

Palynology and correlation of Permian sediments in the Perth, Collie, and Officer Basins, Western Australia

by

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Abstract

In southern Western Australia extensive Permian deposits are present in the Perth Basin, in small fault-controlled basins such as the Collie Basin, and in the Officer Basin east of the Yilgarn Craton. Palynomorphs are the only fossils consistently present through these widely separated sequences and are the basis for biostratigraphic correlations outlined here.

The Permian sequence in the recently investigated Collie Basin ranges from Stage 2 into the *Protophloxypinus rugatus* zone (equivalent to lower Stage 5b/c). In the southern Perth Basin, the Stockton Formation and the Sue Coal Measures extend from Stage 2 almost to the beginning of the Triassic. The first appearances of *Camptotriletes warchianus* and *Microbaculispora* sp. A, are used for correlation above the *P. rugatus* datum (lower Stage 5) in the Sue Coal Measures. The overlying Sabina Sandstone contains assemblages dated as probable latest Permian and Early Triassic. These data are used to correlate shallow boreholes on the Vasse Shelf. In the northern Perth Basin a sequence of glaciogenic, marine and coal measure deposits ranges from Stage 2 to the lower part of the *Praeolpatites sinuosus* zone and is unconformably overlain by correlatives of the highest part of the Sue Coal Measures. All assemblages from the Officer Basin fall within Stage 2 or the *Pseudoreticulatispora confluens* Zone.

Periglacial sediments of Stage 2 and *P. confluens* Zone age contain similar palynomorph assemblages over a wide area of southern Western Australia, but regional differences become apparent in the Late Permian.

Sediments of Stage 2 age vary in thickness locally. The *P. confluens* Zone is represented by some 300 m of sediments in the northern Perth Basin and by less than 30 m of section in the southern Perth and Collie basins.

KEYWORDS: Permian, palynology, Australia, Perth Basin, Collie Basin, Officer Basin

Introduction

In the Perth Basin Permian sediments are assumed to underlie at depth all the younger sediments. They are seen in outcrop only in the Irwin River area in the north of the basin, and are intersected in boreholes between the coast and the Irwin River outcrops, and in the southern Perth Basin, mainly south of Busselton.

Permian sediments are known on the Yilgarn Craton in the Collie Basin and from the structurally similar but smaller Wilga and Boyup Basins in the south (Fig. 1).

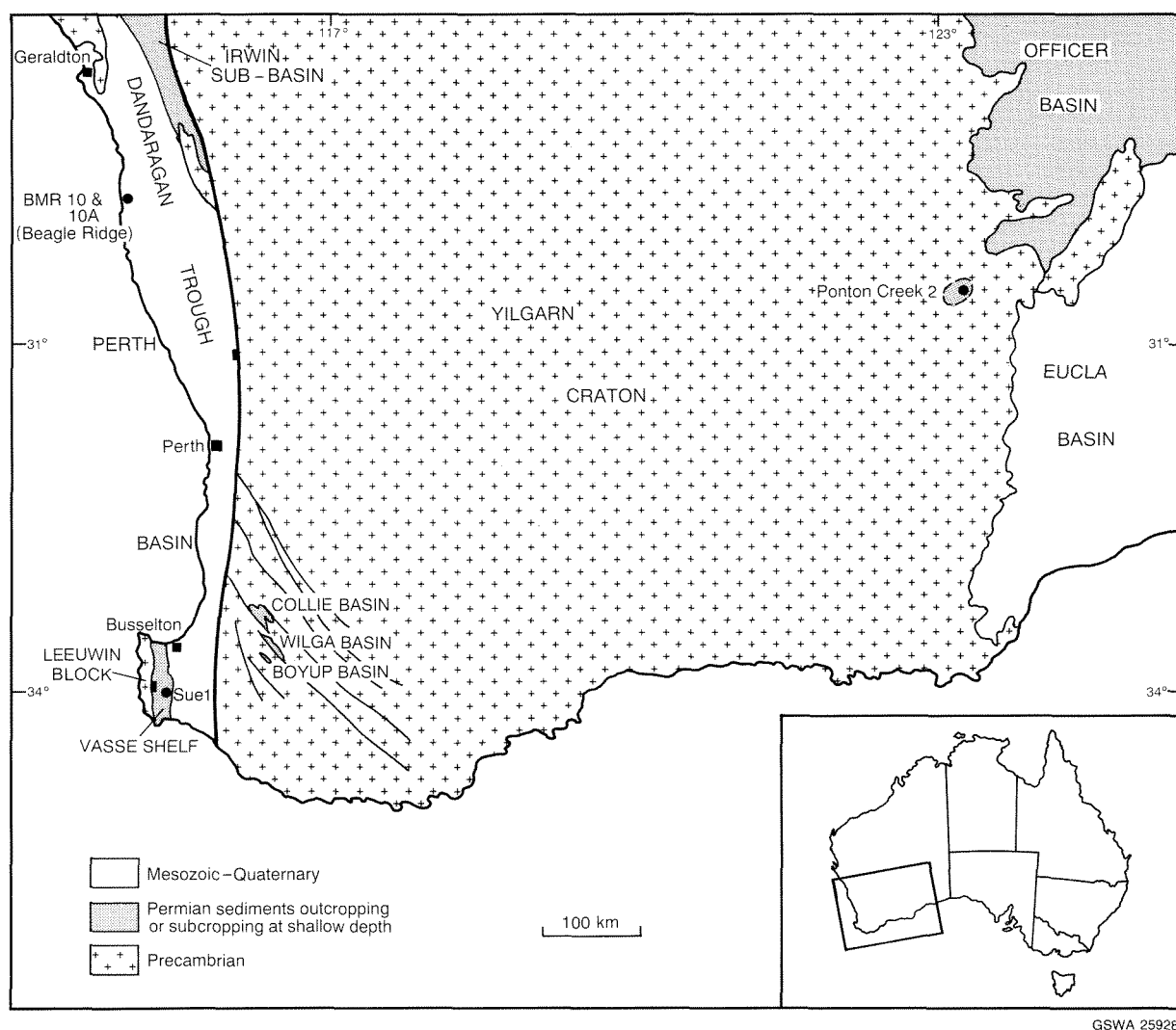
On the eastern margin of the Yilgarn Craton, 700 km east of the Perth Basin, Early Permian sediments of the Officer Basin onlap Archaean igneous and metamorphic rocks, and are overlain by thin Cretaceous and Eocene deposits.

Permian palynomorphs and their stratigraphic distribution in the Collie Basin are the subjects of a recent study (Backhouse, 1991), which presented a detailed palynostratigraphic scheme for the basin. The present

study builds on the results of that investigation by reviewing palynomorph assemblages from other Permian basins in southwestern Australia, in the context of the palynostratigraphy developed in the Collie Basin.

The Collie Basin

Permian sediments in the Collie Basin have been described in detail by Lord (1952), Low (1958), Playford et al. (1975), and more recently by Kristensen and Wilson (1986) and Wilson (1990). The basin contains up to 330 m of Stockton Formation, which includes diamictite in the lower part and periglacial, pale-grey claystone and buff-coloured, well-sorted sandstone in the upper part. At the top of the Stockton Formation in one borehole is a dark shale band a few centimetres thick conformably overlain by poorly sorted sandstone of the Collie Coal Measures (Backhouse, 1991). The Collie Coal Measures is a cyclic sequence of sandstone, siltstone, claystone and coal (Kristensen and Wilson, 1986), with a maximum thickness of about 800 m. Named seams for each Collie Basin sub-



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Figure 1. Location map of southwestern Australia

basin and previously recognized members are shown in Kristensen and Wilson (1986) and Wilson (1990). Earlier authors correlated the Collieburn Member with the Premier Member (=Chicken Creek Member in Kristensen and Wilson, 1986), and the Cardiff Member with the Muja Member. Palynological work has shown these correlations to be only partly correct (Backhouse, 1991). The Collie Basin stratigraphy is being revised (Le Blanc Smith, 1993).

Palynostratigraphy of the Collie Basin

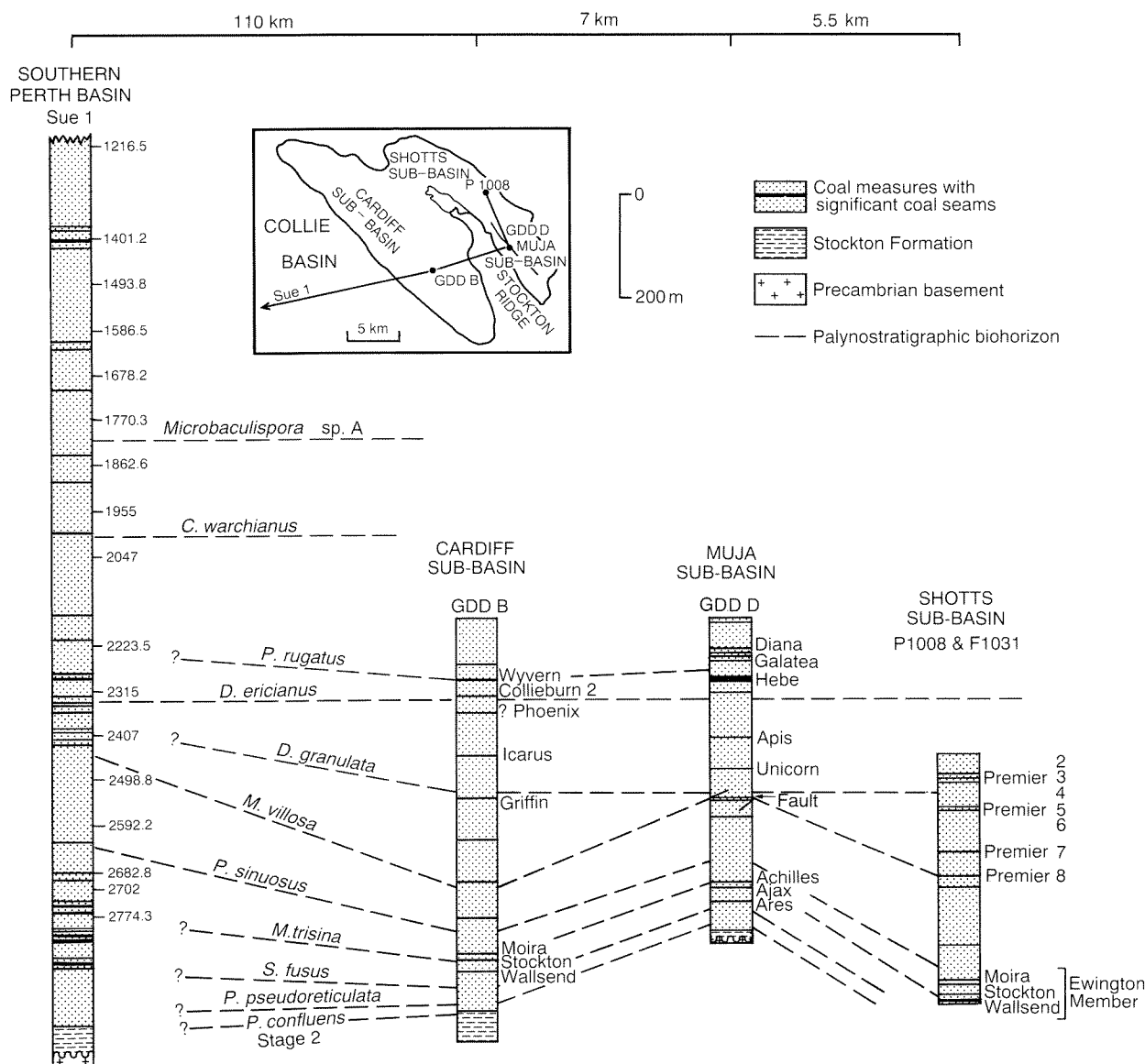
A summary of the palynostratigraphic results from the Collie Basin is presented in Backhouse (1990), and the detailed systematics are covered in Backhouse (1991). The ten palynostratigraphic units used are, in descending order:

Protohaploxylinus rugatus zone
Didecitriletes ericianus zone
Dulhuntyispora granulata zone

Microbaculispora villosa zone
Praecolpatites sinuosus zone
Microbaculispora trisina zone
Striatopodocarpites fusus zone
Pseudoreticulatispora pseudoreticulata zone
Pseudoreticulatispora confluens Oppel-zone (Foster and Waterhouse, 1988)
 Stage 2 (see Kemp et al., 1977)

As used by Backhouse (1990, 1991) and in this report, Stage 2 is equivalent to Upper Stage 2 as defined in Norvick (1971) and Kemp et al. (1977). It also corresponds to the redefined Stage 2 of Powis (1984), although unlike Powis *Microbaculispora micronodosa* and *Horriditriletes tereteangulatus* are not recognized as characteristic components of Stage 2 (see Backhouse, 1991).

The presence of *Pseudoreticulatispora confluens* is a prerequisite for recognition of the *P. confluens* Zone (Foster and Waterhouse, 1988). Foster and Waterhouse (1988) intended this zone to include assemblages



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Figure 2. Correlation of borehole intervals in the southern Perth and Collie Basins. For location of Sue 1 see Figure 3

previously assigned to Stage 2 and possibly to Stage 1 as defined by Kemp et al. (1977), but in the Collie Basin *P. confluens* is restricted to a narrow interval below the *P. pseudoreticulata* zone. Assemblages below this level are referred to Stage 2 (Backhouse, 1991).

Above the *P. confluens* Zone each zone is defined by the first appearance of the eponymous species. Some of the zones, such as the *D. ericianus* and *P. pseudoreticulata* zones, are readily identified because the index species shows a high sample frequency near the base of its range. Other zones, notably the *M. trisina* and *P. rugatus* zones, are difficult to recognize with confidence (Backhouse, 1991).

Using these zones it has been possible to correlate the sequences in the Cardiff, Shotts and Muja Sub-basins of

the Collie Basin (Fig. 2). The Ewington Member (Fig. 2) starts in the upper part of the *S. fusus* zone and extends into the *M. trisina* zone, with the *P. sinuosus* zone starting 20–40 m above the highest Ewington Member seam. The *M. villosa* zone starts at approximately the level of the Premier 8 seam in borehole P 1008 in the Shotts Sub-basin (Fig. 2), and some 160 m below the Griffin Seam in Government Deep Drillhole (GDD) B in the Cardiff Sub-basin. In GDD D in the Muja Sub-basin the stratigraphic distance between the start of the *P. sinuosus* zone and the start of the *D. ericianus* zone is 322 m, 128 m less than the equivalent stratigraphic distance in GDD B. This is taken as the thickness of the section faulted out by the Muja Fault in GDD D.

Dulhuntyispora granulata first appears in GDD B between the Icarus and the Griffin Seams (Fig. 2). In

P 1008 this biohorizon lies between Premier Seams 4 and 5, and in GDD D it lies between a fault zone and the Unicorn Seam. It is suggested that the Icarus Seam correlates with Premier Seams 3 and 4, and the Griffin Seam correlates with Premier Seams 5 and 6, although other minor seams may be involved.

In the Cardiff Sub-Basin the *D. ericianus* zone consistently starts within, or just below, Colliburn 2 Seam and 40–70 m below the thick and economically important Wyvern Seam. In borehole GDD D, in the Muja Sub-Basin, this biohorizon lies 18 to 39 m below the exceptionally thick Hebe Seam. On this evidence it is suggested that the Wyvern and Hebe Seams are probable lateral equivalents. This is supported by the first appearance of *Protophloxypinus rugatus* immediately above the Wyvern Seam in GDD B and near the base of the Galatea Seam, 30 m above the Hebe Seam in GDD D. *P. rugatus* was not recorded from any borehole or mine section below the Hebe or Wyvern Seams.

Wilga and Boyup Basins

No material has been examined for this study from the Wilga and Boyup Basins. The Stockton Formation is present in both basins and the thin coal measure sequences are considered to be equivalent to the Ewington Member of the Collie Basin. This is supported by the small amount of unpublished palynological data on the two basins.

Southern Perth Basin

Permian sediments have been intersected in deep petroleum exploration boreholes in the southern Perth Basin (Fig. 3). In Sue 1 and Alexandra Bridge 1, west of the Busseton Fault, they are present at relatively shallow depth below heavily oxidized sediments of unknown age. Permian strata were intersected at shallow depth on the northern Vasse Shelf in Quindalup 2 and 3 (Fig. 3). Subsequent coal exploration on the Vasse Shelf has provided a large quantity of core material from the Lower Permian. In Blackwood 1 and Canebreak 1 the Permian is present below oxidized sediments of assumed Cretaceous to Triassic age at depths of 2449 m and 1709 m respectively. Farther north the Permian is present at depths greater than 3700 m in Whicher Range 1–3, Wonnerup 1 and Sabina River 1 (Fig. 3).

Vasse Shelf

Sue 1

Sue 1 penetrated over 1800 m of Permian overlying Precambrian granitic basement. It is the longest and best sampled Permian subsurface sequence in the southern Perth Basin and is used by Backhouse (1990) and in this report as a reference section for palynostratigraphic correlation.

The Permian sequence in this borehole is the type section for the Sue Coal Measures (Playford and Low,

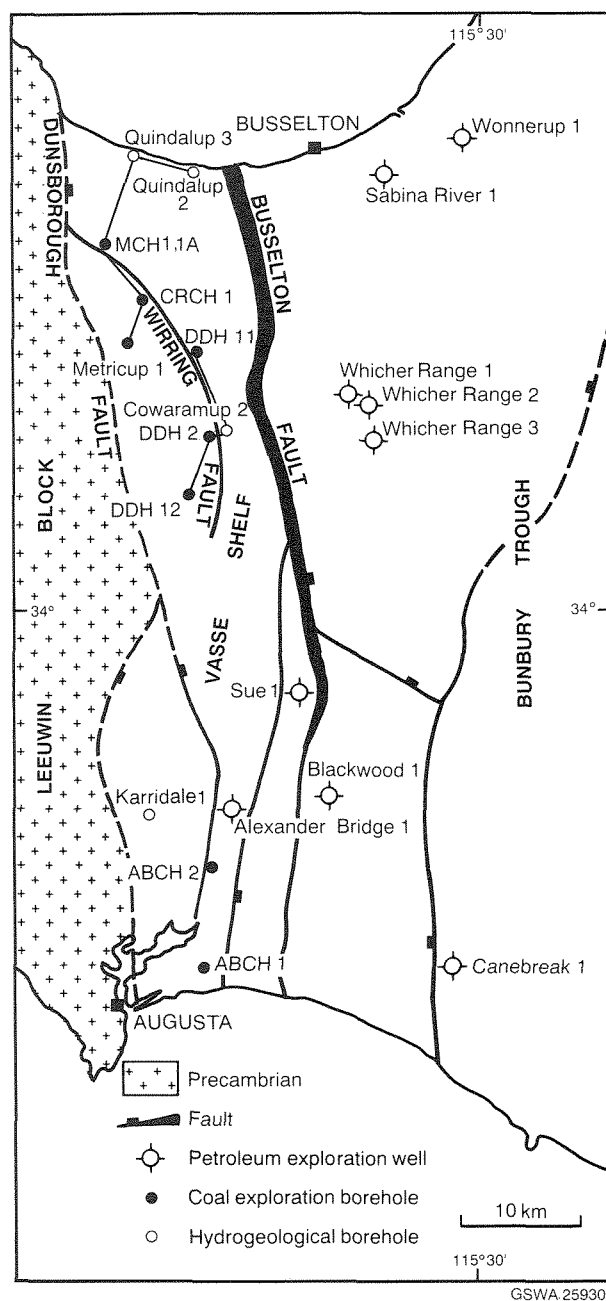
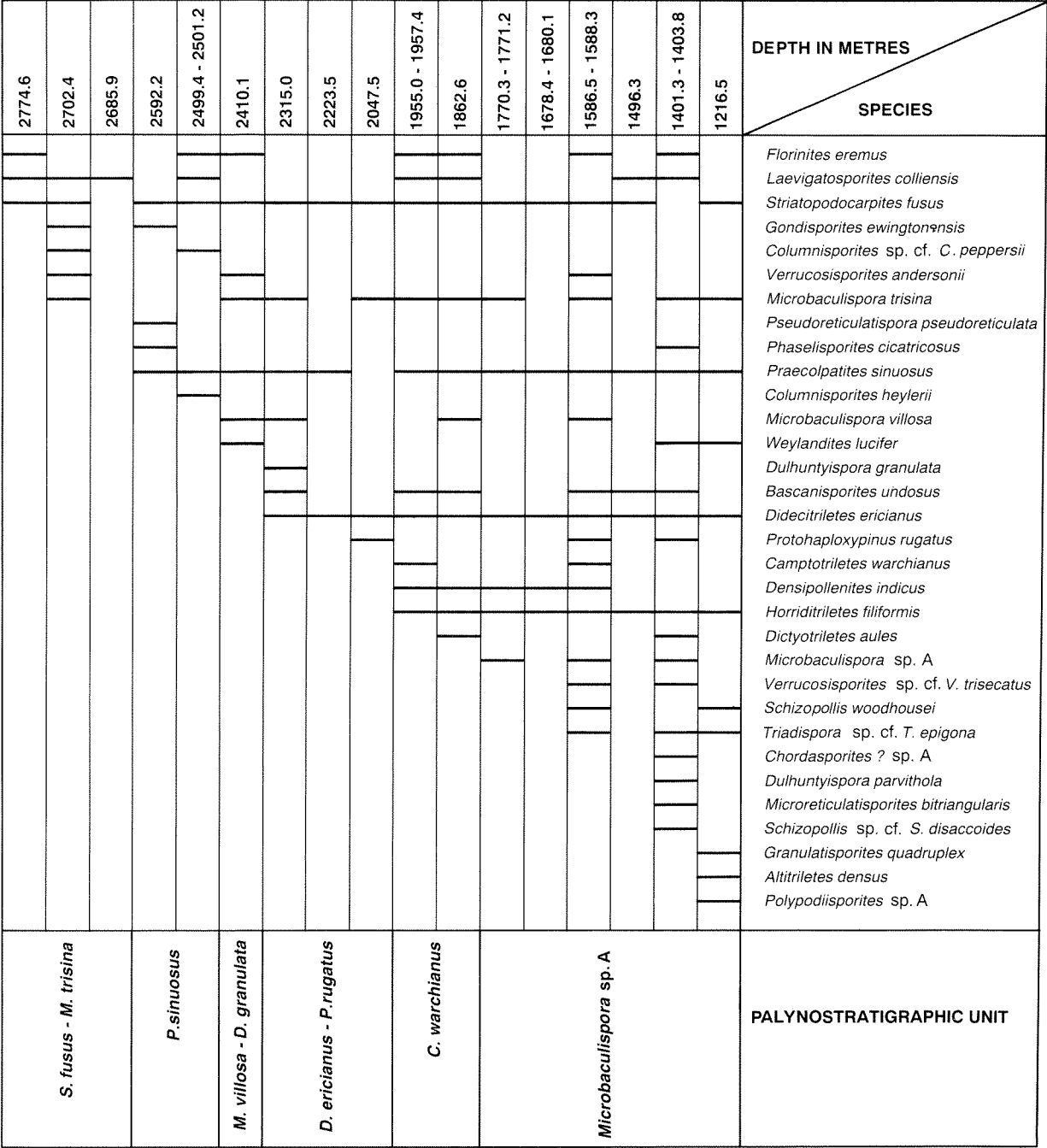


Figure 3. Location map of boreholes in the southern Perth Basin

1972). A glaciogene unit is recognized at the base of the sequence (Backhouse, 1990). On the basis of limited lithologic and palynological data it seems probable that the lowest 54 m of Permian sediments in Sue 1 belongs in this unit. Pending a comprehensive review of Permian stratigraphic nomenclature it is proposed to refer this glaciogene unit to the Stockton Formation of the Collie Basin, which it closely resembles. The type section of the Sue Coal Measures is emended to 1216–3003 m in Sue 1.

Figure 4 is a distribution chart for selected palynomorph species in Sue 1. No reliable samples are available from the section below 2774.6 m, but from the well-completion report (Williams and Nicholls, 1966) it seems likely that the section below 3003 m belongs in the



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Figure 4. Distribution of selected palynomorphs in Sue 1

P. confluens Oppel-zone, and/or Stage 2. This is supported by the presence of these zones at the base of the Permian sequence farther north on the Vasse Shelf (see below).

The sample at 2774.6 m contains *Striatopodocarpites fusus*, *Florinites eremus*, *Laevigatosporites colliensis* and abundant *Horriditriletes tereteangulatus*. This sample belongs in the *S. fusus* or *M. trisina* zone. A sidewall core at 2702.4 m contains *Microbaculispora trisina* and *Gondisporites ewingtonensis*, which indicates a position

in the upper part of the *M. trisina* zone. A core sample from 2592.2 m that contains *Praecolpatites sinuosus* and *G. ewingtonensis* falls within the *P. sinuosus* zone. The first appearance of *Microbaculispora villosa* is at 2407.5 m and *Didecitriletes ericianus* first occurs in a coal sample from a core at 2315.0 m (Fig. 4). This squeezes the *P. sinuosus*, *M. villosa* and *D. granulata* zones into a relatively short interval between 2682.8 and 2315.0 m (Fig. 2). However, better sample coverage would probably reveal the presence of index species at lower stratigraphic

levels. Several other species appear in Sue 1 at higher stratigraphic levels than might be anticipated from their known ranges in the Collie Basin.

The 2315.0 m sample contains forms of *D. ericianus* with short spines, morphologically transitional to *M. villosa*. The same morphotype is present in the Collie Basin at the base of the *D. ericianus* range. The 2315.0 m level is therefore taken to be near the base of the *D. ericianus* zone in Sue 1 (Fig. 2).

A correlation of Sue 1 with borehole GDD B in the Collie Basin (Fig. 2) displays the similarity in overall thickness of coal measures between the Collie and Perth Basins up to the *D. ericianus* zone. Above this level several forms are present in Sue 1 that are not recorded from the Collie Coal Measures. At 1955–1957.4 m a diverse assemblage contains *Camptotriletes warchianus* and *Densipollenites indicus*. At a slightly higher level (1770.3–1771.2 m) a distinctive species of *Microbaculispora* first appears — *Microbaculispora* sp. A (Fig. 5), a morphotype which displays widely spaced, large, low grana over the entire exinal surface. The first occurrences of *C. warchianus* and *Microbaculispora* sp. A are potentially useful biohorizons and are shown in Figures 2 and 12. Several other unusual forms of *Microbaculispora* are present above this level, together with some undescribed spore species. Other species present above 1678.4–1680.1 m that are not known from the Collie Basin include: *Verrucosiporites* sp. cf. *V. triseatus*, *Dulhuntyispora parvithola*, *Shizopollis* sp. cf. *S. woodhousei*, *Triadispora* sp. cf. *T. epigona* and *Chordasporites?* sp. A.

The highest sample in Sue 1 (1216.5 m) contains *Polypodiisporites* sp. A (= *Tuberculatosporites modicus* in Segroves, 1970) and *Granulatisporites quadruplex*, species present in the Wagina Sandstone of the northern Perth Basin.

Segroves (1970, fig. 4) shows *G. quadruplex* ranging through the Early Permian High Cliff Sandstone and Irwin River Coal Measures, whereas his illustrated specimens are from a sample he indicates to be from the Wagina

Sandstone. Re-examination of this sample has confirmed the Wagina Sandstone provenance.

Other borehole intervals on the Vasse Shelf

Assemblages similar to those in the upper part of the Sue Coal Measures in Sue 1 are present in the Permian interval in Alexandra Bridge 1 from a core at 612.6–615.7 m and a sidewall core at 410.9 m.

In addition to petroleum exploration wells, a large number of shallower boreholes have penetrated Permian sediments on the Vasse Shelf (Fig. 3). Most of the boreholes are located in the northern part of the Vasse Shelf, to the west of the Wurring Fault, and penetrate the Early Permian. Others located to the east of the Wurring Fault and in the south penetrate younger Permian sediments (Fig. 3).

The boreholes CRCH 1, Metricup 1, DDH 2 and probably Quindalup 2 reached the Stockton Formation (Fig. 6), which in this area is 100–250 m below the lowest coal seams. In Metricup 1 the lowest sample (575.1 m) contains a Stage 2 assemblage without *Pseudoreticulatispora confluens*, although *P. confluens* is present at 514.3 and 492.2 m. In CRCH 1 *P. confluens* is present in the two lowest samples (567.0 and 561.7 m) in a thin interval of Stockton Formation overlying granitic basement. A weathered zone occupies the top of the Stockton Formation in DDH 2. Stage 2 assemblages below the weathered zone do not contain *P. confluens*. The restriction of *P. confluens* to the uppermost Stockton Formation and the lowermost few metres of coal measures is consistent with the range of this species in the Collie Basin.

DDH 12 is the only borehole studied in detail from west of the Wurring Fault that did not reach the Stockton Formation.

To the north and west of the Wurring Fault Quindalup 3, MCH 1 and 1A, DDH 11 and Cowaramup 2A penetrate younger Permian sediments that contain *Camptotriletes warchianus* (Fig. 6). A crude correlation

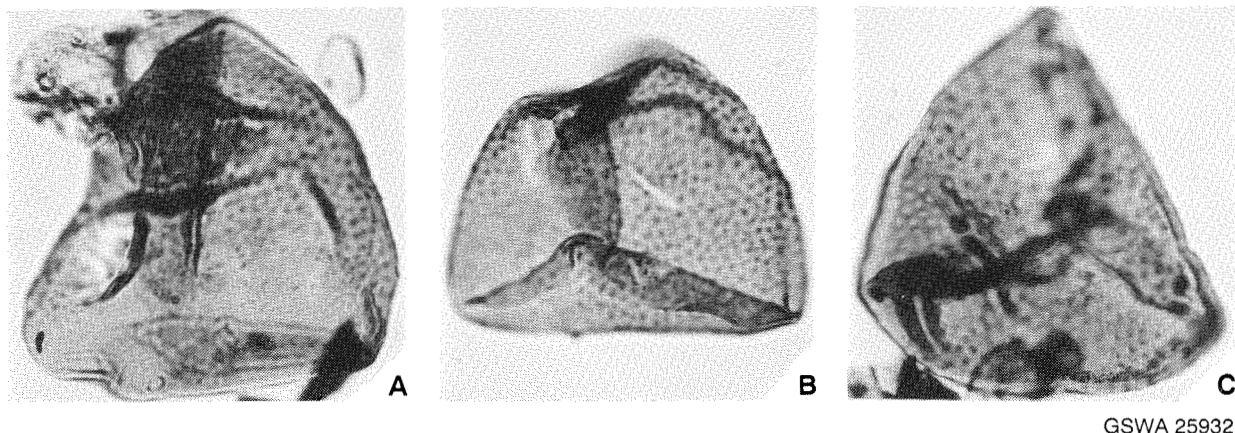


Figure 5. *Microbaculispora* sp. A, all figures x750. A,B, Sue 1, 1403.8 m; C, Sue 1, 1770.3 m

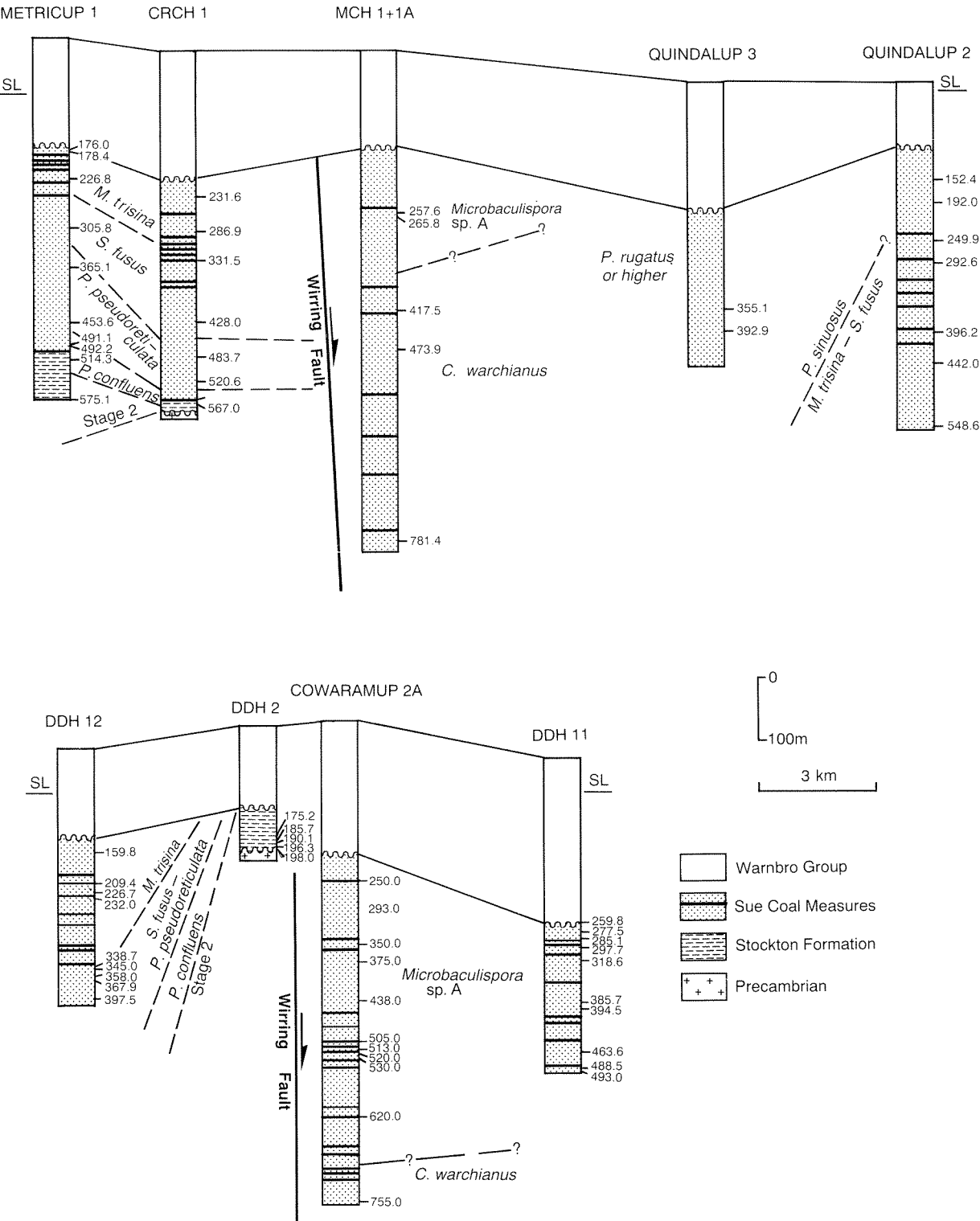


Figure 6. Borehole correlation on the northern Vasse Shelf. See Figure 3 for line of section

can be made between the 620 m sample in Cowaramup 2A and the 1770.3 m sample in Sue 1 based on the first appearance of *Microbaculispora* sp. A, and between the 350 m sample in Cowaramup 2A and the 1586.5 m sample in Sue 1 based on the first appearance of *Verrucosiporites* sp. cf. *V. trisecatus*. Using these tentative correlations, and assuming a uniform stratigraphic thickness down to the top of the Stockton Formation, the throw on the Wurring Fault between DDH 2 and Cowaramup 2A is estimated at 1650–1750 m (Fig. 6).

ABCH 1 and 2 on the southern Vasse Shelf penetrated Late Permian sediments that yielded *Didecitriletes ericianus*, *Camptotriletes warchianus*, *Polypodiisporites* sp. A, *Densipollenites indicus*, and *Triadispora* sp. cf. *T. epigona*. Apart from the absence of *Microbaculispora* sp. A the assemblages from these two boreholes are similar to those from Sue 1 above 1955 m.

The borehole series CRCH, MCH, and ABCH were drilled by CRA Exploration Pty Ltd, the DDH series by Mallina Holdings Ltd and Bond Corporation Pty Ltd joint venture, and Metricup 1 by BHP Co. Ltd. The Quindalup, Cowaramup, and Karridale hydrogeological boreholes were drilled by the Geological Survey of Western Australia.

Bunbury Trough

In the southern Bunbury Trough, Blackwood 1 and Canebreak 1 palynomorph assemblages from the Permian intervals correspond to the *D. ericianus* zone, or above.

Five wells have been drilled into the Permian in the northern Bunbury Trough (Fig. 3). They all intersected the Sue Coal Measures at depths greater than 3800 m. A few samples of equivocal Late Permian age were obtained from the immediately overlying Sabina Sandstone.

Samples from the top of the Sue Coal Measures in Wonnerup 1 yield typical Permian morphotypes, but samples from 4058.7 m and 4078.2 m (Fig. 7), in the lower part of the Sabina Sandstone, contain *Limatulasporites fossulatus*, *Lundbladispota* sp., *Densoisporites playfordii*, *Guttulapollenites hannonicus*, *Ephedripites* sp. and *Weylandites lucifer*. Other miospores are referable to the genera *Falcisporites*, *Horriditriletes*, *Punctatosporites*, *Lundbladispota* and *Protohaploxypinus*. These assemblages (designated *G. hannonicus* in Figure 7) contain few species in common with assemblages from the Sue Coal Measures, nor do they contain *Triplexisporites playfordii* or *Playfordiaspora velata*. *P. velata* is present in a cuttings sample at 4075.2 m, which suggests its presence within or just above the 4058.7–4078.2 m interval. The next sidewall core sample uphole at 3842.3 m contains *Densoisporites playfordii*, *Kraeuselisporites cuspidus*, *K. saeptatus* and *Lundbladispota wilmottii*. These species are present in the Early Triassic Kockatea Shale of the northern Perth Basin. This interval probably falls within the Triassic *Lunatisporites pellucidus* or *Protohaploxypinus samoilovichii* Zones of Helby et al. (1987) (Fig. 7).

Samples from core 1 (3898.3 and 3899.9 m) in Whicher Range 2 contain the following unequivocally Permian species:

Horriditriletes sp. cf. *Acanthotriletes superbus*
Dictyotriletes aules
Indospora clara
Plicatipollenites sp.
Protohaploxypinus amplus
Striatopodocarpites fusus
Leschikisporites sp.
Weylandites lucifer

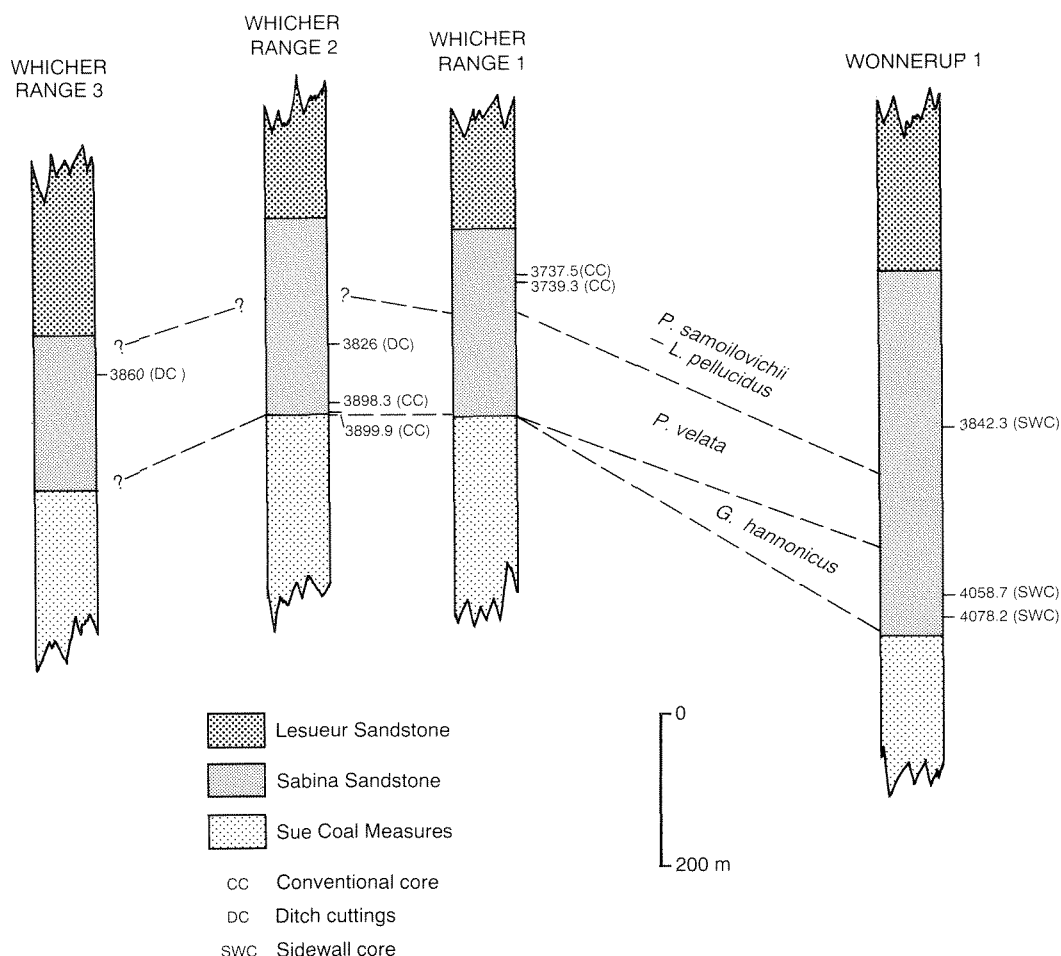
Triplexisporites playfordii, *Playfordiaspora velata* and a number of unidentified spores, which include species of *Polypodiisporites*, are also present. These assemblages are designated *P. velata* in Figure 7, and probably correlate with the *Weylandites* Zone of Kemp et al. (1977) and the *Playfordiaspora velata* (*crenulata*) Zone of Foster (1982), although the precise relationship to the eastern Australian zones is necessarily speculative. A similar assemblage is present at 3860 m in Whicher Range 3 (Ingram, 1982).

Samples from core 20 (3737.5, 3739.3 m) in Whicher Range 1 yielded rich and diverse assemblages with *P. velata*, *T. playfordii*, *Densoisporites playfordii*, *Kraeuselisporites cuspidus*, *K. saeptatus*, *Limatulasporites fossulatus*, *Taeniaesporites obex* and rare *Aratrisporites* sp. This assemblage is considered to be Early Triassic in age and similar in age to the assemblage in Wonnerup 1 at 3842.3 m.

The suggested stratigraphic relationship of samples from the Sabina Sandstone is shown in Figure 7. A more closely spaced series of samples through the Sabina Sandstone is required to fully resolve the palynostratigraphy at this level in the southern Perth Basin.

Northern Perth Basin

In the northern Perth Basin Permian sediments outcrop in the Irwin Sub-basin, located between the Urella and Darling Faults (Fig. 8), and underlie Mesozoic strata in the Dandaragan Trough to the west of the Urella Fault. Segroves (1967, 1969, 1970) studied palynofloras from all the Permian units and assembled these data in a palynostratigraphic scheme for the Permian of the Perth Basin (Segroves, 1972). The following samples originally studied by Segroves were reprocessed: Campbell's Water Bore (Holmwood Shale), UWA 4 (Woolaga Creek) Borehole (Wagina Sandstone), Eradu Coal Bore (Wagina Sandstone), seven samples from BMR 10 and 10A (Carynginia Formation to Fossil Cliff Member of Holmwood Shale), six samples from the 47 1/4 Mile Bore (Wagina Sandstone and Carynginia Formation), four samples from Wicherina X49 (Wagina Sandstone) and five samples from Wicherina 1 (Wagina Sandstone to Holmwood Shale). Additional material was examined from Wicherina 1, Abbarwardoo 1 and Yardarino 2. The top part of the Holmwood Shale was sampled in Per 7, IRRC 1 and IRRC 2, and the Carynginia Formation and Irwin River Coal Measures were sampled in IRCH 1 (Fig. 8).



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Figure 7. Correlation of the uppermost Permian and the basal Triassic in Whicher Range 1-3 and Wonnerup 1

The boreholes Per 7, IRRC 1 and 2, and IRCH 1 were drilled by CRA Exploration Pty Ltd.

Nangetty Formation and Holmwood Shale

The basal Permian unit, the glaciogene Nangetty Formation, attains a thickness of 1500 m near the Urella Fault (Playford et al., 1976). The Holmwood Shale conformably overlies the Nangetty Formation and attains a maximum thickness of 450 m in the Irwin Sub-basin. It contains several lenses of fossiliferous limestone and three of them, the Fossil Cliff, Woolaga and Beckett Members, are named units recognized in outcrop.

The distribution of palynomorphs in the Nangetty Formation and Holmwood Shale is shown in Figure 9. The three samples from the Nangetty Formation yielded few palynomorphs and more species may be present in this unit than are recorded here (see Segroves, 1969, 1970).

The Holmwood Shale can be divided into a thick lower part that contains *Jayantisporites pseudozonatus*, and a rather thin upper part from which this species is absent, but in which

Pseudoreticulatispora pseudoreticulata is present (Figs 9, 13); *P. pseudoreticulata* is absent from samples in the lower section of the unit. The upper section of the lower part of the Holmwood Shale (Abbarwardoo 1, 497 and 607 m) is placed in the *P. confluens* Zone. The 972 and 1103 m samples from Whicherina 1 contain specimens transitional between *Microbaculispora grandegrana* and *Pseudoreticulatispora confluens*, but do not contain true *P. confluens* morphotypes. On this evidence the lowest part of the Holmwood Shale is considered to lie within Stage 2 (Figs 9, 13).

The fossiliferous members can not be reliably identified in boreholes, and the relationship of the samples listed in Figure 9 to the outcropping members is not known. The palynoflora from the Fossil Cliff Member described in Foster et al. (1985) belongs in the *P. pseudoreticulata* zone and therefore corresponds to the upper Holmwood Shale as delineated in this paper.

The available samples do not clarify the age of the Holmwood Shale/Nangetty Formation boundary. It is assumed, in the absence of any contrary evidence, that the Nangetty Formation falls entirely within Stage 2.

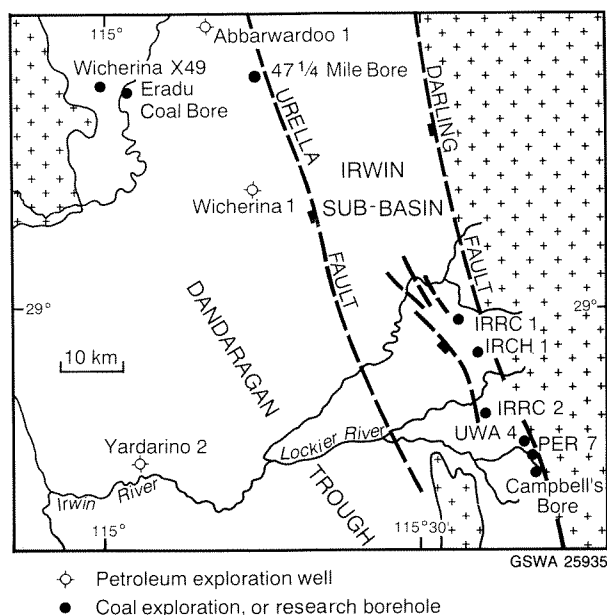


Figure 8. Location map for boreholes in the northern Perth Basin

Irwin River Coal Measures and Carynginia Formation

The Holmwood Shale is conformably overlain by the High Cliff Sandstone, and above this unit lie the Irwin River Coal Measures and the Carynginia Formation. Segroves (1969, 1970) did not differentiate the palynoflora of the High Cliff Sandstone from the Irwin River Coal Measures, and no samples from it were examined as part of this study. The High Cliff Sandstone probably correlates with part of the sandstone section between the Stockton Formation and the lowest coal seams in the Collie and southern Perth Basins.

The Irwin River Coal Measures in IRCH 1 (Fig. 10) contain *Microbaculispora trisina* (small specimens), *Gondisporites ewingtonensis*, *G. wilsonii*, *Laevigatosporites colliensis*, *Striatopodocarpites fusus*, *Weylandites magnus* and *Mehlisphaeridium fibratum*. These species indicate a correlation with the *S. fusus* and *M. trisina* zones of the Collie Basin. This is supported by the abundance of *Horriditriteles tereteangulatus* and the absence of *Praecolpatites sinuosus*.

Praecolpatites sinuosus is recorded from the lowest Carynginia Formation sample in borehole IRCH 1 (Fig. 10), but unequivocal examples of *P. sinuosus* are absent from all other samples from this unit. Segroves (1970, 1972) shows this species ranging down to the High Cliff Sandstone, but this range is not supported by the present data. Other significant species to appear in the Carynginia Formation are *Weylandites lucifer*, *Columnisporites* sp. cf. *C. peppersii* and *Maculatasporites* sp. A. *Gondisporites ewingtonensis* ranges into the upper part of the unit. *Altitriteles densus*, *Dictyotriteles aules* and *Microbaculispora villosa* are absent. These data indicate a correlation with the lower part of the *P. sinuosus* zone.

Spinose acritarchs, mainly *Microhystridium* and *Veryhachium*, are frequent in the upper part of the Carynginia Formation, but rare in the lower part, an indication that more open marine conditions prevailed in the later phase of deposition.

Samples from IRCH 1 at 28.3 and 41.3 m were examined for microfossils by Dr V. Palmieri (1989, pers. comm.) who suggests a cold, marginal marine environment of deposition for the Carynginia Formation, based on foraminifers.

Wagina Sandstone

The species identified from the Wagina Sandstone are listed in Figure 11. The presence of *Dulhuntyispora parvithola*, *Camptotriteles warchianus*, *Microreticulatisporites bitriangulatus*, *Verrucosisporites* sp. cf. *V. trisecatus* and *Triadispora* sp. cf. *T. epigona* suggests a correlation with the upper part of the Sue Coal Measures, although *Microbaculispora* sp. A is absent. Several species not recorded in the Sue Coal Measures are present in the Wagina Sandstone and *Polypodiisporites* sp. A, which is extremely rare in the southern Perth Basin, is an abundant component of many assemblages.

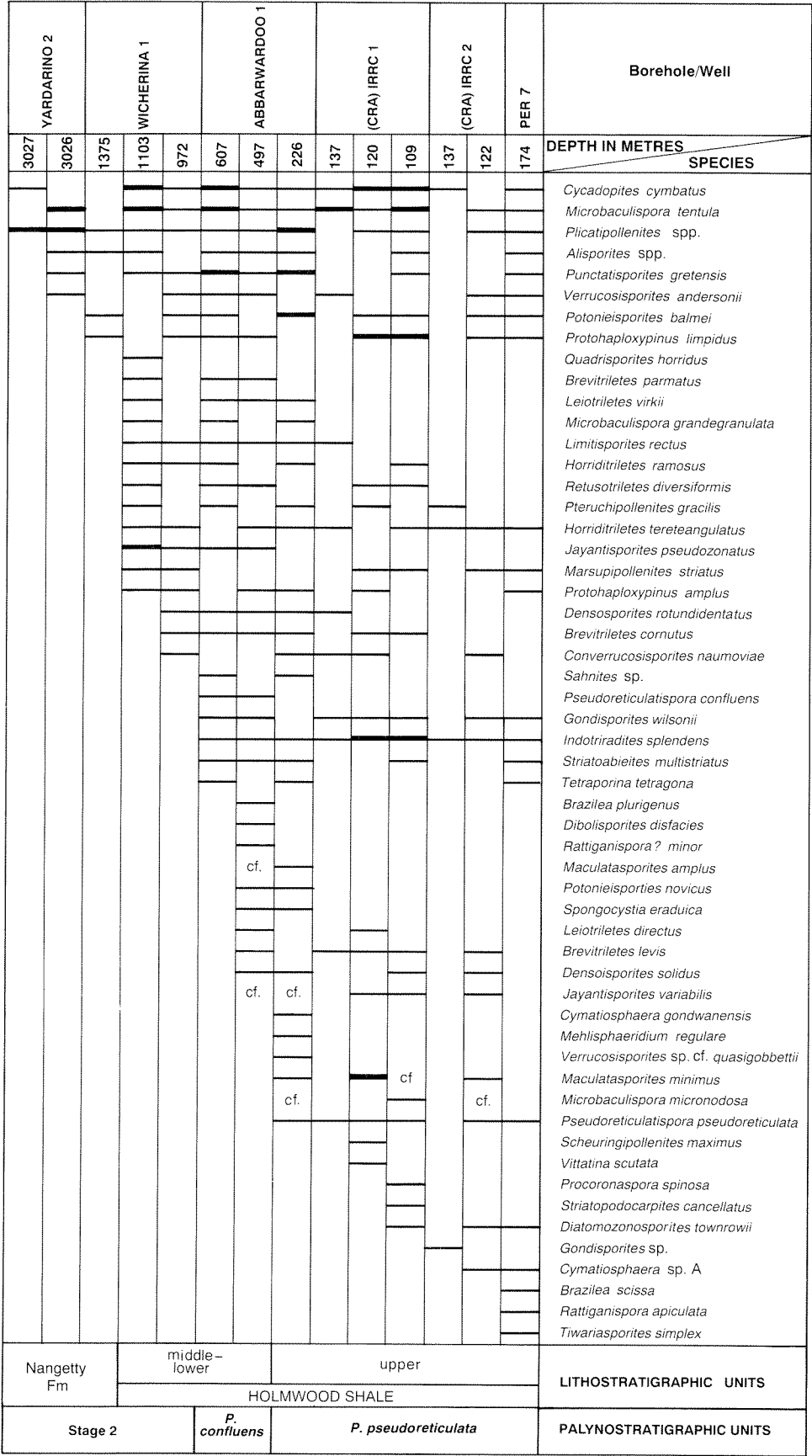
The Wagina Sandstone clearly post-dates the youngest Permian sediments of the Collie Basin. On palynological grounds it correlates broadly with the 1216.5–1955 m interval in Sue 1, but it may be synchronous with only part of this interval.

Age of the sequence

The ages of the upper part of the Holmwood Shale, the High Cliff Sandstone and the Carynginia Formation, based on macrofossil evidence, are discussed in detail by Archbold (1982) and Archbold et al. (in press). The ages suggested by these authors for units in the Perth Basin from the Asselian to the Early Baigendzhinian are shown in Figure 12. Ages shown above this level are largely speculative.

Officer Basin

In the Officer Basin Late Palaeozoic sediments are represented by the Paterson Formation, a flat-lying sequence of diamictite, sandstone, siltstone and claystone. Palynomorphs from the Paterson Formation were described by Kemp (1976), who assigned them all to Stage 2. In Ponton Creek 2 on the Yilgarn Craton, just beyond the southwestern margin of the Officer Basin (Fig. 1), approximately 48 m of late Eocene sediments overlie 509 m of Paterson Formation, which includes 272 m of diamictite and laminated claystone at the base overlain by 237 m of silty, blue-grey claystone with a thin sandstone bed near the top. Samples from the diamictite below 285 m yielded sparse Stage 2 assemblages in which *Punctatisporites gretensis* and radially monosaccate pollen are the most consistent components. More diverse Stage 2 assemblages are present in the overlying claystone



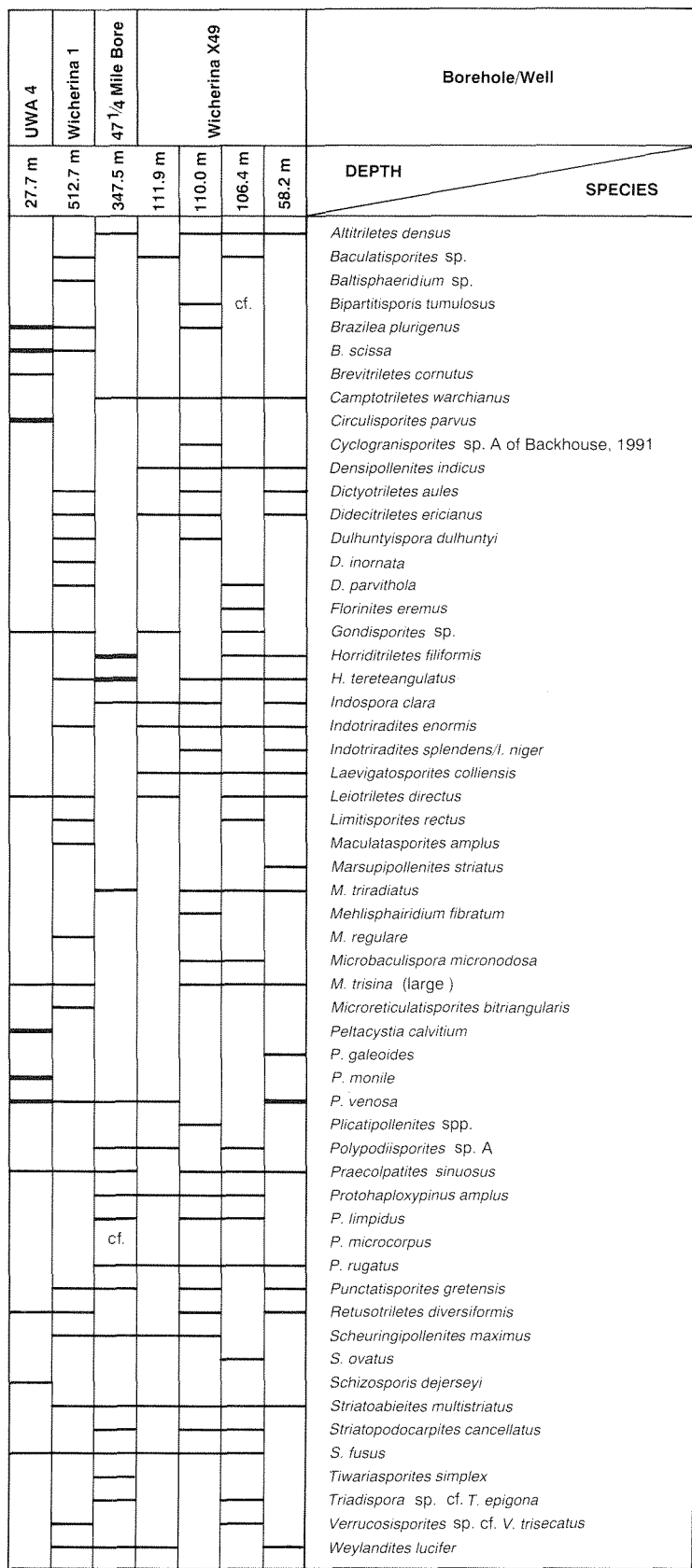
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Figure 9. Palynomorph distribution in the Nangetty Formation and Holmwood Shale

IRWIN RIVER COAL MEASURES				CARYNGINIA FORMATION						STRATIGRAPHIC UNIT	
152.5	123.0	103.5	91.4	87.0	66.0	49.5	34.3	28.3	25.3	DEPTH IN METRES	SPECIES
											<i>Brevitriletes cornutus</i>
											<i>B. levis</i>
											<i>Brazilea scissa</i>
											<i>Florinites eremus</i>
											<i>Gondisporite</i> sp. cf. <i>G. raniganjensis</i>
											<i>Horriditriletes ramosus</i>
											<i>H. tereteangulatus</i>
											<i>Indotriletes splendens</i> / <i>I. niger</i>
											<i>Jayantisporites</i> sp. A of Backhouse, 1991
											<i>J. variabilis</i>
											<i>Laevigatosporite colliensis</i>
											<i>Leiotriletes directus</i>
											<i>Marsupipollenites striatus</i>
											<i>M. triradiatus</i>
											<i>Microbaculispora micronodosa</i>
											<i>M. tentula</i>
											<i>Potonieisporites</i> sp.
											<i>Protohaploxylinus amplus</i>
											<i>P. limpidus</i>
											<i>Quadratisporites horridus</i>
											<i>Scheuringipollenites maximus</i>
											<i>S. ovatus</i>
											<i>Striatopodocarpites cancellatus</i>
											<i>S. fusus</i>
											<i>Alisporites</i> spp.
											<i>Gondisporites ewingtonensis</i>
											<i>G. wilsonii</i>
											<i>Interradispore robusta</i>
											<i>Mehlisphaeridium fibratum</i>
											<i>M. regulare</i>
											<i>Pteruchipollenites gracilis</i>
											<i>Tiwarisporites simplex</i>
											<i>Verrucosisporites andersonii</i>
											<i>Weylandites magnus</i>
											<i>Retusotriletes diversiformis</i>
											<i>Microbaculispora trisina</i> (small)
											<i>Peltacystia venosa</i>
											<i>Plicatipollenites</i> sp.
											<i>Sahnites</i> spp. (see Backhouse 1991)
											<i>Micrhystridium</i> sp.
											<i>Baculatisporites bhardwaji</i>
											<i>Praecolpatites sinuosus</i>
											<i>Brazilea plurigenus</i>
											<i>Pseudoreticulatispora pseudoreticulata</i>
											<i>Vittatina fasciolata</i>
											<i>Weylandites lucifer</i>
											<i>Leschikisporis cestus</i>
											<i>Grandispora</i> sp. A of Segroves, 1970
											<i>Secarisporites lacunatus</i>
											<i>Limitisporites rectus</i>
											<i>Peltacystia monile</i>
											<i>Procoronaspora spinosa</i>
<i>M. trisina</i>				<i>P. sinuosus</i>						PALYNOSTRATIGRAPHIC UNIT	

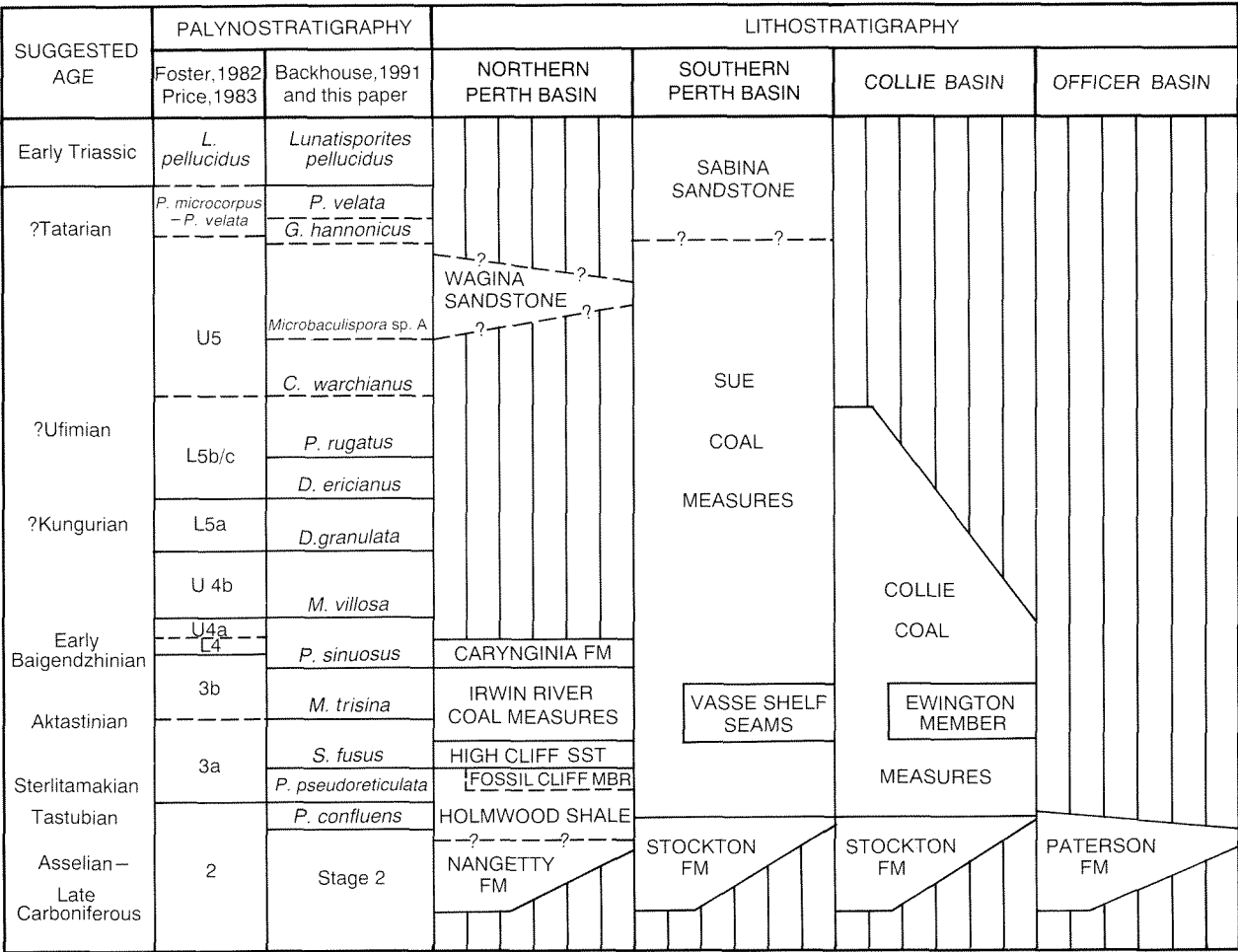
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Figure 10. Palynomorph distribution in the Irwin River Coal Measures and Carynginia Formation in (CRA) IRCH 1



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Figure 11. Palynomorph distribution in samples from the Wagina Sandstone



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Figure 12. Correlation of palynostratigraphic and lithostratigraphic units in the Perth, Collie and Officer Basins

sequence. A single sample from the top of the claystone (87–90 m) contained *Pseudoreticulatispora confluens* and *Indotriradites splendens*. The palynostratigraphic sequence is therefore similar to the Collie and southern Perth basins, with a thick Stage 2 followed by a thin *P. confluens* Zone.

Permian sediments younger than the *P. confluens* Zone are not known from the Officer Basin.

Summary

A correlation of the Permian sequences from the Perth, Collie and Officer basins, based on palynological data, is shown in Figure 12. The lowest parts of each sequence are correlated, using true stratigraphic thicknesses, in Figure 13.

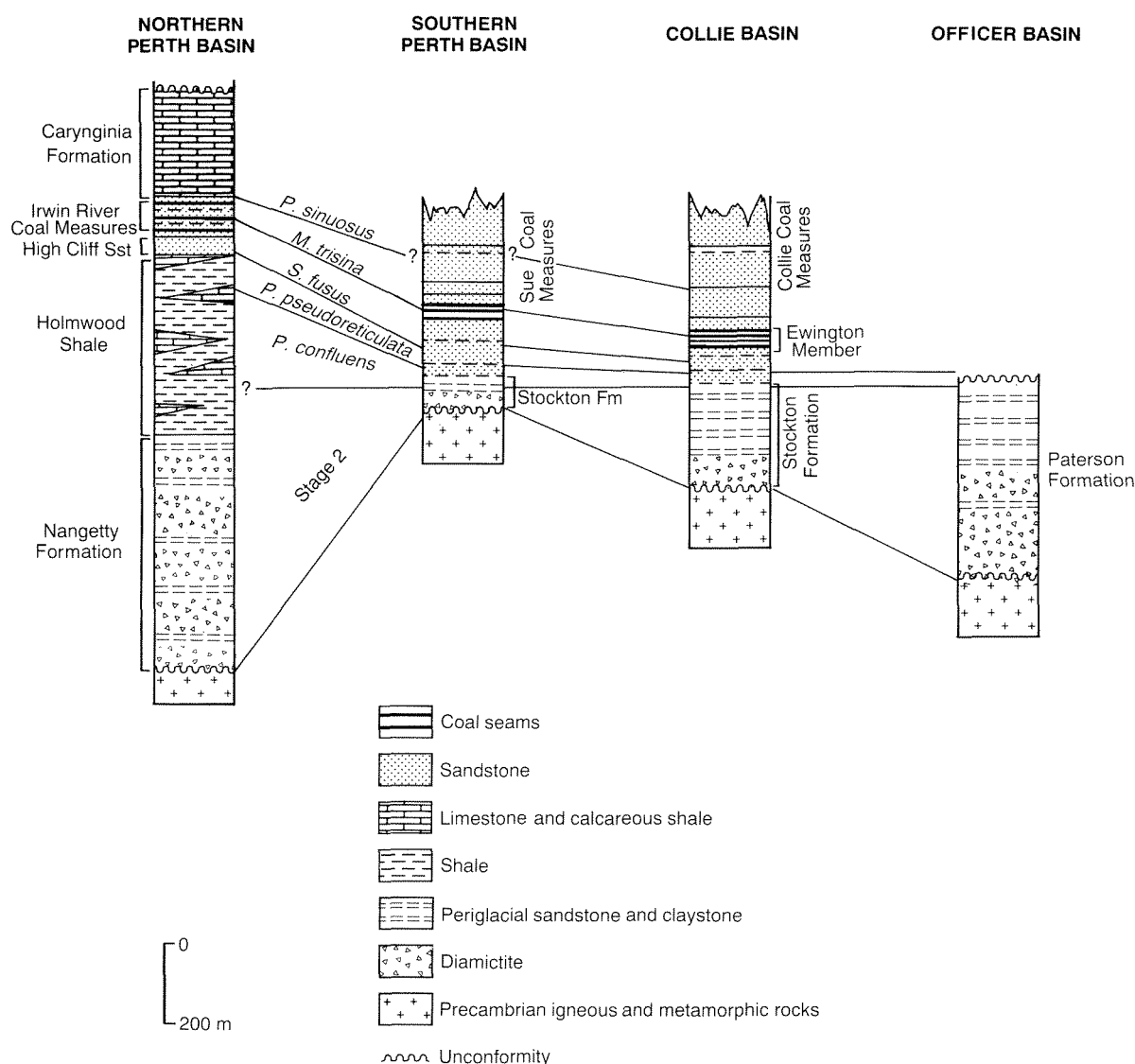
The thickest glaciogene periglacial sequence is represented by the Nangetty Formation and Holmwood Shale in the northern Perth Basin. On lithological and palynological grounds the Paterson and Stockton formations correlate with the Nangetty Formation and all three units belong largely in Stage 2. Where the Stockton Formation overlies a basement high it is thin and may fall entirely within the *P. confluens* Zone; where it is thick only

the uppermost part, transitional to the overlying coal measures, contains *P. confluens*.

In the Collie and southern Perth basins the *P. confluens* Zone occupies the uppermost claystone bands of the Stockton Formation and the basal few metres of the Collie and Sue Coal Measures. It is succeeded by the *P. pseudoreticulata* zone, which occurs in fluvial sandstone and shale. The *S. fusus* zone starts within the sandstone and shale sequence about half way between the top of the Stockton Formation and the lowest coal seams.

In the northern Perth Basin the lowest part of the Holmwood Shale is Stage 2 and the rest of the Holmwood Shale falls within the *P. confluens* and *P. pseudoreticulata* zones. The succeeding High Cliff Sandstone probably belongs to the *S. fusus* zone, and the Irwin River Coal Measures fall within the *S. fusus* and *M. trisina* zones. The Irwin River Coal Measures are therefore the same age as the Ewington Member of the Collie Coal Measures and the lowest Sue Coal Measures, as represented by seams on the Vasse Shelf.

This early period of coal formation extended over most of the area now occupied by the Perth Basin, and over the southwestern Yilgarn Craton. The eastern limit of the coal measures is not known, but they may have originally



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Figure 13. Correlation of earliest Permian units in the Perth, Collie and Officer Basins, showing true stratigraphic thicknesses

covered most of the southern Yilgarn Craton (Backhouse, 1990). Coal measures of the same age are present in the Arckaringa, Pederika and Cooper Basins of South Australia (Thornton, 1979).

The marine period represented by the Carynginia Formation was restricted to the northern Perth Basin. In the south, coal measure deposition continued into the Late Permian.

The palynological biostratigraphy of the latest Permian and earliest Triassic in the southern Perth Basin is not fully resolved. Significant sedimentological changes between the Sue Coal Measures and the Sabina Sandstone evidently led to rapid changes in the palynoflora. The palynological evidence suggests a hiatus between the Sue Coal Measures and the Sabina Sandstone.

The Wagina Sandstone of the northern Perth Basin is equivalent in age to the upper part of the Sue Coal Measures. No sediments of latest Permian age, equivalent to those of the Sabina Sandstone, are present in the northern Perth Basin.

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Basil Balme and Gina Rockette of the University of Western Australia made available slides, residues and rock material from the University of Western Australia collection. This assistance is gratefully acknowledged. Staff of CRA Exploration Pty Ltd, Mallina Holdings Ltd, and West Australian Petroleum Pty Ltd kindly made available material from boreholes in the Perth Basin, and Western Collieries Ltd and The Griffin Coal Mining Company Ltd allowed access to borehole and mine material from the Collie Basin.

Alphabetical list of miospore and acritarch species mentioned in this paper

Miospores

- Altitriletes densus* Venkatachala and Kar 1968
Baculatisporites bharadwaji Hart 1963
Bascanisporites undosus Balme and Hennelly 1956
Brevitriletes cornutus (Balme and Hennelly) Backhouse 1991
Brevitriletes levis (Balme and Hennelly) Bharadwaj and Srivastava 1969
Brevitriletes parvatus (Balme and Hennelly) Backhouse 1991
Camptotriletes warchianus Balme 1970
Columnisporites heylerii Doubinger *emend.* Alpern and Doubinger 1973
Columnisporites sp. cf. *C. peppersii* Alpern and Doubinger 1973
Converrucosporites naumoviae (Hart) Backhouse 1991
Cycadopites cymbatus (Balme and Hennelly) Segroves 1970
Cyclogranisporites sp. A (Backhouse, 1991)
Densipollenites indicus Bharadwaj 1962
Densoisporites playfordii (Balme) Dettmann 1963
Densoisporites solidus Segroves 1970
Densosporites rotundidentatus Segroves 1970
Diatomozonotriletes townrowii Segroves 1970
Dibolisporites disfacies Jones and Truswell (in press)
Dictyotriletes aules Rigby in Rigby and Hekel 1977
Didecitriletes ericianus (Balme and Hennelly) Venkatachala and Kar 1965
Dulhuntyispora dulhuntyi Potonié *emend.* Price 1983
Dulhuntyispora granulata Price 1983
Dulhuntyispora inornata Segroves *emend.* Price 1983
Dulhuntyispora parvithola (Balme and Hennelly) Potonié 1960
Ephedripites sp.
Florinites eremus Balme and Hennelly 1955
Gondisporites ewingtonensis Backhouse 1988
Gondisporites raniganjensis Bharadwaj 1962
Gondisporites wilsonii Backhouse 1988
Grandispora sp. A (Segroves, 1970)
Granulatisporites quadruplex Segroves 1970
Guttulapollenites hannonicus Goubin 1965
Horriditriletes filiformis (Balme and Hennelly) Backhouse 1991
Horriditriletes ramosus (Balme and Hennelly) Bharadwaj and Salujha 1964
Horriditriletes sp. cf. *Acanthotriletes superbus* Foster 1979
Horriditriletes tereteangulatus (Balme and Hennelly) Backhouse 1991
Indospora clara Bharadwaj 1962
Indotriradites enormis (Segroves) Foster 1979
Indotriradites niger (Segroves) Backhouse 1991
Indotriradites splendens (Balme and Hennelly) Foster 1979
Interradispora robusta (Foster) Foster 1979
Jayantisporites pseudozonatus Lele and Makada 1972
Jayantisporites sp. A (Backhouse, 1991)
Jayantisporites variabilis (Anderson) Backhouse 1991
Kraeuselisporites cuspidus Balme 1963
Kraeuselisporites saeptatus Balme 1963
Laevigatosporites colliensis (Balme and Hennelly) Venkatachala and Kar 1968
Leiotriletes directus Balme and Hennelly 1956
Leiotriletes virkii Tiwari 1965
Leschikisporis cestus Segroves 1970
Limatulasporites fossulatus (Balme) Helby and Foster 1979
Limitisporites rectus Leschik 1956
Lundbladispora sp. A (Foster, 1979, 1982)
Lundbladispora wilmottii Balme 1963
Marsupipollenites striatus (Balme and Hennelly) Foster 1979
Marsupipollenites triradiatus Balme and Hennelly 1956
Microbaculispora grandegranulata Anderson 1977
Microbaculispora micronodosa (Balme and Hennelly) Anderson 1977
Microbaculispora sp. A (this paper)
Microbaculispora tentula Tiwari 1965
Microbaculispora trisina (Balme and Hennelly) Anderson 1977
Microbaculispora villosa (Balme and Hennelly) Bharadwaj 1962
Microreticulatisporites bitriangulatus Balme and Hennelly 1956
Phaselisporites cicatricosus (Balme and Hennelly) Price 1983
Playfordiaspora velata (Leschik) Stevens 1981
Polypodiisporites sp. A (= *Tuberculatosporites modicus* Balme and Hennelly in Segroves, 1970)
Potonieisporites balmei (Hart) Segroves 1969
Potonieisporites novicus Bharadwaj 1954
Praecolpatites sinuosus (Balme and Hennelly) Bharadwaj and Srivastava 1969
Procoronaspora spinosa (Anderson) Backhouse 1991
Protohaploxypinus amplus (Balme and Hennelly) Hart 1964
Protohaploxypinus limpidus (Balme and Hennelly) Balme and Playford 1967
Protohaploxypinus microcorpus (Schaarschmidt) Clarke 1965
Protohaploxypinus rugatus Segroves 1969
Pseudoreticulatispora confluens (Archangelsky and Gamero) Backhouse 1991
Pseudoreticulatispora pseudoreticulata (Balme and Hennelly) Bharadwaj and Srivastava 1969
Pteruchipollenites gracilis (Segroves) Foster 1979
Punctatisporites gretensis Balme and Hennelly 1956
Rattiganispora apiculata Playford and Helby 1968
Rattiganispora? minor (Anderson) Backhouse 1991
Retusotriletes diversiformis (Balme and Hennelly) Balme and Playford 1967
Sahnites spp. (Backhouse, 1991)
Scheuringipollenites maximus (Hart) Tiwari 1973
Scheuringipollenites ovatus (Balme and Hennelly) Foster 1975
Schizopollis sp. cf. *S. disaccoides* Venkatachala and Kar 1964
Secarisporites lacunatus (Tiwari) Backhouse 1991
Shizopollis sp. cf. *S. woodhousei* Venkatachala and Kar 1964

Striatoabieites multistriatus (Balme and Hennelly) Hart 1964
Striatopodocarpites cancellatus (Balme and Hennelly) Hart 1963
Striatopodocarpites fusus (Balme and Hennelly) Potonié 1956
Taeniaesporites obex Balme 1963
Tiwariasporites simplex (Tiwari) Maheshwari and Kar 1967
Triadispora sp. cf. *T. epigona* Klaus 1964
Triplexisporites playfordii (de Jersey and Hamilton) Foster 1979
Verrucosporites andersonii (Anderson) Backhouse 1988
Verrucosporites sp. cf. *V. gobbettii* Jones and Truswell (in press)
Verrucosporites sp. cf. *V. trisecatus* Balme and Hennelly 1956
Vittatina fasciolata (Balme and Hennelly) Bharadwaj 1962
Vittatina scutata (Balme and Hennelly) Bharadwaj 1962
Weylandites lucifer (Bharadwaj and Salujha) Foster 1975
Weylandites magmus (Bose and Kar) Backhouse 1991

Acritarchs

Brazilea plurigenus (Balme and Hennelly) Foster 1979
Brazilea scissa (Balme and Hennelly) Foster 1975
Chordasporites? sp. A (Foster, 1979).
Cymatiosphaera gondwanensis (Tiwari) Backhouse 1991
Cymatiosphaera sp. A (Backhouse, 1991)
Maculatasporites amplus Segroves 1967
Maculatasporites minimus Segroves 1967
Maculatasporites sp. A (Backhouse, 1991)
Mehlisphaeridium fibratum Segroves 1967
Mehlisphaeridium regulare Anderson 1977
Peltacystia calvitium Balme and Segroves 1966
Peltacystia galeoides Segroves 1967
Peltacystia monile Balme and Segroves 1966
Peltacystia venosa Balme and Segroves 1966
Quadrifidites horridus Hennelly ex Potonié and Lele 1961
Schizosporis dejerseyi Segroves 1967
Spongocystia eraduica Segroves 1967
Tetraporina tetragona (Pant and Mehtra) Anderson 1977

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