G E O S C I E N C E   A U S T R A L I A

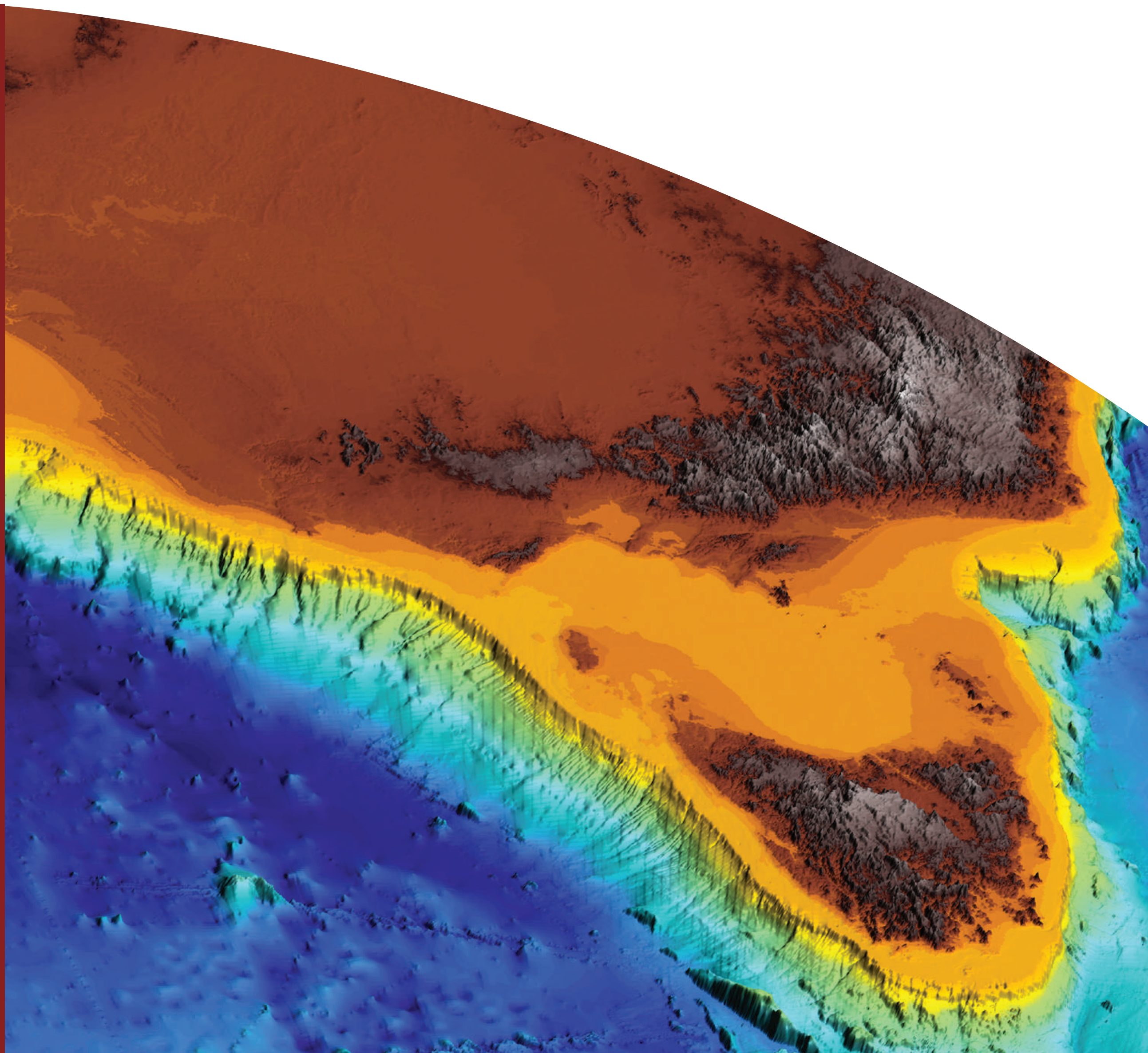
Australian Government
Geoscience Australia

VCEMP
Virtual Centre of Economic Micropalaeontology & Palynology

Palynostratigraphy of WOOLSTHORPE #1: a revision

P.L. Price

Record
2004/27



S P A T I A L   I N F O R M A T I O N   F O R   T H E   N A T I O N

Palynostratigraphy of Woolsthorpe #1: a revision

Geoscience Australia
Record 2004/27

by

P.L. Price

Petroleum & Marine Division, Geoscience Australia
GPO Box 378, Canberra, ACT 2601

Department of Industry, Tourism and Resources
Minister for Industry, Tourism and Resources: The Hon. Ian Macfarlane, MP
Parliamentary Secretary: The Hon. Warren Entsch, MP
Secretary: Mark Paterson

Geoscience Australia
Chief Executive Officer: Dr Neil Williams

ISSN 1448-2177
ISBN 1 920871225

Bibliographic reference: Price, P.L., 2004. Palynostratigraphy of Woolsthorpe #1: a revision. Geoscience Australia, Record 2004/27.

APG Consultants

Report 643/04

Palynostratigraphy of Woolsthorpe #1 Otway Basin Victoria

for
Geoscience Australia

P.L. Price
29th June, 2002

APG Consultants PO Box 682, Kenmore, Qld 4069 Australia

Woolsthorpe #1 Palynostratigraphy

Table of Contents

Woolsthorpe #1 Palynostratigraphy

Introduction

Woolsthorpe #1 was one of several wells examined on behalf of Shell Development (Australia) Pty Ltd that were pivotal in Dettmann's revision (Dettmann and Douglas 1976 and Dettmann 1986) of the palynostratigraphic subdivision of Dettmann 1963 and Dettmann and Playford, 1969. These wells influenced her conclusion (Dettmann 1981, 1986, Dettmann *et al* 1992) that there were significant differences in the order of appearance for certain of the Early Cretaceous index taxa between the Eromanga and Otway Basin.

When examined initially by Dettmann in 1968, the Woolsthorpe palynofloral succession was interpreted in terms of the east Australian Palynostratigraphic units defined by Dettmann and Playford, 1969 assigning 4300ft to 6230ft to the *D. speciosus* Zone and 6380ft tentatively to the *C. stylosus* Zone. The *C. hughesii* Subzone (the lower subunit of the *D. speciosus* Zone) was recognised from 4515ft to 6230ft with the uppermost sample (4300ft) unresolved in terms of the two *D. speciosus* Zone's subzones. From Dettmann's 1968 species lists, the Woolsthorpe assemblages can be assigned to the revised units of Dettmann and Douglas, 1976 and Dettmann, 1986 with either the *C. striatus* Subzone or upper *C. hughesii* Subzone represented at 4300ft (1310.6m); middle *C. hughesii* Subzone at 4515ft (1376.2m); and lower *C. hughesii* Subzone from 5005ft (1535.5m) to 6230ft (1898.9m). If the 1968 lists are interpreted in terms of the units of Price, 2000 the 4300ft (1310.6m) assemblage is representative of APK3; from 4515ft (1376.2m) to 5495ft (1674.9m) assigned to APK31 - APK22; 6230ft (1898.9m) to APK122, and 6380ft (1944.6m) to APK11 - APJ62. From the same 1968 data, Morgan's 1995 *P. notensis* Zone extends from 4300ft (1310.6m) to 5495ft (1674.9m); lower *F. wonthaggiensis* Zone at 6230ft (1898.9m); and *C. australiensis* Zone or *R. watherooensis* Zone at 6380ft (1898.3m).

The extent of APK31 - APK22 and *P. notensis* Zone to 5495ft in Woolsthorpe (and the inference that the Eumeralla - Crayfish unconformity lies close to this level) seems too low in terms of the lithostratigraphy suggested by log correlation from the Digby #1 and Mocamboro #11 sections (Appendix 1, Figures 7, 8 & 9); however, the placement of this section in the lower *C. hughesii* Subzone is less of a problem in terms of this correlation. The difference in these palynostratigraphic interpretations based on the original data set relates to their differing reliance upon the distribution of *P. notensis* relative to *Foraminisporis asymmetricus* and *F. wonthaggiensis* in the Otway. In terms of the Woolsthorpe section, the interpretation based on the units of Dettmann 1986, which is not reliant upon the distribution of *P. notensis*, seems plausible.

The present restudy of the Woolsthorpe section is directed towards resolving these differing interpretation and testing the usefulness of *P. notensis* in the palynostratigraphies of Morgan, 1995 and Price, 2000.

The slides of the SWC samples examined in this study were Dettmann's 1968 original mounts prepared using the methods of Dettmann, 1967 (HF digestion; $ZnBr_2$ separation; glycerine gel mounts). For the present study, the slides were scanned with either 16/0.50 or 25/0.80 Plan-Neofluar oil objectives (depending upon the palynomorph density on the slides) with taxa identifications established under 40/1.0, 63/1.40 and 100/1.35 Planapochromat oil objectives; taxa counts of about 100 taxa per sample (where sufficient palynomorphs were recovered) were taken with the 100/1.35 objective. Species lists were compiled from these examinations (Appendix 3) together with the relative abundance and diversity of species within various palynomorph groups which are presented graphically (Appendix 4). The results of the biostratigraphic investigation are presented on the Palynostratigraphic Data Table (Appendix 2) and are plotted against the wireline logs and lithostratigraphy of Woolsthorpe and some adjacent wells (Appendix 1) reviewed by Price, 2000.

The palynostratigraphic determinations given on the Data Tables follow the convention of offering an assignment defining the most probable biostratigraphic limits for the sampled horizon. This confident, but often rather broad, assignment is supplemented by a more specific interpreted ("best guess") determination but with varying degrees of uncertainty depending upon the perceived potential for contamination, preservation and diversity of the palynoflora recovered. The inferred lithostratigraphic and Age assignments are based upon this latter, more speculative, palynostratigraphic estimate.

Otway Basin Stratigraphic Nomenclature

Review of Palynostratigraphies Applied to the Lower Otway Section

The units of Dettmann, 1963 and 1986, Dettmann and Playford, 1969; Burger, 1973, 1988 and 1989; Morgan, 1985, 1988, 1989 and 1992; Helby *et al* 1987 have been used widely in Otway Basin studies and their relationships are summarised on Appendix 1, Table 1. These nomenclatures however, have been applied in different ways in the various well sections giving some confusion as to what is represented by a particular unit in any given study. The confusion is heightened where same named units have been applied with changed definitions in the Great Australian (Artesian) Basin (GAB) region and in West Australia. Further, there is no absolute consensus as to the precise order of appearance of certain of the Early Cretaceous index taxa in the Otway Basin (and other Early Cretaceous Australian provinces) as their introduction is blurred by factors including the extent of the Eumeralla - Crayfish unconformity, facies constraints, differing concepts as to the morphological limits of the index taxa and, possibly, floral migration if the interpretation of Dettmann, 1986 is accepted.

The differing order of appearance of certain of the index taxa given by Dettmann, 1986 (figure 3 page 85) relative to that of the GAB or to the order accepted by Morgan *et al*, 1995, Price, 1998 and 2000 perhaps relates to the data set available to Dettmann, 1986 which lacked an axial well with a complete basal Eumeralla - upper Crayfish sequence (such as Katnook #2) and her data set included the rather anomalous and puzzling (in terms of the sections reviewed by Price, 2000) distribution of *P. notensis* in Woolsthorpe #1.

Price, 1998 noted a close similarity of the Eastern Penola Trough APK3 - APK1 section to the equivalent in the Eromanga Basin particularly with respect to the order of entry of the various index taxa and perhaps, coincidently, the gross sedimentary succession. Alley and White, 1996, also in contrast to Dettmann, 1986, record an identical palynofloral succession to the Otway Basin with respect of the order of entry of index taxa in the Eromanga Basin; however, as discussed below (Page 17), Price. 2000 notes some differences with respect to *T. reticulatus* and *F. wonthaggiensis* ranges.

The order of pollen and spore taxa entry given for the Western Australian section by Helby *et al* 1987 and Backhouse, 1988 remains somewhat enigmatic in relation to the Eromanga and Otway palynofloral succession. Almost all of the index taxa lying between the entry of *Ruffordiaspora (=Cicatricosisporites) australiensis* and *Foraminisporis asymmetricus* in eastern Australia appear at about the one level in the West (that of the *R. australiensis* oldest occurrence datum; Helby *et al* 1987 Fig 13 and Backhouse 1988 Fig 34). This gives the impression of an older (earlier) entry (with respect of the *F. asymmetricus* and *Ruffordiaspora* oldest occurrence horizons) for many of these index taxa (eg *P. notensis*) in West Australian sections. Compounding the problem of east - west correlation (and also for the Eromanga to Otway correlation), is the differing perceptions of the base of the range of *Foraminisporis asymmetricus* in the Otway Basin; (for example, compare Dettmann, 1986 Fig 3 with the present interpretation on Appendix 1, Tables 1 and 4).

Morgan *et al*, 1995 reviewed and revised the Otway Basin palynostratigraphy as part of the comprehensive stratigraphic review of the western Otway Basin by MESA (Morton and Drexel Eds., 1995). The revised nomenclature of Morgan *et al*, 1995 gives some stability to the Otway Basin palynostratigraphy overcoming the ambiguity of the "*C. hughesii* Zone" by proposing the "*P. notensis* Zone". The difficulty related to different concepts of the *C. hughesii* Subzone as established by Dettmann and Playford, 1969 (top *C. stylosus* to base *C. striatus* together with some assemblage constraints particularly in respect of the base of the Subzone) and the "*C. hughesii* Zone (or Subzone)" in its various guises as used by Morgan 1980, 1985, 1992, Price *et al* 1985, Helby *et al* 1987 and Burger, 1973, 1988 (Appendix 1, Table 1).

By definition (interval between base *C. striatus* datum and base *P. notensis* datum) the *P. notensis* Zone includes APK32, APK31 and APK22 of Price 2000 but in its application Morgan (*pers com*, 1999) often (but not always) excluded the APK22 palynofloras (typically with isolated *P. notensis* occurrences) assigning them to the underlying "*F. wonthaggiensis* zone" *sl* (eg Mocamboro #11, Digby #1 and Katnook #2; compare Appendix 1, Figure 1 with fig 5.14 of Morton *et al* 1995). Morgan (*pers com*, 1999) tends to regard these isolated occurrences of *P. notensis* (particularly those with the presence of *M. evansii*) as being unreliable stratigraphic markers (perhaps laboratory or drilling mud contamination) preferring to place the base of the *P. notensis* Zone at the base of notable and consistent *Pilosisporites spp*; this corresponds more or less to the *P. parvispinosus* oldest occurrence datum (= base APK321). Additionally, Morgan 1995 has placed significance in the uppermost *Microfasta evansii* occurrence with respect of the base *P. notensis* datum (Pages 16-17).

In contrast, Price 1998, 1999 & 2000, regards these intermittent occurrences of *Pilosisporites spp* (including *P. notensis*) below the *P. parvispinosus* datum **when associated** with the distinctive *Ruffordiaspora - Cyathidites* palynofacies as being palynostratigraphically significant. This distinctive association forms a widely distributed correlatable horizon spanning from the Robe Trough (in Churinga and Nunga Mia) through the Penola trough (Viewbank, Killanoola, Penley) into the Merino High. Additionally, Price 1998, 1999 & 2000, finds that *Microfasta evansii* extends into typical APK321 / *P. notensis* Zone palynofloras and so does not rely on its extinction as an indicator of pre-APK321 or pre-*P. notensis* Zone section.

The retention by Morgan *et al,* 1995 of the "*F. wonthaggiensis* Zone" for the interval between the entry (base) of *D. speciosus* and base *P. notensis* seems unfortunate in respect of the different definition used for this zone in other parts of Australia and the GAB region in particular. The data of Price, 1998 and 2000 suggests that the range of *D. speciosus* is more like its range in the GAB (eg Burger 1980, 1989) where it extends down closer to the oldest occurrence of *C. hughesii* (= base APK121 datum) than to the oldest occurrence of *F. wonthaggiensis* (= base APK21 datum) (Appendix 1, Table 3). Isolated specimens of *D. speciosus sl* have been recorded in the Casterton Formation of Sawpit #1 and possibly Camelback #1 and the Westbourne Formation (close to the base *Ruffordiaspora spp* datum (= base APK1)) of the Eromanga Basin (Page 21). In the context of potential palynostratigraphic nomenclatural confusion at this stratigraphic level, it is worth noting that Burger, 1989 regarded the base of his 1973 "*C. australiensis* Subzone" as being at the base *D. speciosus* datum (= base APK122) and not at the oldest occurrence *R. australiensis* datum (Burger,1989 fig 3); ie the "*C. australiensis* Subzone" *sensu* Burger, 1973 would lie **within** the "*F. wonthaggiensis* zone" *sensu*

Morgan *et al* 1995; (note that the base of the "*C. australiensis* Zone" *sensu* Burger, 1989 is the definition adopted by most others; that is, the base *R. australiensis* datum).

Thus, the use of *D. speciosus* to define the base of the "*F. wonthaggiensis* Zone" significantly extends its stratigraphic span in terms of both Burger's 1973 original concept (from base *F. asymmetricus* and *P. notensis* to base *R. ludbrookiae* and *F. wonthaggiensis*) and that of Helby *et al* 1987 (from base *F. asymmetricus* to base *F. wonthaggiensis*). In stratigraphic terms, the "*F. wonthaggiensis* Zone" *sensu* Morgan *et al*, 1995 (equivalent to APK122 + APK21) part of the Crayfish Group is the equivalent of the Cadna Owie + Murta + much of the Namur rather than just the Cadna Owie if an equivalence of the *F. wonthaggiensis* Zone *sensu* Helby *et al*, 1987 and Burger, 1973 1989 (equivalent to APK2) of the Eromanga Basin is accepted (Appendix 1, Table 3).[1] In terms of the Eromanga Basin concept of the *F. wonthaggiensis* Zone *sensu* Burger, 1989, the "upper *F. wonthaggiensis* zone" of Morgan, 1993 and Morgan *et al* 1995 is closer to its stratigraphic span; for example, in Katnook #2, Heathfield #1, Laira #1, and Viewbank #1 there is some 200m or less separating the base *T. reticulatus* datum and base *F. wonthaggiensis* datum. In contrast the "lower *F. wonthaggiensis* zone" in Sawpit #1 (some 1,000m+) spans almost all of the upper *C. australiensis* Zone of Burger, 1989.

Price, 2000 introduced threefold subdivisions of both APK122 and APK21 and are outlined in some detail below (Pages 13, 17 & 21; Appendix 1, Table 4). In terms of the Morgan's 1995 "upper *F. wonthaggiensis* Zone" and Price's 1998 "APK212" subunit, Upper APK21 plus Middle APK21 more or less correspond (Appendix 1 Tables 1 & 4). These subunits of Price, 2000 were rather vaguely defined relying in part upon assemblage characteristics and remain to be tested on a wider data set either from other parts of the Otway Basin or in the Eromanga Basin. However, although tentatively defined, these subunits support the discrimination of the upper Laira Formation of Katnook, Viewbank and Heathfield regions from the lower Crayfish above the "Sawpit Sandstone" in Sawpit (Appendix 1, Figures 1 and 2). Their recognition were crucial also

[1] [Note that the present interpretation of the lithostratigraphic range of some of the index taxa in the Eromanga Basin differs from that given by Alley and White, 1996].

to the correlation suggested by Price, 2000 (and relied upon in this study) of the Merino High Crayfish section. The absence of Middle and Lower APK21 (= “upper *F. wonthaggiensis* zone” or “APK212“) is the principal biostratigraphic evidence of erosion at the top of the Crayfish Group in the Nunga Mia - Churinga region of the Robe Trough and the Penley - Killanoola region of the Penola Though.

Application of Adopted Palynostratigraphic Nomenclature

Introduction

The biostratigraphic nomenclature adopted for this study is based upon that of Price *et al*, 1985 and Filatoff & Price, 1988 developed initially for the Surat and Eromanga Basin sections but adapted for the Otway Basin by Price, 1993, 1995, 1996, 1997, 1998, 1999 and 2000. The units and their relationship to the nomenclatures of Morgan, 1985 and 1992, Dettmann, 1986 and Dettmann and Playford, 1969 and Morgan *et al*, 1995 are summarised on Appendix 1, Table 1 and the relationship of the palynostratigraphic units to the Otway Basin and Eromanga Basin lithostratigraphy is presented on Appendix 1, Tables 2 and 3; their relationship to the Katnook #2, Sawpit #1 and Laira #1 Penola Trough Reference Sections are given on Appendix 1 Figures 1a, 2 and 3.

The lithostratigraphical conventions of Morton *et al* 1995 for the Otway Basin have been adopted with some modifications. The evidence for a major time break or significant regional unconformity between the Casterton Formation and the lower Crayfish Group (hence the exclusion of the Casterton Formation from the Otway Supergroup) is questioned and there is a need for revision and formal definition of the various lithofacies of the Pretty Hill Formation. The differentiation of the Windermere Sandstone Member from the Katnook Sandstone (and their placement in the Eumeralla Formation and Crayfish Group respectively) needs review on the basis of the palynostratigraphic data and interpretation given by Price, 1998 & 2000 in conjunction with the distribution data for *Ruffordiaspora spp, Foraminisporis asymmetricus* and *Pilosisporites notensis* given by Morgan, 1989 and Price, 2000 for Katnook #2.

The lithostratigraphic subdivision of the Woolsthorpe section (Appendix1, Figures 9 & 10) reflects the correlation of the units in Digby #1 and Mocamboro #11 adopted by Price, 2000 and given on Appendix 1, Figures 7 and 8).

The relationship of the palynostratigraphic units to the Otway Basin and Eromanga Basin lithostratigraphy is presented on Appendix 1, Tables 2 and 3; their relationship to the Katnook #2, Laira #1 and Sawpit #1 Penola Trough Reference

Sections are given on Appendix 1, Figures 1 to 3. The range of selected index taxa relative to the present palynostratigraphic units is given on Appendix 1, Table 4; these ranges draw on data both from the GAB region and the Otway Basin.

The present nomenclature's units are based mostly upon oldest occurrence datum of individual taxa arranged hierarchically (Appendix 1 Tables 1 & 4) more or less according to their regional and facies extent and ease of application (but biassed somewhat towards the Eromanga Basin). The application of individual units to a particular well section is tempered by local factors such as preservation and the palynofacies association. It should be noted that a number of taxa are undescribed and many of those described have been used with a more restricted morphological range than may be accepted by other workers; the "splitting" of established taxa has been in an attempt to increase palynostratigraphic resolution. The philosophy of the units and species concepts are more fully described by Price and Filatoff, 1987 and Price, 1997.

In addition to the more established regional units, three fold subdivisions of units APK122 and APK21 was introduced Price, 2000; these are based partly on assemblage concepts (supported by some species oldest occurrences). While they follow the general palynofloral succession in the GAB, they are based primarily on the Otway associations and remain to be tested and refined on a more regional basis.

Palynofacies Associations

In an attempt to better define the index taxa distribution in terms of environmental and facies constraints, the broad species abundance data were used to define several "palynofacies" associations. These are recorded on the appended Palynostratigraphic Data Tables and their palynofloral characteristics summarised below.

"***Ruffordiaspora - Cyathidites* Palynofacies**" Ferns dominant; mostly *Cyathidites*; *Cyathidites* mostly *C. minor*; *Ruffordiaspora* notable &/or modestly diverse; *Pilosisporites* scarce or absent.

"***Pilosisporites - Cyathidites* Palynofacies**" Ferns dominant; mostly *Cyathidites*; *Cyathidites* mostly *C. minor*; *Pilosisporites* notable and diverse; *Ruffordiaspora* notable &/or modestly diverse.

"***Pilosisporites - Osmundacidites* Palynofacies**" Ferns dominant; *Osmundacidites* ≥ *Cyathidites*; *Pilosisporites* notable and diverse.

"***Ruffordiaspora - Osmundacidites* Palynofacies**" Ferns dominant; *Osmundacidites* ≥ *Cyathidites*; *Ruffordiaspora* notable &/or modestly diverse; *Pilosisporites* scarce or absent; Lycopods conspicuous.

"**Conifer - *Ruffordiaspora* Palynofacies**" Conifer pollen dominant with inaperturate pollen conspicuous to prominent. Fern spores prominent; *Ruffordiaspora* conspicuous to notable; *Pilosisporites* scarce or absent. Lycopod spores notable.

"***Osmundacidites - Retitriletes*** **Palynofacies"** Ferns dominant; *Pilosisporites* absent; *Ruffordiaspora* scarce or absent; *Osmundacidites* ≅ or ≥ *Cyathidites*; *Cyathidites* mostly *C. australis*; Lycopods conspicuous or notable and relatively diverse.

"***Osmundacidites*** **Palynofacies"** Ferns dominant; *Pilosisporites* absent; *Ruffordiaspora* scarce or absent; *Osmundacidites* ≫ *Cyathidites*; *Cyathidites* mostly *C. australis*; Lycopods scarce.

"***Cyathidites*** **Palynofacies"** Ferns dominant; *Pilosisporites* absent; *Ruffordiaspora* scarce or absent; *Cyathidites* > *Osmundacidites*; *Cyathidites* mostly *C. australis*; Lycopods scarce.

"Lycopod Palynofacies" Lycopod > Ferns ≥ Gymnosperms.

Conifer - *Osmundacidites* Palynofacies" Gymnosperm ≥ cryptogams; Ferns prominent; *Pilosisporites* absent; *Ruffordiaspora* scarce or absent; *Osmundacidites* ≥ *Cyathidites*; *Cyathidites* mostly *C. australis*; Lycopods notable and modestly diverse.

"Conifer Palynofacies" Gymnosperm ≫ cryptogams. *Pilosisporites* absent; *Ruffordiaspora* scarce or absent.

"Casterton Palynofacies" Palynodebris diffuse; Palynoflora restricted; mostly conifer remnants.

"Casterton aquatic Palynofacies" Palynodebris diffuse; Palynoflora restricted; mostly conifer and leiosphere remnants

Penola Trough - Merino High Correlation

Introduction

The following discussion relating to the application of the palynostratigraphy to the correlation of the lower Eumeralla Formation, Crayfish Group and Casterton Formation across the Penola trough and Merino High is taken from Price, 2000. The individual sample details and species lists for the sections examined are not presented again here; only the annotated log sections of the wells are appended (Appendix 1, Figures 1 to 8). The boundary definitions and relation to the ranges of some palynomorph taxa are given on Appendix 1 Table 4.

Unit APK321

The distinctive palynofloras of APK321 are usually represented by the diverse "*Pilosisporites - Cyathidites*" and "*Pilosisporites - Osmundacidites*" Palynofacies which include a wide morphological variation within *Pilosisporites* complex (with both *P. parvispinosus* and *P. notensis* represented). A variant of *Foraminisporis wonthaggiensis* (*F. wonthaggiensis "lunaris"* 1519) seems confined to APK321 and perhaps does not extend to the very base; *F. wonthaggiensis "wonthaggiensis"* 662 is usually consistent to the base of APK321 but becomes scarce and intermittent below. The distinctive acritarch *Microfasta evansii* extends (sometimes in modest numbers) up into the lower APK321 associations.

APK321 palynofloras offer the most consistent and easily recognised palynostratigraphic datum in the Eumeralla - Crayfish section. This contrast with the GAB where the base of *Foraminisporis asymmetricus* range (base APK31 datum) seems a more reliable and easily established datum. As discussed above (Page 5), in many cases the base of APK321 coincides with the placement of the base *P. notensis* Zone by Morgan Palaeo Services.

Despite the distinctiveness of the typically rich and diverse APK321 associations, defining its lower extent can be difficult in some sections. Interspersed with and sometimes immediately underlying the diverse APK321 palynofloras are both fern dominated and conifer dominated associations that are very restricted in species diversity. Some of these restricted Eumeralla palynofloras are almost indistinguishable from the older Crayfish Group APK12 associations (*eg* Churinga #1 SWC16 1225.0m; Nunga Mia #1 SWC24 1302.5m and SWC22 1349.0m; Penley #1 SWC29 1075m and also in many of the Merino High wells). Thus, the reliable placement of the base of APK321 often requires close sampling; the base of the unit could not be defined in the sparsely sampled upper section of Sawpit #1 for example (Appendix 1, Figure 2).

Units Upper APK21, APK22 and APK31

Below the range of *P. parvispinosus*, *Pilosisporites spp* rapidly decline in abundance and become restricted in morphological diversity; they have their deepest occurrence (base APK22) within the APK2 associations. *Foraminisporis asymmetricus* makes its appearance (base APK31) above the oldest occurrence of the *Pilosisporites spp*; however, stratigraphic separation of these two taxa is difficult to resolve in many sections. APK22 and APK31 palynofloras can be reasonably diverse including a consistent and modest diversity of *Ruffordiaspora spp* together with the last of the morphologically similar taxon *Plicatella spp* (*P. giganticus* 1283 and *P. sp cf P. problematicus* 915). Many of these palynofloras however. are restricted fern dominated (often mostly *Cyathidites minor*) associations and conifer dominated palynofloras both with very rare, intermittent occurrences of *P. notensis* and / or *F. asymmetricus*. These restricted assemblages perhaps reflect sand facies; for example, note the Katnook #2 diversity plots of Price, 2000 appendix 1 figures 13 and enclosures 3 & 5.

Individually, in the absence of the index taxa, these associations are difficult to assign; however, the consistent occurrence of notable numbers and modestly diversity (in terms of two or more 'species' being represented) *Ruffordiaspora spp* (and related forms) characterise the Upper APK21 - APK22 - APK31 palynofloras. *Foraminisporis wonthaggiensis sl* and some other bryophyte-like forms are reasonably consistent in the more diverse of these associations. These subunits have been resolved in closely sampled wells across the eastern Robe Trough (eg Nunga Mia #1, Churinga #1), Penola Trough (eg Penley #1, Killanoola #1 and Katnook #2) and Merino High of Victoria where they form a consistent palynostratigraphic interval.

While the individual units of Upper APK21, APK22 and APK31 can be resolved with confidence sometimes, often the restricted assemblages that characterise the interval give a broad assignment to "Upper APK21 to APK31" or "no older than Upper APK21". The poor resolution is accentuated in the more arenaceous sections where the sampling and recoveries are sparse. As noted above (Page 12), these restricted "no older than Upper APK21" association can occur also within the diverse associations of APK321 and blur the resolution of APK321 from the "Upper APK21, APK22 and APK31" section.

It is of interest to note that the deepest occurrence of the rare, morphologically distinctive *Plicatella giganticus* 1283 and *Cicatricosisporites "burgeri"* 818 and the base of the *Ruffordiaspora* "consistent occurrence of notable numbers and modest diversity" interval (base Upper APK21) have a similar distribution in the Otway (both present at the base of the APK22 - APK31 sequence in Churinga #1 for example) as they do in the Surat and Eromanga Basins. *C. "burgeri"* 818 extends to about the base *F. wonthaggiensis* datum but *P. giganticus* seems to extend no lower than the base *P. notensis* datum.

There is a suggestion that isolated occurrences of *P. notensis* may occur lower in the Crayfish Group in section that would otherwise be regarded as APK122; for example, those of Woolsthorpe #1 and Penley #1. However, both these occurrences are thought to represent contamination (Page 27). Thus, emphasis is placed on the association of a modest diversity of *Ruffordiaspora* complex and other palynofacies criteria in association with these isolated to rare *P. notensis* occurrences in terms of the placement of the lower APK22 boundary.

The separation of the oldest occurrence datum of *F. asymmetricus* and *P. notensis* in the GAB seems essentially coincident. While this probably reflects the absence of very close sampling in most GAB well sections, perhaps there is a suggestion of a slight hiatus in parts of the Eromanga Basin as the APK2 - APK3 boundary lies near the top of the Cadna Owie and the base of the marine influenced Wallumbilla sediments.[2] The stratigraphic separation of these taxa in the Otway Basin seems relatively small also. However, this is difficult to fully assess as *F. asymmetricus* is very patchy in its distribution in the Otway section below APK321 particularly in the more specialised *Cyathidites* and Conifer dominated palynofacies from parts of the Windermere Sandstone where all Bryophytic forms can be scarce.

Thus, the distinction between section assigned to any one of Upper APK21, APK22 or APK31 individually should be accorded a degree of scepticism unless there is very close sampling including some reasonably diverse associations. Nevertheless, their separation from APK32 (above) or Middle APK21, Lower APK21 and APK122 (below) is much more easily sustained and reliable.

The Eumeralla - Crayfish Regional Unconformity

In many parts of the Otway Basin the mid Otway Supergroup unconformity is readily defined by the contrast of the diverse APK321 Eumeralla associations directly overlying the bland APK122 Crayfish palynofloras. In some locations (eg Nunga Mia #1 SWC22 1349.0m; Churinga #1 SWC 13 1252m) these associations are separated by a thin veneer Upper APK21 - APK31 section often associated with a sand (interpreted by Price, 2000 to be the Windermere Sandstone Member). These sections lack the Middle APK21 and Lower APK21 associations (including those with notable proportions of the

---

[2] [Alley and White, 1996 fig 6.1 and Alexander and Sansome 1996 fig 5.17 show a significant separation but there may be some confusion over the different definitions of "PK22" (an Eromanga Basin unit) of Price *et al* 1985 (base *Trilobosporites purverulentus*) and "APK22" of the present nomenclature (base *Pilosisporites notensis*)].

algae *Microfasta evansii*) of the Laira Formation represented in Katnook #2, Laira #1, Viewbank #1, and Heathfield #1 (amongst others) suggesting this part of the Laira Formation is missing.

Katnook #2 well contains the most complete section sampled over the basal Eumeralla and Laira Formations on the basis of both log correlation and the palynostratigraphic succession. It is probable that the Eumeralla - Crayfish sediments are conformable in this well as the palynological succession seems complete. The widely accepted lithostratigraphic interpretation of Morton *et al* 1995 (depicted on Appendix 1 Figure 1a) places the Eumeralla - Crayfish boundary at 1892.0m separating the Windermere Sandstone Member from the Katnook Sandstone and is coincident with their placement of the *P. notensis* Zone - *"F. wonthaggiensis* Zone" boundary (Morton *et al* 1995 fig 5.14). However, *Pilosisporites notensis sl* extend down lower to at least 1896.5m and possibly 2103.0m (depending on whether the latter isolated specimen is considered as being endemic or contamination) while *Foraminisporis asymmetricus* extends to 1925.0m.

Thus, in the type section of the Katnook Sandstone, the *P. notensis* Zone (or APK22 - APK32) extends at least **into** the top of the Katnook Sandstone (to at least 1896.5m) and possibly encompasses it if Price's 2000 interpretation of the Katnook #2 palynostratigraphy is accepted. Irrespective of whether it is accepted that the *P. notensis* at 2103.0m is contamination or not, the assemblages to 2155.0m and probably 2177.0m are representative of the Upper APK21 - APK31 transition associations. In assessing the distribution of Upper APK21 - APK22 - APK31 and *P. notensis* in Katnook #2, it should be noted that many of the palynomorph recoveries over the interval 1875m to 2132m were low and restricted (Price, 2000 appendix 1 fig. 13 and enclosures 3 & 5) and no diagnostic assemblages were recovered from between 1932m and 2103m.

It seems reasonable to associate the "Upper APK21 to APK31" section with the Eumeralla depositional cycle in areas where Upper APK21 - APK22 - APK31 associations directly overly APK122 Crayfish sediments (with the Middle APK21 and Lower APK21 Laira palynofloras missing) and an angular unconformity is clearly visible on seismic (eg

Churinga, Nunga Mia), However, if it is accepted that the Eumeralla - Crayfish boundary is conformable in the Katnook #2 reference section, there is no prerequisite for the APK22 / APK21 (*P. notensis* Zone / *"F. wonthaggiensis* Zone") boundary to coincide with this lithostratigraphic boundary (and the interpretation of Price, 2000 suggests it does not). The modified lithostratigraphic subdivision given on Appendix 1 Figure 1b reflects this interpretation in which the lithostratigraphic boundaries are not tied to the biostratigraphic boundaries and Units Upper APK21 and probably APK22 extend into the top (rarely preserved part) of the Crayfish Group.

In parts of the Penola Trough and Robe Trough where APK321 extends down to the unconformity and directly overly APK122 this is not an issue; however, where the APK22 - APK31 units are present between APK321 and APK122, they are often associated with a sand unit (eg Nunga Mia #1 SWC22 1349.0m; Churinga #1 SWC 13 1252m) and their relation to the Eumeralla - Crayfish unconformity becomes relevant. If it is accepted that they are confined to the Eumeralla depositional cycle, perhaps they represent the basal channel sands deposited on the Crayfish erosional surface (analogous to the lower Precipice Sandstone of the Surat Basin) offering better hope of a predictable exploration target rather than a chance occurrence of an intra Crayfish sand being close to the unconformity surface. The lithostratigraphic relationships of the APK31 and APK22 sections therefore are particularly significant in the interpretation of both the Merino High succession and the Nunga Mia region of the Robe Trough.

In considering the distribution of the Upper APK21 - APK22 - APK31 in relation to the basal Eumeralla - uppermost Laira sections in the individual wells, account must be taken of the palynomorph recoveries when applying the subunits. In Laira #1 and Gordon #1 for example, the log signature and position would suggest the interval should be APK31 but neither *F. asymmetricus* not *P. notensis* were located indicating an Upper APK21 assignment. While it is possible that with a basal sand there may have slight variation in age between disparate channel fills on the Crayfish unconformity surface and/or a minor local hiatus between the Windermere sand and Eumeralla Shale, it is more likely that it is a reflection of the fickleness of the index taxa distribution. The palynofloras therefore, are best broadly assigned to "Upper APK21 to APK31". Indeed, in the areas where the "Upper APK21 - APK22 - APK31" associations lie directly on APK122 (*ie* where there is the erosion/non deposition break) it is probable that these represent an impoverished APK22 or APK31 association.

The other palynostratigraphic criterion that has been used previously to distinguish the the *P. notensis* Zone basal Eumeralla from the "*F. wonthaggiensis* Zone" Crayfish is the extinction (youngest occurrence) of the presumed algae *Microfasta evansii* (Morgan *et al,* 1995). However, recent studies (Price, 2000) indicate that this acritarch frequently occurs (sometimes as a notable component) with *Pilosisporites spp* both in typical APK321 palynofloras; (eg Woolsthorpe #1 at 4300ft and 4515ft, Casterton #1 at 1096m, Mocamboro #11 at 832.6m, Gordon #1 at 1118.0m, Digby #1 at 1096.8m) and in APK22 - APK31 associations (eg Nunga Mia #1 at 1349m, Churinga #1 at 1252m, Digby #1 at 1220.8m, Gordon #1 at 1184.0m, Penley #1 at 1075m) in the eastern Robe Trough, Penola Trough and Merino High.

In the case of the Katnook #2 reference section, it occurs within the lower Eumeralla Formation (1874.46m, 1874.97m, 1877.24m) and is conspicuous at 1877.24m in the Eumeralla Formation immediately above the Windermere Sandstone Member. Its occurrence in APK321 and APK31 - APK22 section is consistent with its distribution recorded in the GAB sequence (eg Burger,1973, 1982, 1989 who recorded its extinction at the top of his *F. asymmetricus* Zone (that is, in the uppermost part of APK321)) and has been recovered in APK321 section in the onshore Gippsland Basin (eg Dettmann, 1986).

Thus, *Microfasta evansii* is not the "golden bullet" (infallible indicator) for the identification of pre-*P. notensis* Zone Crayfish section.

Units Middle APK21 & Lower APK21

The APK22 and APK31 palynofloras of the Otway Basin (and the GAB equivalents) typically include a diversity (but often are only a minor component of the palynoflora) of liverwort forms such as *Aequitriradites spp, Cooksonites spp, C. variabilis, "Verrucosasporites" spp, Januasporites spp* and, in particular, *Triporoletes reticulatus* together with the fern spore *Crybelosporites berberioides*. These forms decline down section in Middle APK21 and are generally absent in the Lower APK21 and APK1 associations. A similar down section decline is noted in the Eromanga and Surat Basins, but some of these forms may become established again (albeit sporadically) in units APK11, APJ6 and APJ5.

The base of the consistent occurrence of *Triporoletes reticulatus* defines the base of Middle APK21 of Price, 2000 separating it from Lower APK21. The base of APK2 (and Lower APK21) is defined by the entrance of *Foraminisporis wonthaggiensis*. This stratigraphic relationship of these taxa seems inconsistent with their distribution in the Eromanga Basin where *T. reticulatus* is known to extend down below the range of *F. wonthaggiensis* to just above the base of *D. speciosus* albeit as very rare, scattered occurrences[3].

In the Otway Basin it is assumed that the *T. reticulatus* datum is above the *F. wonthaggiensis* datum (as opposed to the "*F. wonthaggiensis* zone" *sensu* Morgan *et al* 1995); however, in many sections *F. wonthaggiensis* and *T. reticulatus* appear to have similar oldest occurrence points (eg, the Katnook #2 data of Morgan, 1989 and Price, 2000; Heathfield #1, Morgan, 1989; Viewbank #1, Price 1997; Laira #1 Morgan, 1990, 1993 and Price, 2000).[4] In this context, it is worth considering that *T. reticulatus* is reasonably consistent in the Eromanga Basin down to within APK21 and very rare and sporadic below the base *F. wonthaggiensis* datum. The present estimation of their Otway distribution may be obscured by their scarcity at the base of their range, preservation problems with the lower Crayfish Group palynofloras and by the assumption that the "*F. wonthaggiensis* Zone" is the equivalent unit in both the GAB and Otway Basin. Thus, it is possible the relative stratigraphic distribution of *T. reticulatus* relative to *F. wonthaggiensis* and *D. speciosus* in the Otway Basin will prove

---

[3][Note that Alley and White, 1996 Fig 6.1 show *T. reticulatus* appearing above *F. wonthaggiensis* in the Eromanga Basin but this differs from its distribution given by Burger, 1974, Price *et al* 1985 or Dettmann, 1986]

[4][Note that Morton *et al* 1995 Fig 5.14 indicate that the "upper *F. wonthaggiensis* zone" extends down only to about 2150m in Katnook #2 but the taxa distribution data of Morgan, 1989 and Price, 2000 indicate *T. reticulatus* is present to at least 2595.5m].

to be similar to that of the Eromanga Basin; perhaps its distribution in East Avenue #1 (Hooker, 1998) may be giving a hint of this (Price, 1999).

Thus, Middle APK21 perhaps is best considered as an assemblage zone with the consistent presence of *T. reticulatus* as being but one of its characteristics and the unit is left with a somewhat vaguely defined base.

Although somewhat vaguely defined, the recognition of Middle and Lower APK21 allows the discrimination of the upper Laira Formation of Katnook, Viewbank and Heathfield regions from the lower Crayfish above the "Sawpit Sandstone" in Sawpit and may facilitate the resolution of the upper Cadna-Owie from the lower Cadna-Owie and Murta in the Eromanga Basin. Their recognition is crucial to the resolution of the Merino High Crayfish section and their absence is the principal biostratigraphic evidence of erosion at the top of the Crayfish Group in the Nunga Mia - Churinga region of the Robe Trough and the Penley - Killanoola region of the Penola Though. The Lower APK21 - Middle APK21 and the APK122 - Lower APK21 boundaries lie within the lower Laira in Katnook #2 and Laira # 1 and parallel the acritarch - log correlation of Hill, 1995 between these wells (Appendix 1 Figs. 1a & 3).

Upper Laira Formation Correlation

As discussed above (Page 12 & 14-15) the Upper APK21 - APK22 - APK31 interval is usually either lost to the Eumeralla - Crayfish unconformity or preserved as thin veneer with the commencement of the Eumeralla deposition. In the conformable Katnook #2 sequence it is represented at the top of the Laira where Upper APK21 and APK22 span the upper Laira Formation litho-units 5 and 4 (Appendix 1, Figures 1a)[5]. They seem absent in the top of the Laira in Laira #1 where Middle APK21 is represented confirming the erosion of the top Laira implied by log correlation (Appendix 1, Figure 3). In Sawpit #1 the youngest Laira preserved is representative of the base of Lower

[5][note that Price,2000 regards this part of the Laira of Morton *et al* 1995 as being part of the Eumeralla depositional cycle and better associated with the Windermere; see discussion Pages 14-15 and Appendix1, Figure 1b)

APK21; the distinctive Middle APK21 and Upper APK21 associations of the upper Laira Formation (which, in Laira and Katnook, include a prominence of *Microfasta evansii*) were not present. Thus, in Sawpit #1 all but the lower part of the Laira has been eroded (Appendix 1, Figure 2).

Within the Middle APK21 sequence of Laira #1 several assemblages (SWC37 1945m, SWC35 1961 and SWC31 2204m) included two or more species of *Ruffordiaspora* and related forms. While it is tempting to assign the shallowest two of these to Upper APK21 (in keeping with the litho-subunit 4 assignment which, in Katnook #2, yielded Upper APK21 palynofloras), they are inter-dispersed with typical Middle APK21 associations and the *Ruffordiaspora* are a very scarce component. Similar "Middle APK21 - like" palynofloras with sparse *Ruffordiaspora* were encountered in the Merino High wells of Digby #1 (1318.1m & 1364.4m) and Mocamboro #11 (942.7m & 943.0m). In this case, their assignment was less clear cut and influenced by an isolated *P. notensis* recorded in Mocamboro #11 at 965m by Morgan, 1991; this occurrence implies that APK22 is represented and the section is a Windermere Sandstone correlative. The log signature of these wells is not easily interpreted in terms of the "usual" Penola Trough Crayfish log pattern and the possibility of contamination of SWC at 965m must be considered with respect of the *P. notensis* (some contamination is noted in adjacent samples in Morgan's 1991 study).

Despite the thinness of the Crayfish Group on the Merino High, Middle APK21 were recovered in Gordon #1, Mocamboro #11 and possibly Digby #1 underlying the APK22 - APK31 Windermere equivalents. This suggests a mid Laira Formation equivalent is represented although in Digby #1 and Mocamboro #11 it is a rather arenaceous section perhaps more typical of the Pretty Hill in lithological character. In Gordon #1 the Middle APK21 associations overlie Upper APK122 section representative of the basal Laira and upper Pretty Hill; it seems possible that either a fault intersection or a mid Crayfish hiatus is present to account for the loss of the Lower APK21. A similar pattern seems to occur in the Mocamboro and Digby sections although no lower Laira Formation seems present and the underlying APK122 is representative of the upper Pretty Hill Formation.

Unit APK12

As noted above (Pages 6-7), the base *D. speciosus* 824 datum (base APK122) lies well down into the Crayfish Group within the Sawpit #1 "basal shale" unit (the top of subunit B "McEachern Sandstone" equivalent; Appendix 1, Figure 2). Isolated specimens of *D. speciosus sl* have been recorded almost to the base of APK1 in the upper Westbourne Formation of Eromanga Basin and also in the Casterton of Sawpit #1 and possibly in Killanoola #1 and Camelback #1; of those examined recently, the deeper occurrences seem to conform to *D. speciosus "strigosus"* 4668. Thus, the base of APK122 is taken as the base of consistent *D. speciosus sensu lato* in general and *D. speciosus "speciosus"* 824 in particular. It should be noted that the distribution of the APK1 index taxa in the Otway Basin is often limited by the decline of preservation down section reflecting the increase of maturity and the generally poor preservation of the palynofloras in the silt and sand facies of the lower Crayfish. For example, in Katnook #2 *D. speciosus* is not recorded below 3035m which is the deepest sample with reasonable palynomorph recoveries and diversity (Price, 2000 appendix 1 fig. 13 and enclosures 3 & 5); its absence in the sparse palynofloras below this cannot be taken as an indication of the section's antiquity (of it being older than APK122).

Three subunits have been established in Unit APK122 in the Sawpit #1 reference section reflecting the deepest consistent occurrence of liverwort - like forms particularly *Aequitriradites spinulosus* (base Upper APK122) and the deepest occurrence of the "large" *Ruffordiaspora* including *R. ludbrookiae "parallelus"* 5057, *R. ludbrookiae "controversius"* 680 and *R. "mega-australiensis"* 5047 (base Middle APK122). These boundaries fall above and below (respectively) the Pretty Hill "Sawpit Sandstone" member. The distribution of these subunits has not tested outside of the study area but is consistent with broad trends in the Eromanga Basin palynomorph succession.

These subzones have their limitations in terms of their recognition in the Otway sections. The Upper APK122 index taxa are rather delicate and easily lost in poorly preserved assemblages and the Lower APK122 forms are extremely rare and sporadic in their distribution. Thus, many of the APK122 sections will remain undifferentiated with the subunits being applicable only closely sampled sections with some reasonably diverse assemblages (and the time and perseverance to find the index taxa!). The preservation and recoveries in the APK122 associations of Katnook #2 and the lower parts of Laira #1, Casterton #1, Gordon #1, Mocamboro #11 and Digby #1 limit their application in these sections; however, they suggest that the lower sands in Mocamboro #11 are younger than the "Sawpit Sandstone" member and that the lower shale in Digby and Woolsthorpe is likely to be younger than the Casterton of Sawpit or Gordon.

The base *Cyclosporites hughesii* 693 and 4662 datum (base APK121) is only a little below the *D. speciosus* datum (base APK122) and, in the Sawpit #1 reference section, lies at the top of what was considered by Price, 2000 to be the Casterton Formation (Appendix 1, Figure 2) and is in a similar position in Bus Swamp #1. It should be noted that Morton *et al* 1995 (Morton *et al* 1995, fig 5.10) and Price, 1993, 1996, 1997 regarded the lowest sub unit of the "basal shale" in Sawpit #1 (2450m - 2461.5m) as being part of the Pretty Hill Formation (and Crayfish Group); however, a recent compilation by the Minerals and Petroleum Victoria (MPV) considered it as being the uppermost part of the Casterton Formation. This broader concept of the Casterton Formation was accepted by Price, 1997, 1998 & 2000 and applied in this study.

Basal Laira - Pretty Hill Formation Correlation

The palynological interpretation favours a partly overlapping relation of the lower Laira and Pretty Hill sections in Sawpit and Katnook #2 more or less equivalent to the Morton *et al* 1995 fig 5.13b correlation in which the upper Laira Formation is eroded in Sawpit at the Eumeralla - Crayfish unconformity and the "Sawpit Sandstone" member lies below the extent of the Katnook well section. In the correlation by Price, 2000 of Sawpit #1 (Appendix 1, Fig. 2), only the Lower APK21 basal Laira is preserved with the distinctive Middle and Upper APK21 assemblages and associated *M. evansii* "blooms" of the upper and middle Laira Formation not being represented. There is a suggestion from seismic evidence that the top of the Pretty Hill in Sawpit may be abbreviated by faulting but this is beyond the resolution of the palynostratigraphic sampling.

The alternative correlation (Morton *et al*, 1995 figure 5.15a), in which it is suggested that the well sections cover much of the same extent of the Laira and upper Pretty Hill with the "Sawpit Sandstone" representing the top Pretty Hill sand in Katnook #2, is seductive if the well log sections are considered in isolation from the palynostratigraphy. The palynological data from the Pretty Hill could be interpreted to lend support by correlation of the "no older than Middle APK122" assignment at 2870.6m and 2875.5m in Katnook #2 (at the Laira - Pretty Hill boundary; Appendix 1, Fig. 1) with the Sawpit #1 "Middle APK122" assignments from the top of the "Sawpit Sandstone" and lower part of the overlying "Sawpit upper shale" (1751m to 1890m; Appendix 1, Fig. 2). This correlation however, does not conform with the Upper APK122 assignment over the basal Laira Formation in Laira #1 (2630m and 2676.5m; Appendix 1, Fig. 3) nor to the positioning of the Upper APK122 *Microfasta evansii* deficient associations from between 1292.5m to 1743m in Sawpit #1 opposite the Middle APK21 and Upper APK21 *M. evansii* rich palynofloras from Laira #1 (1938.0m to 2204m) and Katnook #2 (2111.5m to 2595.5m). Additionally, the seismic data indicates the need to accommodate some 1300m of Pretty Hill at the base of and below Katnook #2 well section (Morton *et al* 1995 fig 5.13) in the 575m top "Sawpit Sandstone" to base "Sawpit Basal Shale" interval of Sawpit. This can be achieved either by thinning (reduced depositional/subsidence rate) of the total interval (however, the seismic does not show significant convergence of the Pretty Hill horizons between Katnook and Sawpit); or by onlap of the upper Pretty Hill over the basal Pretty Hill (the part below the Katnook well section) across the Casterton Formation (however, no angularity or truncation of the lower Pretty Hill against the Casterton boundary can be seen on seismic; the palynological evidence in Sawpit indicates the Casterton and basal Pretty Hill are conformable with no significant time break (Page 25)).

The correlation of the Crayfish Group from the axial reference sections east to the Victorian Merino High was not significantly changed by Price, 2000 which generally supported the conclusions of Price, 1998. In this region there are few assemblages recovered from the basal Pretty Hill McEachern Sandstone Member and none have sufficient recoveries to be certain that they are representative of Lower APK122 as apposed to being from the Middle or Upper APK122 subunits.

Immediately above the McEachern Sandstone in Gordon #1, an assemblage (SWC40 1761m) indicated that Middle APK122 is represented; this broadly supports the Price, 1998 correlation of this part of the section with the upper part of the Sawpit "Basal Shale" unit and the overlying sand to the "Sawpit Sandstone" member. In Casterton #1 the assemblages from 1711.2m and 1374.0m are typical of Upper APK122. The presence of Upper APK122 at 1711,0m indicates that the Pretty Hill sand immediately above this sample is younger than the "Sawpit Sandstone" rather than its correlative as suggested by Price, 1998. In view of this, the sand underlying the sample at 1711.2m is now thought to equate with the "Sawpit Sandstone" and suggests that there is a degree of thickening of the overall lower Pretty Hill section from Casterton to Gordon (compare Appendix 1, Figure 6 with Figure 5). No other sample from this interval in the McEachern - Casterton - Gordon region of the Merino High had a sufficient recovery to be relied upon in terms of the finer subdivision of AKK122. The suggestion discussed by Price, 1998 of a mid Crayfish unconformity separating the Pretty Hill from the Laira in this region remains a point for consideration.

Further to the south east, the Mocamboro #11 data suggests the lower Pretty Hill sands there are younger than the Sawpit Sandstone equivalent (being assignable to Upper APK122; Appendix 1 Fig. 7) and the basal shale in Digby #1 probably is younger than the Casterton Formation of Sawpit or Gordon with a no older than Middle APK122 assemblage being recorded from the only sample with reasonable recoveries (Appendix 1 Fig 8). The base Digby shale is probably the equivalent of the shale above the "Sawpit Sandstone" and the Upper APK122 dated deepest sand of Mocamboro #11 (equivalent on log correlation to the Digby sand that overlies the Middle APK122 shale) is younger than the "Sawpit Sandstone". Thus, contrary to the conclusion of Price, 1998 that the "Sawpit Sandstone" and younger Pretty Hill was lost (to the mid Crayfish unconformity) in the Mocamboro - Digby region, it seems that it is McEachern Sandstone and the "Sawpit Sandstone" equivalent that is absent with the Mocamboro - Digby basement being emergent in Casterton and early Pretty Hill times.

Unit APK11 & Casterton Formation

The assignment of the Casterton palynofloras has a posed a problem as they are usually very restricted in species diversity sometimes reflecting poor preservation due to thermal maturity but also as a function of the specialised palynofloras associated with the lacustrine, swamp and peat bog environments. These association are typically dominated by inaperturate pollen (wind dispersed conifer pollen) and leiospheres (aquatic algae); these phylogenetically disparate groups are often hard to distinguish in the indifferent preservation conditions. However, the presence (albeit as isolated specimens) of *Ruffordiaspora spp* almost to the base of Gordon #1 (the best preserved Casterton palynofloras recovered to date) and *Cyclosporites "quasihughesii"* 839 within the Casterton Formation (in its broader sense) of Gordon #1, Sawpit #1, Killanoola #1 and Casterton #1 suggests that the Casterton Formation lies wholly within APK1 with its upper limits probably extending into APK121.

The presence of APK121 in the uppermost Casterton Formation (depending on how the Sawpit, Robertson and Bus Swamp sections are interpreted) in the context of the APK121 - APK122 boundary lying within the Pretty Hill (not its base) suggests that the Casterton Formation and the Pretty Hill Formation are conformable at least in the Penola Trough and probably also in the Merino High sections. In the GAB region APK121 is relatively thin and probably confined to the lower Namur Sandstone and possibly the uppermost Westbourne Formation (Appendix 1 Table 3); it seems the Casterton Formation is the time equivalent (more or less) of the Westbourne Formation.

Woolsthorpe #1 Palynostratigraphy

Unit APK321; 4300ft - 4515ft; Eumeralla Formation

The association from 4300ft was dominated by fern spores including a prominence of *Ruffordiaspora spp* while that from 4515ft was dominated by conifer pollen; *Pilosisporites* (including both *P. notensis* and *P. parvispinosus*) were notable in both and *Cooksonites variabilis* present. These associations are typical of those from unit APK321 and are representative of the lower Eumeralla Formation. The distinctive acritarch *Microfasta evansii* was present at 4300ft and notable in 4515ft suggesting that the lower part of APK321 is represented. *Crybelosporites stylosus*, a form usually associated with assemblages lower in the Early Cretaceous, may represent reworking across the Eumeralla - Crayfish unconformity section or is at the upper limit of its range where it extremely rare and sporadic in its distribution.

Unassigned section; 4750ft - 4841ft

The samples from 4750ft and 4841ft yielded sparse restricted palynofloras (Appendix 4). The presence of *Dictyotosporites speciosus* at 4841ft indicates the section is no lower than APK122 and the presence of *Cooksonites variabilis* in both samples suggests that it interval may be no lower than Middle APK21 as, in the Otway Basin, this form is very scarce and sporadic in its distribution below the range *Triporoletes reticulatus* .

APK122 - APK2; 5005ft - 6380ft; Crayfish Group

The associations form 5005ft and 5178ft were more diverse than those at 4750ft and 4841ft, but they were still too restricted to offer a precise palynostratigraphic assignment. They included *Dictyotosporites speciosus, Cooksonites variabilis, Crybelosporites stylosus, Couperisporites tabulatus* and *Aequitriradites spinulosus* suggesting they are no older than Upper APK122 and possibly no younger than Middle APK21. SWC 5275ft gave a very low yield but was also modestly diverse; while including the *C. stylosus* and *D. speciosus*, it lacked a diversity of some of the liverwort forms (perhaps for reasons of poor preservation) and is more broadly assigned to APK122 - APK21.

A very sparse but moderately diverse palynoflora was recovered from SWC 5495ft which included *Pilosisporites notensis* and *P. parvispinosus* together with *Crybelosporites stylosus, Cooksonites variabilis* and *Stoverisporites microverrucatus "asymmetricus"* sp1194 suggesting that the lower part of APK321 is represented and the section is from the lower Eumeralla Formation. It should be noted however, that the SWC lithological description given in the Well Completion Report (Leslie & Sell, 1968) was "**Quartz Sandstone**, dense to slightly porous, white, medium grained, well sorted, abundant white clay cement, rose quartz, very friable, local yellow staining of quartz". Such a lithology suggests strongly oxidising depositional conditions and seems an extremely poor prospect for any palynomorph recoveries. Thus, it seems likely the recovered palynoflora may not be representative of the sampled horizon; perhaps there has been drilling mud and cuttings contamination or sample miss-labelling.

The recovery from SWC 5900ft was extremely meagre with few identifiable forms all of which were long ranging Mesozoic taxa and, from the variable preservation, some were clearly contaminants. The extremely poor recovery is more in keeping with the lithological description (also a white quartz sandstone) and contrasts with the recovery from 5495ft. SWC 6090ft yielded a sparse palynoflora including only forms which range through out the latest Jurassic and Early Cretaceous.

The palynoflora recovered from SWC 6230ft was poorly preserved and dominated by conifer pollen fragments. The cryptogam component was somewhat restricted but included *Dictyotosporites speciosus* and *Ruffordiaspora ludbrookiae "parallelus" 5057* (a large variety of *Ruffordiaspora*). The association is representative of Middle APK122 although it is possible it may be as young as APK2. The association recovered from SWC 6380ft was poorly preserved, sparse and restricted but included *Dictyotosporites speciosus* and thus is no older than APK122.

Woolsthorpe Correlation

The correlation of the Otway wells in Western Victoria has proved difficult as the palynostratigraphic resolution of the Crayfish Group is relatively coarse been hampered by poor recoveries in these sand prone sections. Price, 2000 attempted to correlate Crayfish in some of these wells applying additional palynostratigraphic sub units and, while finding their application difficult in individual wells, built a correlation using the scattered, more reliable palynostratigraphic determinations in conjunction with the wire line logs. This approach has been extended to the Woolsthorpe section as the wire line logs of the lower Eumeralla and Crayfish bear a similar pattern to those of Mocamboro #11 and Digby #1. The lithostratigraphy adopted and given on the Woolsthorpe section (Appendix 1 Figures 9 & 10) reflects this.

The lower Eumeralla Formation in Woolsthorpe seems represented by the lower APK321 associations at 4300ft and 4515ft and, as in Mocamboro #11 and Digby #1 equivalents, include *Microfasta evansii*. Unit APK321 represents the most readily recognised and consistent of the palynofloras in the Otway Basin Early Cretaceous section giving reliable datum above the Eumeralla - Crayfish unconformity. However, as with many things, there are exceptions that test the rule. The APK321 association at 5495ft seems rather anomalous in the context of the extent of APK321 in the other well sections (including the thicker sequences of Katnook #2 and Laira #1) reviewed by Price 2000. As SWC 5495ft was described as a white, fine to medium, quartz sand, the assemblage seems likely to be contamination (Page 27) and, thus, is considered not to be indicative of the Eumeralla Formation extending to this depth. It should be acknowledged however, that another anomalously low occurrence of APK321 elements has recorded by Price, 1999 in Penley #1 but, again, the SWC (a very small sediment recovery of very soft puggy formless mud) was thought to include drilling mud contamination.

Below 4515ft, sample gaps (forced by sand units) and poor recoveries, with resulting broad assignments, leave the palynostratigraphic correlation tentative and the Eumeralla - Crayfish unconformity and Crayfish Group poorly resolved. However, as the APK321 associations at 4515ft and 4750ft represent the lower parts of this unit, the unconformity is unlikely to significantly lower than 4750ft. The first definitive samples below the APK321 palynofloras are at 5005ft and 5178ft and indicate the section is probably Upper APK122 to Middle APK21. This is broadly consistent with the Middle

APK21 assignment suggested for the equivalent Mocamboro #11 section thought to represent part of the Laira Formation equivalent. Thus, the present palynological data indicates the Eumeralla - Crayfish unconformity lies between 4750ft and 5005ft.

The poor recoveries in the arenaceous section below 5178ft (excluding that at 5495ft considered to be contamination) offered little resolution of the section when considered in isolation from the determinations in the other wells. The possible assignment of 6235ft to Middle APK122 is consistent with the assignments at the base of the Digby section. When considered in conjunction with the Upper APK122 association towards the base of Mocamboro #11, they suggest the upper part of the Pretty Hills (that above the Sawpit Sandstone) Crayfish section is represented at the base of Woolsthorpe #1, Digby #1 and Mocamboro #11 rather than the Casterton suggested by some earlier interpretations.

The broad APK122 assignment of the basal sample at 6380ft reflects the poor recovery rather than its antiquity but indicates that the section is no lower than the "Basal Shale" / McEachem Sandstone member from the base of the Pretty Hills Formation.

References

Alexander, E.M. and Hibburt, J.E. (Eds) 1996. The Petroleum Guide of South Australia. Vol 2: Eromanga Basin. *South Australia Department of Mines and Energy. Report Book,* 96/20.

Alexander, E.M. and Sansome, A., 1996. Lithostratigraphy and Environments of Deposition. **IN:** Alexander and Hibburt (Eds) The Petroleum Guide of South Australia. Vol 2: Eromanga Basin. *South Australia Department of Mines and Energy. Report Book,* 96/20: 49-86.

Alley, N.F. 1987. Age and Correlation of Palynofloras from the Type Cadna-Owie Formation, southwestern Eromanga Basin. Report South Australia Department Mines and Energy 85/82

Alley, N.F., 1988. Age and Correlation of Palynofloras from the Type Cadna-Owie Formation, southwestern Eromanga Basin. *Mem. Assoc. Australas. Palaeontol., 5*, 187-194.

Alley, N.F. and White, M.R., 1996, Dating and Correlating Eromanga Basin Sediments. **IN:** Alexander and Hibburt (Eds) The Petroleum Guide of South Australia. Vol 2: Eromanga Basin. *South Australia Department of Mines and Energy. Report Book,* 96/20: 87-100.

Backhouse, J., 1988. Late Jurassic and Early Cretaceous Palynology of the Perth Basin, Wester Australia. *Bulletin Gelogical Survey of Western Australia 135*

Benson, J.M., 1993. A Review of the Palynostratigraphy and Palaeoenvironments of the Murta Member, Eromanga Basin. SANTOS Ltd Palynological Report 1993/2

Burger, D. 1973. Palynological zonation and sedimentary history of the Neocomian an the Great Artesian Basin, Queensland. **In** Mesozoic and Cainozoic Palynostratigraphy: Essays in honour of Isabel Cookson. Eds Glover & Playford. *Geological Society of Australia Special Publication 4* 87-118.

Burger, D. 1976. Some Early Cretaceous Plant Microfossils from Queensland. *Bulletin of the Bureau of Mineral Resources, Geology & Geophysics Australia 160* **1-22**

Burger, D. 1980. Palynology of the Lower Cretaceous in the Surat Basin. *Bulletin of the Bureau of Mineral Resources, Geology & Geophysics Australia 189*

Burger, D. 1988. Early Cretaceous environments in the Eromanga Basin; palynological evidence from GSQ Wyandra-1 core hole. *Mem. Assoc. Australas. Palaeontol., 5*, 173-186.

Burger, D. 1989. Stratigraphy, Palynology and Palaeoenvironments of the Hooray Sandstone, Eastern Eromanga Basin, Queensland and New South Wales. *Queensland Department of Mines Report 3,* 28pp

Burger, D. 1993. Palynological Examination of DEM Bus Swamp #1 Stratigraphic Hole, Otway Basin, Victoria. **IN** Bus Swamp Well Completion Report Appendix 9

Dettmann, M.E. 1963. Upper Mesozoic microfloras from south eastern Australia. *Proceedings of the Royal Society of Victoria,* 77, 1-148.

Dettmann, M.E. 1981. The Cretaceous flora. In *Ecological biogeography of Australia* (ed. Keast, A.), pp 357-375 (Junk the Hague).

Dettmann, M.E. 1983. Dullingari #11 - Murta #7, Dullingari #13, 14, 15, 21. Mines Administration Palynological Laboratory Report 13/146

Dettmann, M.E. 1985. Ingella #1; Aptian - Cenomanian. CSR Oil and Gas Division Palynological Report 13/203

Dettmann, M.E. 1986. Early Cretaceous palynofloras of subsurface strata correlative with the Koonwarra Fossil Bed, Victoria. *Memoirs of the Association of Australasian Palaeontologists, 3*, 79-110.

Dettmann, M.E. & Clifford, T. 1992. Phylogeny and biogeography of *Ruffordia, Mohria* and *Anemia* (Schizaeaceae) and *Ceratopteris* (Pteridaceae): evidence from *in situ* and dispersed spores. *Alcheringa 16 (4)*, **269 - 314**

Dettmann, M.E. & Douglas, J.G. 1976. Palaeontology. In *Geology of Victoria* (ed. Douglas, J.G. & Ferguson, J.A.), pp 164-176 (Geological Society of Australia Inc., Victoria Division, Melbourne).

Dettmann, M.E. & Filatoff, J.F., 1985. Tartulla #1; Cretaceous and Jurassic Sections. Delhi Petroleum Palynological Report 13/147

Dettmann, M.E., Molnar, R.E., Douglas, J.G., Burger, D., Fielding, C., Clifford, H.T., Francis, J., Jell, P., Rich, T., Wade, M., Rich, P.V., Pledge, N., Kemp, A. & Rozefelds, A. 1992. Australian Cretaceous terrestrial faunas and floras: biostratigraphic and biogeographic implications. *Cretaceous Research, 13,* 207-262.

Dettmann, M.E. & Playford, G. 1969. Palynology of the Australian Cretaceous: a review. In *Stratigraphy and palaeontology: essays in honour of Dorothy Hill* (ed. Campbell, K.S.W.), pp 174-210 (Australian National University Press, Canberra).

Dettmann, M.E., and Williams, A.J., 1985. The Cretaceous of the Southern Eromanga Basin; a palynological Review. Delhi Petroleum Palynological Report 274/26

Evans, P.R. 1966. Mesozoic stratigraphic palynology in Australia. *Australasian Oil and Gas Journal, 12*, 58-63.

Evans, P.R. & Mulholland, R.D. 1970. Palynology of Esso Lake Eliza-1, PEL 8, South Australia.

Filatoff, J. 1975. Jurassic palynology of the Perth Basin, Western Australia. *Palaeontographica B, 154*, 1-113.

Filatoff, J. 1985. Ingella #1; Neogene - Triassic Section. CSR Oil and Gas Division Palynological Report 13/203

Filatoff, J. 1985. Cowan #1; Jurassic - Early Cretaceous. CSR Oil and Gas Division Palynological Report 13/166

Filatoff, J. and Price, P.L. 1986. Mulapula #1. CSR Oil and Gas Division Palynological Report 492/1

Filatoff, J. and Price, P.L. 1988. A pteridacean spore lineage in the Australian Mesozoic. *Mem. Assoc. Australas. Palaeontol., 5*, 89-124.

Filatoff, J. and Price, P.L. 1988. Kercummurra #1. CSR Oil and Gas Group Palynological Report 553/6

Hooker, N.P., 1998. Palynology of East Avenue #1, onshore Otway Basin, South Australia. Morgan Palaeo Associates Report.

Helby, R., Morgan, R. & Partridge, A., 1987. A Palynological Zonation of the Australian Mesozoic. *Memoir of the Association of Australian Palaeontologists 4,* **1-94**

Leslie, R.B. & Sell, B.H., I.O.L. Woolsthorpe No 1 Otway Basin, Victoria. Well Completion Report

Lovibond, R., Suttill, R.J., Skinner, J.E. & Aburas, A.N., 1995. The hydrocarbon potential of the Penola Trough, Otway Basin. *APEA Journ.* **35 (1)** 358 - 371

Morgan, R. 1980. Palynostratigraphy of the Australian Early and Middle Cretaceous. *Mem. Geol. Surv. N.S.W., Palaeont., 18*, 1-153.

Morgan, R. 1985. Palynology review of 13 Otway Basin (South Australia) wells. *Unpublished Report*.

Morgan, R., 1985. Palynology of Esso Lake Eliza-1, Otway Basin, Palyn. Rept. for Ultramar Australia.

Morgan, R., 1987. Palynology of Crankshaft-1, Onshore Otway Basin, South Australia. Palyn. Rept. for Hartogen.

Morgan, R., 1987. Palynology of Hartogen Camelback-1, Otway Basin, South Australia. Palyn. Rept. for Hartogen.

Morgan, R., 1988. Palynology of Mosaic Greenways-1, Otway Basin, South Australia. Palyn. Rept.

Morgan, R. 1988. Palynology of Ultramar Katnook-1, Otway Basin, South Australia. *Unpublished Report*.

Morgan, R., 1989. Palynology of Hartogen Lake Hawdon-1, Otway Basin, Australia. Palyn. Rept. for Hartogen.

Morgan, R. 1989. Palynology of Ultramar Katnook-2, Otway Basin, South Australia. *Unpublished Report*.

Morgan, R. 1989. Palynology of Tullich #1, Casterton #1 and Heathfield #1, Otway Basin. Morgan Palaeo Associates Report.

Morgan, R., 1993. New palynology of the Laira Shale in the Katnook 1, 2 & 3, Banyula 1, Laira 1, Ladbroke Grove 1 and Kalangadoo 1 Otway Basin, South Australia. Morgan Palaeo Associates Report for SAGASCO

Morgan, R., Alley, N.F., Rowett, A.I. and White, M.R., 1995. Chapter 6; Biostratigraphy. **In** Morton and Drexel Eds *Petroleum Geology of South Australia. Volume 1: Otway Basin.* Mines and Energy South Australia **Report Book 95/12** 95-101

Morton, J.G.G., 1990. Revisions to the stratigraphic nomenclature of the Otway Basin, South Australis. *S.A. Geol Surv. Quarterly Geological Notes* 116: 2-19.

Morton, J.G.G., Alexander, E.M., Hill, A.J. & White, M.R., 1995. Lithostratigraphy and environments of deposition. **In** Morton and Drexel Eds *Petroleum Geology of South Australia. Volume 1: Otway Basin.* Mines and Energy South Australia **Report Book 95/12** 95-101

Morton, J.G.G. & Drexel, J.F., (Eds) 1995. *Petroleum Geology of South Australia. Volume 1: Otway Basin.* Mines and Energy South Australia **Report Book 95/12.**

Price, P.L., 1993. Palynostratigraphy, Organic Facies and Geochemistry of Sawpit #1, Otway Basin for Oil Company of Australia. APG Consultants Report 264/13.

Price, P.L., 1994. Otway Basin Maturity Models. Report for Oil Company of Australia APG Consultants Report 264/20

Price, P.L. 1995, Palynostratigraphy and Organic Facies Analysis of Digby #1, Otway Basin. APG Consultants Report 634/01.

Price, P.L., 1996. A review of the Palynostratigraphy of some Otway Basin Wells. APG Consultants Report 264/24

Price, P.L., 1997. Palynostratigraphy and Organic Facies of Viewbank #1, Penola Trough, South Australia . APG Consultants Report 264/33

Price, P.L., 1997. Palynostratigraphy Organic Facies and Oil Geochemistry of Nunga Mia #1, Robe Trough, South Australia . APG Consultants Report 264/33

Price, P.L. 1997, Palynostratigraphy of SANTOS Gordon #1, Otway Basin, Victoria for Santos Ltd. APG Consultants Report 640/05

Price, P.L. 1997. A Review of the Palynostratigraphy and Organic Facies of the lower Pretty Hill and Casterton Formation, Penola Trough for Oil Company of Australia. APG Consultants Report 264/42.

Price, P.L., 1998. Palynostratigraphic Review of PEP 119, Otway Basin, Victoria for SANTOS Ltd. APG Consultants Report 640/06.

Price, P.L., 1998. Palynostratigraphy Organic Facies and Oil Geochemistry of Killanoola #1, Penola Trough, Otway Basin for Oil Company of Australia Ltd. APG Consultants Report 264/46

Price, P.L., 1999. Palynostratigraphy of Churinga #1, Robe Trough, South Australia for Oil Company of Australia Ltd. APG Consultants Report 264/48

Price, P.L., 1999 Palynostratigraphy of BERL Penley #1, Penola Trough, South Australia for Boral Energy Resources Ltd. APG Consultants Report 650/01

Price, P.L., 2000. Review of the Penola Trough Palynostratigraphy for Santos Ltd and Origin Oil Resources Ltd. APG Consultants Report 651/01

Price, P.L. & Filatoff, J. 1990. Applications of morphological lineages in Australian palynostratigraphy. *Review of Palaeobotany and Palynology, 65*, 195-207.

Price, P.L., Filatoff, J., Williams, A.J., Pickering, S.A., & Wood, G.R. 1985. Late Paleozoic and Mesozoic palynostratigraphical units. *CSR Oil and Gas Div., Palynol. Facil. Rep., 274/25*, 1-20 (Queensland Dep. Mines Open File Rep. 14012).

Williams, A.J., 1985. Palynology of the Cadna-Owie Formation in Kercummurra #1 and Bolderwood #1. Delhi Petroleum Report 13/271