Palynological analysis of Core-1 at top of Waarre Formation in Boggy Creek-1, onshore Port Campbell Embayment.

by

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Biostrata Report 2005/21

7th October 2005

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Summary

Palynological analyses have been performed on four samples from Core-1 in Boggy Creek-1, to investigate the age and environment of deposition of the top of the Waarre Formation. The shallowest sample at 1673-1673.1m from the very top of the core contained a Santonian age assemblage which is interpreted to represent material caved from the Belfast Mudstone. The next sample at 1674–1674.2m was dominated by spores of *Gleicheniidites circinidites* (28%)[1] and *Cyathidites minor* (31%)[1], associated with abundant fungal spores and hyphae (21%)[2]. Although in this instance extracted from a mudstone lithology, similar assemblages are characteristic of coals in Unit Cb of the Waarre Formation. No microplankton were recorded in this sample, which is therefore interpreted as deposited in a non-marine environment. In contrast, the bottom two samples at 1676.55m and 1679.25m contain common marine dinocysts (average 14%)[3] and are interpreted to be deposited in shallow-marine environments. These two samples also contain an overlap in the ranges of the key spore-pollen species *Hoegisporis trinalis* ms, *Laevigatosporites musa* ms and the dinocyst *Isabelidinium evexus* ms, a combination suggestive of a stratigraphic position close to the boundary between the *H. trinalis* and *L. musa* Subzones and Units Ca and Cb of the Waarre Formation.

Introduction

This new palynological study of conventional core samples from Boggy Creek-1 is part of a larger joint project with Dr Tom Bernecker of the Minerals and Petroleum Division, Geoscience Victoria, investigating the correlation and environment of deposition of the Waarre Formation, the principal hydrocarbon reservoir unit in the onshore Port Campbell Embayment.

The broad objective of the joint project is to better understand the distribution of lithologies (facies) and time-rock units (palynological subzones) within the Waarre Formation to better map and ultimately predict the distribution of the best reservoir sands. Studies by the author (Partridge, 1996; 2001) have established a more detailed palynological zonation of the lower part of the Sherbrook Group, and this better time-subdivision of the succession can be integrated with the lithological data and electric logs to significantly improve the identification and correlation of the subdivision of the Waarre and Flaxman formations into Units A to D, as originally proposed by Buffin (1989).

Unfortunately, most early exploration wells (and many recent exploration wells) drilled in the Port Campbell Embayment have very low densities of analysed palynological samples through the Waarre Formation, and therefore it is not yet possible to confidently identify and correlate the new palynological subzones throughout the embayment. The problem is exacerbated by the lack of detailed sidewall core sampling and limited number of conventional cores in most wells. Although cuttings samples can be utilised, their reliability is diminished by extensive down-hole caving of the Belfast Mudstone section, which mask the *in situ* assemblages. In consideration of these limitations, the initial approach has been to focus on the quantitative palynological analysis of samples from the available conventional cores. This will provide a link between the palynological assemblages and the sedimentological data and will improve the understanding of the changes in the palynological

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[1] As percentage of spore-pollen count
[2] As percentage of combined spore-pollen and fungal microfossil count.
[3] As percentage of combined spore and microplankton count.

assemblages over short stratigraphic intervals. Both aspects will enable better interpretation of cuttings assemblages over those intervals lacking any core control.

The Boggy Creek-1 well, was drilled by Gas & Fuel Exploration N.L. in permit PEP 104 in the onshore Otway Basin, with a primary exploration objective of the Waarre Formation, and secondary objectives of the younger and shallower Pebble Point Formation and Nullawarre Greensand. The well was suspended as a potential CO_2 producer from the Waarre Formation. In Boggy Creek-1, a single conventional core was cut between 1673 and 1682m just below the top of Unit C of the Waarre Formation, which was picked at 1688.5m in the Well Completion Report (Akbari, 1992). The core is mostly fine to coarse-grained sandstone but does contain thin shaly and carbonaceous beds or layers suitable for palynological analysis. Comparison of the electric log character with Langely-1 suggested the core may have sampled the uppermost sand/shale couplet of the Waarre Unit Cb established by Partridge (2001; fig.6), and it was an objective of the study to determine whether this could be confirmed by the palynology. Another objective was to find out if there was any decline in marine influence through the uppermost Waarre Formation compared to wells in the more central portion of the embayment, such as Langely-1.

Previous palynological work on the well is restricted to the original analysis of Macphail (1992) in which nine sidewall cores are analysed between 939.5 and 1836 metres. Only three of these samples fall within the 100 metre interval displayed on the range chart accompanying this report. These three earlier samples all conform to the broad *Phyllocladidites mawsonii* and *Palaeohystrichophora infusorioides* zones, but can also be assigned to the new microplankton subzones. The shallowest sample at 1668m belongs to the *Kiokansium. polypes* Subzone based on the common presence of *Valensiella griphus* while the two deeper samples are interpreted to belong to the *Cribroperidinium edwardsii* Acme subzone, based on the frequent occurrence of the eponymous species at 1715m.

Materials and Methods

The samples analysed were collected by the author at the Werribee Core Library on Friday 27th May and were sent to Core Laboratories Australia Pty Ltd for processing. The palynological slides were returned for examination on Wednesday 8th June. Initial results from microscope analysis of the samples were provided in a Provisional Report issue on 21st June 2005. The final revised zone picks are provided in Table 1.

Basic sample data comprising the lithologies and weights of the samples processed are given on Table 2, while the basic assemblage data comprising the visual organic residues yields, the concentration and preservation of the palynomorphs observed on the slides, and the number of species of spore-pollen and microplankton recorded from individual samples are provided in Table 3. In summary, an average of 15 grams of each sample was processed to give high residue yields containing mostly moderate to high concentration of palynomorphs, whose preservation is poor to fair. Spore-pollen diversity was moderate averaging 24+ species per sample while the diversity of microplankton varied from nil to moderate (max. 13+ species per sample).

The distribution of the palynomorphs identified in the samples are presented on the accompanying StrataBugs™ range chart, which displays the recorded palynomorph species in the samples proportional to their depth in the well and in terms of their relative abundance (as a percentage). The palynomorphs recorded are also split between different categories. The terrestrial spore and pollen are divided between spores, gymnosperm pollen and angiosperm pollen, which are plotted in separate panels. The next panel labelled Neves effect represents the percentage sum of all species of the gymnosperm pollen *Araucariacites* and *Dilwynites* in the spore-pollen count. This is followed by a panel showing the total count of marine and non-marine microplankton, and as a separate category the colonial algae *Amosopollis cruciformis*, as percentages relative to the combined spore-pollen and microplankton counts. Next the percentage abundance of individual species in the microplankton count are displayed in the panel labelled Microplankton. Then plotted are Other Palynomorphs, with abundances expressed as a percentage of sum of the total Spore-Pollen plus Other Palynomorphs counted. Because all the samples are cores the species are plotted within the panels according to their deepest or oldest occurrences.

The following codes or abbreviations apply to the individual species occurrences and abundances on the range chart:

Numbers	=	Abundances expressed as percentage
+	=	Species outside of count
C	=	Caved species
R	=	Reworked species
?	=	Questionable identification of species.

Author citations for the recorded spore-pollen species can be sourced from papers by Dettmann (1963), Dettmann & Playford (1968), Helby *et al.* (1987) and Stover & Partridge (1973), while the author citations for the microplankton species can be sourced from the indexes for dinocysts and other organic-walled microplankton prepared by Fensome *et al.* (1990) and Williams *et al.* (1998). Manuscript species names and combinations are indicated by “sp. nov.” or “comb. nov.” on the range chart, and “ms” after their binomials names in the text and tables.

Geological Discussion

All the obvious finer grained horizons in the core were sampled for palynology. The three deepest core samples contain Turonian age assemblages consistent with Unit C of the Waarre Formation, while the fourth sample at the top of the core contains a much younger Santonian age assemblage, which is interpreted to be caved from Belfast Mudstone above 1658m.

The greenish-grey colour, and identification of glauconite in the shale/mudstone at the top of the core made the author highly suspicious that the top 10 cm of the core was caved material. The rock was sampled and analysed to resolve this suspicion. The results confirm the empirical rule that glaucony is rare in the Waarre Formation, and all situations where the author has challenged the identification of supposedly *in situ* glaucony by palynological analysis the lithologies have proved to be caved.

The three deeper samples have also yielded results comparable to elsewhere in the Port Campbell Embayment. Although the predominantly sandstone composition of the core is highly suggestive of non-marine and fluvial deposition, two-out-of-three samples analysed contain moderate abundance and diversity of cosmopolitan marine dinocysts. The conclusion must be drawn that even though fine-grained clastics represent only 10 to 15% of the core, the bulk of these finer grained sediments contain emphatic palynological evidence of paralic to nearshore marine environments of deposition. Indeed, the core in Boggy Creek-1 was partly selected to examine whether a western limit of marine influence could be mapped within Unit C of the Waarre. The results obtained clearly indicate that such a boundary must lie still further west or north-west of the Boggy Creek-1 location. While this report is not an appropriate place to provide a wide ranging discussion of the distribution of depositional environments within the Waarre Formation, it is nevertheless worthwhile to stress that any depositional model for the reservoir sandstones of the Waarre needs to be able to account for the occurrence of abundant and diverse marine dinocysts in the interbedded shaly sediments. This juxtaposition of medium to coarse sandstone (which often superficially appear to be fluvial) with marine palynomorphs is even more striking when the bottom two samples from the core are considered. Both samples were collected from thin ~5mm thick muddy or carbonaceous laminae within the sandstone, yet they contain moderate abundances (14% of count) and low diversities of cosmopolitan marine dinocysts. In contrast, the only non-marine palynological assemblage at 1674-74.2m was from the thickest shale bed in the core.

The other objective of identifying whether the core was cut in Unit Ca or Unit Cb of the Waarre Formation was only moderately successful. The assemblages recovered contain an overlap in the ranges of the key index species *Hoegisporis trinalis* ms with *Laevigatosporites musa* ms and *Isabelidinium evexus* ms. All three species are rare in the assemblages. In the original description of the zonation and stratigraphic scheme by the author (Partridge, 1999), the extinction of the former species was considered to be the marker species for the top of Unit Ca (= top of *H. trinalis* Subzone), while the association of the two latter species was considered diagnostic of Unit Cb (= base of *I. evexus* and *L. musa* subzones). More recent work by other palynologists suggests however, there may be a significant overlap between the three species. Sharp & Wood (2004; fig.12) for example identify a Upper *H. trinalis* Subzone overlapping a Lower *I. evexus* Subzone. Although this overlap of the subzones has not been independently documented elsewhere by the author, it may provide the most reasonable explanation for the assemblages recovered in Boggy Creek-1. A position close to the boundary between Units Ca and Cb is therefore advocated for the samples from Core-1.

Based on the above idea, the shale beds on the gamma ray log in Boggy Creek-1 at 1676-77m and 1678.5-80m are suggested to correlate with the shale at 1752-53.5m in Langley-1 (Partridge, 2001; fig.6). A similar position is also suggested by comparison to the idealised diagram labelled "*Waarre reservoir stratigraphy and depositional environments*" presented by Sharp & Wood (2004; fig.12). At the top of Waarre Ca on their diagram is an overlap interval between their "Upper *H. trinalis*" and "Lower *I. evexus*" subzones which correlates with a prominent shaly character on their idealised Gamma Log. If such a correlation is accepted, Unit Cb in Boggy Creek-1 may only be represented by the overlying sandy interval 1668.5 to 1676m. As this ~7 metre thick section is significantly thinner than the 21 metre assigned to Unit Cb in Langley-1 between 1731 and 1752m (Partridge, 2001; fig.6), this greatly reduced thickness of Unit Cb in Boggy Creek-1 may account for most of the ~20 metres reduction in thickness noted in the Well Completion Report (Akbari, 1992), between the predicted and actual thickness of the Waarre Formation.

Comment is also worthwhile on the results of the earlier palynological study by Macphail (1992), for those samples plotted on the accompanying StrataBugs™ range chart. The sidewall core at 1668m is interpreted to contain an assemblage diagnostic of the *K. polypes* Subzone, and this confirms the identification of the Flaxman Formation between 1658 and 1668.5m. Note that, in the Well Completion Report this interval was assigned to Unit D of the Waarre Formation following Buffin (1989). The two deeper sidewall cores at 1715 and 1722.5m are both interpreted to belong to the *C. edwardsii* Acme subzone based on the reported frequent occurrence of *Cribroperidinium edwardsii* at 1715m. As the true acme of this index species is typically restricted to Unit B of the Waarre Formation the boundary between Units B and A is recommended to be shifted from 1707m down to 1726m. This change is consistent with the log character in Langley-1 were Unit B is characterised by two prominent shales separated by 10 metres of sandstone (Partridge, 2001; fig.6).

Discussion of Assemblages

The samples analysed are initially classified according to the Australian standard spore-pollen and microplankton zonation schemes established by Helby *et al.* (1987), with finer subdivisions in the form of local Otway Basin subzones established by Partridge (1999, 2001). A recent review of zonation schemes can also be found in the latest edition of the *Geology of Victoria* (Partridge & Dettmann, 2003).

***Tricolporites apoxyexinus* spore-pollen Zone and**
***Isabelidinium cretaceum* microplankton Zone**
Core sample at: 1673-1673.1 metres
Age: Santonian.

The sample yielded an abundant marine microplankton assemblage (34% of SP + MP count), dominated by *Heterosphaeridium* spp. (35% of MP count) and containing the index species *Odontochitina porifera* and *Isabelidinium cretaceum* which are diagnostic of the younger microplankton zones within the Belfast Mudstone. The associated spore-pollen assemblage is not particularly diverse but the presence of *Tricolpites confessus* is consistent with the upper part of the *Tricolporites apoxyexinus* Zone. The spore-pollen assemblage is dominated by *Podocarpidites* pollen (25%) and spores of *Gleicheniidites circinidites* (14%) and contains a weak Neves effect[4] with *Araucariacites* and *Dilwynites* pollen 15% of the SP count.

***Phyllocladidites mawsonii* spore-pollen Zone and**
upper *Hoegisporis trinalis* to lower *Laevigatosporites musa* spore-pollen Subzones
Core interval: 1676.5 to 1679.25 metres, probably extending to 1674-74.2 metres
Age: Early to mid Turonian.

The top of the *H. trinalis* Subzone was originally defined by the LAD (Last Appearance Datum) of the eponymous species and on this criteria the two deepest samples analysed would belong to this subzone. However, it has subsequently been found that *Hoegisporis trinalis* ms can occur very rarely in the younger *L. musa* Subzone and this is thought to be the case with the core samples in Boggy Creek-1. Supporting this younger zone assignment is the rare occurrence of the dinocyst *Isabelidinium evexus* ms at 1679.25m, and the rarity of the spore *Appendicisporites distocarinatus*, which is generally both consistent and frequent to common in the older *H. trinalis* Subzone. In contrast, favouring an older zone assignment is the rarity of the colonial algae *Amosopollis cruciformis*, which typically increases in abundance in the *L. musa* Subzone, and the absence of secondary index species *Tricolporites variverrucatus* ms, which first occurs in the younger *L. musa* Subzone. On balance therefore the assemblages are best interpreted as transitional between the two subzones.

The dominant species categories recorded in the three in place core samples are tabulated below:

	1674.0-74.2m*	**1676.55m***	**1679.25m***
Cyathidites spp.	31%	13%	19%
Gleicheniidites circinidites	28%	6%	10%
Araucariacites australis	1%	8%	10%
Dilwynites spp.	NIL	7%	9%
Microcachryidites antarctica	2%	7%	5%
Podocarpidites spp.	14%	19%	15%
Trichotomosulcites subgranulatus	2%	12%	10%
Total of main categories:	**78%**	**72%**	**78%**

* Percentages are rounded up to nearest whole number.

4 **Neves effects** are the tendency for certain fossil gymnosperm pollen to occur in greater abundance in distal marine environments. In the Australian Late Cretaceous and Cenozoic palynological succession Neves effects have empirically been found to be displayed by the species *Araucariacites australis* and the various species of the genus *Dilwynites*. When the combined abundance of these two pollen types exceeds 20% of the total count of the terrestrial spores and pollen a strong Neves effect is indicated.

The major compositional differences in the assemblages are interpreted to reflect the depositional environment. The sample at 1674.0-74.2m is interpreted as non-marine as the assemblage lacks any microplankton and contains both abundant spores of *Gleicheniidites circinidites* and abundant fungal microfossil. Near identical abundances of these two categories have been recorded from thin coals in the uppermost Waarre Formation. Although the lithology of the sample in Boggy Creek-1 is a mudstone rather than a coal a analogous ephemeral swampy environment is envisaged. In contrast, the two deeper samples are interpreted to reflect paralic or nearshore marine environments of deposition based on the presence of common marine dinocysts (average 14%), and the occurrence of weak Neves effects[4].

***Palaeohystrichophora infusorioides* microplankton Zone**
Core interval: 1676.5 to 1679.25 metres,
Age: Turonian.

The two deeper cores samples also conform to broad *P. infusorioides* Zone, as identified in the Otway Basin. In general, the assemblages are dominated by long ranging cosmopolitan species and lack the defined index species of the older and younger zones (see Helby *et al.* 1987). The only short ranging species identified is the rare occurrence of *Isabelidinium evexus* ms in the deepest sample. The FAD of this species defines the base of the *I. evexus* Subzone.

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*Confidence Ratings used in STRATDAT database and applied to Table 1.

Alpha codes: Linked to sample		**Numeric codes:** Linked to fossil assemblage		
A	Core	**1**	**Excellent confidence:**	High diversity assemblage recorded with key zone species.
B	Sidewall core	**2**	**Good confidence:**	Moderately diverse assemblage with key zone species.
C	Coal cuttings	**3**	**Fair confidence:**	Low diversity assemblage recorded with key zone species.
D	Ditch cuttings	**4**	**Poor confidence:**	Moderate to high diversity assemblage without key zone species.
E	Junk basket	**5**	**Very low confidence:**	Low diversity assemblage without key zone species.

Table 1: Interpretative data for Boggy Creek-1, onshore Otway Basin.

Sample Type	Depth metres	Spore-Pollen Zone (Microplankton Zone)	CR*	Comments and Key Species Present
Core-1	1673-1673.1	*T. apoxyexinus* Zone (*I. cretaceum* Zone)	A1 (A3)	Marine MP = 34%, with *Amosopollis cruciformis* ~0.5% in MP + SP count. Assemblage contains FADs of dinocyst *Isabelidinium cretaceum* and angiosperm pollen *Tricolpites confessus* confirming zone assignments. Sample is clearly **out-of-place** and interpreted as caved rubble at top of core.
Core-1	1674-1674.2	*P. mawsonii* Zone Subzone indeterminate.	A4	Poorly preserved **non-marine** assemblage with abundant spores of *Gleicheniidites circinidites* (31%) and fungal spores and hyphae (21%). No MP recorded and no index species diagnostic of spore-pollen subzones were recorded.
Core-1	1676.6	*P. mawsonii* Zone and upper *H. trinalis* to lower *L. musa* Subzones (*P. infusorioides* Zone)	A2 A5 (A5)	MP = 14% dominated by *Heterosphaeridium* spp. (>80%). *Amosopollis cruciformis* surprisingly not recorded and the absence of this species in association with LAD of rare *Hoegisporis trinalis* ms favours older subzone.
Core-1	1679.3	*P. mawsonii* Zone and upper *H. trinalis* to lower *L. musa* Subzones (*P. infusorioides* Zone and *I. evexus* Subzone)	A1 A5 (A2 A3)	MP = 14% dominated by *Heterosphaeridium* spp. (>50%). Although the presence of very rare *Isabelidinium evexus* ms associated with *Laevigatosporites musa* ms favours younger subzone, the low abundance of *Amosopollis cruciformis* (<2%) and presence of rare *Hoegisporis trinalis* ms favours older subzone.

SP & MP = Spore-Pollen and Microplankton; FAD & LAD = First and Last Appearance Datums
MP% = Percentage abundance of marine microplankton relative to spore-pollen and *Amosopollis cruciformis*.

Table 2. Basic sample data for Boggy Creek-1, onshore Otway Basin.

Sample Type	Depth metres	Wt grams	Lithology
Core-1	1673-1673.1	16.8	Dark grey-green hard glauconitic mudstone.
Core-1	1674-1674.2	17.2	Dark grey massive hard mudstone.
Core-1	1676.6	15.6	Dark grey silty mudstone (5mm thick laminae).
Core-1	1679.3	15.0	Carbonaceous layer in sandstone <5mm thick.

Table 3. Basic assemblage data for Boggy Creek-1, onshore Otway Basin.

Sample Type	Depth metres	Visual Yield	Palynomorph Concentration	Preservation	No. SP Species	No. MP Species
Core-1	1673-1673.1	High	High	Poor-fair	28+	11+
Core-1	1674-1674.2	High	Low	Poor	15+	NR
Core-1	1676.6	High	Moderate	Poor-fair	25+	4+
Core-1	1679.3	High	Moderate-high	Poor-good	31+	13+
				Averages:	**24+**	**6+**

NR = Not recorded.

Well Name : Boggy Creek-1

Operator : GFE N.L.
Well Code : BOGGYCREEK-1
Lat/Long : 38°31' 34.10"S 142°49' 28.10"E
Interval : 1645m - 1745m
Scale : 1:300
Chart date: 07 October 2005

Spudded : 21 December 1991
Completed : 12 January 1992
INTERPRETATIVE Range Chart
Sample interval 1668 to 1722.5m
Microscope analysis by Alan D. Partridge

Boggy Creek-1

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