REPORT 51

GOVERNMENT OF WESTERN AUSTRALIA

PERMIAN STRATIGRAPHY AND PALYNOLOGY OF THE CARNARVON BASIN, WESTERN AUSTRALIA

by A. J. Mory and J. Backhouse

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 51

PERMIAN STRATIGRAPHY AND PALYNOLOGY OF THE CARNARVON BASIN, WESTERN AUSTRALIA

by
A. J. Mory and J. Backhouse

Perth 1997

MINISTER FOR MINES
The Hon. Norman Moore, MLC

ACTING DIRECTOR GENERAL
L. C. Ranford

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Pietro Guj

Copy editor: A. C. Davis

REFERENCE
The recommended reference for this publication is:
MORY, A. J., and BACKHOUSE, J., 1997, Permian stratigraphy and palynology of the Carnarvon Basin, Western Australia: Western Australia Geological Survey, Report 51, 46p.

National Library of Australia
Cataloguing-in-publication entry

Mory, A. J. (Arthur John), 1953–.
Permian stratigraphy and palynology of the Carnarvon Basin, Western Australia

Bibliography.
ISBN 0 7309 6563 5

1. Geology, Stratigraphic — Permian
2. Palynology — Western Australia — Carnarvon Basin

I. Backhouse, John, 1946–.
II. Geological Survey of Western Australia.
III. Title. (Series: Report (Geological Survey of Western Australia); no. 51).

ISSN 0508–4741

Cover photograph:
Fossiliferous limestone surface in the Callytharra Formation near Mount Sandiman, east of Kennedy Range.

Contents

Abstract 1
Introduction 1
Biostratigraphic review 2
Previous biostratigraphic schemes 2
Palynological zonation used in this report 5
Stage 2 5
Pseudoreticulatispora confluens Zone 5
Pseudoreticulatispora pseudoreticulata Zone 5
Striatopodocarpites fusus Zone 5
Didecitriletes byroensis Subzone 5
Microbaculispora trisina Zone 6
Praecolpatites sinuosus Zone 6
Microbaculispora villosa Zone 6
Dulhuntyispora granulata Zone 6
Didecitriletes ericianus Zone 6
Dulhuntyispora parvithola Zone and higher biostratigraphic units 6
Summary of individual wells 7
BHP Wandagee 1 7
Bidgemia 1 7
BMR Glenburgh 8 and 9 7
BMR Kennedy Range 6 and 7 10
Burna 1 11
Candace 1 14
Direction 1 14
Fortescue 1 14
Gascoyne 1 14
Giralia 1 16
GSWA Ballythanna 1 16
Hope Island 1 17
Kennedy Range 1 17
Merlinleigh 1–5 17
Moogooree 1 19
Onslow 1 19
Quail 1 19
Remarkable Hill 1 20
Sholl 1 20
Stratigraphy 20
Lyons Group 21
Callytharra Formation 21
Winnemia Sandstone Member 21
Ballythanna Sandstone Member 22
Wooramel Group 22
Cordalia Formation 22
Moogooloo Sandstone 23
Billidee Formation 23
Keogh Formation 23
Byro Group 23
Kennedy Group 25
Thermal alteration (maturation) 25
Acknowledgements 26
References 27

Appendices

1. Petroleum and mineral wells referred to in this study 29
2. Palynology summary for individual wells 30
3. Species names used in this report 35
4. *Didecitriletes byroensis* sp. nov., a new Early Permian spore species from the Carnarvon Basin 36
5. Permian stratigraphy of the Carnarvon Basin (modified from Hocking, 1990a) 38
6. Permian formation tops for selected wells 41

Plate (in pocket)

1. Correlation of Wooramel Group and Callytharra Formation from Remarkable Hill 1 to Ballythanna 1

Figures

1. Location map of wells in the Carnarvon Basin 2
2. Detailed range chart — species against zones 3
3. Stratigraphy and palynological zonation for the Carnarvon Basin 4
4. Cross-section from Bidgemia 1 to Pells Range 7
5. Stratigraphic correlation from Gascoyne 1 to outcrop section in Pells Range 8
6. Stratigraphic correlation of BMR Kennedy Range 6 and 7 with Kennedy Range 1 10
7. East–west structural cross sections through Kennedy Range 1 and BMR Kennedy Range 6 and 7 11
8. Correlation of the Permian from Hope Island 1 to Candace 1 12
9. Geological sketch map of the Jimba Jimba Syncline 14
10. Comparison of present and previous stratigraphic nomenclature for the Jimba Jimba Syncline area 14
11. Outcrop of the Winnemea Sandstone Member in the Jimba Jimba Syncline 15
12. Outcrop of the Moogooloo Sandstone in the Jimba Jimba Syncline 16
13. Stratigraphic correlation of Kennedy Range 1 with Onslow 1 18
14. Comparison of nomenclature used in this report with Hocking et al. (1987) 20
15. Stratigraphic correlation from Quail 1 to measured outcrop sections along Gooch Range 24

Permian stratigraphy and palynology of the Carnarvon Basin, Western Australia

by

A. J. Mory and J. Backhouse

Abstract

Marine to nearshore siliciclastics dominate the Permian succession of the Carnarvon Basin, and are up to 5000 m thick in the Merlinleigh Sub-basin. The basin contains a virtually uninterupted sequence of Permian palynological zones from Stage 2 (Late Carboniferous–Asselian) to the *Dulhuntyispora parvithola* Zone (Kazanian–Tatarian), although no single well contains all zones. On the basis of these zones, the stratigraphy and age of the Carnarvon Basin Permian succession is revised from earlier work that depended on macrofossil control.

A new early Artinskian subzone, named after a new spore species (*Didecitriletes byroensis*), is recognized at the top of the *Striatopodocarpites fusus* Zone. This subzone provides tight biostratigraphic control at this level over a wide area of the basin. It is consistently present at the top of the Callytharra Formation or within the Cordalia Formation and indicates that these two units are, in part, laterally equivalent. Outcrop previously referred to the Jimba Jimba Calcarenite Member in the Jimba Jimba Syncline is now placed within the upper part of the Callytharra Formation. The sandstone unit within the redefined Callytharra Formation is here named the Winnemia Sandstone Member.

A major mid-Permian break in deposition, spanning the *Microbaculispora trisina* to *M. villosa* Zones is evident in wells on the Peedamullah Shelf. During this period over 1500 m of sediment was deposited in the Merlinleigh Sub-basin (Wooramel and Byro Groups).

The Chinty Formation, which is restricted to the Peedamullah Shelf, conformably overlies siliciclastics similar to, and coeval with, the Kennedy Group in the Merlinleigh Sub-basin and, therefore, is now included as the highest unit in the Kennedy Group. On the Peedamullah Shelf deposition of the Kennedy Group was continuous from the *Dulhuntyispora granulata* Zone into the *D. parvithola* Zone, whereas in the Merlinleigh Sub-basin there is no record of zones younger than *D. granulata*.

On the basis of spore colour, the only wells in this study to contain clearly mature Permian sedimentary rocks in the Merlinleigh Sub-basin, in terms of petroleum generation, are Giralia 1, Kennedy Range 1 and Quail 1. On the Peedamullah Shelf the Permian succession in all the studied wells is mature for petroleum generation.

KEYWORDS: Permian stratigraphy, palynology, biostratigraphy, maturation, Byro and Merlinleigh Sub-basins, Peedamullah Shelf, Carnarvon Basin, Western Australia.

Introduction

Permian sedimentary rocks in the Carnarvon Basin are predominantly shallow marine–paralic in origin and from outcrop, well and seismic data, attain a maximum thickness of approximately 5000 m in the Merlinleigh Sub-basin. Existing Permian correlations within the Carnarvon Basin are either largely lithostratigraphic, (e.g. Condon, 1967; Hocking et al., 1987), or are strongly constrained by the lithostratigraphy (e.g. Archbold, 1993). The main objective of this report is to develop a biostratigraphic framework for the Permian sequence, and demonstrate the lithostratigraphic relationships within the basin and with other Permian basins.

Permian sedimentary rocks in the Carnarvon Basin are now largely confined to the Merlinleigh and Byro Sub-basins, and the Peedamullah Shelf. The Giralia area, previously the northern part of the Gascoyne Platform (Hocking et al., 1987), contains a Permian succession and is now included within the Merlinleigh Sub-basin (Crostella and Iasky, 1997). Permian rocks probably extend north of the Peedamullah Shelf into the offshore part of the basin but they are at depths that are unlikely to be drilled in the near future. West of the Merlinleigh Sub-basin, on the Gascoyne Platform, Permian strata are thin, or were not deposited. This report presents a detailed synthesis of the Permian palynological zones in the Carnarvon Basin, and reviews the Permian lithostratigraphy, based largely on 8 petroleum exploration wells, 11 stratigraphic wells (Fig. 1) and several shallow mineral bores (Appendix 1).

Biostratigraphic review

Most of the palynological material examined consists of pre-existing slides from petroleum exploration and stratigraphic wells prepared by the operators, mainly West Australian Petroleum Pty Ltd (WAPET), soon after the wells were drilled. Additional samples from these wells, and mineral exploration bores, have been processed by the Geological Survey of Western Australia (GSWA) for this study. Samples from outcrop or from depths of less than 40 m, are rarely productive because of oxidation of near-surface rocks. Data from existing palynology reports for all wells have been re-assessed, where practicable, by re-examining the slides on which the original reports were based. If the slides were not readily available, unverified data from the report have been included as necessary, if considered accurate.

Appendix 2 contains details of all sample points utilized for this report, including palynological zone data, thermal alteration indices (TAI) and information on the environment of deposition from the palynoflora. The ranges of stratigraphically useful spore and pollen species are summarized, in terms of the zones used in this report, in Figure 2.

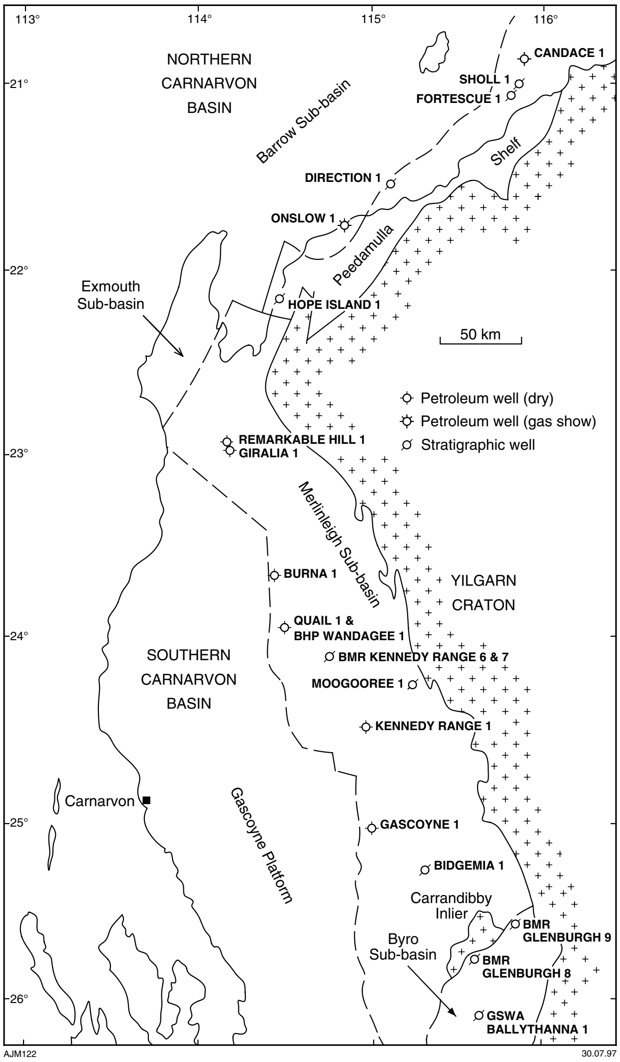


Figure 1. Location map of wells in the Carnarvon Basin

Previous biostratigraphic schemes

The only previous study devoted entirely to the palynology of Carnarvon Basin Permian sequences was an unpublished honours thesis by MacLeod (1973), describing Early Permian palynomorphs from stratigraphic wells in the Byro Sub-basin. Palynological studies of material from petroleum exploration wells and mineral exploration boreholes, however, have been made over many years. From these reports, it is clear that palynostratigraphic schemes developed in the Canning, Perth and Collie Basins can be applied in the Carnarvon Basin because of the general overall similarity of the palynofloras.

It is not intended to review here all the zonal schemes developed for Permian palynomorphs in Australia. Only those subdivisions that are most widely in use are mentioned.

The Permian palynomorph subdivision of Balme (*in* Kemp et al., 1977) for the Canning Basin has been compared several times with the eastern Australian subdivisions of Evans (1967, 1969) and Price (1976, 1983) — see Kemp et al. (1977), Foster (1979), Backhouse (1991) and Cooper (1991). Powis (1984) added some much needed detail regarding the exact palynomorph content of some of the lower units, which he consolidated into the eastern Australian palynological zonal system of stages. The detailed palynostratigraphy of the Carnarvon Basin, and in particular the Lower Permian of the Merlinleigh Sub-basin seems more similar to the Perth and Collie Basins as outlined by Backhouse (1991, 1993).

Many points of similarity exist between the zonal schemes of eastern and western Australia and broad correlation using the more consistent first appearance datums, such as those for *Pseudoreticulatispora pseudoreticulata*[1], *Microbaculispora villosa* and *Didecitriletes ericianus*, is widely accepted. More detailed correlation of all zones or subzones is not so apparent, partly because detailed data are not readily available for many basins, but also because local phytogeographic factors may affect palynomorph assemblages, and particularly influence the relative abundance of some species. This study attempts to

[1] Species names including authorship are listed in Appendix 3.

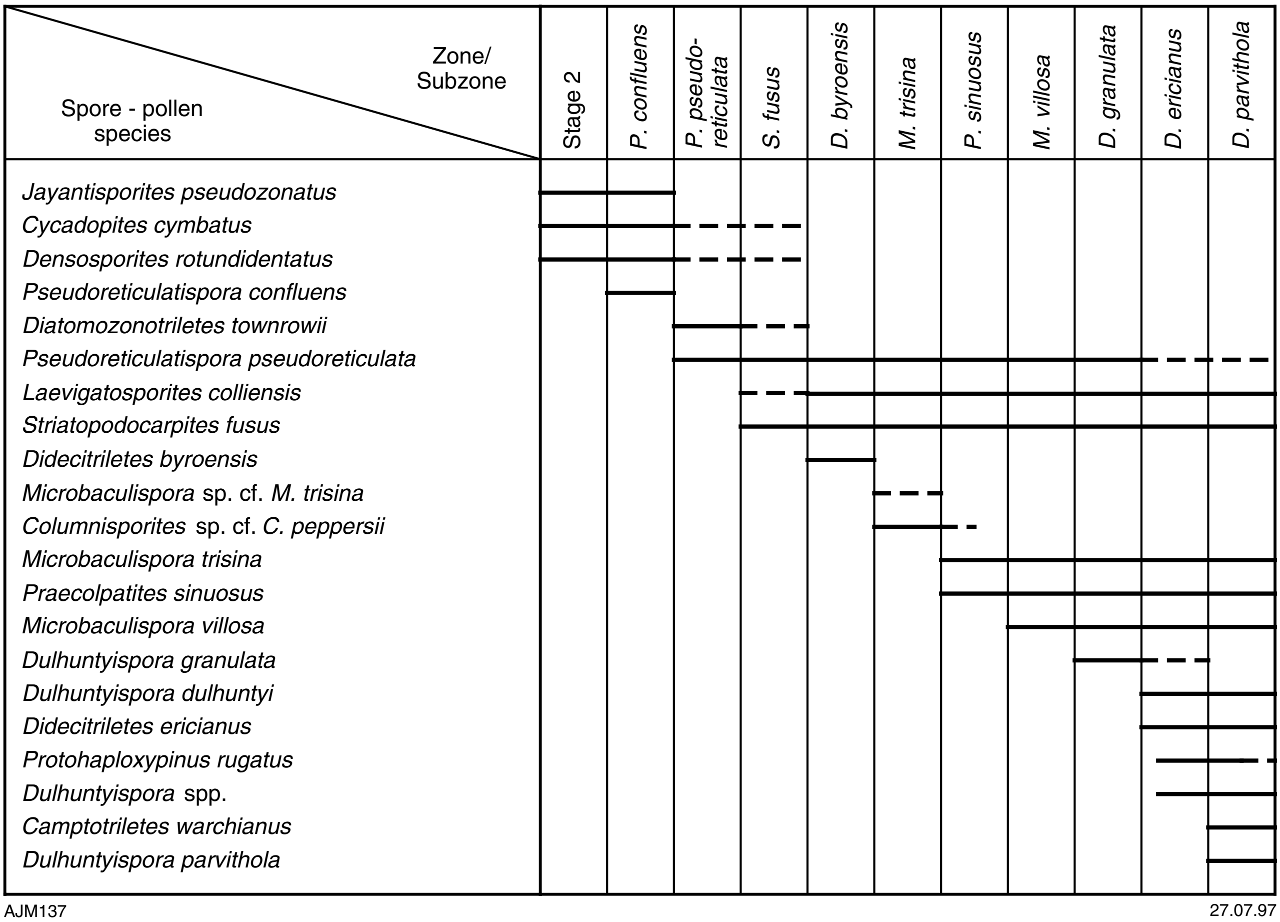


Figure 2. Detailed range chart — species against zones

demonstrate how palynological correlation, as detailed as the sampling intervals and palynomorph yields permit, can provide strict time controls for stratigraphic correlation at the sub-basin scale, in this case for the Lower Permian in the Merlinleigh and Byro Sub-basins and Peedamullah Shelf of the Carnarvon Basin.

The zonal scheme in this study is based on that of Backhouse (1991) for the Collie Basin. That scheme has been applied, with some modification, to the Perth Basin (Backhouse, 1993). Similarly, the scheme has been modified again for the Carnarvon Basin to reflect minor differences in the palynoflora from that basin (Figs 2 and 3).

International palynological correlations are not well established for the Permian at present. The ages assigned to palynological zones (Fig. 3), in terms of international stages, are based largely on ages suggested for ammonoid, brachiopod and molluscan faunas in the Perth, Carnarvon and Canning Basins. On the basis of these fossils approximate ages have been established for many formations in the Carnarvon Basin. There has been no attempt to correlate palynofloras from the basin directly with those of type stages and there is, therefore, no independent age determination based solely on evidence from the palynofloras. The most recent discussion and summary of macrofossil age determinations are presented in Archbold (1993). Of particular interest in relation to this report is the postulated age for brachiopods and molluscs from the Coolkilya Sandstone. Archbold and Skwarko (1988) indicate a Kungurian age for material from the top of the Coolkilya Sandstone, whereas Archbold (1993) is more circumspect and suggests an early Ufimian age based on the ammonoid data. In this report samples from the Coolkilya Sandstone in the subsurface are shown to range from the *Praecolpatites sinuosus* Zone into the *Microbaculispora villosa* Zone.

Archbold and Shi (1993, 1995) and Archbold (1995a,b) give additional data that generally supports the current age correlations. Archbold and Shi (1993) suggest an Aktastinian (early Artinskian) age for a brachiopod fauna from the type section of the Jimba Jimba Calcarenite. Archbold (1995a) examined material from core 32 (912.5–915.5 m) in the Lyons Group in BMR[2] Glenburgh 8[3], and assigned it a somewhat tentative

[2] Bureau of Mineral Resources, currently the Australian Geological Survey Organisation (AGSO).

[3] The name of the organisation is included in the name of government stratigraphic wells or mineral exploration boreholes to avoid confusion with petroleum exploration wells.

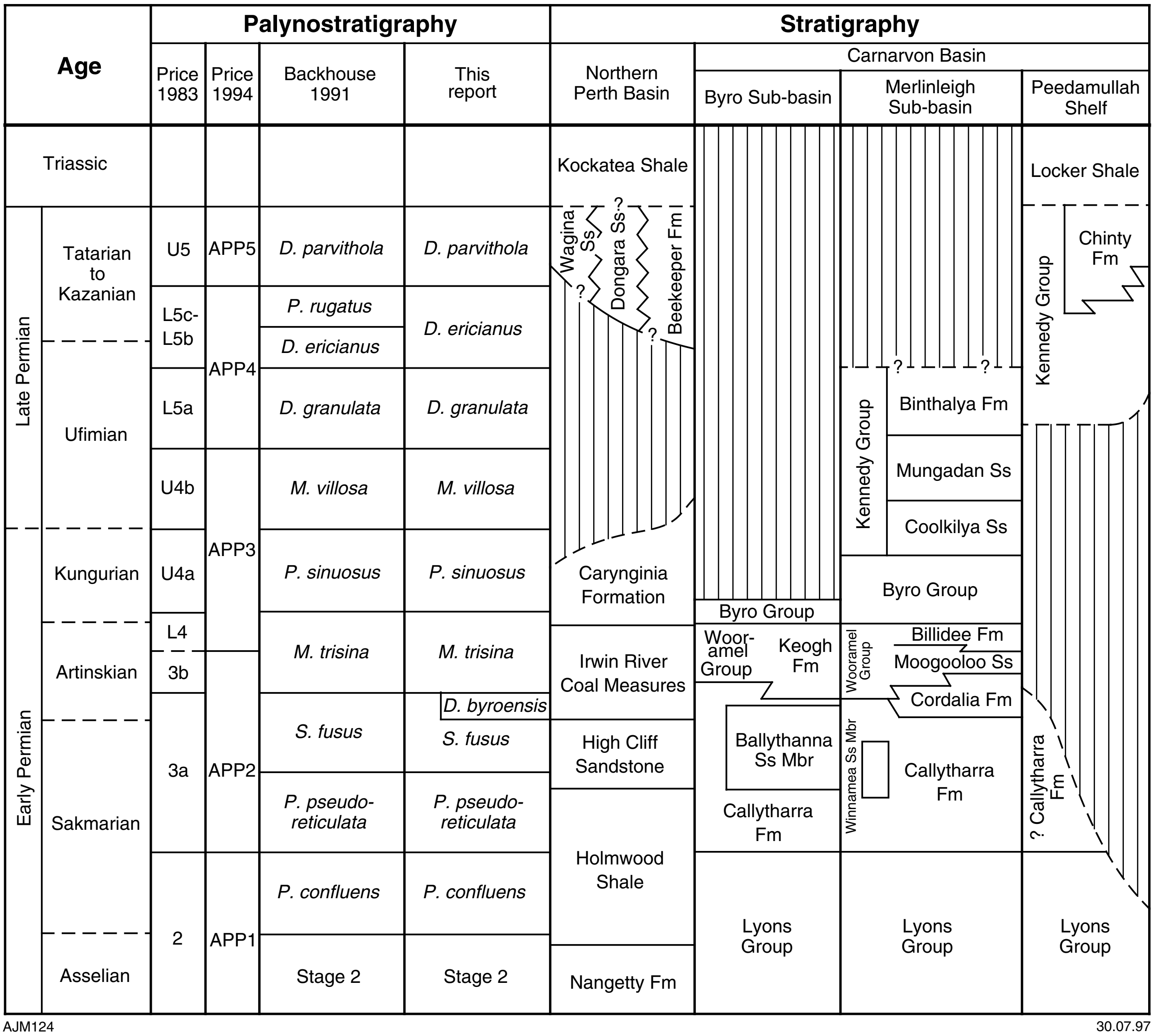


Figure 3. Stratigraphy and palynological zonation for the Carnarvon Basin showing correlation with northern Perth Basin stratigraphy

Asselian age. Material from slightly higher in this well (507.5–509.3 m), in the lowest Callytharra Formation, was dated as late Tastubian (early Sakmarian). Archbold (1995b) suggested an Ufimian age for brachiopods from Beharra Springs 2, in the Perth Basin. This material is from an interval within, or just below, the range of *Dulhuntyispora parvithola,* and is close to the suggested age of Kazanian–Tatarian for the *D. parvithola* Zone as used in this report.

On a broad scale the macrofossil ages assigned to lithostratigraphic units from more recent work correspond reasonably well with the ages previously presented for the palynomorph zones, although the macrofossil dates are likely to be modified as further data become available. A recent report on SHRIMP zircon dates from eastern Australia (Roberts et al., 1996) broadly supports the ages assigned to palynological zones presented here. However, in this report the base of Stage Lower 5b, which is equivalent to the base of the *Didecitriletes ericianus* Zone, is placed at the start of the Ufimian. On the basis of conodont data supplied by R. Nicoll of AGSO, and Archbold's (1993) suggestion of an Ufimian age for ammonoid faunas from the Coolkilya Sandstone, the base of the *M. villosa* Zone is correlated approximately with the Kungurian–Ufimian boundary. Previously the base of the Ufimian had been correlated with the base of the *D. ericianus* Zone (Backhouse, 1991, 1993).

The emergence of a broad consensus on the age of many palynological zones and sedimentary units should encourage the rigorous application of palynostratigraphic control in all major Permian basins in Western Australia. The ages assigned to both macrofaunal and palynological biostratigraphic units, however, probably will be modified when better correlations with the type areas of the stages, mostly in Russia, become available.

Palynological zonation used in this report

The palynological zonal scheme used in this record is based on the scheme developed by Backhouse (1991) for the Collie Basin, which in turn uses many of the stratigraphic markers applied in earlier zonal schemes (see discussion above). The zones used are listed below in ascending order as shown in Figure 2.

Stage 2

Assemblages assigned to Stage 2 are the oldest that are considered here to be of Permian age, although it is recognized that the zone may extend into the Carboniferous. The differentiation of Stage 2 from the *Pseudoreticulatispora confluens* Zone is discussed in Backhouse (1991) and essentially depends on the absence of *P. confluens*.

Stage 2 is questionably present in a few wells from this study but, because of poor palynomorph yields, a clear separation of Stage 2 and the *P. confluens* Zone is not practical in many intervals.

Pseudoreticulatispora confluens Zone

As defined by Foster and Waterhouse (1988), the base of this zone is defined by the first appearance up-section of *P. confluens*, and the top of the zone is marked by the first appearance of *Pseudoreticulatispora pseudoreticulata*. The difficulty in locating good examples of *P. confluens* in sparse assemblages has rendered the base of this zone equivocal in most wells. The top of the zone marks a significant palynofloral boundary. *Jayantisporites pseudozonatus*, and for practical purposes *P. confluens*, are not seen above this level. Many other species, such as *Cycadopites cymbatus* and *Densosporites rotundidentatus*, which are common within the zone are relatively infrequent in overlying zones.

The upper part of the Lyons Group invariably falls within this zone, but the zone has not been identified in the overlying Callytharra Formation (Fig. 3).

Pseudoreticulatispora pseudoreticulata Zone

The base of the zone is marked by the lowest occurrence of *P. pseudoreticulata*, typically just above the last occurrence of *P. confluens*, but other workers have noted some overlap (Foster, C. B., 1996, pers. comm.). The top of the zone was defined by Backhouse (1991) as the first up-hole occurrence of *Striatopodocarpites fusus*. *Diatomozonotriletes townrowii* first occurs near the base of this zone and is a useful accessory marker species. In terms of Powis' (1984) zones in the Canning Basin this zone corresponds to Stage 3a/b, based on the first appearance and consistent presence of *D. townrowii*.

In the Carnarvon Basin this zone typically occurs within the lower to middle Callytharra Formation. An unusual interval is present in Ballythanna 1 at the base of the Callytharra Formation, from 339 to 375.2 m, where poorly preserved assemblages with zonate spores occur and both *P. confluens* and *P. pseudoreticulata* are lacking. This interval effectively lies between the *P. confluens* and *P. pseudoreticulata* Zones, and therefore has not been assigned to either zone. Further borehole data from the Byro Sub-basin are required to demonstrate the real extent of this interval.

Striatopodocarpites fusus Zone

The first up-hole appearance of unequivocal *S. fusus* is used here as the base of the *S. fusus* Zone. In the coal measure of the Collie Basin the first appearance of the bisacate pollen *S. fusus*, usually accompanied by the first appearance of the monolete spore *Laevigatosporites colliensis*, is a useful datum (Backhouse, 1991). In the largely marine sediments of the Carnarvon Basin, however, *S. fusus* is generally less abundant and its first appearance is not as readily determined. This situation is compounded by the poor yields from many samples at this level. Nevertheless, in wells in which the zone has been observed, an interval that contains *S. fusus* occurs below the first appearance of *Didecitriletes byroensis*. In this report, the top of the undifferentiated *S. fusus* Zone is taken as the highest occurrence of *D. byroensis*, or, in the absence of this spore, the first occurrence of small spores with similar exine thickness and granulose sculpture to *Microbaculispora trisina* (*Microbaculispora* sp. cf. *M. trisina* in this report). Specimens of the larger form of *M. trisina* are not recorded until approximately the base of the *P. sinuosus* Zone.

The *S. fusus* Zone consistently occurs in the upper part of the Callytharra Formation.

Didecitriletes byroensis Subzone

A previously undescribed spore, *Didecitriletes byroensis* (Appendix 4), has been found consistently in the upper part of the *S. fusus* Zone (Fig. 3). Re-examination of material from Burna 1 and Gascoyne 1 showed that the spore identified as *Didecitriletes dentatus* in palynology reports in the well completion reports is, in fact, *D. byroensis*. This spore has not been recorded to date in the Perth or Collie Basins.

Didecitriletes byroensis has been identified over a narrow interval in seven wells, often in only one or two samples per well, and always within the uppermost Callytharra Formation, as used in this report, or the lower Cordalia Formation. Because it appears to have a limited stratigraphic range and has a distinctive morphology, this species has proved to be an extremely useful datum in the otherwise poorly delimited *S. fusus* and *M. trisina* Zones.

A suite of undescribed, small, mainly spherical and probably marine, acritarchs is usually found in association with *D. byroensis*, but with a greater stratigraphic range. In Ballythanna 1 these acritarchs appear at about the base of the *S. fusus* Zone and range up through the *D. byroensis*

Subzone. Other spinose acritarchs, predominantly *Micrhystridium* spp., are also relatively common through this interval. Spinose acritarchs are rare in the overlying *M. trisina* Zone and, where they occur, are simple *Micrhystridium* types.

Microbaculispora trisina Zone

The base of this zone is marked by the first up-hole appearance of small spores referred to here as *Microbaculispora* sp. cf. *M. trisina*. As noted previously (Backhouse, 1991), the first appearance of *M. trisina* is not always readily determined in the Collie Basin and it is this small form which is found at this level also in the Carnarvon Basin. Because of the infrequency of *M.* sp. cf. *M. trisina* at this level in the Carnarvon Basin, little reliance is placed on this datum for high resolution correlation. Nevertheless, with the exception of one well, the first occurrence of *M.* sp. cf. *M. trisina* is always above the *Didecitriletes byroensis* Subzone.

The top of the zone is marked by the first appearance of *Praecolpatites sinuosus*. Again, this datum is not always easily detected in the Carnarvon Basin. The base of this zone lies near the top of the Callytharra Formation, as used in this report and, apart from the Cordalia Formation, the entire Wooramel Group can be placed within it (Fig. 3).

Praecolpatites sinuosus Zone

The base of the zone is marked by the first appearance of *P. sinuosus* but, as noted above, it is difficult to determine accurately, especially as palynomorph preservation is poor in the wells where this datum is intersected. It may be possible to use an accessory index species such as *Altitriletes densus* to determine the approximate base of this zone but, until more is known of the comparative ranges of these two species, it seems prudent to retain the first appearance of *P. sinuosus* as the datum. The top of the zone is marked by the first appearance of *Microbaculispora villosa*. In the best sampled intervals, the base of the *P. sinuosus* Zone lies within the Coyrie Formation, near the base of the Byro Group and the top of the zone lies in the lower Coolkilya Sandstone (Fig. 3).

Microbaculispora villosa Zone

The first appearance of *M. villosa* marks the base of this zone, which is quite thin in the few wells in which it is encountered. The top of the zone is the first appearance of *Dulhuntyispora granulata*.

Kennedy Range 1 is the only well in the Merlinleigh Sub-basin that passes through the entire zone. In this well the zone is between 200 and 350 m thick and is present in the Coolkilya and Mungadan Sandstones.

Dulhuntyispora granulata Zone

The first appearance of *D. granulata* marks the base of the zone, and the first appearance of *Didecitriletes ericianus* marks the top of the zone. No well interval in the Merlinleigh Sub-basin intersects the top of the *D. granulata* Zone so the thickness of the zone in this sub-basin cannot be ascertained. It appears to be at least 140 m thick in the Mungadan Sandstone and Binthalya Formation in the Kennedy Range area. The lower part of the Kennedy Group on the Peedamullah Shelf (Fig. 1), immediately above the mid-Permian unconformity, is assigned to the *D. granulata* Zone.

Didecitriletes ericianus Zone

The base of the zone is marked by the first appearance of the distinctive spore *D. ericianus*, and the top by the appearance of *Dulhuntyispora parvithola*. In the Perth and Collie Basins the first appearance of *D. ericianus* is considered to be one of the more consistent and reliable biostratigraphic horizons, and it also appears to be a reliable datum in the Carnarvon Basin. The *Protohaploxypinus rugatus* Zone of the Collie Basin has not been used for this report as examples of *P. rugatus* have a low sample frequency in some wells, and it is considered that an attempt to apply this zone would not benefit biostratigraphic subdivision of the Permian in the Carnarvon Basin. *D. dulhuntyi* is often common in this zone and, within the upper part of the zone spores of the genus *Dulhuntyispora* show a diversity of morphotypes, some similar to forms described previously and some possibly new. This diversity of forms appears to continue through much of the overlying *D. parvithola* Zone.

The *D. ericianus* Zone is not seen in the Merlinleigh Sub-basin where rocks of this age are either weathered, eroded, were never deposited or possibly have not been sampled owing to the inaccessibility of the Binthalya Formation. On the Peedamullah Shelf the zone is over 200 m thick in Onslow 1 and Hope Island 1.

Dulhuntyispora parvithola Zone and higher biostratigraphic units

The *D. parvithola* Zone is the youngest biostratigraphic subdivision used in this report. Slightly younger bio-stratigraphic units in terms of Price's 1983 scheme may be present in the Peedamullah Shelf where acritarchs similar to *Micrhystridium evansii* are present in some samples. Price (1983) uses this acritarch as a marker for his biostratigraphic unit Upper Stage 5c. The highest Permian sample in Onslow 1 (2098.5 m) contains frequent *Weylandites lucifer*, but other forms indicative of the *Weylandites* Zone of Kemp et al. (1977) are not present. Given the current inadequate knowledge of other, possibly higher, palynostratigraphic zones, it is considered undesirable to try to apply such biostratigraphic units in this report. The whole of the Permian sequence above the first appearance of *D. parvithola*, therefore, is assigned to the *D. parvithola* Zone, which as used here is equivalent to the whole of Upper Stage 5 of Price (1983). A greater diversity of spores is evident in this zone, with a number of species, such as *Camptotriletes warchianus* recorded for the first time. Further work may allow this zone to be subdivided in the Carnarvon Basin. The *D. parvithola* Zone is not recorded in the Merlinleigh Sub-basin, but much of the undifferentiated Kennedy Group and the Chinty Formation on the Peedamullah Shelf belongs in the zone.

Summary of individual wells

BHP Wandagee 1

Dampier Mining drilled BHP Wandagee 1 40 m west of Quail 1 in 1975 to investigate thin coals in that well. The borehole was fully cored from 11 m to a total depth (TD) of 397.5 m from the Coyrie to Cordalia Formations (Dampier Mining, 1975). In 1994 the core was discovered in an abandoned shed on Wandagee Station by a GSWA field party and sampled for geochemistry and palynology. The geochemical results were encouraging (Ghori, 1996) and the interval from 150 to 375 m, which was in good condition, was transported to the GSWA core library in Perth. The stratigraphic and age information from BHP Wandagee 1 have been incorporated with that for Quail 1 in Plate 1, because of the close proximity of the two wells.

No previous palynological studies have been carried out on this borehole. For this study the borehole was sampled from 16 to 370 m. Over this interval *Striatopodocarpites fusus* was present consistently, and *Columnisporites* sp. cf. *C. peppersii* was observed in most samples. *Microbaculispora trisina*, *M.* sp. cf. *M. trisina* and *Praecolpatites sinuosus* were not observed, and the *Didecitriletes byroensis* Subzone was not encountered. It was concluded that the section in this well lies either entirely above or below the *D. byroensis* Subzone. Based on the presence of *C.* sp. cf. *C. peppersii*, which is not known in Western Australia from the *S. fusus* Zone, this interval is placed in the *M. trisina* Zone.

Bidgemia 1

Bidgemia 1 (Fig. 1) is one of three shallow wells drilled by Hartogen in 1972. The aim of the well was ‘to investigate the porosity of the Moogooloo Sandstone ... below the influence of surface weathering effects’ (Koluzs, 1972). The well was spudded in the Coyrie Formation northwest of Pells Range. At 122 m the well encountered limestone and shale that Hartogen assigned to the Jimba Jimba Calcarenite. Drilling was terminated in that unit at 212 m. The well was not geophysically logged as it apparently did not reach its objective horizon. No core analysis or palynology was carried out for the well completion report (Koluzs, 1972).

In an alternative interpretation, M. A. Condon (*in* Koluzs, 1972) suggested that at 73 m the well intersected 49 m of Moogooloo Sandstone below the Billidee Formation and that the well was terminated in the Callytharra Formation. Coring began at 122 m in limestone and shale and the presence of the Moogooloo Sandstone higher in the well may be inferred by reference to outcrop in Pells Range 5 km to the south. Figure 4 shows dips to the northwest in the order of 1°, and that the thickness for the Moogooloo Sandstone in the well is comparable to that measured in Pells Range. No faults are present on the north side of Pells Range near the well. The presence of the *P. pseudoreticulatus* and *S. fusus* Zones in the cored interval (Fig. 5) also confirms Condons’ interpretation.

A set of palynology slides was prepared from core samples by ESSO in 1985 and reported on by Hannah (1985a). The interval 169–210.1 m was assigned to Stage 3a/b of Powis (1984), whereas the overlying productive interval, up to 153.3 m, yielded assemblages considered to be too sparse for zonal assignment. All the productive ESSO slides between 153.3 m and 210.1 m were re-examined in this study. The interval from 171 to 210.1 m can be assigned to the *P. pseudoreticulata* Zone, although some of the higher samples are only tentatively placed in this zone. Above this level two samples are tentatively assigned to the *S. fusus* Zone, and the two highest productive samples belong in the *Didecitriletes byroensis* Subzone. Acritarchs of the same suite as those associated with the *D. byroensis* Subzone in other wells are present in the 153.3–171 m interval.

BMR Glenburgh 8 and 9

BMR Glenburgh 8 and 9, previously known as BMR 8, Mount Madeline, and BMR 9, Daurie Creek, (hereafter referred to as BMR 8 and 9) are stratigraphic wells drilled in 1959 by the BMR to provide information on source-rock potential in the Byro Sub-basin. BMR 8 was located on the east flank of the Madeline Anticline. Although the well was planned to investigate the Permian–Precambrian contact at depth, drilling was terminated within the Lyons Group at 916 m. BMR 9 was drilled on the Monument Syncline, 32 km northeast of BMR 8, to investigate the possibility of a facies change between outcrop to the east and the Carrandibby Inlier to the west. The well was also terminated within the Lyons Group at 916 m (Mercer , 1967). A report on the macrofauna is included in the well completion report (Mercer, 1967).

A set of slides from BMR 8 was borrowed from AGSO. The palynoflora of BMR 9 was not examined for this report. Unfortunately only 8 of the 32 cores in BMR 8 were sampled and palynological data from the uppermost 300 m are not available. Below 309 m the borehole passed through the Ballythanna Sandstone Member and then through undifferentiated Callytharra Formation into the Lyons Group. In this borehole that

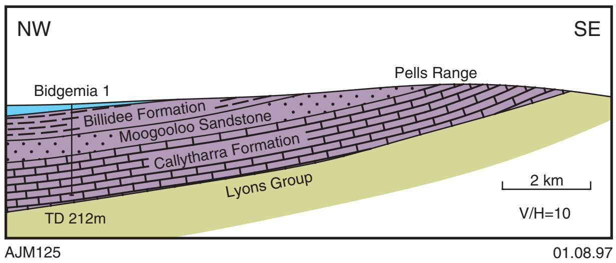


Figure 4. Cross-section from Bidgemia 1 to Pells Range

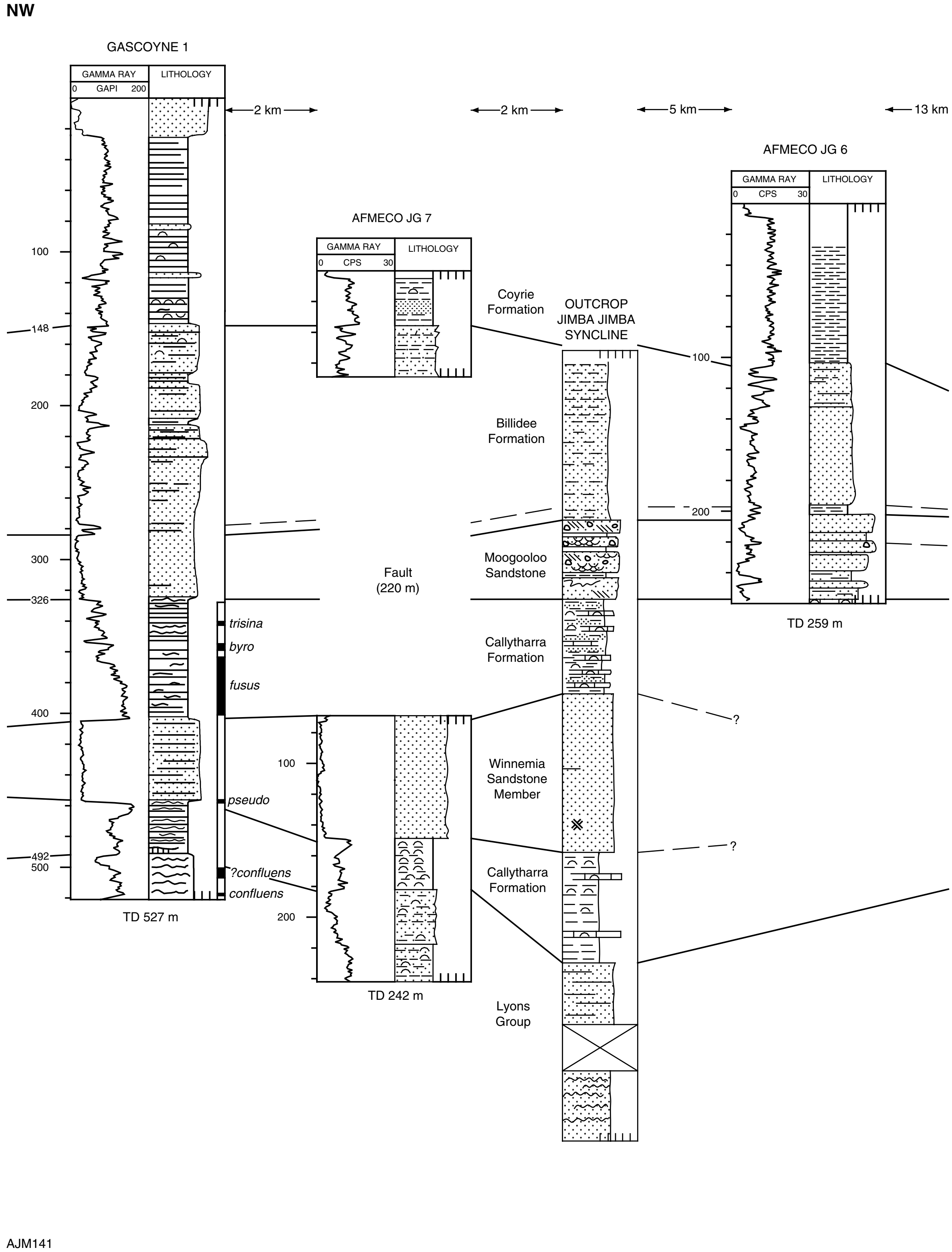
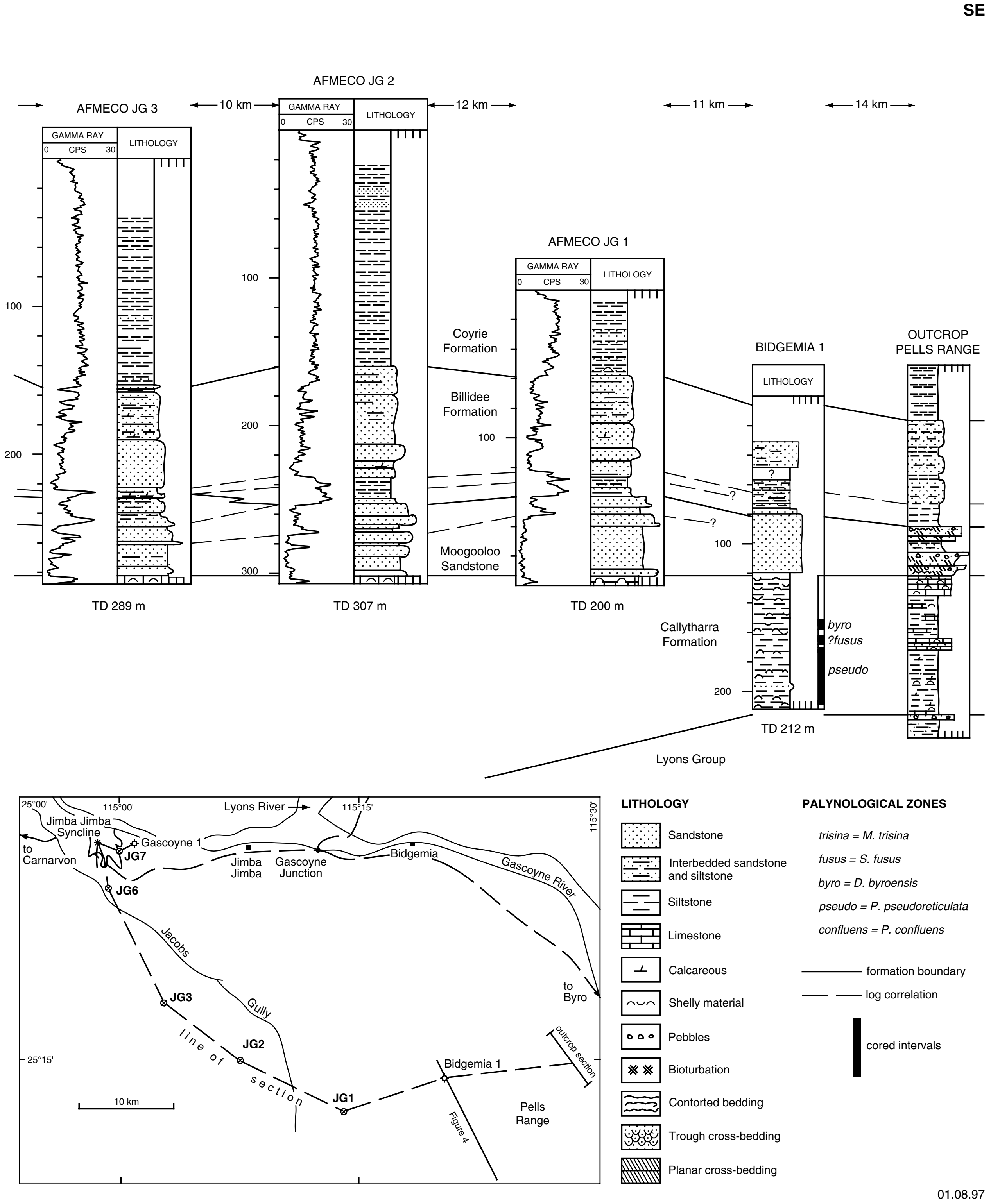


Figure 5. Stratigraphic correlation from Gascoyne 1 to outcrop section in Pells Range. Datum top of Callytharra Formation


SE
AFMECO JG 3
10 km
AFMECO JG 2
12 km
11 km
14 km
GAMMA RAY
0 CPS 30
LITHOLOGY
AFMECO JG 1
Coyrie Formation
Billidee Formation
Moogooloo Sandstone
BIDGEMIA 1
OUTCROP PELLS RANGE
TD 289 m
TD 307 m
TD 200 m
TD 212 m
Callytharra Formation
Lyons Group
byro
?fusus
pseudo
Jimba Jimba Syncline
Gascoyne 1
to Carnarvon
JG7
JG6
JG3
JG2
JG1
Lyons River
Jimba Jimba
Gascoyne Junction
Bidgemia
Gascoyne River
Jacobs Gully
line of section
to Byro
outcrop section
Bidgemia 1
Pells Range
Figure 4
10 km
25°00'
25°15'
115°00'
115°15'
115°30'
LITHOLOGY
Sandstone
Interbedded sandstone and siltstone
Siltstone
Limestone
Calcareous
Shelly material
Pebbles
Bioturbation
Contorted bedding
Trough cross-bedding
Planar cross-bedding
PALYNOLOGICAL ZONES
trisina = M. trisina
fusus = S. fusus
byro = D. byroensis
pseudo = P. pseudoreticulata
confluens = P. confluens
formation boundary
log correlation
cored intervals
01.08.97

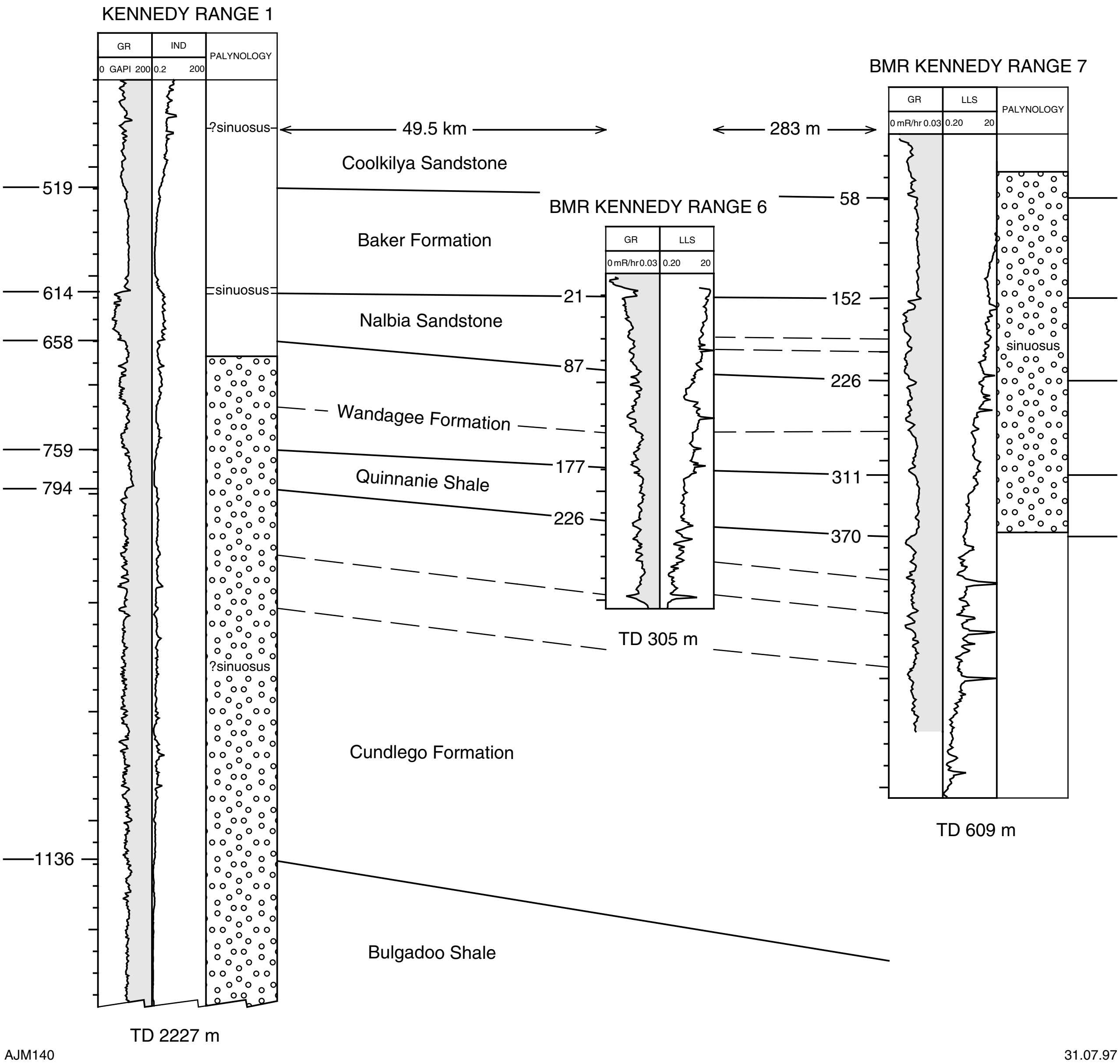


Figure 6. Stratigraphic correlation of BMR Kennedy Range 6 and 7 with Kennedy Range 1. Datum top of Nalbia Sandstone

part of the Callytharra Formation is assigned to the *P. pseudoreticulata* Zone. The upper part of the Lyons Group clearly falls within the *P. confluens* Zone. As convincing specimens of *P. confluens* were not detected in the samples from cores 30 and 32, the lowest level in this well is placed in Stage 2 with some reservation.

Archbold (1995a) has recently examined brachiopods from BMR 8 and gives a probable age of Asselian to core 32 (912.5–915.5 m), and suggests a late Tastubian (early Sakmarian) age for material from core 18 (507.5–509.3 m).

BMR Kennedy Range 6 and 7

BMR Kennedy Range 6 and 7 are stratigraphic wells that were drilled 283 m apart by the BMR in 1958 to investigate the nature of the Middalya Fault. At the time of drilling, these boreholes were named BMR 6 and 7, Muderong; but they are now known as BMR Kennedy Range 6 and 7 (hereafter referred to as BMR 6 and 7). In the well completion report it was postulated that BMR 6 had intersected a fault or unconformity at 90 m based on dips of 30° in core 4 (Perry, 1965). A correlation of the well logs (Fig. 6), however, indicates a similar section in both wells and that a fault with a throw of approximately 130 m separates them (Fig. 7). The correlation also suggests that the original formation picks were not consistent between the two wells.

In BMR 7, the deeper of the two wells, 25 conventional cores were cut at regular intervals down to TD at 608.7 m. Previous biostratigraphy on the borehole consists of a report on foraminifera by Belford (*in* Perry, 1965), which gives little information on the age of the material.

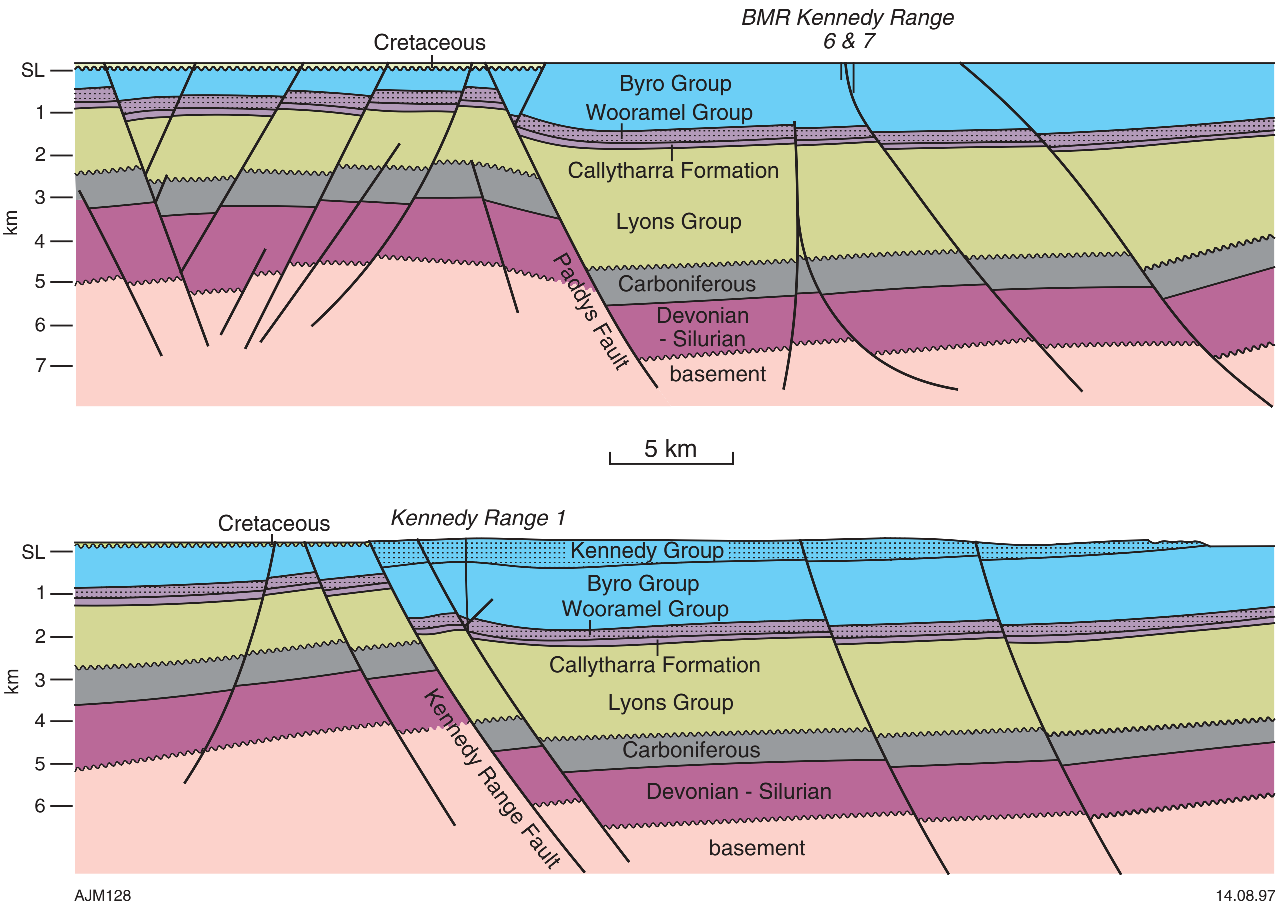


Figure 7. East–west structural cross sections through Kennedy Range 1 based on part of seismic section K82A-123, and BMR Kennedy Range 6 and 7 based on part of seismic section K82A-109.

For this study samples from BMR 7 were prepared successfully from cores 1 to 7, 9, 11, 16 and 17 (from 33.6 to 366.6 m). This interval is placed in the *P. sinuosus* Zone somewhat cautiously in the case of the lowest three sparse samples. This places the lower Coolkilya Sandstone to Quinnanie Shale in this zone, similar to the results from the Byro Group in Kennedy Range 1.

Marine acritarchs, mainly *Micrhystridium* spp., are present at all levels in this borehole and are strong evidence that the upper Byro Group was predominantly , if not entirely , deposited under marine conditions.

Burna 1

Burna 1 was drilled by ESSO Australia in 1984, to test the hydrocarbon potential of the Wooramel Group. The well was fully cored from 424 m to 767.6 m (TD) in order to gain the maximum amount of stratigraphic information. In the ESSO interpretation the well was spudded in the Cundlego Formation but, given the poor outcrop near the well and the lack of samples from the top of the well, it is difficult to verify such an interpretation. The well was terminated within the upper Lyons Group (Plate 1).

Numerous palynology samples are available from the cored interval and were reported on by Hannah (*in* ESSO, 1985a). Hannah records a zonal range from 'no older than Lower Stage 4' at 453.89 m to Stage 3a at 767 m and dates this interval as Early Permian to Late Carboniferous.

In this review 31 samples were re-examined from the original slide set prepared by ESSO. Some poor assemblages are present in this set of samples, but these were not examined in detail. Most yields from this well are poor and as a result many of the zonal picks are tenuous. The interval between 544.55 and 569.6 m contains common *Micrhystridium* spp. and represents a strongly marine interval in the Cordalia Formation. Much of the remainder of the section could be marine, but marine indicators were seen in only two samples.

Didecitriletes byroensis is present from 544.55 m to 569.6 m, effectively the interval that can also be assigned to the *S. fusus* Zone. The interval above 544.55 m is assigned to the *M. trisina* Zone based on a single specimen of *M.* sp. cf. *M. trisina* at 536.7–539.7 m, the presence in the same sample of *Columnisporites* sp. cf. *C. peppersii*, and the absence of *P. sinuosus* and other indicator species for higher palynological zones. The well was terminated in the *P. confluens* Zone.

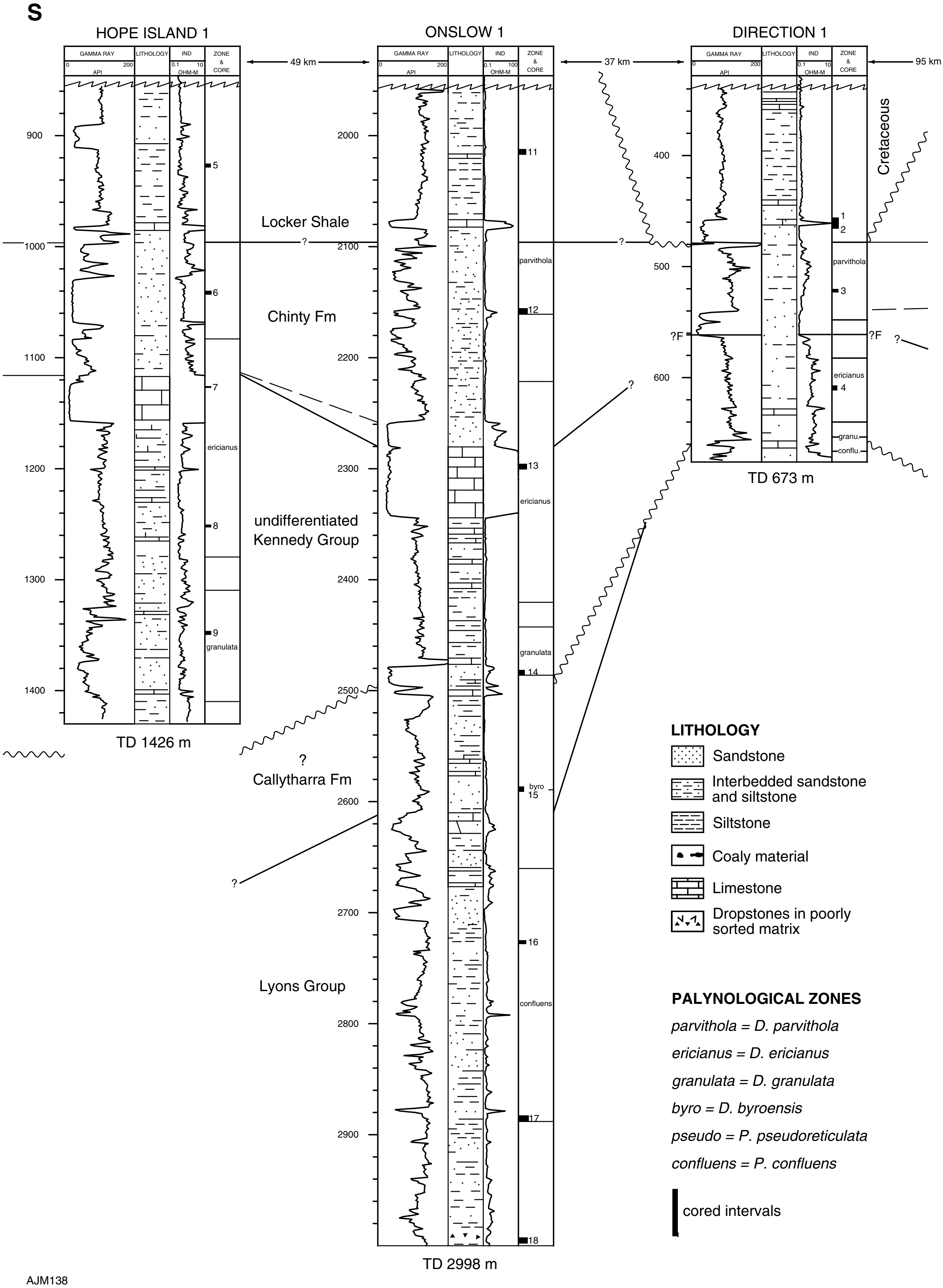
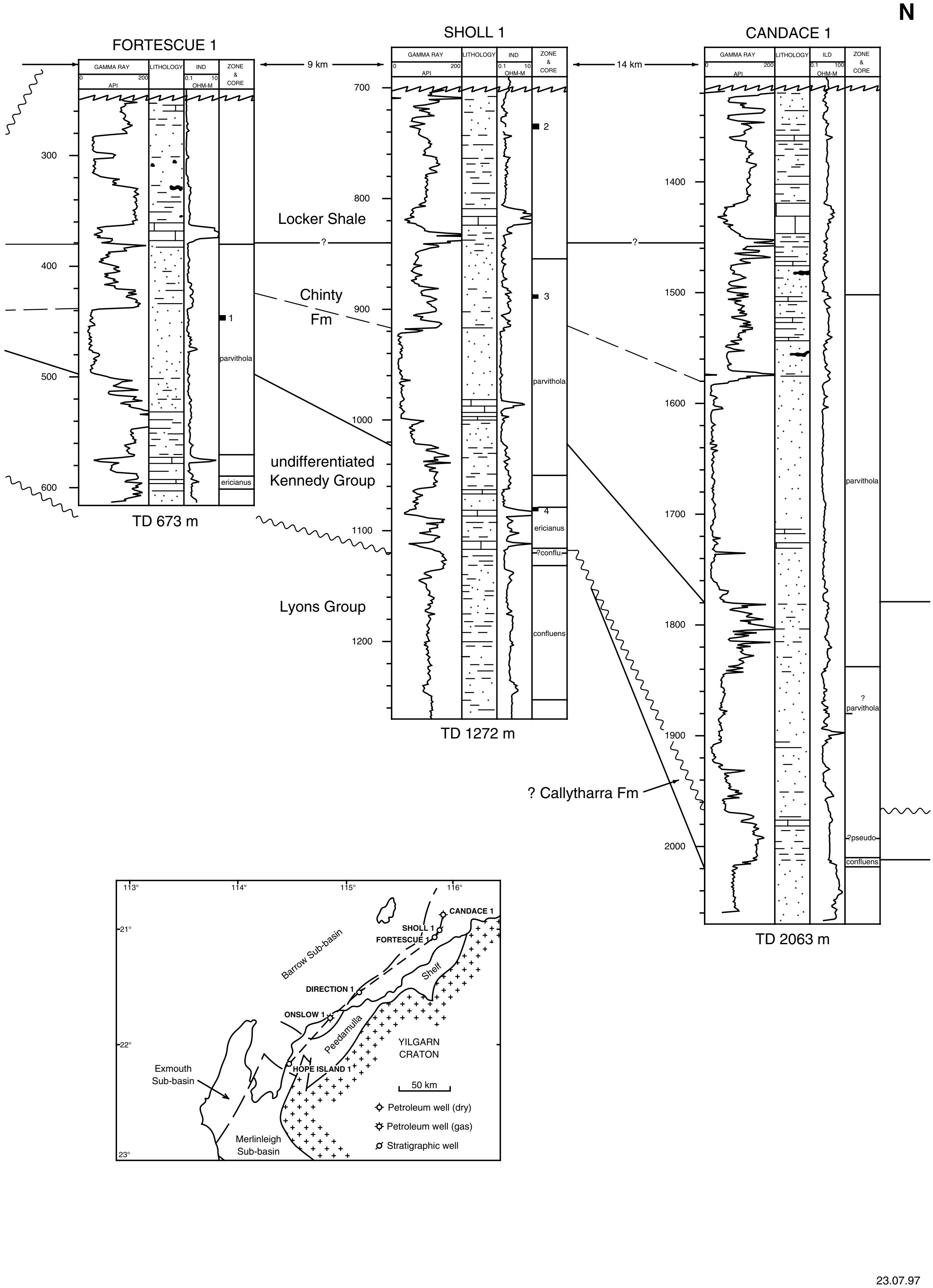


Figure 8. Correlation of the Permian from Hope Island 1 to Candace 1. Datum top of Chinty Formation


N
FORTESCUE 1
SHOLL 1
CANDACE 1
9 km
14 km
GAMMA RAY
API
LITHOLOGY
IND
ILD
OHM-M
ZONE & CORE
Locker Shale
Chinty Fm
undifferentiated Kennedy Group
Lyons Group
? Callytharra Fm
parvithola
ericianus
?conflu
confluens
? parvithola
?pseudo
TD 673 m
TD 1272 m
TD 2063 m
CANDACE 1
SHOLL 1
FORTESCUE 1
Barrow Sub-basin
DIRECTION 1
ONSLOW 1
Shelf
Peedamulla
YILGARN CRATON
HOPE ISLAND 1
Exmouth Sub-basin
Merlinleigh Sub-basin
50 km
Petroleum well (dry)
Petroleum well (gas)
Stratigraphic well
23.07.97

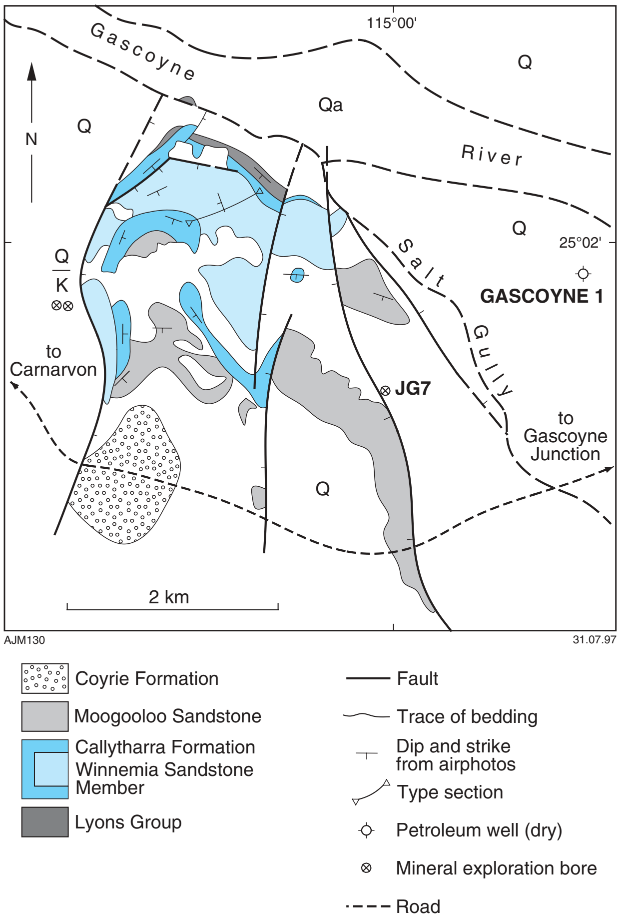


Figure 9. Geological sketch map of the Jimba Jimba Syncline adapted from Condon (1967, fig. 76)

Candace 1

Candace 1 was drilled in 1982 by Australian Occidental Petroleum to test an anticline within the Permian succession. The well encountered a section with sandstone, limestone and claystone from 1844.5 to 1912 m that was placed within the Byro Group on lithological grounds by Australian Occidental Petroleum (1983), but which is here included in the Kennedy Group based on a correlation with wells to the south (Fig. 8). The probable presence of the *P. pseudoreticulata* Zone at 1994 m (immediately above the *P. confluens* Zone at 2008 m) below the *D. parvithola* Zone at 1879.5 m indicates a major timebreak at the base of the Kennedy Group in this well. Drilling was terminated within the Lyons Group at 2063 m.

Direction 1

Direction 1 is a stratigraphic well drilled on Direction Island (Fig. 1) to 673 m by WAPET in 1968 to evaluate the hydrocarbon potential of the Lower Cretaceous and the pre-Cretaceous section. In the well completion report an unconformity was placed between the Kennedy and Lyons Groups at the base of a thick sandstone at 561 m, on the basis of Late Permian and Sakmarian ages from core at 520 and 670 m, respectively (Reid, 1968). In this study the *D. granulata* Zone was identified at 655.3 m, immediately below younger zones, and the *P. confluens* Zone was identified at 670 m (Fig. 8). The contact between the Kennedy Group and the Lyons Group is here modified slightly from the original pick and placed at a log break at 656 m. A small fault may be present at the base of the Chinty Formation (564 m) based on a correlation with Onslow 1, almost 40 km to the south (Fig. 8).

Fortescue 1

Fortescue 1 was drilled on Long Island by WAPET in 1969 to test the Permian in a possible fault trap. In the well completion report the lower part of the Permian, represented in the interval 560 to 610 m (TD), was assigned to the Byro Group based on a correlation with Sholl 1, but without the support of biostratigrahic evidence (Reid, 1969). Based on the presence of *D. ericianus* Zone palynofloras that interval is here assigned to undifferentiated Kennedy Group (Fig. 8). There is no biostratigraphic evidence for Lower Permian rocks in this well.

Gascoyne 1

Gascoyne 1 was drilled in 1984 in a faulted anticline 2 km east of outcrop in the Jimba Jimba Syncline (Fig. 9), to test the hydrocarbon potential of the Lower Permian Wooramel Group. The well was fully cored from 328 m to 527 m (TD) in order to gain the maximum amount of stratigraphic information and was terminated in the top of the Lyons Group. The upper, uncored part of the well was believed to represent the interval from the Bulgadoo Shale to the Wandagee Formation, but ESSO was unable to differentiate those units either in the cuttings or on the electric logs (ESSO, 1985b).

Previous stratigraphic nomenclature for the Jimba Jimba Syncline and adjacent area is summarized in Figure 10. Inconsistencies between ESSO's thicknesses for

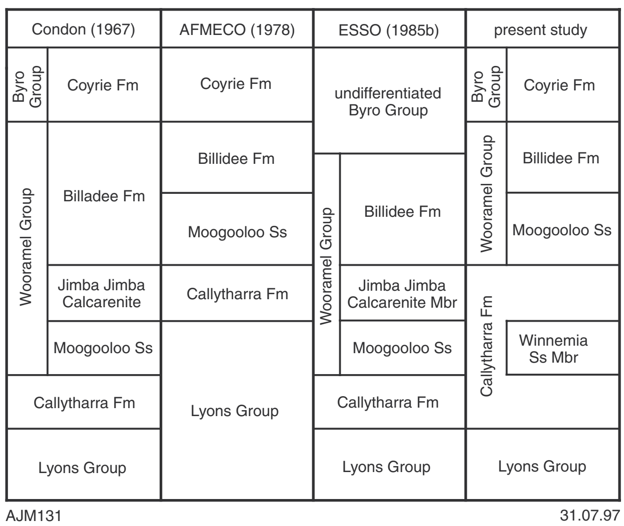


Figure 10. Comparison of present and previous stratigraphic nomenclature for the Jimba Jimba Syncline area

Figure 11. Outcrop of the Winnemea Sandstone Member in the Jimba Jimba Syncline

units in the well, and those measured from the outcrop by Condon (1967) were originally assumed to be real (Percival and Cooney, 1985) or possibly due to fault repetition (Hocking et al., 1987). Part of the difficulty in correlating between the two locations is the presence of two lithologically very similar fossiliferous limestone siltstone units supposedly separated by the Moogooloo Sandstone (Callytharra Formation and Jimba Jimba Calcarenite Member of the Billidee Formation *sensu* Condon, 1967, and Hocking et al., 1987). The interval that ESSO assigned to the Moogooloo Sandstone in Gascoyne 1 is fine- to medium-grained, shows little structure apart from minor silty laminae, and is 54 m thick. Outcrop that Condon (1967) assigned to the unit is lithologically very similar (massive, and fine- to medium-grained), but is approximately 130 m thick (Fig. 11).

The outcrop immediately above the Jimba Jimba Calcarenite Member (supposedly Billidee Formation) consists of approximately 50 m of cross-bedded, medium- to very coarse-grained sandstone (Fig. 12). This outcrop is more typical of the Moogooloo Sandstone than the Billidee Formation. The presence of the *D. byroensis* Subzone above the massive sandstone in Gascoyne 1 (Fig. 5, Plate 1) suggests that this level is within the Callytharra Formation and not the Jimba Jimba Calcarenite Member as claimed by ESSO (1985b). A correlation from Pells Range to Gascoyne 1 utilizing mineral exploration wells (Fig. 5) drilled by AFMECO (1978) also indicates that the Jimba Jimba Calcarenite Member is the upper part of the Callytharra Formation and that the massive sandstone (Winnemia Sandstone Member herein) lies within that formation. Preliminary identifications of brachiopod species from above the sandstone member, at the same level as the *S. fusus* Zone, in Gascoyne 1 support this correlation (Archbold, N. W., 1997, pers. comm.)

A palynological report by M. J. Hannah (*in* ESSO, 1985b) recorded a zonal range from Stage 3b at 356.1 m, to Stage 3a/b at 454.16 m. Samples above this interval were indeterminate. The 24 samples originally prepared by ESSO are included in this review. Many of these show extremely low yields of palynomorphs and consequently many of the zonal picks are equivocal.

The highest samples from this well are tentatively included in the *M. trisina* Zone and the lowest samples fall in the *P. confluens* Zone. *D. byroensis* is present in two samples (356.1 and 361.1 m), probably at the top of the *S. fusus* Zone. Samples from the lower part of the Callytharra Formation have particularly poor yields of palynomorphs, a situation encountered in some other wells. An interval with frequent *Micrhystridium* spp. and other acritarchs occurs between the highest sample (120 m) and 391.69 m.

Figure 12. Outcrop of the Moogooloo Sandstone in the Jimba Jimba Syncline

Giralia 1

Giralia 1 was drilled to a depth of 1244 m, by WAPET in 1955, at a crestal location on the Giralia Anticline, primarily to test the shallow Lower Cretaceous Birdrong Sandstone. A secondary objective was to examine the stratigraphy and petroleum possibilities of the underlying Permian section to the top of the Lyons Group (Johnson, 1955). In the Permian section 54 cores were cut successfully (cores 11 to 77) making this one of the best sampled wells in the region for a palynological study of the Permian (Plate 1).

No previous reports on Permian palynology from Giralia 1 seem to exist. In this study numerous samples were examined, mainly existing preparations made by WAPET, but including some new preparations. The highest zone identified is the *P. sinuosus* Zone, with the lowest occurrence of *P. sinuosus* in the upper Coyrie Formation. The interval between 227.1 and 942.1 m, which extends from the middle of the Coyrie Formation to the Cordalia Formation, is placed in the *M. trisina* Zone. Many samples between 318.5 and 751.3 m are extremely sparse and, therefore, the index species is rare in this interval. The *S. fusus* Zone is recognized only as the *D. byroensis* Subzone in the interval 949.5–951 m near the top of the Callytharra Formation, but may extend over the interval of barren samples down to 982.1 m. An interval of about 50 m, in which all samples are extremely unproductive, separates the *P. pseudoreticulata* and *P. confluens* Zones. This interval belongs in the Callytharra Formation, the lower part of which is often palynologically unproductive.

GSWA Ballythanna 1

This fully-cored well (hereafter referred to as Ballythanna 1) was drilled in 1995 by the GSWA to test the source rock potential of the Callytharra Formation in the Byro Sub-basin. The well was spudded in the centre of the Ballythanna Anticline near outcrop mapped as Moogooloo Sandstone (Williams et al., 1983a) and drilling was terminated at 466 m in the Lyons Group (Mory, 1996). Correlation of the well with BMR 8 and 9 suggests that in the north of the Byro Sub-basin the Keogh Formation directly overlies the Callytharra Formation, and that outcrop of sandstone in that area, previously assigned to the Moogooloo Sandstone, should be referred to the Ballythanna Sandstone Member in the upper part of the Callytharra Formation (Plate 1; Mory, 1996).

Biostratigraphic control is provided by palynology, with a total of 21 samples processed and examined. The *D. byroensis* Subzone is represented better in this borehole than in most other wells in the basin. Three samples ranging from 60.7 m to 112.6 m contain this spore species and the coeval suite of small acritarchs. Many of these acritarchs range down to 298.28 m, the base of the Ballythanna Sandstone Member. The *M. trisina* Zone is taken to start at 54.45 m within the upper part of the

Callytharra Formation. Assemblages from shales within the Ballythanna Sandstone Member contain abundant and diverse microplankton and indicate deposition under marine conditions for this interval.

An interval of low-yielding assemblages with poorly preserved palynomorphs extends from 339 to 375.2 m. Assemblages in this interval are dominated by zonate spores of the *Indotriradites* type. This interval has not been assigned to a zone although it is probably coeval with the *P. pseudoreticulata* Zone, even though that species is apparently absent. The *P. pseudoreticulata* Zone, however, is present in the immediately overlying interval.

Hope Island 1

Hope Island 1 is a stratigraphic well drilled to 1426 m by WAPET in 1968, on the island of that name on the eastern side of Exmouth Gulf (Fig. 1). The objectives of the well included evaluating the pre-Cretaceous section. The palynology results in the well completion report suggest that all of the pre-Cretaceous section correlates with the Kennedy Group (Bowering, 1968), including a distinctive limestone horizon that, in Onslow 1, had been assigned to the Byro Group (Jones, 1967). The present palynology confirms the original correlation and shows a thick Upper Permian interval that belongs in the *D. ericianus* and *D. granulata* Zones. The *D. parvithola* Zone was not recorded in this well, but it could be present in the unsampled Permian interval above 1082 m (Fig. 8).

Kennedy Range 1

Kennedy Range 1 is located on a surface anticline (Merlinleigh Anticline) on the western margin of the Merlinleigh Sub-basin. The well was drilled by WAPET in 1966–67 to a depth of 2227 m and was terminated near the top of the Lyons Group (Plate 1). To date this is the only well to penetrate a complete section of the Byro Group.

Kennedy Range 1 is a key well for correlation in the Merlinleigh Sub-basin because it penetrates all units of the Kennedy, Byro and Wooramel Groups, although in the Kennedy Group only the lower part of the Coolkilya Sandstone was sampled (Fig. 13). This problem is partially overcome by the availability of cuttings from the Mungadan Sandstone and basal Binthalya Formation in the nearby Merlinleigh boreholes.

Correlation with BMR 6 and 7, almost 50 km to the north, shows that some revisions of the formation picks in the well completion report are necessary for the upper Byro Group (Fig. 6). Formation tops within the Kennedy Group are also amended to correlate better with outcrop west of the well.

Previous palynological studies of Kennedy Range 1 are available in the well completion report (Balme *in* Lehmann, 1967) and from Powis (1981). Reasonably good assemblages have been obtained from samples down to core 11 (1434.1–1437.1 m), but below this level poor preservation precludes reliable identification of key elements in the palynoflora. Cores 12–15 have not yielded palynomorphs despite processing by several workers, although a few samples below this level have yielded sparse assemblages.

The current review includes data from some new preparations, a restudy of WAPET slides held in the GSWA Relinquishment Collection, and data from Balme (*in* Lehmann, 1967) and Powis (1981). Significant results from this well and the nearby Merlinleigh boreholes show that the upper part of the Permian section up to core 1 (303.9–306.9 m), in the upper part of the Coolkilya Sandstone, ranges up to the *M. villosa* Zone. Evidence from the Merlinleigh boreholes (see below) indicates that the lowest Mungadan Sandstone may be within the *M. villosa* Zone, whereas the upper part of the sandstone and the lowest part of the Binthalya Formation lie in the *D. granulata* Zone.

Nearly 1000 m of the section in Kennedy Range 1 is tentatively assigned to the *P. sinuosus* Zone (see Appendix 2). This section contains consistent *M. trisina* but only infrequent specimens of *P. sinuosus* or *Praecolpatites ovatus* below core 3. Other evidence, such as the occurrence of *Altitriletes densus* and large forms of *M. trisina* down to core 10, suggest this interval is more likely to fall within the *P. sinuosus* Zone than the *M. trisina* Zone, as defined in the Collie Basin (Backhouse, 1991). Below this level low yields and greater thermal maturity largely precludes zonal assignments. Balme's data suggest that the *M. trisina* Zone may extend down to core 17 (2012.9–2017.5 m), but there is little useable material below that level.

In the lower part of the well, a series of sidewall cores between 2104.9 m and 2215.3 m produced only a few identifiable palynomorphs, most notably the identification of *Pseudoreticulatispora confluens* at 2215.3 m. Only the productive samples from this interval are listed in Appendix 2.

Merlinleigh 1–5

As seismic qu ality over the Kennedy Range is poor, and the northern end of the Merlinleigh Anticline is obscured by surficial sediments, structural control for Kennedy Range 1 was provided by five shallow boreholes drilled less than 3 km from the deep test by WAPET (Brownhill, 1965). These boreholes are up to 306 m deep and have yielded the youngest Permian palynomorphs in the sub-basin from the Binthalya Formation (*D. granulata* Zone).

Samples from Merlinleigh boreholes 1, 2 and 5 were prepared in order to assess the highest units of the Kennedy Group near Kennedy Range 1. In Merlinleigh 1, *Dulhuntyispora granulata* was recorded in cuttings in the intervals 70.1–73.2 m and 106.7–109.7 m, both in either the Binthalya Formation or Mungadan Sandstone according to the present stratigraphic interpretation. *D. dulhuntyi* is present in the interval 79.2–82.3 m, but this does not necessarily indicate that the sample is from the *D. ericianus* Zone as *D. dulhuntyi* has been observed previously below the *D. ericianus* Zone (Backhouse,

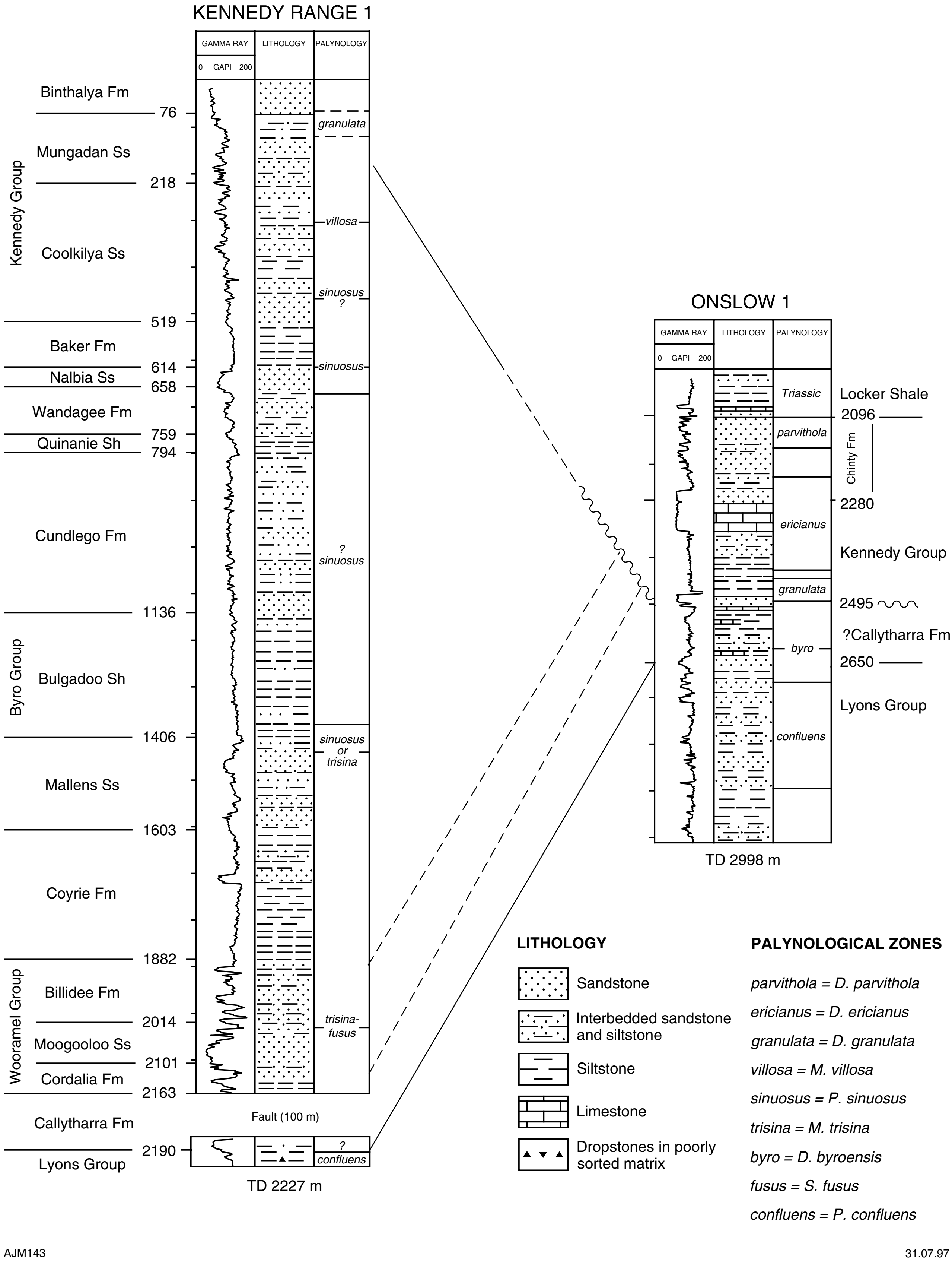


Figure 13. Stratigraphic correlation of Kennedy Range 1 with Onslow 1

1991). *M. villosa* is present down to the 149.4–152.4 m interval, thus supporting the placement of the *M. villosa* Zone within the Coolkilya Sandstone. In Merlinleigh 2, *D. granulata* is recorded from the interval 128.0–131.1 m near the base of the Binthalya Formation and from the interval 149.4–152.4 m in the Mungadan Sandstone. Samples from the Binthalya Formation in Merlinleigh 5 were barren and a sparse assemblage with *M. villosa* was recorded from the interval 167.6–170.7 m in the Mungadan Sandstone. From these observations it is concluded that the upper Mungadan Sandstone and the basal Binthalya Formation in the Merlinleigh boreholes fall within the *D. granulata* Zone. The middle part of the Coolkilya Sandstone falls within the *M. villosa* Zone and the lowest part of that formation is in the *P. sinuosus* Zone. Palynological data are not currently available for the Binthalya Formation above the lowest part because of the weathered condition of the unit in all available borehole intersections.

Moogooree 1

This shallow borehole (128 m TD) was drilled adjacent to outcrop, by Hartogen in 1972 to investigate the reservoir potential of the Moogooloo Sandstone below the weathered zone. Core was cut from the interval 31–128 m, and the well was terminated in the Callytharra Formation, 8.5 m below the target interval (Plate 1; Koluzs, 1972). No palynological or palaeontological studies were included in the well completion report.

Five palynological samples were prepared from the well between 66.2 m and 120.5 m (Appendix 2). The lowest sample contains *Didecitriletes byroensis* and is assigned to the *D. byroensis* Subzone. *S. fusus* is present throughout the sampled interval, but *Microbaculispora* sp. cf. *M. trisina* is only recorded from the 73.3 m sample. The base of the *M. trisina* Zone is taken at the 118.3 m sample where *Columnisporites* sp. cf. *C. peppersii* is present.

Onslow 1

Onslow 1 was drilled (2998 m TD) in 1966 by WAPET to investigate the stratigraphy of the Onslow Embayment and the hydrocarbon potential of a seismically-defined anticline. Gas shows were recorded in the Lower Cretaceous. Otter Exploration subsequently drilled higher on the structure, 7.5 km to the southwest of Onslow 1, and discovered the Tubridgi gasfield in 1981. Onslow 1 (Figs 8 and 13) has the most completely sampled interval of Upper Permian sediments in the Southern Carnarvon Basin.

The Permian succession in the well (2096–2998 m) contains the type section of the Upper Permian Chinty Formation (Hocking et al., 1987) between 2096 and 2258 m, immediately below the Triassic Locker Shale. The Chinty Formation was previously referred to the Kennedy Group by Jones (1967) based largely on perceived similarities of the palynoflora to that in the Coolkilya Sandstone in Merlinleigh 1. The formation was originally separated from the Kennedy Group by Hocking et al. (1987) because of doubts about its correlation with the group. On lithological grounds the underlying limestone was considered to belong to the Byro Group (Jones, 1967; Warris, 1994, fig. 6).

Palynology was carried out for the well completion report by B. E. Balme and a brief review was done by P. & R. Consultants (Purcell, 1994). Neither study included material prepared by WAPET from sidewall core samples. The well completion report includes macrofossil identifications by P. J. Coleman from core 13 at 2304.9 and 2306 m. Coleman suggested these fossils were Artinskian in age and probably from the Callytharra Formation. The original material examined by Coleman could not be located but, from the faunal list in the well completion report, N. W. Archbold (1996, pers. comm.) tentatively suggested a correlation with the upper Byro Group. This is a better agreement with the palynology results reported here (Fig. 13), which place this depth within the *D. ericianus* Zone, still younger than the ages suggested by the macrofossils.

Fourteen sidewall core samples and nine conventional core samples were examined for this report. They show that the *D. ericianus* Zone, and hence sediments that could be considered as Late Permian in age, extend down to 2432.3 m (Fig. 8). The large time break that was previously thought to exist between the Chinty Formation and immediately lower units does not exist. A substantial time break, however, appears to be present between cores 14 and 15, i.e. between 2492.3 m and 2592.9 m, from which palynofloras of the *D. granulata* Zone and *Didecitriletes byroensis* Subzone were observed, respectively. The Callytharra Formation is tentatively identified below the Kennedy Group from the presence of the *D. byroensis* Subzone.

Onslow 1 contrasts with wells in the Merlinleigh Sub-basin in two major respects. Firstly, it has a well-developed Upper Permian interval, approximately 350 m thick, that is apparently absent in the Merlinleigh Sub-basin. Secondly, part of the Lower Permian covering at least the *P. sinuosus* and most of the *M. trisina* Zones is absent in contrast to Kennedy Range 1 in which the *P. sinuosus* Zone is possibly as much as 1000 m thick (Fig. 13).

Quail 1

This well was drilled by WAPET in 1963–64 to investigate the hydrocarbon potential of Carboniferous–Devonian reservoirs in the Quail Anticline (Pearson, 1964). The well was terminated at 3580 m in the Silurian Tumblagooda Sandstone. Quail 1 and Remarkable Hill 1 are the only two wells in the basin to have intersected a complete section of the Lyons Group.

Previous palynological studies on Quail 1 are by Balme (*in* Pearson, 1964) and Powis (1981). Dickins (*in* Pearson, 1964) identified Permian brachiopods of Callytharra Formation aspect from core 4. Palynomorph yields in this well are particularly poor and consequently few of the palynological determinations can be made with any authority. This review is based on samples held in the GSWA Relinquishment Collection with data for some samples obtained from the reports by Balme and Powis.

The upper part of the succession in Quail 1 is better sampled in the nearby BHP Wandagee 1 borehole (Plate 1). In Quail 1 Permian palynomorph zones can be tentatively recognized down to core 7 (1436.4–1432.3 m). Below this level Carboniferous palynomorphs can be identified at least in core 12 (2230.8–2231.4 m) and it is possible that Carboniferous strata are present above this level.

Remarkable Hill 1

Remarkable Hill 1 was drilled on a surface anticline by Marathon in 1968–69 to investigate the petroleum potential of the Lower Palaeozoic succession. The well was terminated at 3206 m in a Carboniferous siltstone. The well intersected a complete section of the Wooramel Group, Callytharra Formation and Lyons Group. The palynoflora of that interval was not examined as only three cores were cut above the Lyons Group in this well, and the well is only 10 km from Giralia 1 which is considerably better sampled (Plate 1).

Previous palynological work on Remarkable Hill 1 consists of a brief report by E. M. Kemp (*in* Berven, 1969) on cores 8–12 and a report by Hannah (1985b) for ESSO. Only the sample from 1071.1 m (3514 ft) that was prepared by ESSO is relevant to this study. This sample was placed in Stage 3a by Hannah, but is now placed in the *P. confluens* Zone.

Sholl 1

Sholl 1, the third well in WAPET's Island Drilling Program, was a stratigraphic test drilled on Sholl Island in 1967. In the well completion report the Permian section from 832 to 1061 m was assigned to the Kennedy Group, and the interval from 1061 to 1272 m (TD) was assigned to the Byro Group on the brachiopod evidence from 1078–1083 m in core 4 (Coleman, *in* Brownhill, 1967). By comparison, Delphos and Dedman (1988) included all of the section down to 1135 m in the Kennedy Group based on a log correlation with Candace 1 and Fortescue 1.

In the first processing of sidewall core samples from this well, WAPET employed the unfortunate practice, in some instances, of combining material from two or more adjacent sidewall cores into one residue. Two of the sidewall cores treated in this manner were those from 1109.8 and 1119.2 m (3641 and 3672 ft). The slides from this preparation show a rich and diverse assemblage clearly referable to the *D. ericianus* Zone. Another preparation, presumably made from the remains of the 1119.2 m sidewall core alone, yielded an assemblage that belongs in the *P. confluens* Zone. The conclusion is that the 1109.8 m sidewall core is from the Kennedy Group and the 1119.2 m sidewall core is from the Lyons Group. The present palynological examination suggests, therefore, that there is a substantial time break at the base of the Kennedy Group (at a depth of approximately 1115 m, Fig. 8).

Stratigraphy

The first comprehensive stratigraphic studies on the Permian of the Carnarvon Basin were based on the exploration activities of Oil Search Limited in the 1930s (e.g. Condit, 1935; Condit et al., 1936; Raggat, 1936). The BMR commenced a detailed study of the basin in 1948, with fieldwork continuing until 1956. The Permian part of this work was presented by Condon (1954, 1962, 1967) and Konecki et al. (1958). WAPET commenced its assessment of the Permian of the Carnarvon Basin in 1953 (McWhae et al., 1954) and continued to have an active interest in the Permian of the basin until the late 1960s. Much of the WAPET work was incorporated into the BMR reports and into later GSWA reports. GSWA mapping in the 1970s resulted in significant modifications, and a simplified nomenclature, compared to the earlier stratigraphy (Hocking et al., 1980, 1987). Some amendments to this work were made by Hocking (1990b) as a result of reconnaissance trips in the late 1980s. The most complete review of previous stratigraphic nomenclature is by Skwarko (1993, table 2). The present work represents a revision of previous GSWA stratigraphy (Fig. 14) emphasizing the well data, and the correlation of that data with outcrop. The Permian stratigraphy is summarized in Figure 3 and Appendix 5, and formation picks for

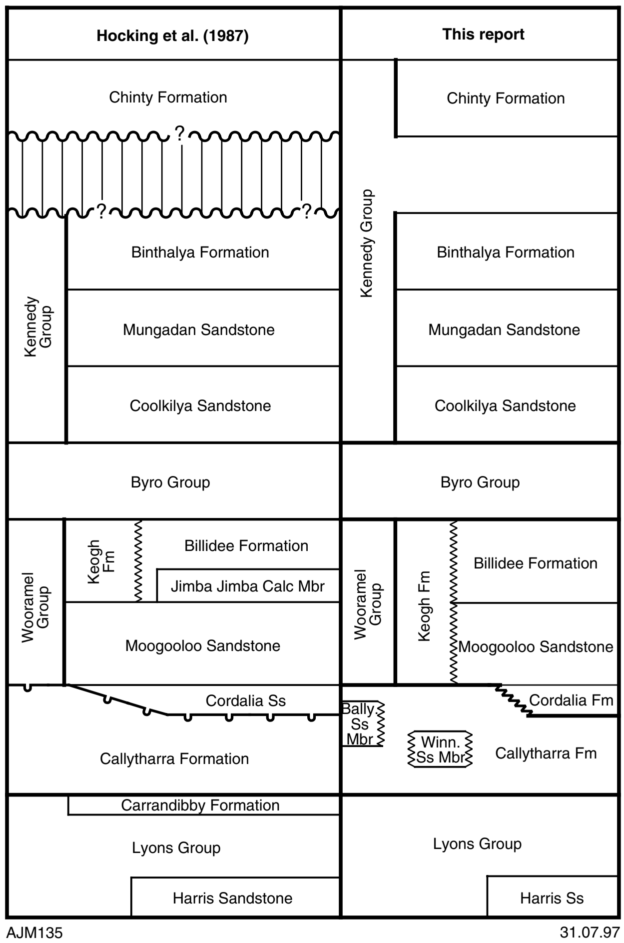


Figure 14. Comparison of nomenclature used in this report with Hocking et al. (1987)

petroleum wells used in the study are presented in Appendix 6.

Lyons Group

The Lyons Group shows ample evidence of glacial activity with quartzitic, granitic and igneous dropstones, very poorly sorted sedimentary breccia and tillite, contorted bedding often with micro-syndepositional faults, and minor varved shale. The unit unconformably overlies Lower Carboniferous, Devonian and Precambrian rocks. Palynofloras of Stage 2 and the *Pseudoreticulatispora confluens* Zone indicate an Asselian–Tastubian (early Sakmarian) age. Only Quail 1 and Remarkable Hill 1 have completely penetrated the unit and demonstrate thicknesses of 1509 m and 1457 m, respectively (Appendix 6). Seismic data, however, suggest that the unit may reach thicknesses approaching 3000 m (Fig. 7).

Originally the group was subdivided into seven formations by Condon (1962, 1967) but Hocking et al. (1987) abandoned that subdivision as their work indicated that the formations could only be reliably identified in the type areas. The Lyons Group was left largely undifferentiated with two discontinuous formations at the base (Harris Sandstone) and top (Carrandibby Formation). Neither formation, however, can be readily identified in the subsurface.

Marine macrofossils from the Lyons Group are present in outcrop within the Merlinleigh Sub-basin, and BMR 8 and 9 in the north of the Byro Sub-basin. Spinose acritarchs are apparently absent in the palynological samples from this unit suggesting a restricted marine environment of deposition or, possibly, that climatic conditions were unfavourable for acritarchs.

Callytharra Formation

The Callytharra Formation consists of fossiliferous limestone, siltstone and claystone with minor sandstone. Two local sandstone bodies within the upper part of the formation are accorded member status: the southern sandstone (Ballythanna Sandstone Member) is restricted to the Byro Sub-basin; and the northern sandstone (Winnemia Sandstone Member) has been recognized only in the vicinity of the Jimba Jimba Syncline. Palynomorphs of the *Microbaculispora trisina, Striatopodocarpites fusus* and *Pseudoreticulatispora pseudoreticulata* Zones indicate a late Sakmarian–early Artinskian age for the formation.

The Carrandibby Formation proved impossible to differentiate from the Callytharra Formation in core and is not recognized here as a separate unit. In outcrop the Carrandibby Formation may be distinguished from the overlying Callytharra Formation as it ‘locally contains scattered glacial erratics’ and has a low faunal diversity (Hocking et al., 1987) but this definition is difficult to apply to core (and clearly impossible on electric logs alone). The only dropstone present in core above the undifferentiated Lyons Group is in Ballythanna 1 and consists of a red and green chert pebble 30 cm above the base of the Callytharra Formation. In Ballythanna 1 and Gascoyne 1 the abundance of macrofossils did not change appreciably towards the Lyons Group suggesting the Carrandibby Formation is not present in these wells. The Carrandibby Formation was deposited in an environment similar to that of the Callytharra Formation but with a stronger glacial influence. Although the units may be distinguished in outcrop, the distinction is difficult to make in the subsurface. In outcrop the Carrandibby Formation is restricted to the Byro Sub-basin and an area south and east of Pells Range in the south of the Merlinleigh Sub-basin. On the geological map of the latter area (Williams et al., 1983b) the unit has a patchy distribution, possibly as a function of inconsistent mapping. The only other record of glacial influence in the Callytharra Formation is in the Mia Mia–Middalya area where a thin limestone, containing dropstones, was referred to as Carrandibby Formation equivalent by Hocking et al. (1987, fig. 51).

The fossiliferous carbonaceous siltstone and limestone in the Callytharra Formation indicate deposition in a quiet marine environment. The presence of small amounts of pyrite throughout the carbonaceous siltstone, in the lower part of the formation, suggests anaerobic conditions for this part of the unit.

Winnemia Sandstone Member

The Winnemia Sandstone Member (new name — from Winnemia Pool on the Gascoyne River) is restricted to exposures previously assigned to the Moogooloo Sandstone in the Jimba Jimba Syncline (Fig. 9) and in Gascoyne 1 (Fig. 5). The member consists of massive fine- to medium-grained sandstone with rare bioturbation. Bedding is rarely perceptible on an outcrop scale but indistinct bedding trends are evident on aerial photographs. The type section runs across the northeast end of the syncline where the only complete, non-faulted section of the unit is present at 25°02'10"S, 114°59'30"E (Fig. 9). Condon (1967, fig. 67) estimated that the unit is approximately 128 m thick but from the dips the thickness is approximately 100 m.

A palynology-based correlation of Bidgemia 1 with Gascoyne 1 clearly shows that the member is restricted to the Callytharra Formation in the latter well where it lies between occurrences of the *P. pseudoreticulata* and *S. fusus* Zones (Fig. 5, Plate 1). The overlying part of the Callytharra Formation, previously assigned to the Jimba Jimba Calcarenite Member at the base of the Billidee Formation (Hocking et al., 1987), is not maintained as a member within the Callytharra Formation as it can only be differentiated where the Winnemia Sandstone Member is present. Brachiopods in the upper part of the Callytharra Formation in the Jimba Jimba Syncline (the type section of the Jimba Jimba Calcarenite Member) indicate an Aktastanian (early Artinskian) age, apparently somewhat younger than other faunas to the south and west of the Jimba Jimba Syncline (Archbold and Shi, 1993). This younging, however, is not confirmed by the palynoflora in Gascoyne 1 (Fig. 5, Plate 1) nor by the conodont fauna from the outcrop (Nicoll, R. S., 1996, pers. comm.). A marine shelf environment is envisaged for the Winnemia

Sandstone Member as it lies between marine fossiliferous siltstone and limestone of the Callytharra Formation.

Ballythanna Sandstone Member

The type section of the Ballythanna Sandstone Member is the interval 65–298 m in Ballythanna 1 (Mory, 1996). The unit thins to the north and in BMR 8 and 9 the member is 176 m and 120 m thick, respectively. The unit consists of fine- to medium-grained, clean, cross-bedded sandstone grading into carbonaceous and bioturbated quartz sandstone. The only macrofossils known in the unit are small shell fragments in the basal one metre of the type section. At least five coarsening-up cycles up to 20 m thick are present. Irregular to wavy carbonaceous siltstone laminae and beds up to 1 cm thick constitute less than 2% of the member. Where carbonaceous material is more common bioturbation has effectively masked the original bedding.

In the type area of the formation near Callytharra Springs the lower part of the formation is faulted against a sandstone unit. At a locality in the bed of the Wooramel River, approximately 1 km upstream from outcrop of the Callytharra Formation, the sandstone unit contains a carbonaceous siltstone bed that yielded *M. trisina* Zone palynomorphs of an apparently non-marine facies. The presence of this palynoflora suggests that the sandstone is the Moogooloo Sandstone and that, at least in the immediate vicinity of the type section, the Ballythanna Sandstone Member is absent.

In the Byro Sub-basin Konecki et al. (1958) and Condon (1967) used several names for sandstone units in the Wooramel Group (Nunnery Sandstone, and One Gum, Monument and ?Curbur Formations) which are now believed to be, at least in part, equivalent to the Ballythanna Sandstone Member. These names were later abandoned and the units placed within the Moogooloo Sandstone (van de Graaff et al., 1977). It cannot be demonstrated that these names were applied to precisely the same interval as the Ballythanna Sandstone Member. Van de Graaff et al. (1977) suggested that the Nunnery Sandstone and One Gum Formation, which outcrop to the northwest of Ballythanna 1, refer to the same unit on the northern and southern side of a splay in the Madeline Fault. If this relationship is correct then the upper contact of the Nunnery Sandstone and lower contact of the One Gum Sandstone cannot be defined. Nevertheless, the type section of the Nunnery Sandstone (Konecki et al., 1958) contains a basal, strongly ferruginous, fossiliferous ?carbonaceous siltstone that, according to N. W. Archbold (1996, pers. comm.), may be correlated to the upper undifferentiated part of the Callytharra Formation. The type section of the Curbur Formation, southeast of Ballythanna 1, is faulted and the Callytharra Formation is missing in this section. In addition, much of this section may belong to the Keogh Formation and ?Moogooloo Sandstone (Hocking, 1990b). The change from coarse- to fine-grained sandstone, between the Monument Formation in its type section (Daurie Creek) and the overlying Keogh Formation, conflicts with the change in grainsize observed in Ballythanna 1. Consequently, the upper contact of the Monument Formation does not necessarily correspond to the top of the Ballythanna Sandstone Member. It is stressed that all of these stratigraphic units, which are now believed to be, at least in part, equivalent to the Ballythanna Sandstone Member, historically were included within the Wooramel Group rather than the underlying Callytharra Formation.

Because large sections of the Ballythanna Sandstone Member consist of massive to cross-bedded sandstone and the only marine macrofossils in the type section are restricted to the basal metre, and are probably reworked, a fluvial environment of deposition seems possible. The unit, however, is enclosed by marine fossiliferous beds, and the palynoflora from shales within the type section is composed of up to 50% spinose acritarchs clearly indicating a marine environment. A lower delta plain or tidal channel environment is invoked for the Ballythanna Sandstone Member (Mory, 1996).

Wooramel Group

The Wooramel Group represents a succession of medium- to coarse-grained sandstone with minor conglomerate and siltstone, 50 to 460 m thick, that lies conformably between the finer grained Callytharra Formation and Byro Group. In the Byro Sub-basin the group comprises only the Keogh Formation, which is approximately 50 m thick. In the Merlinleigh Sub-basin the group comprises the Cordalia Formation, Moogooloo Sandstone and Billidee Formation, in ascending order (Plate 1). The Cordalia Formation is known only north of 24°30'S. The Wooramel Group is not identified as such in the Peedamullah Shelf either because of mid-Permian erosion or because in that sub-basin the entire Artinskian was a period with relatively little deposition. In outcrop, palaeocurrent directions throughout the group are predominantly to the north-northwest.

An unconformity at the base of the group was proposed by Condon (1954, 1967) and subsequent workers including Hocking et al. (1987). This relationship was deduced from the presence, in the south of the Merlinleigh Sub-basin, of a strongly karstified contact between the Moogooloo Sandstone and underlying limestone of the Callytharra Formation, and the assumption that the Cordalia Formation is a lateral equivalent of the Moogooloo Sandstone. The palynological evidence, however, indicates that the Cordalia Formation is a lateral equivalent of the upper Callytharra Formation suggesting that if there is a break in sedimentation at the base of the Wooramel Group it is too brief to detect with the palynological control available at present. In addition, the karst evidence for a hiatus has been questioned recently by Crostella (1995).

Cordalia Formation

The Cordalia Formation (Cordalia Sandstone of Hocking et al., 1987) outcrops along Gooch Range where it consists of very fine- to medium-grained sandstone. In the subsurface the unit is present as far south as Kennedy Range 1 and is predominantly a carbonaceous siltstone that coarsens upwards towards the base of the overlying

Moogooloo Sandstone (Fig. 15). The name is emended here to describe more accurately its lithology. Both the palynoflora (*S. fusus* Zone) and the character of the gamma ray log indicate that the unit is laterally equivalent to the upper part of the Callytharra Formation to the south (compare Burna 1 with Gascoyne 1 in Plate 1).

From outcrop Hocking et al. (1987) interpreted the Cordalia Formation as a prodelta unit based largely on its stratigraphic position below the Moogooloo Sandstone, its relatively finer grainsize, and the coarsening-upwards sequence into the Moogooloo Sandstone. Such an environment is certainly likely west of the outcrop where the unit is dominated by carbonaceous siltstone devoid of macrofossils and which probably represent deposition in an anoxic environment. The outcrop is dominated by thin bedded, bioturbated, fine-grained sandstone, and a more proximal position on the palaeoslope, such as a lower delta-front environment, is likely for those locations.

Moogooloo Sandstone

The Moogooloo Sandstone consists of fine- to coarse-grained sandstone, with thin beds of conglomerate and siltstone (Fig. 12). The unit is restricted to the Merlinleigh Sub-basin, and ranges in thickness from 30 m in the southeast, to 115 m in Giralia 1. The unit conformably overlies the Callytharra Formation south of Gooch Range and Kennedy Range 1, whereas to the north the Moogooloo Sandstone lies conformably above the Cordalia Formation. Correlation of the unit between Pells Range and the Jimba Jimba Syncline shows that the top of the unit interfingers with the basal part of the overlying Billidee Formation (Fig. 5). An early to mid-Artinskian age for the unit is indicated by the presence of the *S. fusus* and *M. trisina* Zones. A fluvial to fluvial-dominated delta-front depositional setting is suggested for the unit with the unit becoming more marine to the north (Hocking et al., 1987).

Billidee Formation

The Billidee Formation is the uppermost unit of the Wooramel Group and consists of interbedded sandstone and siltstone with minor conglomerate. Based on the brachiopod faunas (Archbold, N. W., 1997, pers. comm.) limestone outcrops on the western margin of the Merlinleigh Sub-basin, that were previously included within the formation as the Jimba Jimba Calcarenite Member (Hocking et al., 1987), appear to be part of the stratigraphically lower Callytharra Formation (the cover photograph is from one of these outcrops). In the subsurface both upward-coarsening and fining cycles are evident in the Billidee Formation from wireline logs but are difficult to correlate between individual wells (Fig. 5, Plate 1). The unit increases in thickness to the north reaching almost 210 m in Giralia 1.

Hocking et al. (1987) suggested two low-energy depositional settings were active during deposition of the Billidee Formation; a tidally-influenced marine shelf to offshore marine environment, and a tidally dominated delta-plain environment. Hocking (1990b) noted that the formation represented a second phase of deltaic progradation, with lower energy conditions than the underlying Moogooloo Sandstone.

Keogh Formation

The Keogh Formation is restricted to the Byro Sub-basin and varies from a clayey siltstone through silty fine- to coarse-grained sandstone to conglomerate. An Artinskian age is suggested from the stratigraphic position of the unit above the Callytharra Formation, in agreement with Condon (1967) and Hocking et al. (1987). Both the stratigraphic position of the unit and its implied age suggest that the Keogh Formation is laterally equivalent to the Moogooloo Sandstone and Billidee Formation in the Merlinleigh Sub-basin.

In the outcrop near Ballythanna 1 and 32 km to the east-southeast (Mulyajingle Peak), the Keogh Formation is a predominantly silty unit that overlies medium- to coarse-grained sandstone mapped as Moogooloo Sandstone (Williams et al., 1983a; Hocking, 1990b). Correlation of Ballythanna 1 with BMR 8 and 9, however, suggests that the unit mapped as Moogooloo Sandstone along the northwestern margin of the Byro Sub-basin is the Ballythanna Sandstone Member of the Callytharra Formation (Mory, 1996). Detailed outcrop mapping in the Byro Sub-basin is required to clarify this inconsistency as, if accepted at face value, it suggests the Moogooloo Sandstone is missing in the north of the Byro Sub-basin and that the Keogh Formation is disconformable on the Callytharra Formation in that area. Alternatively, it may be possible to divide the Keogh Formation into a predominantly sandy lower part and a largely silty upper part. If such a division can be verified from detailed outcrop mapping, then the name Keogh Formation could be abandoned and replaced with Moogooloo Sandstone and Billidee Formation. Until these inconsistencies are resolved it is proposed to include the few outcrops mapped as Moogooloo Sandstone near Ballythanna 1 within the Keogh Formation, as suggested by Mory (1996).

On the basis of sedimentary structures indicating tidal conditions as well as the intercalation of high- and low-energy facies Hocking et al. (1987) suggested that the lower part of the Keogh Formation was deposited in a tidally influenced delta-plain environment. Outcrop of the formation near Mulyajingle Peak was considered by Hocking (1990b) to have been deposited in an interdistributary bay environment.

Byro Group

The Byro Group consists of a succession of carbonaceous siltstone and mudstone with fine-grained, hummocky cross-stratified and bioturbated sandstone. The lower seven formations within the group make up three upward-coarsening cycles (Coyrie Formation–Mallens Sandstone, Bulgadoo Shale–Cundlego Formation, and Quinnanie Shale–Wandagee Formation–Nalbia Sandstone, in ascending order) with a predominantly fine-grained unit (Baker Formation) at the top of the group. The only well

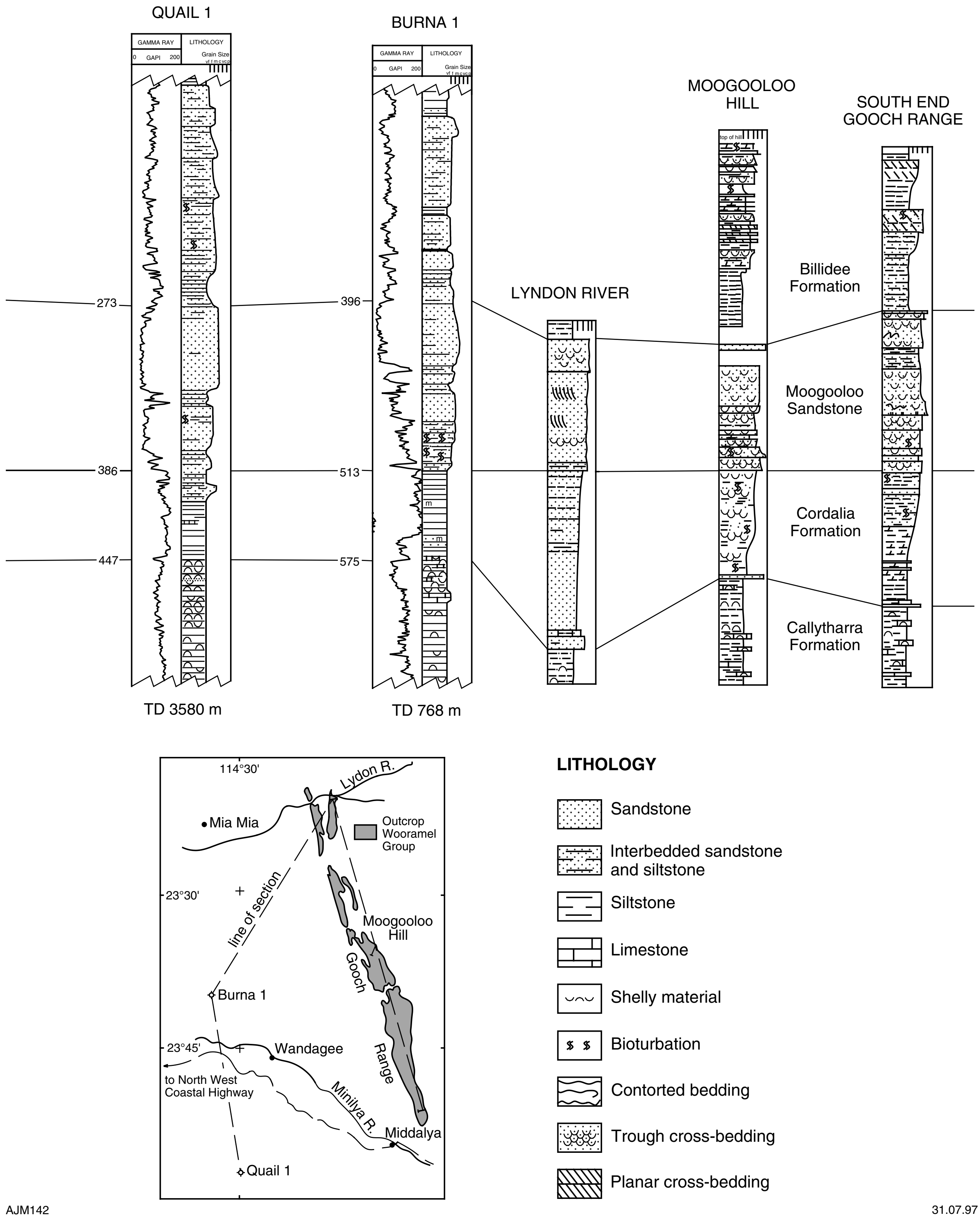


Figure 15. Stratigraphic correlation of the interval from the Callytharra to Cordalia Formations from Quail 1 and Burna 1 to measured outcrop sections along Gooch Range. Datum top of Cordalia Formation

with a complete section (1363 m) of the Byro Group is Kennedy Range 1 (Fig. 13). The group probably does not exceed 1500 m in thickness based on outcrop and seismic data. The group appears to be entirely restricted to the *P. sinuosus* Zone making this a time of extremely rapid sedimentation (approximately 300 m/Ma). The Byro Group is absent from the Peedamullah Shelf (Figs 8 and 13).

The yield of palynomorphs from the group is low, especially in Kennedy Range 1, largely because of rapid sedimentation.

A storm-dominated marine shelf environment is suggested for the group (Moore et al., 1980a; Hocking et al., 1987).

Kennedy Group

The Kennedy Group was originally defined for the dominantly sandy succession above the Byro Group that outcrops between the Gascoyne and Minilya rivers, comprising the Coolkilya Sandstone, Mungadan Sandstone and Binthalya Formation (Condon, 1954, 1967). Subsequently the group was extended north into the subsurface based on the similarity of the palynoflora in wells such as Onslow 1 (Balme, *in* Jones, 1967), Hope Island 1 (Balme, *in* Bowering, 1968) and Cunaloo 1 (Wiseman and Dolby, *in* Meath, 1972) to that of Merlinleigh 1. The subsurface occurrences in the north of the basin were later referred to the Chinty Formation as they were thought to be younger than, and therefore distinct from, the Kennedy Group in the Merlinleigh Sub-basin (Hocking, 1985; Hocking et al., 1987). The type section of the Chinty Formation was placed in Onslow 1 (2096–2258 m) as this well contains the most complete section. In that well the predominantly coarse-grained siliciclastic Chinty Formation overlies a 60 m thick limestone that, on lithological criteria, originally was considered part of the Byro Group. The present review of the palynoflora in Onslow 1, however, shows that the *D. ericianus* Zone in the lower half of the Chinty Formation extends a further 140 m below that formation, well below the limestone (Fig. 13). The presence of the *D. granulata* Zone immediately below indicates that this part of the section correlates with the upper part of the Kennedy Group in Kennedy Range 1 (Fig. 13), and shows that there is no discernible break in sedimentation between the Kennedy Group in the outcrop area and the Chinty Formation in the Peedamullah Shelf. Therefore, the formation is included within the Kennedy Group and the group, as here defined, extends in age from approximately the uppermost *P. sinuosus* Zone to the *D. parvithola* Zone (Fig. 3). The interval 2258–2495 m below the type section of the Chinty Formation is here identified as undifferentiated Kennedy Group (Fig. 8).

Thick limestones within the Kennedy Group have a patchy distribution on the Peedamullah Shelf and are present in Hope Island 1 (40 m), Abduls Dam 1 (>30 m), Onslow 1 (60 m), Dill 1 (>47 m), Fennel 1 (>297 m) and Crackling 1 (>31 m). The latter three wells were terminated within the limestone and, as they did not penetrate a complete section of the group, the palynoflora of these wells was not assessed in this study. Nevertheless, onshore the thick limestone lies within the *D. ericianus* Zone whereas in the wells to the north the limestone appears to belong within the *D. parvithola* Zone. This distribution suggests that these limestone horizons may belong to two different stratigraphic levels but, given the small number of wells in which such limestone is present, no attempt is made here to name them.

Correlation of the Kennedy Group based on the present palynology indicates a northerly shift in the depocentre for the Kennedy Group between the *D. ericianus* and *D. parvithola* Zones. In addition, the base of the Chinty Formation becomes younger to the north shifting from high in the *D. ericianus* Zone to within the *D. parvithola* Zone (Fig. 8).

On most of the Peedamullah Shelf the Kennedy Group rests disconformably on the Lyons Group. The Callytharra Formation is present below the group only in Onslow 1 and possibly Candace 1 (Fig. 8).

Moore et al. (1980b) proposed two depositional models for the Kennedy Group: a moderate palaeoslope model with a narrow transition between shoreface and offshore environments corresponding to the Coolkilya Sandstone, and a broad sandy shelf with a low palaeoslope corresponding to the Mungadan Sandstone and Binthalya Formation. Hocking (1990b) suggested that the Mungadan Sandstone represented renewed deltaic progradation, in a subaqueous but fluvially-dominated setting. For the younger part of the Kennedy Group preserved on the Peedamullah Shelf, Hocking et al. (1987) suggested deposition in a sandy marine shelf.

Thermal alteration (maturation)

Changes in the colour of spores and pollen can be used to assess the degree of thermal alteration that organic material in a rock has been subjected to. This can then be used to assess the relative maturity for petroleum generation of the organic particles in a sedimentary rock. The thermal alteration index (TAI) for well samples is shown in Appendix 2. The base reference for the TAI is Pearson's colour chart illustrated by Traverse (1988, plate 1) which gives TAI values of 1 to 5. According to Traverse (1988) values of 2 or less indicate immature organic thermal maturity, values of 2+ to 3+ indicate the mature phase for liquid petroleum generation, and values greater than 3+ indicate overmature organic material.

It is not possible to determine a TAI value for all samples. Useable kerogen (unoxidized) slides are not available for many sample depths, although in a few wells approximate TAI assessments have been made from slides of oxidized residues.

On the basis of spore colour, the only wells in the Merlinleigh Sub-basin to contain mature Permian sediments are Kennedy Range 1, Quail 1 and Giralia 1. By comparison, all the wells on the Peedamullah Shelf, for which kerogen slides are available, contain mature Permian sediments.

Kennedy Range 1 represents the thickest drilled Permian section above the Lyons Group in the Merlinleigh Sub-basin. According to the spore colouration, TAI values range from about 2+ in core 1 to 4- or more in the lowest sample at 2215.3 m. From these figures the upper 2000 m of the well, and particularly the interval from 1000 to 2000 m, can be placed in the mature zone for hydrocarbon generation. The lower interval, from the Callytharra Formation down to at least 2215.3 m, is overmature for liquid hydrocarbon generation. These results are comparable to those based on vitrinite reflectance values which indicate that the interval 600–1700 m is in the oil-generation window, and below that depth is in the gas-generation window (Ghori, 1996, fig. 27). The vitrinite reflectance values for this well are believed to be anomalously high due to the presence of a nearby local intrusion (Ghori, 1996).

Quail 1 contains mature organic material (TAI 3) at relatively shallow depth (about 500 m) in the Callytharra Formation. Higher samples may also be marginally mature. Vitrinite reflectance modelling similarly suggests that Quail 1 is mature for oil generation from surface to 1500 m, and that below that depth the lower part of the Lyons Group is in the gas-generation window (Ghori, 1996, fig. 28).

Giralia 1 contains organic material that is marginally mature (TAI 2+). Organic material from wells on the Peedamullah Shelf indicates that a mature Permian section for hydrocarbon generation is present from depths as shallow as 430 m in Fortescue 1 to about 3000 m in Onslow 1.

In all the shallow wells (total depth less than 1000 m) from the southern Merlinleigh Sub-basin in this study, thermal maturity is not greater than TAI 2 suggesting that the Lower Permian in those wells is immature for petroleum generation. Vitrinite reflectance modelling, by comparison, suggests that the Permian in these shallow wells is within the early- to mid-mature window for oil generation (Ghori, 1996, figs 23–26).

Acknowledgements

We thank AGSO and WAPET for providing slides and core material. We also thank Bob Nicoll and Clinton Foster (AGSO), and Neil Archbold (Deakin University) for reviewing the manuscript.

References

AFMECO Pty Ltd, 1978, Results of 1978 drilling programme, Jacobs Gully area (TR 6785, 6786), Carnarvon Basin: Western Australia Geologial Survey, M-series, Item 806 A8461 (unpublished).

ARCHBOLD, N. W., 1993, A zonation of the Permian faunas of western Australia, *in* Gondwana Eight, assembly, evolution and dispersal, *edited by* R. H. FINDLAY, R. UNRUG, M. R. BANKS and J. J. VEEVERS: A.A. Balkema, Rotterdam, p. 313–321.

ARCHBOLD, N. W., 1995a, Studies on Western Australian Permian brachiopods 12. Additions to the late Asselian–Tastubian faunas: Proceedings of the Royal Society of Victoria, v. 107, p. 95–112.

ARCHBOLD, N. W., 1995b, Ufimian (early Late Permian) brachiopods from the Perth Basin, Western Australia: Memoir Association of Australasian Palaeontologists, v. 18, p. 153–163.

ARCHBOLD, N. W., and SHI, G. R., 1993, Aktastinian (Early Artinskian, Early Permian) brachiopods from the Jimba Jimba Calcarenite, Wooramel Group, Carnarvon Basin, Western Australia: Proceedings of the Royal Society of Victoria, v. 105, p. 187–202.

ARCHBOLD, N. W., and SHI, G. R., 1995, Permian brachiopod faunas of Western Australia: Gondwanan-Asian relationships and Permian climate: Journal of Southeastern Asian Earth Sciences, v. 11 (30), p. 207–215.

ARCHBOLD, N. W., and SKWARKO, S. K., 1988, Brachiopods and bivalves of Kungurian (late Early Permian) age from the Coolkilya Sandstone, Carnarvon Basin, Western Australia: Western Australia Geological Survey, Report 23, p. 1–15.

AUSTRALIAN OCCIDENTAL PETROLEUM, 1983, Candace No. 1 well completion report: Western Australia Geological Survey, S-series, S2202 A12 (unpublished).

BACKHOUSE, J., 1991, Permian palynostratigraphy of the Collie Basin, Western Australia: Review of Palaeobotany and Palynology, v. 67, p. 237–314.

BACKHOUSE, J., 1993, Palynology and correlation of Permian sediments in the Perth, Collie and Officer Basins, Western Australia: Western Australia Geological Survey, Report 34, p. 111–128.

BERVEN, R. J., 1969, Remarkable Hill No. 1 well completion report: Western Australia Geological Survey, S-series, S443 A1 (unpublished).

BOWERING, O. J. W., 1968, Hope Island No. 1 well completion report: Western Australia Geological Survey, S-series, S412 A1 (unpublished).

BROWNHILL, M. H., 1965, Report on Merlinleigh Anticline structure drilling: Western Australia Geological Survey, S-series, S300 A1 (unpublished).

BROWNHILL, M. H., 1967, Sholl No. 1 well completion report: Western Australia Geological Survey, S-series, S296 A1 (unpublished).

CONDIT, D. D., 1935, Oil possibilities in Northwest District, Western Australia: Economic Geology, v. 30(8), p. 860–878.

CONDIT, D. D., RAGGATT, H. G., and RUDD, E. A., 1936, Geology of Northwest Basin, Western Australia: American Association of Petroleum Geologists, Bulletin 20(8), p. 1028–1070.

CONDON, M. A., 1954, Progress report on the stratigraphy and structure of the Carnarvon Basin, Western Australia: Australia BMR, Report 15, 163p.

CONDON, M. A., 1962, Kennedy Range, W.A. Sheet SG 50–1: Australia BMR, 1:250 000 Geological Series Explanatory Notes, 28p.

CONDON, M. A., 1967, The geology of the Carnarvon Basin, Western Australia, Part 2 — Permian stratigraphy: Australia BMR, Bulletin 77, 191p.

COOPER, B. J., 1991, Late Palaeozoic spore/pollen stratigraphy in Australia: Geological Society of India, Memoir 20, p. 109–129.

CROSTELLA, A., 1995, Structural evolution and hydrocarbon potential of the Merlinleigh and Byro Sub-basins, Carnarvon Basin, Western Australia: Western Australia Geological Survey, Report 45, 36p.

CROSTELLA, A., and IASKY, R. P., 1997, Structural interpretation and hydrocarbon potential of the Giralia area, Carnarvon Basin: Western Australia Geological Survey, Report 52.

DAMPIER MINING, 1975, Final report for Temorary Reserve 5951H, Merlinleigh Basin, Western Australia: Western Australia Geological Survey, S-series, S1100 (unpublished).

DELPHOS, E., and DEDMAN, R., 1988, The petroleum potential of the Peedamullah Shelf, *in* The North West Shelf, Australia *edited by* P. G. PURCELL and R. R. PURCELL: Proceedings of Petroleum Exploration Society Australia (W.A. Branch), p. 147–156.

ESSO AUSTRALIA LIMITED, 1985a, Burna 1 well completion report, *compiled by* S. A. GREENWOOD: Western Australia Geological Survey, S-series, S2629 A3 (unpublished).

ESSO AUSTRALIA LIMITED, 1985b, Gascoyne 1 well completion report, *compiled by* S. A. GREENWOOD: Western Australia Geological Survey, S-series, S2631 A4 (unpublished).

EVANS, P. R., 1967, Upper Carboniferous and Permian palynological stages and their distribution in eastern Australia: Australia BMR, Record 1967/99 (unpublished).

EVANS, P. R., 1969, Upper Carboniferous and Permian palynological stages and their distribution in eastern Australia: Gondwana Stratigraphy, IUGS. 1st Gondwana Symposium, Buenos Aires, 1967, UNESCO, p. 41–53.

FOSTER, C. B., 1979, Permian plant microfossils of the Blair Athol Coal Measures, Baralaba Coal Measures, and basal Rewan Formation of Queensland: Geological Survey of Queensland, Publication 372, 244p.

FOSTER, C. B., 1982, Spore-pollen assemblages of the Bowen Basin, Queensland (Australia): their relationship to the Permian/Triassic boundary: Review of Palaeobotany and Palynology, v. 36, p. 165–183.

FOSTER, C. B., and WATERHOUSE, J. B., 1988, The *Granulatisporites confluens* Oppel-zone and Early Permian marine faunas from the Grant Formation in the Barbwire Terrace, Canning Basin, Western Australia: Australian Journal of Earth Sciences, v. 35, p. 135–157.

GHORI, K. A. R., 1996, Petroleum source rocks, Merlinleigh and Byro Sub-basins, Carnarvon Basin, Western Australia: Western Australia Geological Survey, Record 1995/5, 102p.

HANNAH, M. J., 1985a, Palynological analysis Bidgemia 1 Merlinleigh Sub-basin: Western Australia Geological Survey, S-series, S805 A1 (unpublished).

HANNAH, M. J., 1985b, Palynological analysis of samples from Cane River 1, Minderoo 1 and Remarkable Hill 1: Western Australia Geological Survey, S-series, S2892 A2 (unpublished).

HOCKING, R. M., 1990a, Carnarvon Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 457–495.

HOCKING, R. M., 1990b, Field guide for the Carnarvon Basin: Western Australia Geological Survey, Record 1990/11, 74p. (plus 7p. undated supplement).

HOCKING, R. M., MOORE, P. S., and MOORS, H. T., 1980, Modified stratigraphic nomenclature and concepts in the Palaeozoic sequence of the Carnarvon Basin, W.A.: Western Australia Geological Survey, Annual Report 1979, p. 51–55.

HOCKING, R. M., MOORS, H. T., and van de GRAAFF, W. J. E., 1987, Geology of the Carnarvon Basin, Western Australia: Western Australia Geological Survey, Bulletin 133, 289p.

JONES, D. K., 1967, Onslow No. 1 well, Western Australia, well completion report: Western Australia Geological Survey, S-series, S313 A1 (unpublished).

JOHNSON, M. H., 1955, Giralia No. 1 test, geological completion report: Western Australia Geological Survey, S-series, S51 A1 (unpublished).

KEMP, E. M., BALME, B. E., HELBY, R. J., KYLE, R. A., PLAYFORD, G., and PRICE, P. L., 1977, Carboniferous and Permian palynostratigraphy in Australia and Antarctica — a review: BMR Journal of Australian Geology and Geophysics, v. 2, p. 177–208.

KOLUZS, D., 1972, Hartogen Moogooree No. 1 and 2, and Bidgemia No. 1 well completion reports: Western Australia Geological Survey, S-series, S781 A1 (unpublished).

KONECKI, M. C., DICKENS, J. M., and QUINLAN, T., 1958, The geology of the coastal area between the lower Gascoyne and Murchison rivers, Western Australia: Australia BMR, Report 37, 144p.

LEHMANN, P. R., 1967, Kennedy Range 1 well completion report: Western Australia Geological Survey, S-series, S322 A1 (unpublished).

MacLEOD, M., 1973, Preliminary investigation of the palynology of the Permian section of the Byro Sub-basin, Western Australia: University of Western Australia, Hons thesis (unpublished).

McWHAE, J. R. H., PARRY, J. C., and STANLEY, D. J., 1954, The geology of the Gascoyne-Wooramel area, Coastal District, Western Australia: Western Australia Geological Survey, S-series, S142 A1 (unpublished).

MEATH, J. R., 1972, Cunaloo No. 1 well completion report: Western Australia Geological Survey, S-series, S693 A2 (unpublished).

MERCER, C. R., 1967, Completion report BMR 8, Mount Madeline and 9, Daurie Creek, Byro Basin, Western Australia: Australia BMR, Report 108, 19p.

MOORE, P. S., DENMAN, P. D., and HOCKING, R. M., 1980a, Sedimentology of the Byro Group (Permian), Carnarvon Basin, Western Australia: Western Australia Geological Survey, Annual Report 1979, p. 55–64.

MOORE, P. S., HOCKING, R., M., and DENMAN, P. D., 1980b, Sedimentology of the Kennedy Group (Permian), Carnarvon Basin, Western Australia: Western Australia Geological Survey, Annual Report 1979, p. 65–72.

MORY, A. J. (compiler), 1996, GSWA Ballythanna 1 well completion report, Byro Sub-basin, Carnarvon Basin, Western Australia: Western Australia Geological Survey, Record 1996/7, 48p.

PEARSON, G. R., 1964, Quail No. 1 well completion report: Western Australia Geological Survey, S-series, S67 A1 (unpublished).

PERCIVAL, I. G., and COONEY, P. M., 1985, Petroleum geology of the Merlinleigh Sub-basin, Western Australia: APEA Journal, v. 25, p. 190–203.

PERRY, W. J., 1965, Completion Report, Stratigraphic and Structural Bores BMR 6 and 7, Muderong, Western Australia: Australia BMR, Report 81, 20p.

POWIS, G. D., 1981, Palynological report on four wells from the Merlinleigh Sub-basin, Western Australia: Western Australia Geological Survey, S-series, S30200 A1 (unpublished).

POWIS, G. D., 1984, Palynostratigraphy of the Late Carboniferous sequence, Canning Basin, W.A., *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia (PESA); Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 429–438.

PRICE, P. L., 1976, Permian palynology of the Bowen Basin, *in* A guide to the geology of the Bowen and Surat Basins in Queensland *edited by* A. R. JENSEN, N. F. EXON, J. C. ANDERSON and W. H. KOPPE: 25th International Geological Congress, Excursion Guide 3C.

PRICE, P. L., 1983, A Permian palynostratigraphy for Queensland, *in* Permian Geology of Queensland: Symposium on Permian Geology of Queensland, Brisbane 1982, Proceedings Geological Society of Australia, Queensland Division, p. 155–211.

PURCELL, R., 1994, Palynology review — Onslow 1, Hope Island 1 and Mermaid 1: Western Australia Geological Survey, S-series, S30409 A1 (unpublished).

RAGGATT, H. G., 1936, Geology of North-West Basin, Western Australia, with particular reference to the stratigraphy of the Permo-Carboniferous: Royal Society of New South Wales Journal, v. 70, p. 100–174.

REID, A. G., 1968, Direction No. 1 well completion report: Western Australia Geological Survey, S-series, S424 (unpublished).

REID, A. G., 1969, Fortescue No. 1 well completion report: Western Australia Geological Survey, S-series, S467 A1 (unpublished).

ROBERTS, J., CLAOUÉ-LONG, J. C., and FOSTER, C. B., 1996, SHRIMP zircon dating of the Permian System of eastern Australia: Australian Journal of Earth Sciences, v. 43, p. 401–421.

SKWARKO, S. K., 1993, Palaeontology of the Permian of Western Australia: Western Australia Geological Survey, Bulletin 136, 417p.

TRAVERSE, A., 1988, Palaeopalynology: Boston, Unwin Hyman, 600p.

van de GRAAFF, W. J. E., HOCKING, R. M., and DENMAN, P. D., 1977, Revised stratigraphic nomenclature and interpretations in the east-central Carnarvon Basin, W.A.: Western Australia Geological Survey, Annual Report 1976, p. 37–39.

WARRIS, B. J., 1994, The hydrocarbon potential of the onshore Carnarvon Basin: *in* West Australian Basins *edited by* P. G. PURCELL and P. R. PURCELL: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, 1994, p. 365–372.

WILLIAMS, I. R., WALKER, I. M., HOCKING, R. M., and WILLIAMS, S. J., 1983a, Byro, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 27p.

WILLIAMS, S. J., WILLIAMS, I. R., and HOCKING, R. M., 1983b, Glenburgh, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 25p.

Appendix 1

Petroleum and mineral wells referred to in this study

Name	*Item-No.*	*Latitude (S)*	*Longitude (E)*	*Class*	*Elevation*	*Rig elevation*	*TD (m)*	*Bottomed in*	*Year*	*Company*	*Hydro-carbon status*	*Comp-letion status*	*Gas*	*Oil*
Abduls Dam 1	S20097	21°57'02"	114°49'44"	NFW	4	8	770	U. Permian	1991	Pan Pacific	D	PA	Poor	Nil
AFMECO JG 1	M2368	25°17'50"	115°13'55"	Mineral	?180	?180	200	L. Permian	1978	AFMECO	–	A	–	–
AFMECO JG 2	M2368	25°15'05"	115°07'25"	Mineral	?180	?180	307	L. Permian	1978	AFMECO	–	A	–	–
AFMECO JG 3	M2368	25°11'45"	115°02'30"	Mineral	?190	?190	289	L. Permian	1978	AFMECO	–	A	–	–
AFMECO JG 6	M2368	24°59'50"	114°59'15"	Mineral	?140	?140	259	L. Permian	1978	AFMECO	–	A	–	–
AFMECO JG 7	M2368	25°02'45"	115°00'00"	Mineral	?140	?140	242	L. Permian	1978	AFMECO	–	A	–	–
BHP Wandagee 1	S1100	23°57'09"	114°30'03"	Mineral	115	115	398	L. Permian	1975	BHP	–	A	–	–
Bidgemia 1	S805	25°16'00"	115°20'20"	STR	189	190	212	L. Permian	1972	Hartogen	D	PA	Nil	Nil
BMR 6 Kennedy Range	S3046 V1	24°05'55"	114°46'20"	STR	175	176	305	L. Permian	1958	BMR	D	PA	Nil	Nil
BMR 7 Kennedy Range	S3046 V2	24°05'55"	114°46'30"	STR	174	176	609	L. Permian	1958	BMR	D	PA	Nil	Nil
BMR 8 Glenburgh	S3047 V1	25°44'50"	115°38'23"	STR	244	245	916	L. Permian	1959	BMR	D	PA	Nil	Nil
BMR 9 Glenburgh	S3047 V2	25°33'17"	115°53'17"	STR	274	275	701	L. Permian	1959	BMR	D	PA	Nil	Nil
Burna 1	S2629	23°39'58"	114°26'24"	NFW	81	86	768	U. Carboniferous	1984	ESSO	D	PA	Nil	Nil
Candace 1	S2202 A5	20°49'37"	115°55'07"	NFW	–21	32	2 063	L. Permian	1982	Occidental	D	PA	Nil	Nil
Crackling 1	S20201	21°11'14"	115°33'29"	NFW	–12	32	625	U. Permian	1993	Command	D	PA	Poor	Fair
Cunaloo 1	S693	22°00'48"	114°53'47"	STR	12	15	797	U. Permian	1972	WAPET	D	PA	Nil	Nil
Dill 1	S20139	21°25'40"	115°10'24"	NFW	–14	34	1 162	U. Permian	1992	WMC	D	PA	Fair	Good
Direction 1	S424	21°32'03"	115°07'42"	STR	5	6	673	L. Permian	1968	WAPET	D	PA	Nil	Nil
Fennel 1	S2595	21°22'33"	115°15'04"	NFW	–14	33	1 561	U. Permian	1985	WMC	D	PA	Poor	Poor
Fortescue 1	S467	21°01'10"	115°51'24"	STR	5	6	610	L. Permian	1969	WAPET	D	PA	Nil	Nil
Gascoyne 1	S2631	25°02'20"	115°01'09"	NFW	127	128	526	U. Carboniferous	1984	ESSO	D	PA	Nil	Nil
Giralia 1	S51 V8	22°59'38"	114°10'05"	NFW	109	112	1 244	L. Permian	1955	WAPET	D	W	Nil	Nil
GSWA Ballythanna 1	S20327	26°03'42"	115°40'11"	STR	270	270	465	L. Permian	1995	GSWA	D	A	Nil	Nil
Hope Island 1	S412	22°09'39"	114°28'42"	STR	5	9	1 426	L. Permian	1968	WAPET	D	PA	Nil	Nil
Kennedy Range 1	S322	24°29'50"	114°59'19"	NFW	295	299	2 227	L. Permian	1966	WAPET	D	PA	Fair	Nil
Merlinleigh 1	S300 V1	24°29'48"	114°59'15"	STR	290	292	305	L. Permian	1966	WAPET	D	PA	Nil	Nil
Merlinleigh 2	S300 V2	24°28'45"	114°59'27"	STR	293	294	306	L. Permian	1966	WAPET	D	PA	Nil	Nil
Merlinleigh 3	S300 V3	24°29'08"	114°59'53"	STR	294	295	166	L. Permian	1966	WAPET	D	PA	Nil	Nil
Merlinleigh 4	S300 V4	24°29'08"	114°58'57"	STR	290	291	136	L. Permian	1966	WAPET	D	PA	Nil	Nil
Merlinleigh 5	S300 V5	24°28'27"	114°59'07"	STR	290	292	175	L. Permian	1966	WAPET	D	PA	Nil	Nil
Moogooree 1	S781	24°15'20"	115°15'30"	STR	253	254	128	L. Permian	1972	Hartogen	D	PA	Nil	Nil
Onslow 1	S313	21°45'56"	114°52'17"	NFW	5	10	2 998	L. Permian	1966	WAPET	Gas	A	Good	Nil
Quail 1	S67	23°57'09"	114°30'04"	NFW	115	118	3 580	Silurian	1963	WAPET	D	PA	Nil	Nil
Remarkable Hill 1	S443	22°57'20"	114°09'20"	NFW	107	111	3 206	U. Carboniferous	1968	Marathon	D	PA	Nil	Nil
Sholl 1	S296	20°57'00"	115°53'50"	STR	–	9	1 272	L. Permian	1967	WAPET	D	PA	Nil	Nil

NOTE: A = abandoned, D = dry, m = GSWA m series, NFW = new field wildcat, PA = plugged and abandoned, S = GSWA S series, STR = stratigraphic, TD = total depth, W = water bore; U = Upper; L = Lower

Appendix 2

Palynology summary for individual wells

Depth (metres)	*Depth (feet)*	*Sample type*	*Stratigraphic unit*	*Palynology yield*	*TAI*	*Environment*	*Zone*
BHP WANDAGEE 1							
16	–	core	Coyrie Fm	moderate	2 to 2-	nonmarine	*M. trisina*
69	–	core	Billidee Fm	moderate	2 to 2-	nonmarine	*M. trisina*
154	–	core	Billidee Fm	high	2 to 2-	nonmarine	*M. trisina*
174	–	core	Billidee Fm	high	2 to 2-	nonmarine	*M. trisina*
183	–	core	Billidee Fm	high	2 to 2-	nonmarine	*M. trisina*
213.8	–	core	Billidee Fm	low	2 to 2-	nonmarine	*M. trisina*
239	–	core	Billidee Fm	low	2 to 2-	nonmarine	*M. trisina*
290	–	core	Moogooloo Ss	low	2 to 2-	nonmarine	*M. trisina*
334	–	core	Moogooloo Ss	moderate	2 to 2-	nonmarine	*M. trisina*
340	–	core	Moogooloo Ss	moderate	2 to 2-	nonmarine	*M. trisina*
370	–	core	Moogooloo Ss	high	2 to 2-	nonmarine	*M. trisina*
BIDGEMIA 1							
123.3	404'9"	core	Callytharra Fm	barren			
128.6	421'11"	core	Callytharra Fm	barren			
131.6	431'9"	core	Callytharra Fm	barren			
140.6	461'2"	core	Callytharra Fm	barren			
145.3	476'10"	core	Callytharra Fm	barren			
149.5	490'7"	core	Callytharra Fm	barren			
153.3	503'	core	Callytharra Fm	low	~ 2	marine	*D. byroensis*
159.5	523'4"	core	Callytharra Fm	low	~ 2	marine	*D. byroensis*
163.9	537'9"	core	Callytharra Fm	very low	~ 2	?nonmarine	*S. fusus*
169	554'4"	core	Callytharra Fm	moderate	~ 2	marine	*S. fusus*
171	561'1"	core	Callytharra Fm	moderate	~ 2	marine	*P. pseudoreticulata*
176.8	580'2"	core	Callytharra Fm	moderate	~ 2	marine	*P. pseudoreticulata*
180	590'8"	core	Callytharra Fm	moderate	~ 2	?nonmarine	*P. pseudoreticulata*
184	603'9"	core	Callytharra Fm	low	~ 2	?nonmarine	*P. pseudoreticulata*
186.9	613'3"	core	Callytharra Fm	moderate	~ 2	?nonmarine	*P. pseudoreticulata*
191.2	627'3"	core	Callytharra Fm	moderate	~ 2	?nonmarine	*P. pseudoreticulata*
197.7	648'7"	core	Callytharra Fm	moderate	~ 2	marine	*P. pseudoreticulata*
201.6	661'5"	core	Callytharra Fm	moderate	~ 2	?nonmarine	*P. pseudoreticulata*
206.7	678'2"	core	Callytharra Fm	moderate	~ 2	?nonmarine	*P. pseudoreticulata*
210.1	689'4"	core	Callytharra Fm	moderate	~ 2	?marine	*P. pseudoreticulata*
BMR KENNEDY RANGE 7							
33.6	110'3"	core 1	Coolkilya Ss	moderate	2	marine	*P. sinuosus*
34.4	112'9"	core 1	Coolkilya Ss	moderate	2	marine	*P. sinuosus*
35.6	116'8"	core 1	Coolkilya Ss	moderate	2	marine	*P. sinuosus*
36.1	118'5"	core 1	Coolkilya Ss	moderate	2	marine	*P. sinuosus*
63.1	207'0"	core 2	Baker Fm	moderate	2	marine	*P. sinuosus*
89.6	293'11"	core 3	Baker Fm	moderate	2	marine	*P. sinuosus*
89.7	294'4"	core 3	Baker Fm	moderate	2	marine	*P. sinuosus*
112.8	370'0"	core 4	Baker Fm	moderate	2	marine	*P. sinuosus*
122.2	401'0"	core 5	Baker Fm	moderate	2	marine	*P. sinuosus*
122.5	402'0"	core 5	Baker Fm	low	2	marine	*P. sinuosus*
151.8	498'0"	core 6	Baker Fm	low	2	marine	*P. sinuosus*
156.7	514'0"	core 7	Nalbia Ss	low	2	?nonmarine	*P. sinuosus*
157.9	518'0"	core 7	Nalbia Ss	moderate	2	marine	*P. sinuosus*
215.2	706'0"	core 9	Nalbia Ss	low	2	marine	*P. sinuosus*
250.9	823'0"	core 11	Nalbia Ss	low	2	marine	*P. sinuosus*
251.8	826'0"	core 11	Nalbia Ss	moderate	2	marine	*P. sinuosus*
331.3	1 087'0"	core 16	Quinnanie Sh	moderate	2	marine	*P. sinuosus*
333.3	1 093'8"	core 16	Quinnanie Sh	low	2	marine	Prob. *P. sinuosus*
365.2	1 198'3"	core 17	Quinnanie Sh	low	2	marine	Prob. *P. sinuosus*
366.6	1 202'9"	core 17	Quinnanie Sh	low	2	marine	Prob. *P. sinuosus*
BMR GLENBURGH 8							
309.1–309.4	1 014'2"–1 015'	core 11	Ballythanna Ss Mbr	moderate	~2	?nonmarine	*P. pseudoreticulata*
334.4–334.7	1 097'3"–1 098'	core 12	Ballythanna Ss Mbr	moderate	~2	?nonmarine	*P. pseudoreticulata*
365.5–365.7	1 199'1"–1 199'10"	core 13	Callytharra Fm	moderate	~2	?nonmarine	*P. pseudoreticulata*
365.9–366.2	1 200'6"–1 201'4"	core 13	Callytharra Fm	moderate	~2	?nonmarine	*P. pseudoreticulata*
390.4–390.7	1 280'9"–1 281'8"	core 14	Callytharra Fm	low	~2	?nonmarine	?
481.4–482.1	1 579'4"–1 581'8"	core 17	Lyons Gp	low	~2	?nonmarine	*P. confluens*
509.2–509.4	1 670'8"-1 671'4"	core 18	Lyons Gp	very low	~2	?nonmarine	?
851–851.3	2 792'–2 793'	core 30	Lyons Gp	low	~2	?nonmarine	?Stage 2
914.3–914.6	2 999'10"–3 000'8"	core 32	Lyons Gp	very low	~2	?nonmarine	?
915.1–915.4	3 002'4"–3 003'2"	core 32	Lyons Gp	low	~2	?nonmarine	?Stage 2
915.4–915.6	3 003'2"–3 004'	core 32	Lyons Gp	very low	~2	?nonmarine	?Stage 2
BURNA 1							
430.47	–	core 2	Moogooloo Ss	low	2-	?nonmarine	*M. trisina*
446.84	–	core 7	Moogooloo Ss	low	2-	?nonmarine	*M. trisina*

Appendix 2 (cont.)

Depth (metres)	Depth (feet)	Sample type	Stratigraphic unit	Palynology yield	TAI	Environment	Zone
BURNA 1 (cont.)							
453.7–456.7	–	core 11	Moogooloo Ss	low	2-	?nonmarine	*M. trisina*
480.7	–	core 20	Cordalia Fm	very low	2-	?nonmarine	*M. trisina*
481.7–484.7	–	core 21	Cordalia Fm	low	2-	?nonmarine	*M. trisina*
487.29	–	core 22	Cordalia Fm	very low	2-	?nonmarine	*M. trisina*
498.77	–	core 27	Cordalia Fm	low	2-	marine	*M. trisina*
510.34	–	core 30	Cordalia Fm	very low	2-	?nonmarine	*M. trisina*
510.7–513.7	–	core 31	Cordalia Fm	moderate	2-	?nonmarine	*M. trisina*
519.72	–	core 34	Cordalia Fm	very low	2-	?nonmarine	*M. trisina*
521.7–524.7	–	core 35	Cordalia Fm	low	2-	?nonmarine	*M. trisina*
527.7–530.7	–	core 37	Cordalia Fm	very low	2-	?nonmarine	*M. trisina*
533.7–536.7	–	core 39	Cordalia Fm	low	2-	?nonmarine	*M. trisina*
536.7–539.7	–	core 40	Cordalia Fm	low	2-	?nonmarine	*M. trisina*
544.55	–	core 42	Cordalia Fm	moderate	2-	marine	*D. byroensis*
545.7–548.7	–	core 43	Cordalia Fm	low	2-	marine	*D. byroensis*
555.7–558.7	–	core 47	Cordalia Fm	low	2-	marine	*D. byroensis*
566.1–568.1	–	core 51	Cordalia Fm	low	2	marine	*D. byroensis*
569.6	–	core 52	Cordalia Fm	moderate	2	marine	*D. byroensis*
596.43	–	core 61	Callytharra Fm	low	2	?nonmarine	*P. pseudoreticulata*
615.95	–	core 68	Callytharra Fm	low	2	?nonmarine	*P. pseudoreticulata*
647.66	–	core 79	Callytharra Fm	low	2	?nonmarine	*P. pseudoreticulata*
665.7	–	core 85	Callytharra Fm	low	2	?nonmarine	*P. pseudoreticulata*
675.17	–	core 88	Callytharra Fm	low	2	?nonmarine	*P. pseudoreticulata*
713.34	–	core 100	Callytharra Fm	low	2	?nonmarine	*P. pseudoreticulata*
715.65	–	core 101	Callytharra Fm	very low	2	?nonmarine	*P. pseudoreticulata*
721.7	–	core 103	Callytharra Fm	very low	2	?nonmarine	*P. pseudoreticulata*
730.8	–	core 106	Callytharra Fm	low	2	?nonmarine	*P. pseudoreticulata*
744.82	–	core 111	Lyons Gp	moderate	2	?nonmarine	*P. confluens*
754.4	–	core 113	Lyons Gp	low	2	?nonmarine	*P. confluens*
762.77	–	core 117	Lyons Gp	low	2	?nonmarine	?
CANDACE 1							
1 506	–	SWC	Chinty Fm	high	2+	marine	*D. parvithola*
1 522	–	SWC	Chinty Fm	moderate	2+	marine	*D. parvithola*
1 576.5	–	SWC	Chinty Fm	very low			
1 601	–	SWC	Chinty Fm	very low			
1 613	–	SWC	Chinty Fm	barren			
1 695	–	SWC	Chinty Fm	very low			
1 796.5	–	SWC	undiff. Kennedy Gp	high	3-	?non-marine	*D. parvithola*
1 808.5	–	SWC	undiff. Kennedy Gp	low	3-	?non-marine	*D. parvithola*
1 829	–	SWC	undiff. Kennedy Gp	high	3-	marine	*D. parvithola*
1 836	–	SWC	undiff. Kennedy Gp	high	3-	?non-marine	*D. parvithola*
1 879.5	–	SWC	undiff. Kennedy Gp	low		?non-marine	*?D. parvithola*
1 961	–	SWC	undiff. Kennedy Gp	barren			
1 969	–	SWC	undiff. Kennedy Gp	barren			
1 994	–	SWC	?Carynginia Fm	moderate		marine	*?P. pseudoreticulata*
2 008	–	SWC	Lyons Gp	moderate	3- to 3	?non-marine	*P. confluens*
2 015.5	–	SWC	Lyons Gp	moderate	3- to 3	?non-marine	*P. confluens*
DIRECTION 1							
479.1	1 572	SWC	Chinty Fm	very low		?marine	*D. parvithola*
500.5	1 642	SWC	Chinty Fm	very low		?non-marine	*D. parvithola*
516.3	1 694	SWC	Chinty Fm	moderate		?non-marine	*D. parvithola*
520.9	1 709	SWC	Chinty Fm	high		?non-marine	*D. parvithola*
539.5	1 770	SWC	Chinty Fm	moderate		?non-marine	*D. parvithola*
549.8	1 804	SWC	Chinty Fm	moderate		?non-marine	*D. parvithola*
581.9	1 909	SWC	undiff. Kennedy Gp	low		?non-marine	*D. ericianus*
596.2	1 956	SWC	undiff. Kennedy Gp	low		marine	*D. ericianus*
606.9	1 991	SWC	undiff. Kennedy Gp	moderate		?non-marine	*D. ericianus*
626.1	2 054	SWC	undiff. Kennedy Gp	moderate		?non-marine	*D. ericianus*
640.4	2 101	SWC	undiff. Kennedy Gp	moderate		?non-marine	*D. ericianus*
655.3	2 150	SWC	undiff. Kennedy Gp	low		?non-marine	*D. granulata*
670	2 198	core 4	Lyons Gp	moderate		?non-marine	*P. confluens*
FORTESCUE 1							
380.4	1 248	SWC	Chinty Fm	low		marine	*D. parvithola*
403.6	1 324	SWC	Chinty Fm	low		?marine	*D. parvithola*
433.1	1 421	SWC	Chinty Fm	low	2+ to 3-	marine	*D. parvithola*
535.8	1 758	SWC	undiff. Kennedy Gp	low		?marine	*D. parvithola*
558.4	1 832	SWC	undiff. Kennedy Gp	low		?non-marine	*D. parvithola*
570.6	1 872	SWC	undiff. Kennedy Gp	moderate		marine	*D. parvithola*
590.1	1 936	SWC	undiff. Kennedy Gp	moderate	2+ to 3-	marine	*D. ericianus*
604.1	1 982	SWC	undiff. Kennedy Gp	moderate	2+ to 3-	?non-marine	*D. ericianus*
GASCOYNE 1							
120	–	cutt	undiff. Wooramel Gp	moderate	2-	marine	*M. trisina*
140–145	–	cutt	undiff. Wooramel Gp	moderate	2-	marine	*M. trisina*

Appendix 2 (cont.)

Depth (metres)	*Depth (feet)*	*Sample type*	*Stratigraphic unit*	*Palynology yield*	*TAI*	*Environment*	*Zone*
GASCOYNE 1 (cont.)							
343.29	–	core	Callytharra Fm	low	2-	marine	*M. trisina*
356.1	–	core	Callytharra Fm	low	2-	marine	*D. byroensis*
361.1	–	core	Callytharra Fm	moderate	2-	marine	*D. byroensis*
365.7	–	core	Callytharra Fm	low	2-	marine	*S. fusus*
376.5	–	core	Callytharra Fm	moderate	2-	marine	*S. fusus*
384.7	–	core	Callytharra Fm	moderate	2	marine	*S. fusus*
391.69	–	core	Callytharra Fm	low	2	marine	*S. fusus*
399.5	–	core	Callytharra Fm	moderate	2	?nonmarine	*S. fusus*
402.3	–	core	Callytharra Fm	low	2	?nonmarine	*S. fusus*
454.16	–	core	Ballythanna Ss Mbr	moderate	2	marine	*P. pseudoreticulata*
455.87	–	core	Ballythanna Ss Mbr	moderate	2	?nonmarine	*P. pseudoreticulata*
459.97	–	core	Callytharra Fm	very low		?nonmarine	*P. pseudoreticulata*
462.75	–	core	Callytharra Fm	very low			?
476.42	–	core	Callytharra Fm	very low			?
478.9	–	core	Callytharra Fm	very low			?
482.05	–	core	Callytharra Fm	very low			?
485.76	–	core	Callytharra Fm	very low			?
488.13	–	core	Callytharra Fm	very low			?
498.3	–	core	Lyons Gp	low		?marine	?
503.57	–	core	Lyons Gp	moderate	2	marine	?
509.13	–	core	Lyons Gp	moderate	2	?marine	?
521.12	–	core	Lyons Gp	low	2	?marine	*P. confluens*
GIRALIA 1							
115.8–118.9	380–390	core 11	Coyrie Fm	moderate		marine	*P. sinuosus*
134.1–137.2	440–450	core 12	Coyrie Fm	moderate	2	marine	*P. sinuosus*
153.9	505	core 13	Coyrie Fm	moderate	2	marine	*P. sinuosus*
172.2	565	core 14	Coyrie Fm	moderate	2	marine	*P. sinuosus*
190.5	625	core 15	Coyrie Fm	moderate	2	marine	*P. sinuosus*
208.8	685	core 16	Coyrie Fm	moderate	2	marine	*P. sinuosus*
227.1	745	core 17	Coyrie Fm	moderate	2	marine	*M. trisina*
245.4	805	core 18	Coyrie Fm	moderate	2	marine	*M. trisina*
263.7	865	core 19	Coyrie Fm	moderate	2	marine	*M. trisina*
281.9	925	core 20	Coyrie Fm	moderate	2	marine	*M. trisina*
300.2	985	core 21	Coyrie Fm	moderate	2	marine	*M. trisina*
318.5	1 045	core 22	Coyrie Fm	very low			?
355.1	1 165	core 24	Coyrie Fm	very low			?
410	1 345	core 27	Coyrie Fm	very low			?
428.2	1 405	core 28	Coyrie Fm	low		?nonmarine	*M. trisina*
453.8	1 489	core 32	Coyrie Fm	very low			?
486.8	1 597	core 34	Billidee Fm	low	2	?nonmarine	*M. trisina*
507.5	1 665	core 37	Billidee Fm	low	2	?nonmarine	*M. trisina*
540.1	1 772	core 40	Billidee Fm	very low			?
556.9	1 827	core 41	Billidee Fm	low		?nonmarine	*M. trisina*
576.1	1 890	core 42	Billidee Fm	low		?nonmarine	*M. trisina*
578.5	1 898	core 43	Billidee Fm	barren			
594.7	1 951	core 44	Billidee Fm	low		?nonmarine	*M. trisina*
624.8	2 050	core 47	Billidee Fm	very low			?
643.1	2 110	core 48	Billidee Fm	very low			?
679.7	2 230	core 50	Billidee Fm	very low			?
698	2 290	core 51	Moogooloo Ss	very low		?nonmarine	*M. trisina*
715.4	2 347	core 52	Moogooloo Ss	very low			?
734.6	2 410	core 53	Moogooloo Ss	very low			?
750.7	2 463	core 57	Moogooloo Ss	low	2+	?nonmarine	*M. trisina*
750.7–751.3	2 463–65	core 57	Moogooloo Ss	low		?nonmarine	*M. trisina*
797.4	2 616	core 61	Moogooloo Ss	low	2+	?nonmarine	*M. trisina*
829.1–830.6	2 720–25	core 62	Cordalia Fm	low		?nonmarine	*M. trisina*
861.4	2 826	core 63	Cordalia Fm	low		?nonmarine	*M. trisina*
893.1–894.6	2 930–35	core 64	Cordalia Fm	low		?nonmarine	*M. trisina*
894	2 933	core 64	Cordalia Fm	low		?nonmarine	*M. trisina*
917.4–919	3 010–15	core 65	Cordalia Fm	moderate		?nonmarine	*M. trisina*
918.1	3 012	core 65	Cordalia Fm	very low			?
920.5	3 020	SWC	Cordalia Fm	very low			?
942.1	3 091	SWC	Cordalia Fm	very low			*M. trisina*
949.5–951	3 115–20	core 66	Callytharra Fm	low		marine	*D. byroensis*
951	3 120	core 66	Callytharra Fm	barren			
981.5–982.7	3 220–24	core 67	Callytharra Fm	barren			
982.1	3 222	core 67	Callytharra Fm	barren			
1 013.5–1 015	3 325–30	core 68	Callytharra Fm	moderate		?nonmarine	*P. pseudoreticulata*
1 045.5–1 047	3 430–35	core 69	Callytharra Fm	moderate		?nonmarine	*P. pseudoreticulata*
1 077.8	3 536	core 70	Callytharra Fm	very low			?
1 102.2	3 616	SWC	Callytharra Fm	very low			?
1 110.1	3 642	core 71	Callytharra Fm	low	2+	?nonmarine	*P. pseudoreticulata*
1 142.1	3 747	core 72	Callytharra Fm	low	2+	?nonmarine	*P. pseudoreticulata*
1 156.7	3 795	SWC	Callytharra Fm	very low			?
1 158.2	3 800	SWC	Callytharra Fm	barren			

Appendix 2 (cont.)

Depth (metres)	*Depth (feet)*	*Sample type*	*Stratigraphic unit*	*Palynology yield*	*TAI*	*Environment*	*Zone*
GIRALIA 1 (cont.)							
1 164.9	3 822	core 73	Callytharra Fm	very low			?
1 182	3 878	core 74	Callytharra Fm	very low			?
1 208.8	3 966	SWC	Lyons Gp	very low			?
1 214	3 983	SWC	Lyons Gp	low		?nonmarine	*P. confluens*
1 236.5	4 057	core 76	Lyons Gp	moderate	2+	?nonmarine	*P. confluens*
GSWA BALLYTHANNA 1							
54.45	–	core	Callytharra Fm	high	~2	marine	*M. trisina*
60.7	–	core	Callytharra Fm	moderate	~2	marine	*D. byroensis*
63.5	–	core	Callytharra Fm	moderate	~2	marine	*D. byroensis*
112.6	–	core	Ballythanna Ss Mbr	low	~2	marine	*D. byroensis*
121.52	–	core	Ballythanna Ss Mbr	moderate	~2	marine	*S. fusus*
148.55	–	core	Ballythanna Ss Mbr	moderate	~2	marine	*S. fusus*
176.7	–	core	Ballythanna Ss Mbr	high	~2	marine	*S. fusus*
257.9	–	core	Ballythanna Ss Mbr	low	~2	marine	*S. fusus*
290.8	–	core	Ballythanna Ss Mbr	moderate	~2	marine	*S. fusus*
297.9	–	core	Ballythanna Ss Mbr	moderate	~2	marine	*S. fusus*
298.28	–	core	Callytharra Fm	moderate	~2	marine	*S. fusus*
301.3	–	core	Callytharra Fm	moderate	~2	?nonmarine	*P. pseudoreticulata*
311.6	–	core	Callytharra Fm	moderate	~2	?nonmarine	*P. pseudoreticulata*
325.9	–	core	Callytharra Fm	moderate	~2	?nonmarine	*P. pseudoreticulata*
339	–	core	Callytharra Fm	low	~2	marine	?
351	–	core	Callytharra Fm	low	~2	marine	?
369.2	–	core	Callytharra Fm	low	~2	?nonmarine	?
375.2	–	core	Callytharra Fm	low	~2	marine	?
377.6	–	core	Lyons Gp	very low	~2	?nonmarine	?
380.5	–	core	Lyons Gp	moderate	~2	?nonmarine	*P. confluens*
388.4	–	core	Lyons Gp	moderate	~2	?nonmarine	*P. confluens*
433.2	–	core	Lyons Gp	moderate	~2	?nonmarine	*P. confluens*
461.2	–	core	Lyons Gp	moderate	~2	?nonmarine	*P. confluens*
HOPE ISLAND 1							
1 082	3 550	SWC	Chinty Fm	low	2+	marine	*D. ericianus*
1 097.3	3 600	SWC	Chinty Fm	low	2+	?nonmarine	*D. ericianus*
1 082–1 097.3	3 550–3 600	SWC	Chinty Fm	moderate		marine	*D. ericianus*
1 112.5	3 650	SWC	Chinty Fm	moderate		marine	*D. ericianus*
1 153.4	3 784	core 7	undiff. Kennedy Gp	barren		?nonmarine	
1 158.2	3 800	SWC	undiff. Kennedy Gp	barren		?nonmarine	
1 173.5	3 850	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. ericianus*
1 188.7	3 900	SWC	undiff. Kennedy Gp	low	2+	?nonmarine	*D. ericianus*
1 204	3 950	SWC	undiff. Kennedy Gp	low	2+ to 3-	?nonmarine	*D. ericianus*
1 219.2	4 000	SWC	undiff. Kennedy Gp	moderate		marine	*D. ericianus*
1 234.4	4 050	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. ericianus*
1 251	4 105	SWC	undiff. Kennedy Gp	low	2+ to 3-	marine	*D. ericianus*
1 280.2	4 200	SWC	undiff. Kennedy Gp	high	2+ to 3-	?nonmarine	*D. ericianus*
1 295.4	4 250	SWC	undiff. Kennedy Gp	low	2+ to 3-	?nonmarine	*D. ericianus*
1 310.6	4 300	SWC	undiff. Kennedy Gp	moderate	2+ to 3-	?nonmarine	*D. granulata*
1 310.6–1 325.9	4 300–4 350	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. granulata*
1 325.9	4 350	SWC	undiff. Kennedy Gp	moderate	2+ to 3-	?nonmarine	*D. granulata*
1 341.1–1 344.2	4 400–4 410	core 9	undiff. Kennedy Gp	high		?nonmarine	*D. granulata*
1 342.6–1 344.2	4 405–4 410	core 9	undiff. Kennedy Gp	high	~3-	?nonmarine	*D. granulata*
1 342.9	4 406	core 9	undiff. Kennedy Gp	high		?nonmarine	*D. granulata*
1 356.4	4 450	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. granulata*
1 371.6	4 500	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. granulata*
1 386.8	4 550	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. granulata*
1 402.1	4 600	SWC	undiff. Kennedy Gp	very low	~3-	?nonmarine	
1 417.3	4 650	SWC	undiff. Kennedy Gp	moderate		?marine	*D. granulata.*
KENNEDY RANGE 1							
303.9–306.9	997–1 007	core 1	Coolkilya Ss	high	2+	?marine	*M. villosa*
464.2–467.9	1 523–1 535	core 2	Coolkilya Ss	very low	2+	marine	Prob. *P. sinuosus*
611.1–614.8	2 005–2 017	core 3	Coolkilya Ss	moderate	2+	marine	*P. sinuosus*
673.3–676.0	2 209–2 218	core 4	Wandagee Fm	moderate	2+	marine	Prob. *P. sinuosus*
858.0–861.7	2 815–2 827	core 5	Cundlego Fm	moderate	2+	marine	Prob. *P. sinuosus*
979.9–982.4	3 215–3 223	core 6	Cundlego Fm	moderate	2+	marine	Prob. *P. sinuosus*
1 100.9–1 103.7	3 612–3 621	core 7	Cundlego Fm	moderate	2+	marine	Prob. *P. sinuosus*
1 194.5–1 197.6	3 919–3 929	core 8	Bulgadoo Sh	moderate	3-	?marine	Prob. *P. sinuosus*
1 268.9–1 271.6	4 163–4 172	core 9	Bulgadoo Sh	low	3-	?marine	Prob. *P. sinuosus*
1 376.2–1 378.0	4 515–4 521	core 10	Bulgadoo Sh	moderate	3-	?nonmarine	Prob. *P. sinuosus*
1 434.1–1 437.1	4 705–4 715	core 11	Mallens Ss	low	?3	?nonmarine	*P. sinuosus* or *M. trisina*
1 554.5–1 557.5	5 100–5 110	core 12	Mallens Ss	barren			
1 669.4–1 672.4	5 477–5 487	core 13	Coyrie Fm	barren			
1 685.5–1 688.6	5 530–5 540	core 14	Coyrie Fm	barren			
1 812.0–1 815.1	5 945–5 955	core 15	Coyrie Fm	barren			
1 882.7–1 886.4	6 177–6 189	core 16	Billidee Fm	low	?3	marine	?
2 012.9–2 017.5	6 604–6 619	core 17	Billidee Fm	low	?3	marine	*M. trisina*

Appendix 2 (cont.)

Depth (metres)	*Depth (feet)*	*Sample type*	*Stratigraphic unit*	*Palynology yield*	*TAI*	*Environment*	*Zone*
KENNEDY RANGE 1 (cont.)							
2 161	7 090	SWC 11	Cordalia Ss	very low	?3+		?
2 183	7 162	SWC 12	Callytharra Fm	very low	?4-		?
2 190.9	7 188	SWC 14	Lyons Gp	very low	4-		?*P. confluens*
2 215.3	7 268	SWC 19	Lyons Gp	very low	4-		?*P. confluens*
MERLINLEIGH 1							
64–67.1	210–220	cutt	Binthalya Fm	very low	~2	?nonmarine	?
70.1–73.2	230–240	cutt	Binthalya Fm	moderate	~2	marine	*D. granulata*
73.2–76.2	240–250	cutt	Mungadan Ss	moderate	~2	?nonmarine	*D. granulata*
79.2–82.3	260–270	cutt	Mungadan Ss	moderate	~2	?nonmarine	*D. granulata*
106.7–169.7	350–360	cutt	Mungadan Ss	high	~2	marine	*D. granulata*
149.4–152.4	490–500	cutt	Mungadan Ss	moderate	~2	marine	*M. villosa*
MOOGOOREE 1							
66.2	217'2"	core	Billidee Fm	low		?nonmarine	*M. trisina*
73.3	240'6"	core	Billidee Fm	low		?nonmarine	*M. trisina*
99.8	327'6"	core	Moogooloo Ss	very low			?
118.3	388'	core	Moogooloo Ss	moderate		?nonmarine	*M. trisina*
120.5	395'6"	core	Callytharra Fm	moderate		marine	*D. byroensis*
ONSLOW 1							
2 098.5	6 885	SWC	Chinty Fm	low		marine	*D. parvithola*
2 153.7	7 066	SWC	Chinty Fm	low	2+	marine	*D. parvithola*
2 165.9	7 106	core 12	Chinty Fm	high	2+	?nonmarine	*D. parvithola*
2 166.2	7 107	core 12	Chinty Fm	moderate		?nonmarine	*D. parvithola*
2 166.5	7 108	core 12	Chinty Fm	moderate		?nonmarine	*D. parvithola*
2 224.4	7 298	SWC	Chinty Fm	low		?marine	*D. ericianus*
2 249.4	7 380	SWC	Chinty Fm	moderate		?nonmarine	*D. ericianus*
2 306.1	7 566	core 13	undiff. Kennedy Gp	barren			
2 347	7 700	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. ericianus*
2 401.8	7 880	SWC	undiff. Kennedy Gp	moderate	2+	?nonmarine	*D. ericianus*
2 432.3	7 980	SWC	undiff. Kennedy Gp	moderate	2+	?marine	*D. ericianus*
2 444.5	8 020	SWC	undiff. Kennedy Gp	moderate		?nonmarine	*D. granulata*
2 490.2–0.3	8 170–77	core 14	undiff. Kennedy Gp	low		?nonmarine	*D. granulata*
2 492.3	8 177	core 14	undiff. Kennedy Gp	moderate		marine	*D. granulata*
2 510	8 235	SWC	?Callytharra Fm	low		marine	?
2 542	8 340	SWC	?Callytharra Fm	barren			
2 554.2	8 380	SWC	?Callytharra Fm	low	3-	marine	?
2 567	8 422	SWC	?Callytharra Fm	low	3-	?nonmarine	?
2 592.6–2 595.7	8 506–16	core 15	?Callytharra Fm	low		Marine	?
2 592.9	8 507	core 15	?Callytharra Fm	low	3-	Marine	*D. byroensis*
2 638	8 655	SWC	Lyons Gp	very low			?
2 665.5	8 745	SWC	Lyons Gp	low		marine	*P. confluens*
2 739.5	8 988	core 16	Lyons Gp	moderate	3- to 3	?nonmarine	*P. confluens*
2 742.9	8 999	core 16	Lyons Gp	moderate	3- to 3	?nonmarine	*P. confluens*
2 891	9 485	core 17	Lyons Gp	moderate		?nonmarine	*P. confluens*
2 997.4	9 834	core 18	Lyons Gp	very low	~4-	?nonmarine	?
QUAIL 1							
154.2–158.8	506–521	core 1	Billidee Fm	very low	2 to 2+	?nonmarine	*M. trisina*
218.8–222.5	718–730	core 2	Billidee Fm	very low		?nonmarine	*M. trisina*
274.3–285.6	900–937	core 3	Moogooloo Ss	low		?nonmarine	*M. trisina*
344.4	1 130	SWC	Moogooloo Ss	very low			?
350.5	1 150	SWC	Moogooloo Ss	very low			?
359.7	1 180	SWC	Moogooloo Ss	very low			?
364.2	1 195	SWC	Moogooloo Ss	very low			?
368.2	1 208	SWC	Moogooloo Ss	very low			?
544.1–546.5	1 785–1 793	core 4	Callytharra Fm	moderate	~3	?nonmarine	*P. pseudoreticulata*
711.1–713.5	2 333–2 341	core 5	Lyons Gp	moderate	3	?nonmarine	*P. confluens*
1 061.0–1 063.4	3 481–3 489	core 6	Lyons Gp	low	3+ to 4-	?nonmarine	*P. confluens* or Stage 2
1 430.4–1 432.3	4 693–4 699	core 7	Lyons Gp	low	4-	?nonmarine	?Stage 2
1 569.7–1 571.2	5 150–5 155	core 9	Lyons Gp	very low	4-	?nonmarine	?
1 871.8–1 872.7	6 141–6 144	core 10	Lyons Gp	very low		?nonmarine	?
1 993.4–1 996.4	6 540–6 550	core 11	Lyons Gp	very low		?nonmarine	?
REMARKABLE HILL 1							
1 071.1	3 514	core 4	Lyons Gp	low	2- to 2	?nonmarine	*P. confluens*
1 887	6 191	core 7	Lyons Gp	very low			?
SHOLL 1							
854	2 802	SWC	Chinty Fm	low		?nonmarine	*D. parvithola*
854–880.9	2 802–2 890	3xSWC	Chinty Fm	low		marine	*D. parvithola*
880.9	2 890	SWC	Chinty Fm	very low		?nonmarine	*D. parvithola*
885.7–889.1	2 906–2 917	core 3	Chinty Fm	high		marine	*D. parvithola*
898.9	2 949	SWC	Chinty Fm	low	2+ to 3-	marine	*D. parvithola*
912.9	2 995	SWC	Chinty Fm	high		?nonmarine	*D. parvithola*

Appendix 2 (cont.)

Depth (metres)	*Depth (feet)*	*Sample type*	*Stratigraphic unit*	*Palynology yield*	*TAI*	*Environment*	*Zone*
SHOLL 1 (cont.)							
921.7–942.7	3 024–3 093	3xSWC	Chinty Fm	low		?marine	*D. parvithola*
962.9	3 159	SWC	Chinty Fm	moderate	2+ to 3-	?nonmarine	*D. parvithola*
987.9	3 241	SWC	Chinty Fm	moderate		?marine	*D. parvithola*
1 018.3	3 341	SWC	Chinty Fm	moderate	2+ to 3-	marine	*D. parvithola*
1 022.6	3 355	SWC	Chinty Fm	moderate	2+ to 3-	?nonmarine	*D. parvithola*
1 035.7	3 398	SWC	undiff. Kennedy Gp	very high	2+ to 3-	?nonmarine	*D. parvithola*
1 051.6	3 450	SWC	undiff. Kennedy Gp	very high		marine	*D. parvithola*
1 068.3	3 505	SWC	undiff. Kennedy Gp	moderate		marine	*D. ericianus*
1 078.4–1 083.3	3 538–3 554	core 4	undiff. Kennedy Gp	low		marine	*D. ericianus*
1 096.7	3 598	SWC	undiff. Kennedy Gp	high		?nonmarine	*D. ericianus*
1 109.8–1 119.2	3 641–3 672	2xSWC	undiff. Kennedy Gp	high		marine	*D. ericianus*
1 119.2	3 672	SWC	Lyons Gp	low	3-	?nonmarine	*?P. confluens*
1 130.2	3 708	SWC	Lyons Gp	low		?nonmarine	*P. confluens*
1 142	3 747	SWC	Lyons Gp	moderate		?nonmarine	*P. confluens*
1 159.5–1 175	3 804–3 855	2xSWC	Lyons Gp	moderate		?nonmarine	*P. confluens*
1 188.7–1 204	3 900–3 950	2xSWC	Lyons Gp	low		?nonmarine	*P. confluens*
1 220.4–1 249.1	4 440–4 098	3xSWC	Lyons Gp	very low		?nonmarine	*P. confluens*
1 263.7–1 269.2	4 146–4 164	2xSWC	Lyons Gp	low		?nonmarine	*?P. confluens*

NOTES: Sample depths are given in both feet and metres only where the well was originally drilled in feet as core and samples from those wells are still labelled in feet. Core numbers not given for wells with continuous core. cutt = cuttings; SWC = sidewall core. TAI (Thermal Alteration Index) values are approximate and only given where suitable kerogen slides are available. The environment of deposition is considered marine if spinose acritarchs (*Veryhadrium* spp. or *Micrhystridium* spp.) are present. If these acritarchs are not present the sample is listed as ?nonmarine as a marine environment cannot be ruled out.

Appendix 3

Species names used in this report

Altitriletes densus Venkatachala and Kar 1968
Camptotriletes warchianus Balme 1970
Columnisporites peppersii Alpern and Doubinger 1973
Cycadopites cymbatus (Balme and Hennelly) Segroves 1970
Densosporites rotundidentatus Segroves 1970
Diatomozonotriletes townrowii Segroves 1970
Didecitriletes byroensis sp. nov. Backhouse this report
Didecitriletes dentatus (Balme) Venkatachala and Kar 1965
Didecitriletes ericianus (Balme and Hennelly) Venkatachala and Kar 1965
Dulhuntyispora dulhuntyi Potonié emend. Price 1983
Dulhuntyispora granulata Price 1983
Dulhuntyispora parvithola (Balme and Hennelly) Potonié 1960
Jayantisporites pseudozonatus Lele and Makada 1972
Laevigatosporites colliensis (Balme and Hennelly) Venkatachala and Kar 1968
Microbaculispora trisina (Balme and Hennelly) Anderson 1977
Microbaculispora villosa (Balme and Hennelly) Bharadwaj 1962
Micrhystridium evansii Price 1983
Praecolpatites sinuosus (Balme and Hennelly) Bharadwaj and Srivastava 1969
Praecolpatites ovatus (Anderson) Backhouse 1991
Protohaploxypinus rugatus Segroves 1969
Pseudoreticulatispora confluens (Archangelsky and Gamerro) Backhouse 1991
Pseudoreticulatispora pseudoreticulata (Balme and Hennelly) Bharadwaj and Srivastava 1969
Striatopodocarpites fusus (Balme and Hennelly) Potonié 1956
Weylandites lucifer (Bharadwaj and Salujha) Foster 1975

Appendix 4

Didecitriletes byroensis sp. nov., a new Early Permian spore species from the Carnarvon Basin

by

John Backhouse

Introduction

A comprehensive palynostratigraphic review of Permian rocks in the Carnarvon Basin has shown that most palynomorphs recorded are previously described species already known from Permian strata elsewhere. The principal exceptions are a distictive spinose spore and a suite of small acritarchs, both recorded from the Lower Permian Callytharra Formation. Because the presence of the spinose spore is the basis for a new subzone at the top of the *Striatopodocarpidites fusus* Zone it is given formal status in this appendix.

Systematic palaeontology

Infraturma **Apiculati** Bennie and Kidson *emend*. Potonié 1956

Genus *Didecitriletes* Venkatachala and Kar 1965

Type species: *Didecitriletes horridus* Venkatachala and Kar 1965

***Didecitriletes byroensis* sp. nov.**

Fig. 1a–g

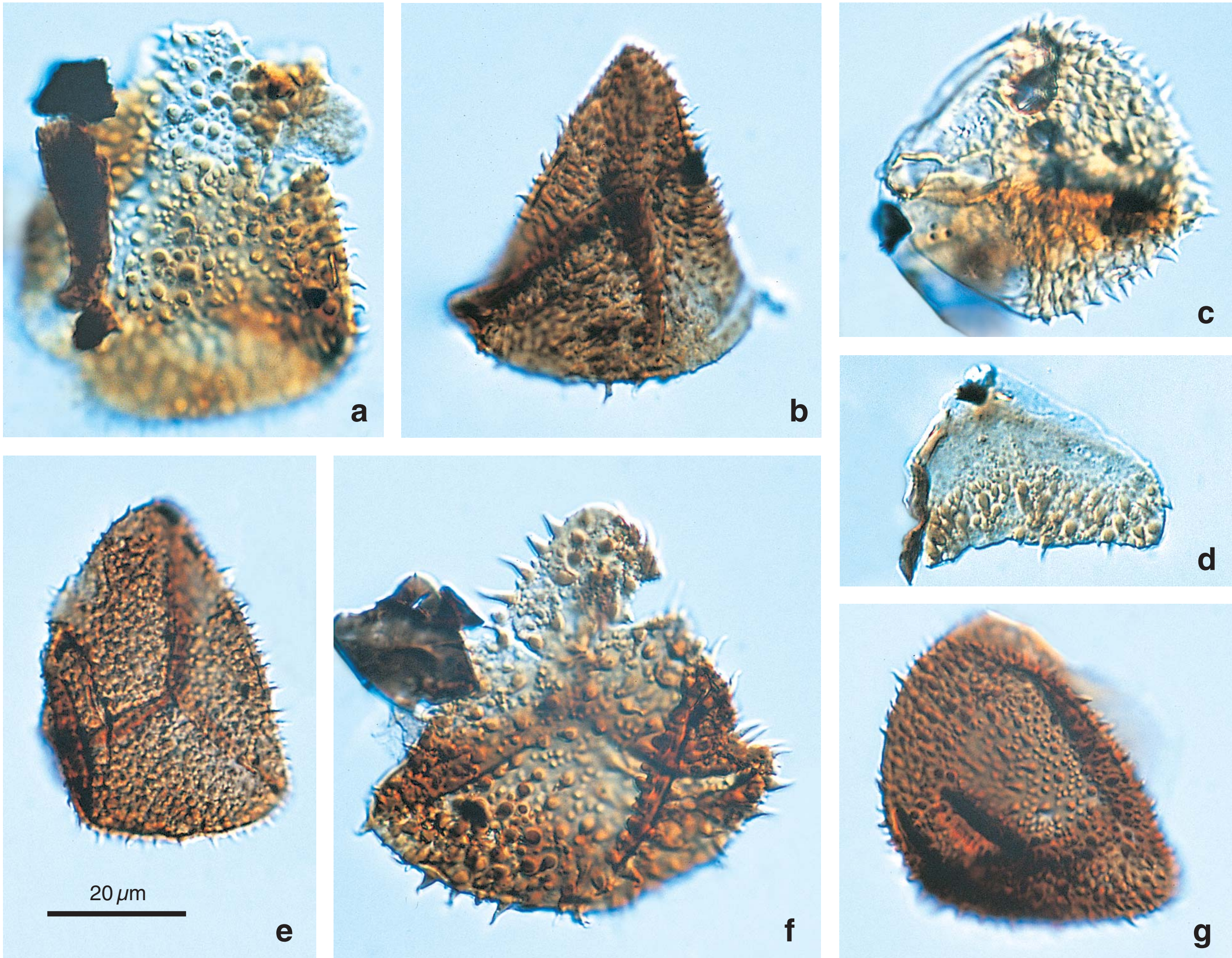
Description: Spores radial, trilete, acavate, azonate, biconvex, frequently folded to produce a cheilocardioid outline. Amb triangular with acute apices and straight to slightly convex sides. Laesurae straight extending almost to apices, bordered by smooth labra up to 5 µm high at proximal pole. Exine 1–1.5 µm thick distally and equatorially, less than 1 µm thick on proximal face, sculptured distally and equatorially by large conical spines interspersed with smaller spines and grana. Large spines evenly tapered, 3.5–7 µm long, 1.5–2.5 µm in basal diameter and spaced 2–5 µm apart, decreasing in size towards apices. Small spines 1–2 µm high, rarely larger. Small sculptural elements usually outnumber larger elements 3:1. Typically one and sometimes two small spines are interspersed between large spines, but on some specimens smaller spines and grana are infrequent and large spines may be adjacent on some parts of the exine. Large spines do not extend onto the proximal face. Proximal face granulose near amb, laevigate adjacent to laesurae.

Dimensions (23 specimens from Ballythanna 1, Bidgemia 1 and Gascoyne 1): Overall equatorial diameter 50 (56.4) 72 µm.

Derivation of name: After the Byro Sub-basin of the Carnarvon Basin.

Type material: Holotype Geological Survey of Western Australia Type Fossil Collection, Registered slide number F49647/2, co-ordinates 27.8, 96.6 on Leica microscope 501089/181383. Ballythanna 1, 63.5 m, upper Callytharra Formation.

Remarks: Fragments from the distal face of this species are more frequently encountered than intact specimens, but the distinctive nature of the distal sculpture makes for ready identification. *Didecitriletes ericianus* Venkatachala and Kar is similar in size and has spines that compare in size to the larger spines on *D. byroensis*, but *D. ericianus* is more robust and has equidimensional spines that extend onto the proximal face and gradually decrease in size towards the apices and laesurae. *D. byroensis* is larger than *Procoronaspora spinosa* (Anderson) Backhouse 1991 which bears smaller, essentially equidimensional spines. *Diatomozonotriletes birkheadensis* Powis 1984 closely resembles *D. byroensis* in shape, size and the distribution of sculptural elements, but again it bears equidimensional and somewhat smaller spines on the distal face.



JB8 11.06.97

Figure 1. ***Didecitriletes byroensis* sp. nov.: (a) distal view and focus, Ballythanna 1, 60.7 m (F49646/3 44.0, 102.1); (b) proximal view, distal focus, Ballythanna 1, 63.5 m (F49647/1 34.5, 103.1); (c) lateral view, Ballythanna 1, 60.7 m (F49646/4 20.3, 94.0); (d) fragment of proximal face showing abrupt termination of major spinose elements at the equator, Ballythanna 1, 63.5 m (F49647/1 50.1, 94.6); (e) distal view and focus, Ballythanna 1, 63.5 m (F49647/1 47.7, 109.6); (f) Holotype, distal view and focus, Ballythanna 1, 63.5 m (F49647/2 27.8, 96.6); and (g) distal view and focus, Ballythanna 1, 63.5 m (F49647/1 61.1, 106.3)**

Appendix 5

Permian stratigraphy of the Carnarvon Basin (modified from Hocking, 1990a)

Age	*Rock unit*	*Thickness (m)*	*Lithology*	*Stratigraphic relationships*	*Type section*	*Fossils & age*	*Depositional setting*	*Remarks*	*References*
	KENNEDY GROUP	200–1 000, top eroded in outcrop	Sandsone with lesser siltstone, shale and limestone	Conformable on Byro Group in Merlinleigh S–b, disconformable on Lower Permian over Peedamullah Shelf		Varied microfauna and microflora, Kungurian–Tatarian	Marine shelf to coastal	Amended herein	Hocking et al. (1987)
LATE PERMIAN	Chinty Formation	up to 320	Silty grey sandstone with lesser siltstone, and shale	Conformable on undifferentiated Kennedy Group	Onslow 1 2 096–2 258 m	Varied microfauna and microflora, Late Permian	Moderate energy shallow marine shelf to coastal	Restricted to Peedamullah Shelf	
	Binthalya Formation	Max. 544	Grey to black siltstone and shale, interbedded fine to medium sandstone	Conformable on Mungadan Sandstone	Near Venny Peak, southwest Kennedy Range 24°50'S; 114°57'E	Varied ichnofauna, rare body fossils, Kungurian, age of upper part uncertain	Low to moderate energy marine shelf		
	Mungadan Sandstone	Max. >116	Pale coloured fine to coarse sandstone with minor siltstone	Conformable on Coolkilya Sandstone	East side, Wandagee Hill, 23°50'10"S; 114°25'50"E	Rare bivalves, Kungurian	Fluvial dominated, nearshore channel complex		
EARLY PERMIAN	Coolkilya Sandstone	110–285	Greenish-grey, fine to very fine silty sandstone, minor siltstone and shale	Conformable on Baker Formation	East side, Wandagee Hill, 23°50'10"S; 114°25'50"E	Varied fauna, mostly shells, Kungurian	Broad, wave-influenced marine shelf, lower part storm-swept		
	BYRO GROUP	up to 1 500	Dark siltstone and fine to medium sandstone	Conformable on Wooramel Group		mid- to late Artinskian	Marine shelf		Hocking et al. (1987)
	Baker Formation	21–90	Grey to black siltstone, sandy siltstone, silty fine sandstone	Conformable on Nalbia Sandstone	North end of Kennedy Range, 24°13'30"S; 115°03'E	Sparse fauna: foraminifers, brachiopods, late Artinskian	Marine shelf, storm swept, low to moderate energy		
	Nalbia Sandstone	40–120	Fine sandstone, minor siltstone, abundant *Zoophycos*	Conformable on Wandagee Formation	4 km north of Wandagee Hill, 23°48'10"S; 114°25'10"E	Locally abundant fauna, late Artinskian	Marine shelf, storm swept, moderate to high energy	Type section poorly exposed	
	Wandagee Formation	116–202	Grey siltstone, fine sandstone, shale	Conformable on Cundlego Formation or Quinnanie Shale	Minilya River, north of Wandagee Hill, 23°44'30"S; 114°25'E	Abundant fauna, mid-Artinskian	Marine shelf, storm swept, moderate to low energy		
	Quinnanie Shale	15–135	Black shale, with grey siltstone in upper part	Conformable on and (to southeast) laterally gradational into Cundlego Formation	Minilya River, north of Wandagee Hill, 23°44'10"S; 114°25'20"E	Sparse fauna, mid -Artinskian	Marine shelf, storm swept, low energy, restricted circulation		

Appendix 5 (cont.)

Age	*Rock unit*	*Thickness (m)*	*Lithology*	*Stratigraphic relationships*	*Type section*	*Fossils & age*	*Depositional setting*	*Remarks*	*References*
	Cundlego Formation	340–412	Grey siltstone interbedded with fine to medium sandstone	Conformable on Bulgadoo Shale	Minilya River, north of Wandagee Hill, 23°45'30"S; 114°25'E	Locally abundant fauna, mid-Artinskian	Marine shelf, storm swept, moderate to high energy		
	Bulgadoo Shale	60–270	Black pyritic shale, minor interbeds of fine sandstone	Conformable on Mallens Sandstone	Minilya River, north of Wandagee Hill, 23°44'40"S; 114°30'E	Locally abundant fauna, mid-Artinskian	Marine shelf, storm swept, low energy, restricted circulation		
	Mallens Sandstone	60–200	Fine to medium sandstone, minor siltstone, commonly intensely bioturbated	Conformable on Coyrie Formation	Northern Kennedy Range, 24°05'S; 115°07'E	Locally abundant fauna, mid-Artinskian	Marine shelf, storm swept, moderate to high energy		
	Coyrie Formation	85–200	Interbedded grey-black siltstone and fine sandstone, minor black shale	Conformable on Billidee or Keogh Formations	Northern Kennedy Range, 24°06'S; 115°08'30"E	Abundant fauna, mid-Artinskian	Marine shelf, storm swept, moderate to low energy, in part restricted circulation		
	WOORAMEL GROUP		Fine to coarse sandstone, minor conglomerate and siltstone	Conformable on Callytharra Formation		Sparse macrofauna, Artinskian	Deltaic to fluvial	Formations generally thicken to northwest	Hocking et al. (1987)
	Keogh Formation	Mostly about 50	Fine and medium quartz sandstone, lesser clayey siltstone, pebble conglomerate	Conformable on Callytharra Formation, laterally equivalent to Moogooloo Sandstone and Billidee Formation	Keogh Hill, southern Byro Plains, 25°51'30"S; 115°54'30"E	Sparse fauna and flora Artinskian, by position	Lower part: delta plain, upper part: delta front	Restricted to Byro Sub-basin	
	Billidee Formation	60–210	Grey siltstone and fine silty sandstone, lesser shale, medium to coarse sandstone, conglomerate	Conformable on Moogooloo Sandstone, laterally equivalent to upper Keogh Formation	Northeastern Kennedy Range, 24°06'30"S; 115°10'0"E	Sparse fauna, Artinskian	Lower part: marine shelf, upper part: prodelta–delta front. Localized deltas throughout	Occurs in Merlinleigh and northern Byro Sub-basins	
	Moogooloo Sandstone	30–120	Fine to coarse quartz sandstone, minor siltstone, conglomerate	Conformable on Cordalia Formation and laterally Callytharra Formation, eqivalent to lower Keogh Formation	South end of Gooch Range, 23°51'10"S; 114°48'30"E	Rare fossils: bryozoa, crinoids, brachiopods, wood, scattered burrows, Artinskian	Fluvial, delta plain and upper delta front		
	Cordalia Formation	up to 140	Silty, fine to very fine sandstone, siltstone	Conformable on, and in part equivalent to, Callytharra Formation	Lyndon River, southeast of Winning Homestead, 23°20'50"S; 114°39'30"E	Rare fossils, in part reworked from below, Artinskian	Prodelta to lower delta front	Absent in southern Merlinleigh and Byro Sub-basins	

Appendix 5 (cont.)

Age	*Rock unit*	*Thickness (m)*	*Lithology*	*Stratigraphic relationships*	*Type section*	*Fossils & age*	*Depositional setting*	*Remarks*	*References*
	CALLYTHARRA FORMATION	60–265	Fossiliferous grey-green calcareous siltstone with hard fossiliferous calcar-enite	Conformable on Lyons Group	Wooramel River, south end of Carrandibby Range, 25°53'30"S; 115°30'00"E	Diverse, abundant fauna, late Sakmarian–early Artinskian	Marine shelf, shallowing upwards	Includes Barra-biddy Formation of previous authors	Hocking et al. (1987)
	Ballythanna Sandstone Member	up to 300	Fine to medium sandstone, crossbedded and strongly bioturbated in places		Ballythanna 1, 65–298 m	Trace fossils, palyno-flora	Marine shelf		Mory (1996)
	Winnemia Sandstone Member	up to 128	Fine to mediun, massive sandstone		Jimba Jimba Syncline, 25°02'10"S; 114°59'30"E	Rare trace fossils	Marine shelf		new name
LATE CARBON-IFEROUS–EARLY PERMIAN	LYONS GROUP	Mostly >1 km, max. ~3 km	Varied, mostly siliciclastic, glacial features unifying theme of group	Unconformable on older rocks		Varied cold water marine fauna; uncommon wood imprints near base, Sakmarian to ?Late Carboniferous	Fluvial and lacustrine to marine shelf, with pronounced glacial influence	Most of group not subdivided, except in limited area in Merlin-leigh Sub-basin	Hocking et al. (1987)
	Harris Sandstone	Mostly <50, max. 332	Fine to coarse quartz sandstone, minor diamictite, and siltstone	Unconformable on older rocks	Northwest of Williambury Homestead, 23°48'20"S; 115°05'50"E	Lepidodendroid plants, Late Carboniferous or Early Permian from position	Fluvial, and glacial outwash deltas	Diachronous and discontinuous unit at base of Lyons Group	

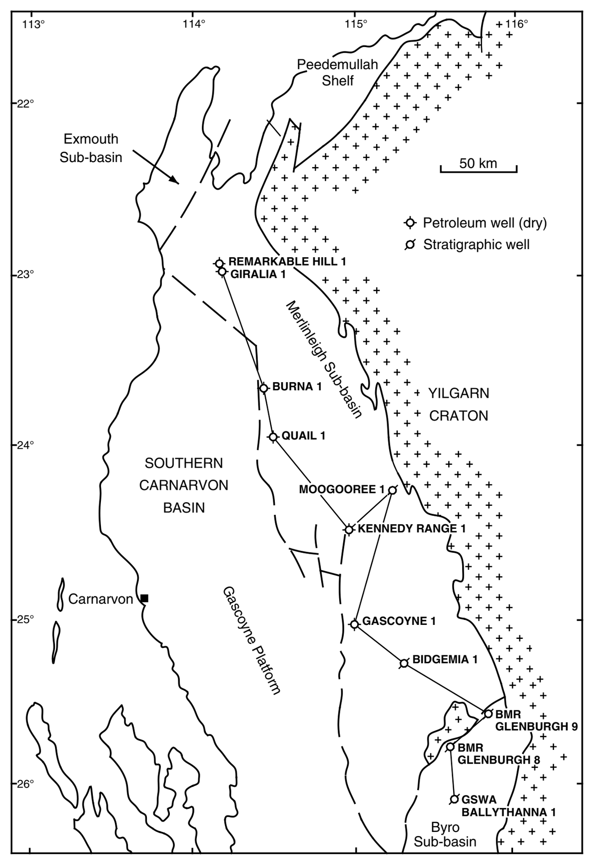
Appendix 6

Permian formation tops for selected wells

Well name	*PKy*	*PK*	*PKb*	*PKm*	*PKc*	*PBk*	*PBn*	*PBw*	*PBq*	*PBu*	*PBb*	*PBm*	*PBc*	*PB*	*PWb*	*PWm*	*PWk*	*PWc*	*Pc*	*Pcb or Pcw*[(a)]	*PL*	*D–C*	*TD (m)*
Bidgemia 1													0		?50	?76	–	–	122	–	np	np	212
BMR Glenburgh 8																	0	–	142	162–338	435	np	916
BMR Glenburgh 9																	0	–	119	131–251	408	np	704
BMR Kennedy Range 6						?6	21	87	177	226	np	np	np		np	np	–	np	np	–	np	np	305
BMR Kennedy Range 7					0	58	152	226	311	370	np	np	np		np	np	–	np	np	–	np	np	609
Burna 1													24		224	396	–	512	575	–	740	np	768
Candace 1	1 458	1 780	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	?1 970	–	2 007	np	2 063
Cunaloo 1	588	701	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	np	–	np	np	798
Direction 1	478	? 564f	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	656	np	673
Fortescue 1	380	498	–	–	–	–	–	–	–	–	–	–	–		np	np	np	np	np	–	np	np	610
Gascoyne 1														24	148	284	–	–	326	[(a)]404–457	492	np	526
Giralia 1													117		481	690	–	866	944	–	1 208	np	1 244
GSWA Ballythanna 1																	0	–	45	65–298	377	np	465
Hope Island 1	997	1 115	–	–	–	–	–	–	–	–	–	–	–		np	np	np	np	np	–	np	np	1 426
Kennedy Range 1			0	76	218	519	614	658	759	794	1 136	1 406	1 603		1 882	2 014	–	2 101	2 163 f	–	2 190	np	2 227
Merlinleigh 1			0	61	198	np	np	np	np	np	np	np	np		np	np	–	np	np	–	np	np	305
Merlinleigh 2			0	134	279	np	np	np	np	np	np	np	np		np	np	–	np	np	–	np	np	306
Merlinleigh 3			0	150	np	np	np	np	np	np	np	np	np		np	np	–	np	np	–	np	np	166
Merlinleigh 4			0	74	np	np	np	np	np	np	np	np	np		np	np	–	np	np	–	np	np	136
Merlinleigh 5			0	153	np	np	np	np	np	np	np	np	np		np	np	–	np	np	–	np	np	175
Moogooree 1															0	74	–	–	119	–	np	np	128
Onslow 1	2 096	2 280	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	?2 495	–	2 610	np	2 998
Quail 1													5		67	273	–	386	447	–	592	2 101	3 580
Remarkable Hill 1															273	459	–	601	695	–	899	2 356	3 206
Sholl 1	840	1 025	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	1 115	np	1 272

NOTE: Formation tops are relative to KB (Kelly Bushing). D–C = undifferentiated Devonian–Carboniferous; PK = undifferentiated Kennedy Group; PKy = Chinty Formation; PKb = Binthalya Formation; PKm = Mungadan Sandstone; PKc = Coolkilya Sandstone; PB = undifferentiated Byro Group; PBk = Baker Formation; PBn = Nalbia Sandstone; PBw = Wandagee Formation; PBq = Quinnanie Shale; Pbu = Cundlego Formation; PBb = Bulgadoo Shale; PBm = Mallens Sandstone; PBc = Coyrie Formation; PW = undifferentiated Wooramel Group; PWb = Billidee Formation; PWm = Moogooloo Sandstone; PWk = Keogh Formation; PWc = Cordalia Formation; Pc = Callytharra Formation; Pcb = Ballythanna Sandstone Member; Pcw = Winnemia Sandstone Member; PL = Lyons Group; np = not penetrated; f = faulted contact; TD = total depth of well.

LOCATION MAP



LITHOLOGY

- Sandstone
- Interbedded sandstone and siltstone
- Siltstone
- Limestone
- Sandy limestone
- Pebbles
- Dropstones in poorly sorted matrix
- Shelly material
- Bioturbation
- Contorted bedding
- Micaceous

KEY TO PALYNOLOGICAL ZONES

- *P. sinuosus*
- *M. trisina*
- *D. byroensis*
- *S. fusus*
- *P. pseudoreticulata*
- *P. confluens*

cored intervals

Correlation by A. J. Mory and J. Backhouse

Edited by A. Davis and G. Loan
Computer assisted drafting by T. Edwards
CAD file: AJM139 (19.08.97)

Published by the Geological Survey of Western Australia.
Copies available from the Mining Information Centre,
Department of Minerals and Energy, 100 Plain Street,
East Perth, W.A. 6004. Phone (08) 9222 3459,
Fax (08) 9222 3444

Printed by the Sands Print Group, Western Australia

The recommended reference for this plate is:
Mory, A. J. and Backhouse, J. 1997, Correlation of
Wooramel Group and Callytharra Formation
from Remarkable Hill 1 to Ballythanna 1:
Western Australian Geological Survey, Report 51, Plate 1.

CORRELATION OF WOORAMEL GROUP AND CALLYTHARRA FORMATION FROM REMARKABLE HILL 1 TO BALLYTHANNA 1

Datum : Top Callytharra or Cordalia Formation

Vertical Scale 1 : 4000

DEPARTMENT OF MINERALS AND ENERGY
L.C. RANFORD, ACTING DIRECTOR GENERAL

GOVERNMENT OF WESTERN AUSTRALIA
HON. NORMAN MOORE, M.L.C.
MINISTER FOR MINES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
PIETRO GUJ, DIRECTOR

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 51 PLATE 1