and *Callialasporites dampieri*. In the deeper sample, the high percentage of *M. antarcticus*, and presence of *Cyathidites australis*, *Rouseisporites reticulatus* and *Foveosporites canalis*, all suggest an association to the *B. limbata* Zone (Backhouse, 1988). The deeper sample also included a number of dinoflagellates, although none could be assigned to any particular species (Backhouse, 1972). These palynological data agree well with the formation tops estimated using lithology and geophysics, which interprets 80 ft of Quaternary sediments overlying the South Perth Formation, which then extends to TD (Commander, 1972).

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Picton Line 1

Depth (feet)	Depth (metres)	Sample type	Zone/age(b)	Report
PL1(a)				
–	27	DC	*?B. limbata*#	(Backhouse, 1975)
–	108	DC	*?B. limbata*#	(Backhouse, 1975)
–	130	SWC	*B. limbata*#	(Backhouse, 2015)
–	195	SWC	barren	(Backhouse, 1974)
–	201	DC	*B. limbata*#	(Backhouse, 2015)
–	242.5	SWC	*D. complex*^ to *M. florida*^	(Backhouse, 2015)
–	277	SWC	barren	(Backhouse, 1974)
–	*375*	SWC	[no data in report]	(Backhouse, 1974)
–	377.3	SWC	*D. complex*^ to *M. florida*^	(Backhouse, 2015)
–	438	DC	*D. complex*^ to *M. florida*^	(Backhouse, 2015)
–	443.3	SWC	barren	(Backhouse, 1974)
–	445.3	SWC	barren	(Backhouse, 1974)
–	501.3	SWC	*D. complex*^ to *M. florida*^	(Backhouse, 2015)
–	509.3	SWC	*D. complex*^ to *M. florida*^	(Backhouse, 2015)
–	540.3	SWC	indeterminate	(Backhouse, 1974)
–	546	DC	*C. turbatus*^	(Backhouse, 2015)
–	664.3	SWC	*C. turbatus*^	(Backhouse, 2015)
–	704	SWC	*C. turbatus*^	(Backhouse, 2015)
–	933.3	SWC	*C. turbatus*^	(Backhouse, 2015)
–	963.3	SWC	*C. turbatus*^	(Backhouse, 2015)
–	993.5	SWC	*C. turbatus*^	(Backhouse, 2015)
–	1078.3	SWC	*C. turbatus*^	(Backhouse, 2015)
–	1197	DC	*C. turbatus*^	(Backhouse, 2015)

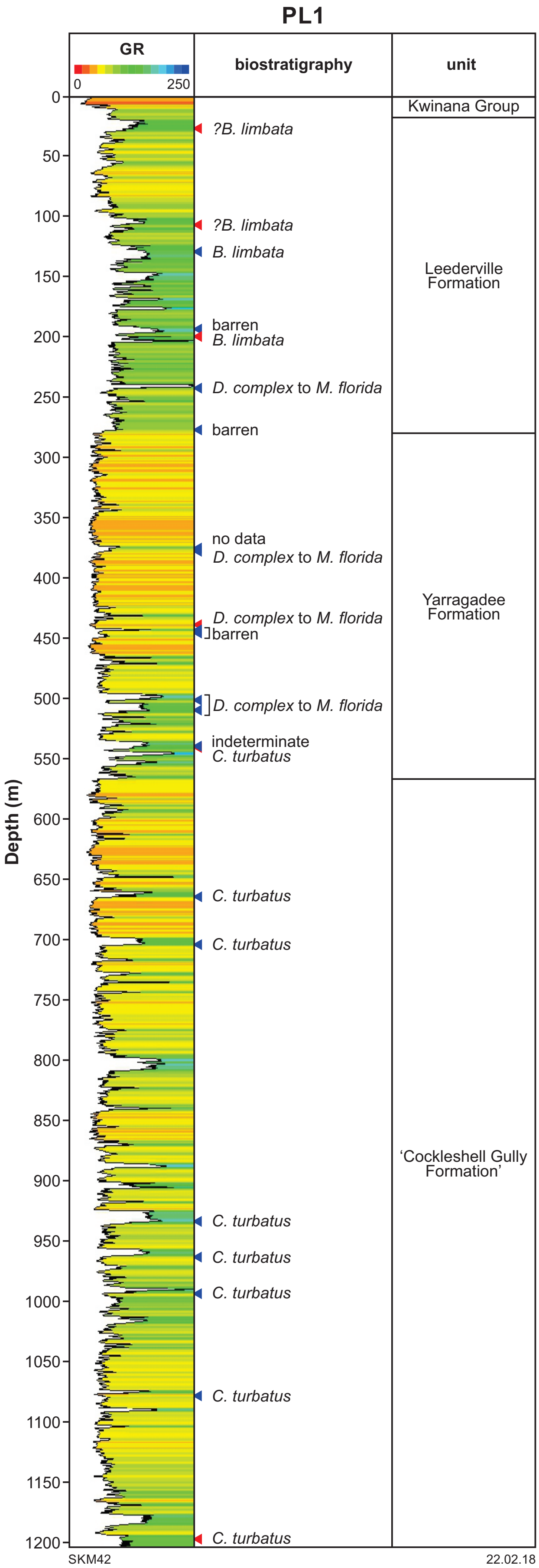
NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone

Line summary

The Picton Line (also described as 'Picton Junction line' in some publications) consists of seven boreholes drilled at four separate sites south and east of Bunbury. Drilled as part of a long-term program to evaluate deep groundwater resources in the Perth Basin, the initial bore, Picton Line 1, was drilled in mid-1974, with Picton Line sites 2–4 drilled in 1978. Although only a single deep borehole was drilled for PL1, extending to a TD of 1200 m, sites 2–4 each had two boreholes designed to test aquifers at different depths — the deep bore at each site being designated A and the shallow bore labelled B. Of the deep bores, PL4A reached a TD of 823 m, PL3A 794 m TD, and PL2A 772 m TD. The shallow bores PL2B, 3B and 4B reached TD of 207, 228, and 45 m respectively (Wharton, 1981).

In each of the four deep bores, a set of ditch cuttings were collected throughout at 3 m intervals, with a set of sidewall cores also collected from siltstone or shale lithologies at roughly 30 m intervals, resulting in comprehensive sample coverage of the drilled sections (Wharton, 1981). A similar sampling process appears to have been conducted on borehole PL3B, based on palynological reporting (Backhouse, 1978), although it is unknown if sidewall cores were cut for PL2B or PL4B.

The targeting of fine-grained lithologies for sidewall cores was designed to aid the palynological assessment of the geology in these sections, which proved to be particularly important due to the lithologically similar nature of the Early Jurassic to Early Cretaceous section in each borehole (Wharton, 1981, p. 14). As a result, palynological studies were conducted on sidewall cores from all deep Picton Line boreholes (PL1, PL2A, PL3A, and PL4A) and one shallow borehole (PL3B). In all cases, the initial palynological assessment was conducted by then-GSWA palynologist J Backhouse and published as a series of informal Paleontology Reports; only the sections from PL3A and PL4A have been subsequently reviewed, in 2011.



PL1

PL1 is the oldest and deepest borehole drilled within the Picton Line, located close to the town of Picton Junction, and therefore falling between PL2A/B (to the west) and PL3A/B (to the east). Seventeen sidewall cores and six ditch cuttings from this borehole were submitted from this borehole for palynological studies, reported in two GSWA Paleontological Reports (Backhouse, 1974, 1975). Of these samples, four sidewall cores (from 195, 277, 443.3 and 445.5 m) proved to be barren of palynomorphs; unfortunately, one of the sidewall core samples (at 438 m) was never assessed in the report and its age remains unknown. In 2015, the results from both reports were reviewed, with the aim of modernizing and updating the biostratigraphic interpretations (Backhouse, 2015).

In the original report, samples were divided into three broad groupings. The first palynoflora extends from the shallowest palynologically assessed sample at 27 m through to 201 m and consists of three ditch cuttings (27, 108, and 201 m) and one sidewall core (130 m). All samples lack dinoflagellates or other microplankton, but contain spore-pollen assemblages of Early Cretaceous aspect, which were assigned to Balme's (1964) *Microcachryidites* Assemblage of general Neocomian to Aptian age. The *Microcachryidites* Assemblage has been equated to Backhouse's (1988) *Biretisporites eneabbaensis* and *Balmeiopsis limbata* Spore-Pollen Zones, although Helby et al. (1987) correlated these zones plus Backhouse's *Retitriletes watherooensis* and *Aequitriradites acusus* Spore-Pollen Zones within the *Microcachryidites* Assemblage. The recent review did not assign these samples to any particular zone, noting them only as similar to assemblages recovered generally from the Warnbro Group. This, plus the generally low diversity and nonmarine nature of these assemblages, suggests a tentative assignment to the *B. limbata* Zone, although none of the zone's index species is recorded. This matches well with the lithological and wireline logging, which assign this section to the Leederville Formation.

The next two deepest samples, sidewall cores from 242.5 and 377.3 m, both yielded similar assemblages to the overlying samples, with the addition of rare *Callialasporites dampieri*, which was considered sufficient evidence that these samples are probably Late Jurassic in age. The next three samples — sidewall cores at 501.3 m and 509.3 m, and a ditch cutting at 516 m — were more diverse, and contained a number of species that were assigned to Balme's (1964) *Dampieri* Assemblage, of

Notes: TD = 1200.1 m; lithostratigraphy based on Wharton (1981); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores

Middle to Late Jurassic age. This assemblage has been correlated to the *Dictyotosporites complex* to *Murospora florida* Spore-Pollen Zones of Helby et al. (1987), but the lack of complete species list in the reports makes it difficult to assign to particular zones without reassessment of the original slides. All three zones are characterized by common *C. dampieri*, common (but not dominant) *Classopollis*, and common *Cyathidites* spp., all of which are seen in these samples. The recent review (Backhouse, 2015) considered all of these five samples to be assignable to a single assemblage, but could only assign them to somewhere within the range of the Late Jurassic *M. florida* to *D. complex* Zones.

The sample at 540.3 m yielded only rare bisaccate pollen, and its age is therefore indeterminate. The remaining six sidewall cores (664.3, 704, 933.3, 963.3, 993.5 and 1078.3 m) and single ditch cutting (1197 m) all yielded very similar assemblages of Early Jurassic age. The 704 m sample contains *Callialasporites turbatus*, *C. dampieri*, *Classopollis classoides* (not dominant), *Staplinisporites caminus*, *Osmundacidites wellmanii*, and *Araucariacites australis*, which together suggest assignment somewhere within the *Callialasporites turbatus* to *M. florida* Spore-Pollen Zones. The underlying sample, at 933.3 m records no *C. turbatus*, but preserves *Exesipollenites tumulus*, a supposedly short-ranging taxon noted by Helby et al. (1987) only found commonly in the lower *C. turbatus* Zone and more rarely in the upper *Corollina torosa* Spore-Pollen Zone. The recent review considers all of these samples to fall within the *C. turbatus* Zone (Backhouse, 2015); although no zone subdivisions are indicated in this review, the change in assemblage from 704 m to 933.3 m suggests a possible transition from the upper to lower parts of this Early Jurassic zone downhole.

Based on the palynological data, it appears that the Jurassic–Cretaceous unconformity falls somewhere between 201 and 242.5 m depth in Picton 1, with another possible break between Middle–Late Jurassic and Early Jurassic assemblages between 516 and 664.3 m. Unfortunately, the large gap between the Late and Early–Middle Jurassic samples makes it unclear whether the Jurassic section is fully conformable in this borehole. This interpretation differs slightly from the formation tops previously picked by Wharton (1981), which indicated an Early Cretaceous – Quaternary boundary (between the Leederville Formation and Kwinana Group) at 19 m, followed by an Late Jurassic – Early Cretaceous (Yarragadee to Leederville Formations) boundary at 280 m depth, and the break between Late and Early–Middle Jurassic units (‘Cockleshell Gully’ to Yarragadee Formations) at ?566 m. However, Wharton (1981) noted that the sedimentary rocks of the Picton Line presented considerable difficulties in picking formations, due to the similarity of Late Jurassic and Cretaceous sandstones; therefore, the Jurassic–Cretaceous pick suggested here based on palynology may be more reliable than this previous effort.

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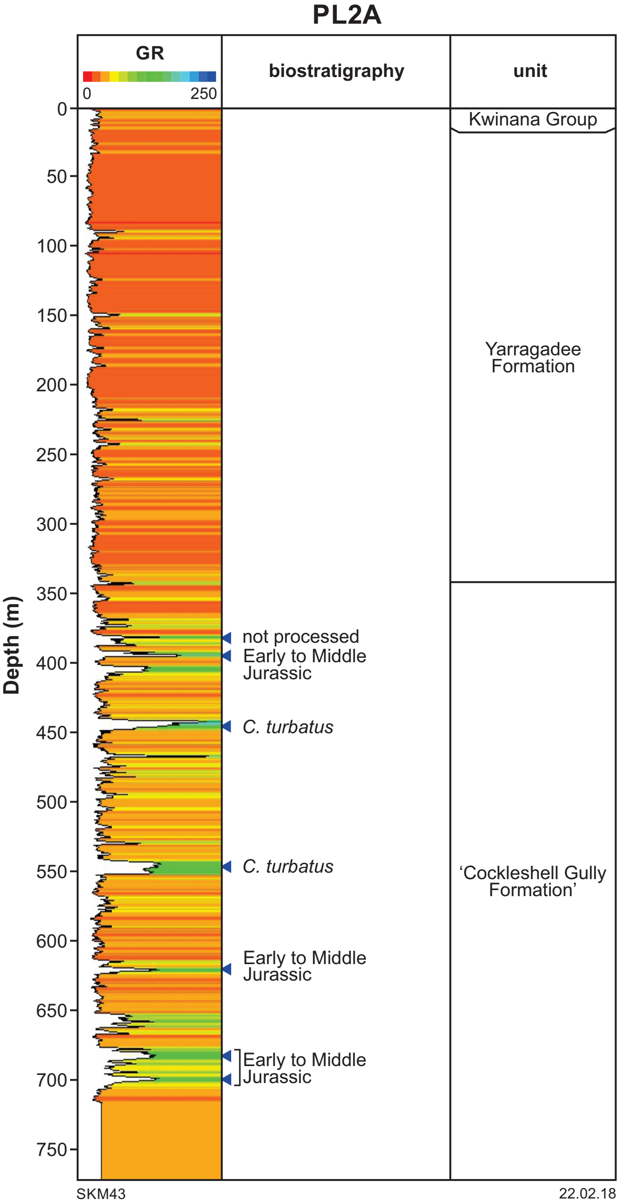
Picton Line 2A

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
PL2A[(a)]				
–	381.5	SWC	not processed	(Backhouse, 1978b)
–	394.5	SWC	Early to Middle Jurassic	(Backhouse, 1978b)
–	445	SWC	*C. turbatus*^	(Backhouse, 2015)
–	546	SWC	*C. turbatus*^	(Backhouse, 2015)
–	620	SWC	Early to Middle Jurassic	(Backhouse, 1978b)
–	682	SWC	Early to Middle Jurassic	(Backhouse, 1978b)
–	699	SWC	Early to Middle Jurassic	(Backhouse, 1978b)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone



Line summary

The Picton Line (also described as 'Picton Junction line' in some publications) consists of seven boreholes drilled at four separate sites south and east of Bunbury. Drilled as part of a long-term program to evaluate deep groundwater resources in the Perth Basin, the initial bore, Picton Line 1, was drilled in mid-1974, with Picton Line sites 2–4 drilled in 1978. Although only a single deep borehole was drilled for PL1, extending to a TD of 1200 m, sites 2–4 each had two boreholes designed to test aquifers at different depths — the deep bore at each site being designated A and the shallow bore labelled B. Of the deep bores, PL4A reached a TD of 823 m, PL3A 794 m TD, and PL2A 772 m TD. The shallow bores PL2B, 3B and 4B reached TD of 207, 228, and 45 m respectively (Wharton, 1981).

In each of the four deep bores, a set of ditch cuttings were collected throughout at 3 m intervals, with a set of sidewall cores also collected from siltstone or shale lithologies at roughly 30 m intervals, resulting in comprehensive sample coverage of the drilled sections (Wharton, 1981). A similar sampling process appears to have been conducted on borehole PL3B, based on palynological reporting (Backhouse, 1978a), although it is unknown if sidewall cores were cut for PL2B or PL4B.

The targeting of fine-grained lithologies for sidewall cores was designed to aid the palynological assessment of the geology in these sections, which proved to be particularly important due to the lithologically similar nature of the Early Jurassic to Early Cretaceous section in each borehole

Notes: TD = 772 m; lithostratigraphy based on Wharton (1981); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores

(Wharton, 1981, p. 14). As a result, palynological studies were conducted on sidewall cores from all deep Picton Line boreholes (PL1, PL2A, PL3A, and PL4A) and one shallow borehole (PL3B). In all cases, the initial palynological assessment was conducted by then-GSWA palynologist J Backhouse and published as a series of informal Paleontology Reports; only the sections from PL3A and PL4A have been subsequently reviewed, in 2011.

PL2A

PL2 is the most westerly borehole in the Picton Line, located south and slightly east of the Bunbury town centre. A total of seven sidewall cores were submitted for palynological assessment, described in a single GSWA Paleontology Report (Backhouse, 1978b). This report has been recently reviewed in order to modernize and clarify its biostratigraphic interpretations (Backhouse, 2015).

Of the sampled sidewall cores, the shallowest sample at 381.5 m was not processed due to the unsuitable lithology it preserved. The remaining six samples, from 394.5, 445, 546, 620, 682 and 699 m, all yielded palynomorphs, and all yielded assemblages of generally Early–Middle Jurassic age. Unfortunately, all but two of these samples were of low yield and diversity and could not be assigned to any particular biostratigraphic unit. The final two samples gave very similar assemblages, although the shallower sample (from 445 m) was more diverse, and the deeper sample (from 546 m) more specimen rich. Both samples contained *Dictyophyllidites harrisii* and *Callialasporites dampieri*, with other species found in one or other of the samples together supporting assignment to the *Dictyophyllidites harrisii* Spore-Pollen Zone of Filatoff (1975), normally correlated with the upper part of the *Callialasporites turbatus* Spore-Pollen Zone of Helby et al. (1987). The review of these two diverse samples confirms this *C. turbatus* Zone pick, although the lower yielding assemblages could not be certainly assigned to this zone, and it is possible that the deepest samples extend into the underlying *Corollina torosa* Spore-Pollen Zone.

Unlike PL1, there is no palynological evidence of either Early Cretaceous or Middle–Late Jurassic rocks (i.e. the Yarragadee or overlying formations) in this borehole, likely due to a lack of sampling in the shallowest 390 m of the hole, and uncertainty in the shallowest yielding sample results. Lithological and wireline logging of this borehole suggests that the Leederville Formation was not intersected in this borehole, with the Quaternary Kwinana Group passing down into the Yarragadee Formation at 15 m depth and the Yarragadee passing into Early Jurassic sediments of the ‘Cockleshell Gully formation’ at 196 m depth (Wharton, 1981). This interpretation does not contradict the observed palynological findings, although none of these boundaries, or the presence or thickness of the Late Jurassic section, can be confirmed.

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Picton Line 3A and 3B

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
PL3A[a]				
–	64.5	SWC	indeterminate	(Backhouse, 2011)
–	77	SWC	?Cretaceous (contaminated by drilling mud)	(Backhouse, 2011)
–	109.5	SWC	indeterminate	(Backhouse, 2011)
–	141	SWC	barren	(Backhouse, 1978b)
–	152	SWC	?Cretaceous (contaminated by drilling mud)	(Backhouse, 1978b)
–	211.5	SWC	*C. turbatus*^	(Backhouse, 2011)
–	232.5	SWC	Early Jurassic	(Backhouse, 1978b)
–	271	SWC	Early Jurassic	(Backhouse, 1978b)
–	452	SWC	Early Jurassic	(Backhouse, 1978b)
–	528	SWC	Early Jurassic	(Backhouse, 1978b)
–	542	SWC	Early Jurassic	(Backhouse, 1978b)
–	655.5	SWC	Early Jurassic	(Backhouse, 1978b)
–	680	SWC	Early Jurassic	(Backhouse, 1978b)
–	693	SWC	*?C. turbatus*^	(Backhouse, 2011)
–	716	SWC	Early Jurassic	(Backhouse, 1978b)
–	735	SWC	Early Jurassic	(Backhouse, 1978b)
–	758	SWC	barren	(Backhouse, 1978b)
–	780	SWC	*?C. turbatus*^	(Backhouse, 2011)
PL3B				
–	60–63	DC	indeterminate	(Backhouse, 1978a)
–	110	SWC	*?B. limbata*#	(Backhouse, 1978a)
–	114	SWC	not processed	(Backhouse, 1978a)
–	142.5	SWC	*?B. limbata*#	(Backhouse, 1978a)
–	154.5	SWC	not processed	(Backhouse, 1978a)
–	194	SWC	barren	(Backhouse, 1978a)
–	201	SWC	*?B. limbata*#	(Backhouse, 1978a)
–	204	SWC	*?B. limbata*#	(Backhouse, 1978a)

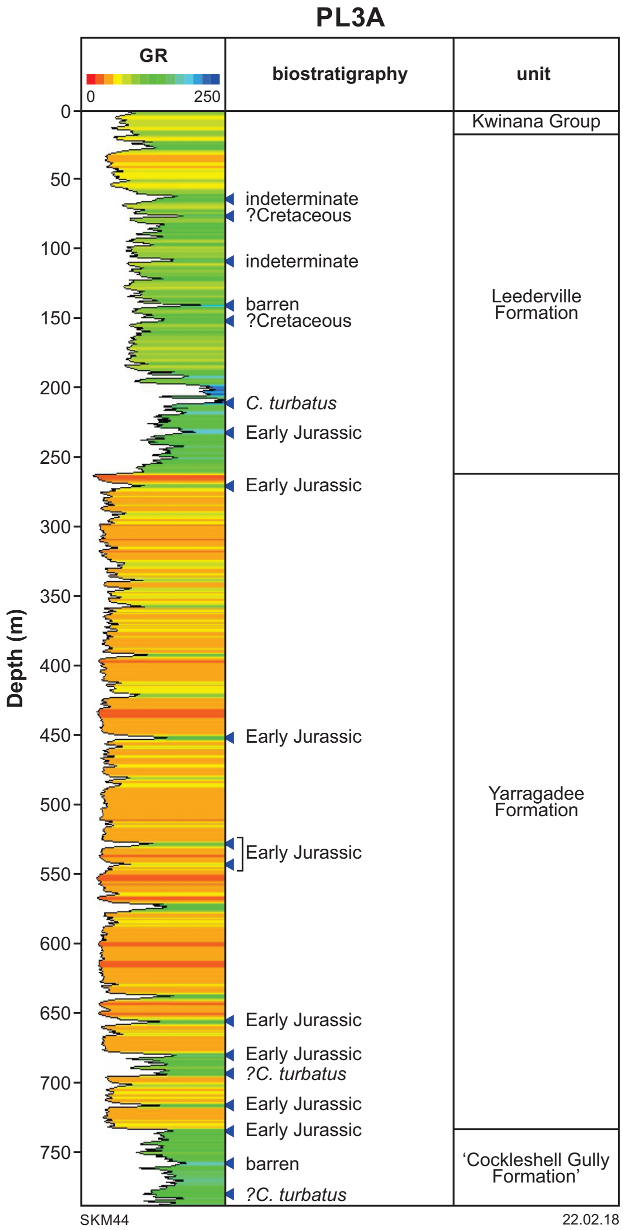
NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone

Line summary

The Picton Line (also described as 'Picton Junction line' in some publications) consists of seven boreholes drilled at four separate sites south and east of Bunbury. Drilled as part of a long-term program to evaluate deep groundwater resources in the Perth Basin, the initial bore, Picton Line 1, was drilled in mid-1974, with Picton Line sites 2–4 drilled in 1978. Although only a single deep borehole was drilled for PL1, extending to a TD of 1200 m, sites 2–4 each had two boreholes designed to test aquifers at different depths — the deep bore at each site being designated A and the shallow bore labelled B. Of the deep bores, PL4A reached a TD of 823 m, PL3A 794 m TD, and PL2A 772 m TD. The shallow bores PL2B, 3B and 4B reached TD of 207, 228, and 45 m respectively (Wharton, 1981).

In each of the four deep bores, a set of ditch cuttings were collected throughout at 3 m intervals, with a set of sidewall cores also collected from siltstone or shale lithologies at roughly 30 m intervals, resulting in comprehensive sample coverage of the drilled sections (Wharton, 1981). A similar sampling process appears to have been conducted on borehole PL3B, based on palynological reporting (Backhouse, 1978), although it is unknown if sidewall cores were cut for PL2B or PL4B.

The targeting of fine-grained lithologies for sidewall cores was designed to aid the palynological assessment of the geology in these sections, which proved to be particularly important due to the lithologically similar nature of the Early Jurassic to Early Cretaceous section in each borehole (Wharton, 1981, p. 14). As a result, palynological studies were conducted on sidewall cores from all deep Picton Line boreholes (PL1, PL2A, PL3A, and PL4A) and one shallow borehole (PL3B). In all cases, the initial palynological assessment was conducted by then-GSWA palynologist J Backhouse and published as a series of informal Paleontology Reports; only the sections from PL3A and PL4A have been subsequently reviewed, in 2011.



Notes: TD = 794.33 m; lithostratigraphy based on Wharton (1981); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: blue, sidewall cores

PL3A and 3B

The PL3 site is located east of PL1, halfway between Picton Junction and Burekup. Unlike PL2 and PL4, palynological studies were undertaken on both the deep (PL3A) and shallow (PL3B) boreholes drilled at this site. As part of the original assessment, a total of eighteen sidewall cores were submitted for processing, ranging from 64.5 to 780 m depth. The additional samples from PL3B consisted of seven sidewall cores and one ditch cutting, ranging from 60 to 204 m depth. For both boreholes, the samples were described in separate GSWA Paleontology Reports (Backhouse, 1978a,b). Backhouse (2011) reviewed all of the retained samples from both PL3 and PL4, which included six slides from PL3A (the only slides registered into the GSWA fossil collection).

Of the original eighteen samples from PL3A, two (141 and 758 m) were considered barren of palynomorphs, and three more (64.5, 109.5, 232.5 m) were deemed so sparse they were unable to be assessed biostratigraphically (Backhouse, 1978b). Of the eight PL3B samples, two (114 and 154.5 m) were not processed due to unsuitable sample lithologies, and one additional sample (194 m) was found to be completely barren of palynomorphs (Backhouse, 1978a). Few of the other samples from either borehole yielded sufficiently rich assemblages to allow easy identification of species or zones.

The shallowest samples in PL3A contained sparse assemblages heavily contaminated in drilling mud, and those from PL3B are more useful for discerning the identity of these shallower palynomorph assemblages. The shallowest sample in PL3B, a ditch cutting from 60 to 63 m, yielded only a single grain of the ubiquitous Mesozoic pollen *Araucariacites australis*, and therefore could not be assigned to either a biostratigraphic zone or age. The remaining samples (excluding the unprocessed and barren samples) yielded similar, sparse assemblages of general Mesozoic spores and pollen; however, representatives of the index species *Balmeiopsis limbata* were also observed in samples at 110, 142.5 and 204 m, and the entire section is tentatively assigned to the *Balmeiopsis limbata* Spore-Pollen Zone on this basis. Backhouse (1978a) noted that this zone tended to be more richly developed throughout the southern Perth Basin, therefore suggesting an unusual nonmarine environment for PL3, where the production or accumulation of palynomorphs was somehow restricted.

The samples from PL3A do not contradict the interpretation from PL3B that Early Cretaceous sediments extend to at least 204 m depth, although they do not provide obvious support either. A revision of the shallowest 64.5 m sample, considered too sparse to be of biostratigraphic use in the original description, came to a similar conclusion, although noted the material within was reminiscent of deeper samples. Whether this was intended to imply heavy sample contamination or that the sample should be assigned to the same biostratigraphic age is uncertain, although the former is most likely. The original description of the 77 m sample was noted to contain a number of forms only known from the Warnbro Group, plus the ubiquitous Late Jurassic to Early Cretaceous palynomorph *Microcachryidites antarcticus*, leading to the conclusion that the Warnbro Group extends 'at least down to this depth'. However, the later revision of this sample instead found heavy sample contamination mostly with *Callialasporites turbatus* Spore-Pollen Zone forms, likely derived from lower in the hole and circulated through with drilling mud. A single spore of the Cretaceous *Ruffordiaspora* was also found, although considered insufficient evidence for the sample's true age. The sample from 109.5 m was considered too sparse to provide age information in both the original description and revision. The sample at 152 m is also sparse, but includes *Aequitriradites verrucosus*, which has not been known to extend into the *B. limbata* Zone (Backhouse, 1988) in the Perth Basin, perhaps suggesting that this sample is from older units. However, the highly contaminated nature of all of these samples makes any conclusions on their age very suspicious.

Between 211.5 and 735 m, the palynomorph assemblages become slightly richer and more diverse, although still contaminated with drilling mud. Backhouse (1978b) considered that the palynomorphs are still rare in this section, perhaps due to the dominance of sandy lithologies. However, the samples are dominated by *A. australis, Callialasporites dampieri* and *C. turbatus*, with *Classopollis* spp. fairly rare, and the samples were interpreted to represent a general Middle–Late Jurassic age. The deepest sample from this set, at 780 m, was considered to be moderately rich, and included a form identified as *Lecaniella foveolatus*, which Backhouse (1978a) noted as previously being recorded only from the top of the *Dictyophyllidites harrisii* Spore-Pollen Zone in the northern Perth Basin, within the Cadda Formation (Filatoff, 1975). Reassessment of the retained samples from the deeper portion of this borehole (specifically three samples from 211.5, 693 and780 m) found that the shallowest of these samples is most likely assignable to the *C. turbatus* Zone, with the deeper samples also likely assigned to this zone, although representing an unusual assemblage where *Dictyophyllidites*/*Cyathidites* spp. dominate. This broadly agrees with the original interpretation of the *D. harrisii* Zone for the deepest sample, as this zone was considered to equate to the upper part of the *C. turbatus* Zone in the Helby et al. (1987) spore-pollen scheme. However, Backhouse's review rejected an association with the marine, northern Perth Basin Cadda Formation, instead suggesting a link to the Cattamarra Coal Measures (as per Crostella and Backhouse, 2000), which in this part of the basin may be partly equivalent in age to the marine unit.

Overall, the palynological data appear to indicate an unconformity between the Lower Cretaceous and Lower–Middle Jurassic units between 204 and 211 m, with suggestions of the *B. limbata* Zone above and *C. turbatus* Zone below. However, the strong contamination of these samples makes all of these conclusions fairly speculative, and a campaign of resampling from this borehole is likely required to clarify the age of the sediments and the position of any unconformities.

Keeping in mind its tentative nature, these biostratigraphic data conflict with the units and formation tops interpreted from lithological and geophysical studies, which places a Leederville–Yarragadee Formation unconformity at 244 m depth, and a boundary between the Yarragadee Formation and 'Cockleshell Gully Formation' at 715 m depth (Wharton, 1981). The palynological data contain no evidence of Late Jurassic (Yarragadee) assemblages, instead suggesting a downhole transition from Early Cretaceous (Warnbro Group) to Early–Middle Jurassic (Cattamarra Coal Measures equivalent). This absence of Late Jurassic strata also conflicts with the observed succession in neighbouring borehole PL1, and may indicate some structural influence, such as a fault.

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Picton Line 4A

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age[(b)]*	*Report*
PL4A[(a)]				
–	60	SWC	not processed	(Backhouse, 1978c)
–	69	DC	Early Cretaceous	(Backhouse, 1978a)
–	82	SWC	?Jurassic or Cretaceous	(Backhouse, 2011)
–	195	SWC	*C. cooksoniae*^ to *M. florida*^	(Backhouse, 2011)
–	256	SWC	*C. cooksoniae*^ to *M. florida*^	(Backhouse, 2011)
–	314	SWC	?*C. turbatus*^	(Backhouse, 2011)
–	372	SWC	?*C. turbatus*^	(Backhouse, 2011)
–	447–458	DC	?*C. turbatus*^	(Backhouse, 1978c)
–	449	SWC	?*C. turbatus*^	(Backhouse, 1978c)
–	511	SWC	?*C. turbatus*^	(Backhouse, 2011)
–	533	SWC	barren	(Backhouse, 1978c)
–	645	SWC	not processed	(Backhouse, 1978c)
–	709.5	SWC	not processed	(Backhouse, 1978c)
–	759	SWC	indeterminate	(Backhouse, 1978c)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: SWC, sidewall core; DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone

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In each of the four deep bores, a set of ditch cuttings were collected throughout at 3 m intervals, with a set of sidewall cores also collected from siltstone or shale lithologies at roughly 30 m intervals, resulting in comprehensive sample coverage of the drilled sections (Wharton, 1981). A similar sampling process appears to have been conducted on borehole PL3B, based on palynological reporting (Backhouse, 1978b), although it is unknown if sidewall cores were cut for PL2B or PL4B.

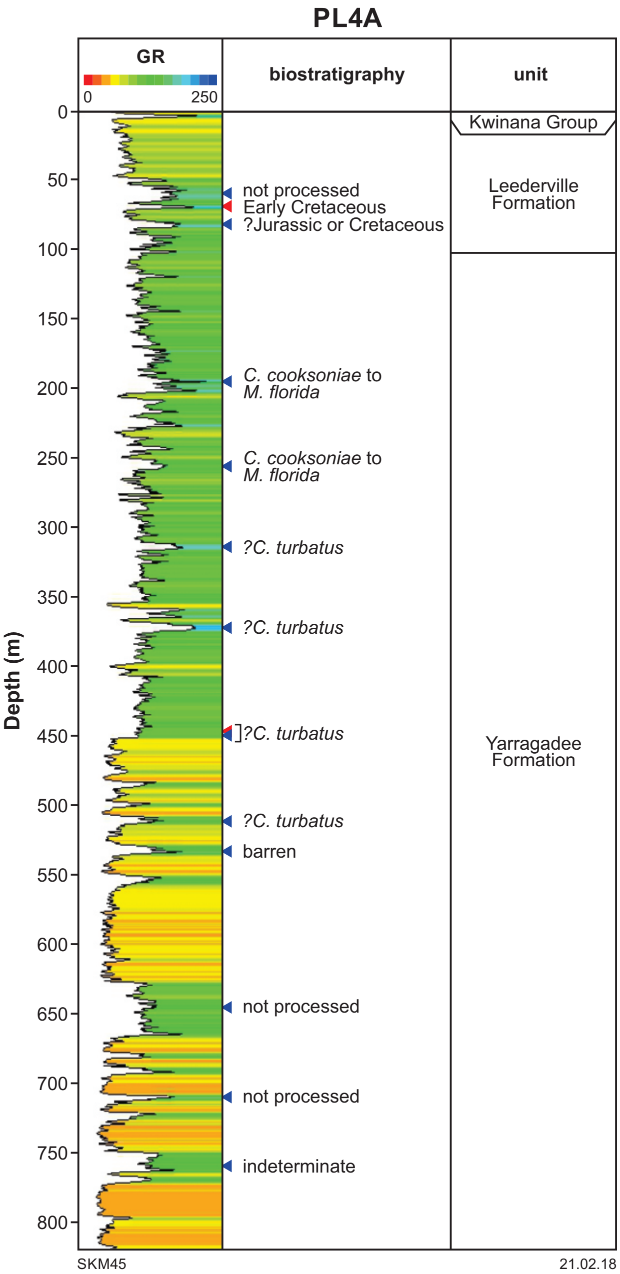
The targeting of fine-grained lithologies for sidewall cores was designed to aid the palynological assessment of the geology in these sections, which proved to be particularly important due to the lithologically similar nature of the Early Jurassic to Early Cretaceous section in each borehole (Wharton, 1981, p. 14). As a result, palynological studies were conducted on sidewall cores from all deep Picton Line boreholes (PL1, PL2A, PL3A, and PL4A) and one shallow borehole (PL3B). In all cases, the initial palynological assessment was conducted by then-GSWA palynologist J Backhouse and published as a series of informal Paleontology Reports; only the sections from PL3A and PL4A have been subsequently reviewed, in 2011.

PL4A

The most easterly bore on the Picton line, PL4 is located due east of both PL1 and PL3, and roughly south of the town of Burekup. In total, 13 sidewall cores and two ditch cuttings were originally submitted for palynological analyses, described in two GSWA Paleontology Reports (Backhouse, 1978a,c). Backhouse (2011) later reviewed all of the retained samples from both PL3 and PL4, which included six slides from PL4A (the only slides registered into the GSWA fossil collection).

Of the 15 samples submitted, three sidewall cores (60, 645, 709.5 m) were not processed due to unsuitable lithologies, and one sidewall core sample (533 m) was barren; the deepest sample of the set, at 759 m, was processed despite its contamination with drilling mud in the hope of providing information from the deeper part of the borehole (Backhouse, 1978c).

The shallowest yielding sample from the borehole is a ditch cutting from 69 m depth. The sample contains an undoubtedly Early Cretaceous assemblage, although it is difficult to assess whether the sample should be assigned to the *Biretisporites eneabbaensis* or *Balmeiopsis limbata*



Notes: TD = 823 m; lithostratigraphy based on Wharton (1981); quoted biostratigraphic units are spore-pollen zones unless marked with an asterisk (*) indicating a dinocyst zone; arrows indicate sample type used for palynology: red, ditch cuttings; blue, sidewall cores

Spore-Pollen Zone. Considering the low diversity of the assemblage, and data from surrounding boreholes, an association with the *B. limbata* Zone seems most likely, although the sample is not specifically assigned to a zone in this Report due to this ambiguity. The next deepest sample at 82 m contains a sparse assemblage of long-ranging Late Jurassic to Early Cretaceous forms, making its age indeterminate, even after the slides were reviewed in 2011.

In the original palynological assessment of PL4A, samples from 195 m to 511 m were all considered similar enough to belong to a single biostratigraphic zone (Backhouse, 1978c). The shallowest of these samples was the most diverse, and contained species including *Contignisporites cooksoniae*, *Neoraistrickia truncata* and *Conbaculatisporites* sp. cf. *C. mesozoicus*, which together suggested assignment to the upper *Contignisporites cooksoniae* Spore-Pollen Zone. A reassessment of two of these slides (198 and 256 m) noted that, although the samples contained *C. cooksoniae* and lacked index species from any younger (or older) zones, the overall assemblage suggests a spore-pollen zone possibly as young as *Murospora florida*, making its true age slightly more ambiguous (Backhouse, 2011). In comparison to the original study, the reassessment considered the deeper samples (specifically from 314, 372 and 511 m) to differ from these Late Jurassic assemblages, particularly in the numbers and dominance of *Dictyophyllidites/Cyathidites* and *Classopollis* specimens. Overall, Backhouse (2011) professed a suspicion that these samples were in fact Early–Middle Jurassic in age, possibly assignable to the *Callialasporites turbatus* Spore-Pollen Zone and most similar to the lowermost, unusual palynomorph assemblage seen in PL3A (Backhouse, 2011). The deepest sample (759 m) processed from PL4A was badly contaminated with drilling mud, and the palynoflora could not be certainly determined as either in situ or a reflection of downhole contamination (Backhouse, 1978c).

Therefore, although contamination or caving were not obvious in the samples from PL4A, the assemblages were still relatively enigmatic and poorly constrained. However, the available palynological information suggests that the shallowest sequence is Early Cretaceous in age, with the unconformity between this sequence and the overlying Late Jurassic sediments falling somewhere between 69 and 198 m. It seems likely that the final boundary, between the Late Jurassic and Early Jurassic, exists between 256 and 314 m. Again, these data differ greatly from previous determined formation tops in PL4A, which suggest an unconformity between the Early Cretaceous Leederville Formation and Late Jurassic Yarragadee Formation at roughly 59 m depth, and the Yarragadee Formation extending through to TD (Wharton, 1981).

References

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Waroona Junior High School bore 1

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
WJHS1[a]				
50–60	15.2 – 18.3	DC	barren	(Backhouse, 2015)
140–150	42.7 – 45.7	DC	?*C. torosa*^	(Backhouse, 2015)
–	78	DC	Early Jurassic	(Backhouse, 2015)
390–410	118.9 – 125.0	DC	?*C. torosa*^	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone

Line summary

Between 1974 and 1976, a set of four relatively shallow water bores was drilled in the Waroona township to provide water for the local junior high school. Of these four boreholes, the deepest is Waroona Junior High School No. 4, drilled to a depth of 304 m; borehole 3 had a TD of 230 m, and boreholes 1 and 2 were the shallowest at 132 and 130 m, respectively. Only samples from boreholes 1 and 3 were submitted for palynological assessment, all of which were conducted in 1975. The original slides have not been reviewed since.

WJHS1

A total of four samples were submitted for palynological analysis from Waroona Junior High School 1 borehole, described in two reports (Backhouse, 1975a,b). Although one of these reports refers to the borehole as ‘Waroona High School 1’ rather than ‘Waroona Junior High School 1’, there is only one government high school in town, and it appears that both reports are referring to the same well. The results from these reports were reviewed in 2015, in order to bring the biostratigraphic interpretations in line with current usage (Backhouse, 2015).

All of the samples submitted for analysis were from ditch cuttings, from the following depths: 15.2 – 18.3, 42.7 – 45.7, 78–90 and 118.9 – 125.0 m. Of these, the shallowest sample from 15.2 – 18.3 m proved to be barren, and the remaining three samples yielded spore-pollen assemblages broadly similar in age. No dinoflagellates were recovered and the samples are assumed to represent nonmarine environments.

The samples at 42.7 and 118.9 m yielded only sparse palynomorph assemblages, heavily dominated by *Araucariacites australis*, and species of *Classopollis* and *Cyathidites*. Therefore, although the assemblages were considered Early Jurassic in age, they could not be formally associated with any particular spore-pollen zone. The palynologist describing this material noted that the shallower sample contained rich plant material, suggesting that this sparse palynomorph assemblage is not a result of taphonomic or diagenetic influences (Backhouse, 1975b).

The sample from 78–90 m was not highly diverse, but was considered by Backhouse (1975a) to be Early Jurassic in age based on the presence of both *Classopollis classoides* and a new *Classopollis* species previously recorded by Filatoff (1975) from the lower part of his *Exesipollenites tumulus* Assemblage Zone, which is generally equated with the *Corollina torosa* Spore-Pollen Zone of Helby et al. (1987). This, plus the low assemblage diversity (and those immediately surrounding it), and the presence of *Cibotiumspora jurienensis* and *Anapiculatisporites dawsonensis* in the same sample could suggest assignment to the *C. torosa* or possibly the lowermost *Callialasporites turbatus* Spore-Pollen Zones.

The recent review (Backhouse, 2015) considered that these reports provide little solid evidence to support the interpretation of an Early Jurassic age, but concluded that if this interpretation is correct, the material may be assignable to the *C. torosa* Zone, or less likely the *C. turbatus* Zone.

As the shallowest yielding sample from this borehole suggests an Early Jurassic age, it can be assumed that younger Jurassic, Cretaceous and Quaternary sediments, seen in other parts of the study area, are either absent or thin (less than 40 m thick) in the Waroona area. This is similar to other boreholes located close to the Darling Fault, such as MH15 and Alcoa Pinjarra borehole AE2.

References

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Waroona Junior High School bore 3

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
WJHS3[(a)]				
490–500	149.4 – 152.4	DC	*C. torosa*^ or *C. turbatus*^	(Backhouse, 2015)
720–730	219.5 – 222.5	DC	*C. torosa*^ or *C. turbatus*^	(Backhouse, 2015)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone

Line summary

Between 1974 and 1976, a set of four relatively shallow water bores was drilled in the Waroona township to provide water for the local junior high school. Of these four boreholes, the deepest is Waroona Junior High School No. 4, drilled to a depth of 304 m; borehole 3 had a TD of 230 m, and boreholes 1 and 2 were the shallowest at 132 and 130 m, respectively. Only samples from boreholes 1 and 3 were submitted for palynological assessment, all of which were conducted in 1975. The original slides have not been reviewed since.

WJHS3

Only two ditch cuttings samples were submitted for palynological assessment from Waroona Junior High School bore 3, from the depths 149.4 – 152.4 m and 219.5 – 222.5 m. These samples were described together in a single GSWA Paleontology Report (Backhouse, 1975). The results from this report were reviewed by Backhouse (2015), in an attempt to clarify any zone identifications and modernize biostratigraphic interpretations made.

Both samples yielded palynomorphs, and revealed very similar spore-pollen assemblages lacking dinoflagellates. Dominated by *Classopollis* pollen, the assemblage contained only a few other species, most notably *Cyathidites minor* and *Araucariacites australis*. Based on these taxa, Backhouse (1975) indicated an Early Jurassic age, but did not identify any particular spore-pollen zones.

The recent review (Backhouse, 2015) considered the evidence for Early Jurassic age for these samples to be far stronger than that reported for Waroona Junior High School bore 1, and based on the evidence in this borehole, it was considered that samples in both boreholes are Early Jurassic in age, likely assignable to the *Corollina torosa* Spore-Pollen Zone, or perhaps *Callialasporites turbatus* Spore-Pollen Zone. Although it is assumed that the post-Jurassic sediments in this borehole are thin, as in Waroona Junior High School 1, there is no palynological evidence of the composition or age of the shallowest ~150 m of this section.

References

Backhouse, J 1975, Palynology of Waroona Junior High School no. 3 borehole: Geological Survey of Western Australia, Paleontology Report 1975/43, 1p.

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PWD Yunderup bore 3

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
YN3[(a)]				
140	42.7	DC	barren	(Grey, 1973)
150	45.7	DC	*B. limbata*[#]	(Grey, 1973)
200	61.0	DC	barren	(Grey, 1973)
240	73.2	DC	barren	(Grey, 1973)
260	79.3	DC	barren	(Grey, 1973)
280	85.3	DC	barren	(Grey, 1973)
330	100.6	DC	barren	(Grey, 1973)
338	103.0	DC	barren	(Grey, 1973)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone

PWD Yunderup bores

The PWD Yunderup line consists of three boreholes drilled by the Public Works Department to provide domestic water for Mandurah (Commander, 1975). Of the three boreholes, YN1 and YN2 were drilled in 1965 to TD of 282 and 331 ft (85.95 and 100.89 m), respectively, whereas YN3 was drilled in 1973 and reached a TD of 375 ft (114.3 m). Only YN3 has been assessed for palynology.

YN3

Although eight ditch cuttings from the borehole were collected for paleontological assessment (Cockbain, 1973; Grey, 1973), only the sample from 150 ft was considered suitable for processing; the remaining samples were noted to contain only unidentified bivalve shell fragments (240 ft), plant and wood fragments (280, 330 and 338 ft), or both (140 200 and 260 ft).

Unfortunately, the palynomorph assemblages recovered from the 150 ft sample were noted to be of low diversity and poor preservation, although the assemblage includes both miospores and microplankton, indicating a marine environment of deposition. Despite the low diversity, the presence of *Dingodinium cerviculum* suggests that the assemblage belongs within the *Balmeiopsis limbata* Spore-Pollen Zone, somewhere between the *Phoberocysta lowryi* and *Fromea monilifera* Dinocyst Zones (Backhouse, 1988). Aside from this poor palynomorph assemblage, the 150 ft sample was also noted to contain fish teeth, plant fragments, fragments of the foraminifera *Marginulina*, and fragments of the bivalve *Maccoyella* sp. cf. *M. barklyi* (Cockbain, 1973; Grey, 1973).

References

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Cockbain, AE 1973, The bivalve *Maccoyella* from the Leederville Formation in Yunderup No.3 borehole: Geological Survey of Western Australia, Paleontology Report 1973/56, 3p.

Commander, DP 1975, Hydrogeology of the Mandurah-Pinjarra area, Perth Basin, W.A: Geological Survey of Western Australia, Record 1975/3, 41p.

Grey, K 1973, Palaeontological examination of sludge samples from Yunderup No. 3 borehole: Geological Survey of Western Australia, Paleontology Report 1973/54, 2p.

Coolup, Brownes dairy bore 1

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
BROWNES[(a)]				
410	125.0	DC	indeterminate Jurassic or Cretaceous	(Ingram, 1966)
420	128.0	DC	indeterminate Jurassic or Cretaceous	(Ingram, 1966)
434	132.3	DC	indeterminate Jurassic or Cretaceous	(Ingram, 1966)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)

Brownes dairy bore (also known as Browne's bore or Brown's bore), is a privately drilled water bore located east of Coolup. The borehole was drilled in 1965, and reached a TD of 132.3 m (Commander, 1975). A total of three cuttings samples from this borehole were collected for palynological analysis, with all samples reported in a single Paleontology Report (Ingram, 1966). No species lists were provided in this report, and Ingram noted that none of the assemblages was very distinctive, consisting only of long-ranging Jurassic to Early Cretaceous taxa. As such this, material is indeterminate until the slides can be reviewed.

References

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Ingram, BS 1966, Three sludge samples from a private bore in Coolup: Geological Survey of Western Australia, Paleontology Report 1966/07, 1p.

Burekup, Edwards bore

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
EDWARDS[(a)]				
140	42.67	DC	*B. limbata*[#]	(Edgell, 1964)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone

Edwards bore is a private water bore drilled on the property of PW Edwards in the Burekup area. Drilled in 1963, this borehole reached a TD of 42.67 m. A ditch cuttings sample from the bottom of this borehole was collected by geologist DC Lowry as GSWA sample number 14325, and submitted for palynological assessment as part of a set of shallow samples from the southern Perth Basin (Edgell, 1964). The sample yielded a diverse assemblage of Early Cretaceous miospores, but lacked any dinoflagellates or other marine indicators. Edgell (1964) considered the assemblage to belong to Balme's (1964) *Microcachryidites* Assemblage, and the presence of taxa such as *Balmeiopsis limbata* and *Acanthotriletes levidensis* suggest assignment to the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988).

References

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Balme, BE 1964, The palynological record of Australian pre-Tertiary floras, in Ancient Pacific Floras edited by LM Cranwell: University of Hawaii Press, Honolulu, Hawaii, USA, p. 49–80.

Edgell, HS 1964, Palynological examination of survey samples from the southern Perth Basin: Geological Survey of Western Australia, Paleontology Report 1964/24, 4p.

Halls Head ED2

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
HH ED2[(a)]				
–	20	CC	*B. jaegeri*‡	(Backhouse, 1981)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core
Zone/age column: ‡Backhouse (1988) Dinocyst Zone

Halls Head ED2 is a private water bore that was drilled in 1981 for Parry's Esplanade Development; the bore hole TD was 30 m. Work on the borehole was conducted by Rockwater Pty Ltd consultancy, and it was this company who submitted a single core sample (from 20 m) to GSWA palynologist J Backhouse for palynological assessment. The results from this sample were reported in a single Paleontology Report (Backhouse, 1981). This sample yielded a moderately rich assemblage of miospores indicating either the Early Cretaceous *Biretisporites eneabbaensis* or *Balmeiopsis limbata* Spore-Pollen Zones, although the regular presence of *Classopollis chateaunovi* (if it is assumed that this species is synonymous with *Classopollis torosus*), and dominance of *Microcachryidites antarcticus* and saccate pollen suggests assignment to the *B. limbata* Zone (Backhouse, 1988). In addition to the nonmarine spores and pollen, Backhouse (1981) noted the presence of acritarchs (unnamed in the report) and specimens of the dinoflagellate *Horologinella lineata*, suggesting a nearshore or marginal marine environment of deposition for this sample. *H. lineata* is a very unusual taxon within the Perth Basin, noted only at three locations — in the Attadale bore, Woodman's Point 2, and here in Halls Head ED2 (Backhouse, 1988). Backhouse (1988) considered this taxon to be restricted to his *Batioladinium jaegeri* Dinocyst Zone.

References

Backhouse, J 1981, Palynology of a core sample from Halls Head, Mandurah: Geological Survey of Western Australia, Paleontology Report 1981/24, 2p.

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Yunderup, Hills bore

Depth (feet)	Depth (metres)	Sample type	Zone/age(b)	Report
HILLS(a)				
170–179	51.8 – 54.56	DC	*?B. jaegeri*‡	(Edgell, 1963)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: ‡Backhouse (1988) Dinocyst Zone

This private water bore was drilled in 1958, on the property of Mr Hill in the Yunderup area. A single ditch cuttings sample, which was noted to be distinctly glauconitic, was later collected from the bottom of the hole (TD of 179 ft = 54.56 m) by GSWA hydrogeologist CC Emmenegger in 1963 (Emmenegger, 1964), and submitted to HS Edgell for palynological assessment (Edgell, 1963).

Edgell (1963) noted that although sparse, palynomorphs were well preserved in this sample. The spores and pollen in this assemblage were particularly low diversity, and although Edgell assigned this sample to Balme's (1957, 1964) *Microcachryidites antarcticus* Assemblage, the four taxa seen (*Baculatisporites comaumensis*, *Araucariacites australis*, *Microcachryidites antarcticus*, and *Podocarpidites ellipticus*) are now considered only generically Late Jurassic to Early Cretaceous (*Retitriletes watherooensis* to *Balmeiopsis limbata* Spore-Pollen Zones) in age (Backhouse, 1988). In addition to these miospores, the assemblage contains a number of microplankton, supporting the interpretation (based on lithology) that the assemblage is marine in origin. Edgell (1963) compared this sample to similar microplankton assemblages at 450 ft in Mandurah 1 borehole, which he later ascribed to his *Dingodinium cerviculum* Dinocyst Zone (Edgell, 1964). Helby et al. (1987) later correlated this zone with their *Muderongia australis* Dinocyst Zone, which here is considered equivalent to the *Batioladinium jaegeri* Dinocyst Zone of Backhouse (1988). This agrees generally with Backhouse (1988), who noted glauconitic sediments associated with his *Fromea monilifera* Dinocyst Zone (equivalent to Helby et al.'s [1987] *M. australis* to *Odontochitina operculata* Dinocyst Zones) in the Bunbury Trough.

References

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Emmenegger, C 1964, Report on exploratory drilling for underground water at Mandurah, Perth Basin, W.A: Geological Survey of Western Australia, Record 1964/15, 35p.

Helby, R, Morgan, R and Partridge, AP 1987, A palynological zonation of the Australian Mesozoic: Association of Australasian Palaeontologists, Memoir 4, p. 1–94.

North Dandalup, Runcimans bore

Depth (feet)	Depth (metres)	Sample type	Zone/age(b)	Report
RUNCIMAN(a)				
145	44.2	DC	Early Cretaceous	(Edgell, 1963a)
140–150	42.7 – 45.7	DC	*B. limbata*# / ?*B. jaegeri*‡	(Edgell, 1963a)
240	73.2	DC	?*B. limbata*#	(Edgell, 1963a)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)
Zone/age column: #Backhouse (1988) Spore-Pollen Zone; ‡Backhouse (1988) Dinocyst Zone

Runcimans bore is a privately drilled water bore in the North Dandalup area. Drilled in 1963 to a depth of 73.2 m, the bore was sampled by then GSWA hydrogeologist C Emmenegger, with geological and water flow data used in this author's study on subsurface water in the Mandurah area (Emmenegger, 1964). Emmenegger submitted three ditch cuttings from this borehole for palynological examination, with all three samples described by GSWA paleontologist HS Edgell in a single GSWA Paleontology Report (Edgell, 1963a). The assemblages have not been reviewed since this original work.

All three samples – from 145, 140–150 and 240 ft — yielded Early Cretaceous palynomorphs, although the shallowest sample yielded only a very lean and low diversity assemblage of pollen and microplankton. Due to the low diversity, this assemblage cannot be certainly linked to any spore-pollen or dinoflagellate zone. Edgell (1963a) assigned both remaining samples to Balme's (1957, 1964) *Microcachryidites* Assemblage, although the deepest sample (240 ft) yielded a nonmarine spore-pollen assemblage that only contained long-ranging Early Cretaceous forms.

In comparison to these samples, the central sample yielded a diverse and rich assemblage of both miospores and microplankton, indicating a marine environment of deposition. Edgell (1963a) considered that the combination of microplankton seen in this assemblage indicated a correlation to the upper *Dingodinium cerviculum* Dinocyst Zone in Mandurah Line 1 (around 450 ft depth). Assuming this corresponds to his own microplankton zonation scheme (Edgell, 1963b, 1964), the assemblage can be considered as most likely assignable to the Helby et al. (1987) *Muderongia australis* Dinocyst Zone, and therefore to the *Batioladinium jaegeri* or possibly to the lower *Fromea monilifera* Dinocyst Zones of Backhouse (1988). For the miospores, the combination of *Balmeiopsis limbata*, *Acanthotriletes levidensis*, and *Ruffordiaspora australiensis* indicates that this assemblage at least is assignable to the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988).

References

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Emmenegger, C 1964, Report on exploratory drilling for underground water at Mandurah, Perth Basin, W.A: Geological Survey of Western Australia, Record 1964/15, 35p.

Helby, R, Morgan, R and Partridge, AP 1987, A palynological zonation of the Australian Mesozoic: Association of Australasian Palaeontologists, Memoir 4, p. 1–94.

Burekup miscellaneous samples

Depth (feet)	*Depth (metres)*	*Sample type*	*Zone/age*[(b)]	*Report*
BKP8[(a)]				
–	56–58	CC	*B. limbata*[#]	(Backhouse, 1982)
BKP10				
–	36–38	CC	*B. limbata*[#]	(Backhouse, 1982)
–	48–50	CC	*B. limbata*[#]	(Backhouse, 1982)
–	58–60	CC	*B. limbata*[#]	(Backhouse, 1982)
GSWA14332				
20	6.1	HS	Pleistocene to Recent	(Edgell, 1964)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional coreHS, hand sample
Zone/age column: [#]Backhouse (1988) Spore-Pollen Zone

BKP8 and BKP10

These mineral boreholes are part of a series of holes drilled just east of the Darling Fault in the Burekup area in the 1980s. Unfortunately, the GSWA Palynology Report (Backhouse, 1982) is the only known record of these boreholes, as there is no mention of them in any mineral exploration report held by GSWA. Backhouse recorded that material from two of these boreholes (Burekup no. 8 and no. 10) was submitted for palynological assessment by the project's geological consultants, TE Johnstone and Associates, but only rough map references were provided for locality information. Although Burekup hole no. 10 lies outside the study area, all assemblages from this hole were noted to be very similar to that in BKP8, and they are included here for convenience.

Although all assemblages yielded palynomorphs, the sample from BKP8 was of low diversity. All except the deepest BKP10 hole contained *Balmeiopsis limbata*, and other aspects of the assemblage, including common *Classopollis* spp., *Podocarpidites ellipticus* and *Microcachryidites antarcticus* (in the shallowest BKP10 sample), and the presence of *Antulsporites clavus*, *Reticuloidosporites arcus* (in BKP10 58–60 m) and *Ceratosporites equalis* (in BKP10 36–38 m), all suggest assignment of the samples to the *Balmeiopsis limbata* Spore-Pollen Zone. An unidentifiable simple dinoflagellate or acritach was noted in BKP10 36–38 m, which suggests deposition of that assemblage within a lagoonal or nearshore marine setting, but does not provide additional age information for this sample (Backhouse, 1982).

Burekup, GSWA 14332

This hand sample was collected by GSWA geologist DC Lowry in 1964, from the bottom of a 20 ft deep drainage channel in the Burekup area. The single sample submitted for palynological assessment was studied by HS Edgell and reported within a single Paleontology Report (Edgell, 1964). The samples yielded a small assemblage of angiosperm pollen, attributable to either the extant taxon *Myrtaceidites eucalyptoides* or the Graminae (grasses). Edgell considered this assemblage to be Pleistocene to Recent in age.

References

Backhouse, J 1982, Palynology of two boreholes east of the Darling Fault, near Burekup: Geological Survey of Western Australia, Paleontology Report 1982/04, 3p.

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Edgell, HS 1964, Palynological examination of survey samples from the southern Perth Basin: Geological Survey of Western Australia, Paleontology Report 1964/24, 4p.

Coastal Property bore 1

Depth (feet)	Depth (metres)	Sample type	Zone/age[(b)]	Report
COASTAL1[(a)]				
–	116.5 –118.0	DC	indeterminate Late Jurassic or Early Cretaceous	(Backhouse, 1974)
–	116.5 m or above	DC	barren	(Backhouse, 1974)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: DC, ditch cuttings (including bit, bailed, and sludge samples)

Two ditch cutting samples from this borehole were submitted for palynological assessment in 1974 by GSWA hydrogeologist AS Harley. The samples were assessed by J Backhouse the same year, and reported in a single Paleontology Report (Backhouse, 1974). The coal sample (from ‘116.5 m or above’) proved to be barren of palynomorphs, and the other sample yielded a low-diversity assemblage of spores and pollen, lacking dinoflagellates or other marine indicators. Backhouse (1974) noted that the specimens were taphonomically unusual, suggesting abnormal depositional conditions. Specifically, it was suggested that the specimens were transported for a period of time prior to deposition, and were sifted and broken down during this period of transport. The assemblage itself was found to be undiagnostic, containing only long-ranging Late Jurassic to Early Cretaceous taxa, such as *Murospora florida*, *Contignisporites cooksoniae* and *Cyathidites minor*. As a result, the age of this sample could not be determined with any precision (Backhouse, 1974).

Little is known about the location or nature of this borehole, as no reference can be found to it within water or mineral bore databases. The fact that it was a hydrogeologist who submitted the samples for analysis suggests it is a water bore, and it may be that the hole is listed under another name in DWER’s WIR database, or was accidently omitted from that dataset. As a result, the borehole location used in this Report was estimated based on the information provided in the Paleontology Report (Backhouse, 1974).

Reference

Backhouse, J 1974, Palynology of Coastal Property No.1 borehole: Geological Survey of Western Australia, Paleontology Report 1974/45, 1p.

Leschenault Inlet boreholes

Depth (feet)	Depth (metres)	Sample type	Zone/age[b]	Report
LESCH A[a]				
–	24.55 – 24.80	CC	indeterminate	(Backhouse, 1982)
LESCH B(i)				
–	29.85 – 30.50	CC	*B. limbata*#	(Backhouse, 1982)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core
Zone/age column: #Backhouse (1988) Spore-Pollen Zone

Line summary

A single core sample from each of these boreholes was prepared for palynological analysis by West Australian Petroleum Pty Ltd, with the samples examined and reported on by J Backhouse in a single Paleontology Report (Backhouse, 1982). The location and drilling details of these boreholes is uncertain as no reference can be found within any listings of water, mineral or petroleum bores. As a result, the location information used in this Report is an estimate only, based on the generalized information provided in the Paleontology Report (Backhouse, 1982).

Leschenault Inlet borehole A

The sample from Leschenault Inlet borehole A yielded only a poor assemblage of fossils, consisting of a small number of unidentified foraminifera and a single specimen of dinoflagellate identified as *Spiniferites* sp. This combination suggests that the sample was deposited in a marine environment, but reveals nothing about its age and the assemblage is considered indeterminate. Backhouse (1982) considered that the lack of palynomorphs indicates that sample was collected from within the weathered zone, and that the *Spiniferites* specimen might be a laboratory contaminant.

Leschenault Inlet borehole B(i)

Unlike Leschenault Inlet bore A, the sample from borehole B(i) yielded a diverse assemblage of spores and pollen, although no dinoflagellates or other marine indicators were observed. The assemblage contains a number of taxa that together are considered indicative of the Early Cretaceous *Balmeiopsis limbata* Zone, including *Balmeiopsis limbata*, *Cicatricosisporites* sp. cf. *C. hughesi*, *Reticuloidosporites arcus*, and *Laevigatosporites belfordii* (Backhouse, 1988).

References

Backhouse, J 1982, Palynology of two samples from Leschenault Inlet near Australind: Geological Survey of Western Australia, Paleontology Report 1982/02, 2p.

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Wagerup bore holes

Depth (feet)	Depth (metres)	Sample type	Zone/age(b)	Report
ALCOA WAG(a)				
–	12.6 m (52954)	CC	indeterminate	(Backhouse, 1980a)
–	24.0 m (52955)	CC	indeterminate	(Backhouse, 1980a)
–	28.6 m (52956)	CC	*C. turbatus*^	(Backhouse, 1980a)
–	42.7 m (52957)	CC	indeterminate	(Backhouse, 1980a)
WAGERUP A				
–	101	SWC	?*B. limbata*#	(Backhouse, 1980b)
–	144	SWC	barren	(Backhouse, 1980b)
–	263	SWC	barren	(Backhouse, 1980b)
WAGERUP B				
–	133.5	SWC	?*B. limbata*#	(Backhouse, 1980b)
–	285	SWC	barren	(Backhouse, 1980b)
–	338	SWC	barren	(Backhouse, 1980b)
–	412	SWC	barren	(Backhouse, 1980b)

NOTES:
(a) Well or bore name abbreviations taken from Appendix 1
(b) Age or zone taken from most recent study or review
Abbreviations: Sample type column: CC, conventional core; SWC, sidewall core
Zone/age column: ^Helby et al. (1987) Spore-Pollen Zone; #Backhouse (1988) Spore-Pollen Zone

Alcoa Wagerup bore

Four conventional core samples were submitted in 1980 by GSWA geologist LJ Furness for palynological assessment, and were reported within a single Paleontology Report (Backhouse, 1980a). In that report, the samples were only identified by their GSWA number (GSWA 52954 to 52957), as it appears the collector did not provide sample depths; however, sample depths have been identified for the current Report using the collector's field sample books. Unfortunately, the location of this borehole is presently unknown, as it does not appear to be recorded within any known water or mineral bore database. It is possible that the borehole was drilled privately by Alcoa, perhaps for engineering purposes, or that the hole is registered in DWER's Water Reporting Information database in a way that it is now difficult to link to the Paleontology Report (Backhouse, 1980a). As a result, the location used in the present Report is an estimate only, based on information provided in that Paleontology Report.

Of the four samples processed, three proved to be barren on processing, with only a single assemblage at 28.6 m (GSWA 52956) able to be assessed biostratigraphically. This sample yielded a relatively diverse assemblage of typically Early Jurassic spores and pollen, completely lacking dinoflagellates or any other marine indicators. Based on the common, but not dominant, *Classopollis* spp., and the presence of taxa such as *Retitriletes austroclavatidites*, Backhouse (1980a) considered the assemblage to be indicative of Filatoff's (Filatoff, 1975) *Dictyophyllidites harrisii* Zone, which is equivalent to the upper portion of Helby et al.'s (1987) *Callialasporites turbatus* Zone.

Wagerup A and B

In total, three sidewall cores from Wagerup A and four sidewall cores from Wagerup B were submitted for palynological assessment by GSWA hydrogeologist AD Allen in 1980, with all samples reported in a single Paleontology Report (Backhouse, 1980b). Like the Alcoa Wagerup bore, little is known about these boreholes beyond the information provided in the Paleontological Report (Backhouse, 1980b) as the boreholes do not appear in any known database for mineral or water bores. Considering the sample was submitted by a hydrogeologist, it seems most likely that the samples relates to water bores uncaptured in the DWER's Water Reporting Information database. As a result, the locations used for these sites in the present Record are estimates only, based entirely on information provided in the Paleontology Report (Backhouse, 1980b).

Of the sidewall core samples submitted for palynological analysis, two samples from Wagerup A (144 and 263 m) proved to be barren of palynomorphs after processing, and were still found to be barren when the samples were reprocessed. In Wagerup B, samples from 285, 338 and 412 m were deemed lithologically unsuitable for palynological studying; on processing, all samples were found to be barren. As a result, only a single productive sample was recovered from each of Wagerup A (101 m) and Wagerup B (133.5 m). Unfortunately, neither of these samples contains index or characteristic taxa for any particular spore-pollen zone, with only long-ranging, generic, Late Jurassic to Early Cretaceous forms recorded. Despite this, Backhouse (1980b) considered the overall assemblage to be more characteristic of the Warnbro Group, and based on this, the samples were tentatively assigned to the *Balmeiopsis limbata* Spore-Pollen Zone (Backhouse, 1988). Neither assemblage preserves dinoflagellates or other marine indicators.

References

Backhouse, J 1980a, Palynology of a borehole at Wagerup: Geological Survey of Western Australia, Paleontology Report 1980/22, 1p.

Backhouse, J 1980b, Palynology of Wagerup boreholes A and B: Geological Survey of Western Australia, Paleontology Report 1980/03, 2p.

Backhouse, J 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia: Geological Survey of Western Australia, Bulletin 135, 233p.

Filatoff, J 1975, Jurassic palynology of the Perth Basin, Western Australia: Palaeontographica Beiträge Zur Naturgeschichte der Vorzeit.Abteilung B: Paläophytologie, v. 154, p. 1–113.

Helby, R, Morgan, R and Partridge, AP 1987, A palynological zonation of the Australian Mesozoic: Association of Australasian Palaeontologists, Memoir 4, p. 1–94.

Appendix 3

Taxonomic data for species listed in text

The following is a list of all taxa (genera and species) quoted in text (including appendices), and author information for each taxon. The listing is separated into taxonomic groups, beginning with the microflora — miospores (spores and pollen) and microplankton (dinoflagellates, acritarchs). Also included are discussions regarding the taxonomic usage in this report of the problematic genera *Classopollis*/*Corollina*/*Circulina* and the related species.

Although botanical author citations generally abbreviate author names and exclude the year of publication, author names and years are quoted in full here in order to allow easier identification of the relevant literature, following Raine et al. (2011).

Microflora

Miospores

Acanthotriletes (Naumova, 1939) ex Potonié & Kremp, 1954

Acanthotriletes levidensis Balme, 1957 [Backhouse (1988) considered this to belong to the genus *Neoraistrickia*, but this has not been actively adopted by many workers (Raine et al., 2011)]

Acanthotriletes tereteangulatus Balme & Hennelly, 1956 [Backhouse (1988) considered this to belong to the genus *Horriditriletes*, but this has not been actively adopted by many workers (Raine et al., 2011)]

Aequitriradites Delcourt & Sprumont, 1955 emend. Cookson & Dettamnn, 1961

Aequitriradites acusus (Balme, 1957) Dettmann, 1963

Aequitriradites hispidus Dettmann & Playford, 1968

Aequitriradites verrucosus (Cookson & Dettmann, 1958) Cookson & Dettmann, 1961

Alisporites Daugherty, 1941

Alisporites grandis (Cookson, 1953) Dettmann, 1963

Anapiculatisporites Potonié & Kremp, 1954

Anapiculatisporites dawsonensis Reiser & Williams, 1969

Antulsporites Archangelsky & Gamerro, 1966

Antulsporites clavus (Balme, 1957) Filatoff, 1975

Antulsporites saevus (Balme, 1957) Archangelsky & Gamerro, 1966

Aratrisporites Leschik, 1956 emend. Playford & Dettmann, 1965

Aratrisporites tenuisporites Playford, 1965

Araucariacites Cookson, 1947

Araucariacites australis Cookson, 1947

Ashmoripollis Helby, 1987

Ashmoripollis reducta Helby, 1987

Baculatisporites Pflug in Thomson & Pflug, 1953

Baculatisporites comaumensis (Cookson, 1953) Potonié, 1956

Balmeiopsis Archangelsky, 1979

Balmeiopsis limbata (Balme, 1957) Archangelsky, 1979

Balmeiopsis robusta Backhouse, 1988

Biretisporites Delcourt and Sprumont, 1955 emend. Delcourt, Dettmann & Hughes, 1963

Biretisporites eneabbaensis Backhouse, 1978

Callialasporites Sukh Dev, 1961

Callialasporites dampieri (Balme, 1957) Sukh Dev, 1961

Callialasporites turbatus (Balme, 1957) Schulz, 1967

Callialasporites segmentatus (Balme, 1957) Srivastava, 1963

Camerosporites Leschik, 1956 emend. Litwin & Skog, 1991

Camerosporites secatus Leschik, 1956

Ceratosporites Cookson & Dettmann, 1958

Ceratosporites equalis Cookson & Dettmann, 1958 [Backhouse (1988) considered this species to belong to the genus *Neoraistrickia*, but this has not been actively adopted by many workers (Raine et al., 2011)]

Cibotiumspora Chang, 1965

Cibotiumspora jurienensis (Balme, 1957) Filatoff, 1975

Cicatricosisporites Potonié & Gelletich, 1933

Cicatricosisporites hughesi Dettmann, 1963

Classopollis Pflug, 1953 [see section below for discussion on genus and species usage]

Classopollis anasillos Filatoff, 1975

Classopollis chateaunovi Reyre, 1970

Classopollis classoides (Pflug, 1953) Pocock & Jansonius, 1961

Classopollis torosus (Reissinger, 1950) Couper, 1958

Conbaculatisporites Klaus, 1960

Conbaculatisporites mesozoicus Klaus, 1960

Concavissimisporites Delcourt & Sprumont, 1955 emend. Delcourt, Dettmann & Hughes, 1963

Concavissimisporites variverrucatus (Couper, 1958) Brenner, 1963

Converrucosisporites Potonié and Kremp, 1954

Converrucosisporites confluens (Archangelsky & Gamerro, 1979) Playford & Dino, 2002 [previously *Pseudoreticulatispora confluens* (Archangelsky & Gamerro, 1979) Backhouse, 1991; the Zone has not yet been officially renamed to reflect the taxonomic name change, and many workers still use the previous combination]

Contignisporites Dettmann, 1963

Contignisporites cooksoniae (Balme) Dettmann, 1963

Contignisporites multimuratus Dettmann, 1963

Coptospora Dettmann, 1963

Coptospora paradoxa (Cookson & Dettman, 1958) Dettmann, 1963

Crybelosporites Dettmann, 1963

Crybelosporites striatus (Cookson & Dettmann, 1958) Dettmann, 1963

Cyathidites Couper, 1953

Cyathidites australis Couper, 1953

Cyathidites concavus (Bolkhovitina, 1953) Dettmann, 1963

Cyathidites minor Couper, 1953

Cyclosporites Cookson & Dettman, 1959

Cyclosporites hughesii (Cookson & Dettmann, 1958) Cookson & Dettman, 1959

Densoisporites (Weyland & Krieger, 1953) Dettmann, 1963

Dictyotosporites Cookson & Dettmann, 1958

Dictyotosporites complex Cookson & Dettmann, 1958

Dictyophyllidites Couper, 1958 emend. Dettman, 1963

Dictyophyllidites equiexinus (Couper, 1958) Dettmann, 1963

Dictyophyllidites harrisii Couper, 1958

Duplexisporites Deak, 1962 emend. Playford & Dettmann, 1965

Duplexisporites problematicus (Couper, 1958) Playford & Dettmann, 1965

Ephedripites Bolkhovitina, 1953 ex Potonié, 1958

Ephedripites macistriatus Dolby, 1976

Exesipollenites Balme, 1957

Exesipollenites tumulus Balme, 1957

Falcisporites Leschik, 1956

Falcisporites australis (de Jersey, 1962) Stevens, 1981

Foraminisporis Krutzsch, 1959

Foraminisporis dailyi (Cookson & Dettmann, 1958) Dettmann, 1963

Foraminisporis wonthaggiensis (Cookson & Dettmann, 1958) Dettmann, 1963

Foveosporites Balme, 1957

Foveosporites canalis Balme, 1957

Gleicheniidites Dettmann, 1963

Gleicheniidites senonicus Ross, 1949 emend. Skarby, 1964

Hoegisporis Cookson, 1961

Ischyosporites Balme, 1957

Ischyosporites crateris Balme, 1957

Ischyosporites scaberis Cookson & Dettmann, 1958) [also known as *Klukisporites scaberis*]

Ischyosporites variegatus (Couper, 1958) Schulz, 1967

Januasporites Pocock, 1962

Januasporites multispinus Backhouse, 1988

Kraeuselisporites Leschik, 1956

Kraeuselisporites cuspidus Balme, 1963

Kraeuselisporites rallus Balme, 1970

Kraeuselisporites saeptatus Balme, 1963

Laevigatosporites Ibrahim, 1933

Laevigatosporites belfordii Burger, 1976

Lunatisporites Leschik, 1956

Lunatisporites pellucidus (Goubin, 1965) Helby, 1972

Mantonisporites Couper, 1958

Mantonisporites crassiangulatus (Balme, 1957) Dettmann, 1963

Microcachryidites Cookson, 1947 ex Couper, 1953

Microcachryidites antarcticus Cookson, 1947

Murospora Somers, 1952

Murospora florida (Balme, 1957) Pocock, 1967

Minutosaccus Mädler, 1964

Minutosaccus crenulatus Dolby in Dolby & Balme, 1976

Myrtaceidites Cookson & Pike, 1954

Myrtaceidites eucalyptoides Cookson & Pike, 1954 emend. Martin, 1973

Neoraistrickia Potonié, 1956

Neoraistrickia truncata (Cookson, 1953) Potonié, 1956

Nevesisporites de Jersey & Paten, 1964

Nevesisporites vallatus de Jersey and Paten, 1964

Osmundacidites Couper, 1953

Osmundacidites wellmanii Couper, 1953

Perotriletes Couper, 1958 emend. Evans, 1968

Perotriletes majus (Cookson & Dettmann, 1958) Evans, 1970

Phimopollenites Dettmann, 1973

Phimopollenites pannosus (Dettmann & Playford, 1968) Dettmann, 1973

Pityosporites Seward, 1914 emend. Manum, 1960

Playfordiaspora Maheshwari & Banerji, 1975 emend. Vijaya, 1995

Playfordiaspora crenulata (Wilson, 1962) Foster, 1979

Podocarpidites Cookson, 1947 ex Couper, 1953

Podocarpidites ellipticus Cookson, 1947

Protohaploxypinus Samoilovich, 1953 emend. Morbey, 1975

Protohaploxypinus microcorpus (Schaarschmidt, 1963) Clarke, 1965

Protohaploxypinus samoilovichii (Jansonius, 1962) Hart, 1964

Pseudoreticulatispora Bharadwaj & Srivastava, 1969

Pseudoreticulatispora pseudoreticulata (Balme & Hennelly, 1956) Bharadwaj & Srivastava, 1969

Pseudoreticulatispora confluens [see *Converrucosisporites confluens*]

Reticuloidosporites Pflug in Thomson & Pflug, 1953

Reticuloidosporites arcus (Balme, 1957) Dettmann, 1963

Retitriletes Pierce, 1961 emend. Döring et al. in Krutzsch, 1963

Retitriletes austroclavatidites (Cookson, 1953) Döring et al. in Krutzsch, 1963

Retitriletes watherooensis Backhouse, 1978

Rogalskaisporites Danze-Corsin & Laveine, 1963

Rogalskaisporites canaliculus Filatoff, 1975

Rouseisporites Pocock, 1962

Rouseisporites reticulatus Pocock, 1962

Ruffordiaspora Dettmann & Clifford, 1992

Ruffordiaspora australiensis (Cookson, 1953) Dettmann & Clifford, 1992 [also known as *Cicatricosisporites australiensis*]

Rugulatisporites Pflug in Thomson & Pflug, 1953

Salicornia Linnaeus, 1753

Samaropollenites Goubin, 1965

Samaropollenites speciosus Goubin, 1965

Staplinisporites Pocock, 1962

Staplinisporites caminus (Balme, 1957) Pocock, 1962

Staplinisporites telatus (Balme, 1957) Döring, 1965

Staurosaccites Dolby in Dolby & Balme, 1976

Staurosaccites quadrifidus Dolby, 1976

Stereisporites Pflug, 1953

Stereisporites antiquasporites (Wilson & Webster, 1946) Dettmann, 1963

Striatopodocarpites Sedova, 1956

Striatopodocarpites fusus (Balme & Hennelly, 1955) Potonié, 1958

Trilobosporites Pant, 1954

Trilobosporites antiquus Reiser and Williams, 1969

Triplexisporites Foster, 1979

Triplexisporites playfordii (de Jersey & Hamilton, 1967) Foster, 1979

Tsugaepollenites Potonié & Venitz, 1934 emend. Potonié, 1958

Verrucosisporites Ibrahim, 1933 emend. Potonié & Kremp, 1954

Vitreisporites Leschik, 1956

Vitreisporites pallidus (Reissinger, 1938) Nilsson, 1958

Microplankton

Aprobolocysta Duxbury, 1977

Aprobolocysta alata Backhouse, 1987

Ascodinium Cookson & Eisenack, 1960

Ascodinium cinctum [see *Ovoidinium cincta*]

Batioladinium Brideaux, 1975

Batioladinium jaegeri (Alberti, 1961) Brideaux, 1975

Bartenia Helby, 1987

Bartenia communis Helby, 1987

Canninginopsis Cookson & Eisenack, 1962 emend. Marshall, 1990

Canninginopsis denticulata Cookson & Eisenack, 1962

Cassiculosphaeridia Davey, 1969

Cassiculosphaeridia magna Davey, 1974

Coronifera Cookson & Eisenack, 1958

Coronifera oceanica Cookson & Eisenack, 1958

Chlamydophorella Cookson & Eisenack, 1958 emend. Duxbury, 1983

Chlamydophorella nyei Cookson & Eisenack, 1958

Conosphaeridium Cookson & Eisenack, 1969

Conosphaeridium striatoconum (Deflandre & Cookson, 1955) Cookson & Eisenack, 1969

Cribroperidinium Neale & Sarjeant, 1962

?Cribroperidinium edwardsii (Cookson & Eisenack, 1958) Davey, 1969

Cribroperidinium muderongense (Cookson & Eisenack, 1958) Davey, 1969

Cyclonephelium Deflandre & Cookson, 1955 emend. Stover & Evitt, 1978

Cyclonephelium attadalicum Cookson & Eisenack, 1962

Cyclonephelium hystrixi (Eisenack, 1958) Davey, 1978 emend. Sarjeant, 1985

Deflandrea Eisenack, 1938 emend. Lentin & Williams, 1976

Deflandrea cincta [see *Ovoidinium cincta*]

Diconodinium Eisenack & Cookson, 1960

Diconodinium davidii Morgan, 1975

Diconodinium multispinum (Deflandre & Cookson, 1955) Eisenack & Cookson, 1960 emend. Morgan, 1977

Dingodinium Cookson & Eisenack, 1958

Dingodinium cerviculum Cookson & Eisenack, 1958

Discorsia Duxbury, 1977 emend. Khowaja-Ateequzzaman et al., 1985

Discorsia nannus (Davey, 1974) Duxbury, 1977

Dissiliodinium Drugg, 1978 emend. Feist-Burkhardt & Monteil, 2001

Dissiliodinium caddaense (Filatoff, 1975) Stover & Helby, 1987

Endoceratium Vozzhennikova, 1965

Endoceratium ludbrookiae (Cookson & Eisenack, 1958) Loeblich & Loeblich, 1966

Endoceratium turneri (Cookson & Eisenack, 1958) Stover & Evitt, 1978

Fromea Cookson & Eisenack, 1958

Fromea monilifera Backhouse, 1987

Fusiformacysta Morgan, 1975

Fusiformacysta tumida Backhouse, 1988

Gagiella Backhouse, 1988

Gagiella mutabilis Backhouse, 1988

Hologinella Cookson & Eisenack, 1962

Horologinella lineata Cookson & Eisenack, 1962

Kaiwaradinium Wilson, 1978

Kaiwaradinium scrutillinum Backhouse, 1987

Lecaniella Cookson & Eisenack, 1962

Lecaniella foveolatus Filatoff, 1975

Moorodinium Backhouse, 1988

Muderongia Cookson & Eisenack, 1958

Muderongia australis Helby, 1987

Muderongia mcwhaei Cookson & Eisenack, 1958

Muderongia testudinaria Burger, 1980

Muderongia tetracantha (Gocht, 1957) Alberti, 1961 emend. Monteil, 1991

Odontochitina Deflandre, 1937 emend. Davey, 1970

Odontochitina operculata (Wetzel, 1933) Deflandre & Cookson, 1955

Oligosphaeridium Davey & Williams, 1966 emend. Davey, 1982

Oligosphaeridium complex (White, 1842) Davey & Williams, 1966

Ovoidinium Davey, 1970

Ovoidinium cincta (Cookson & Eisenack, 1958) Davey, 1970 [also known as *Deflandrea cincta* and *Ascodinium cinctum*]

Phoberocysta Millioud, 1969

Phoberocysta burgeri Helby, 1987

Phoberocysta lowryi Backhouse, 1987

Phoberocysta neocomica (Gocht, 1957) Millioud, 1969 [also known as *Wetzeliella? neocomica*]

Pilasporites Balme & Hennelly, 1956

Pilasporites crateriformis Jain, 1968

Plaesiodictyon Wille, 1970

Plaesiodictyon mosellanum Wille, 1970 emend. Brenner & Foster, 1994

Pterospermella Eisenack, 1972

Pterospermella aureolata (Cookson & Eisenack, 1958) Eisenack, 1972

Pseudoceratium Gocht, 1957 (Helby, 1987)

Pseudoceratium iehiense Helby & May in Helby, 1987

Scriniodinium Klement, 1957

Scriniodinium attadalense (Cookson & Eisenack, 1958) Eisenack, 1967

Senoniasphaera Clarke & Verdier, 1967

Senoniasphaera tabulata Backhouse & Helby in Helby, 1987

Spiniferites Mantell, 1850 emend. Sarjeant, 1970

Systematophora Klement, 1960 emend. Riding & Helby, 2001

Systematophora areolata Klement, 1960

Thymospora Wilson & Venkatchala, 1963

Thymospora ipsviciensis (de Jersey, 1962) Jain, 1965

Xenascus Cookson & Eisenack, 1969

Xenascus asperatus Stover & Helby, 1987

Notes on the usage of *Classopollis* Pflug, 1953 vs *Corollina* Malyavkina, 1949

In this Report, the pollen genera *Corollina* Malyavkina, 1949 and *Circulina* Malyavkina, 1949 are both considered junior synonyms of *Classopollis* Pflug, 1953, following International Code of Botanical Nomenclature (ICBN; now the International Code of Nomenclature for algae, fungi and plants, or ICN) Proposal 1643 (Traverse, 2004), which was ratified in 2005 (Skog, 2005).

Considerable confusion has surrounded the genera *Classopollis*, *Corollina*, and *Circulina* since at least the 1950s. *Corollina* and *Circulina* were defined first, in a single paper published in a little-known Russian publication (Malyavkina, 1949); this paper was very brief, lacked precise locality information, provided the genera diagnoses in the form of morphological keys, and contained no images beyond simple line drawings. Further, Malyavkina's type specimens are now all missing (Traverse, 2008). Traverse (2004) noted that on that basis, many palynologists have considered the definition of *Corollina* and *Circulina* to be inadequate, but in essence none of these features renders either genus formally invalid. In 1953, Pflug proposed the name *Classopollis* for a genus of pollen he had noted from the Early Jurassic of Germany, including good photographic illustrations and a clear description. It was later recognized that *Classopollis*, *Corollina*, and *Circulina* represent the same form, although Pflug's redescription of an already established taxon was apparently accidental and likely caused by the poor distribution of post-war Soviet scientific studies beyond the borders of that nation.

Although all three taxa are essentially valid, with *Corollina* the senior synonym based on page priority, a majority of paleopalynologists accepted Pflug's (1953) better defined genus, *Classopollis*, as the correct name, although other authors continued to use *Corollina* or even *Circulina* in preference. An example of this is Helby et al. (1987), who used the genus *Corollina* preferentially, even applying this genus epithet into their zone names.

To prevent further confusion, a proposal was made in August 2004 to conserve the more commonly used name, *Classopollis*, against the more correct *Corollina* or *Circulina*. This proposal was accepted by the then ICBN at the International Botanical Congress in 2005, rendering *Corollina* and *Circulina* nom. rej. (Skog, 2005). For this reason, *Classopollis* is used preferentially to *Corollina* and *Circulina* in this Report for taxonomic (species) names.

As mentioned above, Helby et al. (1987) used the now incorrect *Corollina torosa* as a spore-pollen zone name, a naming convention that was carried throughout later iterations and revisions of the scheme (Foster, 2001; Helby et al., 2004; Partridge, 2006). Most of these revisions pre-date the taxonomic formalization of *Classopollis* over *Corollina*, and the zone name has never been formally revised. As a result, most, if not all, Australian biostratigraphers still refer to the *Corollina torosa* Zone, despite the fact that the eponymous species is now correctly *Classopollis torosus*. This text follows standard convention in retaining *Corollina torosa* for the zone name, and using *Classopollis torosus* when referring directly to the species.

Notes on the usage of *C. torosus* (Reissinger, 1950) Couper, 1958 and *C. classoides* (Pflug, 1953) Pocock and Jansonius, 1961

Similar taxonomic confusion surrounds the type species of *Classopollis*. Pflug (1953) designated *Classopollis classoides* Pflug, 1953 as the type species of his genus; Couper (1957)[1] later considered *Pollenites torosus* Reissinger, 1950, described three years earlier than *C. classoides*, to be the same species, and therefore the type species by priority. However, Reissinger's (1950) species was described without a diagnosis, and many workers consider it invalid under the ICN (Traverse, 2004). As such, there has been considerable disagreement whether *C. classoides* and *C. torosus* should be synonymized, and which of them can be considered the type species of *Classopollis*. For example, Pocock and Jansonius (1961) considered the two taxa separate, making *C. classoides* the type species, as did Reyre (1970). Cornet and Traverse (1975), on the other hand, followed Couper (1957) in considering the species to be the same, synonymizing *C. classoides* under *C. torosus*. However, as noted by Peyrot et al. (2007), the loss of the types of both species means that it is now impossible to compare the taxa and both are better considered separate based on their differing original descriptions.

In Australia, there is the additional confusion in that there are three *Classopollis* species that are variously considered to be separate or synonymized — *C. torosus* (Reissinger, 1950) Couper, 1958, *C. classoides* (Pflug, 1953) Pocock and Jansonius, 1961, and *C. chateaunovi* Reyre, 1970. Although Helby et al. (1987) and Raine et al. (2011) considered all three species tentatively synonymized, Tosolini et al. (2015) considered them to be separate entities, partly following Peyrot et al. (2007). As a result, the current Report follows the two latter papers in considering all three species as separate. However, it should be noted that the names appear to have been applied interchangeably in palynology reports through time, including a number of reports that eschew the assignment of species altogether (listing the taxa as '*Classopollis* spp.'), and there remains considerable confusion with regard to the assignment of *Classopollis* taxa at the species level. In these cases, it is difficult to confirm assignment of *Classopollis* pollen to a certain species without re-examining the original slides, and the species are best considered as a complex until further studies can be made.

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1 Although this paper by Couper, published in Paleontographica Abteilung B, is regularly quoted in the literature as published in 1958, the publisher itself lists the volume year as 1957; the publisher's publication date is used preferentially here.

Macroflora

Dicroidium Gothan, 1912

Foraminifera

Marginulina d'Orbigny, 1826

Bivalve

Maccoyella Etheridge, 1892

Maccoyella barklyi (Moore, 1870)

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This Report modernizes and collates all of the legacy biostratigraphic information for a portion of the southern Perth Basin from Mandurah in the north to Bunbury in the south. Data were derived from petroleum and stratigraphic wells, water and mineral boreholes, and outcrop localities. Spore-pollen assemblages cover the Early Triassic *Kraeuslisporites saeptatus* (= *Lunatisporites pellucidus*) to Early Cretaceous *Balmeiopsis limbata* (= *Ruffordiaspora australiensis*) Zones; dinoflagellates are less common and restricted to the Early Cretaceous (equivalent to the *B. limbata* Spore-Pollen Zone). Permian and Cenozoic palynological data are also briefly reported. The dataset presented here is primarily biostratigraphic, but has relevance to the paleoenvironmental and stratigraphic interpretation of the southern Perth Basin.

Further details of geological products and maps produced by the Geological Survey of Western Australia are available from:

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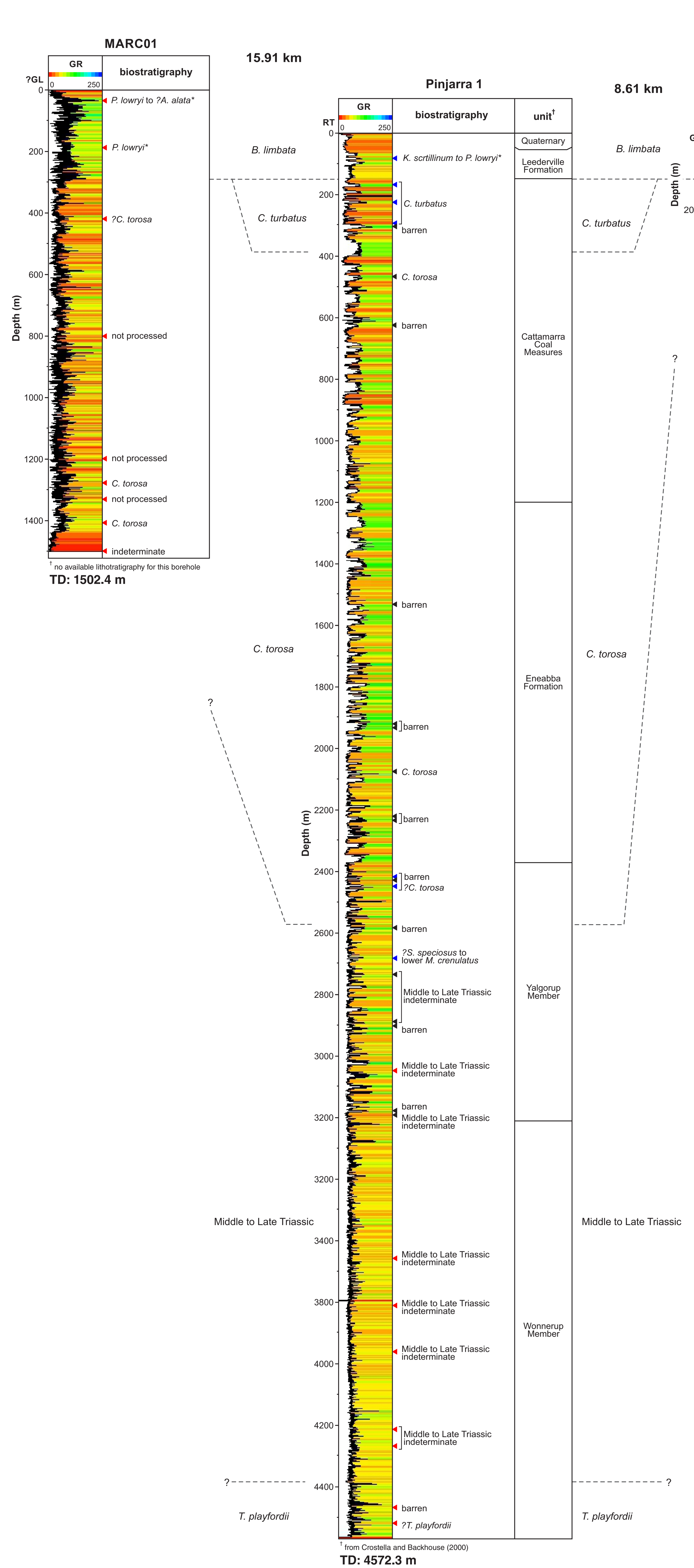
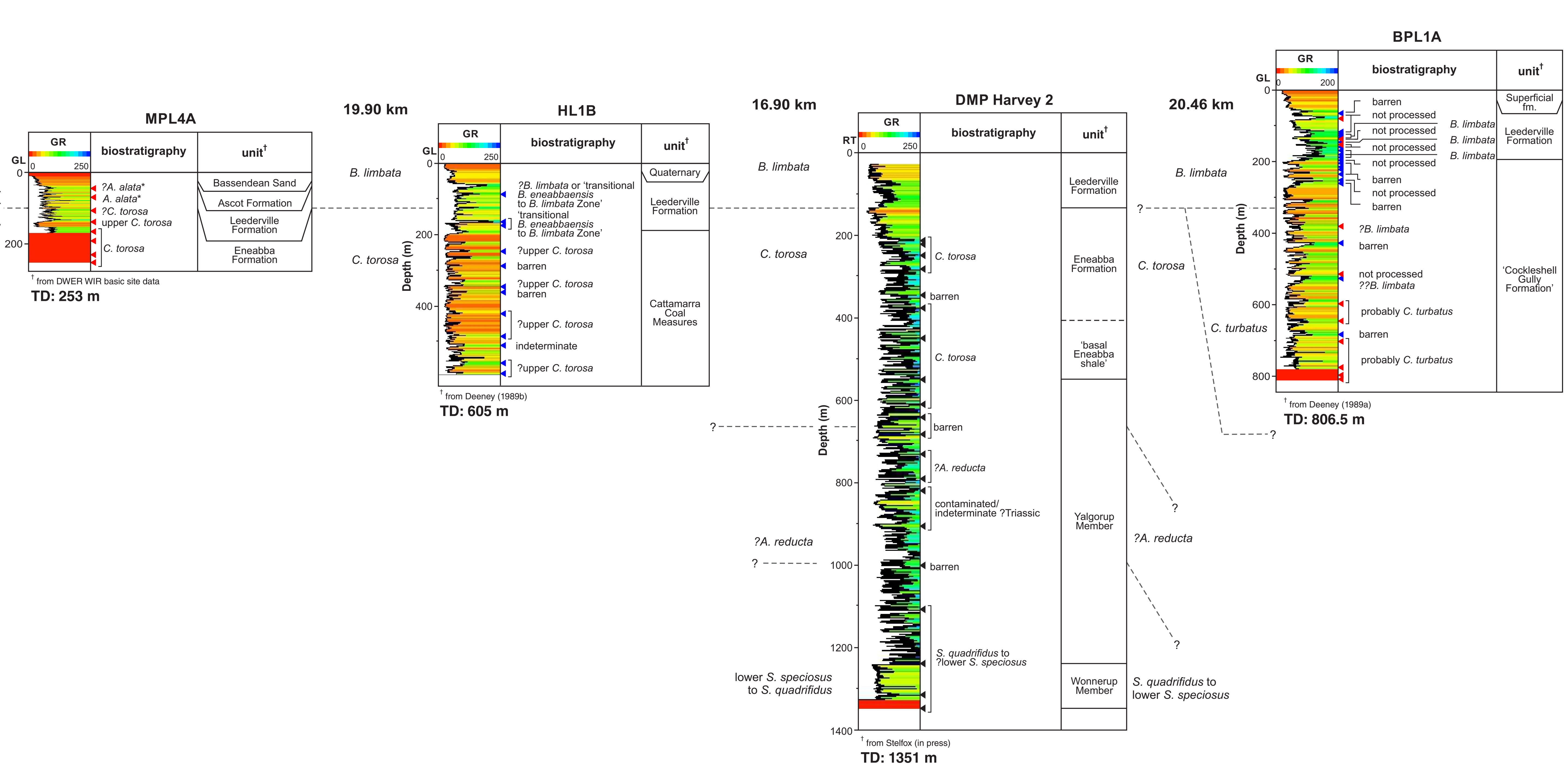
MARTIN

A REVIEW OF PALYNOLOGY FROM THE HARVEY REGION, SOUTHERN PERTH BASIN, WESTERN AUSTRALIA

REPORT 174



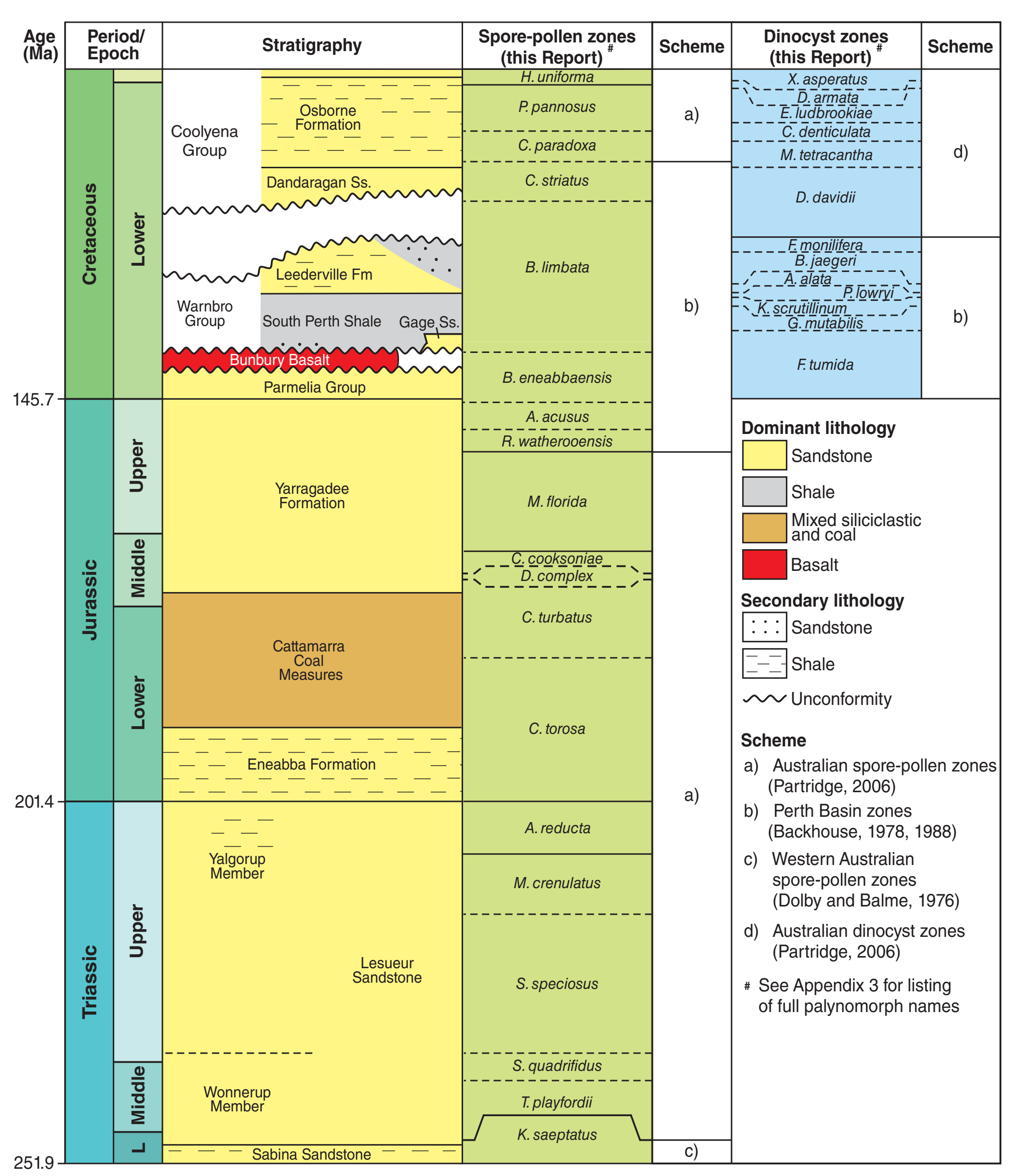


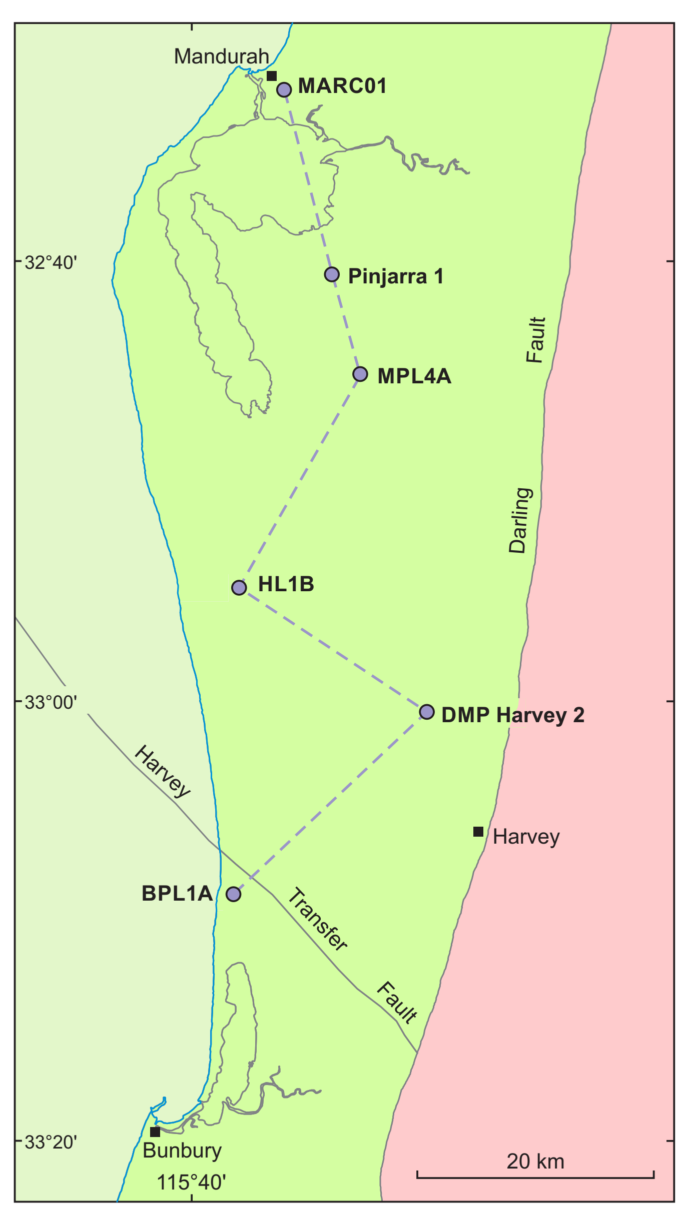
Legend:

- Dinocyst zone
- Conventional core sample
- Sidewall core sample
- Ditch cutting sample
- Estimated biostratigraphic boundary

Notes:

1. Lithostratigraphy based on most recent well picks and not reinterpreted for this Report
2. All biostratigraphic units are spore-pollen zones unless marked otherwise
3. Datum for correlation is Valanginian breakup unconformity
4. See Appendix 2 Introduction for references





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MINISTER FOR MINES AND PETROLEUM

Geological Survey of Western Australia

JEFF HAWORTH, EXECUTIVE DIRECTOR
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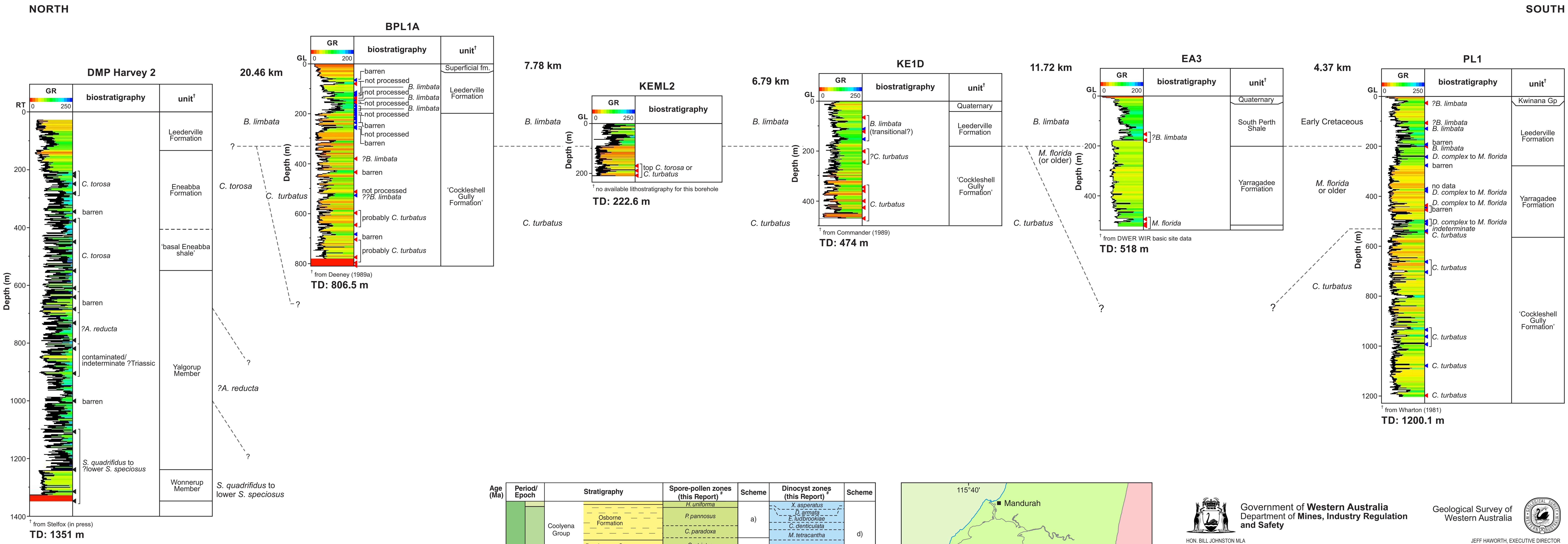
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

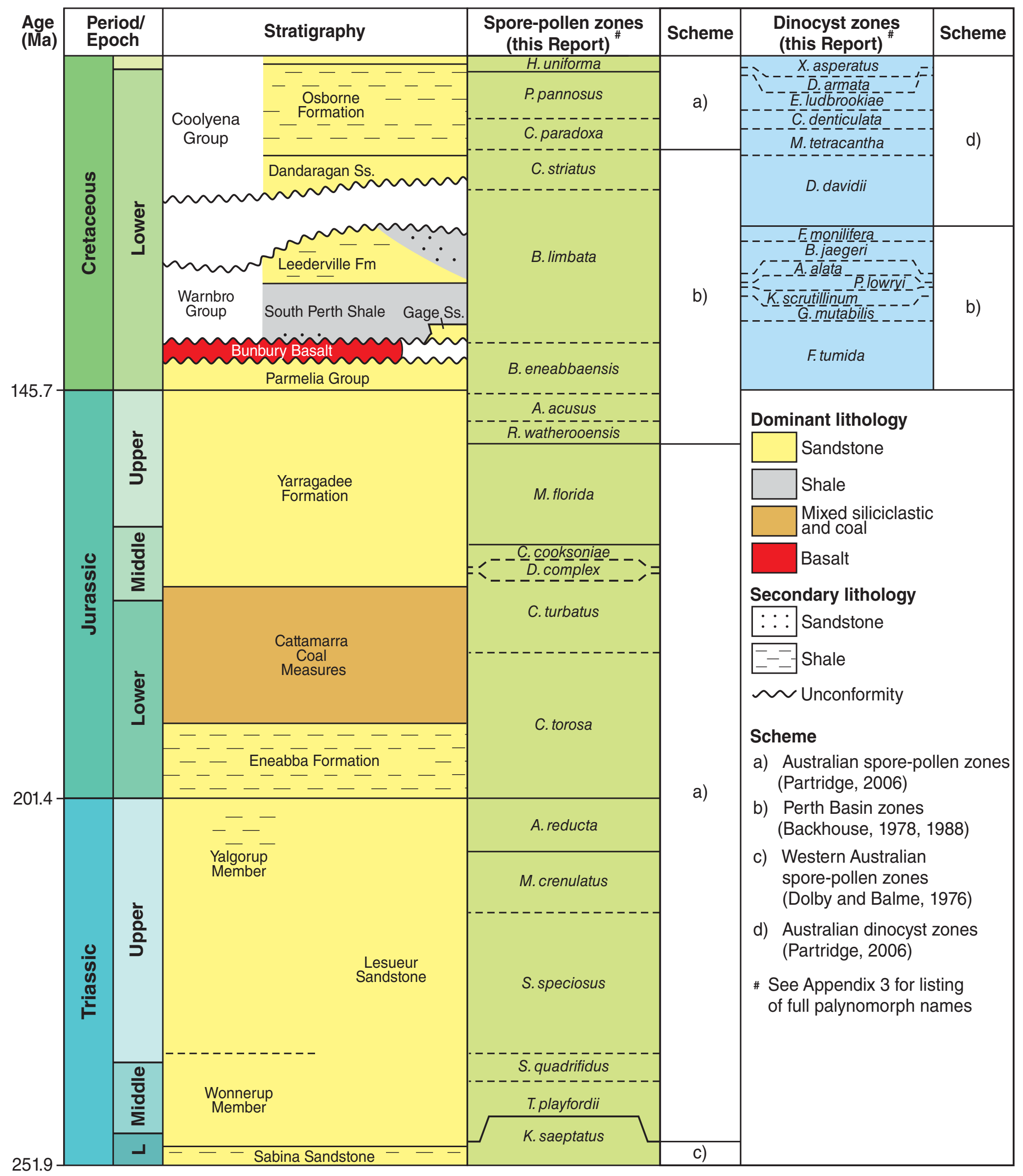
REPORT 174 PLATE 1A

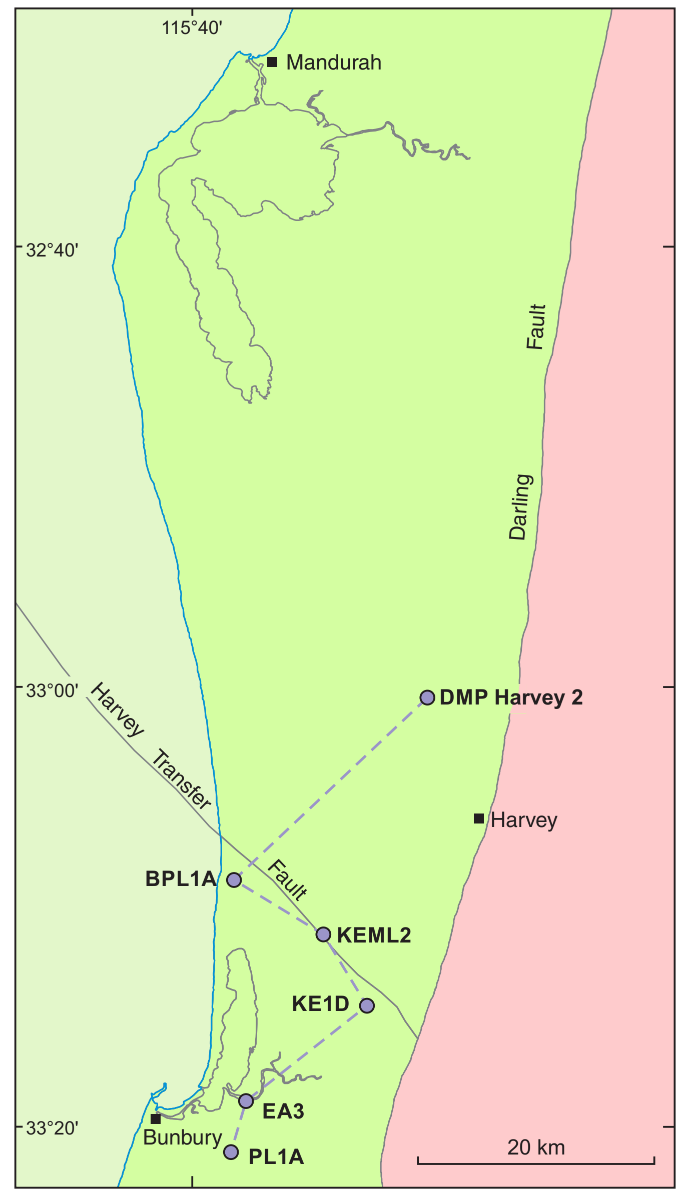
STRATIGRAPHIC CORRELATIONS
SOUTHERN PERTH BASIN

BIOSTRATIGRAPHY OF MANDURAH TERRACE, NORTH–SOUTH PART 1A (MARC01 to BPL1A)

February 2018







Legend:

- Dinocyst zone
- Conventional core sample
- Sidewall core sample
- Ditch cutting sample
- Estimated biostratigraphic boundary

Notes:

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3. Datum for correlation is Valanginian breakup unconformity
4. See Appendix 2 Introduction for references

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

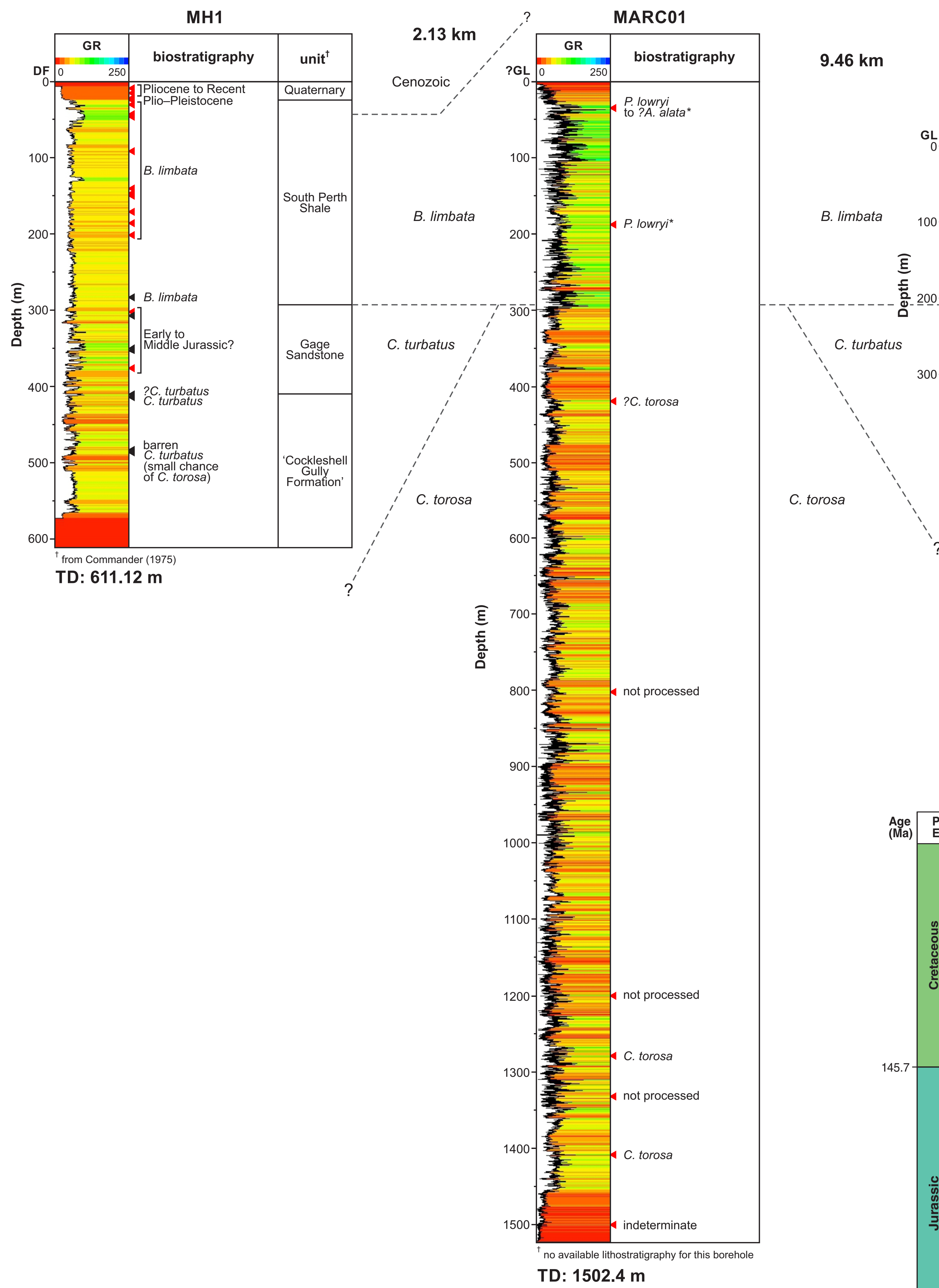
REPORT 174 PLATE 1B

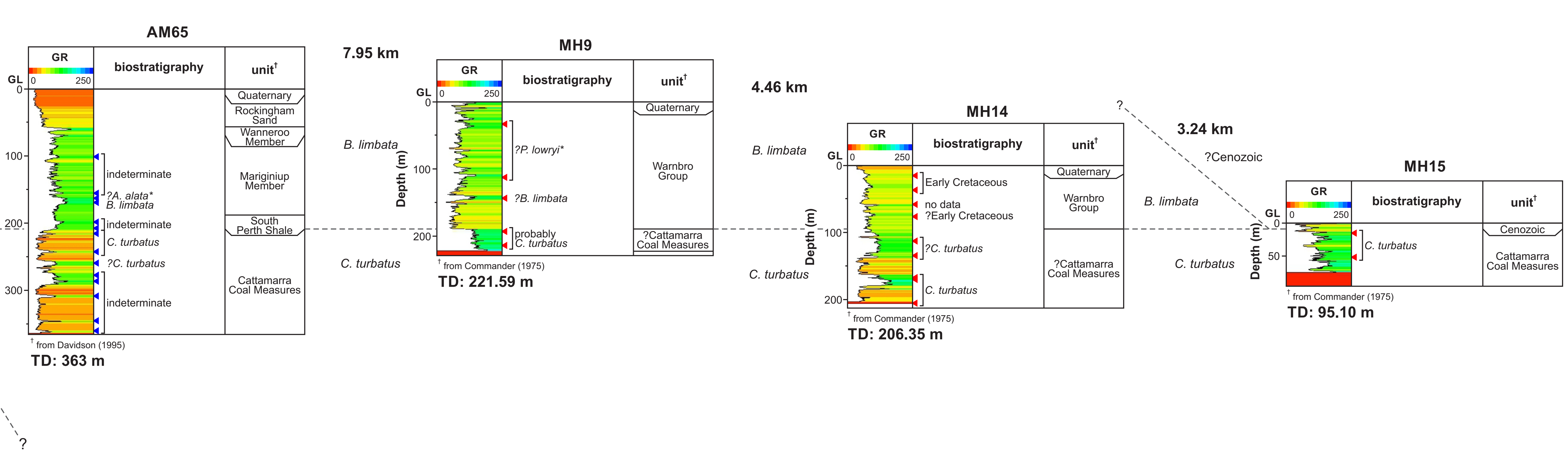
STRATIGRAPHIC CORRELATIONS SOUTHERN PERTH BASIN

BIOSTRATIGRAPHY OF MANDURAH TERRACE AND BUNBURY TROUGH, NORTH–SOUTH PART 1B (DMP Harvey 2 to PL1A)

February 2018

SKM114 15.03.18





Legend:

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- Conventional core sample
- Sidewall core sample
- Ditch cutting sample
- Estimated biostratigraphic boundary

Notes:

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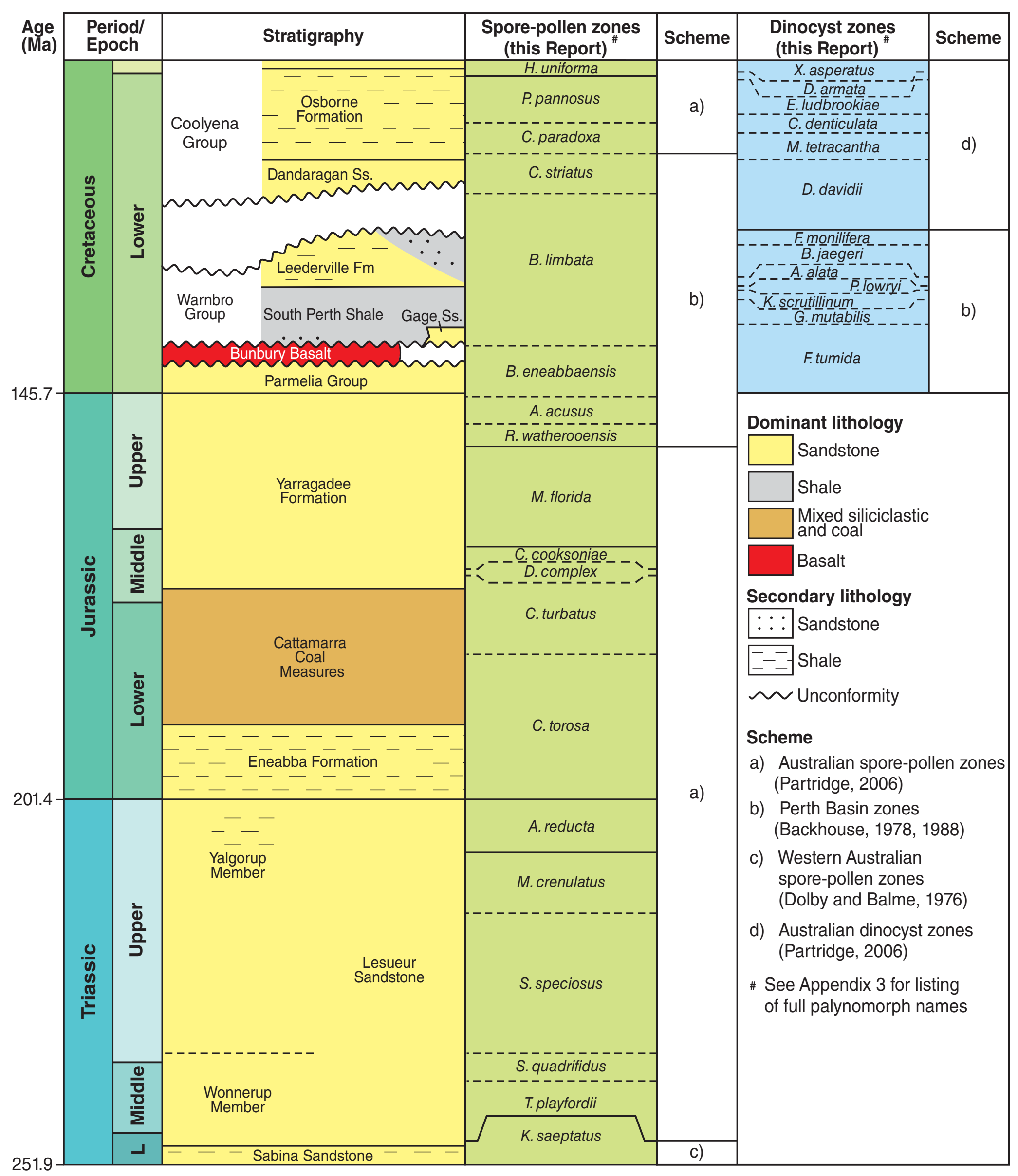

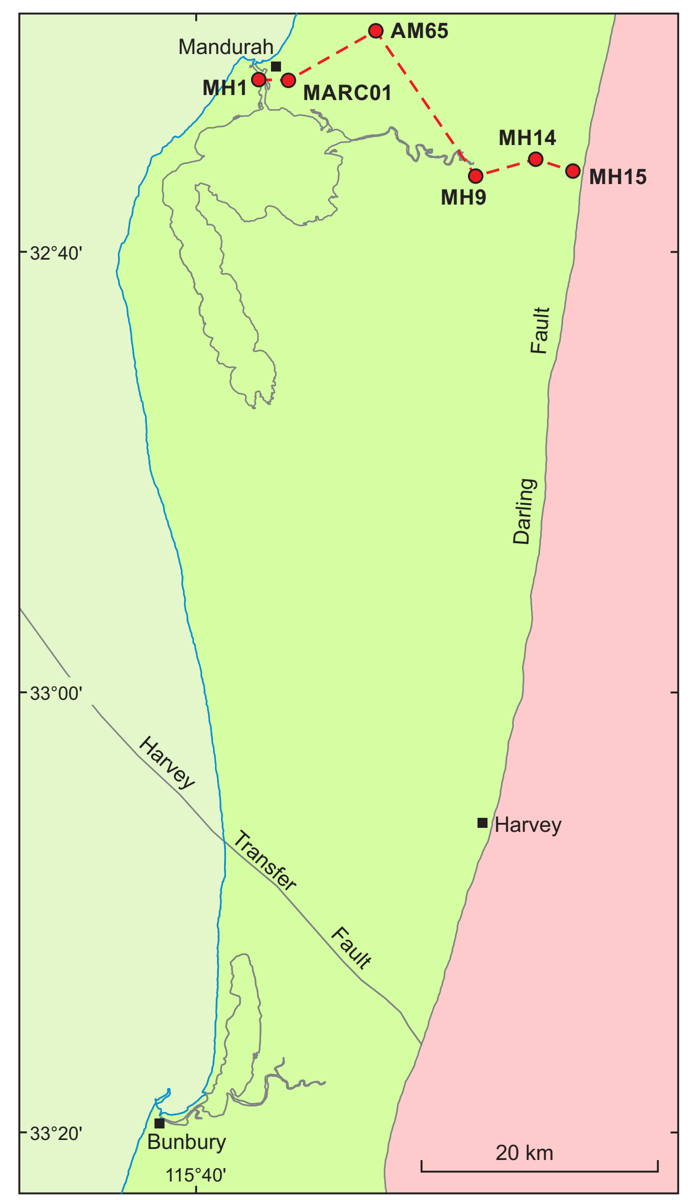

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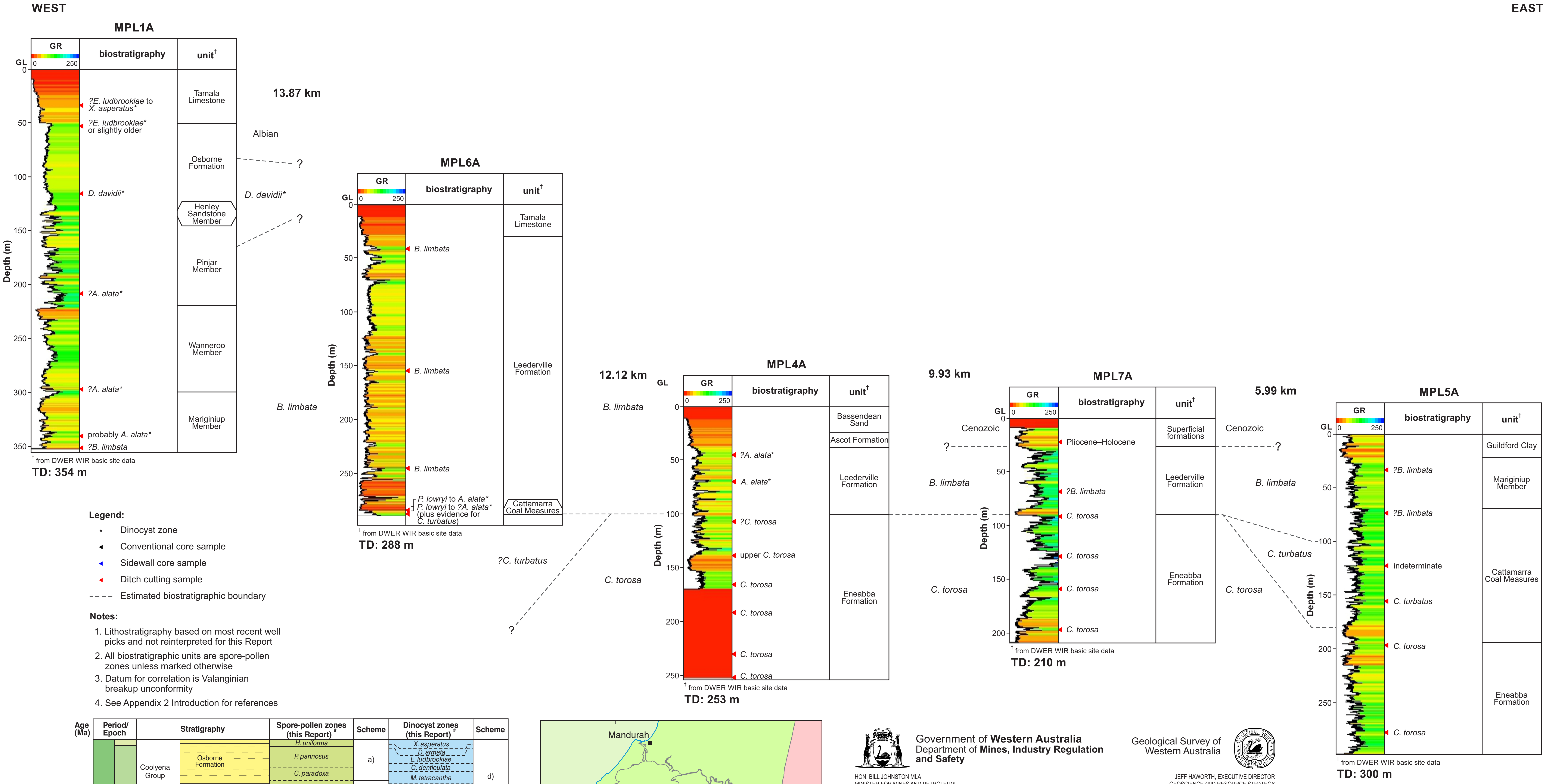
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 174 PLATE 2

STRATIGRAPHIC CORRELATIONS SOUTHERN PERTH BASIN

BIOSTRATIGRAPHY OF NORTHERN MANDURAH TERRACE, WEST–EAST (MH1 to MH15)

February 2018



Legend:

- * Dinocyst zone
- Conventional core sample
- Sidewall core sample
- Ditch cutting sample
- Estimated biostratigraphic boundary

Notes:

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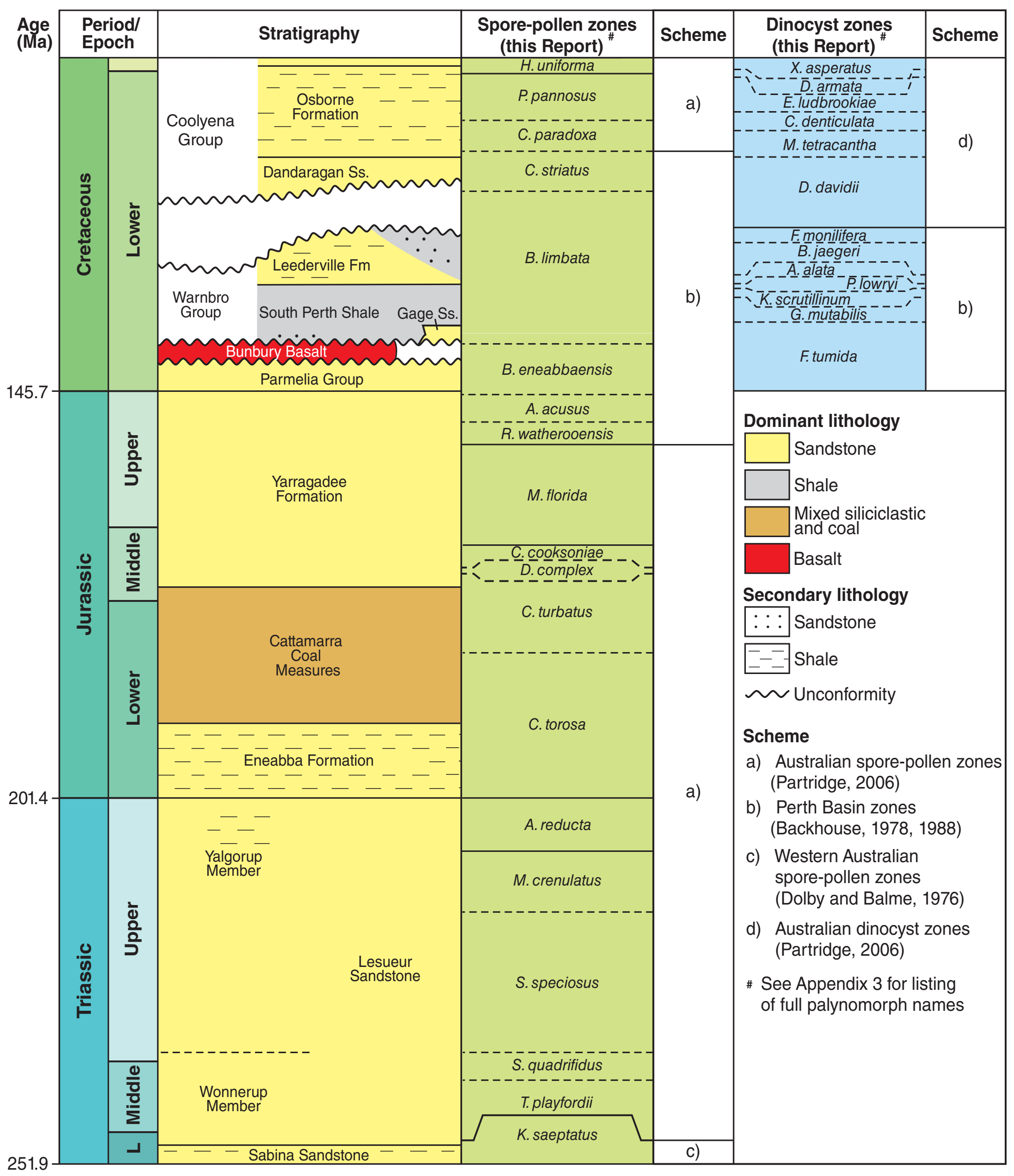

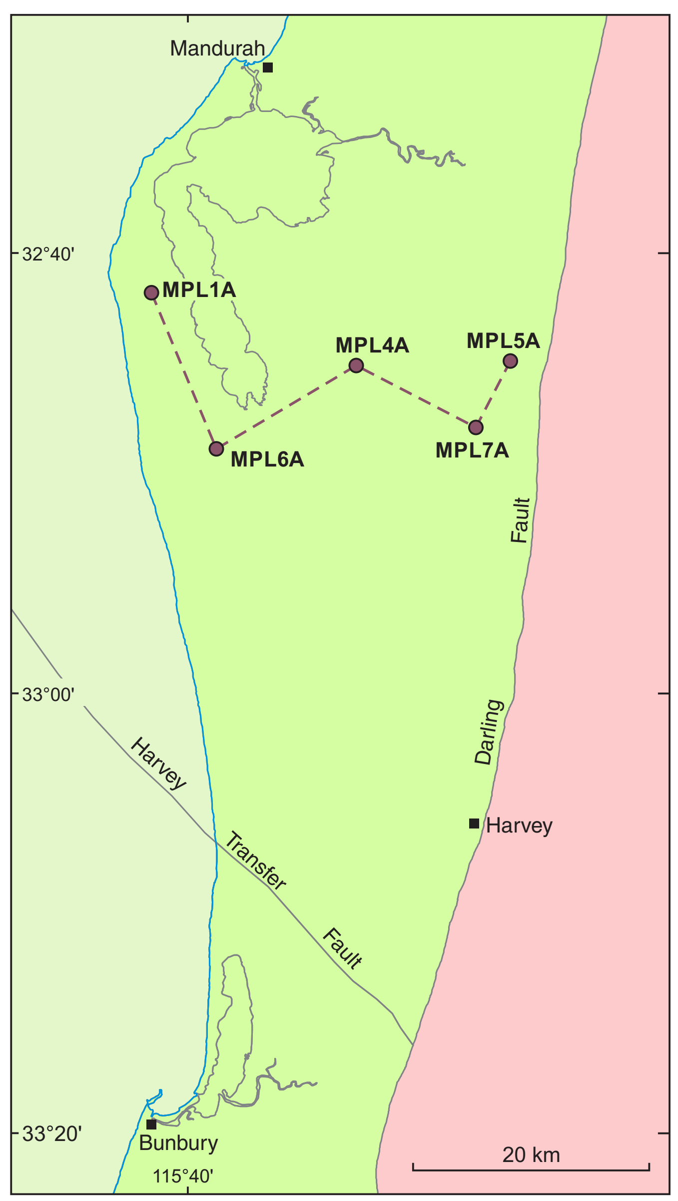

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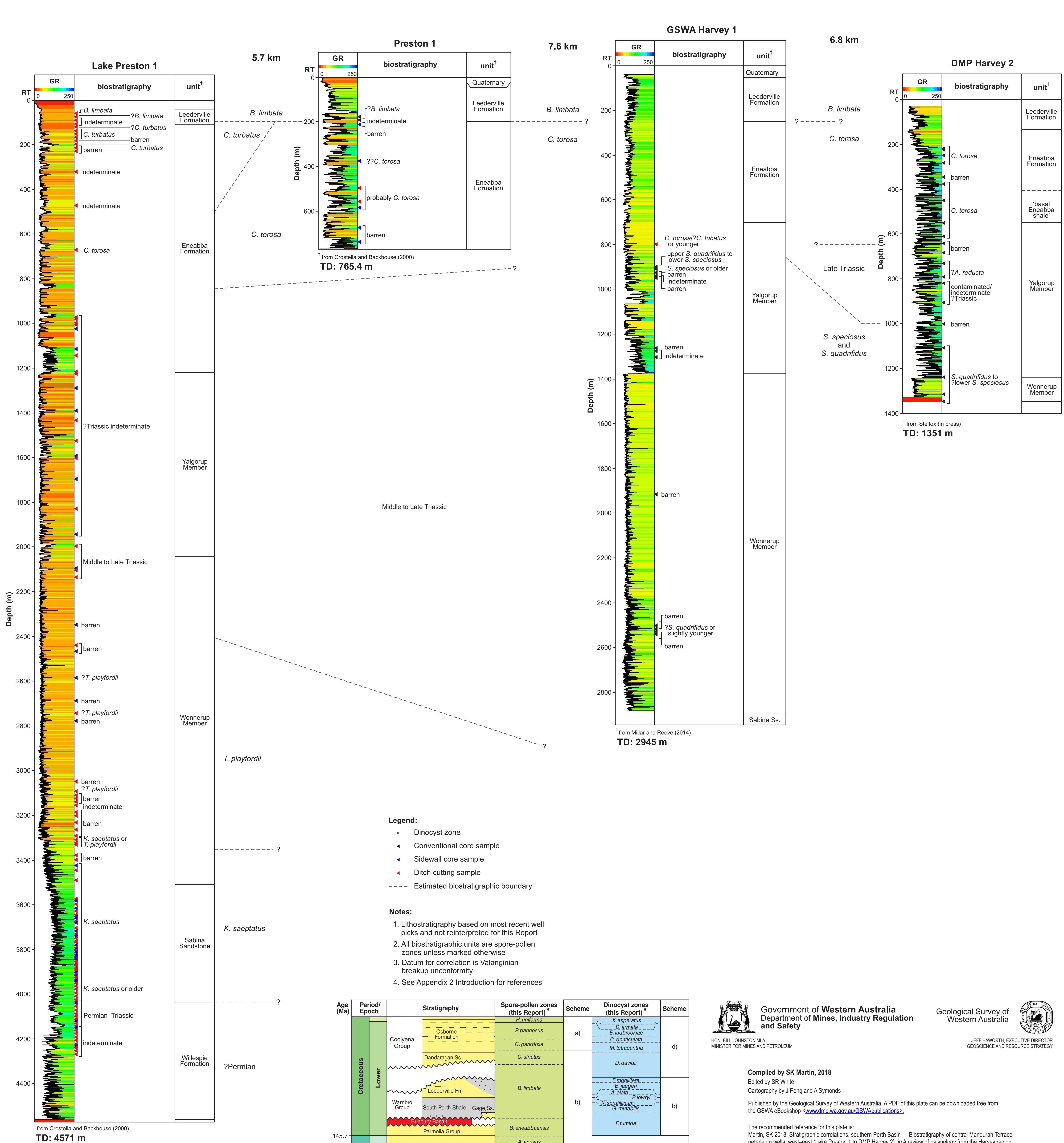
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 174 PLATE 3

STRATIGRAPHIC CORRELATIONS SOUTHERN PERTH BASIN

BIOSTRATIGRAPHY OF CENTRAL MANDURAH TERRACE, WEST–EAST (MPL1A to MPL5A)

February 2018



Legend:

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- Conventional core sample
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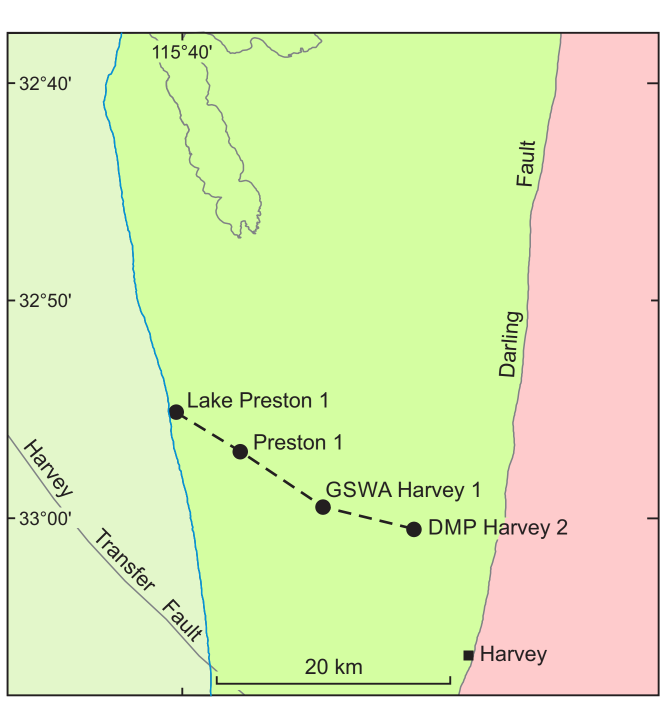
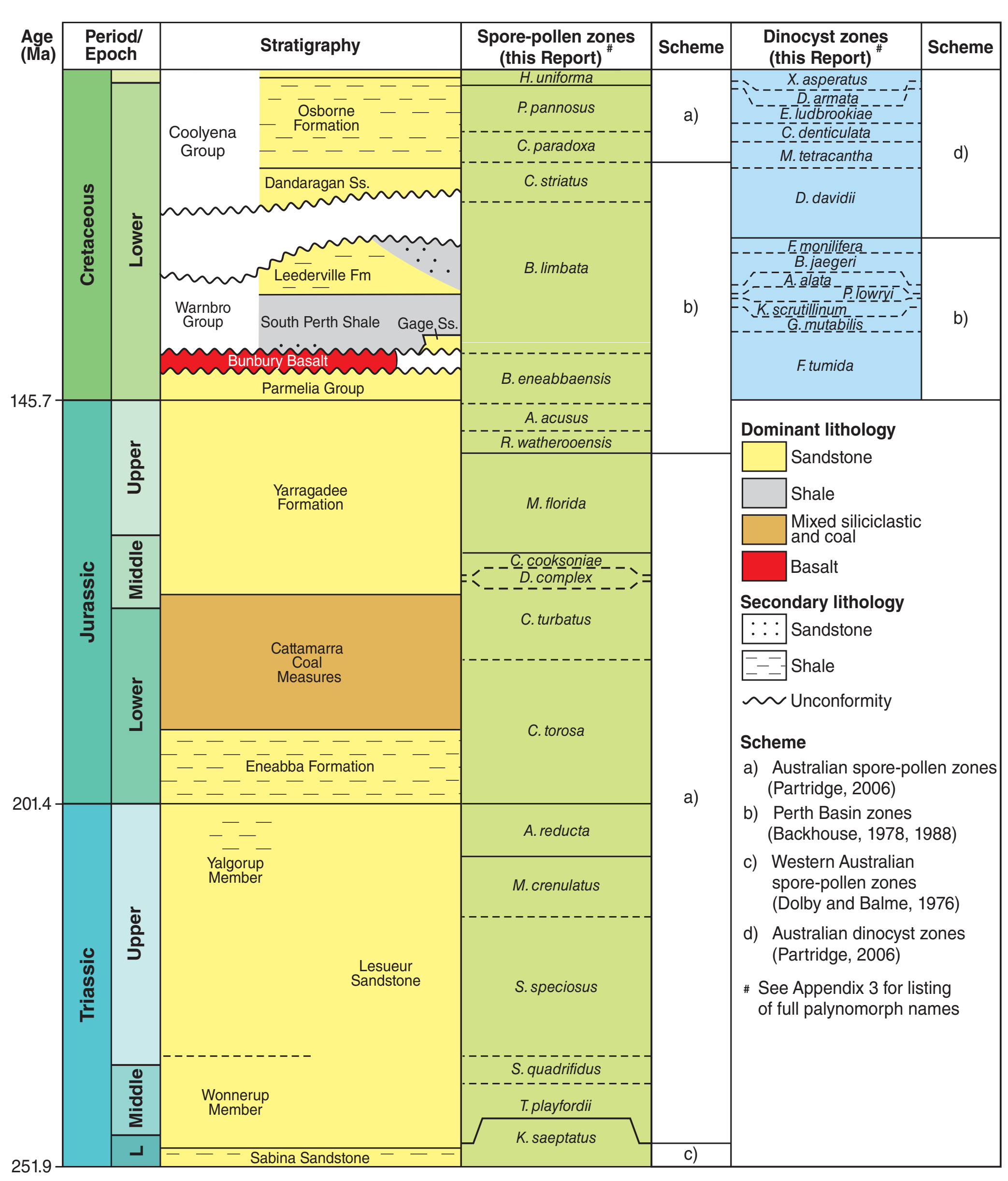
4. See Appendix 2 Introduction for references





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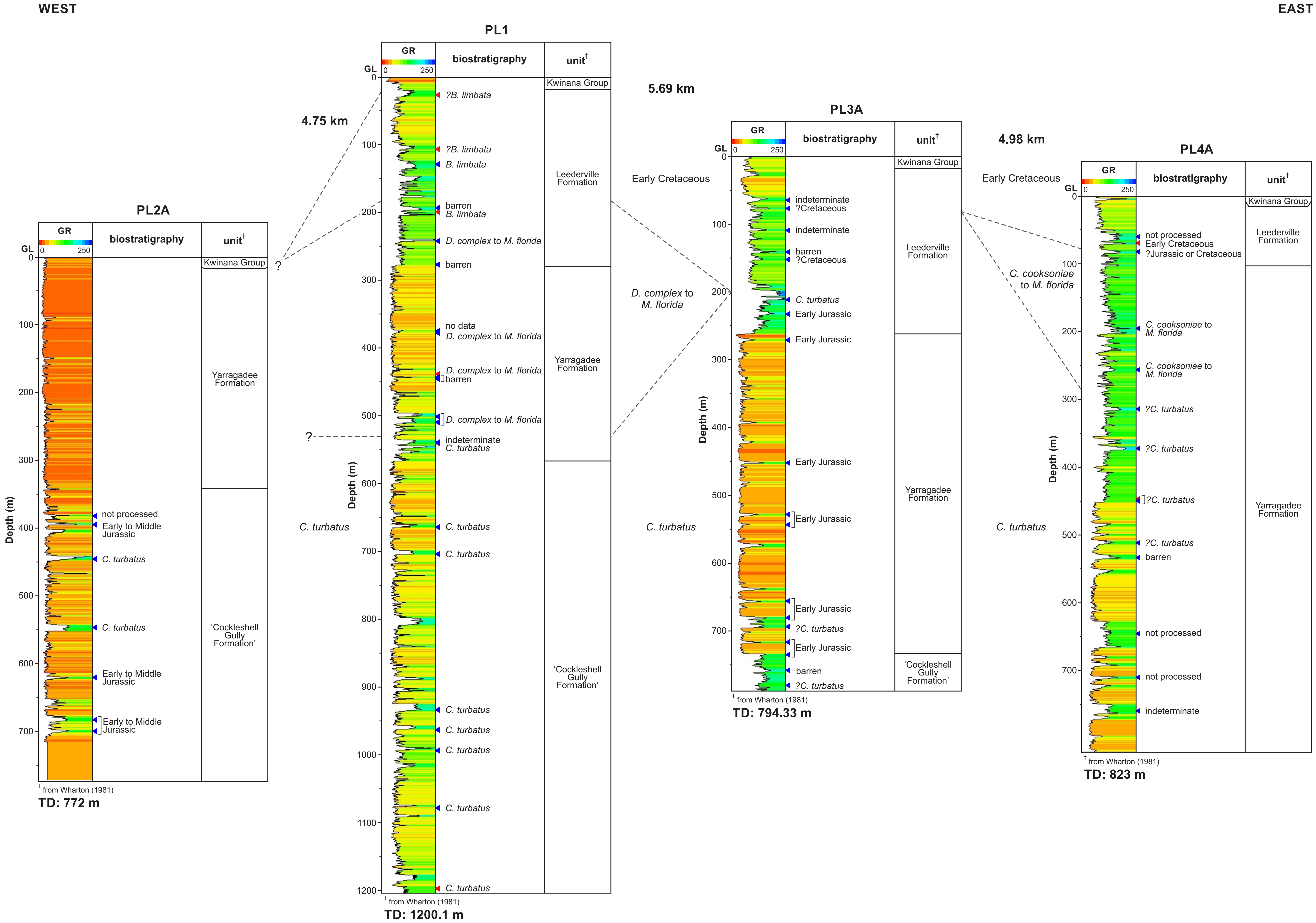
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 174 PLATE 4

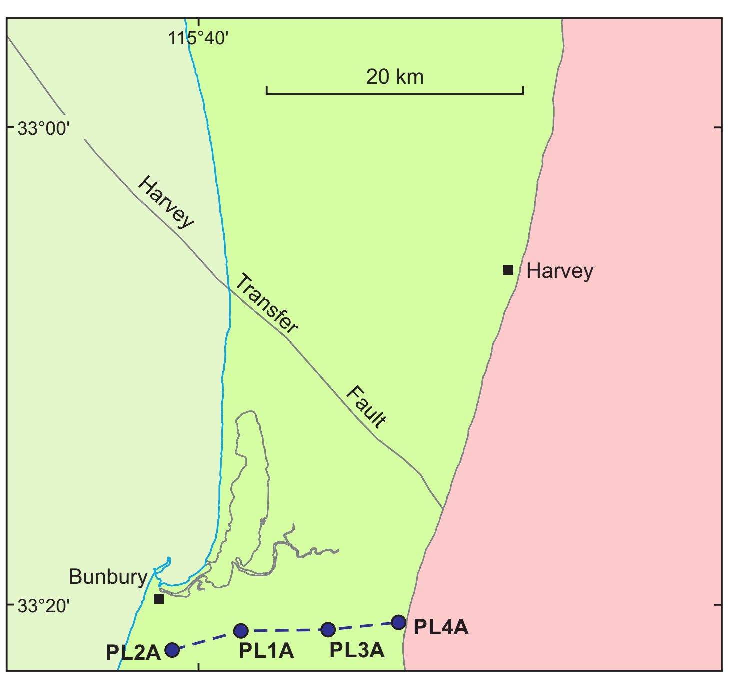
STRATIGRAPHIC CORRELATIONS
SOUTHERN PERTH BASIN

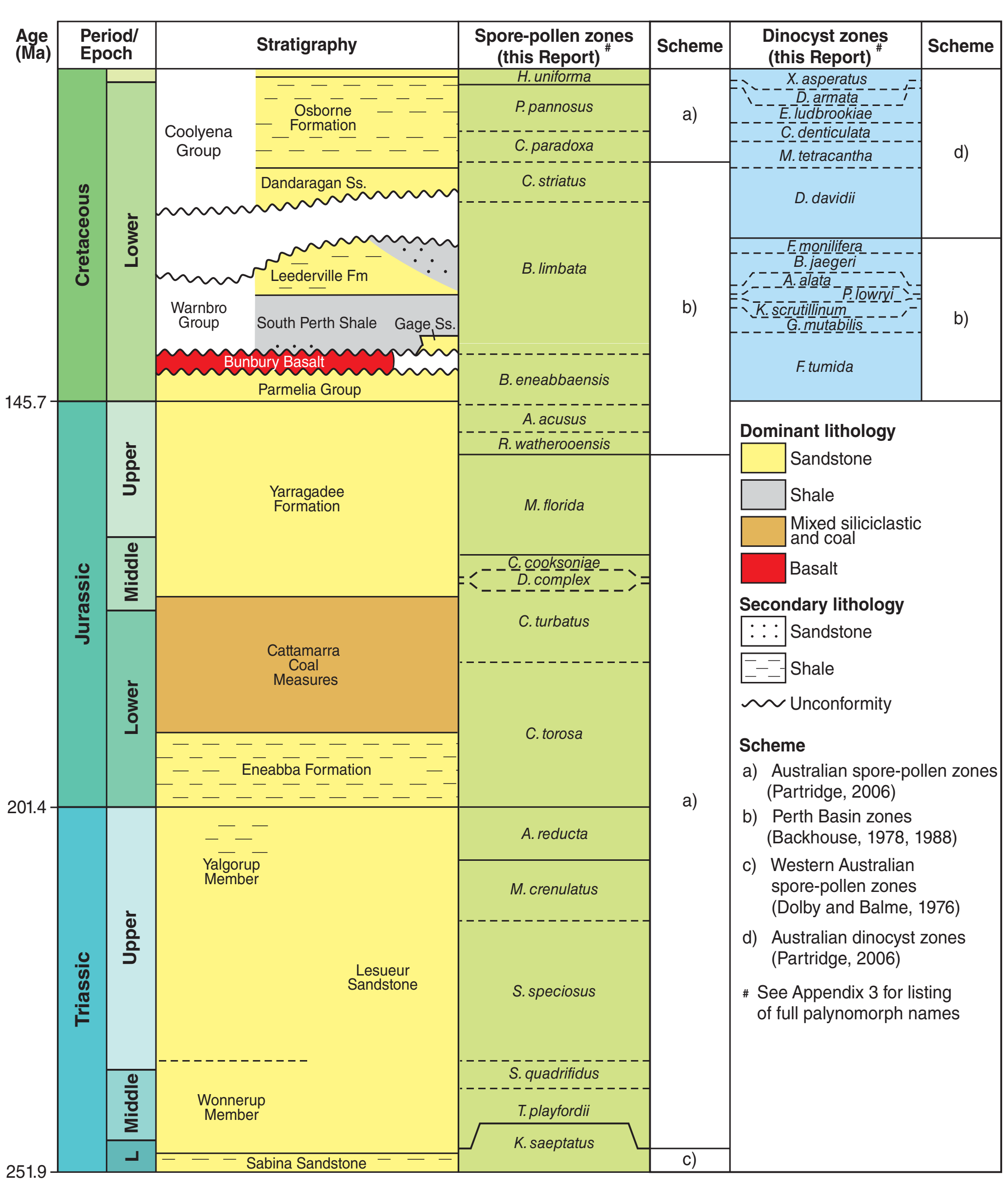
BIOSTRATIGRAPHY OF CENTRAL MANDURAH TERRACE PETROLEUM WELLS, WEST–EAST (Lake Preston 1 to DMP Harvey 2)

February 2018

SKM47 15.03.18







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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 174 PLATE 5

STRATIGRAPHIC CORRELATIONS
SOUTHERN PERTH BASIN

BIOSTRATIGRAPHY OF BUNBURY TROUGH, WEST–EAST (PL2A to PL4A)

February 2018